Jimma University
Jimma Institute of Technology
Faculty of Computing

Incentive Based Node Cooperation in Vehicular Delay-Tolerant Networks

By

Mohammed Adane Tuha

A THESIS SUBMITTED TO THE FACULTY OF COMPUTING IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN COMPUTER NETWORKING

Principal Advisor: Mr. Dawit Kifle (PhD Candidate)

Co-Advisor: Mr. Teferi Kibebew (Msc)

April, 2018

Jimma University

Jimma Institute of Technology

Faculty of Computing

Mohammed Adane

Principal Advisor: Mr. Dawit Kifle (PhD Candidate)

Co-Advisor: Mr. Teferi Kibebew (Msc)

This is to certify that the thesis prepared by *Mohammed Adane* titled: *Incentive Based Node Cooperation in Vehicular Delay-Tolerant Networks* has been read and approved as meeting the requirements of Department of Computing in partial fulfillment for the degree of Master of Science in Computer Networking complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

	Name	Signature
Advisor:	Mr. Dawit Kifle (PhD Candidate)	
Co- Advisor:	Mr. Teferi Kibebew (Msc)	
External Examiner:	________________________	_______________
Internal Examiner:	________________________	_______________

Acknowledgment

This work would not have been possible without the endless support of God (Allah), so I praise always the name of Allah the most gracious and the most merciful. And My sincere gratitude should go to my advisor, Mr. Dawit Kifle, for his patient and ceaseless supervision, advice, respect, encouragement, and comment throughout this thesis work. I would like also to provide special thanks to Mr. Teferi Kibebew for his great supervision, encouragement, respect, and comment. Dear Advisors again, I thank you for everything. It has been an honor and great pleasure for me to have worked with you. As well as, I am so glad to thank all my friends who are positive in all time to help me and for all the idea and knowledge they have shared. Last but not least, my family has to deserve some very special thanks for their unconditional love and support throughout the whole my life.

Table of Contents

List of Figures

List of Tables

List of Equations

Acronyms, Abbreviation and Terminology

Acronyms

ANs: Airborne Networks

DTN: Delay-Tolerant Networks

GUI: Graphical User Interface

IEEE: Institute of Electrical and Electronics Engineers

MANET: Mobile Ad hoc Network

ONE: Opportunistic Networking Environment

PSNs: Pocket Switched Networks

TCP/IP: Transmission Control Protocol / Internetworking Protocol

TFT: Tit-for-Tat

TIS: Threshold Incentive Scheme

UWNs: Under Water networks

VANETs: Vehicular Ad hoc NETworks

VDTNs: Vehicular Delay-Tolerant Networks

Terminologies

Bundle: It is a message which exchange by DTN nodes

Nodes: It is a vehicle which transfer bundles from source to destination

Effort: It is total contribution made by each node.

Rewards: Are the virtual payment made to all the intermediate nodes in the network which are participating in data forwarding

Abstract

The term delay-tolerant networking is created to describe and cover all types of long-delay, disconnected, disrupted or intermittently-connected networks and vehicular ad hoc network is one of delay-tolerant network application which used to enable services and applications by trusting their operation on cooperation between network nodes to share their network resource like a buffer, bandwidth, and energy, in the situation where end-to-end connectivity is not available. But due to the limitation of this network resource, the nodes on this network can be cooperative or non-cooperative, in non-cooperative network environment selfish nodes may receive bundles from other nodes and dropping them immediately after that for the intent of saving their resource. To come up with this problem the existing method which done by other researcher used incentive mechanism by considering the effort of network nodes in terms of time spent to cooperate, to manage those non-cooperative nodes was not good enough, so by considering it, this thesis proposed an efficient incentive-based node cooperation for a vehicular delay-tolerant network. The proposed solution used the concept of Pareto's principle to manage selfish nodes which are not proposed or used in the existing work.

For the simulation, Opportunistic Network Environment Simulator is used. The proposed system is applied to the binary version of Spray-and-Wait routing protocol. The existing incentive approach and the proposed incentive approach has been evaluated, in addition, they were analyzed on three different metrics namely bundle delivery probability, bundle average delay and protocol overhead ratio. Consequently, across all the experiments the simulation results obtained in this thesis show that for the proposed routing approach, the bundle delivery probability is very high, low protocol overhead ratio and bundle average delay.

Chapter 1
Introduction

1.1 Background

The rapid growth of technology and infrastructure has made communication extremely important and made our lives easier, even in an undeserved area when there is no end-to-end connectivity between the communicating device.

Ad hoc is a special purpose network established on the fly. Some well-known ad hoc networks are MANETs, FANETs and VANETs. MANET [2] are kinds of wireless ad-hoc network and a self-configuring network of mobile routers connected by wireless links with no access point. Every mobile device in a network is autonomous. The mobile devices are free to move randomly and organize themselves arbitrarily. VANET [4] is a kind of MANET in which nodes are vehicles that follow particular mobility patterns regulated by vial normative. Mostly, VANET architecture has OBU (On-Board Unit) which use as a communication unit. OBU is mounted usually on-board of a vehicle and a Wireless Access in Vehicular Environment (WAVE) device used for an exchange of information with other OBUs or with Roadside units (RSUs).

These communication units are used to ensure road safety, reduction in traffic problems, essential alerts and accessing comforts and entertainment. But the gain of technology has also caused the traffic hazards and the road accident takes place frequently which causes huge loss of life and property because of the poor emergency facilities. Road traffic accidents (RTAs) are the major public health concerns which are created mainly due to driver's misbehavior [1].

Therefore, to overcome the above problems vehicles need to communicate each other while they are on the move by designing and evaluating effective and efficient message forwarding protocol. This type of communication can be Vehicle-to-Vehicle, Vehicle-to-Infrastructure, and Hybrid [12]. However, this type of network is not able to covenant with disconnection, network partition, and longtime delays. To deal with this problem Delay-Tolerant Networks (DTNs) was introduced one application domain of this DTN is Vehicular Ad hoc Network, a vehicle store data until a connection with other vehicles are available when it gets other contacts, data is forwarded. This process is repeated until it gets the final destination in the form of store-carry and forward strategy [5, 7]. Hence, this vehicular DTN is used for dissemination of non-real-time applications (e.g., notification of blocked roads, accident warnings, advertisements, traffic reports, and parking information) or for providing multi-hop Internet access [5]. To perform successful message exchange in VDTNs node cooperation is a key issue, where nodes use their storage, bandwidth and energy resources to mutually enhance the overall network performance, so the network may have either cooperative or none-cooperative behavior, this behavior can be caused by several reasons, such as, resource limitations (for example, storage, link bandwidth) or malicious behavior. More importantly, it may lead to overall degradation of the network performance [8].

In this thesis, to provide better performance in VDTN a new incentive based VDTN approach will be designed which is called incentive-based node cooperation in VDTN, as we know we peoples are different in some aspects, in which there may be drivers that are willing to relay others messages for the sake of the safety of people not to be harmed or injured in some aspects and on the other side. There are also drivers that are definitely careless about others safety, i.e., in non-cooperative networks selfish nodes may not cooperate to transfer other message during communication. To avoid this problem other researchers are proposed as an incentive mechanism to those selfish nodes to become cooperative. And some other works are proposed to identify and isolate those selfish nodes which have selfish behavior [8] [11]. However, the existing approaches mainly focus on identifying and isolating the non-cooperative nodes from the networks; some works try to stimulate selfish nodes but it is not enough.

In 1906 Vilfredo Pareto study unequal distribution of wealth in his country, he discovers that an approximately 80% of the land in Italy owned by only 20% of the population [3]. After his observation, many other professional notice the same phenomena in their own expertise. E.g., 80% of company profit comes from 20% of employees' effort. Therefore, by adapting this un equal distribution concept, we design new incentive mechanisms to manage non-cooperative nodes efficiently, consequently the proposed system will increase network performance in term of message delivery probability and average delay and overhead ratio.

So, this research will be experimental based research which was conducted by using simulation tools that are compatible both with network simulator and traffic simulator.

1.2 Statement of the Problem

Based on the above discussion in an introduction, in VDTN, routing is much more challenging than other non-DTN based networks, mainly due to a highly dynamic network topology, disruptive and intermittent connectivity. The main problems of VDTN are the communication unit (Onboard Unit) on vehicles have constraints of a buffer. Due to that in non-cooperative networks, many packets are dropped by the non-cooperative nodes to save their buffer and link bandwidth, due to those dropped packets the network delivery probability and average delay will be decreased. To minimize this problem other researchers used different methods, such as paper [10] used virtual credit, to reward selfish node by virtual currency when it relay other bundles and punish when it drops with the help of trusted third party that caused to increase the network cost, by considering this the author at [8] proposed reputation system to identify and isolate selfish nodes from the network, but in an opportunistic network the contact among the nodes are rare, so identifying and isolating instead of stimulating those selfish nodes might bring out negative consequences, to solve this another work at [11] proposed reputations system to identify and stimulate non-cooperative nodes before isolating from the network. This reputation system used volume byte transferred and time spent to cooperate as incentive strategies. Based on the network reputation threshold value those two strategies used to classify a node as cooperative and non-cooperative, as well as to stimulate the non-cooperative nodes.

However, the existing approaches which are done so far are not effective enough in terms of identifying and monitoring non-cooperative network nodes immediately these caused to decrease network performance. Therefore, to overcome such problems this research is useful and contribute a novel result on the non-cooperative VDTN environments.

1.3 Objectives

General Objective

The general objective of this study was to design an efficient incentive-based node cooperation in Vehicular Delay-Tolerant Networks.

Specific Objectives

To accomplish the above stated general objective, the following specific objectives are required.

- To identify and investigate the current incentive-based routing protocol in VDTN
- To study and customize Pareto's principle
- To design algorithm for managing non-cooperative nodes
- To write and implement an algorithm for the proposed solution
- To evaluate the performance of the proposed solution, and to compare its performance with existing incentive approach
- To analyze and interpret the results of the simulation
- Finally, conclude the results and specifies future work

1.4 Methodology

To accomplish this work, as a general approach, this study would use quantitative research approach. The reason why the quantitative research approach was that this research performed experimentally by using a collaborative network and traffic simulation tool. In addition to that, we used the following techniques.

Literature Review

In order to achieve the objectives of this thesis, various resources like books, research papers, and other documents were used for the purpose of understanding incentive-based routing in VDTN and to know how others fulfill their goal. Techniques and approaches appropriate for development of an incentive-based routing algorithm were also reviewed.

Design and Implementation

In the design phase, proposed models and algorithms which are specified in the objective of this thesis were designed. Due to a high cost of VDTN nodes, the proposed incentive-based routing was implemented using a collaborative network and traffic simulation tool called Opportunistic Network Environment (ONE) simulator.

Evaluation of the Proposed Work

An experiment was conducted to test the effectiveness of our proposed reputation system. After conducting the simulation experiments, the results are discussed and interpreted and finally triangulation was conducted to see the effectiveness and efficiency of the proposed incentive mechanism. It was then compared with others in term of bundle delivery probability, bundle average delay and the protocol overhead ratio metrics.

1.5 Scope (Limitations and Delimitations)

The scope of this thesis is limited in a sparse network to manage non-cooperative intermediate network nodes to participate in communication by rewarding reputation score when they relay other data and punish when it drops. The approaches will improve the performance of the existing routing protocols within VDTN by satisfying better performance. The study took attention on providing to increase bundle delivery probability, decrease bundle average delay and protocol overhead ratio.

Our proposed work will not cover the following tasks:

Any security issues rise by the malicious behavior of the non-cooperative network nodes, and it was not tested on the real environment due to testing on the real world needs huge finance.

1.6 Application of Results

The area which has difficulty to get an internet access can use this finding to facilitate the services of Vehicular Delay Tolerant Networks exchanging non-real-time applications in many important situations such as road safety, road congestion avoidance, commercial information entertainment and providing connectivity to rural areas.

1.7 Thesis Organization

This report document contains six chapters including this chapter which deals with the general overview of the study including background, statement of the problem, objectives, and methodology of the research. Chapter Two presents a literature about nature of DTN, VDTN and different routing protocols. Chapter Three introduces related works which are carried out for improvement of VDTN communications on non-cooperative network environments. Chapter Four describe the methodology employed, the proposed incentive-based node cooperation framework and the proposed selfish node stimulation approach to monitor selfish nodes in a non-cooperative network environment. Chapter Five describes the implementation and the experimentation setup in detail. Chapter Six presents the result of the simulation run and discussion. Results of the simulation are also analyzed and interpreted in this Chapter. The conclusion drawn from the result is briefly explained and future work in the area is presented in the last Chapter, Chapter Seven.

Chapter 2
Literature Review

2.1 Introduction

This chapter discusses in detail about the settings involved in Delay Tolerant Network with numerous works concentrated by different authors and is organized as follows. Section 2.2 History of DTN. Section 2.3 provides an overview of delay tolerant networks. First, the DTN architecture and its key concepts are reviewed. Next, some DTN application domain is presented. In Section 2.4 it provides an overview of vehicular delay-tolerant networks. Then, Section 2.5 provides some of the most relevant routing protocols used in VDTN networks are discussed. Finally, In Section 2.6 it provides an overview of node cooperation.

2.2 History of Delay Tolerant Networks (DTNs)

According to [15], the origin of the concepts behind the DTN architecture comes from looking at how to extend the Internet into interplanetary space. This new network paradigm started back in 1994 by the researcher named Vinton Grey (Vint) Cerf, and Adrian Hooke. They claim that the study was not an impact in late 1997 and they began thinking about how to extend the Internet into an interplanetary network and use Internet-style communications for links to spacecraft. The first phase of the Interplanetary Internet (IPN) project ran for about four years and its main output was a description of the problems and a proposed architecture for a communication overlay network that would support the transmission of messages in the IPN environment. This was published in 2001 as IPN: Architectural Definition [47] and set the architectural basis for much of the DTN work that has taken place since that time. The scenarios that the IPN architecture targeted were based on the sorts of extensive delays resulting from interplanetary distances and scheduled communication opportunities that are typical of spacecraft operations.

After the IPN document had been published, researchers began to consider how the architecture could be applied to other situations where communications were subject to delays and disruptions that would make conventional Internet protocols (especially TCP) ineffective. The architectural work in 2002-3 looked at other scenarios, especially terrestrial wireless networks such as wireless sensor networks and Wi-Fi-based local area networks, where communications opportunities were much less predictable. It also provided a framework for dealing with interconnected heterogeneous networks, such as occurs at the gateway between a sensor network which does not usually use IP-based addressing/communications and a conventional IP-based network. By the middle of 2002, when an updated version of the IPN architecture was published [48], Kevin Fall of Intel Research had coined the name Delay-Tolerant Networking (giving the initial use of the acronym DTN).

2.3 Delay Tolerant Networks

DTN is a network designed to operate efficiently over heterogeneous networks without an end-to-end connection. In such environment, long latency may be measured in hours or days is expected. Many types of research on a DTN have been done. According to [14], DTN is defined as a new networking paradigm that allows inter-connection among devices that current networking technology cannot handle, nodes may connect and exchange information in an opportunistic way. Consequently, traditional routing protocols cannot be directly functional in these scenarios for delivering data.

The authors in [15] note that delay tolerant network serves four critical roles in their wireless networking concept: (I) DTN deals with the truth that mobile edge networks may not have complete source-to-destination paths. It uses opportunistic links, data MULEs (Mobile Ubiquitous LAN Extensions), and drops boxes. (II) DTN allows each node in the network to be optimized uniquely and individually, which is different from the traditional one where end to end connectivity is expected and node in the network is not optimized individually. Thus, it deals with congestion, latency, and loss locally, and the content cached at each node. (III). Nodes supply to and request content from the network using the same format - network is aware of information, not just addresses. Cognitive management decides on data storage, replication and other attributes of a router. (IV) DTN hides internal network information (routing, protocols, name services).

2.3.1 Delay-Tolerant Network Architecture

Delay-Tolerant Networking architecture is designed to support a communications network that can have much longer delays, connection disruption and communication latencies. The DTN architecture was initially proposed as an approach to make the Interplanetary Internet [16] a practical networking environment. It was aimed to implement a universal network of networks. Accordingly, more effort was put into interconnection and interoperability issues, the bundle layer and its forwarding capabilities with regard to custody transfers, naming, addressing schemes and store-and-forward capabilities of intermediate nodes. In an early study [14], the author addresses important issues relating to the design of network protocols for challenging environments, and they propose that the DTN architecture should form an overlay that will include all potential challenged environments.

Heterogeneity drives many of the capabilities of the DTN architecture. The architecture in [7] is designed to support a more extensive form of 'internet' where the authors use the original meaning of the word that implied an interconnection of networks. The network elements are not expected to have common addressing formats or addressing semantics, and disparate routing methodologies may be employed.

The architecture of DTNs has been exploited in many works and its architectural layers compared with the conventional TCP/IP (internet) layers [7], [18]. DTN layers and internet layer are identical except that DTN architecture implements store and forward message switching by overlaying a new protocol layer called bundle layer. It is placed on top of transport layers and it ties together the transport layers and below, with application programs to communicate across multiple regions. The bundle layer is proposed to function above the existing protocol layers and provide the function of a gateway when two nodes meet each other. Due to its flexibility, it can be easily linked with the already existing TCP/IP protocol networks or to link two or more networks together. The difference between TCP/IP layer and DTN layer is shown in Figure 2.1.

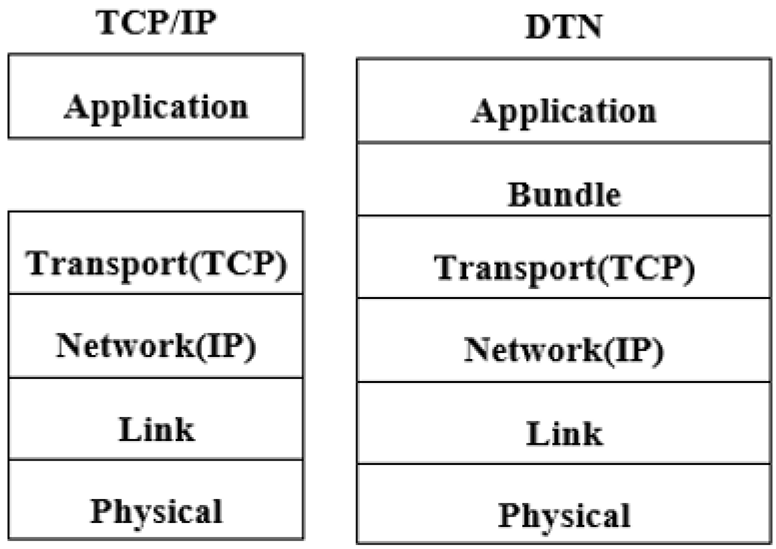

Figure 2-1 Difference between TCP/IP and DTN Architecture [7]

Like IP, DTN operates on top of existing link layer and network protocols, creating DTN overlay network. The key advantage over IP is that DTN effectively copes with long delays, high error rates, and prolonged link disruptions, thus allowing the interconnection of networks with very diverse characteristics. Thus, the DTN uses naming, layering, encapsulation and persistent storage to interconnect heterogeneous portions of a larger 'internet', irrespective of a formal layering model [7].

The key services provided by the DTN architecture are in-network data storage, retransmission, custody transfer with authenticated forwarding, and flexible node naming. Figure 2.2 illustrates an example implementation architecture shows how a bundle forwarder interacts with storage, routing decisions, and convergence layer adapters (forming the convergence layer) to utilize various protocols for delivery [17].

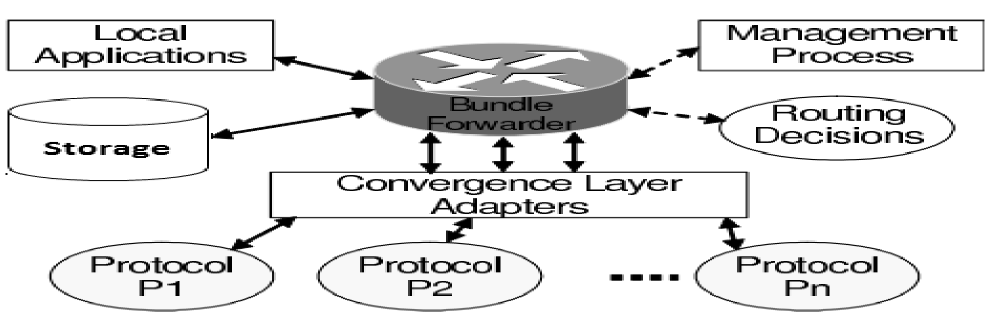

Figure 2-2 The DTN Architecture Implemented within a Single Node [17]

As shown in Figure 2.2 which is referred from [7], bundle forwarder is the core of the mechanism that manages the bundles within the node. During communication, the node can connect to other nodes using a mass of different delivery protocols, including TCP/IP, Bluetooth, Wi-Fi, or hand-carried storage devices. The opposing semantics of the various protocols are hidden from the bundle forwarder by a collection of convergence layer adaptors (CLAs) that map the capabilities of the individual protocols to the functions necessary to transfer bundles to a peer node during a communications opportunity. When a communications opportunity ascends, either because it has been scheduled by the node management process, or because a peer node has been discovered, typically by some wireless mechanism, the bundle forwarder will initiate and manage a link to the peer node using the appropriate CLA. The link will be used to transfer selected bundles stored on this node to the peer node, in accordance with routing decisions provided by the routing decision process. If the policy requires, the bundle may be encrypted or provided with integrity protection before being forwarded [18].

2.3.2 Characteristics of Delay Tolerant Networks

DTNs [30] have some unique characteristics as compared to other forms of wireless networks such as MANETs or cellular networks. Some of the differences are mainly in terms of:

Intermittent Connection

One of the basic characteristics of DTNs is that the end-to-end connection may not exist. Generally, intermittent connections may be happened due to a fault or not. Non-faulty disconnections happen in DTN mostly caused by the node's mobility and also happen due to the non-cooperative behavior of the node. That is to say, the network keeps the status of intermittent connectivity so that there is no guarantee to achieve end-to-end route.

Delivery Latency and High Queue Delay

Delivery latency is the sum of the total delay of each hop on the route. Since many applications can benefit from short delivery times, latency is one of the most important performance metrics of interest. This delay consists of processing, transmission, propagation time overall links as well as queuing delay at each system along the path. The queuing delay is the time it takes to transfer the buffered messages based on the network scheduling policy.

The queuing delay depends on data rate and the amount of competing for traffic traversing loads. In DTNs where an intermittent connection is a common situation, the queuing time could be extremely large, e.g., minutes, hours or even days.

Dynamic Topology

Nodes in DTNs are moving with different speed, and energy depletion, so network topologies are dynamic and communication link are not stable, which may lead to network partitions and intermittent connectivity, which results in dropping out of network

Heterogeneous Interconnection

DTNs uses an overlays protocol layer for transmission of an asynchronous message. Introducing an additional layer called bundle layer below the application layer on TCP/IP protocol stacks, the DTN can run on different heterogeneous network protocol stacks with the help of DTN gateway that ensures the reliable transmission of interconnection message.

Resource limitation

Nodes in DTNs may have limited buffer, energy, and bandwidth than an ordinary computer due to the constraints of a price. And low processing capability and limited memory in a wireless sensor network application scenario, because of end systems consume energy by sending, receiving, storing messages and by performing computation, resulted in higher packet loss rate.

Security

The use of intermediate nodes as relays offers additional opportunities for security attacks, including compromising information authenticity, integrity and user privacy. Particularly among the DTN routing mechanisms, the use of flooding-based may even increase the risks associated with inserting false information into the network. Extra traffic inserted by malicious nodes creates another serious threat due to resource scarcity of DTNs in some application scenarios. Due to this DTNs are vulnerable to many malicious actions and bring a new security challenge.

2.3.3 Types of Contacts in DTN

DTN architecture defines different types of contacts between network nodes. Request for comments (RFC) of DTN [7] describes five types of contacts, which describe as follows:

- **Persistent Contacts**: Persistent contacts are always available (i.e., no connection initiation action is required to instantiate a persistent contact). An 'always-on' Internet connection such as a *Digital Subscriber Line* (DSL) or Cable Modem connection would be a representative of this class.
- **On-Demand Contacts:** On-Demand contacts require some action in order to instantiate, but then function as persistent contacts until terminated. A dial-up connection is an example of an On-Demand contact.
- **Intermittent - Scheduled Contacts**: A scheduled contact is an agreement to establish a contact at a particular time, for a particular duration. An example of a prearranged contact is a link with a low-earth orbiting satellite. A node's list of contacts with the satellite can be constructed from the satellite's schedule of view times, capacities, and latencies.
- **Intermittent - Opportunistic Contacts:** Opportunistic contacts are not scheduled, but rather present themselves unexpectedly. A good example of this type of contacts is an unscheduled aircraft flying overhead and beaconing, advertising its availability for communication. Another type of opportunistic contact might be through an infrared or Bluetooth communication link between a personal digital assistant (PDA).
- **Intermittent - Predicted Contacts:** Predicted contacts are based on no fixed schedule, but rather are predictions of likely contact times and durations based on a history of previously observed contacts or some other information. Given a great sufficient confidence in a predicted contact, routes may be chosen based on this information.

From the contact types discussed above, we considered the Intermittent Opportunistic Contacts for the proposed system.

2.3.4 DTN Application Areas

DTNs span a wide spectrum of application settings. As noted in [15] the study shows that DTNs have been applied to various settings such as interplanetary networks (IPNs), underwater networks, wildlife tracking sensor networks, and networks for developing communities. The application of DTNs which is referred from [37] is shown in Figure 2.3.

As described in [38], DTN improves network access and the distribution of educational and entertainment content in rural environments, despite the relative underdevelopment of more traditional kinds of infrastructure like roads and electricity. Thus, DTN does compromise network reliability and quality of service by introducing unpredictable delays as data is physically relayed from one wireless device to another.

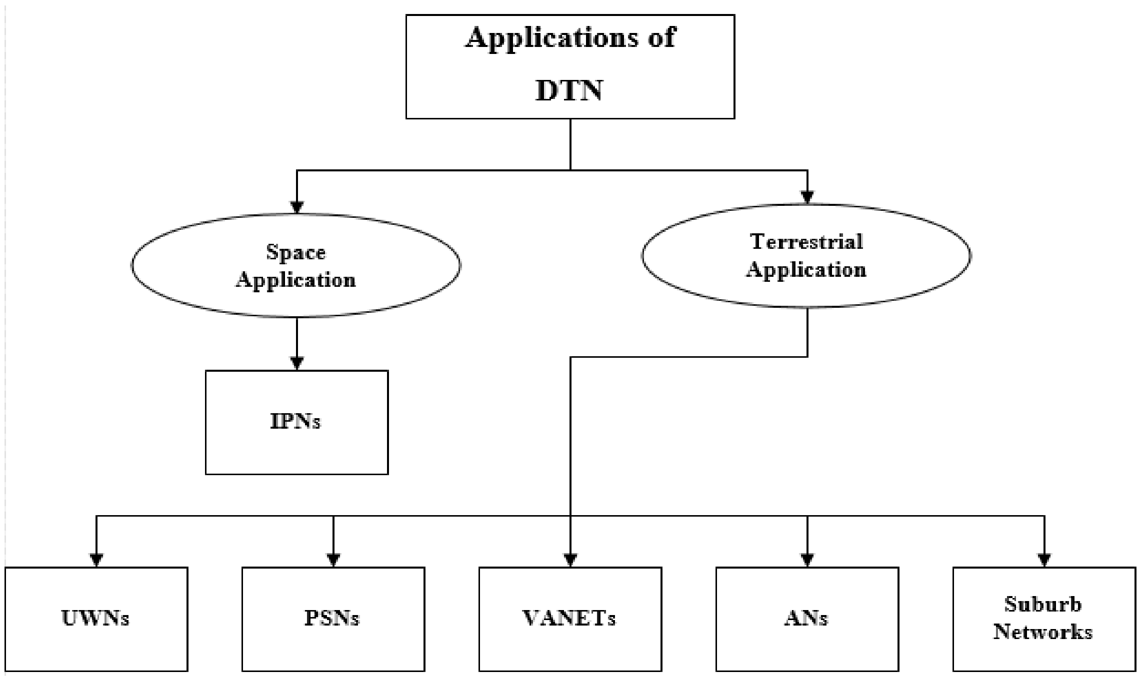

Figure 2-3 Applications of DTNs [37]

2.4 Vehicular Delay Tolerant Networks

Vehicular delay-tolerant networks (VDTNs) [42] appear as new network architecture based on the concept of DTN. As noted in [39] the paper shows that VDTN allows delay-tolerant data traffic from a variety of vehicular applications to be routed over time, exploiting the physical movement of vehicles and the opportunistic links they establish with each other and with other network nodes. VDTNs extend VANETs with DTN capabilities to support long disruptions in network connectivity and it emerged as a new DTN-based network architecture [42], Figure 2.4 which is referred from [39], shows three possible VDTN node types - terminal nodes, stationary relay nodes, and mobile nodes. Terminal nodes act as access points to the VDTN by providing connection to end-users. Mobile nodes (e.g., vehicles) are responsible for physically carrying data between terminal nodes, it can also use as terminal nodes. Stationary relay nodes are devices with store-and-forward capability allowing mobile nodes to drop and pickup data bundles. These nodes increase the number of contact opportunities in sparse scenarios, contributing to improve the delivery ratio and decrease the delivery delay [43]. An example of a VDTN network applied to a rural connectivity scenario is shown in Figure 2.4, according to [41] VDTN can provide a variety of services such as road safety, commercial information, entertainment and providing connectivity to rural areas.

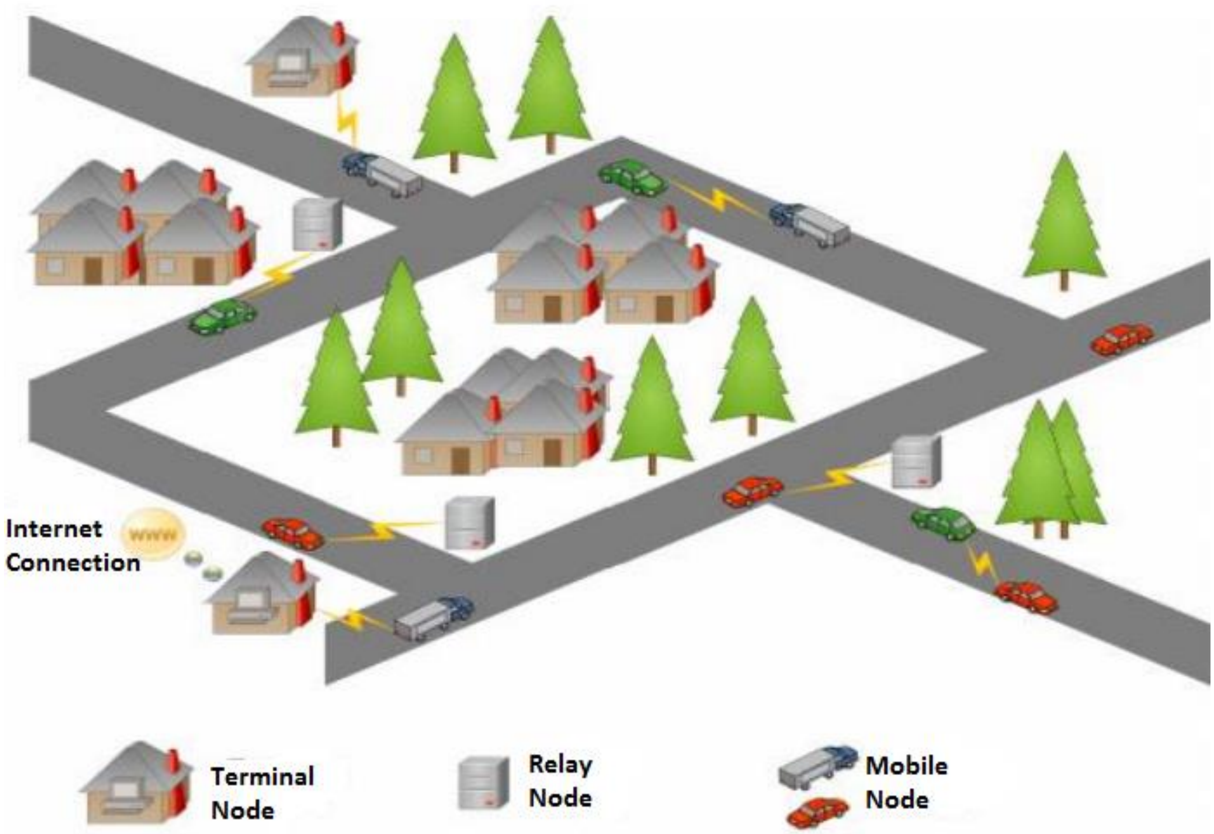

Figure 2-4 Illustration of a VDTN Network [39]

2.5 Routing in Vehicular Delay Tolerant Network

In Delay-tolerant networks, at any given time instant, the network may not be connected due to the absence of end-to-end connectivity, this makes routing/forwarding decision in DTN is more difficult. However, it allows routing in networks where simultaneous end-to-end paths are unstable. Unstable paths can be the result of several challenges at the link layer which are high node mobility, low node density, short radio range, environmental interfaces and non-cooperative behavior of nodes.

Routing protocols in DTN must take more issues into consideration before making decisions in opposite to traditional networks, data is delivered in a DTN using a store-carry-forward model. Nodes in the network transmit data from source to the destination, where existing nodes in the network relay the data from the source to the destination, in one or more hops, and each node along the path receives the data from the previous node and stores it locally. This node then carries the data until it contacts with other nodes, forwards the data. In this way, the data is finally delivered to the destination [23]. Store and forward method is an old method like that used in the postal network. As cited in [24], with the store and forward method, data is transferred from one node to another node until it reached its destination. The store and forward method in DTN are shown in Figure 2.5.

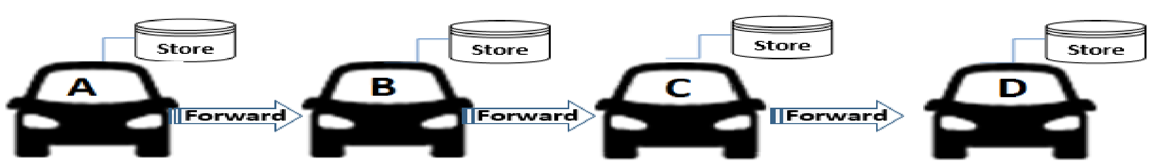

Figure 2-5 DTN Store and Forward Method

In Figure 2.5 which is referred from [24], data forwarding in DTNs typically adopts store-and-forward techniques, but when the communication route towards to the next hop may not be available, in this case, the source node needs to store and carry the message until the next available node is encountered. The routing of messages in DTN is based on a hop by hop, the choice of next hop is done dynamically as per the application scenario as well as the algorithm used. Thus, when a node gets any bundle as per the algorithm, it searches the better relay node to which it can transmit the message.

As noted in [20] [9], In general, routing strategies can be classified as either single-copy and multiple-copies. Single-copy strategies use network topology information and they maintain a single copy of a bundle in the network that is forwarded using the best path. On the contrary, multiple-copies strategies do not need to have information about the network. They replicate bundles at contact opportunities hoping to find a path to a destination. Based on the method used to find destinations, and whether replication of messages is used or not, routing in VDTN can be classified into several categories: flooding based, probabilistic based, information based, infrastructure based, and incentive based. Figure 2.6 shows a general classification of VDTN forwarding algorithms. We did not draw infrastructure based on the classification Figure because they overlay a lot with other categories.

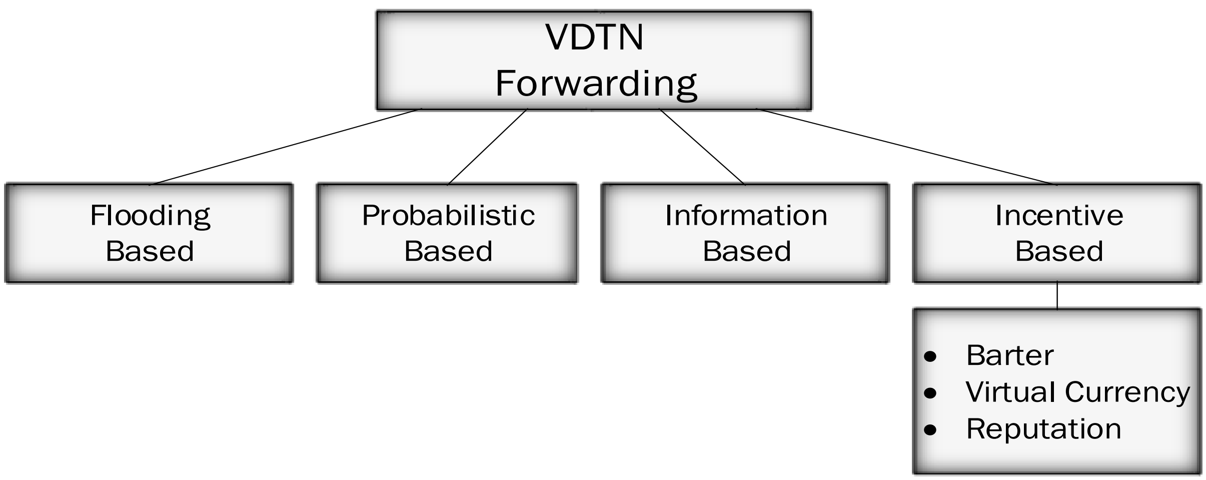

Figure 2-6 Classification of VDTN Forwarding Protocols.

2.5.1 Flooding Based Routing

The schemes in this category do not require a node to have knowledge of delivery probability and meeting probability about other nodes. In this approach, nodes in the network opportunistically forward messages to other nodes until messages reach their destinations. The Flooding based routing is further classified into two types [25].

Replication-Based: Allows the network nodes to create the replicas of the received message. The maximum number of replicas generated within a network for a particular message could be n-1 where n denotes the number of nodes in the network and it is effective in terms of packet delivery, but suffers from the disadvantages of flooding as the node density increases. It creates lots of disagreement for buffer space and requires bandwidth, resulting in many bundles, drops and retransmissions in resource-constrained network environments. In an environment with infinite buffer resources and bandwidth, this protocol provides an optimal solution, since it delivers all the bundles that can possibly be delivered in the minimum amount of time. Epidemic routing [26] is the representative schemes of this category.

Quota Based: In this routing type each message is assigned with fixed amount i.e., the number of replicas for a particular message is limited. Spray and Wait are the popular representative schemes of this category. According to [28] in Spray Phase, every message originating at the source node is passed to a distinct relay in the network i.e., many copies of the message are spread over the network by the source node. In the Wait phase, if the destination was not found in the spray phase, each relay node having a copy of the message performs the direct transmission of the message to the destination itself. Hence, it waits until one of the relays (i.e., nodes) finds the destination node. Two different spraying schemes are proposed for the "spray phase", source spray (also called normal spray) and binary spray. In the source spray scheme, the source node starts with L bundle copies. Each time the source node encounters a new node, it hands one of the L copies and reduces its number of copies left by one.

In the binary spray scheme, the source node also starts with L bundle copies. But, whenever a node with $L > 1$ copies encounters a new node, it hands half of the copies that it stores in its buffer. For both spraying schemes, when a node carries only one bundle copy left, it only forwards it to the final destination. This is the "wait phase". It is important to notice that each bundle has a header field indicating the "number of copies" it represents. As expected, the (actual) bundle is not replicated within a node's buffer.

2.5.2 Probabilistic Based Routing

This type of routing scheme takes place when nodes have some important knowledge about the other nodes in the network. In this scheme no node will generate replicas of the messages, instead, they will search for the best suitable relay nodes and forward the message to them based on nodes' encounter history [29] [19], or nodes' location visiting patterns

[31]. Just to name some examples are, PROPHET [32] and MaxProp [19] are well-known routing algorithms of this scheme.

2.5.3 Information Based Routing

This routing strategy can be efficient in terms of message overhead and buffer consumption because to make route decision this routing schema use different types of information like the history of node encounters, prior knowledge of the network, and location information. In this routing scheme, the mobile nodes which act as ferries are assumed to reach their destination according to the predefined schedule, this might be difficult in the environment where there are so many constraints that inhibit the mobile nodes from reaching its destination. Therefore, there is no VDTN routing protocol that can be considered perfect and suitable for all kinds of vehicular networks, unless 100% delivery reliability is not required. GeOpps [34] and GeoSpray [35] are well-known routing algorithms of this scheme.

GeOpps (Geographical Opportunistic Routing). Geographic routing is one of the most favorable methods for efficient routing, which takes location information of the vehicle into consideration. Geographical opportunistic routing for vehicular networks aims to improve the performance of single-copy routing protocol in VDTNs [34]. It uses the geolocation of vehicles to forward the geographical bundle opportunistically towards the final destination location. Thus, the vehicle that is approaches towards or close to the destination location of the bundle becomes the next bundle carrier. The closest point where a vehicle carries the bundle is called nearest point and used to calculate a minimum estimated time of delivery (METD) as follows: METD = time to nearest point + (remaining distance / average speed). A vehicle with the lowest METD is elect as candidate bundle forwarder. GeOpps assumes that the bundle forwarder always finds another vehicle when it arrives at the nearest point.

GeoSpray (Geographical Spray) uses the ideas of single-copy single-path GeOpps to perform multi-copy multi-path bundle routing method. Multi-copy routing method is noted for their high delivery ratios, low bundle delivery delays, and high overheads due to duplicated copies. Thus, GeoSpray adopts the replication method of the spray-and-wait protocol [28] to limit the number of copies. Initially, it uses multiple copy approaches, which spreads a limited copy of the bundle to uses diverse paths. Afterwards, it switches to a single-copy forwarding approaches. GeoSpray clears the delivered bundles from vehicles' storage by spreading the delivery information. As a result, it improved delivery ratio than GeOpps at the cost of high replication overhead. Though, this overhead is less than the epidemic protocol and similar to spray-and-wait [35]. In Chapter 3 it will discuss Incentive-based routing.

2.6 Node Cooperation

Due to the uncertainty of transmission opportunities between nodes, Vehicular Delay Tolerant Networks adopts a store carry forward method [7]. The effective operation of opportunistic networks depends on the cooperation among network nodes to exchange data over sparse and challenging network environments [40]. This approach requires nodes to store and forward messages in a cooperative way to improve the overall network performance. Until recently, most of the research on these networks have assumed that nodes collaborate with each other, storing and distributing bundles not only in their own interest but also in the interest of other nodes. Such behavior increases the number of a possible transmission path. However, this assumption may not be valid, since network nodes may show different behavior. The authors in [27] define four classifications of nodes behavior (Figure 2.7). cooperative nodes, partly cooperative, selfish and malicious.

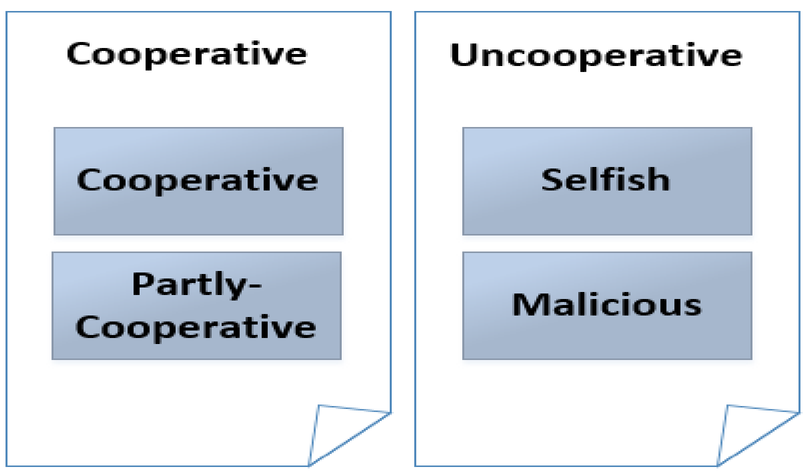

Figure 2-7 Classification of Node Behavior [27]

Cooperative Nodes: store and forward messages to another node without restriction.

Partly-Cooperative: Agree to forward the messages coming from other nodes, but on condition that transmits messages directly to the destination.

Selfish: DTN are resource-constrained networks, so the selfish behaviors may occur among the nodes to preserve its own resources (energy, storage space, CPU…) by ignoring the packet from other nodes and will forward only its own message. Figure 2.8 illustrates a non-cooperative environment, where a network node denies storing and distributing other nodes' bundles, it leads to overall degradation of the network performance [40].

Malicious: The network nodes provide bogus metrics to other nodes that come in contact with and attract packets from them [44]. After getting these forwarded packets, the malicious node can either drop or alter them [33].

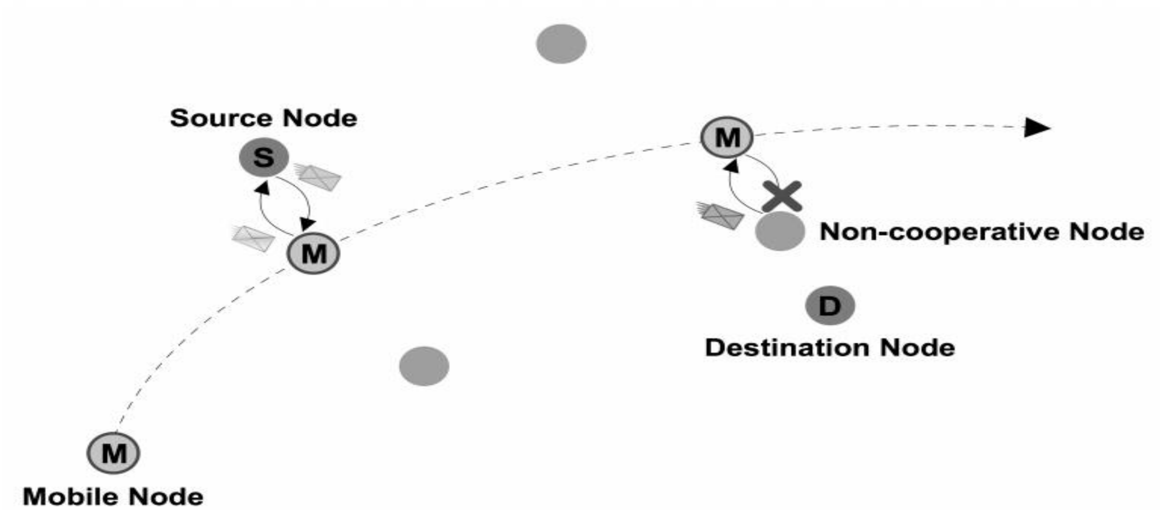

Figure 2-8 Non-Cooperative Network Scenario [40]

When a DTN-based network uses multi hope data forwarding schema to exchange data between source and destination, it is important to keep in mind that cooperation among the network nodes. This dependence may have a big impact on the network when those nodes show uncooperative behavior, the existing research works, based on theoretical analysis models and simulations, demonstrate that the routing performance (i.e., delivery probability, network overhead and delivery latency) is seriously decreased, if a major portion of the nodes in the network is selfish [36].

To reduce the impact of this non-cooperative nodes many researchers are working on incentive-based approaches to improve network performance in underserved areas using the delay tolerant network principle, which is different from the traditional one where end to end connectivity is expected. So, Chapter Three presents some of the papers related to our work.

Chapter 3
Related Work

3.1 Introduction

As describe on the literature review the effective operation of opportunistic networks depends on the cooperation among network nodes to exchange data over sparse and challenging network environments. Because of the negative consequence of those non-cooperative network nodes on the network performance, there are a number of works which are done to manage non-cooperative network nodes to become cooperative. so, this chapter presents some of the papers related to our work into three main categories.

3.2 Barter Based Approaches

It is based on a direct exchange so that two nodes will interchange messages by doing favors for each other. And any long-term state information does not need to be maintained. Authors in [6] proposed incentive-aware routing in DTNs, to mitigate the damage caused by selfish nodes, the pair-wise tit-for-tat (TFT) has been used as a simple and practical incentive scheme for DTNs, TFT is based on the principle that every node forwards as much traffic for a neighbor as the neighbor forwards for it, based on a direct exchange so that two nodes will respond by doing favors for each other without any support from the third party, which means that the intermediate nodes are paid some credit based on forwarded bundles. The author also proposed generous TFT to address the basic TFT scheme problem which thwarts relaying the messages when two nodes meet for the first time, as no message is relayed by another node. However, due to the requirement of responds good or bad behavior only between neighbors simultaneously when the service and its rewards are not simultaneous, there is no way of knowing whether the other node had done some useful favor before doing a service for that node, because of this it would be difficult to achieve direct traffic monitoring or selfish detection in an intermittently connected network.

3.3 Virtual-Currency Based Approaches

To come up with the limitation of barter-based approach, the work which are done on [10], proposed a Threshold Incentive Scheme (TIS) for secure and reliable data forwarding in VDTNs. Which works on the principle of when the nodes must earn some credits by serving others and pay when served by others, for successful message delivery process. Those rewarding and punishing conducted by a virtual bank called central manager with the backbone of a modified model of population dynamics, the communications between central manager and the nodes are delay tolerant. TIS provides each node with equal opportunity in packet forwarding to achieve the fairness in credits offered to nodes in the network. And it also uses time order preserving aggregated signature scheme to resist the layer adding attack raised due to the collusion of intermediate nodes. This approach, however, it incurs implementation overheads due to the requirement of a trusted third party to maintain the records.

3.4 Reputation Based Approaches

It designed to address the implementation overhead problem of virtual-currency based approach. In these approaches, the intermediate nodes are evaluated by its neighboring nodes and assigned a reputation value based on their cooperating behavior with the other nodes. If a node cooperates, its reputation value become increase it helps to get better services. The reputation score of a node is decreased when it shows selfish behavior in forwarding the other nodes messages, by using this principle a reputation system to identify and isolate selfish nodes in VDTNs were proposed in [8]. which main goal is to provide a tool that allows network nodes to prevent contacts with selfish nodes. In order to achieve their goal, four different reputation strategies were implemented. Those are Simple Increment Simple Decrement (SISD), Double Increment Simple Decrement (DISD), Simple Increment Double Decrement (SIDD), and Simple Increment Message Hop Decrement (SIMHD). All strategies base their performance on the number of deliveries and dropped bundles parameters to reward and punish nodes respectively.

However, there are several challenges that must be overcome for instance how to motivate nodes to be cooperate instead of an isolate from the network to minimize the impact of selfish nodes on the overall network performance, by considering this the author as noted in [45] proposed Cooperation Strategies for Vehicular Delay-Tolerant Networks, which main objective is to develop Cooperative Watchdog and Reputation system that monitors selfish node to become cooperative instead of isolating from the network to improve the overall network performance of VDTN. The author used monitoring module to motivate non-cooperative nodes, unfortunately they used the same reputation strategies which has developed on paper [8], this strategy mainly focuses on punishing more rather than rewarding non-cooperative network nodes, it may cause negative consequence on the network performance.

In the final paper that was review the author as noted in [11] proposed a hybrid system to stimulate selfish nodes to cooperate in VDTNs, the main objective is to develop tools that stimulate selfish nodes to relay others message. In order to achieve their goal two new reputation methods are proposed, the first one is Volume of Bytes Transferred (VBT), and the second one is Time Spent to Cooperate (TSC). The main idea behind these two methods is to incentive selfish nodes by their effort to forward bundles. For instance, In the TSC method, each time a node forward bundle, its reputation score increases $2k + h*k*t$ units, where h is the number of bundle hops between the source and the current node, k is a constant value, and t is the percentage of time spent by a node cooperating with other nodes. And it is calculated according to Equation 3.1, where TCi is the time spent by node i cooperating with other nodes. However, the method they used is not efficient in term of improving network performance.

Equation 3-1 Time Spent to Cooperate

$$t = \frac{TC*100}{\sum_{i=1}^{N} TCi} \quad \text{--} \; (3.1)$$

According to their final reports, all the above mentioned proposed incentive approaches improves delivery probability and average delay with incentive-based reputation system as a basis of cooperation among selfish nodes than without any incentive mechanism. But it is not good enough to identify selfish nodes and taking action to monitor efficiently. this makes the network to decrease its performance. The issue above discussed is the motivation for the proposed problem statement. The novel module introduced in this study is new reputation strategies that focus stimulating selfish nodes to improve the network performance based on Pareto's principle which is not proposed or used in the existing work.

3.5 Summary

The summary of related works which has covered above is summarized as follows with some pros & cons.

Table 3-1 Comparison of Some Related Work

Author & Title	**Core Mechanism**	**Incentive Type**	**Some Pros & Cons**	
Shevade et al. [6] Incentive-aware routing in DTNs	Tit-for-tat	Tit-for-tat based incentive mechanism	Pros: Requirement of exchanging the same amount of message Simple to implement, and leads to no overheads	Cons: Responds good or bad behavior only between neighbors When the node has no enough messages to exchange Lack security schemes
Zhou *et al [10]* A Threshold Incentive Scheme for Secure and Reliable Data Forwarding in VDTNs	Use of modified population dynamics model as the basis of Incentive scheme	Virtual currency-based incentive mechanism	Pros: Credits as incentive motivating node to cooperate It addresses the resisting the layer adding attack	Cons: Cannot work when the nodes have a high probability of being selfish to other nodes Require trusted third Party High communication and processing overhead
Dias et al [8] A Reputation System to Identify and Isolate Selfish Nodes in VDTNs	Simple Increment Simple Decrement (SISD) Double Increment Simple Decrement	Reputation based incentive mechanism	Pros: Work well even if a major portion of the nodes are selfish	Cons: Consider the cooperation of intermediate nodes as selfish behavior Lack security schemes Did not consider

	(DISD) Simple Increment Double Decrement (SIDD) Simple Increment Message Hop Decrement (SIMHD)			any stimulation methods for selfish node
Dias et al [11] A hybrid system to stimulate selfish nodes to cooperate in vehicular Delay-Tolerant Networks	Volume of Bytes Transferred (VBT) Time Spent to Cooperate (TSC)	Reputation based incentive mechanism	Pros: Motivate node to increase reputation level by being cooperative Work well even if a major portion of the nodes are selfish	Cons: Consider the cooperation of intermediate nodes as selfish behavior Lack security schemes Not efficient in monitoring selfish nodes

Chapter 4
Proposed Approach

4.1 Introduction

As we have described in Chapter 3, most of the current reputation system strategies work focus how to identify and punish network nodes when they show selfish behavior, though there has not been work that describes strongly punish selfish nodes when they show selfish behavior and rewarding more when it relays other data. So, to achieve the objectives, it made use of the following approach. The idea of this research is to enhance the vehicular communication in sparse areas using the principle of delay tolerant networks because of unlike urban scenarios which have high node density the intermittent connectivity in sparse area is very high. In a non-cooperative network, selfish behavior of the node is the well-known problem in degradation of network performance. Thus, we proposed a new incentive method that reward and punish network nodes based on the Pareto principle.

4.2 The Proposed Incentive Based Node Cooperation in Vehicular Delay-Tolerant Networks

From the related work of literature review, it is understood that different researches have been done in proposing efficient incentive-based routing algorithms for non-cooperative VDTN to make non-cooperative nodes to be cooperative for the purpose of improving the overall network performance. The scenario considered here is mainly focused on how to identify selfish node immediately and make them cooperative based on Pareto principle or 80/20 principle [3]. This principle was invented by Vilfredo Pareto, an Italian economist and sociologist. Pareto states that there is a natural inequity between causes and results, inputs and outputs, and effort and reward, I.e., a minimum of causes, effort or inputs usually lead to a maximum of the results, rewards or outputs. It is often used in management, economics and business to improve productivity and make better decisions [46]. In addition to those fields we also brought and customized this idea to manage non-cooperative nodes in VDTN. So, by adopting these unequal distribution ideas we proposed a new incentive strategy that selfish node get more benefit when they relayed other bundles and more punishment when they dropped other bundles. To elaborate assume if the selfish node has 30% of cooperative effort, during communication when it relays other bundles it will get 70% reward until its reputation score becomes 99. But when it drops it punished by 70% until its reputation score becomes 1 and after monitoring if it continues non-cooperative behavior it will excluded from the network.

4.2.1 Connection Setup

In an opportunistic network, when two nodes encounter one another, they usually need to exchange some meta-messages to avoid sending duplicate data bundles. For this reason, the considered routing protocol in this study is the binary version of Spray-and-Wait routing protocol. In the considered routing, each node's buffer contains messages initiated by the node as well as messages relayed on behalf of other nodes. When two nodes encounter one another to exchange message stored in their buffer, they first establish a connection between them in three phases (Probing phase, the meta-messages exchange phase, and message exchange phase) which is common in an opportunistic network. Probing phase lets the node to broadcast a beacon periodically and listens for the beacons of its neighboring nodes.

When two nodes are coming into the same radio transmission range then, the connection established based on the beacons they receive from each other. Then based on the established connection the meta-messages exchange takes place. Meta-message provides information about messages stored in the node's buffer at this phase, it is also used to provide information about the node such as node type and reputation score in our case. So that it helps each node to determine its neighboring nodes whether selfish or not. Finally, one node sends a message to the other node or they exchange messages they do not have in common previously.

In the proposed incentive system before starting of its process, each network node initializes a reputation table and assign reputation score. The reputation table stores node name and reputation score about all the encounter nodes. As shown in Figure 4.1 the method of the proposed system consists of three components: Reputation module, a Monitoring module, and an Update module- the main goal is to motivate non-cooperative nodes to cooperate with other network nodes.

4.2.2 Reputation Module

The reputation module used by the author at [8] was adapted to operate together with monitoring and update modules. This module builds on each node a reputation table containing node ID and a reputation score, about all the encountered nodes. each time a contact opportunity is available, the reputation score of the encountered node is updated. Nodes reputation score is used to compare it with a network reputation threshold (α) equal to all the network nodes. This allows the proposed system to identify and classify nodes into two categories: cooperative and non-cooperative nodes. If nodes reputation score is higher than α then they are marked as cooperative nodes. Otherwise, they are marked as a non-cooperative node and get into the monitoring module.

4.2.3 Monitoring Module

The monitoring module operation is based on stimulating approach which tries to motivate nodes to cooperate by offering them benefit in exchange for their cooperation. Considering this approach, when the reputation module marks a node as a non-cooperative node, the monitoring module begins to monitor it. Being monitored by this system means that during a predefined period of time (Pt) a selfish node is encouraged (e.g., the reputation score will increase) to share its own resources (like buffer, energy and bandwidth) with other nodes to be part of the network. After this period of time, if the node continues to maintain its non-cooperative behavior it is permanently excluded from the network. On the other hand, if the node starts to be cooperative, it is rewarded by the reputation system with an increase of its reputation score. This process continues until the node reputation score reaches the same value of the network reputation score or until the Pt time expires.

4.2.4 Reputation Update Module

The proposed Pareto principle-based incentive methods, to update node reputation score it use two metrics the delivered bundles and the dropped bundles. The main idea behind this method is to reward/punish selfish nodes with disproportional values when they relay/drop bundles respectively. In this method when non-cooperative node relays others bundle successfully, its reputation score increases by the amount calculated according to Equation 4.1. “E” stands for the effort of the forwarding node or it represents the initial reputation score of the forwarding node. On the other hand, when non-cooperative node drops a bundle without exchanging it at least once, its reputation score decreases by the amount calculated according to Equation 4.1:

Equation 4-1 The Amount of Reputation Score

$$RS = E \pm (100 - E) \quad (4.1)$$

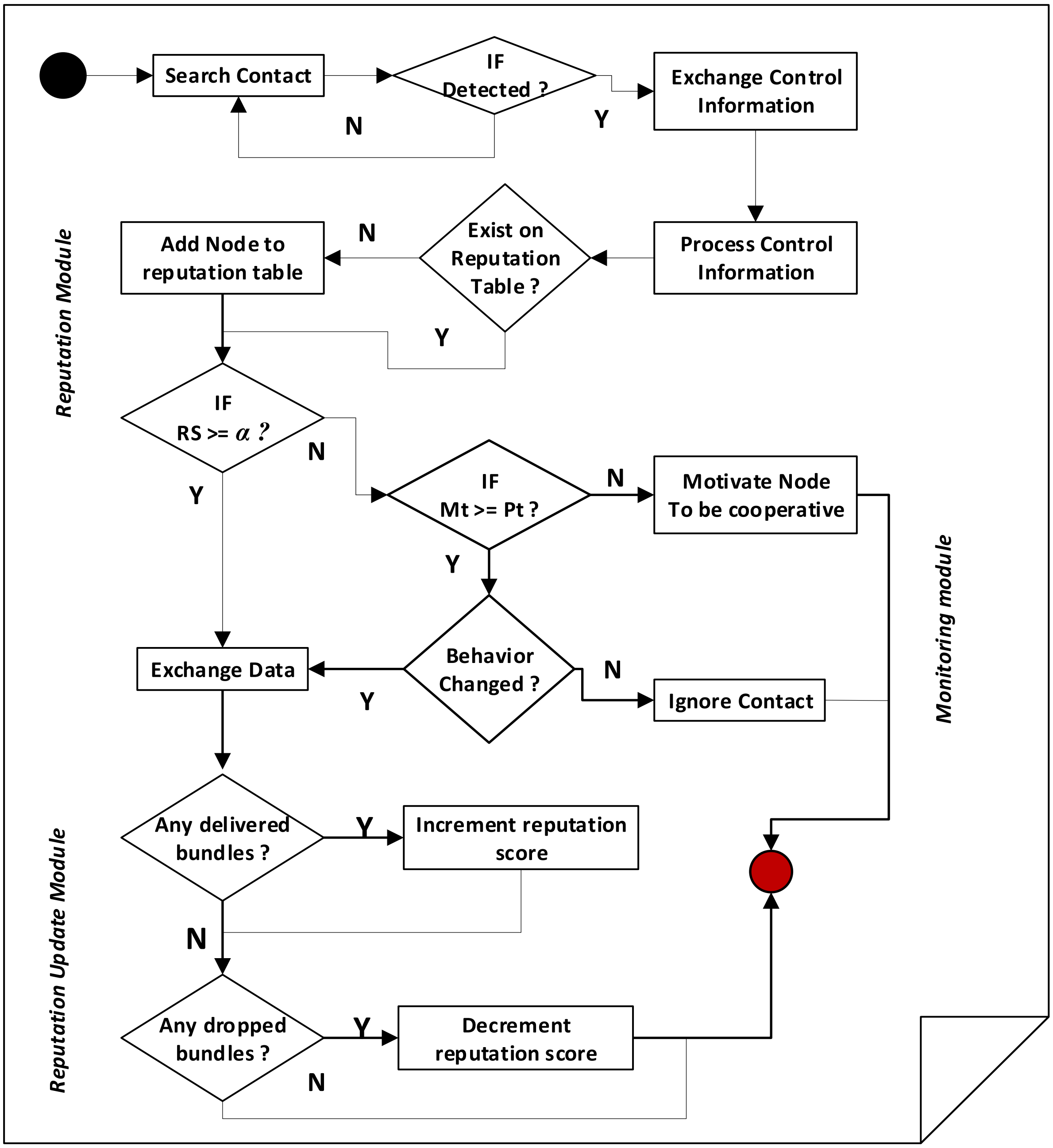

Figure 4-1 Flow Chart of the Proposed Reputation-Based Incentive System

Algorithm: *pseudo code in the form of sequence of steps executed at node n when nodes x and y come in contact.*

Notation

- α - Network Reputation Threshold Value
- RS – Reputation Score
- Mt – Monitoring time
- Pt – Predefined time

```
while (nodeIsDetected)
Begin
exchangeControlInformation
processControlInformation
If (! nodeInfoAvailableOnREPTab)
Begin
addNodeToRepTable
End If
while (RS >= α)
Begin
exchangeData
End while
If (Mt < = Pt)
motivateNodeToBeCooperative
If (BehaviorChanged)
Begin
exchangeData
End If
If (DeliveredMessage! = 0)
         increaseRS
If (DroppedMessage! = 0)
         decreaseRS
else
ignoreContact
End while
```

4.3 Summary

The effective operation of VDTN depends on the cooperation among network nodes to exchange data over sparse and challenging network environments. This approach requires nodes to store and forward messages in a cooperative way to improve the overall network performance. This dependence may have a big impact on the network when those nodes show Non-cooperative behavior. To come up with this problem, we designed a new incentive strategy, and the proposed solution contains three principal modules. First, reputation modules that are used to check whether the neighbor nodes are non-cooperative or cooperative depends on the network reputation threshold values. Second, monitoring modules in which the reputation system stimulates non-cooperative nodes before ignoring contact with them. The third one is reputation information update modules in which the nodes reward when they relay other data. On the other hand, they punish when they drop based on Pareto principles.

Chapter 5
Implementation

5.1 Experimental Environment Setup

The studies are conducted through simulation considering the ONE simulator tool [21]. The ONE simulator implemented in Java and available as open source has been used to demonstrate the proposed system. The simulator supports for generating different node movement models, routing messages between nodes with different DTN routing algorithms, visualizing both mobility and message passing in real time in its graphical user interface (GUI) [21]. Many of the routing algorithms applicable to DTN environment are pre-implemented in the simulator. In this study, the proposed approach is incorporated into existing binary version of Spray-and-Wait routing algorithm to manage non-cooperative nodes. The shortest path map-based movement model provided with the ONE simulator was used and across all the simulation experiments the Well-Known Text (WKT) file of the default map of ONE simulator which represents a part of the city of Helsinki, Finland (Figure 5.1) was used for simulation. Accordingly, the movement model obtains its configuration data using files formatted with a subset of the well-known text format and with the mobility model specified above; the mobile nodes move using roads from the map data.

In the simulation, we used ten terminal nodes which are placed at a fixed point of different part of the cities that act as traffic sink and access points to end-user, and five stationary nodes are located at a fixed point of the crossroad of the map that used to increase the contact opportunities among the mobile nodes through a store and forward the incoming bundles. And, finally 50 mobile nodes (both cooperative and non-cooperative) with store-carry-forward capabilities are used. Out of those mobile nodes, 10 nodes which are randomly selected act as traffic source of the network. Also, it is assumed that all network nodes are equipped with omnidirectional antennas and used the standard IEEE 802.11b with allowing a transmission range of 100m and a transmission data rate of 6 Mb/s.

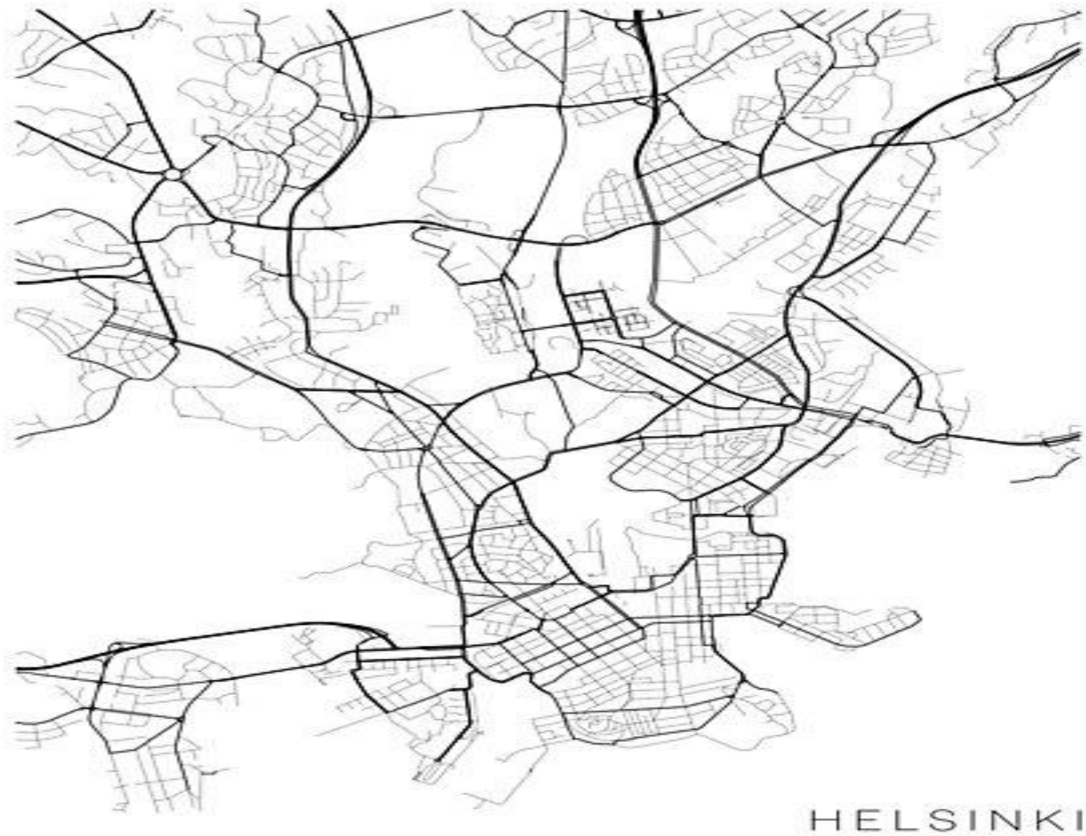

Figure 5-1 Simulated Map of a Part of Helsinki, Finland

5.2 The Simulation Scenario

The analysis phase uses the following scenario for describing the proposed Incentive system using the ONE simulator modeling on node movement; inter-node contacts, routing and message handling. The result of the simulation was analyzed based on the metrics described in section 6.1.

In this study, the following points were considered for the simulation scenario. In order to share the created messages with the help of mobile nodes that store-carry and forward, they stored message when the nearby nodes are encountered opportunistically, and it defines two types of mobile nodes; cooperative and non-cooperative. The scenario was built by defining the simulated nodes and their capabilities. The defined nodes and their capabilities include the basic parameters such as storage capacity, transmit range, bit-rates, movement and routing models and simulation duration. The scenario consists of stationary nodes, terminal nodes, and mobile nodes. It is assumed that each stationary nodes and terminal nodes at the fixed location were having persistent and large storage capacity. But the mobile nodes were having limited buffer space so that they are prone to buffer overflows at a certain point of time due to the flooding of the messages when the nodes are encountered each other. The detail of various simulation parameters for the simulation scenario is shown in table 5.1.

Table 5-1 Simulation Environment Parameters

Parameter	***Value***
Simulation Time	43,500s (12h)
Mobility Mode	Shortest Path Map Based Movement
Routing	Binary Version of Spray-and-Wait
Number of Groups	Four
Transmission Range	100m
Packet transmission speed	6Mbps
Time to Live	180 Minutes (3h)
Number of Terminal nodes	10
Terminal nodes buffer	50MB
Number of Relay nodes	5
Relay nodes buffer	100MB
Number of mobile nodes	50
Mobile nodes buffer	25MB
Mobile Node Speed	50km/h – 100km/h
Mobile node Wait Time	5, 15 Minutes
% Selfish nodes	10%, 20%, 30%, 40%, 50%
Message Size	50Kb, 750Kb
Message Generation Interval (Minutes)	25, 35 Minutes
Number of Message Copies L	8

5.3 Message Generation

The ONE simulator provides two ways to generate application messages inside the simulation. These are message generators and external event files. The first way of message generation (i.e., message generators) which is built-in in the ONE simulator. It creates messages with a random or fixed source, destination, size, and interval. The second way of message generation is external event files. For the simulation scenario, the message generated by the message generator which is pre-implemented in ONE simulator was used. Message event generator set in such a way that it generates the messages in every 25 to 35 minutes and every time message size can also be varied from 50 Kb to 750Kb.

5.4 The Mobility Model

This section provides the movement models of the node opted in the ONE simulator for node mobility. As DTN networks are contingent greatly on physical movement of devices that can store carry and forward messages with other DTN devices, the performance of a DTN would seem to depend on the underlying mobility assumed of the smart vehicle that has onboard units for communication. In this study, the smart vehicles were considered to buffer and exchange messages with other smart vehicles.

For the proposed incentive system, the smart vehicles which have communication board, and each node have IEEE 802.11b interface to exchange the information when it encounters with other nodes. The information exchange takes place when the mobile nodes encounter any other mobile nodes in the network opportunistically. The smart vehicles mobility extends the range of the network, allow data paths to exist over time in networks that suffer from long periods of disconnection. Thus, the onboard unit on the vehicles acts as the communication infrastructure for the network, being opportunistically explored to collect, carry and disseminate data. Once the generated message is delivered to the terminal node, it is assumed that the end user can access the data from the local device.

In this work, the shortest path map-based movement model which is pre-implemented in the ONE simulator is chosen for simulating the node mobility. It is a derivative of the Random Waypoint model, where at decision point’s node chooses a random destination and then follows the map-based shortest path to that destination. Since the node configured with the shortest path map-based movement, models can use the map data, the nodes in the simulation follow the deterministic routes according to the configuration files instead of following any random routes.

5.5 Reporting and Visualization

This section describes the way how the results of the simulation were visualized. These are through an interactive Graphical User Interface (GUI) and with generated images from the information gathered during the simulation. Figure 5.2 shows the GUI displaying the simulation in real-time and it has been used for demonstration purposes. In the main window the node locations, current paths, connections between nodes, number of messages carried by a node, etc. are all visualized. Also, the GUI produces a filtered log of simulation events, such as contacts and message transfer. While the GUI is good for getting over-all picture of what is happening during the simulation, more rigorous ways to visualize node relations, message paths and performance summaries are provided by post processed report files.

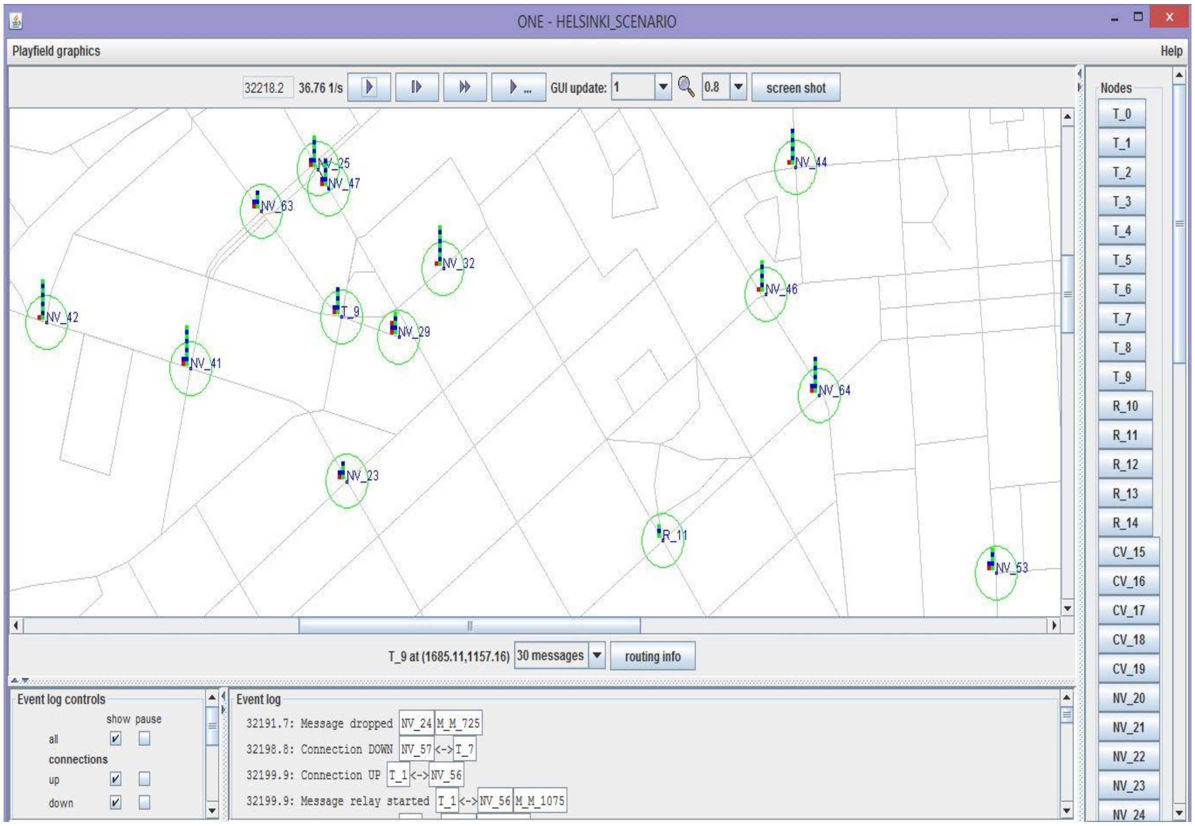

Figure 5-2 Screenshot of the ONE Simulator GUI

Based on the report file generated by ONE simulator, the node connections and other reports module files were used for further analysis. Figure 5.3 and Figure 5.4 show some node connections and the path that the messages have travelled in the network with incentive system and without incentive respectively. Those figures are drawn by GVEdit graph file editor based on Message Graphviz Report file as an input from the ONE simulator reports module.

Notation:

CV - Represent cooperative vehicle

NV - Represent non-cooperative vehicle

T - Represent terminal node

R - Represent stationary relay node

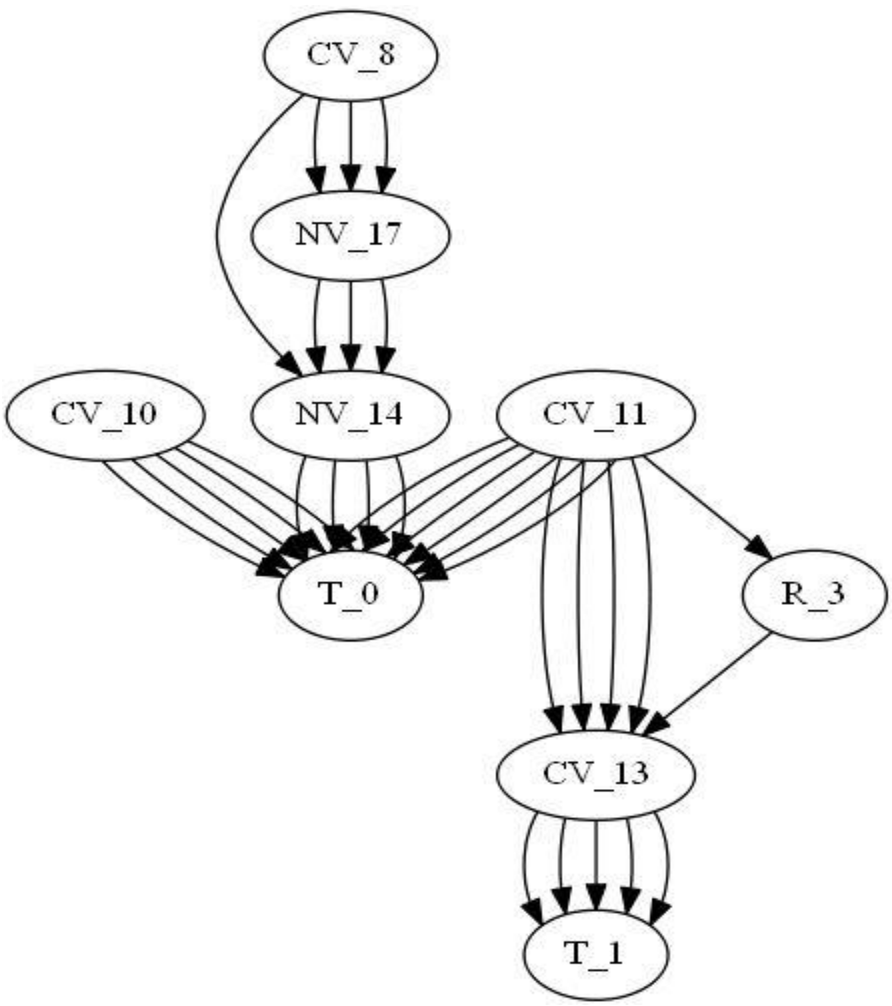

Figure 5-3 Node Connections and the Message Path in the Network with Incentive Mechanism

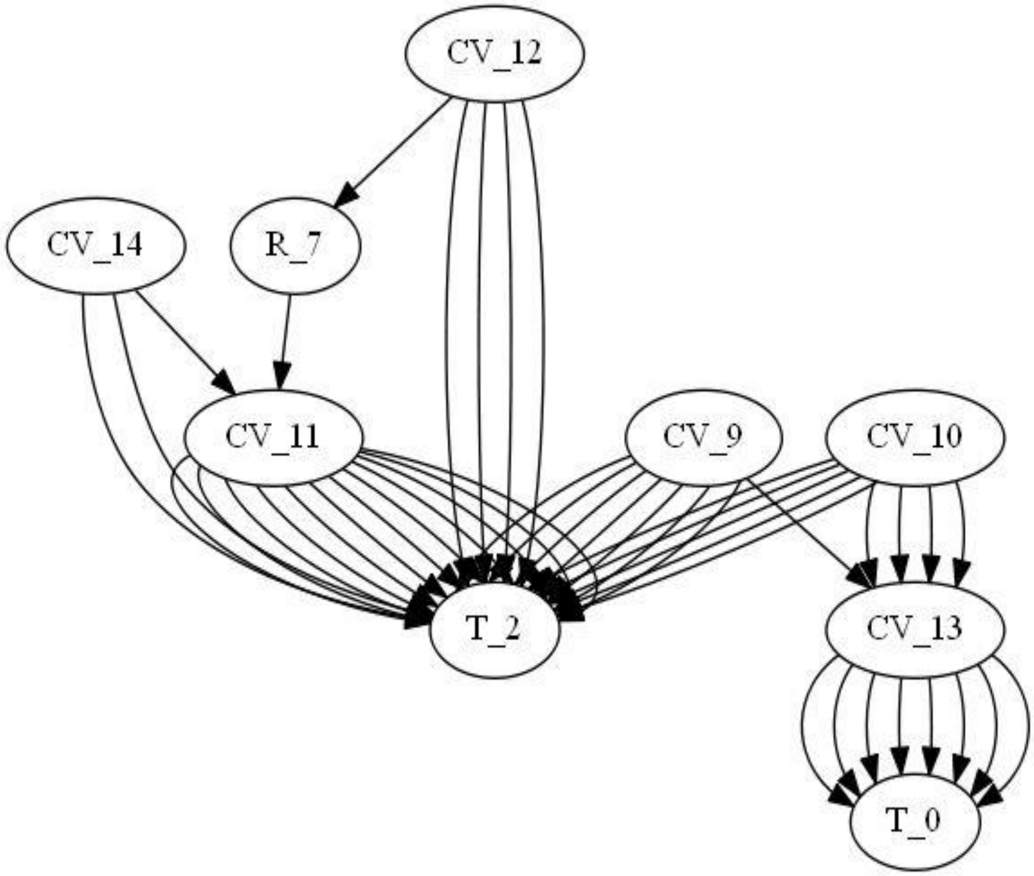

Figure 5-4 Node Connections and the Message Path without Incentive Mechanism

Besides the simulation results of the GUI, the majority of the result used for the analysis was collected primarily through reports generated by report modules during the simulation run. Report modules receive events like message or connectivity events from the simulation engine and generate results based on them [14]. During the simulation run, the simulator generates the message statistics file in the report module that gathers statistics on overall performance (i.e., the number of created messages, message delivery ratio, how long messages stay in node buffers etc.). Accordingly, the report module's output was used to plot a graph for the various message statistics report generated by the ONE simulator as clearly illustrated and discussed in chapter six.

5.6 Summary

The ONE has experienced growth in its acceptance among researchers and more realism to the simulations of Delay Tolerant Networks because of its simplicity and easy customization [21]. It is based on four concepts. First, mobility models: it is used to determine how the nodes move along time. The ONE already provides many of well-known mobility model among them the proposed system used shortest path map-based movement model. Second, connections created when two nodes come within the transmission range they can exchange messages. Third, events which are used to generate a message with a given range of time. The proposed system used the message event generator which is built-in in the ONE simulator. Fourth, routing: it is used to choose the next message carrier among those DTN routing protocols. The proposed system focused on the binary version of Spray-and-Wait routing protocol. In addition, the ONE simulator provides reporting and visualization, and it provides simulation result and graphical user interface respectively for the users. The ONE was designed to work at the network layer and although it considers some physical parameters related to wireless technology (transmitting range and data transfer speed).

Chapter 6
Result and Discussion

This chapter describes the results, analysis and discussion of the scenarios targeted based on the simulation result. The performance metrics for the designed simulation scenario were briefly described and simulation run with various configuration files based on the predefined parameters was analyzed and discussed.

6.1 Performance Metrics

This section of the chapter describes the metrics adopted for evaluating the considered routing algorithms. Routing in the communication networks depends on the definition of performance indicator called routing metrics. As noted in [22], the popular routing metrics in traditional networks are the number of hops, end-to-end delay, jitter, route lifetime and route throughput. However, in delay tolerant networks, these metrics are problematic due to asynchronous specificities. Therefore, DTNs use different routing metrics from the traditional networks as it is clearly defined in [8], [11] and [13]. The incentive algorithm considered in this thesis were analyzed based on three routing metrics namely delivery probability, average latency and the protocol overhead ratio. Detail description of each is explained as follow:

1. **Delivery Probability**: It is the fraction of generated messages that are correctly delivered to the final destination within given time period. It is calculated according to Equation 6.1:

   Notation: D_P = is the bundle delivery probability

   DB = is the total number of unique delivered bundles

   CB = is the total number of unique created bundles

Equation 6-1 Delivery Probability

$$Dp = \frac{\sum DB}{\sum CB} \quad \text{--} \quad (6.1)$$

2. **Average Latency**: It is defined as the average time taken from the source node to transfer the message to the destination node. It is the measure of average time between messages is generated and when it is received by the destination. In other words, average latency is the time it takes for a delivered message to reach its destination. Average latency includes all types of delay such as buffer delay, route discovery process, and delay during retransmission of the message, and propagation time etc. The small value of the end to end delay means the better performance of the protocol. It is calculated according to Equation 6.2:

   Notation: Dd = is the bundle average delivery delay

   Tdi = is the time when the bundle i was delivered

   Tci = is the time when the bundle i was created

   DB = is the total number of unique delivered bundles

   Equation 6-2 Average Delay

$$Dd = \frac{\sum_{i=1}^{DB}(Tdi - Tci)}{DB} \quad \text{---} \quad (6.2)$$

3. **Protocol Overhead Ratio:** This metric is used to estimate the extra number of messages needed by the routing protocol for actual delivery of the messages. It is calculated according to Equation (6.3).

   Notation: Rb = is the total number of relayed bundles

   Db = is the total number of unique delivered bundles

   Equation 6-3 Protocol Overhead Ratio

$$\boldsymbol{Overhead\ Ratio} = \frac{\sum \boldsymbol{Rb} - \sum \boldsymbol{Db}}{\sum \boldsymbol{Db}} \quad \text{---} \quad (6.3)$$

   It provides an indication of the overhead as transmissions of messages that could not reach their destination are also included. It is deal with the assessment of the bandwidth efficiency. Interpreted as the number of created copies per delivered message. That is, the number of replicas necessary to perform a successful delivery.

6.2 Performance Evaluation

In this thesis, the network performance is studied from the application performance point of view. For evaluating the performance of the considered routing protocols, 10-50 percent of non-cooperative nodes have been used those non-cooperative nodes, receiving bundles from other nodes and dropping them immediately after that. To analyze its impact, after marking nodes as non-cooperative, the monitoring module asks this kind of nodes to share their own resources for a pre-defined period of time equal to 60 minutes. The network reputation threshold is equal to 10. This means that a node is considered as a selfish node by the reputation module when its reputation score is below 10. Based on different percent of non-cooperative nodes setting, each simulation run generates a trace file containing all the data packets that are sent between the nodes during the course of the simulated scenario. Accordingly, the performance of the considered routing protocols was determined through analysis of the generated trace file of the simulation.

6.3 Result Analysis and Discussion

This section presents a detailed analysis of the simulation result using a chart which are drawn using OriginLab.OriginPro.v8.1.SR3.Regged-EAT drawing tools based on the generated trace file of the simulation.

The results observed in simulation experiments with Spray and Wait routing protocol proved the importance of the proposed incentive system to identify and monitor selfish nodes. Figure 6.1 shows the existing routing protocol with the existing incentive mechanism and the proposed incentive mechanism. Both the existing and the proposed mechanisms help to reduce the impact of selfish nodes by increasing the number of delivery bundles. The same figure also shows that the proposed mechanism overtakes message delivery probability than the existing one because of identifying non-cooperative nodes and monitored immediately before affecting the network performance. More accurately, the proposed incentive schema presents an improvement of approximately 1.36 %, 2.64%, 4.13%, 6.38 % and 6.37% of bundles (for a percentage of selfish nodes equals to 10, 20, 30, 40, and 50, respectively) when compared to an existing incentive mechanism.

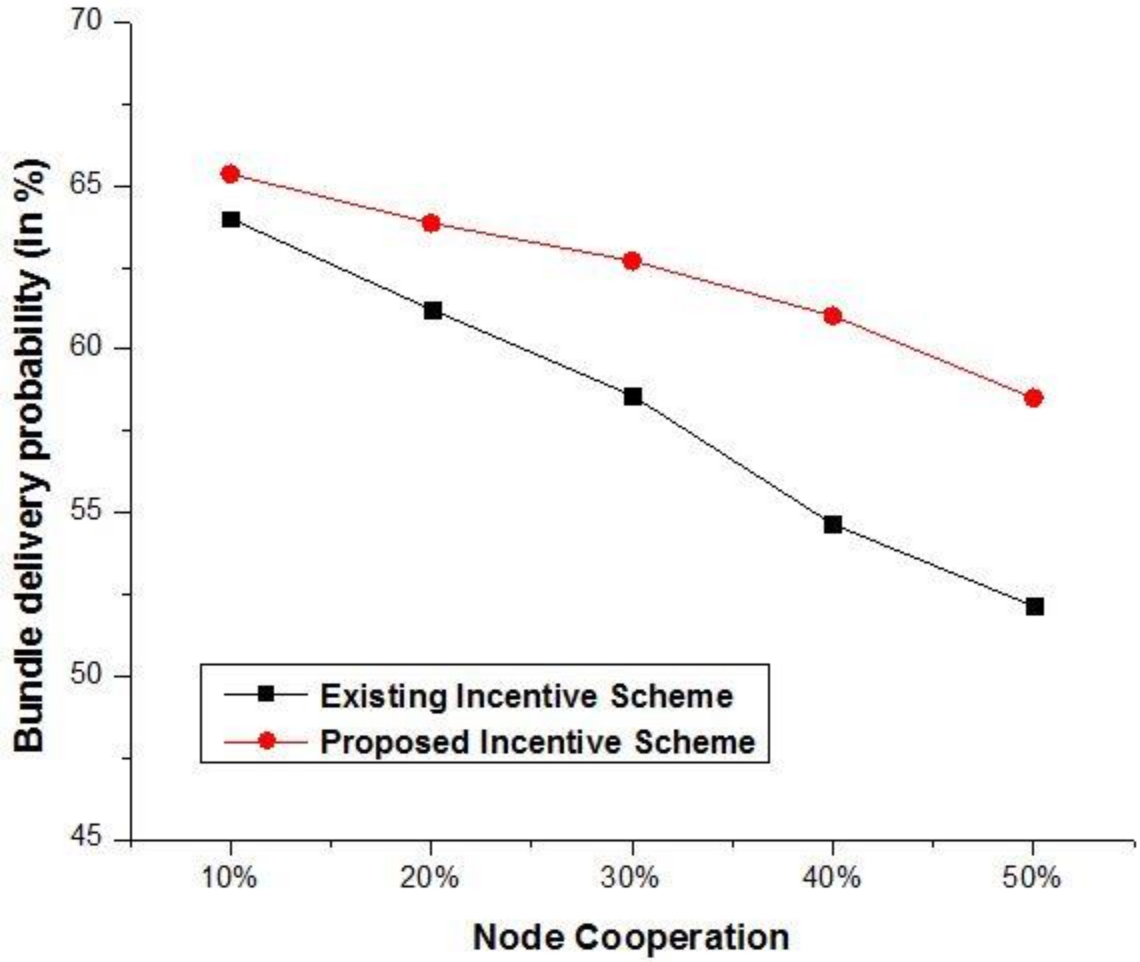

Figure 6-1Bundle Delivery Probability as a Function of the Percentage of Selfish Nodes, Considering the Binary Version of Spray and Wait Routing Protocol and a Network Reputation Threshold Equal to 10.

Figure 6.2 approves the results observed in Figure 6.1. The proposed incentive schemes reward and punish in a disproportional way not only deliver more bundles but also deliver bundles faster. Comparatively, with the existing incentive schemes, the proposed scheme delivers bundles approximately 0.29, 0.54, 1.20, 2.04 and 3.00 minutes sooner (for a percentage of selfish nodes equals to 10, 20, 30, 40, and 50, respectively).

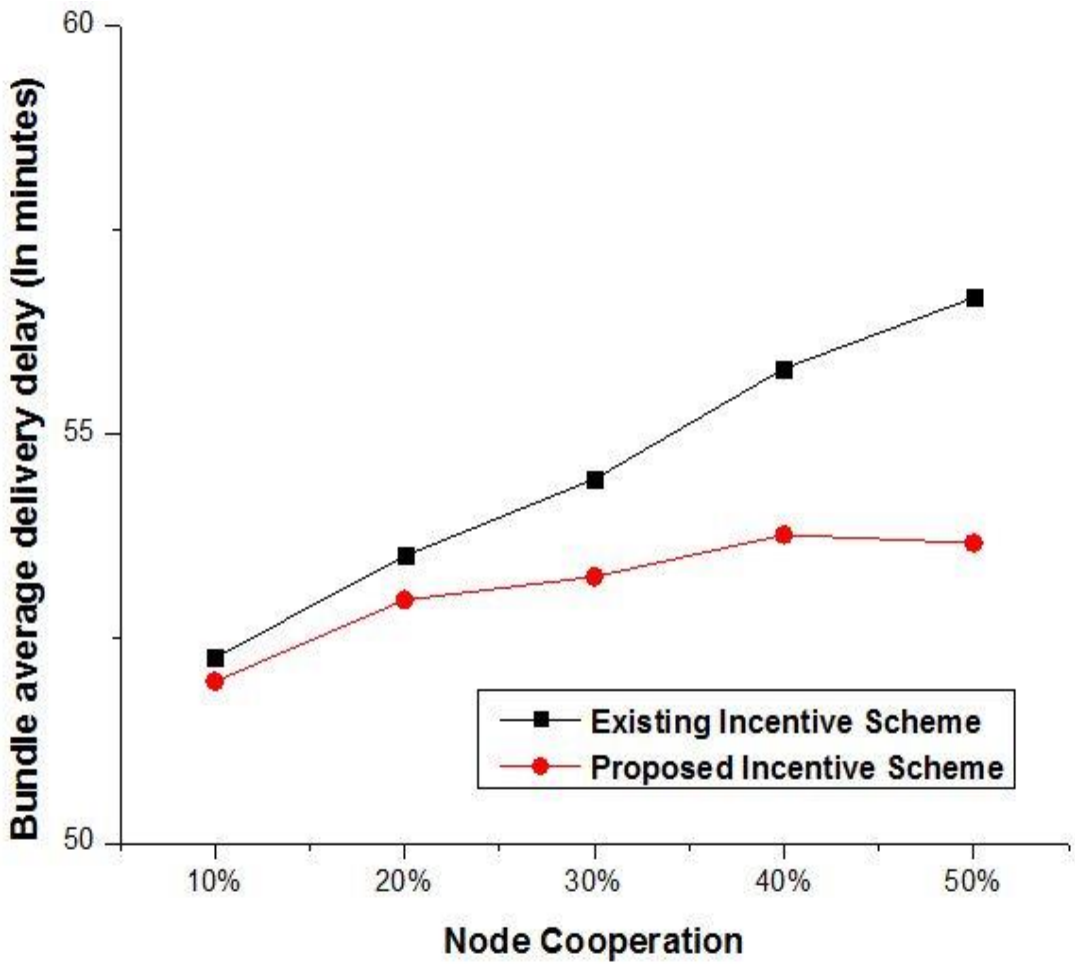

Figure 6-2 Bundle Average Delivery Delay as a Function of the Percentage of Selfish Nodes, Considering the Binary Version of Spray and Wait Routing Protocol and a Network Reputation Threshold Equal to 10.

Figure 6.3 proof the obtained results showing that stimulating non-cooperative nodes to cooperate is a good way to decrease their selfish impact on the network performance. The proposed incentive schema outperforms in contributing to the network resources optimization by decreasing the amount of dropped bundles than others. This approach leads to create protocol overhead approximately less 0.04, 0.04, 0.20, 0.41, and 0.45 amount (for a percentage of selfish nodes equals to 10, 20, 30, 40, and 50, respectively) when compared to the existing incentive mechanism.

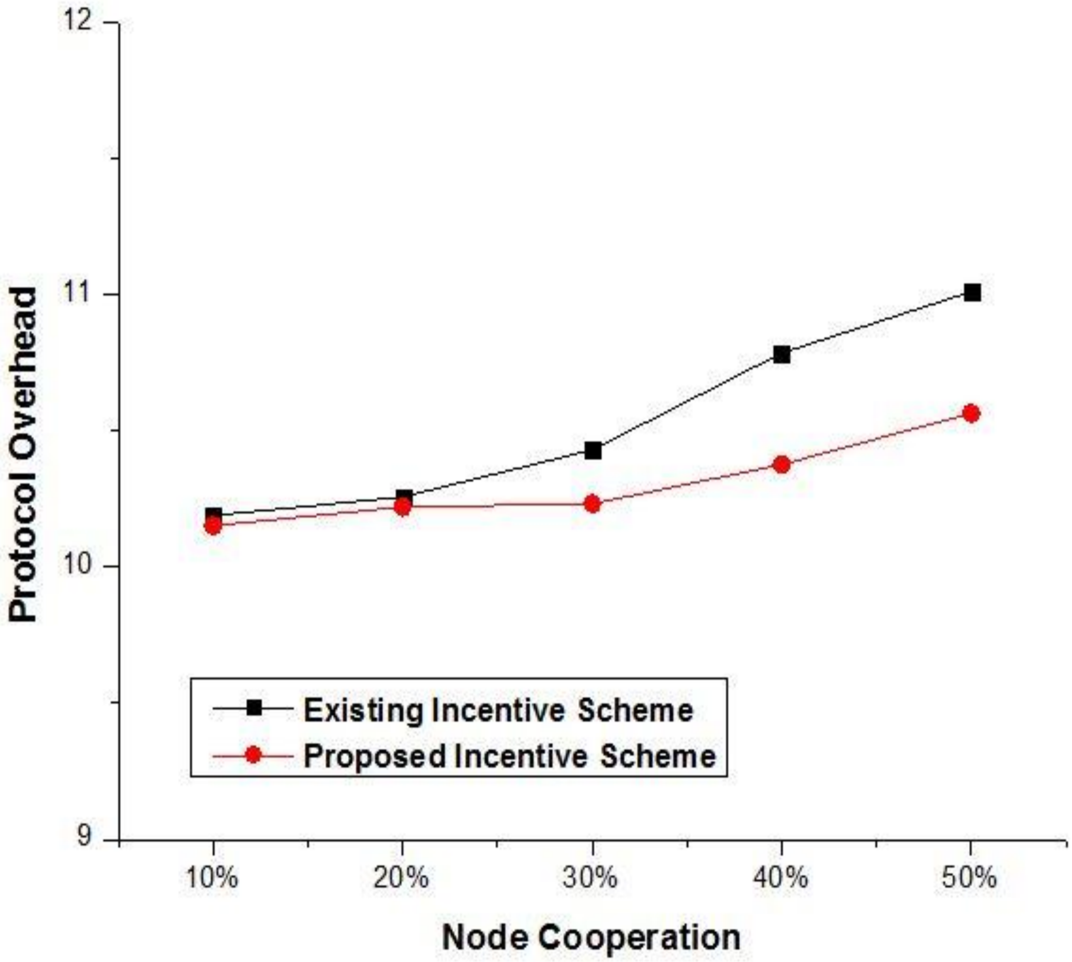

Figure 6-3 Protocol Overhead Ratio as a Function of the Percentage of Selfish Nodes, Considering the Binary Version of Spray and Wait Routing Protocol and a Network Reputation Threshold Equal to 10.

6.4 Performance Evaluation with Respect to Message TTL and Buffer Size

Figure 6.4 show that the proposed incentive scheme increases about 2.51%, 4.55%, 4.61%, 6.38 %, and 6.31% the bundle delivery probability (for the considered bundle TTL of 30, 60, 120, 180, and 240 minutes respectively) when compared with the existing incentive scheme. The gains observed in the bundle delivery probability performance metric are raised when bundles have a bigger TTL. In addition, increasing the TTL support the improvement on average delay that was introduced by the proposed incentive scheme. Figure 6.5 shows that bundles will arrive to its final destination approximately 2.07, 2.04, and 3.23 minutes sooner (for the considered bundle TTL of 120, 180, and 240 minutes respectively). However, increasing the TTL decreased the improvement on Protocol Overhead ration that was introduced by the proposed incentive scheme. Figure 6.6 shows that the proposed incentive schema leads to create protocol overhead approximately less 1.27, 1.01, 0.29, 0.41, and 0.30 amount (for the considered bundle TTL of 30, 60, 120, 180, and 240 minutes respectively) when compared to the existing incentive mechanism.

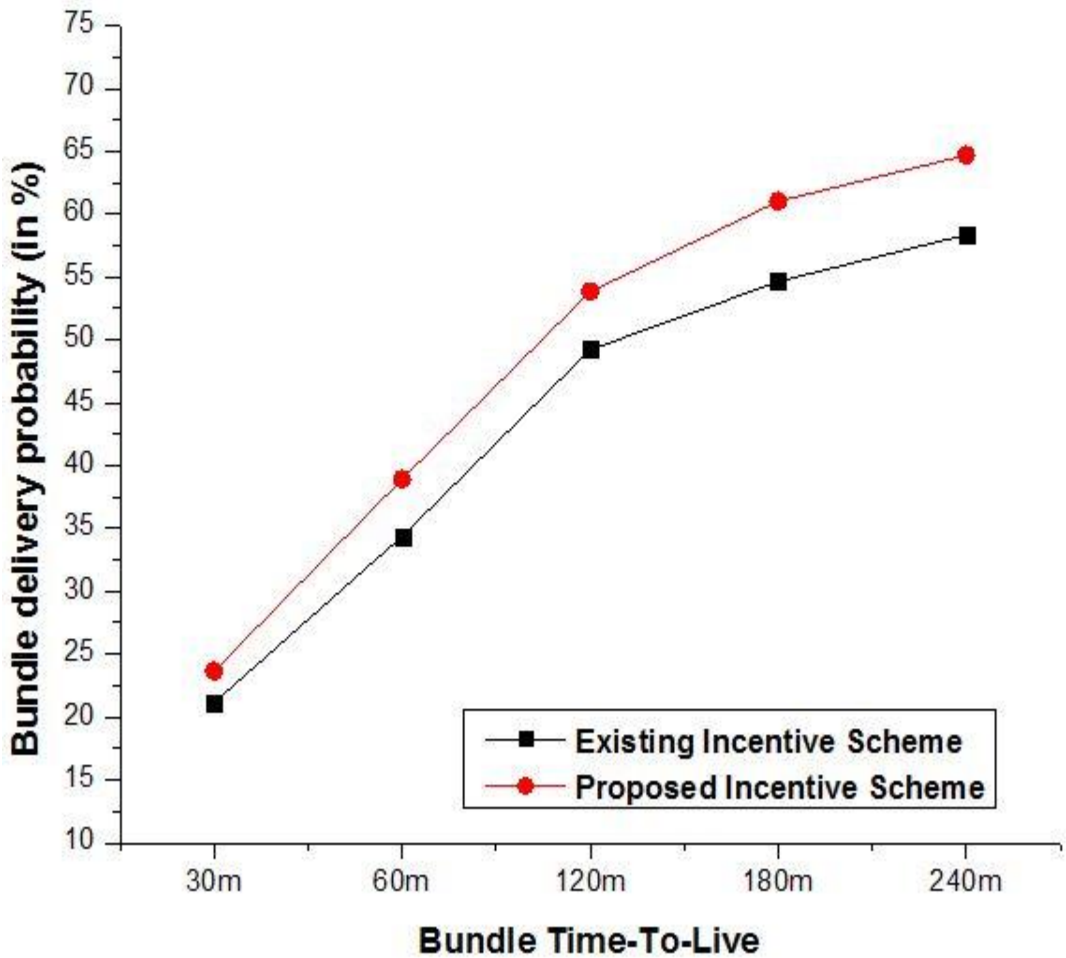

Figure 6-4 Bundle Delivery Probability as a Function of Bundle Time-To-Live, Considering the Binary Version of Spray and Wait Routing Protocol, with 10 Network Reputation Threshold Value and 40% None-cooperative Network Nodes.

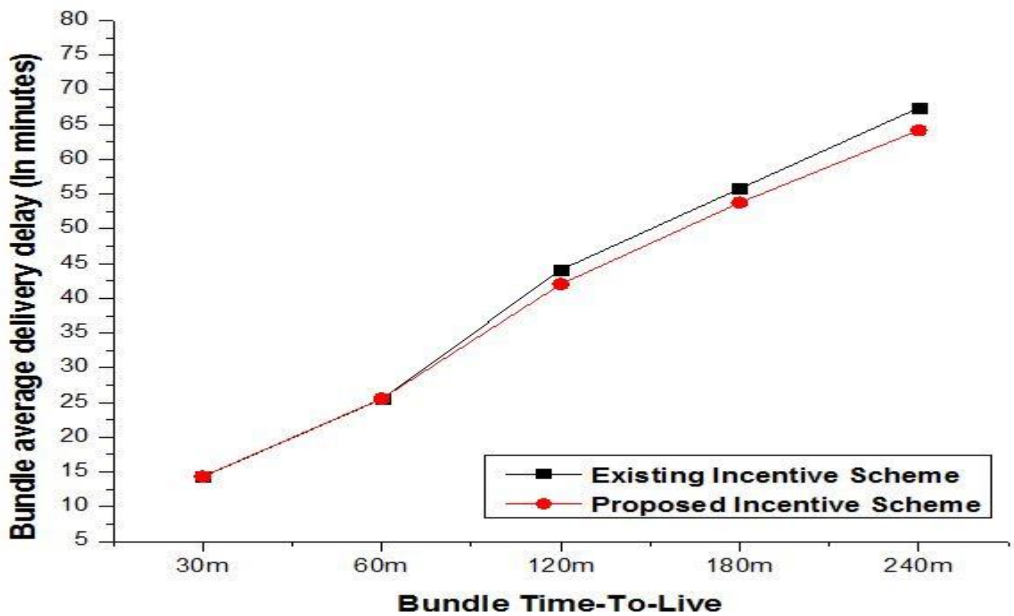

Figure 6-5 Bundle Average Delivery Delay as a Function of Bundle Time-To-Live, Considering the Binary Version of Spray and Wait Routing Protocol, with 10 Network Reputation Threshold Value and 40% None-cooperative Network Nodes.

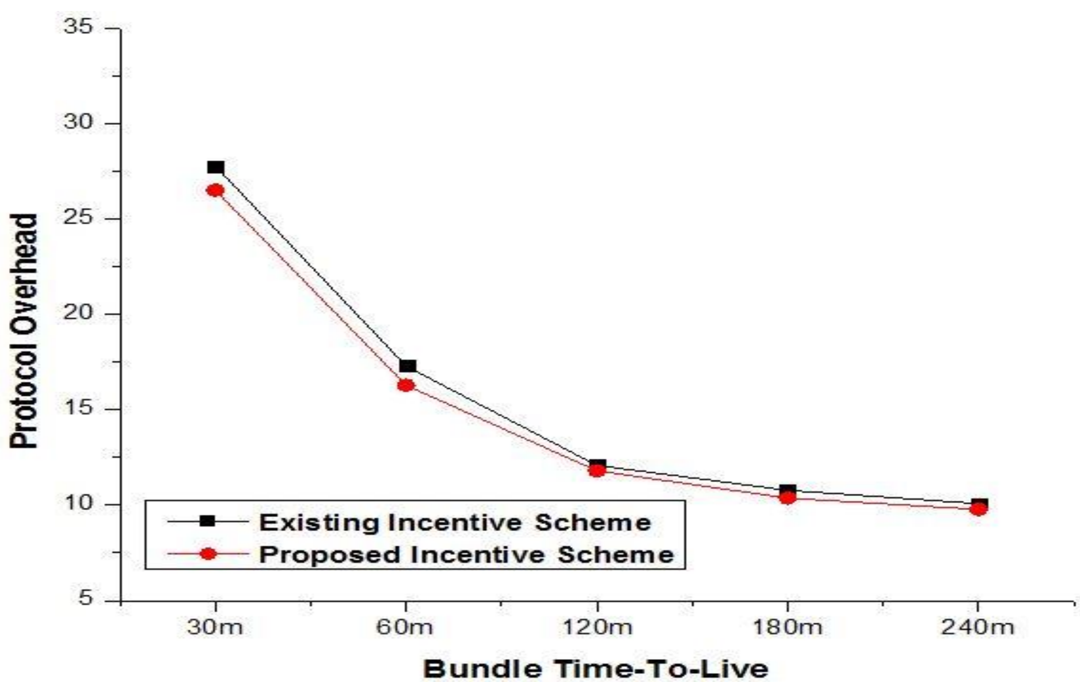

Figure 6-6 Protocol Overhead Ratio as a Function of Bundle Time-To-Live, Considering the Binary Version of Spray and Wait Routing Protocol, with 10 Network Reputation Threshold Value and 40% None-cooperative Network Nodes.

Figure 6.7 show that the proposed incentive scheme increases about 1.29 %, 4.34 %, 6.31 %, 6.17 %, and 6.38% the bundle delivery probability (for the considered Buffer Size of 5MB, 10MB, 15MB, 20MB, and 25MB respectively) when compared with the existing incentive scheme. The gains observed in the bundle delivery probability performance metric are raised when mobile nodes have a bigger Buffer Size. In addition, increasing the Buffer Size support the improvement on average delay that was introduced by the proposed incentive scheme. Figure 6.8 shows that bundles will arrive to its final destination approximately 1.83, 1.49, and 2.04 minutes sooner (for the considered Buffer Size of 15MB, 20MB, and 25MB respectively). Increasing the Buffer Size also increased the improvement on Protocol Overhead ration that was introduced by the proposed incentive scheme. Figure 6.9 shows that the proposed incentive schema leads to create protocol overhead approximately less 0.38, 0.13, 0.34, 0.37, and 0.41 amount (for the considered Buffer Size of 5MB, 10MB, 15MB, 20MB, and 25MB respectively) when compared to the existing incentive mechanism.

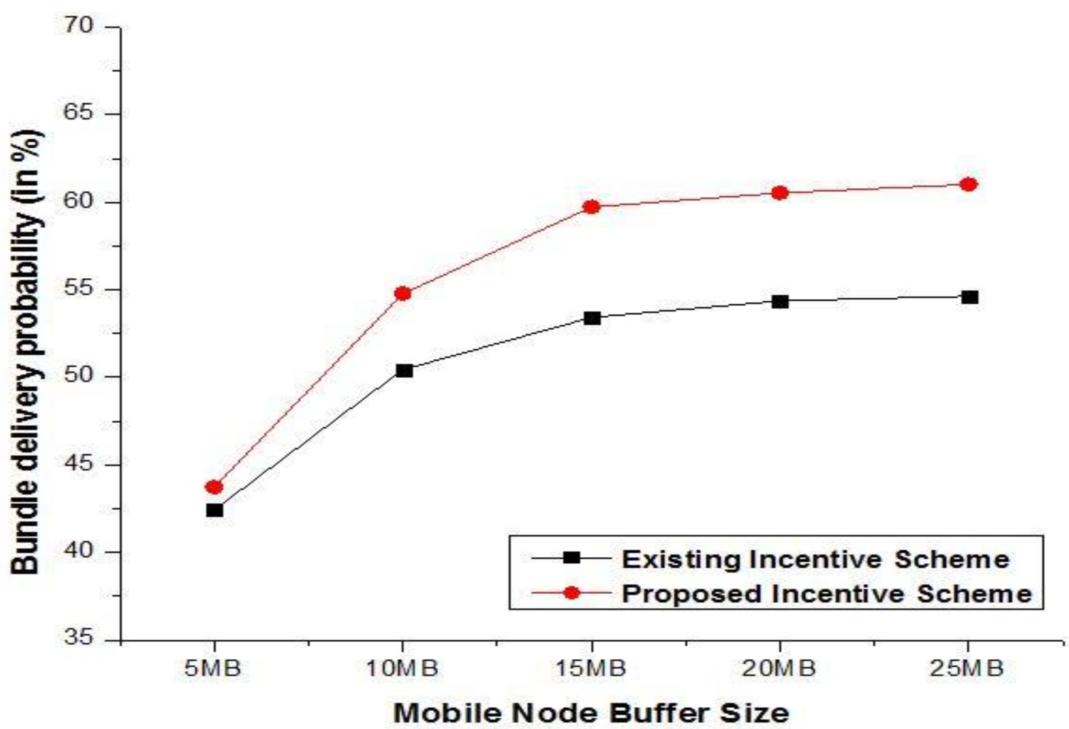

Figure 6-7 Bundle Delivery Probability as a Function of Mobile Node Buffer Size, Considering the Binary Version of Spray and Wait Routing Protocol, with 10 Network Reputation Threshold Value and 40% None-cooperative Network Nodes.

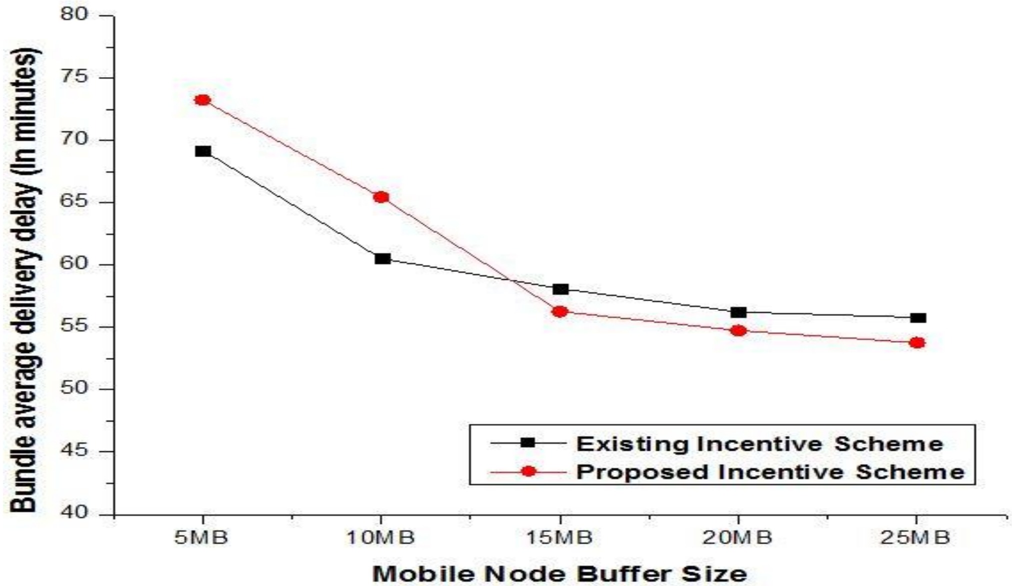

Figure 6-8 Bundle Average Delivery Delay as a Function of Mobile Node Buffer Size, Considering the Binary Version of Spray and Wait Routing Protocol, with 10 Network Reputation Threshold Value and 40% None-cooperative Network Nodes.

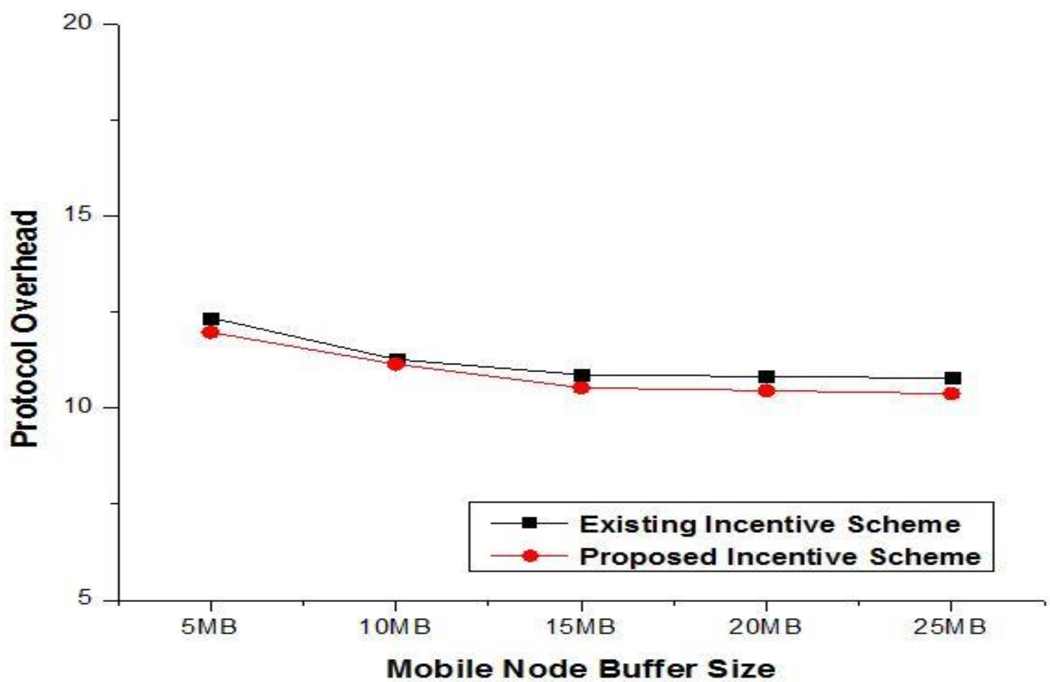

Figure 6-9 Protocol Overhead Ratio as a Function of Mobile Node Buffer Size, Considering the Binary Version of Spray and Wait Routing Protocol, with 10 Network Reputation Threshold Value and 40% None-cooperative Network Nodes.

6.5 Summary

The proposed incentive system has been chosen to evaluate the performance of the binary version of Spray-and-Wait routing protocol with respect to the Percentage of Node Cooperation, Mobile Node Buffer Size, and Bundle Time-To-Live. This is because in the previous study on cooperation in VDTN it was one of the best performing protocol [8]. However, both existing and proposed incentive scheme illustrated an improvement of network performance in VDTN, but the proposed incentive scheme outperform than the existing one. And the following tables summarize the obtained results conducted through simulation studies with respect to the percentage of node cooperation which presented in this thesis.

Table 6-1 Bundle Delivery Probability in %

	% Non-cooperative Nodes				
Approach	**10**	**20**	**30**	**40**	**50**
Existing Incentive Scheme	64	61.22	58.58	54.64	52.14
Proposed Incentive Scheme	65.36	61.22	62.71	61.02	58.51

Table 6-2 Protocol Overhead Ratio

	% Non-cooperative Nodes				
Approach	**10**	**20**	**30**	**40**	**50**
Existing Incentive Scheme	10.19	10.26	10.43	10.79	11.01
Proposed Incentive Scheme	10.15	0.22	10.23	10.38	10.56

Table 6-3 Bundle Average Delivery Delay in minutes

	% Non-cooperative Nodes				
Approach	**10**	**20**	**30**	**40**	**50**
Existing Incentive Scheme	52.27	53.51	54.46	55.81	56.67
Proposed Incentive Scheme	51.99	52.99	53.26	53.77	53.67

Chapter 7
Conclusion and Future Work

7.1 Conclusion

This study has focused on cooperation among nodes in VDTNs; the purpose was to improve the performance of vehicular communication on non-cooperative vehicular delay-tolerant networks. In order to reduce the impact of non-cooperative nodes, an efficient incentive approach was proposed, by brought and customized the idea of pareto's principle to manage non-cooperative nodes in VDTN. So, the proposed system considers Pareto principle-based incentive mechanisms to calculate nodes' reputation scores which is not proposed or used by the existing work. Nodes' reputation scores are compared to the network reputation threshold in order to classify nodes as cooperative or non-cooperative. Then the proposed system may decide whether to exclude or monitor non-cooperative nodes. With this system, we intended to stimulate non-cooperative nodes to cooperate. the performance was evaluated considering the binary version of Spray-and-Wait routing protocol. ONE simulator and scripting languages were used as tools to simulate the proposed system.

From the conducted simulation, results (considering the number of delivery probability, bundles average delivery delay and protocol overhead ratio) showed that the proposed system encouraged non-cooperative nodes to share their own resources. In general, using Pareto principle to identify and monitor non-cooperative nodes provides the novel result when compared to other incentive mechanisms.

7.2 Contribution

In this thesis, we study non-cooperative network nodes which is a fundamental problem in Vehicular DTN. So, the chief contribution of this thesis is discussing the state-of-the-art incentive schemes in VDTN and after study bring the concepts of Pareto's principle in the VDTN environment as a core mechanism to manage non-cooperative network nodes. Finally implemented an efficient incentive mechanism to enhance the performance of vehicular communication on non-cooperative DTN environment in terms of minimized bundle average delay and protocol overhead ratio, and improved bundle delivery probability.

7.3 Future Work

The proposed system considered only the selfish behavior of the network nodes, but some network nodes which have malicious behavior may provide incorrect information like its reputation score or other information to get contact with other nodes. After getting the connection it may perform a malicious activity on the incoming message. Thus, the future research work on security issues will come up with this malicious behavior of the network nodes.

References

[1] T. Beshah and S. Hill. "Mining *Road Traffic Accident Data to Improve Safety: Role of Road-related Factors on Accident Severity in Ethiopia*." 2010

[2] B. P. Kumar, P. Sekhar, N. Papanna. and B. Bharath. "*A Survey on Manet Security Challenges and Routing Protocols*." Int.J. Computer Technology & Applications, Vol 4 (2), March-April, pp. 248-256, 2013

[3] K. Richard*.* "The 80/20 Principle, The Secret of Achieving More with Less*.*" *Nicholas Brealey, London, pp. 4-7, 1998*

[4] J. Issac and M. Shafie. "*VANETs and Its Related Issues: An Extensive Survey*." Journal of Theoretical and Applied Information Technology, 1992-8645, 20^{th} August, 2014

[5] M. C. G. de Paula. "*Construction of a Real Vehicular Delay-Tolerant Network Testbed.*" Covilha, Portugal, 2012

[6] U. Shevade, Y. Zhang. "*Incentive-aware routing in DTNs.*" IEEE International Conference on Network Protocols, pp. 238–247, 2008

[7] V. Cerf, S. Burleigh, and A. Hookeetal. "*Delay-tolerant networking architecture*." Available: https://tools.ietf.org/html/rfc4838, [Accessed: Sep. 2, 2017].

[8] J. A. F. F. Dias, and Joel J.P.C. Rodrigues. "*A Reputation System to Identify and Isolate Selfish Nodes in Vehicular Delay-Tolerant Networks*." Proc. 13th Int'l Conf. ITS Telecommun., Tampere, Finland, Nov. 5–7, pp. 133–38, 2013

[9] N. Benamar, *K*.D. Singh, M. *Benamar*, J. Bonnin, D. l Ouadghiri. "*Routing protocols in Vehicular Delay Tolerant Networks.*" A comprehensive survey. Computer Communication *(*ComCom*)* 48, 141–158, 2014

[10] J. Zhou and Z. Cao. "*TIS: A Threshold Incentive Scheme for Secure and Reliable Data Forwarding in Vehicular Delay Tolerant Networks.*" GLOBECOM - Communication and Information System Security Symposium, 2012

[11] João A. F. F. Dias, Joel J. P. C. Rodrigues, N. Kumar, and Constandinos X. Mavromoustakis. "*A hybrid system to stimulate selfish nodes to cooperate in vehicular Delay-Tolerant Networks.*" IEEE International Conference on

Communications (IEEE ICC 2015), London, England, June 8-12, 2015, pp. 5910-5915, 2015

[12] J. Huiyoung, J. Jaehun, and H. Yonggeun. "*Delay Tolerant Networking Research Trends in vehicle-type network.*" 2017.08.01

[13] N. Mehta and M. Shah. "*Performance Evaluation of Efficient Routing Protocols in Delay Tolerant Network under Different Human Mobility Models*." International Journal of Grid Distribution Computing. Vol.8, pp. 169 -178, No.1 2015

[14] Kevin F. "*A delay-tolerant network architecture for challenged internets.*" SIGCOMM Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications, ACM, New York, NY, USA, pp. 27–34, 2003

[15] D. Elwyn. "*DTN-The State of the Art.*" Networking for Communications Challenged Communities. April 2009

[16] InterPlanetary Networking Special Interest Group. "*Interplanetary internet project.*" International Journal of Grid Distribution Computing, Vol.8, No.1, pp.169 – 178, 2015

[17] K. Fall, Senior Member, IEEE, and S. Farrell. "*DTN: An Architectural Retrospective.*" IEEE Journal on Selected Areas in Communications, Vol.26, No 5, June 2008

[18] K. Scott and S. Burleigh. "*Bundle Protocol Specification*." Available: https://tools.ietf.org/html/rfc5050, November 2007

[19] B. John., G. Brian, J. David. and N. Brian. "*MaxProp: Routing for Vehicle-Based DisruptionTolerant Networks.*" In Proceedings of IEEE Infocom, pp. 1-11, 2006

[20] L. Psaras, L. Woodb and R. Tafazolli. "*Delay-/ Disruption-Tolerant Networking State of the Art and Future Challenges.*" Center for Communication Systems Research (CCSR), UK, 2009

[21] J. O. A. Keränen, and T. Kärkkäinen. "*The ONE Simulator for DTN Protocol Evaluation.*" in Second International Conference on Simulation Tools and Techniques (SIMUTools 2009), Rome, Italy, March 2-6, 2009

[22] M.E. Steenstrup. "*Routing in Communications networks.*" Hertfordshire, UK: Prentice Hall International (UK) Ltd., 1995

[23] S. Kapadia, B. Krishnamachari and L. Zhang L. *"Mobile Ad hoc Network: Protocol Design."* pp. 566-578, January 30, 2011

[24] Mansuras, Amaluddin and Ahmad. "*Implementing Telemedicine for Isolated and Remote Rural Areas using Delay Tolerant Network*." Information Processing Society of Japan. IPSJ SIG Technical Report, 2013

[25] A. Nikunj, V. Ashish and M. Jay. "*Comparative Study of Routing Protocols in Delay Tolerant Networks*." International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. Vol. 3, Issue 2, February 2014

[26] A. Vahdat and D. Becker. "*Epidemic Routing for Partially-Connected Ad Hoc Networks.*" Available: http://issg.cs.duke.edu/epidemic/epidemic.pdf [Accessed: Dec 2, 2017].

[27] S.E. Loudari, M. Benamar, and N. Benamar. "*New classification of nodes cooperation in Delay Tolerant Networks.*" Sept. 2015

[28] T. Spyropoulos, K. Psounis and C.S. Raghavendra. "*Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks*." In Proc. of the ACM SIGCOMM Workshop on Delay-Tolerant Networking, pp. 1-8, 2005

[29] A. Lindgren, A. Doria and O.Schelen. "*Routing Protocols in Infrastructure-less Opportunistic Networks*." International Journal of Advanced Research in Computer Science and Software Engineering. Volume 4, Issue 6, June 2014

[30] C.J. Sangamesh, P. Amaresh. "*The Concept of Delay Tolerant Network Approaches and Issues."* International Journal of Advanced Research in Computer Science and Software Engineering. Volume 3, Issue 4, June 2014

[31] J. Ghosh, H.Q. Ngo and C. Qiao. "*Mobility profile-based routing within intermittently connected mobile ad hoc networks (icman)*." In IWCMC'06, pp. 551–556, 2006

[32] A. Lindgren, A. Doria and O. Scheln "*Probabilistic Routing in Intermittently Connected Network*s." In: SIGMOBILE Mobile Computing and Communication Review, 2004

[33] F. Li, J. Wu, and A. Srinivasan. "*Thwarting blackhole attacks in distruptiontolerant networks using encounter tickets.*" Proc. - IEEE INFOCOM, pp. 2428–2436, 2009

[34] I. Leontiadis and C. Mascolo. "*GeOpps: geographical opportunistic routing for vehicular networks.*" in Proceedings of the IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WOWMOM '07), pp. 1–6, June 2007

[35] V. N. G. J. Soares, J. J. P. C. Rodrigues, and F. Farahmand. "*GeoSpray: a geographic routing protocol for vehicular delay tolerant networks*." Information Fusion, vol.15, no.1, pp.102–113, 2014

[36] J. Miao, O. Hasan, S. Ben Mokhtar, L. Brunie, and K. Yim. "*An Analysis of Strategies for Preventing Selfish Behavior in Mobile Delay Tolerant Networks*." 2012

[37] Y. Cao and Z. Sun. "*Routing in Delay/ Disruption Tolerant Networks: A Taxonomy, Survey and Challenges*." Communications Surveys & Tutorials, pp. 654-677, 2013

[38] G. Adriano, B. Theodoros. and S. Sandra. "*Mobile-Enabled Delay Tolerant Networking in Rural Developing Regions.*" Global Humanitarian Technology Conference, IEEE, Disney Research Zurich 8092 Zurich, Switzerland, pp. 17, 2014

[39] S. Bruno, S. Vasco, and R. Joel. "*Towards Intelligent Caching and Retrieval Mechanisms for Upcoming Proposals on Vehicular Delay-Tolerant Networks*." February 14, 2011

[40] VNG. Soares, J, Rodrigues JJPC. *"Chapter 7: Cooperation in DTN-based network architectures." in Cooperative Networking*, S. Misra and M. Obaidat (eds): Wiley, West Sussex, United Kingdom, pp. 101–115, 2011

[41] R. Paulo, A. Casaca, Joel J. P. C. Rodrigues, Vasco N. G. J. Soares, Joan Triay, and Cristina Cervelló-Pastor. "*From Delay-Tolerant Networks to Vehicular Delay-Tolerant Networks*." IEEE Communications Surveys & Tutorials, vol. 14, no. 4, pp. 11 66-1182, 2012

[42] V. N. G. J.Soares, F. Farahmand and J. J. P. C. Rodrigues. "*A Layered Architecture for Vehicular Delay-Tolerant Networks*." In IEEE Symposium on Computers and Communications (ISCC), Sousse, Tunisia, July 5-8, pp. 122-127, 2009

[43] R. Joel, S. Vasco and F. Farid. "*Stationary Relay Nodes Deployment on Vehicular Opportunistic Networks.*" In Mobile Opportunistic Networks, Sep. 20, 2015

[44] S. Ahnana, F.Z. Saiyari, N. Benamar, M.D. el Ouadghiri. "*Study of DTN routing protocols in vehicular environment in the presence of misbehaving nodes*." Proc. - WINCOM, 2013

[45] João A. F. F. Dias, Joel J. P. C. Rodrigues, N. Kumar, and K. Saleem. *"Cooperation Strategies for Vehicular Delay-Tolerant Networks."* in IEEE Communications Magazine, December 2015

[46] R. Dunford, Q. Su, E. Tamang and A. Wintour, *"The Pareto Principle."* The Plymouth Student Scientist, 2014

[47] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, E. Travis, and H. Weiss, " *Interplanetary Internet (IPN): Architectural Definition*", draft-irtfipnrg-arch-00 (work in progress), May 2001

[48] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, E. Travis, H. Weiss, and K. Fall, "*Delay-Tolerant Network Architecture: The Evolving Interplanetary Internet*", draft-irtf-ipnrg-arch-01 (work in progress), August 2002

Appendix A: Simulation Scenario Configuration File

```
## SENARIO NAME

Scenario.name = Scenario_%%Group.router%%

Scenario.simulateConnections = true

# Detail map

Scenario.updateInterval = 0.1

# SIMULATION TIME

# 24h - 87000

Scenario.endTime = 43500

# NUMBER OF GROUPS

Scenario.nrofHostGroups = 4

## COMMON SETTINGS APPLIED TO ALL GROUPS

#MOVEMENT MODEL

Group.movementModel = ShortestPathMapBasedMovement

# ROUTING PROTOCOL

Group.router = SprayAndWaitRouter_CTime

SprayAndWaitRouter_CTime.binaryMode = true

SprayAndWaitRouter_CTime.nrofCopies = 8

#############################################

#(Selfish nodes detection threshold)

selfishDetectionThreshold = 10

#########################################################

# waitTime in seconds (0,15 minutes = 0,900 seconds; 15,30 minutes = 900,1800)

# TRANSMISSION RANGE
```

```
Group.transmitRange = 100

Group.transmitSpeed = 750k

# Message TTL (minutes)

Group.msgTtl = 180

# SCHEDULING POLICY

Group3.sendQueue = 6

Group4.sendQueue = 5

# DELETE MESSAGES WHEN THEY ARE DELIVERED

Group.deleteDelivered = true

# SET COOPERATIVE SCHEDULING THRESHOLD

Group.hostReputation = 50

#################################

# Terminal nodes group

Group1.groupID = T_

Group1.bufferSize = 50M

Group1.movementModel = MapRouteMovement

Group1.routeFile = data/terminal_nodes.wkt

Group1.routeType = 1

Group1.waitTime = 0, 0

Group1.speed = 0, 0

Group1.nrofHosts = 10

###############################################3

# Relay Nodes

Group2.groupID = R_

Group2.bufferSize = 100M
```

```
Group2.movementModel = MapRouteMovement

Group2.routeFile = data/relay_nodes.wkt

Group2.routeType = 1

Group2.waitTime = 0, 0

Group2.speed = 0, 0

Group2.nrofHosts = 5

# Mobile Nodes moving between villages

Group3.groupID = V_

Group3.bufferSize = 25M

#Only cars can move on roads

Group3.okMaps = 1

# Waiting time between each stop

Group3.waitTime = 300, 900

# Cars Speed -   50 km/h = 13.88 m/s -100 km/h = 27.76m/s;

Group3.speed = 13.88, 27.76

Group3.nrofHosts = 25

#############################################################
###

Group4.groupID = SV_

Group4.bufferSize = 25M

#Only cars can move on roads

Group4.okMaps = 1

# Waiting time between each stop

Group4.waitTime = 300,900

Group4.speed = 13.88, 27.76

Group4.nrofHosts = 25
```

```
## MESSAGE CREATION PARAMETERS

# class of the first event generator

# message ID prefix

# creation interval in minutes

# message sizes (500KB - 2MB)

## MESSAGE CREATION PARAMETERS

Events.nrof = 1

Events1.class = MessageEventGenerator

Events1.interval = 25, 35

Events1.size = 50k, 750k

Events1.hosts = 15, 24

Events1.tohosts = 0,9

Events1.prefix = M_M_

## REPORTS - ALL REPORT NAMES HAVE TO BE VALID REPORT CLASSES

# how many reports to load

Report.nrofReports = 2

# default directory of reports (can be overridden per Report
with output setting)

Report.reportDir = reports/

# Report classes to load

Report.report1 = MessageStatsReport
```

Appendix B: Running Simulation on Batch Mode

C:\Windows\System32\cmd.exe

```
C:\Windows\system32>cd ../..

C:\>cd Users/hp

C:\Users\hp>cd Desktop

C:\Users\hp\Desktop>cd Buffer

C:\Users\hp\Desktop\Buffer>one.bat -b 5 proposed_snw_binary.txt

C:\Users\hp\Desktop\Buffer>java -Xmx512M -Djava.util.Arrays.useLegacyMergeSort=t
rue -cp .;lib/ECLA.jar;lib/DTNConsoleConnection.jar core.DTNSim -b 5 proposed_sn
w_binary.txt
Run 1/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_5M'
60.0 43098: 718.20 1/s
60.5 43500: 1116.39 1/s
Simulation done in 60.53s
Run 2/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_10M'
44.8 43500: 971.44 1/s
Simulation done in 44.76s
Run 3/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_15M'
43.7 43500: 995.59 1/s
Simulation done in 43.68s
Run 4/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_20M'
42.7 43500: 1018.43 1/s
Simulation done in 42.71s
Run 5/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_25M'
41.6 43500: 1045.80 1/s
Simulation done in 41.60s
---
All done in 238.52s

C:\Users\hp\Desktop\Buffer>cd ..

C:\Users\hp\Desktop>cd TTL

C:\Users\hp\Desktop\TTL>one.bat -b 5 proposed_snw_binary.txt

C:\Users\hp\Desktop\TTL>java -Xmx512M -Djava.util.Arrays.useLegacyMergeSort=true
 -cp .;lib/ECLA.jar;lib/DTNConsoleConnection.jar core.DTNSim -b 5 proposed_snw_b
inary.txt
Run 1/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_30'
28.1 43500: 1547.39 1/s
Simulation done in 28.10s
Run 2/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_60'
31.6 43500: 1378.20 1/s
Simulation done in 31.56s
Run 3/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_120'
36.9 43500: 1179.60 1/s
Simulation done in 36.87s
Run 4/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_180'
36.4 43500: 1193.58 1/s
Simulation done in 36.44s
Run 5/5
Running simulation 'Scenario_SprayAndWaitRouter_Proposed_240'
40.0 43500: 1088.02 1/s
Simulation done in 39.98s
---
All done in 185.70s

C:\Users\hp\Desktop\TTL>
```

Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been properly acknowledged.

Name: Mohammed Adane

Signature: _____________

Place: Jimma

Date: ________________

This thesis has been submitted for examination with my approval as a university advisor.

Name: Mr. Dawit Kifle (PhD Candidate)

Signature: 3-April-2018

Place: Addis Ababa

Date: ________________