Geographic Validity Aware Content Retention in Vehicular Networks

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Abstract

In Vehicle-to-Vehicle (V2V) communication, interest-based content dissemination carries equal importance. For example, a group of vehicles involved in a safari may communicate with each other about the location of rare animals. These messages are useful only within a certain geography and within a certain timespan. Hence, messages injected into the V2V network should be retained within these boundaries regardless of the highly dynamic nature of the underlying V2V network. To ensure that the content is retained within the V2V network both efficiently and with high certainty, it is important to address problems such as how and when to disseminate content, how to maintain order and honor priorities of content, how many replicas to maintain, and when to evict the content. However, if the content message is passed every time a pair of vehicles comes into each other's range, it will lead to message implosion while sub-optimally utilizing the wireless links, power, and content storage. Therefore, to ensure that all the vehicles get the message without high certainty and efficiency, it is imperative to identify with what probability a message should be disseminated.

In this research, we identify this probability value that could lead to successful retention of the message within the network given the parameters such as the valid geographical boundary, time span, and vehicle arrival rate. We developed a model that estimates the minimum probability that needs to be maintained to ensure that the specific content is seeded among other nodes. The model was developed for straight roads, T-junctions, and four-way intersections by varying other parameters such as the valid geographic area, vehicle speed, and density. Simulation bases analysis shows that the proposed model could reasonably estimate the minimum probability that needs to be met for the message to be replicated in other nodes.

Acknowledgements

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List of Abbreviations

ABS	Anti-lock braking system
ASTM	American Society for Testing and Materials
CCH	Control Channel
DREAM	Distance Routing Effect Algorithm
DSRC	Dedicated Short Range Communication
DTN	Delay Tolerant Networks
FCC	Federal Communications Commission
GPS	Global Positioning System
GLS	Grid Location Service
IDE	Integrated Development Environment
IVC	Inter-Vehicle Communication
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transportation System
LAN	Local Area Network
MAC	Media Access Control Layer
MANET	Mobile Ad hoc Network
MSG	Message
MSG PSD	Message Passed
MSG RET	Message Retained
NED	Network Description (Language)
OBU	On-Board Unit
ON	Opportunistic Network
PHY	Physical layer
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SCT	Signed Certificate Timestamp
SUMO	Simulation of Urban Mobility
VANET	Vehicular Ad-hoc Network
Veins	Vehicles in Network Simulation
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Any other
WAN	Wide Area Network
WAVE	Wireless Access in Vehicular Environment

1 Introduction

1.1 Motivation

Advances in the Mobile Ad-hoc Networks(MANET) have made way for the development of Vehicular Ad-hoc Networks (VANET) [21], which is mainly used in Vehicle-to-Vehicle (V2V) communication. V2V and Vehicle-to-Infrastructure (V2I) communication have been introduced as a method of predicting the behavior of nearby vehicles and the conditions of the road ahead. In this context, vehicles will communicate with the neighboring vehicles about their next immediate actions and behavior such as the driving speed and direction using Dedicated Short-Range Communication (DSRC) technology [1]. Furthermore, vehicles could interact with the infrastructure to get roadside information such as the traffic, condition of the road ahead, and weather information. Such information enables safe driving, intelligent and dynamic route planning while minimizing potential congestions. Therefore, the combination of vehicles, V2V, and V2I could be defined as an Intelligent Transportations System (ITS).

In V2X (Vehicle to any other), content dissemination could be thought of as one of the core functionalities. The success of content dissemination varies depending on the vehicle density, flow rate, and direction of flow. For example, in a Safari scenario, there will be a limited infrastructure and the vehicle density would be very low. However, there is a high probability that these vehicles would encounter each other during the travel. Even more so, they have a relatively longer communication range. Therefore, it becomes beneficial, if these vehicles could exchange whatever the captured important details and share among other vehicles that they encounter during the travel. For example, the sighting of rare animals, road conditions, and public announcements by the park authority can be shared with each other. However, such messages are only valid within the geography of the park, or even a sub-region of it. Moreover, messages related to animal sighting could be invalid after some time. Therefore, these messages are useful within only a certain geography and a timespan. Moreover, messages may have priorities (alerts by the park authority could have high priority than animal sightings) and their authenticity may need to be verified.

Another example could be, disasters like a rock/landslide, which could affect the neighboring areas within the same time. It is essential that these types of information are passed to the relevant authorities as soon as possible and to the potential vehicles, as facing such situations could even result in life-threatening moment, amidst verifying the validity of such information and acting upon them become crucial for the relevant geological authorities without any delay. For such applications to be useful, it is essential to ensure that the content is retained within the V2V networks with both high certainty and efficiency.

Similarly, in an urban setting message related to safety, traffic, availability of parking lots, or various deals (e.g., giveaways and restaurant deals) could be shared among vehicles. These messages are also relevant only within a certain geography and time span. The high density of vehicles and slow flow rate could affect the quality of content dissemination and retention due to wireless collisions, duplicates, and implosion. Therefore, it is imperative to identify how to achieve geography and time-aware content dissemination during situations, where there could be both high and less vehicle density and flow rates.

1.2 Problem Statement

To ensure that the content is retained within the V2V network both efficiently and with high certainty, it is important to address problems such as how and when to disseminate content, how to maintain order and honor priorities of content, number of replicas to maintain, and when to evict the content. We focus on a problem where there are less infrastructure and relatively low vehicle density. The main challenges could be categorized as successfully delivering the content to closest vehicles so that the content could be spread (i.e., content dissemination) to those who are interested in the considered geographical area, the validity period of the content, identifying the geographic boundary of validity, and the actual validity of the contents.

Consider a set of contents **C**, where each content $c_i \in C$ has valid time c_i^t, valid geography c_i^{geo}. Also, consider a set of vehicle **V** where each vehicle $v_i \in V$ has a speed v_i^{speed}, trajectory v_i^{traj}. Let α be the flow rate of the vehicles. In this context, the specific problem to be addressed can be formulated as follows:

What is the minimum probability that needs to be met to successfully disseminate content c across a set of vehicles V such that their geographic span is maintained, and temporal retention is maximized within a given road structure?

1.3 Objectives

Objectives of this research are as follows:

- To develop a model to estimate the probability of content retention along a straight road while varying content and vehicle-related parameters such as a valid time c_i^t, valid geography c_i^{geo}, vehicle speed v_i^{speed}, trajectory v_i^{traj}, and the vehicle flow rate.
- To extend the model for a T-junction and a four-way intersection.
- Evaluate the developed model for a straight road, T-junction, and four-way intersection and analyze the behavior by applying the derived probability value from the model.

1.4 Outline

Chapter two presents the related work on VANET and V2V. We describe the existing technologies related to V2V such as underlying network, DSRC technology, V2V standards, various routing techniques and V2X content dissemination. In the third chapter, we propose a high-level problem and try to solve this by breaking it into a set of subproblems. For each of the subproblems, we will first try to identify solutions by taking a mathematical approach, providing that these mathematical solutions could be used for analyzing the behavior of the solution for each approach. In chapter four we evaluate the model by showing the output results of the vehicle simulator. Finally, in chapter five we present the conclusion of this research.

2 Literature Review

Advancements in MANET has made way to the existence of VANET. This chapter presents various technology standards, routing mechanisms and different content dissemination strategies available for V2V communication. Section 2.1 presents about the underlying wireless network. Vehicle-to-Vehicle (V2V) communication standards are presented in Section 2.2. Section 2.3 we discuss about different routing mechanisms available in V2V. Section 2.4 describes different methods that could be used for content dissemination. Finally, in Section 2.5 we discuss the about the different tools that were used to simulate the research problem and how these tools are connected with one another.

2.1 Underlying Network

Wireless mobile networks can be grouped into two major categories, infrastructure based and ad-hoc wireless networks. An infrastructure-based wireless network can be distinguished by the characteristic of it having a set of fixed nodes connected via a wired backbone which provides the mechanism to communicate between the wireless nodes and meantime could act as a gateway to other fixed node networks [8]. Alternatively, wireless ad-hoc networks do not have such fixed infrastructure. These networks consist of nodes that communicate directly with one another through (usually) short-range wireless technologies, such as Wi-Fi, Bluetooth, and ZigBee [9]. These connections form a dynamic network topology. To communicate with distant nodes, a multi-hop (store-and-forward) communication mechanism is used, where the message will be delivered through multiple intermediary forwarding nodes (hops). In such a network all nodes act as a host and as a router at the same time.

The third type of category would be hybrid networks, which combines characteristics from both infrastructure-based and ad-hoc mobile networks [9]. Hybrid networks use both infrastructure-based and ad-hoc communication as it fits the situation. It adds great advantage when sharing local information such as file sharing between people in the same room, as it could be done much faster with lower latency, than in long-range infrastructure communications.

2.1.1 Mobile Ad-hoc Networks

MANET could be thought of as a dynamic network that forms with a collection of wireless mobile nodes without any pre-existing fixed network infrastructure. These nodes are equipped with wireless transmitters and receivers. The formation of this network could change at any given point in time due to its dynamic nature, which may result in changes in the transmission power levels and co-channel interference levels, random wireless connectivity, multi-hop graph or ad-hoc network exists between the nodes. While MANET's have many advantages, due to its highly dynamic nature, routing becomes a challenging task. Traffic types involved in MANET could be categorized as follows [10]:

a) Peer-to-Peer – Involves two nodes that are within one hop distance.
b) Remote-to-Remote – Communication involves two nodes beyond a single hop, which will have a stable route between them. Here the nodes will stay within a reachable communication range to each other and move as a group.
c) Dynamic Traffic – Nodes here are moving and frequently changing. The routes between these nodes will have to be reconstructed, which may result in poor connectivity.

MANETs have several features including the following [10]:

a) Autonomous terminal – Each mobile terminal in this could be thought of as an autonomous node, that will either function as a host or a router or both, amidst doing its basic processing. Therefore, the endpoints and Switches are indistinguishable in this environment.
b) Distributed operation – MANET does not have a central control for network operations. Therefore, the control and the management part of the network is distributed among the terminals. Thus, these nodes have to collaborate amongst themselves to implement functions, e.g., security and routing.
c) Multi-hop routing – When delivering data packets from the source to its destination through point-to-point wireless transmission, the packets need to be passed through several intermediary nodes.

d) Dynamic network topology – The dynamic nature of the network causes the topology to change frequently and unpredictably, which will also result in the connectivity between the nodes to vary with time. Therefore, the MANET should be able to get adjusted to the varying network conditions such as varying traffic, dynamic mobility patterns and different propagation conditions of the mobile network nodes. This behavior may cause the node to require access to a fixed public network.

e) Fluctuating link capacity – The nature of the MANET leads to high bit-error rates due to the following reasons:

   a. A single end-to-end path could be shared by several sessions.
   b. The communication channel used by the terminals can introduce problems such as noise, fading, and interference, and may even lack in bandwidth than compared to a wired network.
   c. In some cases, the path between any pair of users may take different routes and these links again can be heterogeneous.

f) Light-weight terminals – Mostly the devices involved in communication are lightweight devices such as mobile devices, which may contain less resource capability. Therefore, MANET requires to have heavily optimized algorithms and mechanisms to proceed with its functionality.

Challenges in MANET can be listed as follows:

a) Routing – every time a mobile node changes its point of attachment, it causes the physical IP address to be changed, which results in a possibility of losing packets during the transmission and breaking the transport layer protocol if mobility is not handled by specific services [7]. This brings in the requirement that the protocol stack should be able to switch networks in the middle of data transfers by breaking its current communication session, with minimum transmission delays and signaling overhead, this is referred to as *mobility Support* [13]**.** Host mobility support is handled by Mobile IPv6. The primary objective of mobile ad hoc networking is to extend mobility to form a fully dynamic, freely governed, mobile wireless domain, where the nodes may act as routers or hosts as and when required, which will lead them to form the network routing infrastructure in an ad-hoc fashion. The dynamic behavior of such a network makes multicast routing a challenging task because the multicast tree will no longer be static due to the randomness of the nodes within the network [7].

b) Security – Because MANET is highly dynamic and with the capability of mobile nodes been able to join in on the fly and create a network on their own, MANET's are vulnerable to a number of attacks such as: passive eavesdropping, active interfering, leakage of secret information, data tampering, impersonation, message replay, message distortion, and denial of service. Some of the reasons for the vulnerability could be listed as follows:
   a. Limited physical protection of each of the nodes.
   b. The sporadic nature of connectivity and the dynamically changing topology.
   c. The absence of a certification authority and the lack of a centralized monitoring or management point.

   Due to that fact that been vulnerable to attacks, it brings in the need for having intrusion detection, prevention, and related countermeasures to be in place [7]. The nature of this environment also introduces the byzantine failures [10], which may encounter within MANET routing protocols, which may result in a set of nodes getting compromised in a way that the incorrect and malicious behavior cannot be directly noted at all.

c) Reliability –Mobility been one of the main characteristics of MANET, it introduces issues such as packet losses, and data transmission errors. Furthermore, due to the wireless connectivity having limited transmission range, the possibility for these issues increases.

d) Quality of Service – QoS could be defined as "the ability of a network element (e.g., an application, a host, or a router) to provide some level of assurance for consistent network data delivery" [7]. The service attributes addressed by QOS includes network delay, delay variance (jitter), available bandwidth, the probability of packet loss (loss rate), and so on.

e) Internetworking – It is also expected to perform internetworking between MANET and fixed networks (mainly IP based) while performing the communication in ad-hoc networks. Moreover, to have routing protocols to support these types of behaviors in such a mobile device brings greater challenges for the harmonious mobility management.
f) Power consumption – Because all devices involved in this are mobile devices with limited power capacity, the functions of this network optimized for lean power consumption.

2.1.2 Vehicular Ad-hoc Network (VANET)

Vehicular Ad Hoc Network (VANET) could be described as a mobile ad-hoc network for Inter-Vehicle Communications (IVC). Here the vehicular nodes are geared with hosts and wireless transmitters and act as nodes in the network. The technological advancements in wireless ad-hoc networks have proved that having inter-vehicle communication based on vehicular ad-hoc networks adds a significant advantage over cellular network-based telematics concerning several aspects such as:

- Faster transmission for emergency messages.
- Costs reduction due to the absence of a central administration.
- Zero cost due to unlicensed frequency bands.
- Network's mesh structure makes it robust.

The reasons for focusing on VANETS are as follows:

- A large variety of applications for ad-hoc communication between vehicles, ranging from intelligent roadside information to personal information such as chatting and distributed games.
- Vehicle manufacturers and their suppliers believe that with VANETs, they could add cutting-edge solutions to future transportation by having better safety features. Which is one of the main reasons for them to invest their money in researches related to ad-hoc networks.
- Governments and public entities show great interest for better vehicles and road security. Therefore, these entities promote researches in the domain of vehicular networks.

- The current trend is to have more intelligent active safety systems such as adaptive airbag, adaptive cruise control, and electronic stability program.
- Having Vehicles to communicate with each other will enable them to have improved active safety features with intelligent on-board systems doing real-time processing to capture and respond fast to an accident that could occur at any given instant.

Many aspects that are problematic in developing ad-hoc networks in other environments are not a constraint in vehicular networks. Vehicles can be easily equipped with the wireless communication gear as additional features to the vehicle which will not be a problem. Then technologies like Dedicated Short-Range Communication (DSRC) or 3G cellular technologies can be used to transmit data between vehicles. Using GPS, vehicles can accurately find out their geographic position and display precise digital road maps, which will make aware of the road topology with great accuracy. Further high-power hosts could be geared to vehicular nodes, which makes computation power and storage space ignorable in inter-vehicle communications development. Therefore, algorithms can be optimized.

Following are some of the focused improvements/areas in vehicular networks:

- The design of Inter-Vehicle Communication (IVC) communication protocols can be a challenging task due to the diversity of application requirements and the tight coupling required between the applications and its underneath protocols.
- The rapid dynamic nature of the network poses challenges where the routing will have to adapt to situations such as in highways where the network topology may not be dense. Alternatively, in the city area, vehicles may not move very fast, and the topology of the network will be very dense. Buildings can cause transmissions issues; therefore, routing algorithms need to work in diverse environments.
- Special features of the vehicle such as GPS, Geographic Information System (GIS), and digital map which will help the vehicle to know its current location and its surrounding could be used to optimize the protocols. Having these types of information gathered will help in predicting the movement of

the vehicles. The motion of vehicles can significantly affect message delivery latency and performance.

- While some of the IVC applications may require the content to be disseminated to a faraway node, applications such as these designed for security warnings and alarming may strictly require the message to be unicasted where the content will be only delivered to nodes within a specific geographical boundary. For such security applications, it is very crucial to have a proper geocast mechanism that will deliver the message to all the nodes in the specified geographic area. This mechanism should be enhanced to support a time-stable geocast, where the message will be retained in the network for a defined period.
- Position information of the nodes to be highly accurate as many of the applications will operate based on the location details of the hosts, and routing protocols will use this position information to deliver the relevant messages.
- Vehicular nodes will have long transmission ranges with virtually unlimited lifetimes due to the large storage and transmission power that they could have.

Designing VANETS with high performance, scalability, and security, poses a very challenging task, but some of the limitations that exist in ad hoc networks could be mitigated. VANET safety applications will have collision detection and prevention safety warning messages, where non-safety applications will be used to gather real-time traffic congestion details and for entertainment purposes such as mobile infotainment, and many others.

2.1.3 DSRC - Dedicated Short-Range Communications

Dedicated Short Range Communication (DSRC) provides two-way short-to-medium range wireless communication capabilities that allow very high data transmission that is needed for active safety applications. In report and order FCC-03-324, a separate 75 MHz of spectrum in the 5.9 GHz band was allocated for Intelligent Transportations Systems (ITS) vehicle safety and mobility applications by the Federal

Communications Commission (FCC) [1]. Connected vehicle ITS applications provide connectivity:

- Between vehicles to avoid any crashes
- Between vehicles and infrastructure to have safety, mobility and environmental sustainability
- Among vehicles, infrastructure, and passengers' wireless devices to provide continuous real-time connectivity to all system users

How DSRC technology is used to prevent crashes and mobility, supports [1]:

- Active safety applications for vehicles
- Better secure communication
- Fast communication speed with low latency
- Not sensitive to weather
- Supports multi-path transmissions
- Designed for interoperability with proper standards

DSRC is the only short-range wireless alternative today that provides the following:

- Designated licensed bandwidth – For secure, reliable communications to take place. It is mainly allocated for vehicle safety applications by FCC Report and order FCC 03-324.
- Low Latency –Quick response in active safety applications is a must without having at least a millisecond delay.
- High Reliability when needed – Active safety applications need a high level of reliability in the communication connectivity. DSRC is not sensitive to extreme weather conditions (e.g., rain, fog, snow, etc.) and therefore able to function in any environmental condition.
- Priority for Safety Applications – Safety applications on DSRC are given priority over non-safety applications.
- Interoperability – Interoperability is one of the main factors for the successful development of active safety applications, using widely accepted standards.

- Security and Privacy – DSRC provides safety message authentication and privacy.

2.2 V2V Standards

There are mainly three categories of standards involved with vehicular networks. Wireless Access in Vehicular Environment, also known as WAVE was introduced by the IEEE 802.11 standard body for V2V networks.

As shown in Figure 2.1 IEEE 802.11p WAVE is one of the components in the protocol stack for V2V operations. The IEEE 802.11p standard is mainly responsible of handling the MAC and PHY layer related functionalities, and the V2V operation side aspect is taken care by the upper layer IEEE 1609 standards, it is intended to operate with IEEE 802.11p.

A separate J2735 standard which will work on the application layer is developed by the Society of Automotive Engineers (SAE). It defines message sets, data frames, and elements that are used for V2V and V2I safety exchanges.

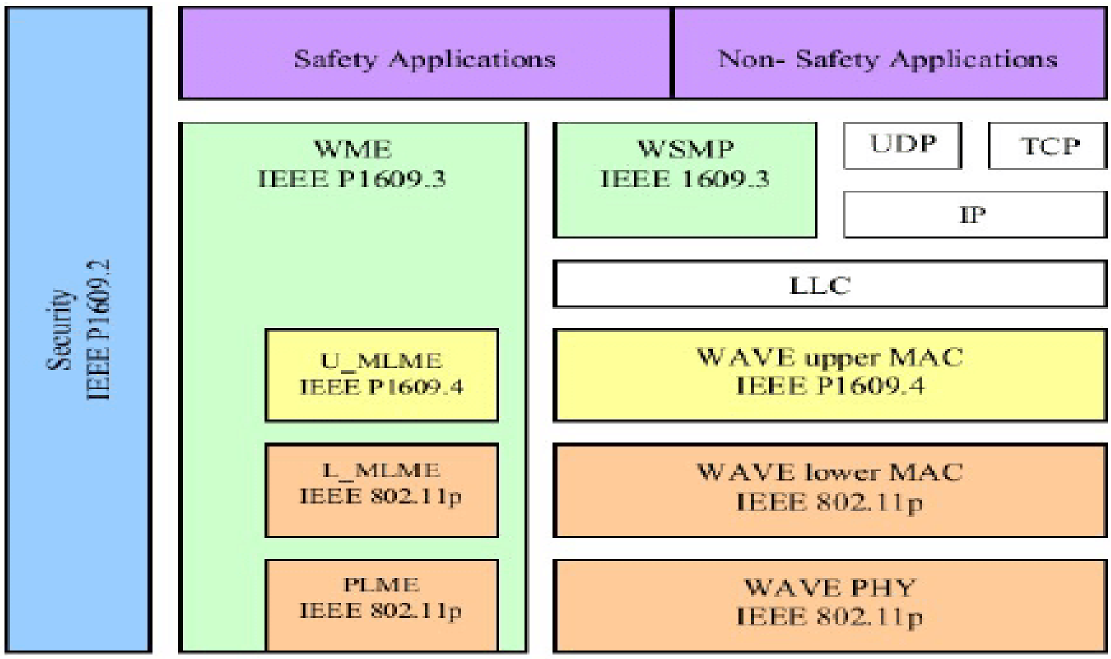

Figure 2.1 V2V standards and communication stacks [10].

2.2.1 IEEE 802.11p (WAVE)

The IEEE 802.11p WAVE standardization process was initiated with the allocation of the DSRC spectrum band in the United States and the initiation taken to standardize the technology that could be used for the DSRC band. In 1999, the U.S. Federal Communication Commission allocated 75MHz of Dedicated Short-Range Communications (DSRC spectrum at 5.9 GHz to be used mainly for V2V and V2I communications. The primary goal of it is to provide public safety applications that can avoid accidents and save lives while improving the traffic flow.

There are seven 10 MHz wide channels in the DSRC spectrum. Channel 178 is dedicated for the control channel (CCH), which is responsible for safety-related communications only. The two channels at the ends of the spectrum band are reserved for special uses. The remaining are service channels (SCH) provided for both safety and non-safety applications.

American Society for Testing and Materials (ASTM) working group in the U.S. initiated the standardization of the DSRC technology. In particular, the FCC rule and order specifically referenced this document for DSRC spectrum usage rules. In 2004, this effort was transferred to the IEEE 802.11 standard group as DSRC radio technology became essential for IEEE 802.11a that is adjusted for low overhead operations in the DSRC spectrum. Within IEEE 802.11 DSRC is known as IEEE 802.11p WAVE. IEEE 802.11p is not a standalone standard. It is intended to amend the overall IEEE 802.11 standard.

One main reason for including the DSRC radio technology in the IEEE 802.11 is that now WAVE is expected to function globally. The IEEE 802.11p standard is meant to:

- To describe the necessary functions and services that are required by the stations that are operating with WAVE, to operate in fast-changing environments and exchange messages without having to join a Basic Service Set (BSS), as in the traditional IEEE 802.11 use case.
- Define the WAVE signaling technique and interface functions that are controlled by the IEEE 802.11 MAC.

2.2.2 IEEE 1609

The IEEE 1609 family of standards defines the following parts [10]:

- architecture,
- communication model,
- management structure,
- security mechanisms and
- Physical access for high speed (< 27 Mbps), short range (< 1,000m) and low latency wireless communications in the vehicular environment.

On-Board Unit (OBU), Road Side Unit (RSU), and WAVE interface are the main architecture components defined in this structure. The IEEE 1609.3 standard covers the WAVE connection setup and management. The IEEE 1609.4 standard sits on top of the IEEE 802.11p and enables operation of upper layers across multiple channels, without requiring knowledge of PHY parameters. The standards also define how applications that utilize WAVE will function in WAVE environment. They provide extensions to the physical channel access defined in WAVE.

2.2.3 SAE J2735

J2735 is developed and maintained by the Society of Automotive Engineers, which defines a message set, its data frames, and data elements. This is mainly targeted to be used by the applications that are intended to use the (DSRC/WAVE) communications systems. J2735 defines the message structure that is required to have when developing active safety applications according to the DSRC standards which enables interoperability for DSRC applications. Content delivered by the communication system at the application layer is defined by the message sets. Therefore, the message payload is defined in the physical layer. Message sets depend on the lower layers of the DSRC protocol stack to make sure that the content is delivered from the source node to the destination node. The IEEE 802.11p standard addresses the lower layers, and the upper layer protocols are covered in the IEEE 1609.x series of standards.

The basic safety message is the most important message type (often informally called *heartbeat* message, as it performs a constant exchange with the nearby vehicles). The other kinds of messages are the following [14]:

- A la carte message – the message is composed by the source node freely, allowing for flexible data exchange.
- Emergency vehicle alert message – an alert may be broadcasted by an emergency vehicle operating in that area, to its nearby vehicles.
- Generic transfer message – will contain general information that could be shared and exchanged with roadside units.
- Probe vehicle data message – will contain status information about the vehicle that can be used by the applications to analyze the traveling conditions on the road.
- Common safety request message – here the vehicular nodes will be exchanging safety messages and warnings that will be used by safety applications.

2.3 Routing in Vehicular Networks

The main requirement of routing protocols is the least consumption of network resources and reaches the least communication time. VANETs also have to be the same as the standard routing protocols. In VANETs, finding the route and maintaining network topology; however, are challenges for vehicles dynamic environments. Therefore, to solve challenges, various routing methods are proposed. As seen in Table 2.1 we classify those routing methods into five groups, namely ad-hoc, position based, broadcast, geo-cast, and clustering-based routing [11]. Because a cluster-based data forwarding scheme has a hierarchical structure for each node based on clustering communications, if one node (cluster header) can forward data unilaterally for each node, it reduces data collision at data communication. However, a cluster-based routing protocol also has drawbacks. As clusters in member nodes have merged to another node or separate another area, they make more the number of counts for cluster reconfigurations.

Table 2.1 Routing protocol types.

Routing Type	Characteristic
Ad-hoc routing	Without having an access point (AP) or a base station, to form a network only with vehicles.
Geographic based routing	After gaining location details of the vehicle via a GPS and transferring these details to the destination. This requires that the nodes involved in the communication, are fully aware of their location details and the source node to be aware of the location details of the destination node. Prior knowledge of the network topology is not necessary.
Broadcast routing	Used to provide an emergency message to all vehicles
Geo-cast routing	By transferring data only to a selected set of vehicles in some area, it will be able to reduce network collision
Cluster-based routing	The protocol will divide the nodes of the ad hoc network into some overlapping or disjoint 2-hop-diameter clusters in a distributed manner. A cluster head is selected for each cluster to maintain cluster membership information. Inter-cluster routes are discovered dynamically using the cluster membership information kept at each cluster head. By clustering nodes into groups, the protocol efficiently minimizes the flooding traffic during route discovery and speeds up this process as well [4].

2.3.1 Broadcasting Techniques in Well Connected Networks

Table 2.2 explains the broadcasting strategies that are used in VANET [5] and how and at what situations they are used. Each of these methods may have advantages and disadvantages over the other depending on the situation. Therefore, using of each strategy depends on the goal that needs to be achieved depending on the importance of the content that needs to be shared, such as it would be suitable to using flooding for a warning message. However, to pass general content such as traffic details of a road using the flooding mechanism may have adverse effects.

Table 2.2 Broadcasting strategies in VANET.

Strategy	Description
Flooding	Each node will forward the packet only once until all nodes in the network gets the packet
Probabilistic Forwarding	In this mechanism, a predefined probability value is used for rebroadcasting the message. In a dense network, most of the nodes may cover the same area when rebroadcasting happens at some probability value, it reduces some network overhead without harming on effectiveness. In sparse networks, the probability value will be higher.
Counter-based broadcasting	Nodes will rebroadcast the message only if it gets the message from less than a particular number of neighbors. The counter is incremented by one each time it gets a duplicate packet. Once the timer is expired, if the counter is less than a predefined threshold then the node will start to retransmit the message.
Location-based scheme	In this, nodes are fully aware of its location by using a technology such as GPS. The node retransmits the message if and only if the additional area covered when the node rebroadcast the message is greater than the threshold A.
Distance-based schemes	In distance-based methods nodes rebroadcast the message if and only if the distance to each neighbor that already retransmitted the message id > D.

2.3.2 Position-based Routing

We can distinguish two different approaches in V2V routing as topology-based and position-based routing. As the name suggests, in Topology-based routing the topology is known prior, and these details are used when forwarding the content. Topology-based routing can be further categorized as proactive (table-driven), reactive (on-demand), and hybrid approaches.

Position-based routing algorithms can overcome some of the limitations faced in topology-based routing protocols, by using additional information such as the location of the nodes involved in the communication to be available prior. Position-based algorithms avoid overhead by requiring only accurate neighborhood information and an estimate of the position of the destination.

In unicast, the sender is required to include the destination address in the packet. When this packet is being inspected at each node, these destination details are checked in order to make the routing decision. Therefore position-based routing could merely avoid maintaining any route details. Therefore, the nodes do not need to maintain any routing tables. This type of service is called geocasting (see Section 2.3.4).

In Position-based routing, the next hop is selected based on the position details in a way that the message is forwarded in the geographic direction of the destination. The forwarding decision is purely made based on local knowledge. It avoids the need for maintaining route information from the sender to the destination. This makes position-based routing highly scalable and very robust against frequent topological changes and therefore fits well for vehicular networks due to the following reasons:

- Involves high-density node count.
- Very general communication pattern with many host pairs communicating.
- Need for low latency first -packet delivery.
- Highly dynamic topology.

Thus, with unicast geographic routing, the task of routing packets from a source to a destination can be separated into two distinct aspects as:

- Finding the location of the destination.
- Making the routing decision based on the destination details.

2.3.3 Location Services

Location services are used to finding out the destination details of a packet that needs to be sent. Location services can be categorized based on how many nodes host the service. This can be either a set of nodes or all nodes of the network. Location servers may maintain the position of some specific or all nodes in the network. The four possible combinations can be abbreviated as some-for-some, some-for -all, all for some, and all-for-all. Some of the location services could be listed as follows:

- DREAM – Distance Routing Effect Algorithm for Mobility - here all the nodes maintains position details of all the other nodes. This location service could be classified as an all-for-all approach. An entry in the position database will have an identifier for the node, the direction, the distance to the node and the time that the record was created. The accuracy of such an entry depends on its age.

- Quorum-based Location service – This uses the concept of quorum that is widely used in distributed database design.
- Grid Location Service (GLS) – this protocol performs in such a way that mobile nodes periodically update the location servers with its current location [16].

2.3.4 Geocasting

Geocasting is a variation on the concept of multicasting, where the data packet is delivered to a set of nodes that are within a specified geographic area. In geocasting, each geocast message is associated with a specific geographic area. If a node resides within the geocast region, it automatically becomes a member of the corresponding geocast group at that time and will receive the geocast packet.

To identify the group membership, nodes are required to be aware of their location coordinate details; this can be accomplished by using the GPS. This requires that the nodes are equipped with GPS devices. A destination geographic address would be represented by some closed polygon such as a [7] a circle (center point, radius) or polygon ($point_1$, $point_2$, …., $point_n$). Here the vertexes are represented using geographic coordinates. This format is used to send the content to any node within the specified geographic area defined by the closed polygon.

A possible application of geocast can be [7]:

- Geographic messaging: passing a message to a specific geographical area defined by latitude and longitude. For example, an emergency safety message to everyone to evacuate from a landslide area.
- Geographic services and advertising: Sharing advertisement details only to clients who will potentially be interested, within a certain geographic range from the server (which may be mobile itself).
- "Who is around" services: identifying other nodes presented in the specified geographic area defined by an arbitrary polygon.

While geocasting is an important service, there can be a situation where we will use multicast rather than broadcast into the geographic areas. Some of the situations could be like, passing a message to all the bikes on a specific roadway, or all police cars, rather than sending the message to everybody. This aspect is called geomulticasting and is another important feature an underlying geographic routing must support.

2.3.5 Multicasting

In multicasting, the sender sends a message to multiple receivers in a single operation. If we are to send the same data from a single sender to multiple clients one by one, it can cost a considerable amount of time and bandwidth. By using multicasting, it allows the sender to pass the content to the intended destination nodes with minimum network resources.

The difference between multicasting and separately unicasting data to several destinations is best described by the host group model [17]: "a host group is a set of network entities sharing a common identifying multicast address, all receiving any data packets addressed to this multicast address by senders (sources)."

Here from the sender's point of view, this model reduces the multicast service interface to a unicast one. Therefore, the purpose of the multicast model was to reduce the many unicast connections into a multicast tree for a group of destination nodes. The groups can have local (LAN) or global (WAN) membership, be transient or persistent in time, and may even have a constant or varying membership. Explicit multicast support could be used in situations such as a single packet to be sent from the sender and replicated at a network node whenever it needs to be forwarded on multiple nodes (in the Internet, ongoing links) to reach the receiver.

2.3.6 GeoNet (Geographic addressing and routing)

GeoNet was introduced as a way of exchanging information that is relevant to a specific area - potentially far away from the information source, we refer to these capabilities as geographic addressing and routing (geo-networking). This is mainly done by combining geo-networking and IPv6 into a single communication architecture, which could be referred to as IPv6 geo-networking [19]. This combination of geo-networking and IPv6 will make way to allow for both IPv6 and non-IPv6 communications.

The vehicle would be equipped with the following:

- An on-board unit (OBU) which will function as a mobile router that is responsible in performing communication with other nodes, road-side units (RSUs), and devices on the Internet, this can also include multiple interfaces of various radio types.
- Several application units (AUs) such as GPS for location services, a dedicated device for safety applications or infotainment devices.

2.4 Content dissemination

Content dissemination in simple could be described as the circulation of related information among the others. Therefore, in the V2V context, these types of content could include such as advertising, traffic warnings and emergency announcements. Dissemination strategies could be categorized as:

i) Push-based technique functions in a way that the aim is to proactively pass the details to a set of nodes which will potentially be interested in the information, and

ii) Pull-based is used when vehicles need to explicitly request specific details.

(a) Push-based dissemination. Popular information is disseminated to all interested vehicles inside the greyed area

(b) Pull-based Dissemination. Vehicles request custom information from a nearby base station. The information is then routed back.

Figure 2.2 Content dissemination methods [03].

Push-based content dissemination enables applications to share details with multiple nodes at the same time (i.e., general information like traffic information). In the example shown in Figure 2.2(a) where a base station that has the relevant information is pushing information about roadworks. The dissemination should be constrained within areas where there are vehicles interested in receiving this information. Here the content-based routing approach can be used to deliver the information only to the affected vehicles. In pull-based dissemination, nodes pull custom information from the nearby base station that has the relevant information. An example is given in Figure 2.2(b) where a node requests for specific information from the base station.

2.4.1 Geographic Opportunistic Routing

In V2V, the information involved is mostly related to specific geographic regions (e.g., landslide). Nodes may even pass this information to know gateways with the intention of reaching other networks (e.g., route content to the closest known V2I). A routing protocol will facilitate multi-hop communication between locations for the details to be passed. Furthermore, it might be required to push out information to specific areas. This may happen in two steps:

i) route the content inside the intended area and
ii) disseminate it around

This brings in the capability of vehicles pulling information from the nearest V2I using geographic routing.

2.4.2 Delay Tolerant Networks

In fixed networks, link failures are usually exceptional, whereas in MANETs they are common. These disconnections are, in most cases, unpredictable and lead to intermittently connected mobile ad-hoc networks. In fact, in most mobile networks the fundamental assumption of an existing path between the communication parties is not valid and, hence, any synchronous communication paradigm is likely to show poor performance. Therefore, the new research area of Delay Tolerant Networks (DTN) has emerged where an asynchronous communication model is employed. These networks are also referred to as Opportunistic Networks (ON). DTN protocols provide communication in such performance-challenged environments, where continuous end-to-end connectivity cannot be assumed, by employing a store-and-forward message switching: fragments of a message (or the whole message) are forwarded from host to host and stored until the message reaches the destination. Data exchange may happen when there are opportunistic contacts of the hosts. The mobility pattern of the host and the selection of the nodes of the next message carrier may determine if the message will eventually be delivered to the intended destination.

Epidemic dissemination or gossip-based methods can be used to pass content to multiple nodes in the network. In this range of protocols, nodes will forward the content to other nodes that they may interact with while in the movement, which will make the new node a carrier of the message. This way the message will get delivered to all the nodes in the network if the mobility patterns allow this.

2.4.3 Vehicle Gossiping

The sparsely populated VANETS are those with very less density of traffic due to being situated in rural areas or highly-secure lanes. These sparsely populated VANETS may have very less V2V communication and makes it difficult to function with the normal VANET's message dissemination process, this is tackled by *gossip spread*, content distribution protocols by which DSRC vehicles cache and then exchange the content while in range with other DSRC nodes. This approach is advantageous as there will be a smaller number of vehicles with V2V capability during the early development years [6]. The methods used in such situations are discussed next.

2.4.3.1 Store, Carry, and Forward Approach

Here the node will select a set of candidate forwarders that will be communicating with the requesting node or moving towards the requesting node [5].

2.4.3.2 Gossip Networks

Signed Certificate Timestamp (SCT) approach using greedy routing; a content is passed to the neighboring node with least distance to the destination. The closeness will be determined by its physical location, as in geographic routing used by ad-hoc networks.

2.5 Simulation Tools

In this section, we describe the different tools that were used in this research to simulate the research problem. OMNeT++, SUMO, and Veins are the most commonly used tools in V2V related researches.

2.5.1 OMNeT++

OMNeT++ has been developed using the Eclipse toolkit which is an extensible, Java-based framework which supports plug-ins. It is mainly used for developing network simulators, and it could be thought of as an Eclipse installation with some additional - simulation related - toolkit.

OMNeT++ has a component-based architecture. These Components are programmed in C++, then packaged into larger components and models using a high-level language (NED). NED (NEtwork Description) is the topology description language of OMNeT++. Components of OMNeT++ include [22]:

i) Simulation kernel library
ii) NED topology description language
iii) OMNeT++ IDE based on the Eclipse platform
iv) GUI for simulation execution, links into simulation executable (Tkenv)
v) command-line user interface for simulation execution (Cmdenv)
vi) utilities (make file creation tool, etc.)

OMNeT++ acts as the main Integration tool between SUMO and Veins and is used to do the necessary programming and customizations to Veins, to simulate our specific research problem.

2.5.2 SUMO (Simulation of Urban MObility)

SUMO is an open source portable road traffic simulator tool that is designed to simulate large road networks. SUMO supports modeling of intermodal traffic systems including road vehicles, public transport and pedestrians which allows simulating real-world scenarios. It also consists of different tools that support tasks such as route finding, visualization, emission calculation and network import. In this research, SUMO was used to design the road network. SUMO Contributes largely to different V2V related researches due to the ability to simulate the road network realistically.

2.5.3 Veins

Veins is an open source framework that has been developed to run vehicular network simulations. It is coupled with two other simulators, OMNeT++ which is an event-based network simulator, and SUMO, a road traffic simulator. Veins provide a rich set of models for Inter-vehicular Communication simulations. These models provide all the necessary components that are needed for V2V communication which makes Veins to be selected for a large number of V2V related researches.

2.5.4 MiXiM

MiXiM is a modeling framework that is used in OMNeT++ to model mobile and fixed wireless networks. It provides detailed models of radio wave propagation, interference estimation, radio transceiver power consumption and wireless MAC protocols. It consists of several OMNeT++ libraries developed for mobile and wireless simulations.

2.5.5 Integration of the Tools

Main integration point of these tools is through OMNeT++. Veins run on top of OMNeT++, similar to a OMNeT++ project, it provides the basic framework that is required for the vehicular network behavior when it comes to V2V communication. SUMO is mainly responsible for handling vehicle network simulation. Network simulation is performed using OMNeT++ along with the physical layer modeling toolkit MiXiM, which makes it possible to employ accurate models for radio interference, as well as shadowing by static and moving obstacles. Both simulators are capable of communicating with each other. This way, the influence of vehicular networks on road traffic can be modeled, and complex interactions between both domains examined. Figure 2.3 shows the overall architecture as to how these tools are connected with each other.

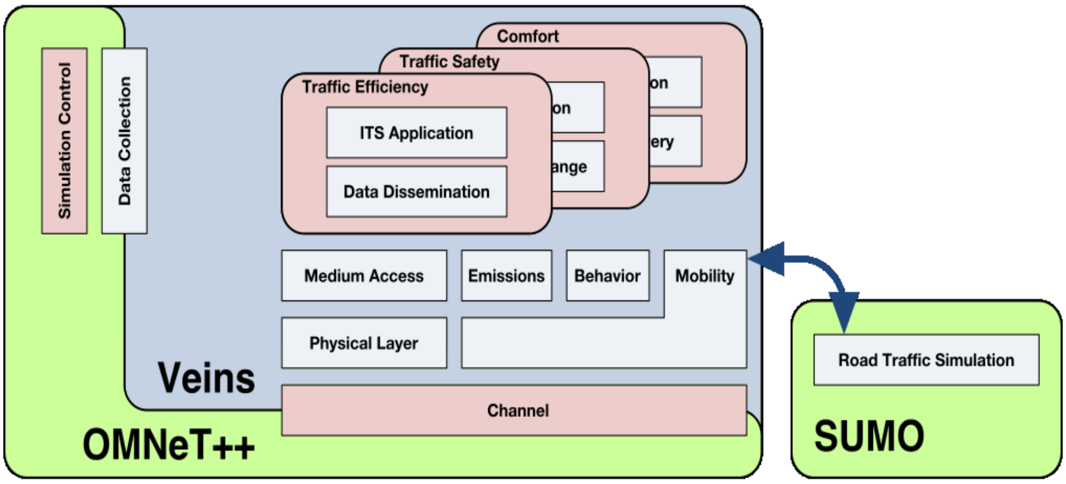

Figure 2.3 High-level architecture of the simulation toolkit [23]

2.5.6 Data Extraction Tool

A customized tool was developed using .Net C#, to extract the relevant data from the OMNeT++ simulation log file. Once the relevant data is extracted, data is then summarized in a preferred format in order to come with the graphs.

2.6 Summary

In this chapter, we looked into various network types such as mobile ad-hoc network, VANET and the DSRC technology spectrum and their strengths, weaknesses and main challenges faced by those networks. Then we described the available standards for V2V communication IEEE 802.11p, IEEE 1609 and SAE J2735, how the initiation took place for IEEE 802.11p and the usage of each of them.

We discussed various Routing mechanism available in for V2V such as the broadcast technique, position-based routing, Location services, Geo Casting, Multicasting and GeoNet and when these mechanisms would fit the best. We then Described how content dissemination strategies such as the Geographic Opportunistic routing, delayed tolerant networks and vehicle gossiping could be used, depending on different scenarios. Finally, we described the simulation tools and frameworks that were used in this research to simulate our research problem and how each of these tools connect with one another.

3 Research Methodology

This chapter describes the possible approaches available to come up with a solution to the problem that is identified and describe the model that was derived after analyzing the behavior of the vehicular network. As explained in Chapter 2, section 2.4.4, geocast mechanism to some extent seems to provide a solution, but relies on GPS navigation systems, as geocasting requires the node to know its GPS location. Situations, where GPS become unavailable, seems to be a major problem. Also, the main importance of this system is finding out to what extent is the particular content is relevant and valid for the selected destination vehicle. Mainly during catastrophic situations, the validity and accuracy of the entire system as a whole are very crucial, and any possibility of error can lead to a disaster.

To ensure that the content is retained within the V2V network both efficiently and with high certainty, it is important to address problems such as how and when to disseminate content, how to maintain order and honor priorities of the content, number of replicas to maintain, and when to evict the content. We focus on a problem where there is no infrastructure and relatively-low vehicle density. The main challenges could be categorized as successfully delivering the information to closest vehicles so that the information could be spread (i.e., content dissemination) to those who are interested in the considered geographical area, the validity period of information, identifying the validity boundary, and the actual validity of the information. Moreover, content dissemination should be aware of the content priority, as well as the availability of resources such as bandwidth, memory, and power.

Consider a set of contents **C**, where each content $c_i \in C$ has a valid time c_i^t, valid geography c_i^{geo}. Also, consider a set of vehicle **V** where each vehicle $v_i \in V$ has speed v_i^{speed}, trajectory v_i^{traj}, content interest v_i^{inst} Let α be the flow rate of the vehicles.

3.1 Proposed System and Approach

The high-level problem could be segregated into three significant subproblems as follows:

a) Vehicles moving towards each other on a straight road (see Figure 3.1), and one vehicle captures an incident, which is valid to a specific geographical boundary and should share this content with potential vehicles to whom this information may be valid. So as shown in Figure 3.1, the vehicle on the left has some content that needs to be shared with another vehicle to whom this content may be valid but within the valid geographical boundary.

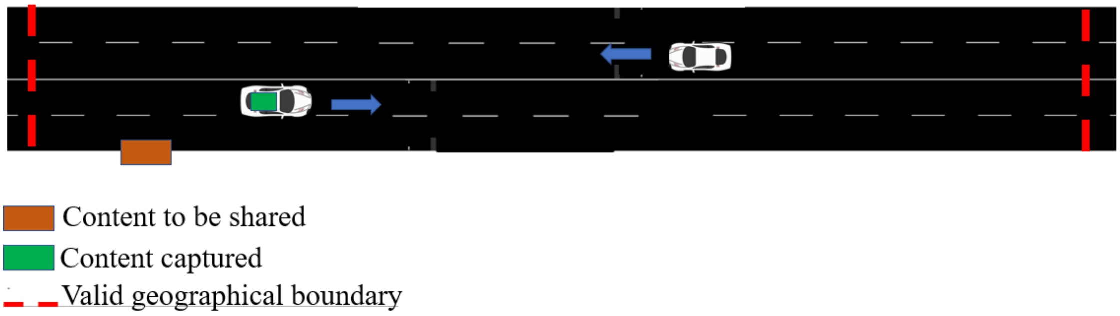

Figure 3.1 Vehicle movement in a straight road.

b) Vehicles passing each other in a T-junction (see Figure 3.2). In this scenario depending on the valid geographical area of the information, the potential vehicles which may require this information may vary as the vehicles could take different routes. One of the most significant challenges in this scenario is that, identifying the valid potential vehicle to whom the content may be valid, which requires knowing the destination of each vehicle.

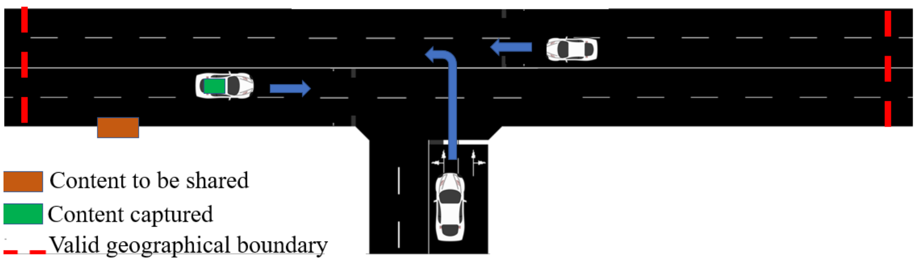

Figure 3.2 Vehicle movement in the T-junction.

c) Vehicles meeting at an intersection (see Figure 3.3) and depending on the interests of the person, data to be shared. Here again, the potential vehicles whom may require the content may vary as the vehicles could take different routes which may lead to various other destinations.

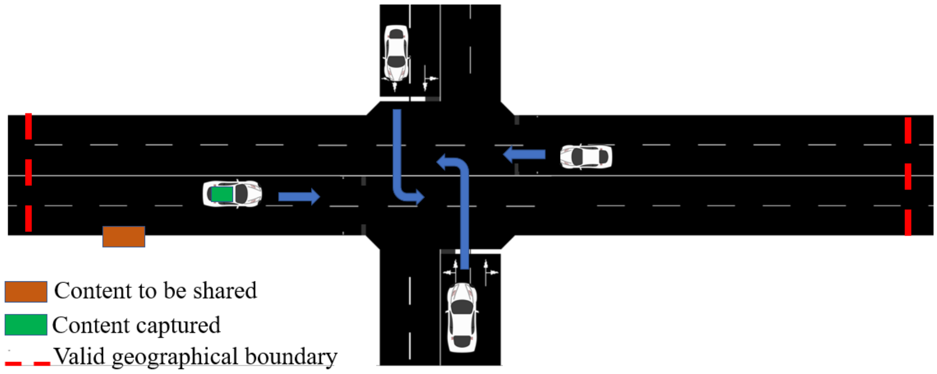

Figure 3.3 Vehicle movement in a four-way junction.

In each of the above, we will first try to come up with a mathematical model to find out the probability of disseminating the content considering the factors such as how and when to disseminate content, how to maintain order and honor priorities of the content, number of replicas to maintain, and when to evict the content. Once we are able to successfully find a solution for all of the above, we can simulate the findings using the SUMU [20] simulator to test the utility of the proposed model.

3.2 Selection of Simulation Tools

Selection of the tools for this research was based on the below criteria:

d) Should support all the possible behavior types that a vehicle could behave on the road such as, overtaking, speed control and variation, parking and turning to different roads.

e) Should be able to include other road infrastructure types such as color lights, junctions, public transport and pedestrians which allows simulating real-world scenarios.

f) Should support V2V communication features that are adhering to the IEEE V2V related protocols and standards.

g) The tool should support adding up of new behavior such as disseminating messages based on some probability. Moreover, vehicle nodes should be able to store and forward messages that are received.

h) Should support event triggering such as an accident in the roadway or capturing any similar type of events such as a landslide.

SUMO supports all the necessary vehicle behavior types and designing of road networks. Veins have been developed on top of OMNeT++ as a V2V simulation framework while adhering to the protocols and standards defined by IEEE and the framework could be customized to add new behaviors such as having a store and forward mechanism for the nodes.

3.3 Model Generation

The primary objective was to identify the breaking point probability value which will decide the retainability or, loss of the information been passed in the network within the area of interest within the specific period. The formula was derived after analyzing the behavior of the network with the store and forward mechanism in place. The formula is described below.

Let p be the probability of content to be disseminated while, d be the distance of the area of interest given in meters, α be the vehicle arrival rate (nodes per minute), v be the vehicle speed (kmph), and r be the communication range in meters. Figure 3.4 shows the parameter details that we have considered to come up with the model.

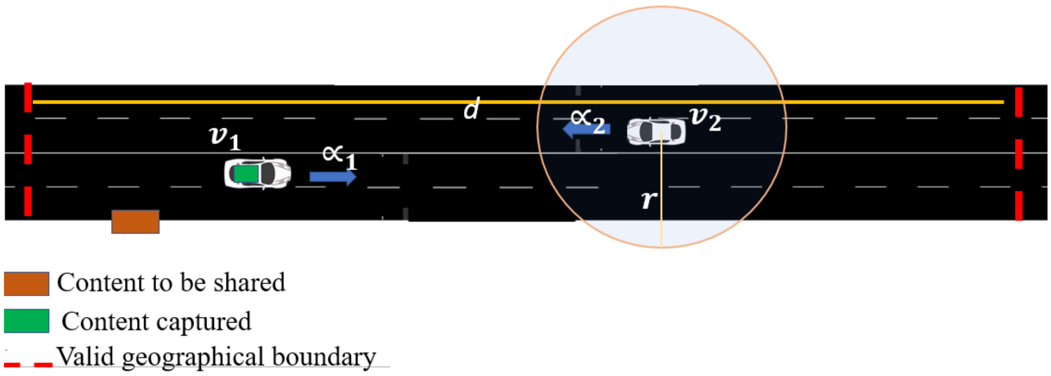

Figure 3.4 Parameters for model generation.

3.3.1 Straight Road

Given the distance of the area of interest d, vehicle arrival rates as $\propto_1$ with a speed of v_1 and $\propto_2$ coming from opposite directions, with a speed of v_2, and the communication range of the nodes as r.

$$\text{Time taken by the vehicle to cover the distance} = \frac{d}{v_x} \qquad (3.1)$$

Provided that the vehicle flow rate as $\propto_x$, then the number of vehicles can be derived as follows:

Number of vehicles = $\frac{d\propto_x}{v_x}$ therefore, the total number of nodes within the AOI for both directions can be derived as follows:

$$\text{Nodes within the AOI} = \frac{d\propto_1}{v_1} + \frac{d\propto_2}{v_2} \qquad (3.2)$$

Given the communication range r (for one direction of the vehicle from the center), the number of nodes that will communicate could be stated as:

$$\text{Number of nodes that communicates} = \frac{2r.\propto_1}{v_1} + \frac{d.\propto_2}{v_2} \qquad (3.3)$$

In the equation 3.3, the $\frac{2\,r.\propto_1}{v_1}$ denotes the vehicle node with the message and the r is multiplied by two, as the node will be communicating with vehicles in front and rear. If p is the probability for at least each node to get the message, then the total number of messages that will be passed will be:

$$\text{number of messages} = p\ (node\ count\ that\ will\ be\ encountered)$$

Hence,

$$\text{Total number of messages} = p\ (\frac{d\propto_1}{v_1} + \frac{d\propto_2}{v_2}) \qquad (3.4)$$

Therefore, if every node needs to have this message

$$p\left(\frac{2\,r.\propto_1}{v_1} + \frac{d\propto_2}{v_2}\right).d.\left(\frac{\propto_1}{v_1} + \frac{\propto_2}{v_2}\right) \geq d.\left(\frac{\propto_1}{v_1} + \frac{\propto_2}{v_2}\right) \qquad (3.5)$$

Therefore, the minimum probability value that needs to be maintained,

$$p \leq \frac{1}{\left(\frac{2r\propto_1}{v_1}\right)+\left(\frac{d\propto_2}{v_2}\right)} \qquad (3.6)$$

3.3.2 T-Junction

Having the model generated for the straight road, we will now try to extend it for a T-junction scenario. As shown in Figure 3.5, there are two vehicles moving towards *Edge 01* with vehicle arrival rates of $\propto_2$ and $\propto_3$, vehicles speeds of v_2 and v_3 and the distance that each of these vehicles will be interacting with the primary vehicle with the content is, d and $d/2$. In this scenario the, destination of the primary vehicle will be *Edge 02*.

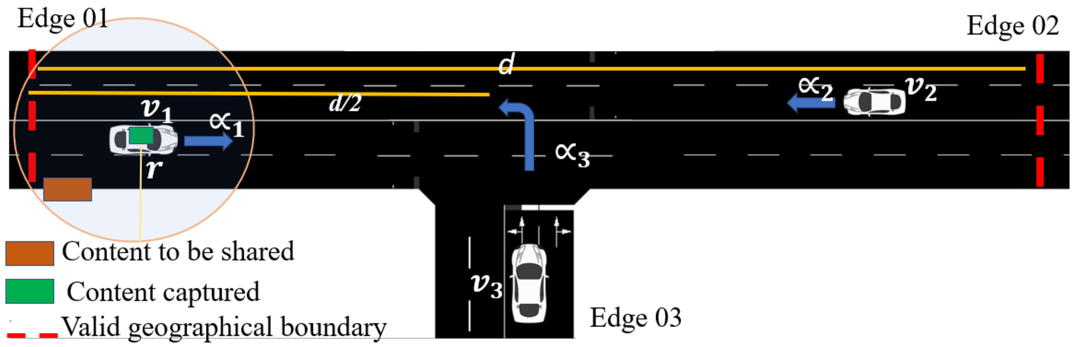

Figure 3.5 Parameters for model generation for the T-junction.

To derive at the final model for the T-junction, we mainly focus on the area that the nodes communicate with each other. Therefore, in this scenario,

$$\text{Number of nodes that communicates} = \frac{2r.\propto_1}{v_1} + \frac{d.\propto_2}{v_2} + \frac{d.\propto_3}{2v_3} \qquad (3.7)$$

Applying this to the final model derived in Section 3.3.1, will result in the following.

$$p \leq \frac{1}{\left(\frac{2r\propto_1}{v_1}\right)+\left(\frac{d\propto_2}{v_2}\right)+\left(\frac{d\propto_3}{2v_3}\right)} \qquad (3.8)$$

3.3.3 Four-way Junction

Similarly, like we extended the model for the T-junction, we could extend it to be applicable for a four-way junction. As shown in Figure 3.6, the vehicle with the content is moving towards *Edge 02* while the other vehicles are moving towards *Edge 01*.

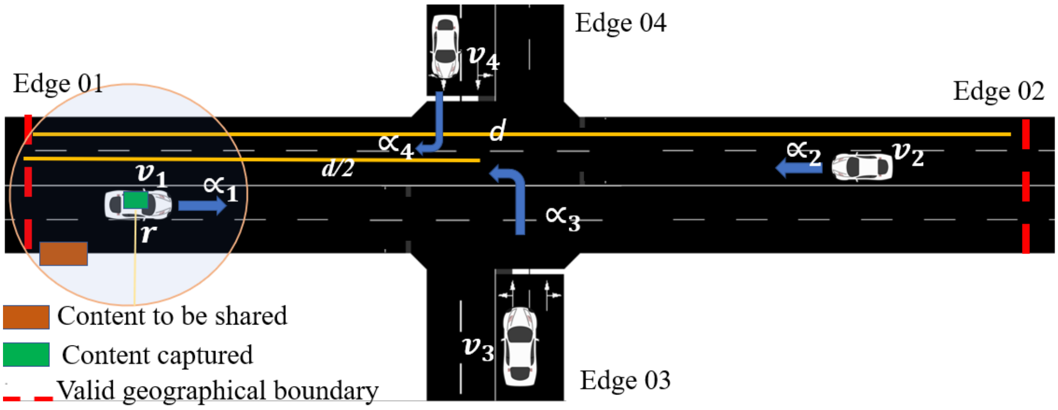

Figure 3.6 Parameters for model generation for the four-way junction.

To derive at the final model for the Four-way Junction, we mainly focus on the area that the nodes communicate with each other. Therefore, in this scenario, for the vehicles that are traveling from *Edge 03* and *Edge 04* towards *Edge 01,* we will calculate the speed and the vehicle arrival rate as shown below,

$$\propto_5 = \propto_3 + \propto_4$$

$$v_5 = (v_3 + v_4)/2$$

Using these values, we can now get the number of nodes that communicate as:

$$\text{Number of nodes that communicates} = \frac{2r.\propto_1}{v_1} + \frac{d.\propto_2}{v_2} + \frac{d.\propto_5}{2v_5} \quad (3.9)$$

Applying this to the final model derived in 3.3.1, will result in the following.

$$p \leq \frac{1}{\left(\frac{2r\propto_1}{v_1}\right)+\left(\frac{d\propto_2}{v_2}\right)+\left(\frac{d\propto_5}{2v_5}\right)} \quad (4.0)$$

3.4 Customizing Veins

Veins had to be customized to make the simulation to have the functionalities that are required for this research and to extract the relevant data that is important to analyze the behavior of the network. Following are the main customizations that were done to the Veins framework:

i) Mechanism to support the store and forward - In the core of the research problem lies identifying how a specific message that is valid to a specific geographical boundary could be effectively communicated to other vehicular nodes that may be interested in the same data. For this matter, the specific message is triggered within the area of interest, and then this message is passed to the other neighbor vehicles or any vehicle that it may meet in the given geographical boundary. Once this message is being passed to another node, provided that the communication happens in the area of interest, it is then stored in the new node, with the same message id with the relevant message and this behavior is then repeated in the new nodes, provided that these nodes are in the area of interest.

ii) Specific message passing to be valid only within the specified geographical boundary – The specific message could be stored in the nodes and then forwarded to the next nodes that the vehicle might meet, but this communication will be only valid within the defined geographical boundary. These boundaries are defined as X and Y coordinates in OMNeT++.

iii) Message to be passed to the nodes with a given probability – A separate method was included, that lets the framework to disseminate the message based on the probability. This probability is checked before the specific message been passed to other nodes.

3.5 Data Extraction

After running the simulator for a specific time (e.g., 30 minutes) with the help of the data extraction tool, the relevant data is extracted from the OMNeT++ logfile and summarized in a manner that the data could be visualized in a graph. Table 3.1 shows an example of such summarized data in tabular format.

Along with the time, the number of nodes that has the specific message within the geographical boundary and the total number of vehicular nodes that were participated in the simulation at that particular time. Table 3.1 shows an example of this data. An example of the graph derived from this data is shown in Figure 3.7. Graph in Figure 3.7 shows the total number of nodes that has the message, that are within the AOI. Graph in Figure 3.7 shows the total number of nodes that has the message, that are within the AOI.

Table 3.1 Node count with the message within the AOI.

Row ID	Time (S)	Node Count with The Message	Total Vehicle Count
1	1	0	2
2	11	0	3
3	16	0	4
10	82.94	1	11
28	275.95	3	32
29	276	3	33

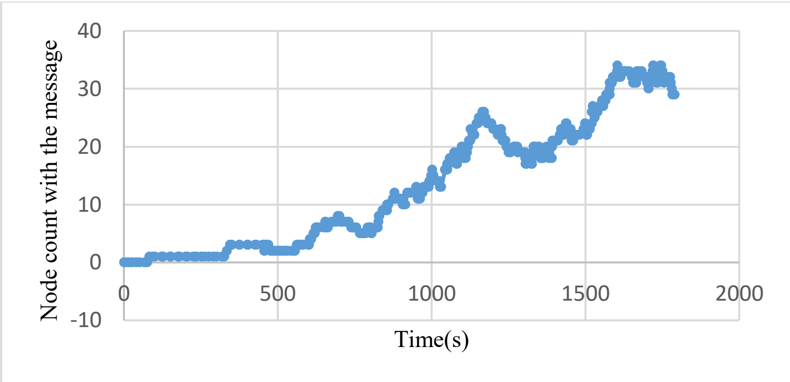

Figure 3.7 Node count with the message with time within the AOI.

3.6 Summary

In this chapter, we described the three approaches we chose to evaluate the model that we derived, straight road, T-junction and finally the Four-way intersection. We then described the derived model and how it was derived. We then described how this model could be used similarly for T-junction and four-way intersection. Finally, we described the customizations that had to be done for Veins framework, for it to have the basic functionalities that are required for this research and how the data was extracted to visualize the results in graphical format.

4 Performance Evaluation

This chapter discusses the evaluation of the model based on the capability of retaining the message in the network. Section 4.2 to section 4.13, presents the resulted graphs in detail and the outcome of different simulation Scenarios based on the formula that was derived. In Section 4.14 a high-level comparison of these data of the resulting graphs to come up with the conclusion.

4.1 Evaluation Scenarios

Six main scenarios were considered to analyze the message passing of the network when different p values were applied:

- Straight road, message passing only within the area of interests.
- Straight road, message passing with additional distance(μ) to the area of interests.
- T-junction, message passing only within the area of interests.
- T-junction, message passing with additional distance(μ) to the area of interests.
- Four-way junction, message passing only within the area of interests.
- Four-way junction, message passing with additional distance(μ) to the area of interests.

For each of these scenarios, performance evaluation is done for both dense and sparse road networks. Vehicle density of a road could be defined as the number of vehicles per unit distance of the roadway [26]. In the dense scenarios simulated in this research, an average of 50 vehicles are occupied in the road network that is with the distance of 5000 meters and in the sparse scenarios average of 15 to 20 vehicle nodes are occupied in the road network with the distance of 5000 meters.

For all scenarios below values were applied:

- Area of interest = 4000m
- Additional distance for each side = 500m
- r = 60m.

α values and the V values were varied depending on the scenario. Simulation time was 30 minutes. For each scenario a p value was calculated based on Equation 3.6 then including the derived p value and two different p values were also tested, a value below the derived p and a value above the derived p. Then for each of this p value, each scenario was analyzed three times.

4.2 Message passing within the area of interest – Straight road

Table 4.1 Model parameters and variables for area of interest on a straight road.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	2.1
Vehicle speed (v_1)	54.5kmph
Distance *(d)*	4000m
Vehicle arrival rate (α_2)	1.3
Vehicle speed (v_2)	68kmph
Derived probability *(P)*	0.012331
Total node count within the simulation time	205

For simulation three probability values, namely 0.008,0.012, and 0.016 were applied, where the derived probability value is 0.012 The results are shown below in Figure 4.1, 4.2, 4.3, and the high-level summary is shown in Table 4.2.

We first consider the case where $p = 0.008$, which is a lower probability value than the derived probability which is 0.012. According to the simulation results in all three attempts the message has not been retained in the network. However, in the second attempt the message has been passed to another node but has failed to retain in the network within the simulation time, its shown in the below Figure 4.1.

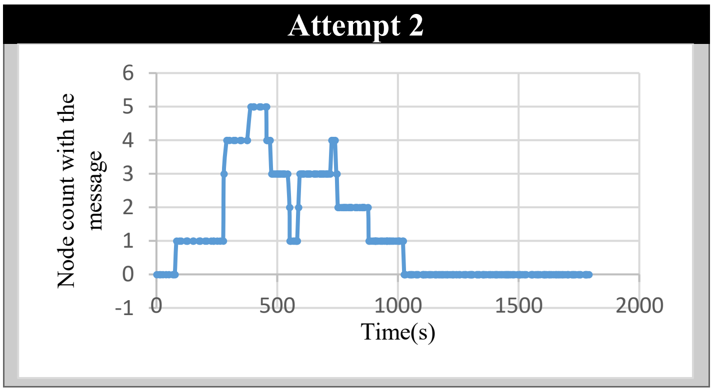

Figure 4.1 Number of nodes with a message within AOI, when $p = 0.008$.

In the case where $p = 0.012$, which is the derived probability value. Simulation results show that in the first attempts the message has not been passed to any of the nodes, and in the second attempt message has been passed but has failed to retain the message in the network by the end of the simulation time. However, in the third attempt message has been successfully retained in the network. The resulted graphs are shown below in Figure 4.2.

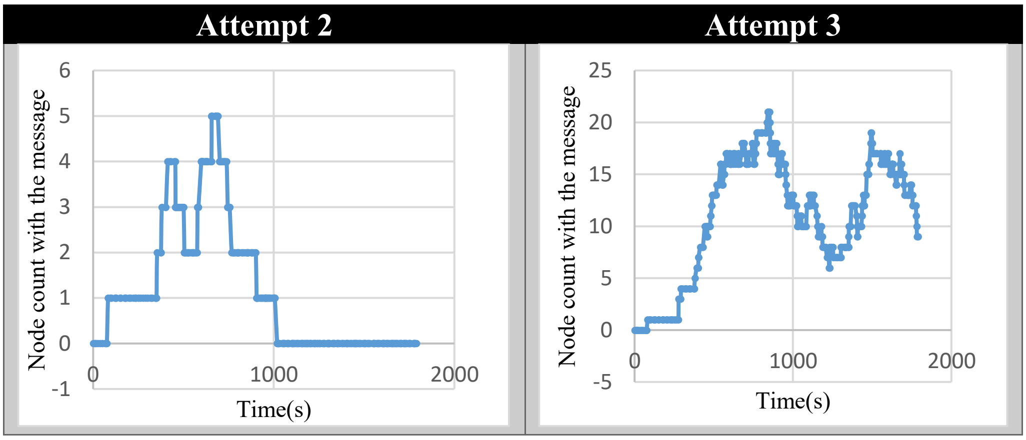

Figure 4.2 Number of nodes with a message within AOI, when $p = 0.012$.

In the case where $p = 0.016$, which is a slightly higher probability value than the derived probability value which was 0.012. Simulation results show that in all three attempts the message has been retained in the network with a high node count having the message at the end of the simulation time. The resulted graphs are shown below in Figure 4.3.

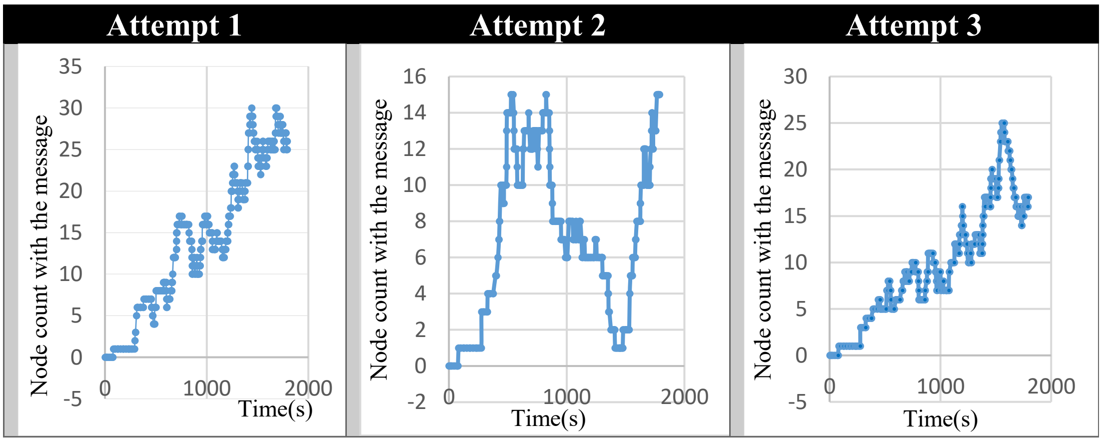

Figure 4.3 Number of nodes with a message within AOI when $p = 0.016$.

A high-level summary of message passing within the area of interest in the straight road is shown below in Table 4.2. It shows that message has been successfully retained in all three attempts when the applied probability was slightly higher than the derived probability.

Table 4.2 Summary of message passing within the area of interest on a straight road.

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.008	No	0	No	Yes	5	No	No	0	No
0.012	No	0	No	Yes	5	No	Yes	21	No
0.016	Yes	30	No	Yes	15	Yes	Yes	25	Yes

4.3 Message passing within the area of interest and soft boundary – Straight road

Table 4.3 Model parameters and variables for the area of interest and soft boundary on a straight road.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	2.1
Vehicle speed (v_1)	54.5kmph
Distance *(d)*	5000m
Vehicle arrival rate (α_2)	1.3
Vehicle speed (v_2)	68kmph
Derived probability *(P)*	0.009979
Total node count within the simulation time	205

For simulation three probability values, namely 0.006,0.010, and 0.014 were applied, where the derived probability value is 0.010. The results are shown in Figure 4.4, 4.5, and 4,6, and the high-level summary is shown in Table 4.4.

In the case where *p* = 0.006, results show that in the first and second attempts the message has been passed but has failed to retain in the network, in the third attempt no message passing has happened. The resulted graphs are shown below in Figure 4.4.

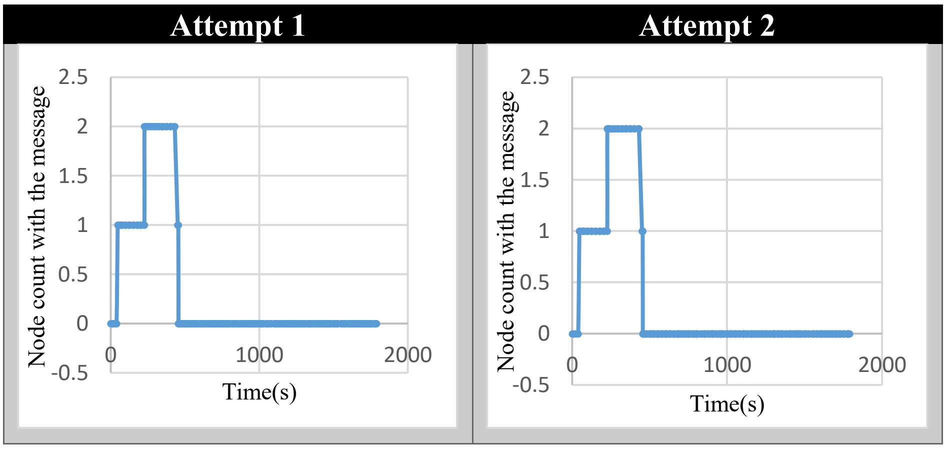

Figure 4.4 Number of nodes with a message within AOI and soft boundary, when *p* = 0.006.

In the case where $p = 0.010$ which is the derived probability value, simulation results shows that there has been no message passing in the first attempt that has happened, however in both second and third attempts the message has been passed to other nodes but has failed to retain the message in the network by the end of the simulation time. The resulted graphs are shown below in Figure 4.5.

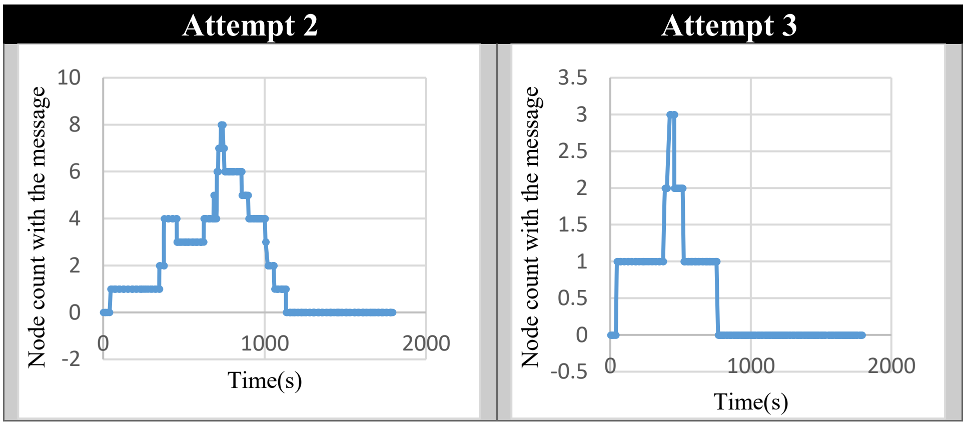

Figure 4.5 Number of nodes with a message within AOI and soft boundary, when $p = 0.010$.

In the case when $p = 0.014$ which is slightly higher value than the derived probability value which was 0.010, simulation shows that in all the three attempts the message has been retained in the network with a high node count having the message at the end of the simulation time. The resulted graphs are shown below in Figure 4.6.

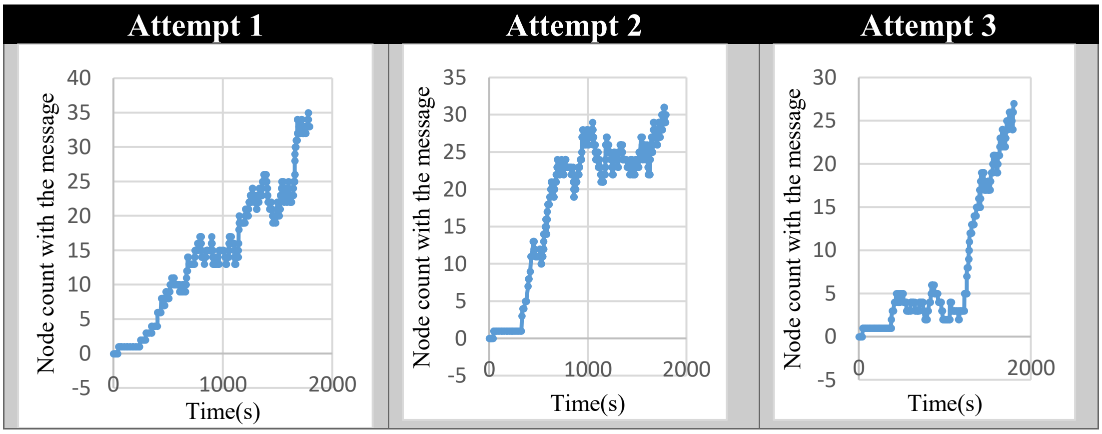

Figure 4.6 Number of nodes with a message within AOI and soft boundary, when $p = 0.014$.

A high-level summary of the results in message passing within the area of interest and soft boundary in straight road shown below in Table 4.4.

Table 4.4 Summary of message passing within the area of interest and soft boundary in the straight road.

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.006	Yes	2	No	Yes	2	No	No	0	No
0.010	No	0	No	Yes	8	No	Yes	3	No
0.014	Yes	35	Yes	Yes	30	Yes	Yes	28	Yes

4.4 Message passing within the area of interest – Straight road, in low vehicle density

Table 4.5 Model parameters and variables for the area of interest on a straight road with low vehicle density.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	1
Vehicle speed (v_1)	50kmph
Distance *(d)*	4000m
Vehicle arrival rate (α_2)	0.2
Vehicle speed (v_2)	60kmph
Derived probability (p)	0.0635
Total node count within the simulation time	53

For the simulation three probability values, namely 0.050,0.065, and 0.080 were applied where the derived probability value is 0.065. The results are shown in Figure 4.7, 4.8, 4.9 and the high-level summary is shown in Table 4.6

In the case where p = 0.050, simulation results show that in the first two attempts the message has been passed to other nodes but has failed to retain in the network, in the third attempt the message has not been passed to any of the nodes. The resulted graphs are shown below in Figure 4.7.

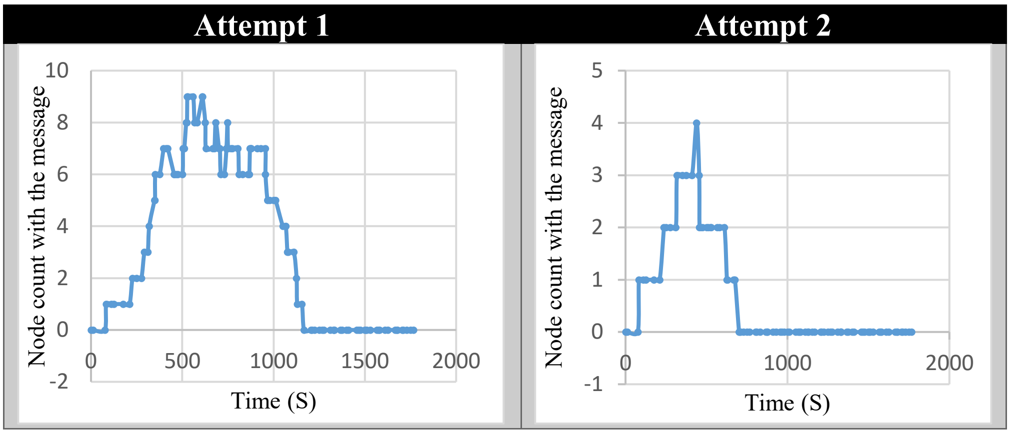

Figure 4.7 Number of nodes with a message within AOI, when p =0.05.

In the case when p = 0.065 which is the derived probability value, simulation results show that in all three attempts the message has been passed to other nodes however it has failed to retain the message by the end of the simulation time. The resulted graphs are shown below in Figure 4.8.

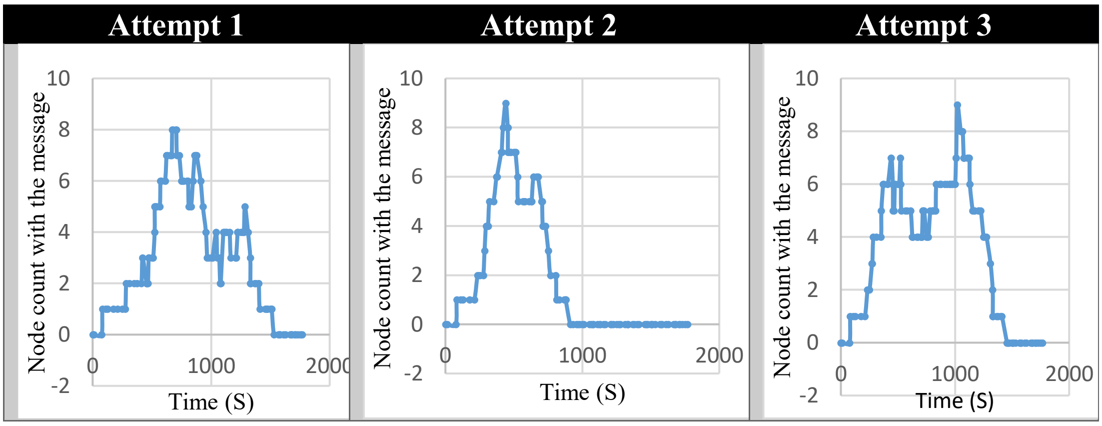

Figure 4.8 Number of nodes with a message within AOI, when p = 0.065.

In the case when p = 0.080 which is slightly a higher probability value than the derived probability, simulation results show that the message has retained in the network with high node counts having the message by the end of the simulation time. The resulted graphs are shown in Figure 4.9.

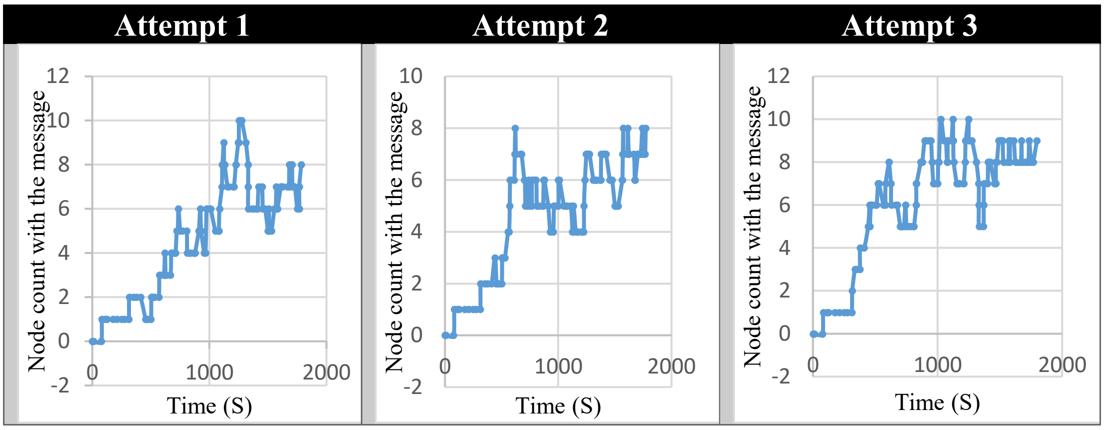

Figure 4.9 Number of nodes with a message within AOI, When p = 0.80.

A high-level summary of the message passing within the area of interest in the straight road in low vehicle density is shown below in Table 4.6.

Table 4.6 Summary of message passing within the area of interest in the straight road in low vehicle density.

Attempt 1				**Attempt 2**			**Attempt 3**		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.050	Yes	9	No	Yes	4	No	No	0	No
0.065	Yes	8	No	Yes	9	No	Yes	9	No
0.080	Yes	10	Yes	Yes	8	Yes	Yes	10	Yes

4.5 Message passing within the area of interest – Soft boundary on the straight road, in low vehicle density.

Table 4.7 Model parameters and variables for the area of interest and soft boundary on a straight road in low vehicle density.

Model Parameters and Variables	**Values**
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	1
Vehicle speed (v_1)	50kmph
Distance *(d)*	5000m
Vehicle arrival rate (α_2)	0.2
Vehicle speed (v_2)	60kmph
Derived probability (p)	0.0524
Total node count within the simulation time	53

For the simulation three probability values, namely 0.035,0.050, and 0.065 were applied where the derived probability value is 0.050. The results are shown in Figure 4.10, 4.11, 4.12 and the high-level summary is shown in Table 4.8.

In the case when $p = 0.035$ which is a lower value than the derived probability value, simulation results show that in the first and in the third attempts, the message has been passed to other nodes but not retained in the network. In the second attempt, no messaging passing has taken place. The resulted graphs are shown below in the Figure 4.10.

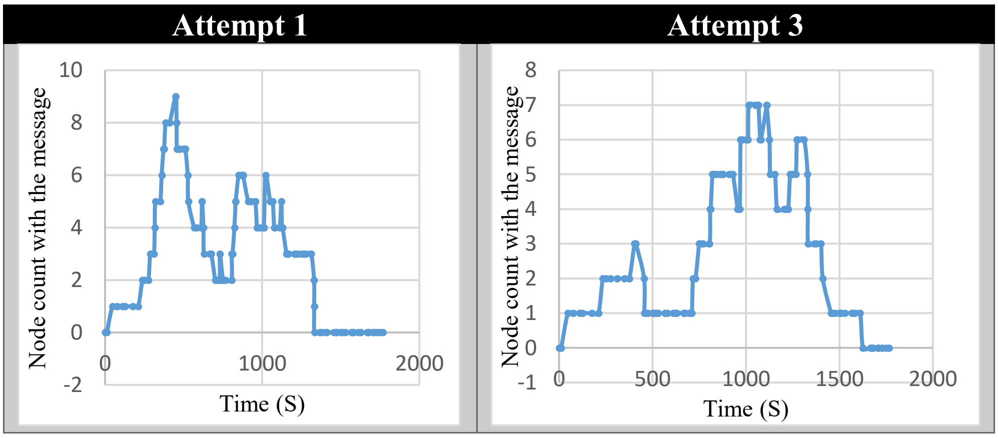

Figure 4.10 Number of nodes with a message within AOI and soft boundary, when $p = 0.035$.

In the case when $p = 0.050$ which is the derived probability value, simulation results show that in all the three attempts the message has been passed to other nodes but has failed to retain the message in the network by the end of the simulation time. The resulted graphs are shown in the Figure 4.11.

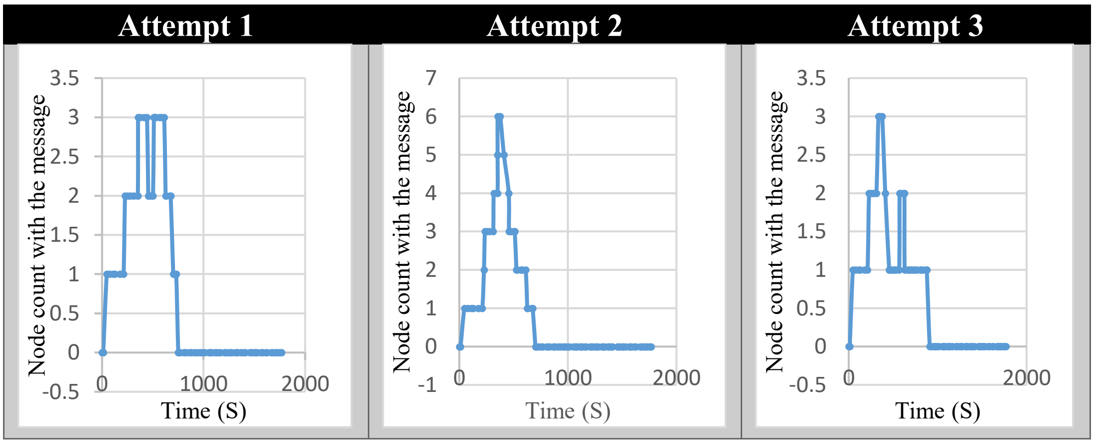

Figure 4.11 Number of nodes with a message within AOI and soft boundary, when $p = 0.050$.

In the case when $p = 0.065$ which is slightly a higher probability value than the derived probability, simulation results show that in all the three attempts the message has been successfully retained in the network. The resulted graphs are shown below in the Figure 4.12.

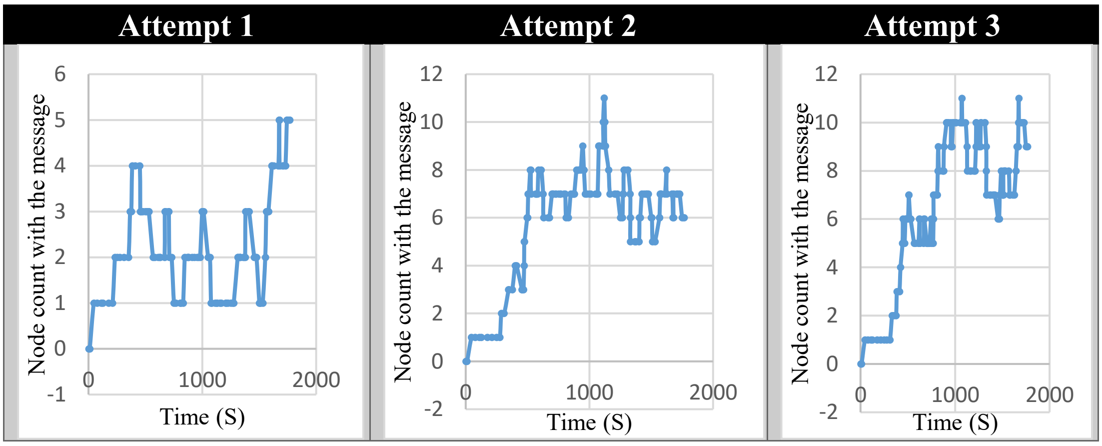

Figure 4.12 Number of nodes with a message within AOI and soft boundary, when $p = 0.065$.

A high-level summary of the results of message passing within the area of interest and soft boundary in the straight road, in low vehicle density is shown below in Table 4.8.

4.8 Summary of message passing within the area of interest and soft boundary in the straight road, in low vehicle density.

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.035	Yes	9	No	No	0	No	Yes	7	No
0.050	Yes	3	No	Yes	6	No	Yes	3	No
0.065	Yes	5	Yes	Yes	11	Yes	Yes	11	Yes

4.6 Message passing within the area of interest on T-junction

Table 4.9 Model parameters and variables for area of interest on T-junction.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	1.7
Vehicle speed (v_1)	75kmph
Distance *(d)*	4000m
Vehicle arrival rate (α_2)	2.1
Vehicle speed (v_2)	80kmph
Vehicle arrival rate (α_3)	0.4
Vehicle speed (v_3)	75kmph
Derived probability (p)	0.00847
Total node count within the simulation time	260

For simulation three probability values, namely 0.005, 0.008, and 0.012 were applied where the derived probability value is 0.008. The results are shown in Figure 4.13, 4.14, 4.15 and the high-level summary is shown in Table 4.10.

In the case when $p = 0.005$, which is a lower probability value than the derived probability, simulation results show that only in the second attempt the message has been passed to another node but still failed to retain the message in the network by the end of the simulation time. The resulted graph is shown below in the Figure 4.13.

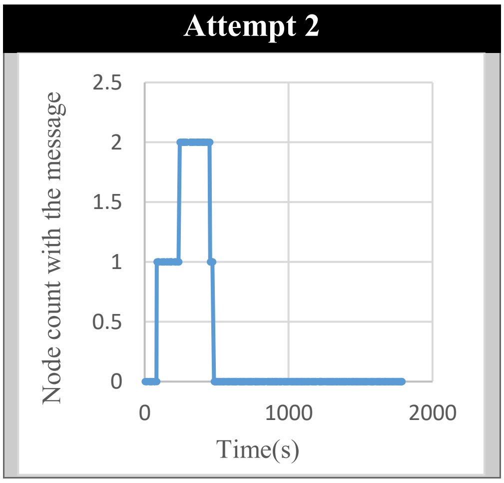

Figure 4.13 Number of nodes with a message within AOI, when $p = 0.005$.

In the case when $p = 0.008$, which is the derived probability value, simulation results shows that there has been no message passing in the second attempt that has happened, however in both the first and third attempts the message has been passed to other nodes but has failed to retain the message in the network by the end of the simulation time. The resulted graphs are shown below in the Figure 4.14.

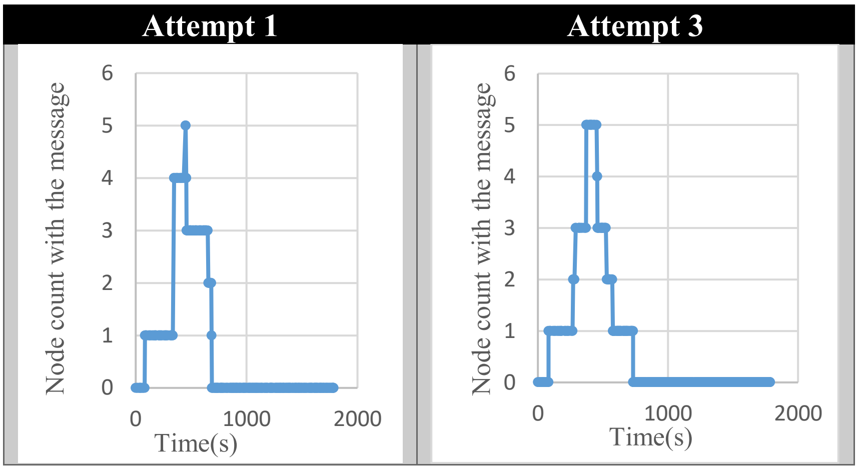

Figure 4.14 Number of nodes with a message within AOI, when p =0.008.

In the case when p = 0.012 which is slightly a higher probability value than the derived probability, simulation results show that the message has been successfully retain in all three attempts with high node counts having the message by the end of the simulation time. The resulted Graphs are shown below in the Figure 4.15.

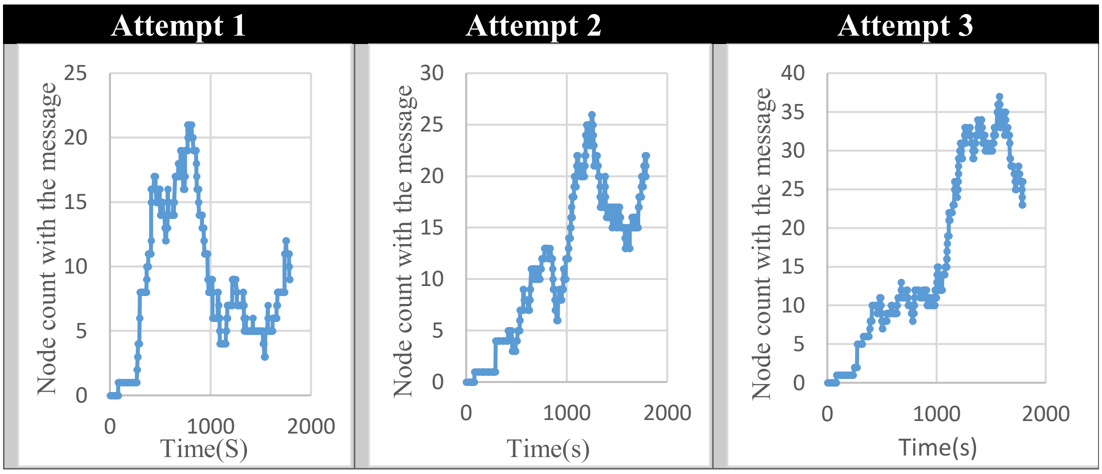

Figure 4.15 Number of nodes with a message within AOI, when p = 0.012.

A high-level summary of the results of message passing within the area of interest in T-junction is shown below in Table 4.10.

Table 4.10 Summary of message passing within the area of interest in T-junction.

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.005	No	0	No	Yes	2	No	No	0	No
0.008	Yes	5	No	No	0	No	Yes	5	No
0.012	Yes	21	Yes	Yes	26	Yes	Yes	37	Yes

4.7 Message passing within the area of interest and soft boundary on T-junction.

Table 4.11 Model parameters and variables for area of interest and soft boundary on T-junction.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	1.7
Vehicle speed (v_1)	85kmph
Distance *(d)*	5000m
Vehicle arrival rate (α_2)	2.1
Vehicle speed (v_2)	80kmph
Vehicle arrival rate (α_3)	0.4
Vehicle speed (v_3)	75
Derived probability (p)	0.0068
Total node count within the simulation time	260

For the simulation three probability values, namely 0.004,0.007, and 0.012 were applied where the derived probability value is 0.007. The results are shown in Figure 4.16, 4.17,4.18 and the high-level summary is shown in Table 4.12.

In the case when $p = 0.004$, which is a lower probability value than the derived probability, simulation results show that there has been a message passing only in the third attempt, however, the system has failed to retain the message in the network by the end of the simulation time. The resulted graph is shown below in the Figure 4.16.

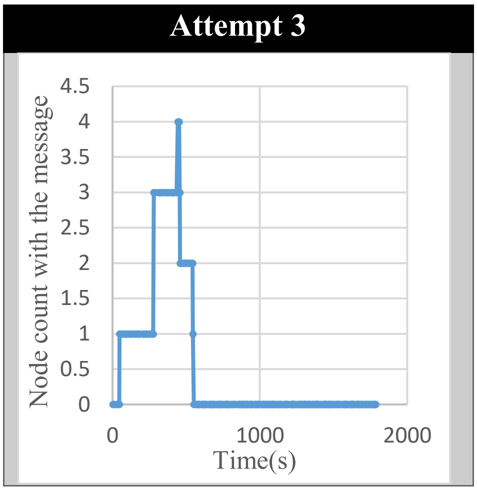

Figure 4.16 Number of nodes with a message within AOI and soft boundary, when $p = 0.004$.

In the case when $p = 0.007$ which is the derived probability, simulation results show that the message has been passed successfully in all three attempts but has failed to retain the message in the network by the end of the simulation time. The resulted graphs are shown below in the Figure 4.17.

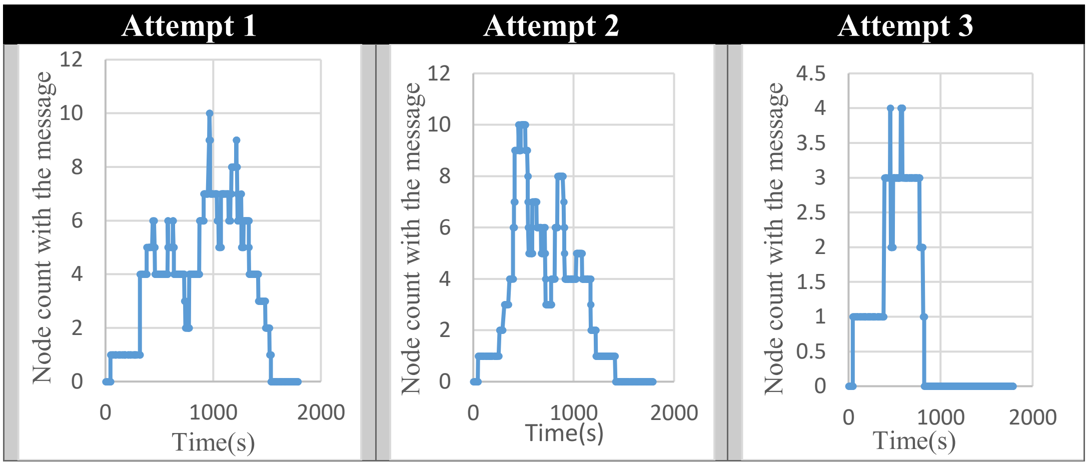

Figure 4.17 Number of nodes with a message within AOI and soft boundary, when $p = 0.007$.

In the case when $p = 0.012$, which is slightly a higher probability value than the derived probability, simulation results show that the message has been successfully retain in all three attempts with high node counts having the message at the end of the simulation. The resulted graphs for the three attempts are shown below in the Figure 4.18.

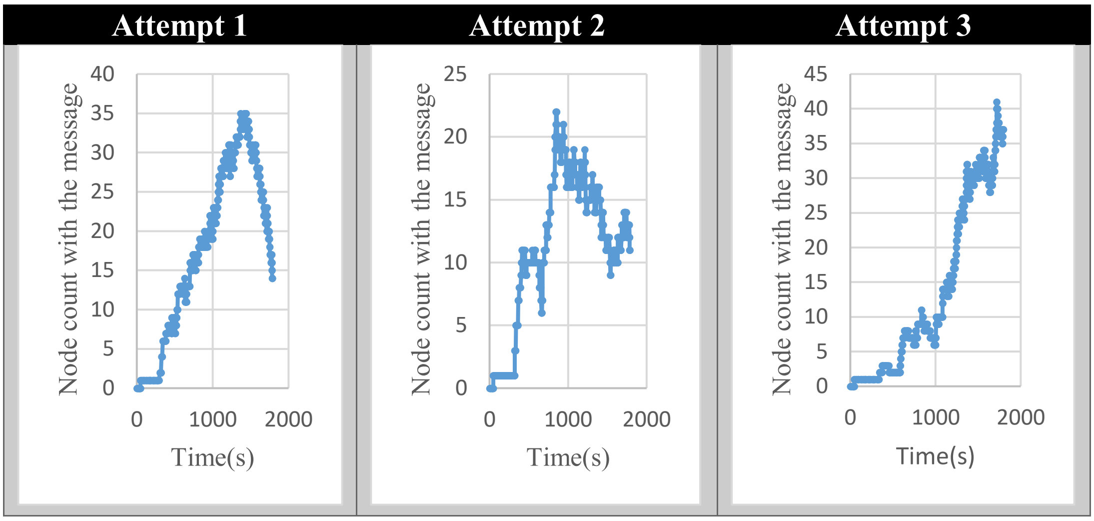

Figure 4.18 Number of nodes with a message within AOI and soft boundary, when $p = 0.012$.

A high-level summary of the results of message passing within the area of interest and soft boundary in T-junction is shown below in Table 4.12.

Table 4.12 Summary of message passing within the area of interest and soft boundary in T-junction.

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.004	No	0	No	No	0	No	Yes	4	No
0.007	Yes	10	No	Yes	10	No	Yes	4	No
0.012	Yes	35	Yes	Yes	22	Yes	Yes	42	Yes

4.8 Message passing within the area of interest in T-junction, in low vehicle density

Table 4.13 Model parameters and variables for the area of interest on T-junction, on low vehicle density.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	0.,6
Vehicle speed (v_1)	85kmph
Distance *(d)*	4000m
Vehicle arrival rate (α_2)	0.4
Vehicle speed (v_2)	80kmph
Vehicle arrival rate (α_3)	0.2
Vehicle speed (v_3)	75
Derived probability (p)	0.038
Total node count within the simulation time	75

For the simulation three probability values, namely 0.025,0.040, and 0.055 were applied where the derived probability value is 0.040. The results are shown in Figure 4.19, 4.20, 4.21 and the high-level summary is shown in Table 4.14.

In the case when $p = 0.025$, which is slightly a lower probability value than the derived probability value, simulation results show that there has been a message passing only in the second attempt but has failed to retain the message in the network by the end of the simulation time. The resulted graph is shown below in the Figure 4.19.

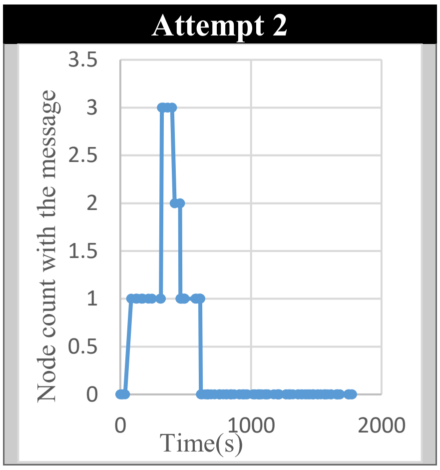

Figure 4.19 Number of nodes with a message within AOI, when $p = 0.025$.

In the case when $p = 0.040$ which is the derived probability value, simulation results show that the message has been passed successfully in all three attempts but has failed to retain the message in the network by the end of the simulation time. Resulted graphs are shown below in the Figure 4.20.

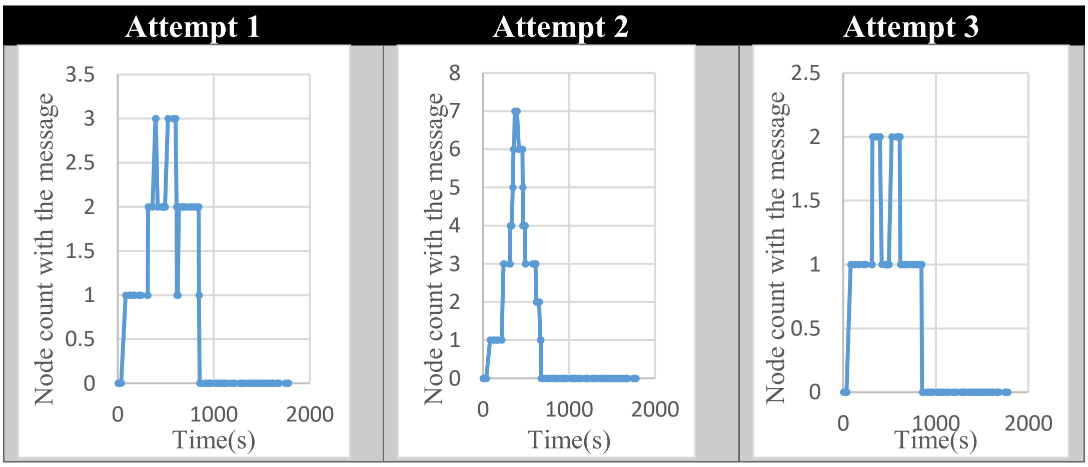

Figure 4.20 Number of nodes with a message within AOI, when $p = 0.040$.

In the case when $p = 0.055$ which is slightly higher than the derived probability value, simulation results show that in all the three attempts the message has been successfully retained in the network. The resulted graphs are shown below in the Figure 4.21.

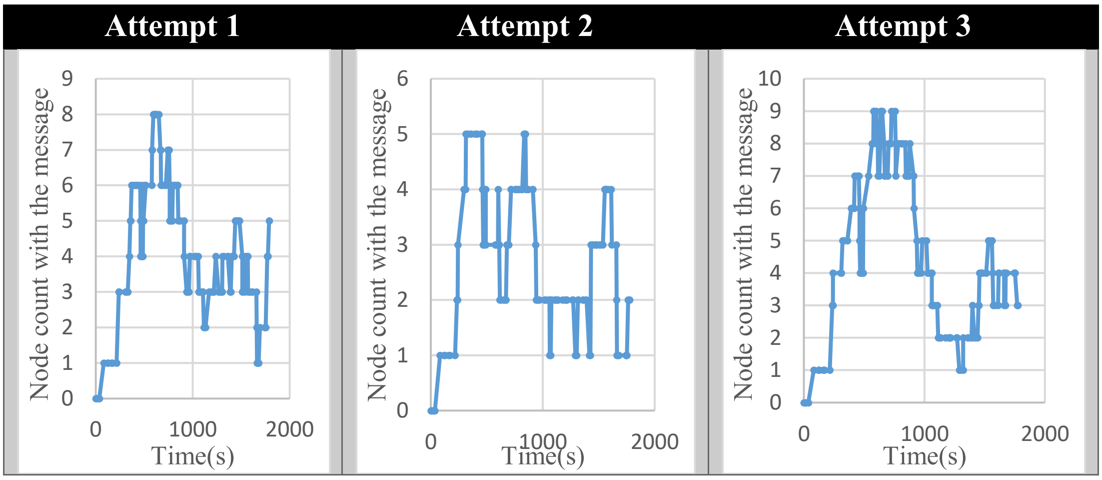

Figure 4.21 Number of nodes with a message within AOI, when $p = 0.055$.

A high-level summary of the results of message passing within the area of interest in T-junction, in low vehicle density is shown below in Table 4.14.

Table 4.14 Summary of message passing within the area of interest in T-junction, in low vehicle density.

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.025	No	0	No	Yes	3	No	No	0	No
0.040	Yes	3	No	Yes	7	No	No	2	No
0.055	Yes	8	Yes	Yes	5	Yes	Yes	9	Yes

4.9 Message passing within the area of interest and soft boundary on T-junction, in low vehicle density

Table 4.15 Model parameters and variables for the area of interest and soft boundary on T-junction, on low vehicle density.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	1.6
Vehicle speed (v_1)	85 kmph
Distance *(d)*	5000m
Vehicle arrival rate (α_2)	0.4
Vehicle speed (v_2)	80 kmph
Vehicle arrival rate (α_3)	0.2
Vehicle speed (v_3)	75
Derived probability (p)	0.030
Total node count within the simulation time	75

For the simulation three probability values, namely 0.015,0.030, and 0.045 were applied where the derived probability value is 0.030. The results are shown in Figure 4.22, 4.23, 4.24 and the high-level summary is shown in Table 4.16.

In the case when p = 0.015 which is slightly a lower value than the derived probability value, simulation results show that there has been a message passing only in the first attempt but has failed to retain the message in the network by the end of the simulation time. The resulted graph is shown below in the Figure 4.22.

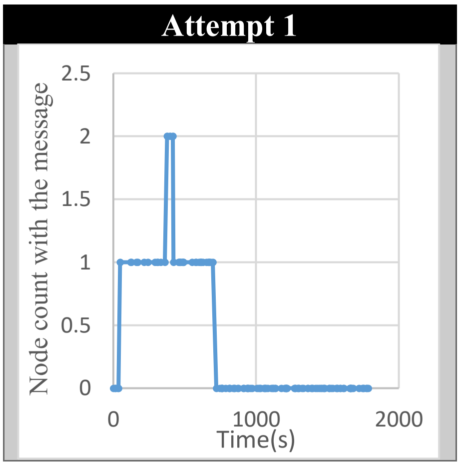

Figure 4.22 Number of nodes with a message within AOI and soft boundary, when p = 0.015.

In the case when p = 0.030, which is the derived probability value, simulation results show that the message has been a message passing in the first and in the third attempts but has failed to retain the message in the network by the end of the simulation time. Resulted graphs are shown below in the Figure 4.23.

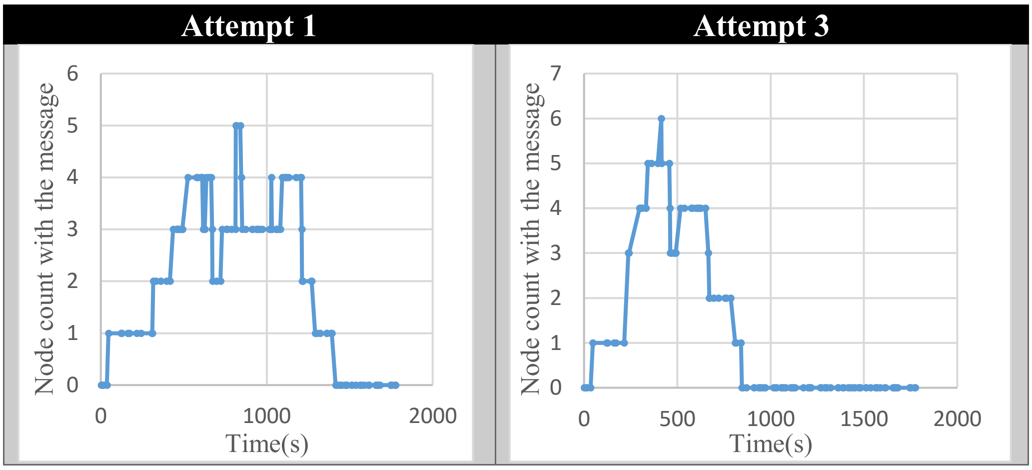

Figure 4.23 Number of nodes with a message within AOI and soft boundary, when p= 0.030.

In the case then $p = 0.045$ which is slightly a higher probability value than the derived probability value, simulation results show that in all the three attempts the message has been successfully retained in the network. The resulted graphs are shown below in the Figure 4.24.

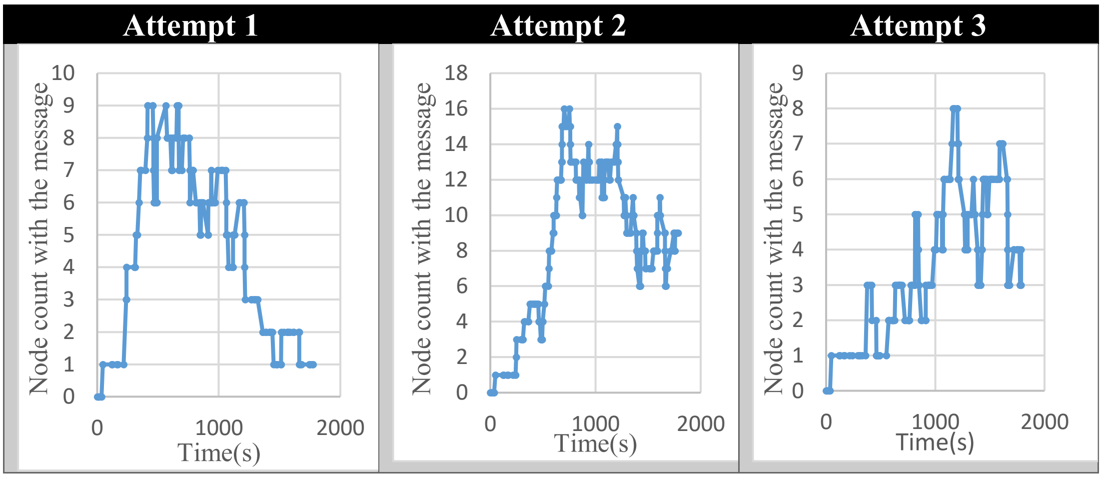

Figure 4.24 Number of nodes with a message within AOI and soft boundary, when $p = 0.045$.

A high-level summary of the results of message passing within the area of interest and soft boundary in T-junction, in low vehicle density is shown below in Table 4.16

Table 4.16 Summary of message passing within the area of interest and soft boundary in T-junction, in low vehicle density

Attempt 1				Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.015	Yes	2	No	No	0	No	No	0	No
0.030	Yes	5	No	No	0	No	Yes	6	No
0.045	Yes	9	yes	Yes	16	Yes	Yes	8	yes

4.10 Message passing within the area of interest on Four-way

Table 4.17 Model parameters and variables for the area of interest on Four-way.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	0.8
Vehicle speed (v_1)	75 kmph
Distance *(d)*	4000m
Vehicle arrival rate (α_2)	0.5
Vehicle speed (v_2)	75 kmph
Vehicle arrival rate (α_3)	0.4
Vehicle speed (v_3)	60 kmph
Derived probability (p)	0.025
Total node count within the simulation time	245

For the simulation three probability values, namely, 0.018,0.025 and 0.030 were applied where the derived probability value is 0.025. The results are shown in Figure 4.25, 4.26, 4.27 and the high-level summary is shown in Table 4.18.

In the case when p = 0.018 which is slightly a lower probability value than the derived probability value, simulation results show that there has been a message passing only in the third attempt but has failed to retain the message in the network. The resulted graph is shown below in Figure 4.25.

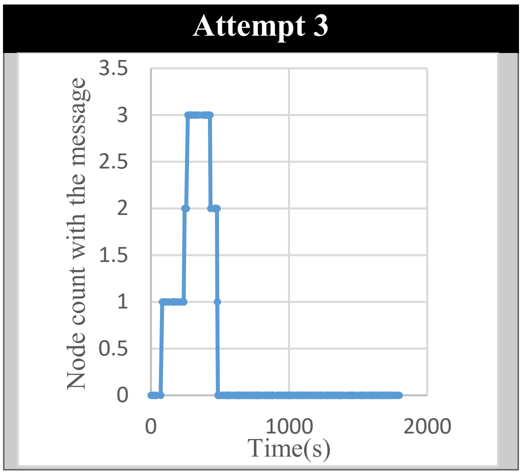

Figure 4.25 Number of nodes with a message within AOI, when $p = 0.018$.

In the case when $p = 0.025$, which is the derived probability value, simulation results show that there has been a message passing in all three attempts but has failed to retain the message by the end of the simulation time. Resulted graphs are shown below in the Figure 4.26.

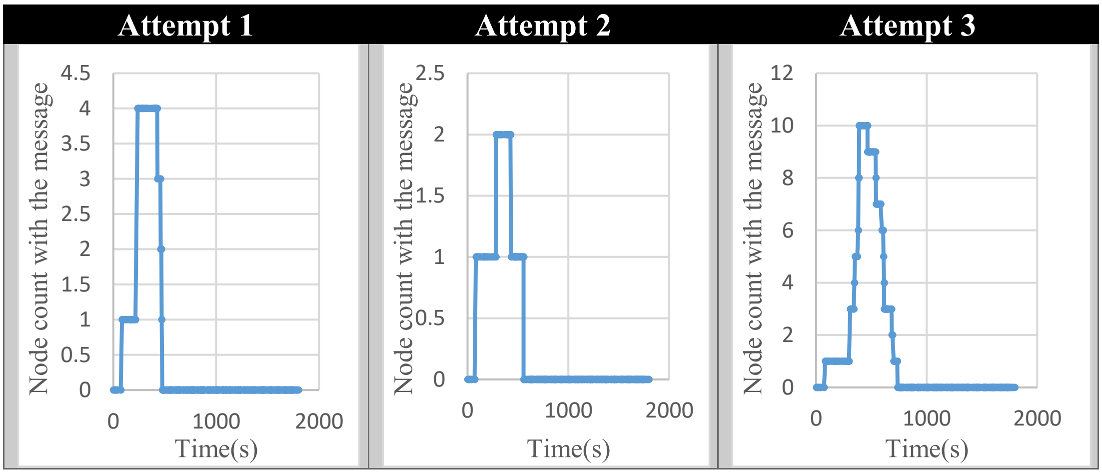

Figure 4.26 Number of nodes with a message within AOI, when $p = 0.025$.

In the case when $p = 0.030$, which is slightly a higher probability value than the derived probability, simulation results show that the message has been successfully retain in all three attempts with high node counts having the message by the end of the simulation time. The resulted graphs for the three attempts are shown below in the Figure 4.27.

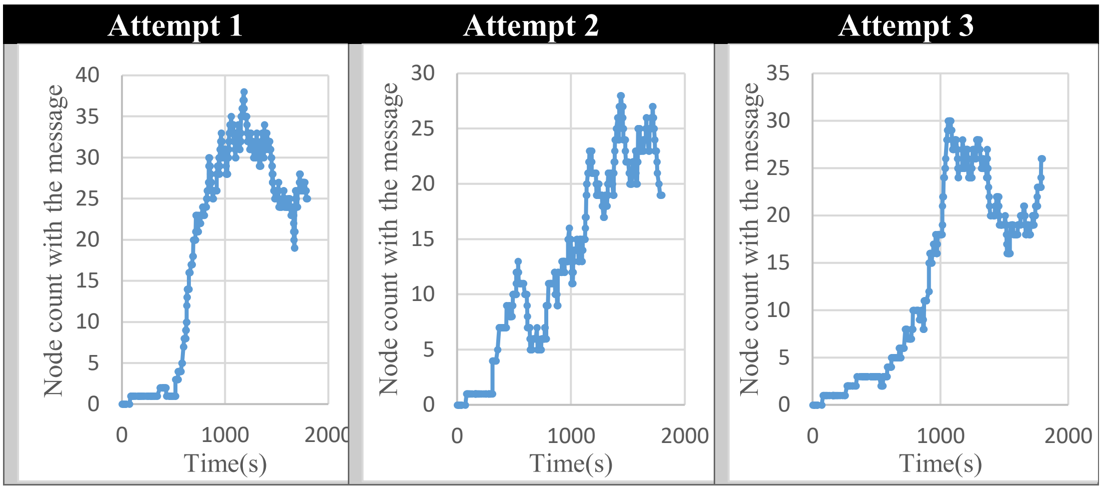

Figure 4.27 Number of nodes with a message within AOI, when p = 0.030.

A high-level summary of the results of message passing within the area of interest in Four-way is shown below in Table 4.18.

Table 4.18 Summary of message passing within the area of interest in Four-way

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.018	No	0	No	No	0	No	Yes	3	No
0.025	Yes	4	No	No	2	No	Yes	10	No
0.030	Yes	38	Yes	Yes	28	Yes	Yes	30	No

4.11 Message passing within the area of interest and soft boundary on Four-way

Table 4.19 Model parameters and variables for the area of interest and soft boundary on Four-way.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	0.8
Vehicle speed (v_1)	75 kmph
Distance *(d)*	5000m
Vehicle arrival rate (α_2)	0.5
Vehicle speed (v_2)	75 kmph
Vehicle arrival rate (α_3)	0.4
Vehicle speed (v_3)	60
Derived probability (p)	0.019
Total node count within the simulation time	245

For the simulation three probability values, namely 0.015,0.020, and 0.025 were applied where the derived probability value is 0.020. The results are shown in Figure 4.28, 4.29, 4.30 and the high-level summary is shown in Table 4.20.

In the case where $p = 0.015$ which is a lower probability value than the derived probability value, simulation results show that there has been a message passing only in the second attempt but has failed to retain the message in the network by the end of the simulation time. The resulted graph is shown below in the Figure 4.28.

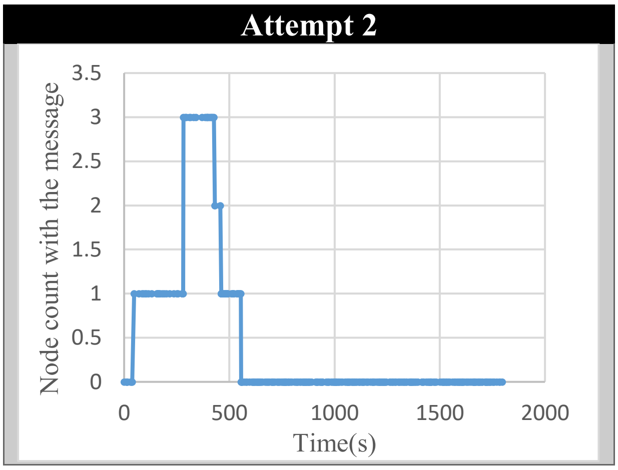

Figure 4.28 Number of nodes with a message within AOI and soft boundary, when $p = 0.015$.

In the case when $p = 0.020$ which is the derived probability value, simulation results show that there has been a message passing in all three attempts; however, has failed to retain the message by the end of the simulation time. Resulted graphs are shown below in the Figure 4.29.

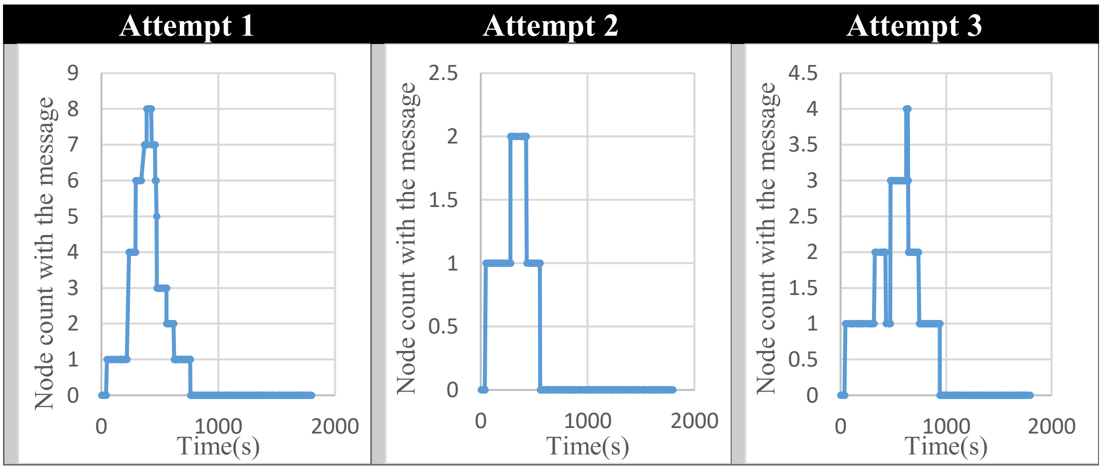

Figure 4.29 Number of nodes with a message within AOI and soft boundary, when $p = 0.020$.

In the case when $p = 0.025$, which is slightly a higher probability value than the derived probability, simulation results show that the message has been successfully retain in all three attempts with high node counts having the message by the end of the simulation time. Resulted graphs are shown below in the Figure 4.30.

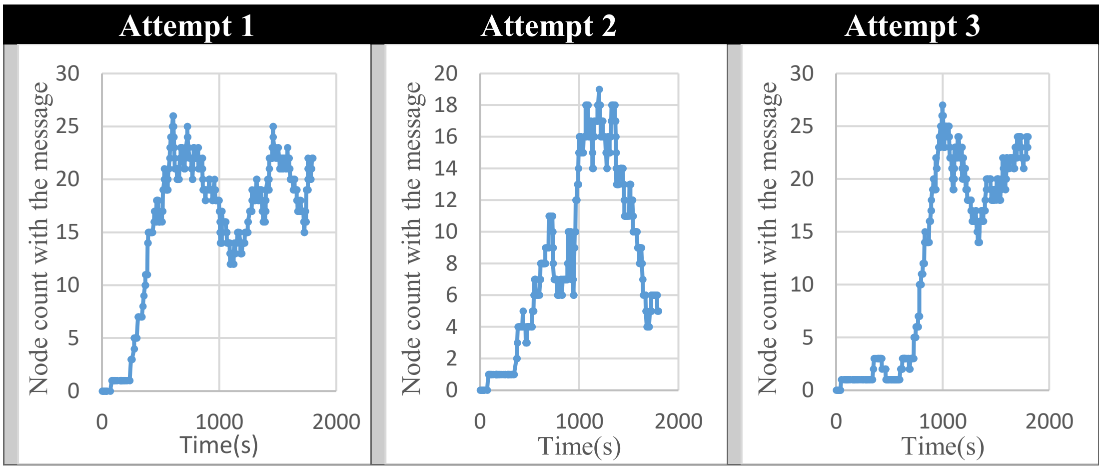

Figure 4.30 Number of nodes with a message within AOI and soft boundary, when $p = 0.025$.

A high-level summary of the results of message passing within the area of interest and soft boundary in Four-way is shown below in Table 4.20.

Table 4.20 Summary of message passing within the area of interest and soft boundary in Four-way.

	Attempt 1			Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.015	No	0	No	Yes	3	No	No	0	No
0.020	Yes	8	No	Yes	2	No	Yes	4	No
0.025	Yes	26	No	Yes	19	Yes	Yes	27	Yes

4.12 Message passing within the area of interest on Four-way, in low vehicle density

Table 4.21 Model parameters and variables for the area of interest on Four-way, in low vehicle density.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	0.1
Vehicle speed (v_1)	75 kmph
Distance *(d)*	4000m
Vehicle arrival rate (α_2)	0.2
Vehicle speed (v_2)	85 kmph
Vehicle arrival rate (α_3)	0.1
Vehicle speed (v_3)	85 kmph
Derived probability (p)	0.085
Total node count within the simulation time	75

For the simulation three probability values, namely 0.070,0.085, and 0.100 were applied where the derived probability value is 0.085. The results are shown in Figure 4.31, 4.32, 4.33 and the high-level summary is shown in Table 4.22.

In the case where $p = 0.070$ which is a lower probability value than the derived probability value, simulation results show that there has been a message passing only in the first attempt but has failed to retain the message in the network by the end of the simulation time. The resulted graph is shown below in the Figure 4.31.

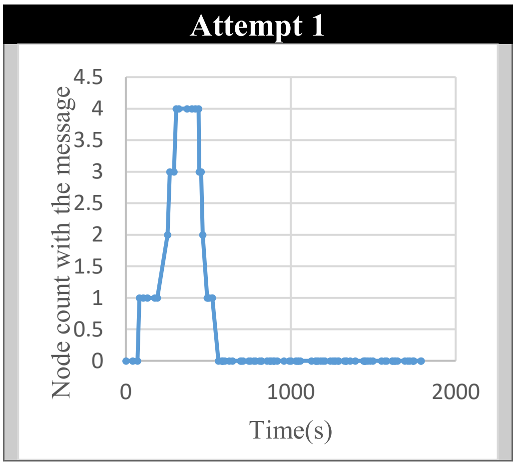

Figure 4.31 Number of nodes with a message within AOI and soft boundary, when $p = 0.070$.

In the case when $p = 0.085$ which is the derived probability value, simulation results show that there has been a message passing in all three attempts, but the message has been retained only in the second attempt. Resulted graphs are shown below in Figure 4.32.

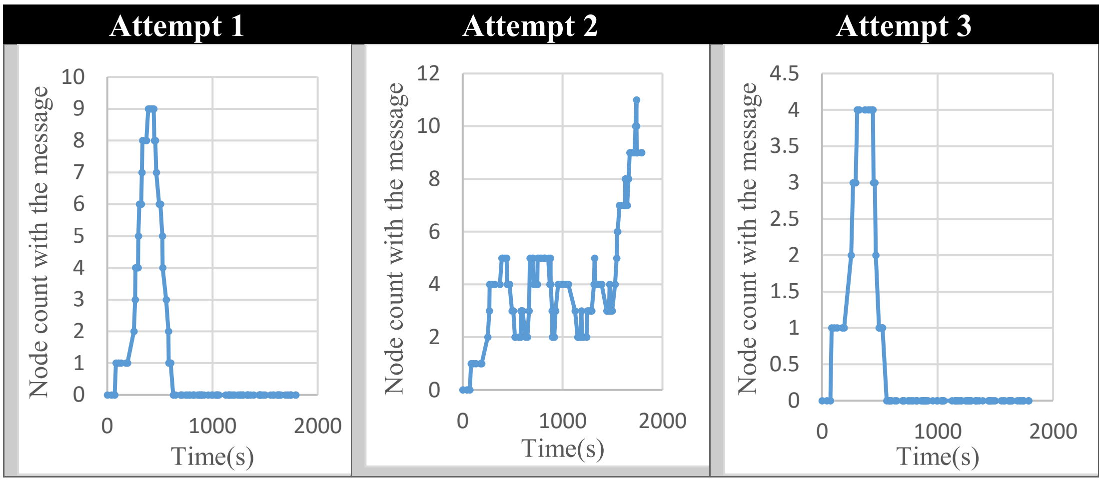

Figure 4.32 Number of nodes with a message within AOI, when $p = 0.085$.

In the case when $p = 0.100$ which is slightly higher value than the derived probability, simulation results show that the message has retained in the network by the end of the simulation time in all three attempts. Resulted graphs are shown below in Figure 4.33.

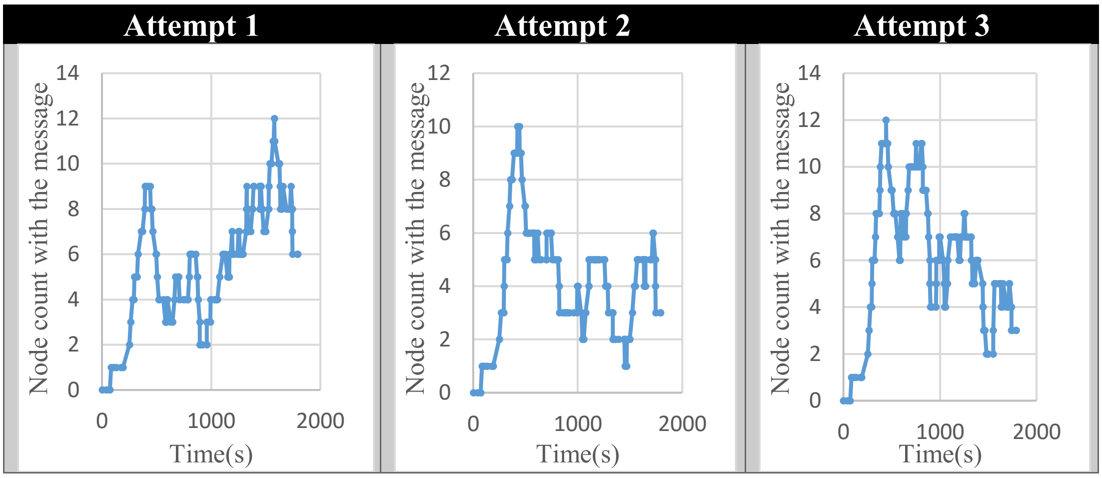

Figure 4.33 Number of nodes with a message within AOI, when $p = 0.100$.

A high-level summary of the simulations results of message passing within the area of interest in Four-way, in low vehicle density is shown below in Table 4.22.

Table 4.22 Summary of message passing within the area of interest in Four-way, in low vehicle density.

Attempt 1				Attempt 2			Attempt 3		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.070	Yes	4	No	No	0	No	No	0	No
0.085	Yes	9	No	Yes	11	Yes	Yes	4	No
0.100	Yes	12	yes	Yes	10	Yes	Yes	12	yes

4.13 Message passing within the area of interest and soft boundary in Four-way, in low vehicle density.

Table 4.23 Model parameters and variables for the area of interest and soft boundary on Four-way, in low vehicle density.

Model Parameters and Variables	Values
Communication range *(r)*	60m
Vehicle arrival rate (α_1)	0.1
Vehicle speed (v_1)	75 kmph
Distance *(d)*	5000m
Vehicle arrival rate (α_2)	0.2
Vehicle speed (v_2)	85 kmph
Vehicle arrival rate (α_3)	0.1
Vehicle speed (v_3)	85 kmph
Derived probability (*P*)	0.067
Total node count within the simulation time	75

For the simulation three probability values, namely 0.055,0.070, and 0.085 were applied where the derived probability value is 0.070. The results are shown in Figure 4.34, 4.35 and the high-level summary is shown in Table 4.24.

In the case where $p = 0.055$ which is a lower probability value than the derived probability value, there has been no message passing in all three attempts that have taken place.

In the case when $p = 0.070$, which is the derived probability value, simulation results show that there has been a message passing in all three attempts but has failed to retain the message in the network by the end of the simulation time. Resulted graphs are shown below in Figure 4.34.

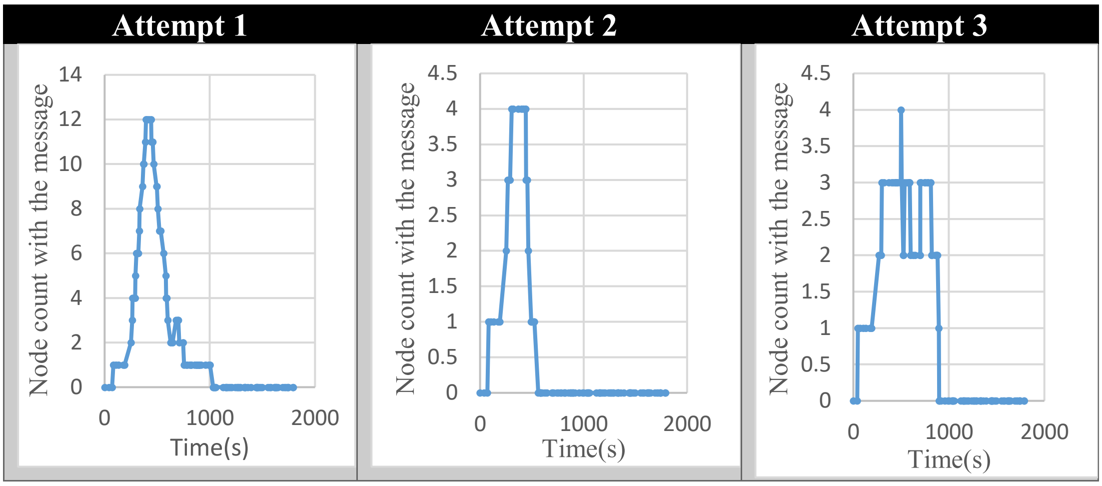

Figure 4.34 Number of nodes with a message within AOI and soft boundary, when $p = 0.070$.

In the case when $p = 0.085$ which is slightly a higher probability value than the derived probability, simulation results show that the message has been passed in all three attempts, but it has been retained in the network by the end of the simulation time only in the third attempt. Resulted graphs are shown below in Figure 4.35.

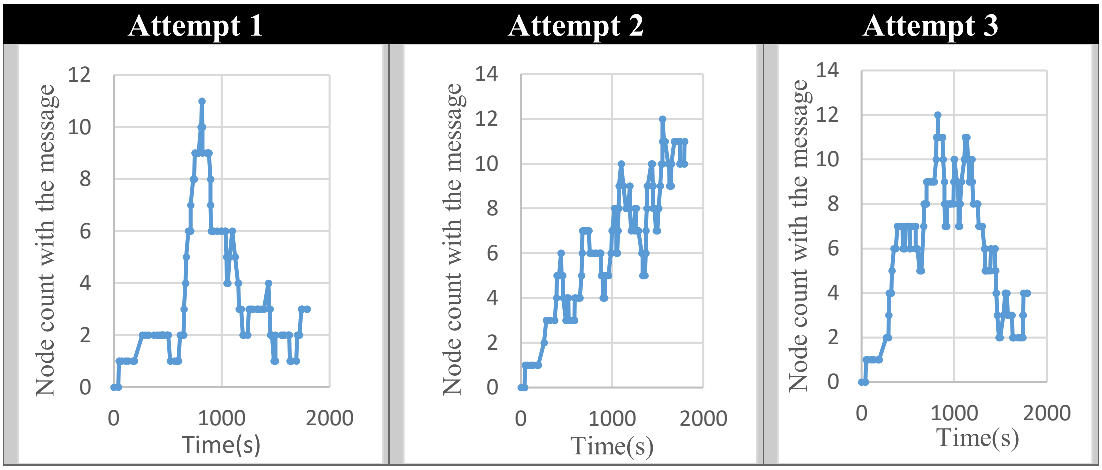

Figure 4.35 Number of nodes with a message within AOI and soft boundary, when $p = 0.085$.

A high-level summary of the simulation results of message passing within the area of interest and soft boundary in Four-way, in low vehicle density is shown below in Table 4.24.

Table 4.24 Summary details of message passing within the area of interest and soft boundary in Four-way, in low vehicle density.

	Attempt 1			**Attempt 2**			**Attempt 3**		
P Value	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**	**Msg Psd**	**Msg Node Count**	**Msg Ret**
0.055	No	0	No	No	0	Yes	No	0	No
0.070	Yes	12	No	No	4	No	Yes	4	No
0.085	Yes	11	No	Yes	12	Yes	Yes	12	yes

4.14 Summary

In this section we will compare the results as a high-level summary. Table 4.25 shows the model results for the straight road, Table 4.26 shows the model results for the T-junction and Table 4.27 shows the model results for the four-way intersection, each of these tables will have both the results for the sparse and dense networks.

Table 4.25 Straight road high-level result comparison, message retention.

Dense			
	Attempt 1	Attempt 2	Attempt 3
P Value	Only in AOI (Calculated p = 0.012)		
0.008	No	No	No
0.012	No	No	Yes
0.016	Yes	Yes	Yes
	With extra distance (Calculated p = 0.010)		
0.006	No	No	No
0.010	No	No	No
0.014	Yes	Yes	Yes
Sparse			
	Only in AOI (Calculated p = 0.065)		
0.050	No	No	No
0.065	No	No	No
0.080	Yes	Yes	Yes
	With extra distance (Calculated p = 0.050)		
0.035	No	No	No
0.050	No	No	No
0.065	Yes	Yes	Yes

[green box] - Successfully message retained in the network.

Table 4.26 T-Junction High Level Result comparison, message retention.

Dense			
	Attempt 1	Attempt 2	Attempt 3
P Value	Only in AOI (Calculated p = 0.008)		
0.005	No	No	No
0.008	No	No	No
0.012	Yes	Yes	Yes
	With extra distance (Calculated p = 0.007)		
0.004	No	No	No
0.007	No	No	No
0.012	Yes	Yes	Yes
Sparse			
	Only in AOI (Calculated p = 0.040)		
0.025	No	No	No
0.040	No	No	No
0.055	Yes	Yes	Yes
	With extra distance (Calculated p = 0.030)		
0.015	No	No	No
0.030	No	No	No
0.045	Yes	Yes	Yes

- Successfully message retained in the network.

Table 4.27 Four-way junction, high-level result comparison, message retention.

Dense			
	Attempt 1	Attempt 2	Attempt 3
P Value	Only in AOI (Calculated p = 0.025)		
0.018	No	No	No
0.025	No	No	No
0.030	Yes	Yes	Yes
	With extra distance (Calculated p = 0.020)		
0.015	No	No	No
0.020	No	No	No
0.025	Yes	Yes	Yes
Sparse			
	Only in AOI (Calculated p = 0.085)		
0.070	No	No	No
0.085	No	Yes	No
0.100	Yes	Yes	Yes
	With extra distance (Calculated p = 0.070)		
0.055	No	No	No
0.070	No	No	No
0.085	Yes	Yes	Yes

- Successfully message retained in the network.

5 Conclusion

In this research, we try to identify the minimum probability that needs to be maintained in order to successfully disseminate the content across a set of vehicles that are within a certain geographical boundary (area of interest) who may be interested in receiving the information. In chapter 3, we derived a model that will give us a probability value based on parameters such as the distance of the area of interest, vehicle arrival rates and the speeds of the vehicles. In chapter 4 we try to evaluate the performance of this derived model based on the capability of retaining the content after applying the derived probability value to different simulation scenarios.

After analyzing the comparison done in Section 4.14 it can be concluded that the derived model has direct link with the simulated scenarios and therefore the model parameters such as the valid geography, speed, vehicle arrival rate, communication range and the probability of the dissemination do matter in retaining the relevant message in the network amidst all the other communication that may happen.

When comparing the results, it can be seen that in all scenarios that were simulated, the probability value that is derived from the derived model of this research could be stated as the breaking point probability value. Out of the twelve scenarios, ten scenarios show that the message has not been retained in the network when the probability value was the value that was derived from the model. However, the detailed analysis done in section 4.2 to section 4.13, shows that at least the message to be passed to few nodes in the given geographical area, the minimum probability should be at least the value derived from the equation. In the final results, it can be seen that the message has been retained successfully in all the attempts in all scenarios where the probability value of dissemination the message was closer to 1.5 times the derived probability value of the introduced model/formula.

5.1 Research Limitations

Most of the limitations that were faced during this research were more of technical ones. Some were overcome by taking different alternatives approaches, such as described below.

Veins Framework currently supports only two types of messages for communication between nodes. Veins Framework currently supports only two types of messages for communication between nodes.

a. WaveShortMessage message type used as the main communication message type between nodes for their vehicle behavior announcements.
b. BasicSafetyMessage to pass Safety messages such as accidents - We had to rely on BasicSafetyMessage type to trigger our specific Message. Relying on this for this research did fit the requirement, however, if this research is to be extended to support multiple message types with varying interest types, then another message type will have to be introduced along with the layers for that particular message will have to be newly written with their behavior.

In this research, the scope of the simulated scenarios was limited to three main scenarios namely, Strait road, T-junction and four-way intersection and did not cover more complex scenarios where there will be more number of junctions in the road network.

5.2 Future work

In this research, we have mainly focused on finding how effectively a specific message could be retained in the network at a given probability value in the relevant geographical area considering several other parameters such as the communication range, vehicle arrival rate. We could extend this research in the following manner.

i) Where the nodes will have different types of interests in the content with varying content sizes (e.g., commercial advertisements, interesting offers in the nearby shops, music videos, etc.). Amidst other parameters such as priority messages that will also have some valid geographical boundary. In such a situation how effectively the most critical messages based on some priority level could be delivered to other nodes effectively. Moreover, to identify if the messages could be effectively retained in the network during a given valid period.

ii) To identify the probability value that needs to be maintained in a rural network, where the actual parameters are not known, but based on historical statistics. Where it could apply to a situation such as safari parks, jungles, etc.

iii) Identify whether the content is relevant to other vehicles depending on the personal interests and depending on the situation. Content during emergency situations will get high priority and should override all other rules and get delivered to the relevant nodes and government authorities.

iv) How long the content based on interests that is valid for a specific geographical area should be cached and shared among other nodes to which the data is relevant and If the content was not seeded to other vehicles, and if it is going to be valid for a period of time, how this particular content could be shared among other potential nodes based on the relevance of the content.

v) Reliability of the content, when a vehicle is trying to share among other nodes or the regional governmental institute such as the police stations. To have a rating mechanism where the individual vehicles can rate each other based on the relevance and validity of the content while the rule-based mechanism will decide how each type of content will be disseminated to what nodes and authorities based on a priority level.

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