# Improving the Performance of Epidemic Routing Protocol using Game Theory Approach for Non-cooperative Node in Delay Tolerant Network

By:

Bereket W/Senbet

A Thesis Submitted to Department of Computer Science and Engineering

School of Electrical Engineering and Computing

Office of Graduate Studies

Adama Science and Technology University

October 2020

Adama, Ethiopia

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## APPROVAL PAGE

We, the undersigned, members of the Board of Examiners of the final open defense by "***Bereket W/Senbet"*** have read and evaluated her thesis entitled "***Improving the Performance of Epidemic Routing protocol using Game Theory Approach for Non-cooperative Node in Delay Tolerant Network***" examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Masters of Science in Computer Science and Engineering

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## DECLARATION

I hereby declare that, this MSC thesis is my original work and has not been presented as partial degree requirement for a degree in any other university and that all sources of materials used for the thesis have been fully acknowledged.

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Date: ____________________________

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

Name: Dr.Ketema Adere

Signature: ____________________________

Date: ____________________________

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AL | Average Latency |
| CP | Cooperation Payoff |
| DR | Delivery Ratio |
| DTN | Delay Tolerant Network |
| DM | Delivered Message |
| ERP | Epidemic Routing Protocol |
| GT | Game Theory |
| GT-ERP | Game Theory Based Epidemic Routing Protocol |
| GSM | Global System for Mobile Communication |
| GUI | Graphical User Interface |
| IDE | Integrated development environment |
| IP | Internet Protocol |
| MANET | Mobile Ad Hoc Network |
| NE | Nash Equilibrium |
| NN | Non-cooperative node |
| NP | Non-cooperation Payoff |
| NS-2 | Network Simulator Version 2 |
| NS-3 | Network Simulator Version 3 |
| OLSR | Optimized Link State Routing |
| OMNET++ | Object Modular Network Tested in C++ |
| ONE | Opportunistic Network Environment |
| OR | Overhead Ratio |
| OTCL | Object-oriented Tool Command Language |

| | |
|---|---|
| RM | Relayed Message |
| SNW | Spray and Wait |
| TCL | Tool Command Language |
| TCP | Transmission Control Protocol |
| TTL | Time to Live |
| UDP | User Datagram Protocol |
| Wi-Fi | Wireless Fidelity |

# ABSTRACT

*Routing is a challenging issue in Delay Tolerant Network (DTN), due to the problem of intermittent connection. Epidemic Routing Protocol (ERP) is the one DTN routing protocol, having the highest delivery ratio with minimum latency features. But these happen only when nodes cooperate. In reality, not all nodes may cooperate, because of limited resources and fewer social ties. Those non-cooperative nodes (NN) drop the message, which contributes to poor routing performance. The existing ERP not considered this behavior of nodes. In our study, a Game Theory Based ERP (GT-ERP) for the NN is developed. In this model, nodes select id 0 and 1 to act as cooperative and NN respectively. We measured the NN effect from [0-100] degree number of the NNs. The proposed GT-ERP motivates this NN to form cooperation among nodes. A theoretical framework for a rational node that maximizes its payoffs has been presented. These were due to nodes have a cooperative mechanism that is reaching Nash Equilibrium (NE) and the nodes never leave that state. Using GT, it is verified that the proposed GT-ERP achieved cooperation among nodes. The proposed GT-ERP is simulated on ONE Simulator. From the simulation result during the first phase the delivered packet increased from1020 to 1166, dropped packet decreased from 438 to 292, delivery ratio increased from 0.7 to 0.8 which is 10% improved by the proposed GT- ERP, the overhead ratio decreased from 14.05 to 13.56. This was due to the proposed GT-ERP has a cooperative mechanism. But the average latency increased from 2045.61 to 2356.21, because of the proposed GT-ERP used time in selecting a strategy. Lastly, as the number of NN reaches 100 the delivered packet increased from 254 to 955, the dropped packet decreased from 1204 to 503, the delivery ratio increased from 0.174 to 0.655, the overhead ratio decreased from 24.58 to 15.38 and the average latency decreased from 3827.98 to 3163.35. We have concluded that as the number of NN increased the proposed GT-ERP achieved better performance in all metrics including average latency in comparison to the original ERP.*

**Keywords***: Cooperative, Delay Tolerant Network, Epidemic Routing Protocol, GT-ERP, NE, non-cooperative node*

# CHAPTER ONE

# 1. INTRODUCTION

## 1.1. Background of the Study

The Mobile ad hoc network is categorized under a wireless network. In MANET using mobile nodes, a temporary network is formed without infrastructure. Since, there's no set infrastructure in MANET that performs dynamic topology. Due every node has the functionality of host and router. From those features multi-hop routing, limited physical security, dynamic topology, no infrastructure, varied links, and inhibited bandwidth included. The path of source and destination is the main issue during using MANET to transmit data packet that fulfills service standards, like throughput, energy, and end-to-end delay. However, in the intermittent network these issues cannot be supported[1]. In MANET there was an assumption that known sender and receiver path for each node exists in the network [2]. Yet, in the real end to end path never happen all time, because of large geographical scope and intermittent connection. To solve this intermittent connectivity issues, DTN is raised. DTN follows store approach and forward [3].

DTN follows the store and forward process for transmitting the data packet within the environment in which continuous connectivity lacks with the absence of communication infrastructure support[4]. DTN is characterized by small mobile devices, low connectivity that stores the message, and carries it until another relay nodes come into the network transmission range[5]. The main issue in DTN is finding the right node which stores and relays data packets. However during selecting the right node, the nodes' behavior is unknown. So it may not want to cooperate with other nodes during that network performance degraded.

From below figure store approach and forward of DTN[6] nodes stores message and forward a replica of messages to relay nodes when the nodes come in transmission contact. This step will be repeated until the message reaches or its TTL expires[7].

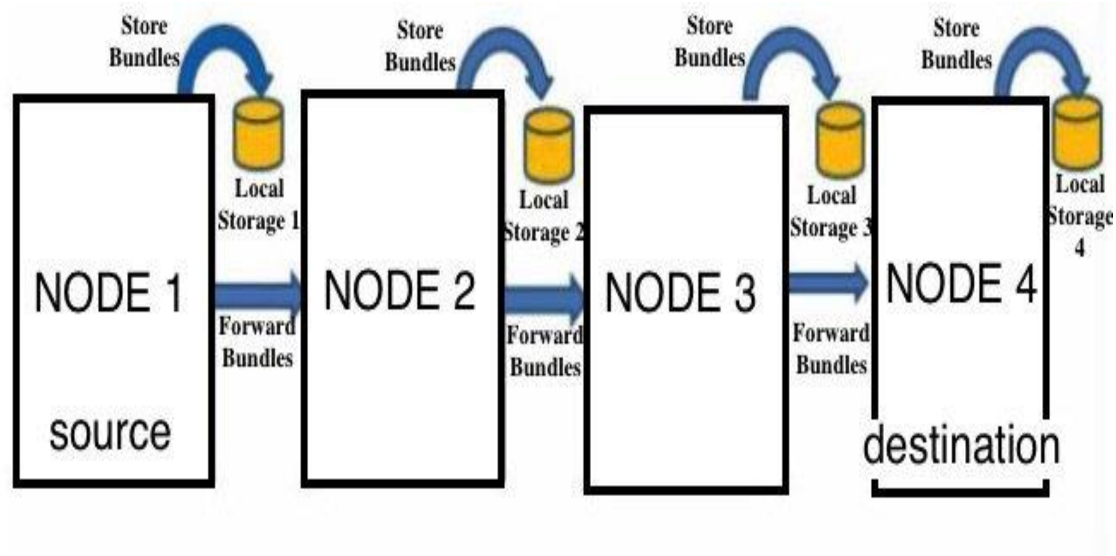


Figure 1.1Store Approach and Forward

It is one of architecture in a computer network that solves problems in the heterogeneous intermittent network where the connectivity of the network becomes less. Example: Environment of terrestrial or space communication network[8]. DTN results in long delay propagation. The nature of the DTN following copy, forward, and store causes many messages in networks[9] that consume the resources of nodes such as buffer, energy, etc. The known DTN routing protocols[10] are PROPHET, Spray and Wait, Epidemic, and MaxProp. Among those DTN routing protocols, we focused only on ERP. In this routing protocol, the route from the relay node to the next can't be found, due to this a replica of the message forwarded to any node that comes in contact. As we compare the ERP to the other routing protocols of DTN, it has the highest delivery ratio and less delay. The flooding approach makes ERP transmit a lot of packet to the destination.

**Epidemic Routing Protocol**

Among DTN routing protocols ERP is one. ERP is a flooding based protocol like disease spreading, which consumes a lot of energy. In ERP, its main goal is delivering a message with high probability and minimum delay. Mostly useful in an environment with infinite buffer space and bandwidth[11]. Recently, lots of methods have been presented to overcome those problems. Figure 1.2 that is taken from[12] explains how messages follow the approach of store and forward in ERP.

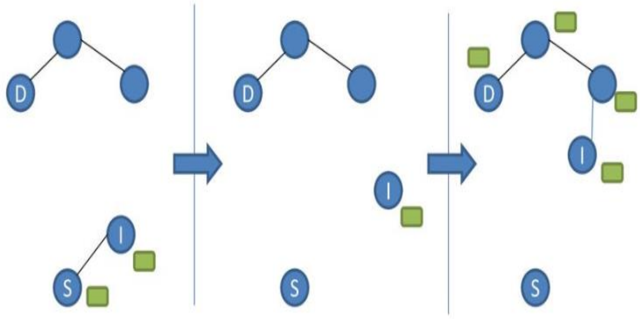


Figure 1.2 Epidemic Routing

If nothing is unknown and resources are available, just send it to everyone! ERP is the DTN equivalent to flooding. If the ERP is used without buffer limitation, the delivery rate is very high. If the precondition is that buffer has a limitation and the buffer size is smaller than the size of the message generated in the network, nodes in this network will drop part of the messages as to store incoming ones. But the nearby nodes may send the already dropped messages to it again since the messages have not yet been delivered. Under these circumstances, ERP may cause heavy traffic problems and a low delivery ratio. All like these issues were studied by many researchers[13]–[19].

The high quality of using epidemic routing[12] as a routing protocol for data exchange enables high packet ratios to be achieved. However, in the transmission, receiving, and storing phases, the nodes may have different behavior. There were cooperative node and the NN. For having the high quality of delivery ratio nodes has to cooperate. Many studies consider nodes as cooperative but in reality, not all nodes that participate in transmission are cooperative. Those NNs degraded the routing performance. In our thesis, we considered those NNs. NN use all resources only for itself, this results in message dropping during transmission. The non-cooperative behavior of the node was the main problem of DTN routing protocols. Solving this issue is difficult in DTN because the network is intermittent. Different researchers tried to improve ERP regardless of this NN behavior. But this is the main problem as it degrades the whole performance of routing. Few papers include the non-cooperative in their study, but the method they used not motivates cooperation among nodes. To overcome the above problem, the proposed solution fills these gaps in ERP using game theory. The main contribution of our thesis was to propose a solution for routing performance issues because of the NN in ERP. Using the proposed GT-ERP a cooperative mechanism is generated by including NN in forwarding service.

## 1.2. Motivation of the Study

In comparison to another left routing protocol of DTN, a high packet delivery ratio existed in ERP[20] with minimum latency, if only nodes cooperate. But not all nodes agreed to participate in the communication that we call NNs. Due to different factors in social ties or resource limitations such as battery power, the nodes refuse to participate with others. As the existence of such a node within the communication, the overall routing performance of ERP decreases. This result to increase rate of dropped packet, decrease the delivered packet, and decrease the delivery ratio. Also in this, the latency increases as the nodes refuse to transmit the packet. That means when nodes drop the message that is forwarded by another relay node, it is difficult for the sender to know whether it dropped or transmitted the data packet because of the intermittent connection. The above issue of ERP motivates us to propose a solution to this concept of DTN related limitation of non-cooperativeness. The main motivation of this work is studying and analyzing the effect of those NN and proposing the GT-ERP algorithm to motivate them to work together. This study simulates a non-cooperative impact with ERP of DTN. The simulation of the thesis work evaluates in terms of those performance metrics like the delivered packet, dropped packet, delivery ratio, overhead ratio, and average latency.

## 1.3. Statement of the Problem

In recent, DTN is the most interesting research area. DTN efficiency is significantly impacted by the actions of its constituent nodes, which must cooperate to provide the basic functionality of the network. DTN is an intermittent network, where each node should collaborate to perform functions of the network but sometimes nodes may behave non-cooperative to conserve their resource like battery power, and bandwidth. Such nodes are called the NN and non-cooperativeness disturbs the network and takes away the network from their regular mission. In DTN different routing protocols are exist among those routing protocols ERP is one. The issue in this protocol was that due to pure flooding a replica of the message transmitted to every node that has contact, the same as epidemic disease. That means the ERP diffuses messages into the network similar to viruses[21]. ERP is a very significant technique of routing in DTN and it decreases delay by replication, but too many copies existed in communication. So there is a big amount of message transmissions in the network. Many research works focus only on improving delivery, reducing energy consumption, and delay. The existing ERP does not take nodes' behavior into account. Some of the previous work depends on data forwarding and signal strength however, they did not consider dropped messages due to NN. Original ERP has the best delivery ratio if nodes cooperate. The behavior of nodes was not considered. Where they are improving, if nodes have selfish behavior, the improvement cannot be achieved. The ERP performance was affected by different factors. The node in the ERP is self-organizing; all network services like routing, mobility retrieved by the node. Instead, because of inadequate resources that need to be saved, it is difficult to work together between the nodes. For this reason, the NN fails to support other nodes in response to the message transmission to save their resources.

The NNs effect in the communication were that it decreases delivery ratio, and increasing an average latency[22][23][24][25]. Every node within the range of communication would get the data message transferred by relay nodes. But the misbehaved node like NN degrades for their resource like a battery. Therefore, the NN refuses to forward the data messages. Non-cooperativeness cause maximum delay and packet loss that become one of the critical issues for routing. In the existence of a NN, the routing performance fades. For this reason identification of NN is needed for the best result. NN in DTN aims to benefit itself. It did not forward packets to spare energy from other nodes; if there are routing-based benefits, it may only forward packets enough to deliver its own. So, partial cooperation or not cooperating at all will result in network degradation. Such non-cooperative has a direct effect on the performance metric[22]. The above issues are solved by the proposed GT-ERP algorithm. The simulation is performed under standard ERP, with GT using a simulation tool called ONE Simulator. From this study, the NN impact under ERP improved using the GT-based approach.

## 1.4.Research Questions

Based on the above problems, the study answers the following questions:

- How to study the effect of non-cooperative nodes on ERP performance?
- How to build a model in order to capture the non-cooperative nodes?
- How to design routing algorithm for non-cooperative nodes?
- How can we evaluate the performance of the newly proposed algorithm with existing ERP?

## 1.5. Objectives of the Study

### 1.5.1. General Objective

The general objective of this research work is to improve the performance of ERP using the game theory approach for non-cooperative node in DTN.

### 1.5.2. Specific Objectives

To achieve the general objective, the following specific objectives are accomplished throughout the study.

- To study the effect of non-cooperative nodes on ERP performance achievements.
- To build a model in order to capture the non-cooperative nodes.
- To design routing algorithm for non-cooperative nodes.
- To evaluate the performance of the newly proposed algorithm with existing ERP.

## 1.6. Methodology

The following methods and techniques are followed to address the above objectives and to answer questions of the research.

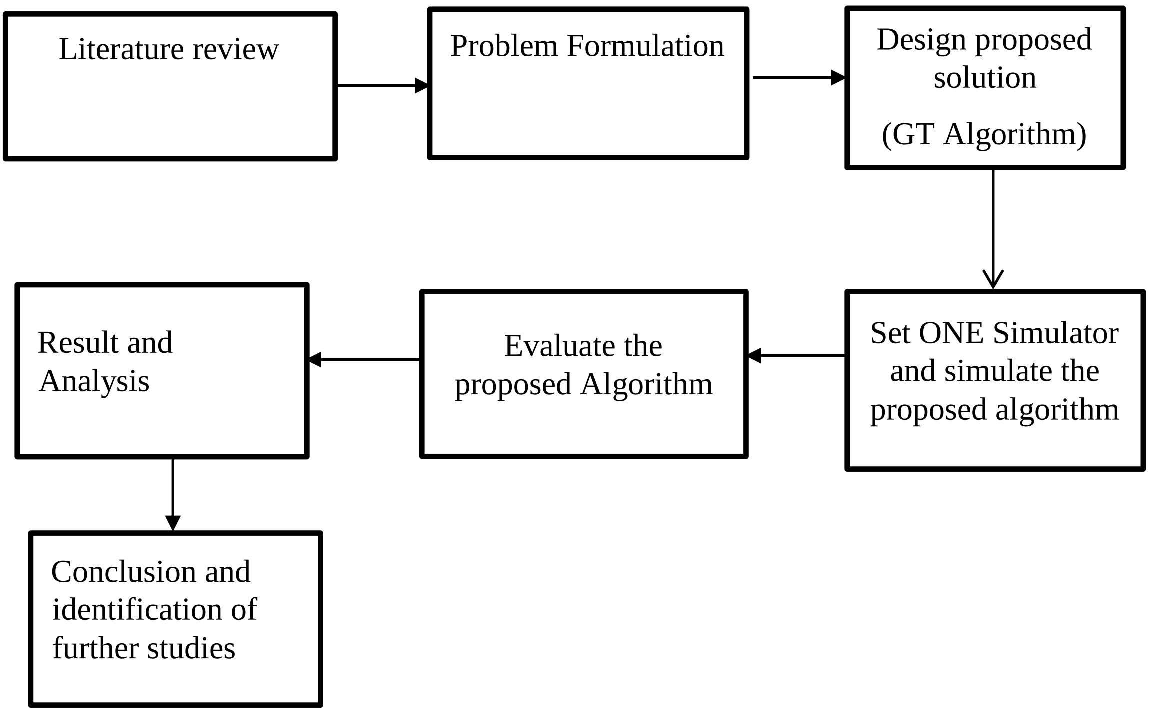


Figure 1.3 Procedure of Study

### 1.6.1. Literature Review

Due to achieving research objectives and collecting relevant information for the research work different works such as Journal articles, Conference papers, research papers, and manual guidelines will be studied.

### 1.6.2 Problem Formulation

After reviewing research articles problems are formulated. This problem was again reviewed with different recent articles.

### 1.6.3 Design Proposed Solution (GT-ERP Algorithm)

The new algorithm was developed based on the original ERP which follows the flooding approach of data transmission. In this, the algorithm considers NNs behavior.

### 1.6.4 Simulate the Algorithm in ONE Simulator

The hardware and software tools are used to simulate the proposed algorithm.

***Software:***

- Operating system:- Microsoft Window 10
- Simulation tool:- ONE Simulator
- Programing Language:-  Java
- Java code editor:- Eclipse IDE
- Draw.io:- To draw the architecture and diagram in the study

***Hardware:***

- RAM: 4.00GB.
- System Type: x64.
- Hard Disk: 500 GB.

### 1.6.5 Evaluating the Proposed Algorithm

The proposed GT-ERP algorithm is evaluated with original ERP and Microsoft Office Excel 2010 is used to plot the comparison result. Lastly, the resulting gain from this simulation discussed clearly and reported. The proposed algorithm can be evaluated based on the following evaluation metrics[26].

- Delivered packet
- Dropped packet
- Delivery ratio
- Overhead ratio and
- Average latency

#### 1.6.6 Result validation

The result of simulation obtained from report directory of ONE Simulator and event log of GUI. These explained with table and graph using Excel with parameters of delivered packet, dropped packet, delivery ratio, overhead ratio and average latency.

## 1.6. Scope and Limitation of the Study

### 1.6.1. Scope of the Study

This study focuses on ERP among the DTN routing protocols. In ERP we only studied on nodes behavior. The proposed algorithm gives id 0 and 1 for cooperative and NN respectively to measure their effect and solves the problem of NNs behavior to improve network performance. The GT-ERP improves the performance of routing in ERP by motivating nodes to cooperate. Performance evaluation metrics are delivered packet, dropped packet, delivery ratio, average latency, and overhead ratio. Nodes simulation is executed by 126 nodes similar to the original ERP nodes.

### 1.6.2. Limitation of the Study

A lot of issues were raised to improve the routing performance of ERP. In this we will not consider investigation for different patterns of mobility on the impact for the deliverance of message. The other issue that was not considered in our study was misbehavior nodes that change the meaning of message. Because these need another further study.

## 1.8. Application of the Study

The result of this work contributes to the ERP performance in DTN. DTN application area is used in intermittent connectivity. This study simulates a non-cooperative impact on ERP. The simulation would be performed under standard ERP, with GT using a simulation tool, which is ONE Simulator. From this, this study would reduce the impact of the NN under ERP using the GT-based approach. The significance of this study is to create cooperation for NNs using the GT-based approach under ERP. The simulation of the thesis work evaluates in terms of those performance metrics like a delivered packet, dropped packet, delivery ratio, overhead ratio, and average latency. We can apply this work to one of the following areas such as Deep Space Exploration, studied wild Zebra, rural communication, and Lake Quality monitoring.

## 1.9. Beneficiary of the research

The set of applications for DTN is varied from large-scale, mobile, highly dynamic networks, to small, static networks that are controlled by power sources.so the person, sector and standards which use DTN are beneficiary of our work. Thus, the user of this work get facilitate services of Delay Tolerant Network (DTN) applications in many significant conditions for sensor-based networks, satellite networks, terrestrial wireless networks and underwater acoustic networks.

## 1.10. Organization of the Thesis Work

This thesis is organized generally into five Chapters. Each chapter is described briefly on different topics. The First Chapter describes the introduction, problem of the statement, motivation, Objectives, methodology, and significance of the thesis work. The Second Chapter explains literature reviews and related work which mainly helps a clue for the reader to know more about the area and the specific issues which issued to solve by the thesis. The Third Chapter describes the proposed Game Theory-based algorithm and the general transmission flow architecture of the GT-ERP algorithm. The Fourth Chapter describes the simulation study and simulation results. Finally, Fifth Chapter describes the conclusion and future work in this research area.

# CHAPTER TWO

# 2. LITERATURE REVIEW AND RELATED WORK

## 2.1. Mobile Ad-Hoc Network

MANET constitutes many movable hosts in which hosts have no central device those mobile nodes can communicate by wireless links [27][28]. In MANET the communication is straightforward, which means there is a known path between in transmission range. In MANET nodes with wireless radio work together with each other to provide network connectivity[29]. Opposite this network, the network was operated where network communication is established and which a dedicated wireless access point is given. GSM and Wi-Fi hotspot are examples of a managed network, their access points are fixed non-mobile and wireless medium shared efficiently because the access points are preconfigured. In MANET routing was a very hot topic in recent years, [29], although the routing strategies for this conventional network MANET indicate that there is at least one entirely interconnected route form the contact point source for the destination. Widely agreed classification of conventional MANET routing protocol was reactive and constructive. As described in [30] Conventional network routing strategy assumes there is a complete path between source to destination.

Nevertheless, if the communication network is intermittent, the assumption given above cannot be precise. In intermittent, there is no full path in source to destination communication, or in another expression, those routes are not stable and may disrupt shortly after the routing has been identified.

## 2.2. Intermittently Connected MANETs

The routing protocols described above section assume that the nodes guarantee a full existence path between sources to destination. If this path may not exist the message will fail to deliver to the receiver. That does not mean communication can never happen in absence of full paths, another solution requisite to be used.

Intermittently linked MANET is a network of scarce or mobile nodes. If the nodes are mobile the contact between nodes is unknown and unpredictable then the communication of nodes is called opportunistic [27].

To resolve these transmission gaps the packets are stored and forwarded in nodes. Because of delays in this network expectations made in most networks are no longer valid. In this system packet transmission between relay, nodes take delivery responsibility of packets. To transmit packets to the node whose location is unknown and the best path to reach is unknown is forwarding to all node which exists in the network. This is done by flooding the algorithm[31]. Another issue was that the source node carries the packet until relay nodes come to the source range[32]. These intermittently connected networks belonging to the wide-ranging of DTN[33]. In this scenario, due to fast topology modifications and the absence of stable connectivity, standard MANET routing protocols like DSR and OLSR will fail.

## 2.3. Delay Tolerant Network

It is the emerging network research area. These emerging networks are applied in an area where the intermittent connectivity environment[8]. In the DTN, end to end route was not established between the sources to the destination. These connections may remain for a long duration. DTN is featured with a long late time and unstable topology of the network, where you can measure the end-to-end delay in days[8]. The DTN has its routing protocol like MANET for routing data packets within the network. This routing mechanism occurs when the relay nodes arrive within the range of transmission. Another issue that makes DTN differ from MANET was that the DTN has memory in which nodes can store data for a required time. But for MANET nodes can function only as data relaying.

DTN gives successful transmission in sparse MANET and the other environment where an end to end route did not exist. The routing protocol [8] performance in DTN was based on different mobility patterns where nodes travel with their characteristics. In comparison, DTNs can be widely applied to challenging networks, such as space communications, mobile sensor networks, and military operations. Characteristics of DTNs are a perfect match in these challenging networks.

Data forwarding in DTNs typically adopts store-and-forward techniques: if the connection is not available at a given time in these techniques, the source node needs to store the message until the next available node is encountered. The below figure 2.1 shows the store-carry-forward approach[8].

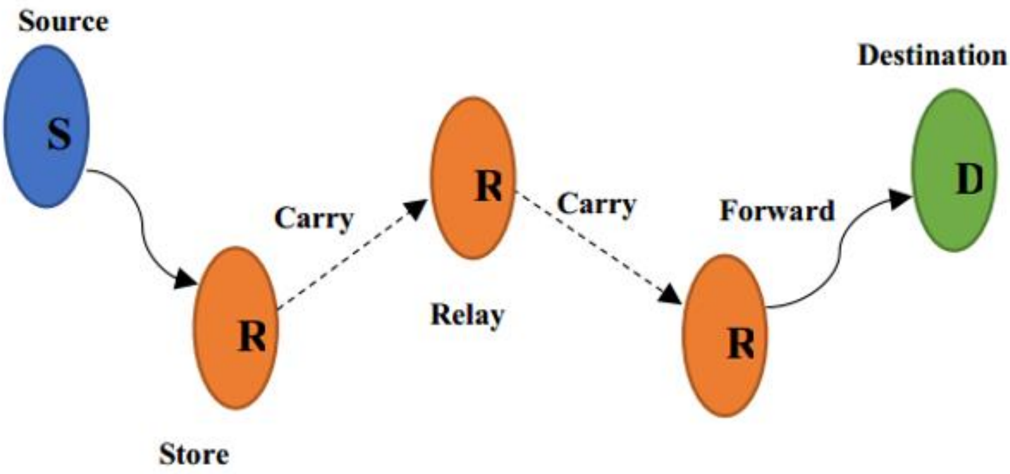


Figure 2.1 Store- carry-forward message in DTN

The data forwarding issue is a fundamental problem for DTN. To deliver messages in such networks, existing algorithms, such as Epidemic and Prophet[8], use flooding or partial flooding with a probability. There is a high probability that any flooding may cause network congestion or high interference, which consumes further resources for processing and switching operations. The key difference between the MANET and DTN communication is the lack of an end-to-end contact route leading to disconnection, variable delay, and high communication error rate.

Transmission of a data packet to reach to destination form the source node, DTN uses the store and forward concept. DTN has numerous knowledge-based routing protocols or a replication technique to send the packet to the receiver successfully. DTN uses a store, and forward approach. According to resource limitation, each node has a fixed-size buffer to store messages. The node stores the message in its buffer before the next custodian finds himself on the path to reach a destination. As the buffer size is limited node should follow some policy to decide which message is dropped when the buffer size is full. Here below table 2.1 describes comparison of DTN and MANET[33].

Table 2.1 DTN Vs MANET

| ***Features*** | ***MANET*** | ***DTN*** |
|---|---|---|
| End to end connectivity | Continuous | Frequent disconnection |
| Propagation delay | Short | Long |
| Transmission reliability | High | Low |
| Link data rate | Symmetric | Asymmetric |

### **2.3.1.** Characteristic of DTN

DTN is characterized by the following features[34].

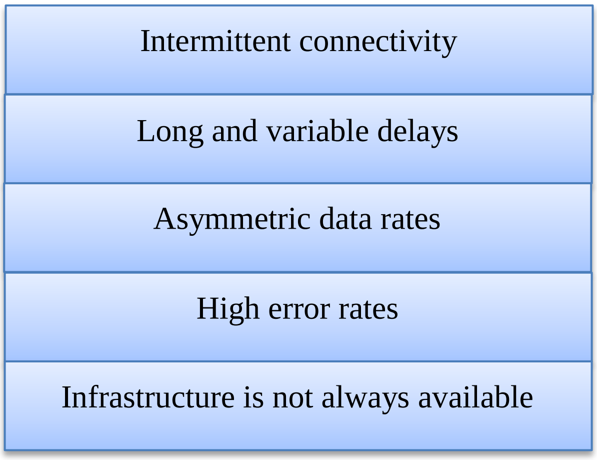


Figure 2.2 Characteristic of DTN

**Intermittency**: It is not a matter for DTN that there is a route from source to destination. Because of interruption within the communication, network partition happens.

**Delay**: There was a high propagation delay within the communication of nodes. These happened because of intermittency nodes can communicate when they were in range. This communication is opportunistic.

**Asymmetric data rates**: There are different features among the source-destination path and that of the reverse path. Bits error may occur because of one may be inaccessible.

**High Error Rates**: DTN connections can also display high error rates for bits (BERs). In space, for instance, communication links have BERs from 10−9 to 10−7.

### 2.3.2. The Architecture of DTN

The main part of the DTN is a bundle node which is also called a DTN node. It transmits and accepts a bundle that is produced by the delay-tolerant network bundle protocol. The categorization of data block protocol forms each bundle. The application and architecture of DTN[35].

**Bundle layer**

The architecture of the DTN introduced a bundle layer above the transport protocol. Transmission of a bundle can be by following storing and forwarding the whole messages among nodes. The bundle layer is easily linked with TCP/IP. This helps to provide a gateway for communication among two nodes when they come contact range[6]. The DTN architecture[36] is described in figure 2.3.

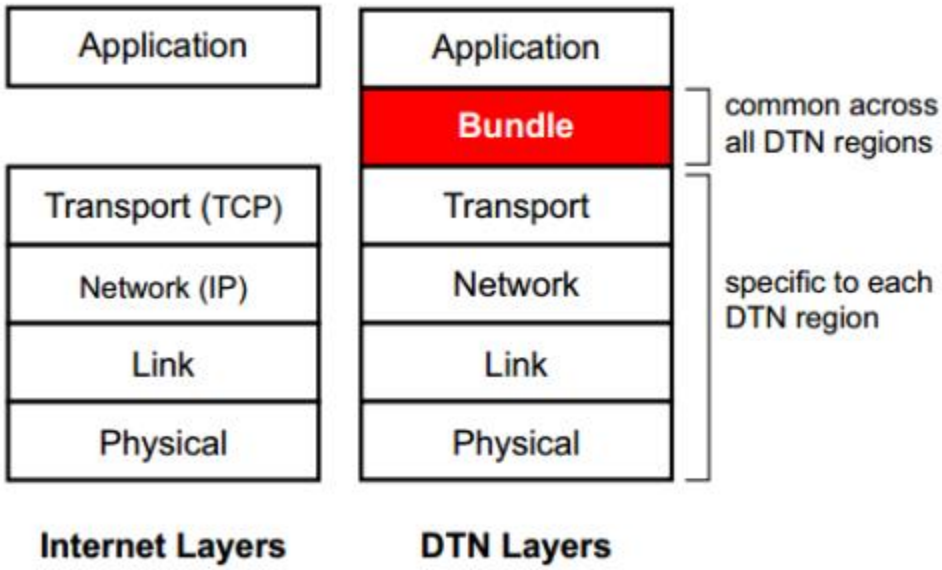


Figure 2.3 Architecture of DTN

The problem of the absence of connectivity and delays overcomes by the idea of the store and forward approach. This idea has a related concept to the service of Postal. In postal service, the letter was processed and forwarded before reaching destination through post officers. In this procedure, messages can be transferred and stored successively in the node till it reaches to destination through network. Every node prefers its persistent storage to back up the message in failures of network.

## 2.4.Mobility of Nodes

Several model-based mobility are commonly used in the DTN simulation[37][38].

1. Random Walk (RW) Mobility Model

RW mobility is the simplest concept for mobility. Each node in this model moves toward a new randomly selected spot. A random path and speed are allocated to the node and the network nodes are independent of each other. Any time any node enters the destination site, a new path from predefined ranges is allocated again. Therefore mobility parameter distributions are a function of time.[38].

2. Random Waypoint (RWP)

RWP is a random mobility model used for testing and evaluating mobile communication systems[38]. In the model, nodes are placed in a random coordinate of the simulation area and move at a constant pace directly to the specified destination, pauses for a while, and then get to a new venue.

3. Map-based Movement (MBM)

MBM constrains the node movement to a given selection. Different types of paths can be defined for all nodes in the network. The nodes are first distributed between any two adjacent positions on the map, and nodes start to move from one point to another[38].

4. Shortest Path Map-based Movement (SPMM)

SPMM is a more sophisticated version of the MBM model. It uses Dijkstra's shortest path algorithm to find its way through the map area[38]. If a mobile node reaches a certain location and it has to wait to make the next movement for some time, a new random map location is chosen and then it moves toward the new destination along with the shortest path which is taken from valid map paths.

## 2.5. DTN Routing Protocol

Routing protocol classification for the DTN network is grouped based on the kind of information that nodes collect and the way they make a routing decision. The routing strategy for DTN is divided into two based on characteristics used to get a path for transmission. One is a flooding approach, in this routing strategy multiple copies of a message are created to reach the destination. The second one Forwarding approach follows a different strategy to select the relay node effectively and for the issue of limited resource and storage, it reinforces the relay node. Classification of DTN routing[39] is presented in below figure 2.4.

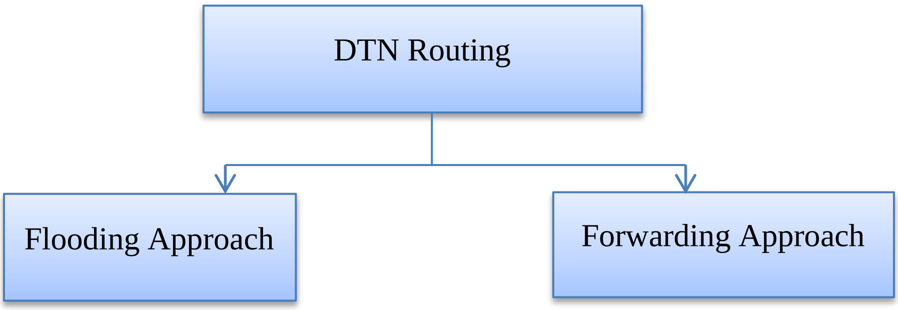


Figure 2.4 DTN Routing Approach

From above the two approaches Spray and Wait, Epidemic, Maxprop, and Prophet routing protocols of DTN will be provided. In this ERP and SNW follows the flooding approach, PROPHET and MAX PROP are classified under the forwarding approach[40].

**1. SNW Routing Protocol**

This SNW routing protocol constitutes two-phase, Spray, and Wait phases (Spyropoulos et al. 2005). The message that was created in this routing protocol network was limited by L copies. The source message will spray one copy during the spray process to L different “relays”. When a relay receives the copy, it enters the waiting phase, where it will simply hold that message until the destination is encountered directly. This routing protocol benefits from the replication-based routing to achieve a high delivery ratio and from forwarding based routing to achieve low resource utilization[26][41].

**2. MAX PROP Protocol**

MAXPROP (Burgess et al. 2006) published the DTN routing protocol to transmit data packet for other relay nodes priority schedule was used. It was based on historical data and some complementary mechanisms. Three methods used here are: head start for new bundles, list of past intermediaries, and system-wide recognition. Head start and priority are given to the new bundles to be transmitted so that all bundles have a chance of being propagated throughout the network. Previous intermediary lists are kept to prevent bundles from being sent to the same node again. System-wide identification is spread across the network to alert nodes to extract redundant copies of bundles that have been shipped to their destination [41].

### 3. PROPHET

PROPHET (Lindgren et al. 2012) is a version of the ERP. It functions by pruning the tree of epidemic distribution to reduce resource use while still trying to achieve the epidemic routing capabilities in best case. This protocol uses the delivery predictability and attempts to predict which node has encounter history, the greater likelihood of successful transmission of a message. A new message copy is only transmitted when two nodes are in the contact range if the other node is more likely to send it to the destination[26][41].

### 4. ERP

Vahdat and Becker et al. (2000) published an epidemic routing algorithm and proposed as a flood-based forwarding algorithm. The goals of this protocol are: to increase the transmission speed of messages, to reduce latency and resource consumption in the delivery of messages[41]. ERP[42] is the first protocol to route the DTN having the technique of replication in nature. Through the DTNs routing scheme, the node receiving a post, forward a copy of it to all nodes it encounters, according to Mehta and Shah (2014). Therefore, mobile nodes disperse the message across the network, and at last, all nodes will have similar data. To reach the destination this algorithm has the best effort. The unique identifier and the message are stored in the buffer of nodes. The description vector is called the list of them. If two neighboring nodes come into contact with each other, their summary vector is shared and compared to recognize which messages they do not have and then query them. When a packet's counter reaches zero, it discards the packet. The packet will keep on getting copied from one route to the other route until its TTL expires. This routing protocol results in ineffective use of the network resources such as power because of forwarding multiple copies of a similar message, in case of the resource.

Nonetheless, it is easy to see that this ERP offers the quickest distributed copies within the network, resulting in the highest distribution speed. Yet flooding in control channels causes a huge amount of control packets, which can lead to network congestion. An ERP is especially useful when there is a lack of information regarding network topology and node mobility patterns.

The below table 2.2 shows the comparison of the routing protocols for DTN [26], [39], [40]. As the comparison table describes Epidemic is the DTN protocol with the highest delivery ratio and less delay as compared to other DTN routing protocols[3][41].

Table 2.2 Routing Protocol Comparison

| | ***Number of copies*** | ***Buffer space*** | ***Delivery ratio*** | ***Delay*** |
|---|---|---|---|---|
| ERP | Unlimited | Limited | High | Less |
| SNW | N-copies | Limited | Medium | High |
| MAXPROP | Unlimited | Unlimited | Medium | High |
| PROPHET | Unlimited | Unlimited | Less | High |

## 2.6. Behavior of Node

Every communication assumption that the user gives was that each user in communication is willing to share their properties with others. But in reality, not all users share their resource. In another way, users can share their resources with one which has a social tie with them and not share the one which has no social tie. When we came to the real life of people, some are selfish and others are not. Why they are selfish arises from different reasons like a limited resource, in this case any individual which contain limited resource cannot share with others. Another issue that was raised was they become selfish due to their selfishness. When we come to network communication nodes behave like cooperative and non-cooperative behavior. MANET has cooperative nodes working in cooperation within the network. Nodes exhibit selfishness to save their resources. Even though the selfish behavior of the nodes will cause packet drop thereby degrading the network performance[43]. There were assumptions that all mobile nodes in MANET are cooperative. Nevertheless, this cooperation cannot be achieved all the time because of many issues like a limited resource of nodes. Since mobile nodes are constrained in terms of energy, nodes may behave selfishly by refusing to forward packets for the benefits of other nodes to save their energy[44] [36].

## 2.7. Non-cooperative Nodes

There is a general conclusion during the application of DTN concepts to MANET that was considering all nodes as willing to participate by sharing their resources to enable the communication among nodes. Nevertheless, this assumption is not true all the time because nodes may make a limited contribution or may never make any communication within the mobile community. Those NNs decrease the effective transmission, but they cannot consume resources in case of dropping the packet. Also, there are nodes which perform partial contribution [45]. Due to these routing in DTN have to take consideration of non-participating nodes. As this node exists in communication, it can low the routing performance[25]. The NNs don't forward and store a message to another relay node. That means this node does not accept any message that needs to be forwarded or may drop that message.

These nodes are greedy and use others for their gain, but do not contribute to the community by reducing their consumption of resources. In the routing of DTN, many routing protocols have existed among those ERP is the one[25]. ERP does not take consideration of nodes' behavior [13]. As described above ERP was the simplest routing protocol having the highest delivery ratio among the other DTN routing protocols. Nodes in ERP transmit their copy to every node that reaches the transmission range. During these, if nodes are not willing to participate, the effectiveness of ERP was not applicable. This problem degrades its performance. There was a unique identifier[18] for the packet that was stored for another relay node to store the packet which comes from source nodes. The hash table helps to maintain which packet was stored in the node store. During transmission when the nodes reach the transmission range they first exchange the hash tables to know which packet is not in the store [24]. Those relay nodes sometimes behave no cooperation behavior. To overcome this kind of problem several techniques were proposed by different researchers.

## 2.8.Algorithms to Solve Non-cooperative Node

In DTN, packet can be transmitted using a store forward approach based on relay nodes. If those relay nodes is selfish node they did not forward the packets. Due to this, the overall network performance is affected because of these nodes' behavior. Many algorithms are proposed for detecting and preventing selfish nodes. Commonly used algorithms for detecting selfish nodes[30][46] are:

### 2.8.1. Barter-based Methodologies

It works on the way that each node forwards an equal number of steps to everyone. The nodes forward to its neighboring node when it is forwarded by its neighbor. It is called an exchange between pairs.

### 2.8.2. Credit-based Systems

Credit-related methods are introduced to circumvent the limitations of the scheme based on bartering. This procedure urges nodes to be pleasing by paying rewards for helpful nodes. The theory is if a node helps send a message to other nodes, and then earn credit as a reward which can be used for its unique value later on.

### 2.8.3. Reputation-based Strategies

In this approach each node evaluates the behavior of other nodes and relegates to each node's credibility, it tests the node’s functioning. The reputation-based approach will operate regardless of the probability that the unkind nodes may be a prominent section.

Table 2.3 Technique for a selfish node identifying

| ***Strategies*** | ***Incentive Attribute*** | ***Advantage*** | ***Disadvantage*** |
|---|---|---|---|
| Barter-based methodologie s | Message number within the node<br>Transmit only if neighbor node transmit | Social ties existed | Because of a lack of trustworthiness, this approach is not working well.<br>Not suitable for DTN network |
| Credit-based systems | Node's credit | This strategy helps the selfish nodes to cooperate better Factor by credit or award to them. | In this model the flooding of messages is high. Never motivates cooperation |
| Reputation-based Strategies | Node's reputation | In this technique, till the last time, two nodes are encountered together and establish the list of up-to-date records as well as the shift in value. | In this strategy the node's behavior of selfishness is high. |

### 2.8.4. Game Theory

Game theory is a mathematical strategy in which activities engaged using rational participants. A set of participants help the decisions that benefit players by increasing their payoffs. This game constitute sets of player, strategies for stating participants decision, the outcome for a decision, and payoff matrix that describes the utility function of players[47]. Game Theory includes analytical instruments for predicting the result. Complex interaction between rational entities in a match the player takes part with a reward depending on the most players on. In the game, nodes of the network considered players, the move of nodes as an action within the game, and the reward for the player was payoff[48][49]. Game theory is useful to act and predict other people's actions and to build structures of multiple participants. Players are also a strategic interplay between rational persons and participants. The players usually describe a set of tactics for each player and a preferential relationship for each player over potential outcomes. A player must give every player in the game the collection of strategy or action. There is a simple and critical rationality principle in the game theory that every player is the tool optimizer. The player has a payoff function to optimize the payoff function. In a cooperative game, players have an interest in combining their action, that helps to have a common goal, called cooperative[47].

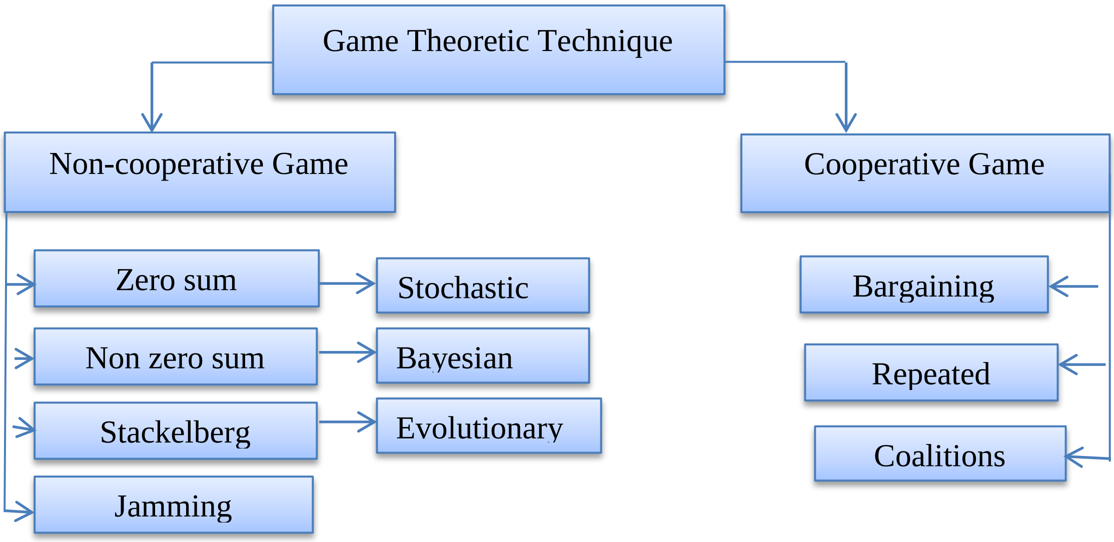


Figure 2.5 Game theory approach

**Cooperative and Non-cooperative Game-Theory**

In **non-cooperative games**, each participant player acts in his interest, and the unit of analysis is always the individual player instead of a group of players. In these types of games, the players are always selfish. That means, they always try to increase their payoffs without taking care of other player’s payoffs in the game.

In the **cooperative**, the player's group is the unit of analysis and the players tend to increase their group payoffs as well as their own. A cooperative game can be considered as a competition among the groups in a game rather than individual players. The cooperative game-theoretical model applications are in the situations where players form groups, called cooperation, and individual or group of player’s contribution towards the game depends on the other agent's actions in the game. Among other cooperative game theory, Bargaining has been modeled to study the individual node's behavior in a network each contributing to cooperation. Modeling message forwarding as a ***Bargaining game*** helps to maximize the cooperative of nodes. Game Theory includes analytical instruments for predicting the result Complex interactions between rational entities; in a match, the player takes part with a reward, depending on the most players on[50][51]. First, the GT assumes that, as opposed to their strategies, each player has knowledge of each other's strategies, and the pay-off matrix constructed. The definition of the solution most widely used in GT is the Nash equilibrium(NE)[52].

***Nash Equilibrium:*** The NE is stated after Jhon Forbes Nash, Jr., in 1950 describing the equilibrium stable state in a multi-participant situation in which no benefits of participants from a change in their strategy unless remaining unchanged for the other participants as well. In other words, when each player stays in the cooperation as long as no different move for other player takes, NE attained. Each player is worse off, so they decide not to move. Dominant strategy: In this no matter how other players perform, means it is the move that optimal for each player. Nash Equilibrium: Which does not specify a specific solution, but rather a kind of shared understanding, each player understands the other player optimal strategies and takes when his strategy is optimized. The optimal state of the game is represented by Nash balance, where both players make optimal moves, but now consider their opponent's moves. In the competition of the game, the players have the right ideas for the other player’s behavior and acting as rationally. The solution for the game forwarding bundles is based on NE. NE Have two main components:-

- The node selects its behavior according to the rational choice model, provided its confidence in the actions of the other Nodes.
- Each node's expectation of the other node's actions is maximization.

NE is an action profile Z* with the property that no player P can do better by choosing different actions to form ZP*, while other players adhere to ZQ*. Explicitly, the players observe function according to the rational choice principle that is forwarding, gives beliefs about other players' behavior, and these beliefs are right. A NE matches to the state of stability, where the players drained from nodes selection at any given match during the setting of idealized. If the action profile is the same NE Z* when the game is played, then no player has chosen any action that differs from their Z*; no incentive is used to improve on the action profile. NE represents a consistent: no player wishes to differ from it if anyone else adheres to it[53].

## 2.9.Related Works

In this section, the research area related to our works that have been done on improving ERP was realized and also the gap relevant to our work was discussed. Almost all researchers who studied the ERP focus on cooperative node's behavior[13]. It works in the flooding way and it will consume too much energy. Recently, different methods have been presented to overcome the problem, such as the probabilistic and hop-based forwarding policy[13][16]. These policies have both strengths and limitations, so how to evaluate their performance is very important.

The work in [13] increases message delivery by comparing the node’s energy level and buffer before transmitting. In this paper, nodes transmit the data message if it has high buffer space and energy than the incoming message. It waits for the node which has not less than the incoming one. This makes the ERP have less traffic in the network but latency was increased. As they work enhanced the ERP taking consideration of all nodes as cooperative. But this is not true in all situations. This degrades their work performance.

The work in [15]explores the ERP performance routing in destination less and destination-oriented. What they conclude was the node's mobility has an impact on the ERP performance. So considering this aspect destination less was suggested for optimizing ERP. Still, this work is also considered a cooperative node's existence. It is acknowledged this doesn't always work.

The author in[17] proposed energy-aware ERP in DTN. This paper shows that the proposed energy-aware ERP performs better consumption of energy, delivery probability, and overhead ratio than the original ERP. The energy level comparison continued to all of its neighbor nodes. But what never constitutes was that NN behavior. The general assumption was that nodes can participate in cooperatively, but not true all the time.

The paper[16] proposed an efficient spreading ERP. This message spreading is chosen as methods of the best to deliver messages during no information available. This work provides a high delivery rate by applying broadcast transmission and a duplicate set. But these can be achieved if nodes are cooperative. So the efficiency of ERP cannot be achieved because of NNs. The above works ignore the NN's behavior.

The author in[46] develops a credit-based scheme to nodes that participate in forwarding messages. As nodes are provided with rewards for transmitting the message, more messages are distributed throughout the network, resulting in an increased likelihood of transmission. This work still does not create motivation among cooperative and NNs.

The work in[54] introduces trust authority to check the behavior of nodes. Each node will also obtain compensation from the Trust Authority if the node passes the investigation of the trust authority successfully. Otherwise, the trust authority will enforce punishment on the node as a punishment. Only giving compensation for the node was proposed. This work never creates motivation among nodes.

Table 2.4 Summary of Related Work

| No | Objective | Year of Publication | Method used and Strength | Limitation |
|---|---|---|---|---|
| 1. | Increasing delivery rate[16] | 2016 | Applying broadcast transmission and duplicate set to providing a high delivery rate. | Considering as all nodes cooperative node<br>Increasing overhead ratio |
| 2. | Increasing the delivery rate and decreasing network traffic[13] | 2018 | Increase message delivery and decrease network traffic by comparing the node’s energy level and buffer before transmitting. | Considering as all nodes cooperative node<br>Increasing latency |
| 3. | Identifying malicious nodes[54] | 2018 | Punishment or compensation is given based on a node's behavior by introducing trust authority. | May the trust did not work well as node changes dynamically<br>Never to create motivation among nodes |
| 4. | Increasing message delivery[46] | 2019 | Developing a novel credit-based scheme to nodes that cooperate in message forwarding | Only motivates cooperative node to continue in their behavior<br>Still not create motivation among other nodes |

## 2.10. Summary of Related Work

The ERP of DTN has been proposed in many papers, the above methods still suffer from certain shortcomings. As ERP has a good delivery ratio feature because of many replicas of the message, the opportunity of message delivering to the destination was high. But this issue was developed by not taking of the node's behavior. Nodes have different behavior due to any reason. Among those cooperating and not-cooperating behavior of node is the main issue that has to consider in studying progress. If nodes participate in the forwarding message process, the performance of ERP was high. If nodes act as non-cooperative, this results in degrading network performance. When we reviewed papers that were done on ERP, almost all of then ignores the NNs behavior and gives an assumption that all nodes are cooperative. However, the incentive and trust-based method were proposed for ERP, but these works never create motivation among nodes. Rather they gave credit for cooperative and giving punishment for non-cooperative one. As this communication was intermittent it is difficult to give rewards for cooperative and punishing non-cooperative one. Therefore, based on the above-stated gaps of the related works, we have proposed a GT-ERP. That helps nodes to think as rational and choosing the best action for the group rather than having individual advantages. This strategy motivates them to cooperate for increasing their payoff by staying at the NE. To maximize its payoff each player selects the optimal strategy, which leads the group to attain NE.

# CHAPTER THREE

# 3. PROPOSED GAME THEORY ALGORITHM

## 3.1. Introduction

ERP is one type of DTN routing protocol. Among other DTN routing protocols, it was the simplest one which follows flooding type of data transmitting. It was called an effective routing protocol because of having a good delivery ratio and less end to end delay; nodes transmit messages copy to every node which comes in its range. Each node's data packet has a unique identifier and the nodes buffer area in the ERP algorithm stores packet which is forwarded by the source as well as relay nodes. The nodes keep a hash table to register which packet was stored in nodes buffer. In their first communication, the nodes first exchange their hash table to know the packet which is not in the storage and transmitting those packets. Nodes were mobile in the communication due to intermittent connection; as there was no direct path from source to destination. So this intermittent issue can be solved by movable nodes, due nodes carry message until it reaches destination.

## 3.2. Overview of GT-ERP

In ERP, the behavior of nodes was not considered. From the related works, a node's behavior was a big limitation that was never considered under many studies. This study measures the effect of NNs in the ERP and proposes a solution for NNs. This was measured by giving id 0 and 1 for cooperative and non-cooperative respectively. During this study, the NNs select 1 and drop the message. To measure its effect degree number for NN given from [0-100].

## 3.3. Proposed Solution

In ERP the number of the replicate message forwarded to every node that comes in transmission range. In ERP, NNs need to save their resource; those nodes ignore the message assigned to it. These issues were addressed by the proposed GT-ERP. The general transmission process of the message in GT-ERP was described in figure 3.1. As the figure show there was two-way communication that is direct communication and communication using intermediate nodes. When the destination comes in the range of source transmission it directly gets the data packet, in this the occurrence of NN did not affect the communication because the destination got the packet directly from the source node. The other one is when the data transmitted via relay nodes whether with a one-hop or multi-hop stage. When nodes reach in the range of transmission they first exchange a summary vector that contains information about messages from the hash table. Then in matching, if the host has the message with that id, it didn't accept the message. During this phase, the NN affects communication. So the relay-based transmission was forwarded based on the proposed GT-ERP. That was due to the proposed motivating nodes cooperation.

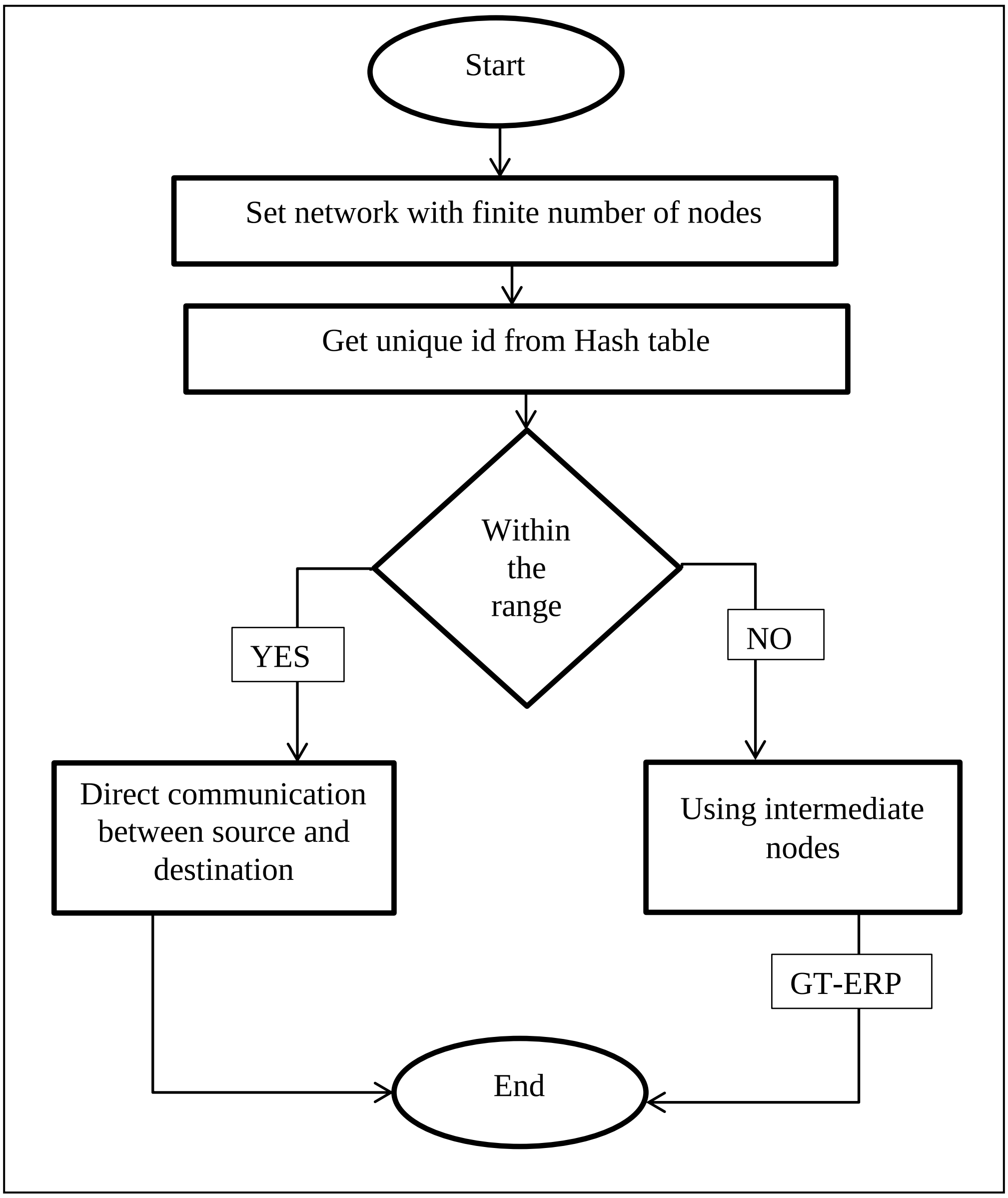


Figure 3.1 Proposed Overall Transmission Flow

The hash table to exchange their message-id can be described in the below algorithm 3.1, which helps nodes to get their id for matching which message exists in the host. The proposed motivates them after matching their id to transmit the data packet.

Algorithm 3.1 Hash table

```
Message m = super.messageTransferred(id, from);
Message res = new Message(this.getHost(),m.getFrom(),
RESPONSE_PREFIX+m.getId(), m.getResponseSize());
this.createNewMessage(res);
this.getMessage(RESPONSE_PREFIX+m.getId()).setRequest(m);
```

The generalized pseudo-code of the proposed transmission flow of GT-ERP was described in algorithm 3.2.

Algorithm 3.2 Pseudo-code of data forwarding

| | | |
|---|---|---|
| Step 1 | : | *Node S is the source carries message m and encounter node D* |
| Step 2 | : | *If(node D is the destination of message m) then* |
| Step 3 | : | *Node S forwards message m to node D* |
| Step 4 | : | *Else if(node S continue to carry message m)* |
| Step 5 | : | *Then* |
| Step 6 | : | *GT-ERP applied to the range of transmission* |
| Step 7 | : | *Node S will forward via a relay node* |
| Step 8 | : | *End* |

## 3.4. Non-cooperative Nodes Scenario in GT-ERP

To analyze the NNs effects we give id 0 and 1 degree for cooperative and NNs respectively. Figure 3.2 shows the deployed 126 nodes of our study. The node with the color red is nodes that select id 1, which means they are NN. As NN added to ERP, the overall the network performance decreased, because they drop the data packets. This study creates cooperation for the NN before the degradation of network performance occurred. This was done through a game theory algorithm. The proposed GT algorithm considers the research challenge that discussed in chapter one section 1.3 and improved it by identifying node behavior in the routing system. To model NN:-

- ***Nodes number***: This describes the subset of nodes within the network (126) nodes.
- ***Degree of selfishness***: Assigning id 0 and 1, 0 for the cooperative, and 1 for the NN.

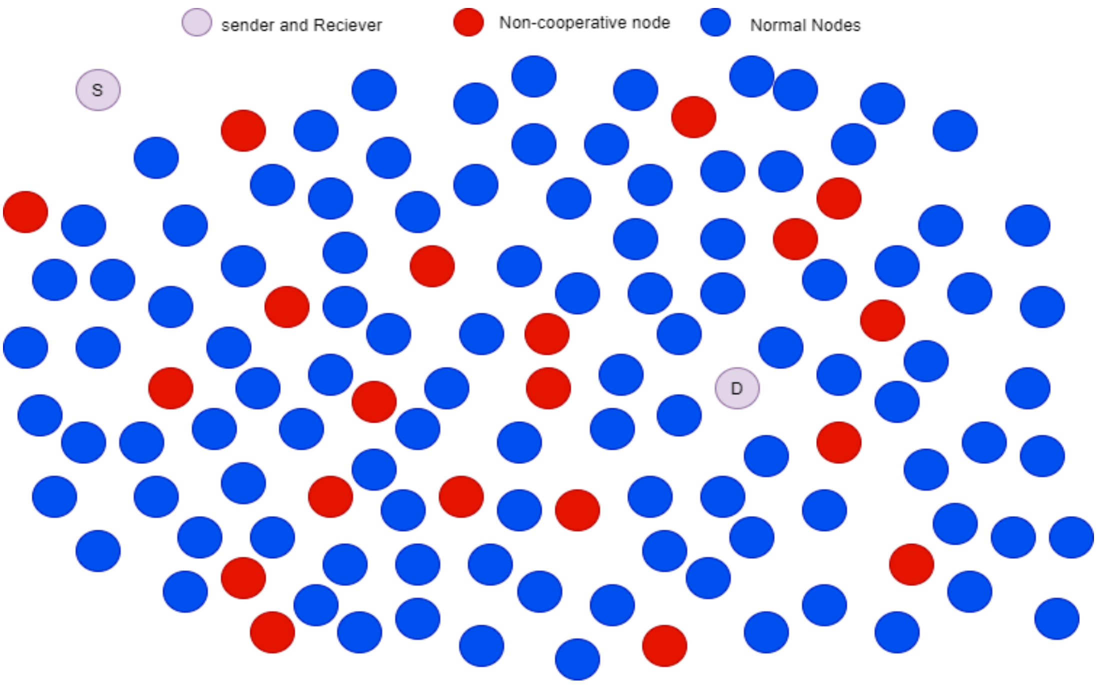


Figure 3.2 Proposed 126 nodes with 20 NN

In algorithm 3.3, the pseudo-code for the detection of the NN presented. As all nodes select id 0, there is no consideration of the NNs in the network. We measured the proposed GT-ERP performance between [0,100] NNs out of 126 nodes number. In our proposed GT-ERP, as starting from 0 it has a great improvement in our performance metric comparison.

Algorithm 3.3 Pseudo-code for measuring NN

| ***Pseudo Code for measuring NN in GT-ERP*** | | |
|---|---|---|
| Step 1 | : | *Set node selfishness degree (0,1)* |
| Step 2 | : | *Selfish node behavior status= True(1)* |
| Step 3 | : | *Set subset of Non-cooperative nodes [0,100]* |
| Step 4 | : | *Create a random $A_n$ number for each node to assign selfish node* |
| Step 5 | : | *If ($A_n$=1) node considered in a subset of selfishness* |

Step 6 : *Else*

Step 7 : *Node is not considered in a subset of selfishness*

Step 8 : *Generate $A_n$ to check the degree of selfish node*

Step 9 : *If ($A_n$=1)*

Step 10 : *Return True;*

Step 11 : *Else*

Step 12 : *Return False;*

Step 13 : *END*

---

## 3.5. General Assumptions

Here is the general assumption in GT-ERP

- Rationality is hypothesized.
- Maximization is also expected.
- Players inside the game are believed to be logical and to seek to maximize their payoffs in the game.
- On your behalf, it presumed that the payouts mentioned comprised the amount of all the payoffs associated with that result.

## 3.6. ERP Routing as Bargain Game

Bargain game is ideal for cooperating decision-makers. During the interaction, decision-makers are stated as players. A possible set of actions stated for each player. Interaction between players modeled by the action of one player; affected by the action of the remaining player, not by its lone action.

Figure 3.3 shows how the message can be transmitted in ERP using GT. As the figure shows first the nodes have to be within the transmission range, then the bargaining game applied for forwarding service. In this forwarding service, both the sender and the receiver are rational. So every selection of its strategy is rational. In this forwarding service, the proposed GT-ERP algorithm is applied, and every player is aware of its alternatives. In this game, the nodes are players, the move of nodes as an action within the game, and the reward for the player was a payoff.

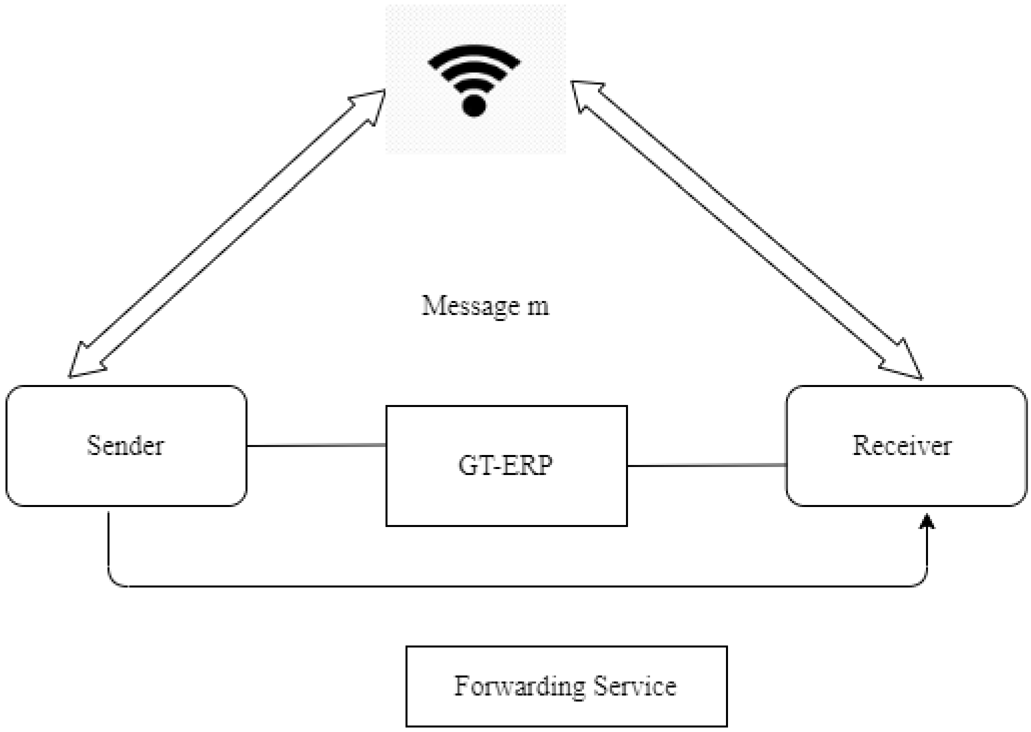


Figure 3.3 Proposed system model of GT

**Defined GT Approach terms for Our System Model:**

- ***Players***: Decision-makers within the game, that are (126) nodes that participated in the proposed algorithm.
- ***Strategy***: Action of players, which is the strategy selected by nodes. That is Accept and Reject shortly (A, R). The strategy Accept includes (storing and forwarding) approaches.
- ***Payoff***: The outcome payout for the player based on the nodes strategy selection, (A, A), (A, R), (R, A), (R, R).
- ***Equilibrium***: When both players meet their goal, which is (A, A). As both nodes willing to accept their messages with each other.

In the Proposed GT-ERP the nodes become cooperate because the nodes never leave equilibrium. In this, if one node transmits the message of the neighbor node, also that neighbor node must transmit the node's message to reach equilibrium. GT based routing is taken as a computerization algorithm and makes intellectual choices on forwarding mechanism.

### 3.6.1. Formulation of Forwarding in GT-ERP

The figure shows the cooperation players' forwarding scenario in the GT-ERP algorithm.

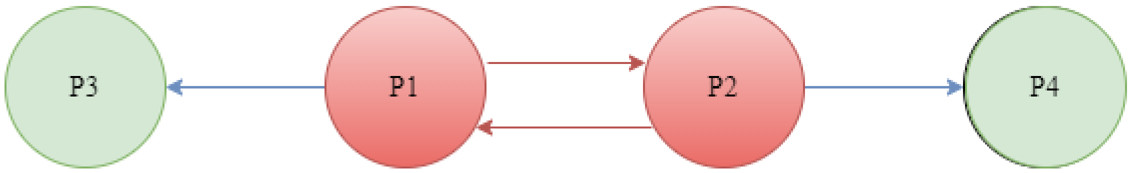


Figure 3.4 Game scenarios of GT-ERP

This section describes a player's packet forwarding scenario for cooperation. In figure 3.4 from 126 modeled nodes, we present sample four nodes P1 to P4 and P2 to P3. P1 and P2 are willing to send packets to destination p4 and P3 respectively. Without the cooperation of P1, P2 is not able to send its packets to P3, and the same too, p1 cannot send packets to P4. The strategies or actions that are available to players are "Accept" or "Reject" the packet of other sources. The best response for every player is reaching NE because the payoff maximized by attaining the state. The payoff is defined as the form of a row and column matrix table, shown below in section 3.8. More than two players can cooperate, to reach the goal NE. The basic assumption in this situation was an agreement between a player's existences. The proposed GT-ERP expressed NE in the game as:

- Examining the best response function of every node.
- Examining the summary of each node that fulfills every node has the best lone response to every node's actions.
- To reach this Equilibrium state if one node transmits the data of another relay node, the relay node also has to transmit the data of the neighbor node.

From figure 3.5 framework of GT-ERP, the joint action of the group of players is analyzed rather than individual action. CP: - the payoff for cooperation and NP: - the payoff for Non-cooperation. As shown in the framework the players to reach Equilibrium state they have to cooperate with the players.

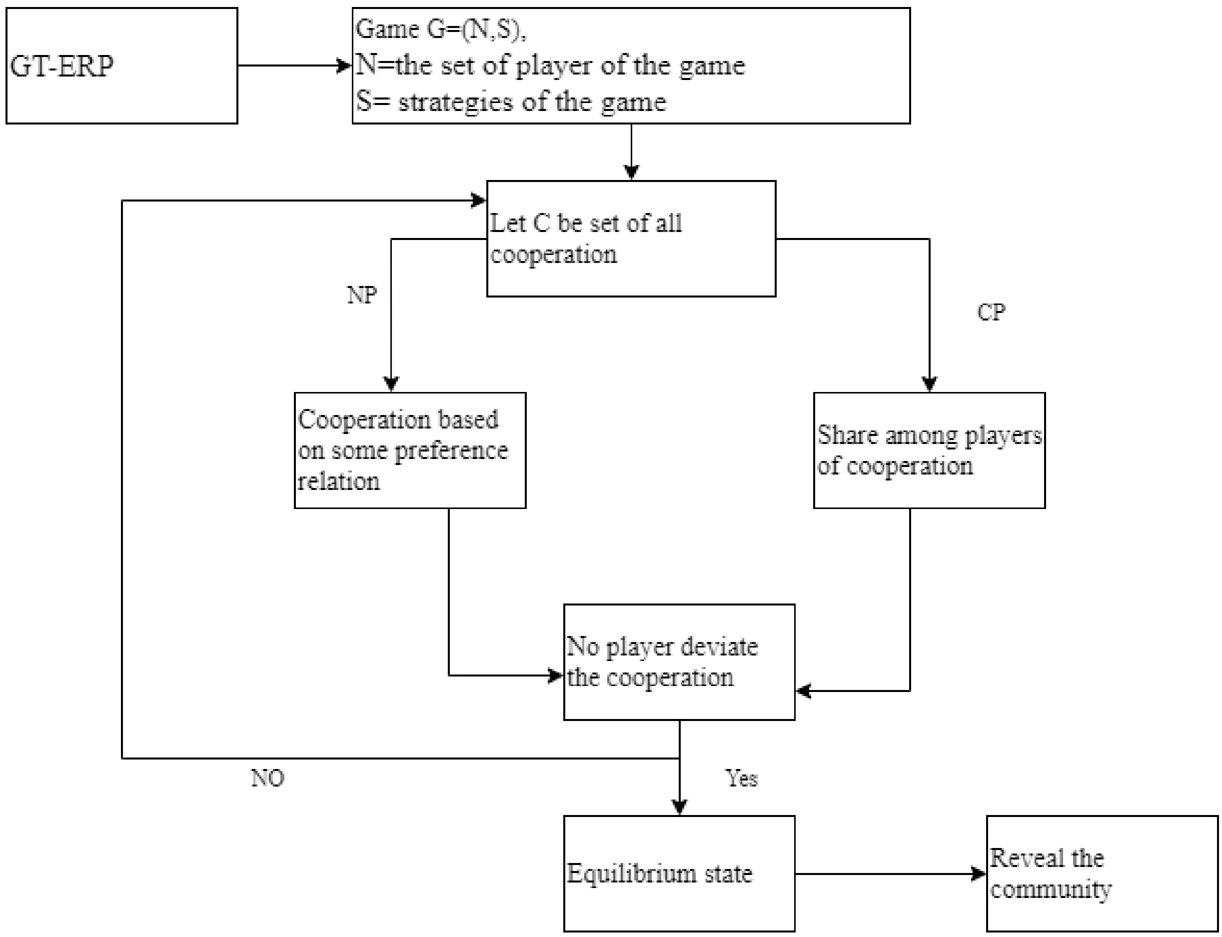


Figure 3.5 Proposed GT-ERP Framework of NE

When the players reach the Equilibrium state, they maximize their product. In this state, no other player can get a better payoff by moving individually, rather cooperating with others.

Let: N be a finite set of player (126) nodes, A= ($A_1$... $A_n$), where Ai set of actions and, P= ($P_1$… $P_n$), Where Pi is the payoff function for 126 nodes. The form of the game was (N, A, P).

$$P_i(A_i, A_{-i}) \geq P_i(A'_i, A_{-i}) \; \forall \; i \in N, \forall \; A'_i \in A \; \ldots\ldots.. eq(1)$$

Where $A_i$ is the player $i_s$ the current strategy of ($A_{-i}$) against all other strategies. The A’ $_i$ are all other strategies of player i. This means the profile A strategy combing with all other strategies profile was the NE for the condition in eq(1) having all players.

A game’s solution is called NE, where each player can’t get a better payoff than the current one by moving individually to another new strategy. Their selection strategy was described in algorithm 3.4.

Algorithm 3.4 Pseudo code of GT

| | | |
|---|---|---|
| | | ***Pseudo-code of GT*** |
| Step 1 | : | *Input →payoff for strategy* |
| Step 2 | : | *A= {payoff for strategy}* |
| Step 3 | : | *Maxi= max (A);* |
| Step 4 | : | *Mini= min (A);* |
| Step 5 | : | *Maximin=min (maxi);* |
| Step 6 | : | *Minimax= max (min);* |
| Step 7 | : | *If (minimax==maximin);* |
| Step 8 | : | *Row =find (mini==minimax);* |
| Step 9 | : | *Col=find (maxi==maximin);* |
| Step 10 | : | *Disp (row);* |
| Step11 | : | *Disp (col);* |
| Step12 | : | *Disp (minimax);* |
| Step 13 | : | *Disp (maxmin);* |
| Step 14 | : | *End;* |

## 3.7. Flow description of GT-ERP

***Step 1***: We modeled 100 nodes to select id 0. That is the original ERP, without adding a NN. But this means that not all are willing to forward their packet. It implies adding the proposed GT-ERP in the original ERP one. What makes a variation in this was that the proposed modeled cooperation mechanisms for nodes.

***Step 2***: We modeled 20 nodes to select id 1 and the remaining select id 0. This implies the 20 NNs and the rest cooperative.

***Step 3***: We modeled 40 nodes to select id 1 and the remaining select id 0. This implies the 40 NNs and the rest cooperative.

***Step 4***: We modeled 60 nodes to select id 1 and the remaining select id 0. This implies 60 NNs and the rest cooperative.

***Step 5***: We modeled 80 nodes to select id 1 and the remaining select id 0. This implies 80 NNs and the rest cooperative.

***Step 6***: We modeled 100 nodes to select id 1 and the remaining select id 0. This implies 100 NNs and the rest cooperative.

The developed GT-ERP motivates NN in routing during all stages. Generalized message transmission of the GT-ERP passes in the following hop.

***One Hop:*** One-hop way of transmission was the fastest transmission stage and also one single copy of each message exists in the network. During this one-hop transmission, the data packet is stored in the source and transmitted to the destination. In this way, NNs never affect because the data packet is delivered directly to the final destination node. The path of one-hop transmission from figure 3.6 was S-D (Source to destination).

***Two Hop:*** Two-Hop way of transmission was transmitting with an intermediate node and have more than one copy of the message. The data packet is stored in the first relay nodes and delivered to the destination node. During this transmission, NNs affect communication because the source to the destination cannot communicate directly. So the GT algorithm starts its model from this stage. The path of two-hop transmission from figure 3.6 was S-A-D and S-C-D.

***Multi-Hop:*** In Multi-Hop transmission stage unlimited copy was exist, as nodes come in transmission range it forwards to every node. In this stage, our proposed algorithm was more applicable. This decision is taken, for example by not carrying messages for a certain destination node, or of a certain size. The path of Multi-hop transmission from figure 3.6 was S-A-B-D, S-C-B-D, and S-A-B-C-D.

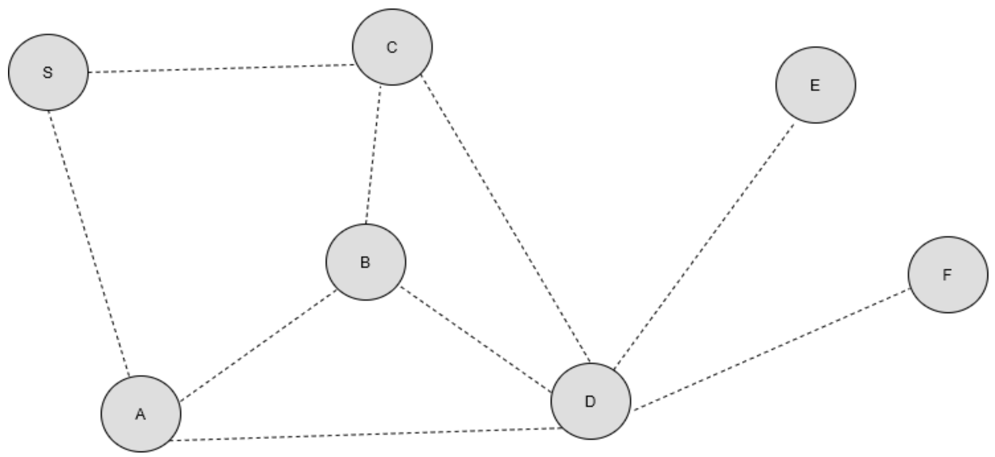


Figure 3.6 Flow of Packet transmission

## 3.8. The Theoretical Model of GT-ERP

In NE, no player would want to change his strategy. This is because in NE all players simultaneously play the best response to each other strategies unless it can harm the player. As the players are rational, they want to reach NE. The best response for every player is NE. To reach equilibrium nodes want to get the dominant strategy. The dominant strategy is the one every single player highest payoff. As two dominant appear at the same point that point is called NE.

In this section, the theoretical model of GT-ERP was described. In this, players are nodes, Accept and Reject are strategies for each of them, and the game outcomes are expressed in the form of a matrix where the payoffs are displayed in the form (Payoff of node1, and node 2 payoffs). Let player-one as node 1 and player-two as node 2. For each player, the numerical result depends on the payoff function used by each player in the situation this game is played in. Any game, when played, consists of the participants named players or agents of the game, each having their own choice or target. Every player of the game has a related amount of benefit or reward, which is earned at the end of the game, called payoff or utility, which calculates the degree of satisfaction an individual player gains from the conflicting situation. The options available for each of the game players are called strategies. The utility function is mapping into a real number of player's choices. To grasp the concepts below table 3.1 introduced, where the Player-one and Player-two come to play this game in strategic interaction.  The game is represented for ease by a matrix, called the payoff matrix, which displays the players' choice and the result for each choice that makes against the others. As seen in the game's payoff matrix between Player-one and Player-two, each must decide to choose either Accept or Reject. If Player-one chooses Accept and gets the payoff A, which means it accepts the message of Player-two to store and transmit. In the same way, the Player-two have to choose the Accept strategy to reach the NE, unless they cannot reach the NE.  In the game (**A, A**) is the NE of two players. So each node wants to have high payoffs due to that they select the best strategy. It has been every player's best behavior. The equilibrium in-game becomes perfect when the player reaches its NE.

Table 3.1 The payoff game routing matrix

| | | ***Player two*** | |
|---|---|---|---|
| | | Accept | Reject |
| ***Player one*** | Accept | **A, A** | A  R |
| | Reject | R,A | R, R |

In this model, P (A) is greater than P(R) is always true, because the payoff of cooperation is always greater than the payoff non-cooperating and maximization occurs only when they choose the best strategy of both nodes, which is cooperating. The other method to prove this solution was based on the dominant strategy. It was the best strategy for player-one and player-two separately. To reach NE the player-one dominant strategy and the player-two dominant strategy selected and when those two players strategy came in the same point that point is NE of the game. This implies as the players are rational each wants to maximize its payoff. Based on this idea each player selects the strategy (Accept) as it has a high payoff than the Reject strategy.

P (player-one) means payoff for player-one and P (player-two) is the payoff for player-two.

| | |
|---|---|
| A, A | A, R |
| R, A | R, R |

***For player-one***: P (player-one) =A if both Players select (Accept Accept) and P (player-one) =R if Player-one select (Reject) and player-two select (Accept)

So, the dominant strategy for player-one is (A) as it has a high payoff than (R).

| | |
|---|---|
| A, A | A, R |
| R, A | R, R |

***For player-one***: P (player-one) =A if Player-one select (Accept) and player-two select (Reject) and P (player-one) =R if both Players select (Reject)

So, the dominant strategy for player-one is (A) as it has a high payoff than (R).

| | |
|---|---|
| A, A | A, R |
| R, A | R, R |

***For player-two***: P (player-two) =A if Player-one select (Reject) and player-two select (Accept) and P (player-two) =R if both Players select (Reject)

So, the dominant strategy for player-two is (A) as it has a high payoff than (R).

| | |
|---|---|
| A, A | A, R |
| R, A | R, R |

***For player-two***: P (player-two) =A if Player-one select (Reject) and player-two select (Accept) and P (player-two) =R if both Players select (Reject).

So, the dominant strategy for player-two is (A) as it has a high payoff than (R).

| | |
|---|---|
| A, A | A, R |
| R, A | R, R |

Finally, the NE occurs when the dominant strategy appears at the same point (row-one, column-one). That point is the **NE**. Therefore; the NE (A, A) is proved using the dominant strategy.

## 3.9. Summary

The proposed GT-ERP motivates the nodes to cooperate. Using GT the importance of each node is maximized by the state of equilibrium inquiry. An individual player whose payout depends on the other player participated in the GT based process. The GT mechanisms activate packet forwarding nodes together with NNs. GT systems are sufficiently strong to implement a high grade of node cooperation and are involved in sending their packets. The impact of NNs was measured by giving id 1 to those nodes. The proposed algorithm was added to the original code of ERP. Modification of code was done on existing ERP within ONE Simulator to integrate the proposed algorithm.

# CHAPTER FOUR

# 4. SIMULATION AND PERFORMANCE EVALUATION

This section describes the performance comparison of the proposed solution based on the ERP with the result of simulation and evaluation performance metrics.

## 4.1. Simulation Tools

In the network environment, there are several methods available for simulation, and the most general simulation was attempted to define. Specific simulation tools are listed for selecting the best fit simulation.

### 4.1.1. NS3 Simulation Tool

NS-3 is a network simulation tool built for NS-2 as a new replacement version. A discrete, network simulator is Ns-3, which focuses on networking in research and education. To create computer network simulations users of Ns-3 can use traffic generator models, protocols like TCP or IP, and channels like Wi-Fi, and analyze or simulate the effects. Simulation plays a crucial role in the research and education process because of the ability to obtain reproducible outcomes for simulations large scale networks, wireless protocol design, and study systems not yet implemented. Ns-3 for using kernel code and actual application kernel code and actual application has the highest degree. Ns-3 funded by three NSF operates as an open-source project, and the French government through Google Summer Code support, but with much of the new contributions from interested students and researchers in the world. The figure taken from[55] shows the general architecture of NS3.

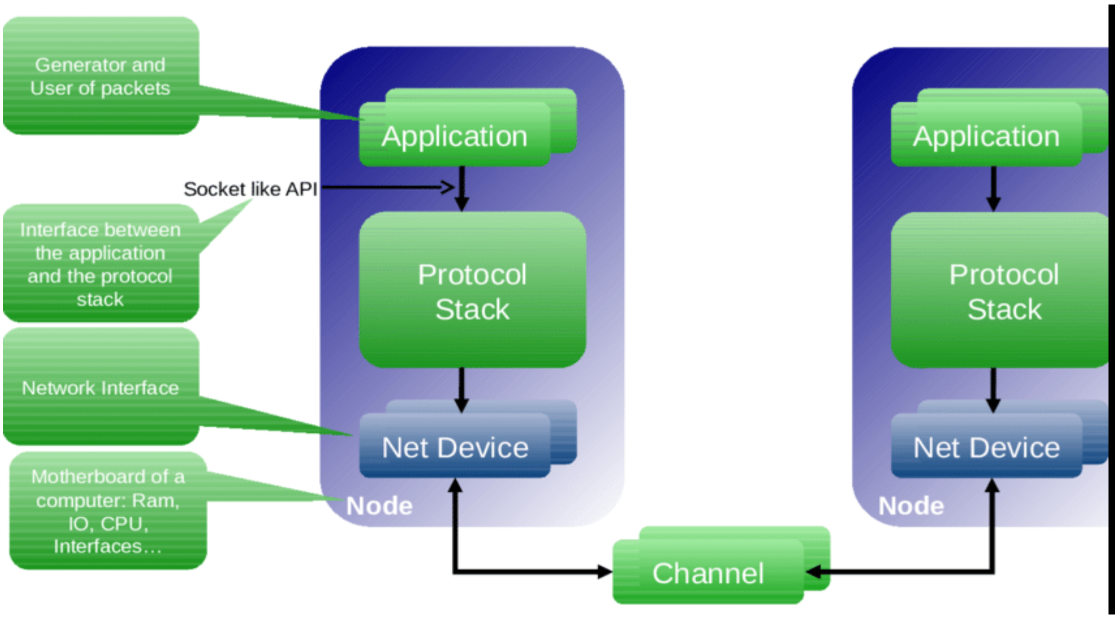


Figure 4.1 Architecture of NS3

### 4.1.2. NS2 Simulation Tool

NS2:- Version 2 of the Simulator Network tool is a tool of network simulation that is often used to study the existence of communication networks. The routing algorithm's (TCP and UDP) wired and wireless network protocol can be simulated using NS2. In general, NS2 offers users a way to define certain network protocols and to simulate their respective behaviors[56]. Otcl is the language of NS2. The figure taken from[56] shows the general architecture of NS2.

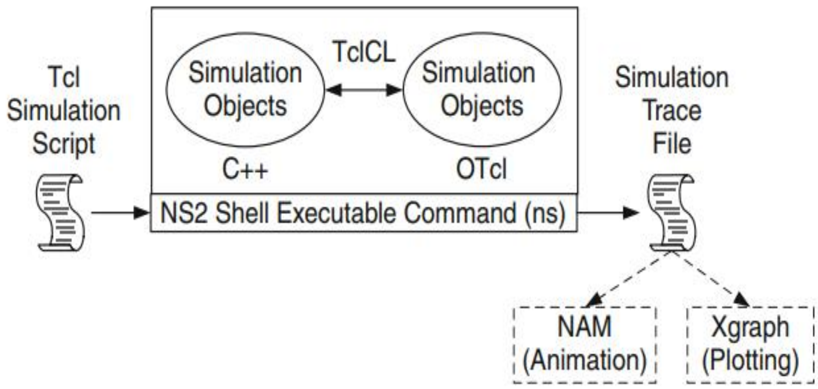


Figure 4.2 Basic Architecture of NS-2

Network simulation version 2 is a simulation tool that can get free and compatible with different platforms Linux, Windows, and MAC. But primarily it was Linux based. It can be simulated both on the Wireless network and cable network using TCL as the scripting language.

### 4.1.3. OMNET ++ Simulation Tool

OMNeT++ is one form of network simulation that has been available to the general public since 1997. The OMNET++ was formed with communication network simulation, distributed system, and multiprocessors, OMNET++ planned used as general. OMNeT++ represents the approach of a framework. The ONE can run in batch and GUI modes. The GUI mode is particularly useful for testing, debugging, and proving Uses the purposes and batch mode to run a large number of Simulations involving different parameter sets. It was developed using a component-oriented approach, which encourages structured and reusable models. OMNET++ additionally has extensive support for GUI and intelligence[57]. The figure[57] shows the structure of OMNET++.

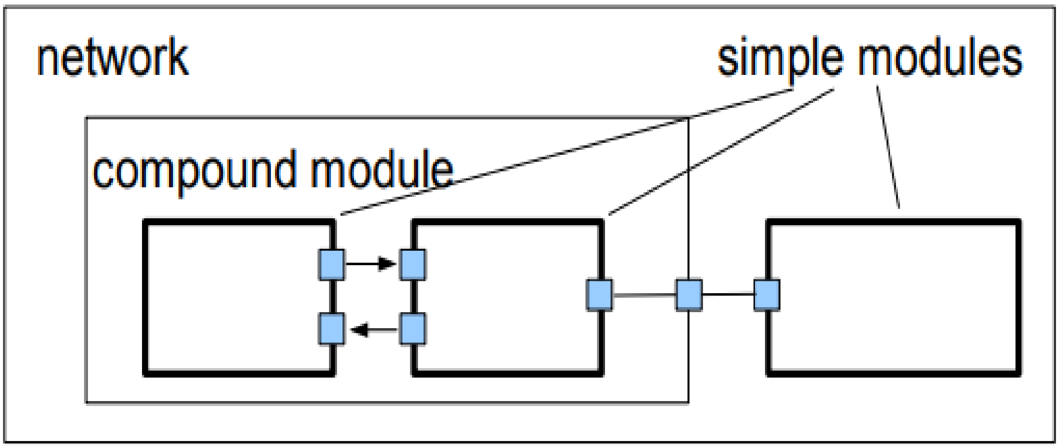


Figure 4.3 Model structure in OMNeT++

### 4.1.4. ONE Simulator Simulation Tool

ONE is a discrete, entity dependent simulation system for events. The engine updates several modules at each simulation phase which implements the main simulation functions. The ONE simulator's key functions are the movement of nodes simulation, internode communications, routing, and handling of messages.

The one has the following features:-

- Various movement models were created for nodes movement.
- Message routing among each node having different DTN routing algorithms.

➢ Mobility and message transmission within real-time in GUI was visualized.

The below figure shows the general environment of ONE Simulator[58].

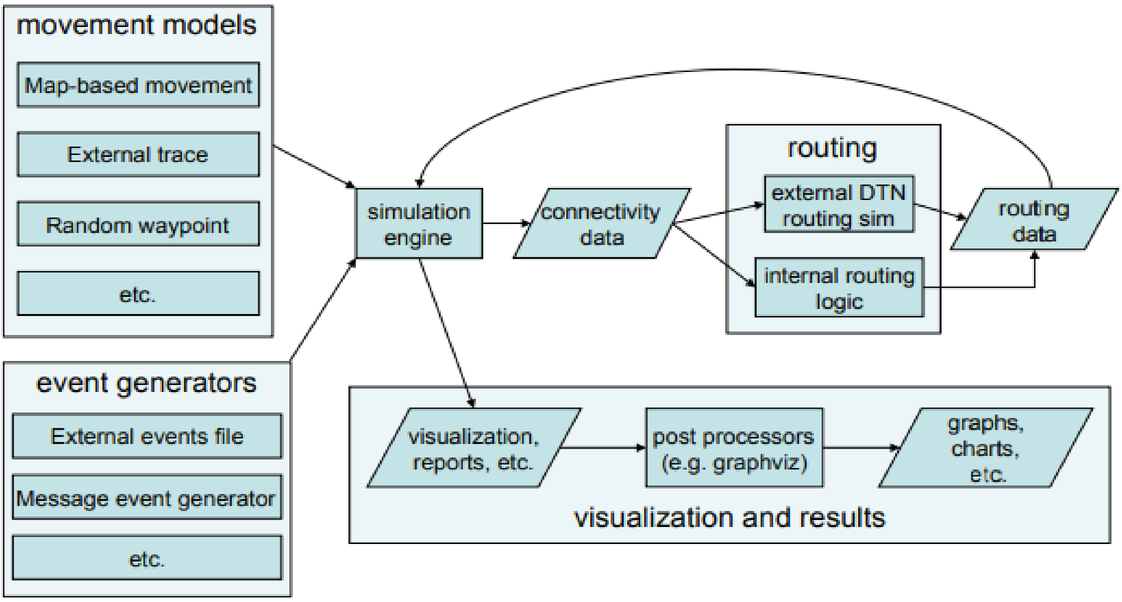


Figure 4.4 Overview of ONE simulation environments

Implementation of nodes movement capability has similarity with the routing of message capability; the ONE simulator includes a framework of rules and algorithm of DTN routing and constitutes the routing protocol of DTN.

### Comparison of Simulation Tools

Generally, different network simulation tools are described in the above concepts. Here we generalize mobility modeling, routing, and language of the tool. The below table 4.1 describes a comparison among simulation tools[59].

Table 4.1 Simulation tools comparison

| | ***Mobility modeling*** | ***Routing*** | ***Language*** |
|---|---|---|---|
| NS3 | Configuring | The new configuration needed for DTN protocols | C++ and Python |
| NS2 | Configuring | Lacks full support of DTN | C++ |
| OMNET++ | Configuring | New configuration needed for DTN protocols | C++ |
| ONE Simulator | Full support with movement model | Comes with the ready implementation of DTN well-known protocols | Java |

As described in table 4.1, the reason why we focused our simulation on ONE Simulator was that it is the best simulation tool for DTN protocols. Because it supports full routing protocols of DTN with their movement model. The other simulation tools lack full support routing protocols of DTN and need another configuration for simulating DTN routing protocols.

## 4.2. Simulation Setup and Performance Metrics

A different simulation setup was used in network simulating, to demonstrate the new algorithm into the protocol. ONE simulator supports different routing protocols of DTN than the other network simulator tools. In this simulation study the performance metrics[60][26] used for comparison of the proposed GT-ERP algorithm listed below. Based on these performance metrics we measure our proposed GT-ERP algorithm with the existing one.

- ***Delivered Packet***: Total messages number that delivered to the destination.
- ***Dropped Packet***: Messages which did not reach successfully to the destination.
- ***Delivery Ratio***: a ratio of messages that are delivered to destination nodes to the message that is generated by source nodes.

  Delivery ratio: $= \frac{\Sigma \text{ Total packet reached to the destination}}{\Sigma \text{ Total packet sends by all source nodes}}$

- ***Overhead Ratio***: Is the message ratio that forwards by all nodes to the total message generated by the source node.

$$\text{Overhead Ratio: } = \frac{RM- DM}{DM}$$

RM= Relayed message and DM= Delivered message

- ***Average Latency***: Duration average time from message created until destination node obtained. Average Delivery Latency: = Average of time (all message reach to destination).

To simulate the proposed algorithm into the original ERP including NN, the below simulation setup was used. ONE Simulator used to develop our proposed algorithm, including updated the existing module of ActiveRouter.java, EpidemicRouter.java, and MessageStatus.java. The original ERP presented with SPMM moving within the specified network area, as comparing it with the other left movement model it achieves better and uses the default map scenario Helsinki city. The message TTL was 300 minutes, nodes buffer size with 5M. The 126 nodes are randomly distributed in the simulation area 4500m × 3400m with a simulation time 43200s. The general simulation setup and parameter list[26] are described in table 4.2.

Table 4.2 Simulation setup parameters

| ***Parameters Description*** | ***Value*** |
|---|---|
| Simulation Area | 4500m × 3400m |
| Simulation Time | 43200s |
| Simulation scenario | Helsinki |
| Routing | ERP |
| Mobility Model | SPMM |
| Number of Nodes | 126 |
| Message size | 500kB - 1MB |
| Message creation interval | 25, 35s |
| Message TTL | 300 minute |
| Nodes buffer size | 50M |

## 4.3. Simulation Result

In this thesis, ONE Simulator is used to perform simulation for obtaining the desired set of results. The ONE Simulator is a DTN simulator. It is a Java-Based Simulator and runs on any platform i.e. either windows or Linux. We run our simulation on ONE Simulator which has 126 nodes including source and a destination node and having the simulation time of 43200.00s. The performance was evaluated by the above performance metrics; delivered packet, dropped packet, delivery ratio, average latency, and overhead ratio. Through the simulation run, NNs selected one randomly to behave selfishly by dropping a packet that was destined for others. A NN means a node that drop packet to save its resource. Cooperative node means node which forward packets.

A random number 0 and 1 selected by nodes to measure the effect of NN from 0 to 100. The node which selects 1 categorized under NN and the node that select 0 is categorized under cooperative nodes.

Figure 4.5 shows the GUI of our ONE Simulator with the 126 nodes. To display the below GUI of ONE Simulator scenario the one.bat was used which is presented in Appendix A.

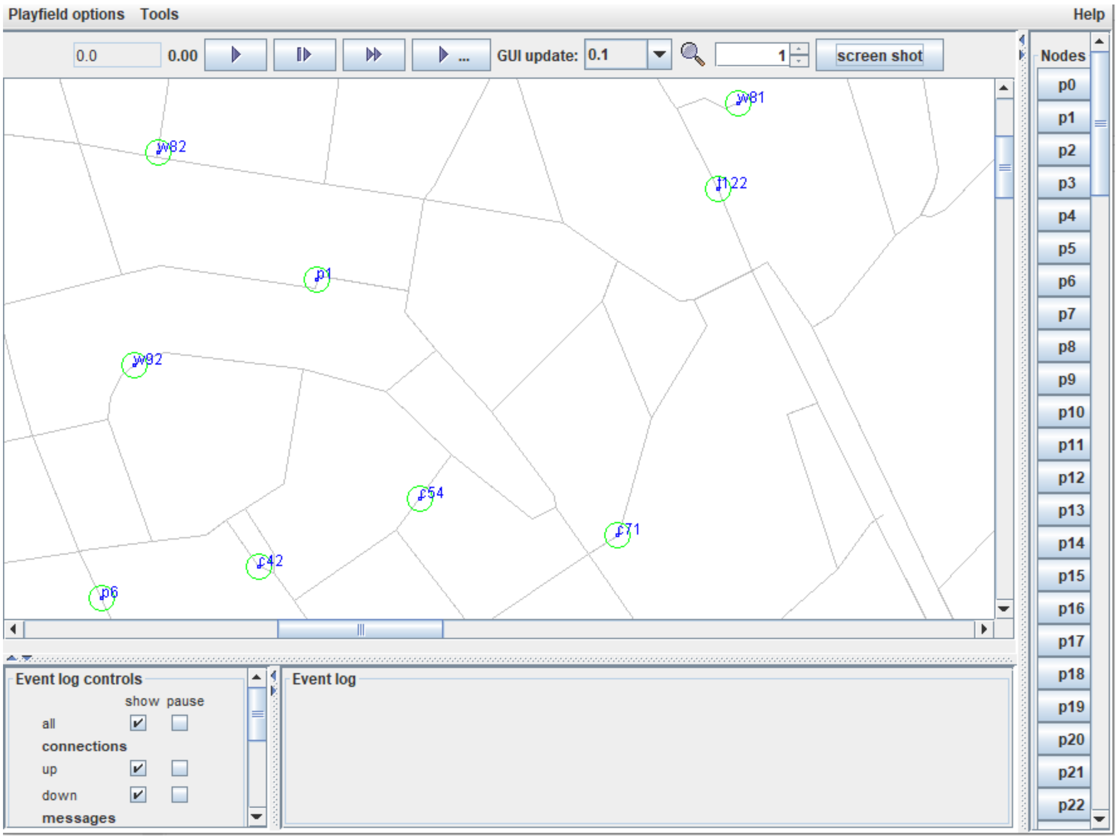


Figure 4.5 Sample GUI simulations for 126 nodes

Figure 4.6 shows a sample of our GUI after the simulation began. The red line shows the SPMM where nodes move. In this all nodes move based on SPMM, as one relay node reaches a receiver, it randomly waits for 10 to 30 seconds. Then, instead of selecting a random location for the next destination, our movement model is configured to give a new destination following a probability. Afterward, a random speed between 10 and 50 km/h is selected, and the mobile node moves there using the SPMM.

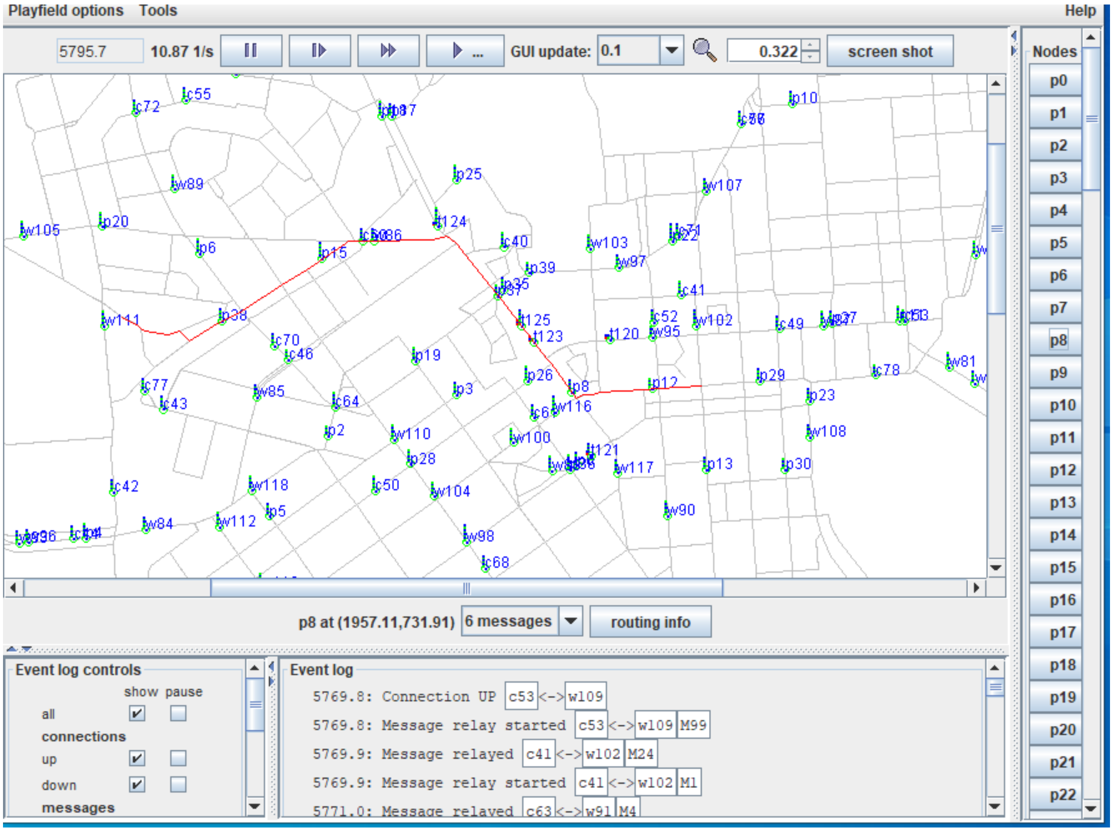


Figure 4.6 Sample GUI with nodes path

Figure 4.7 shows the movement of the nodes using SPMM. The proposed model for the nodes was also modeled on this scenario similar to the original ERP. This SPMM was modeled default by using the Helsinki Scenario.

*GUI.UnderlayImage.fileName = data/helsinki_underlay.png* // GUI underlay image settings

*GUI.UnderlayImage.offset = 64, 20* // Image offset in pixels

Each message has size [500kB - 1MB] of distributed random uniform values. The message has a TTL of 300 minutes. The information about hop count and data packet was displayed in the event log or we get the report from \the-one-1.6.0\reports directory that showed in **Appendix B**.

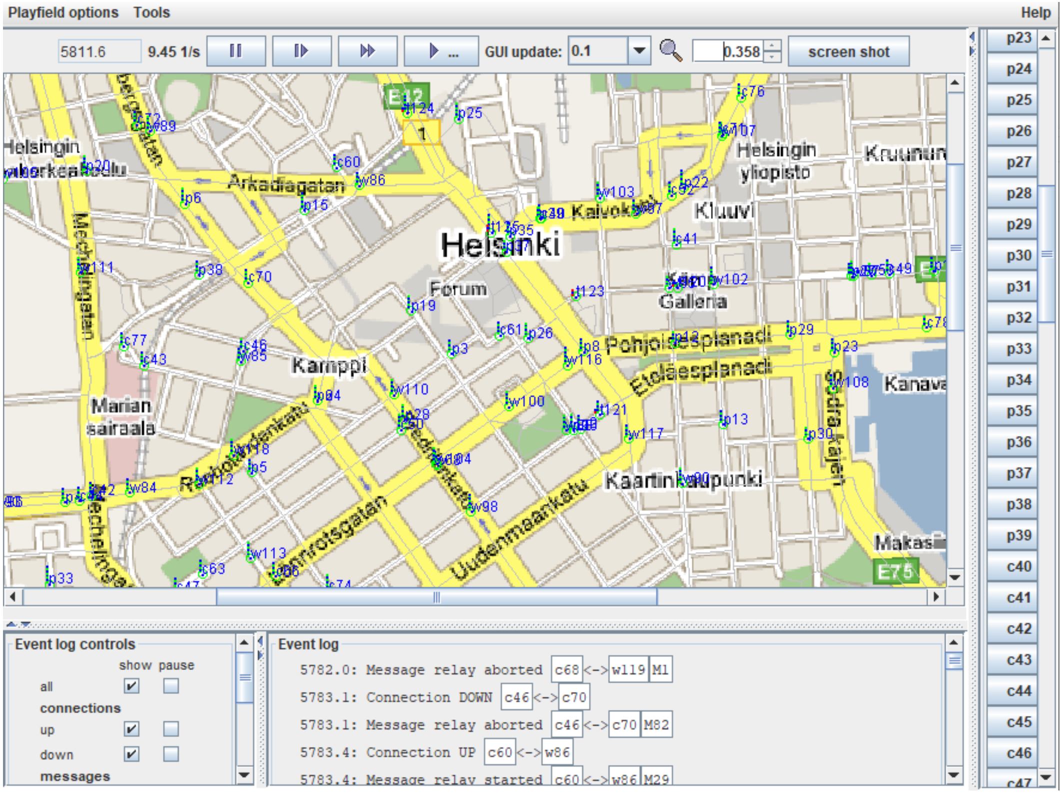


Figure 4.7 GUI Model Scenarios

## 4.4. Analysis of Simulation Result

The simulation graphs show the comparison of the original ERP with the proposed GT-ERP algorithm in the presence of NNs. The ERP has a good delivery ratio with minimum latency than other DTN routing protocols. However, the presence of NNs to this protocol results in the decreased delivery ratio as well as increase latency. The below comparison of ERP and GT-ERP was measured by increasing the number of NNs. The nodes that select 1 considers as NN and the node which selects 0 as a cooperative node. The result was measured by increasing the number of NNs. The range of NNs measured between [0,100]. More of their comparison result was described in the below section.

### 4.4.1. Comparison Result in Terms of Delivered Packets

Figure 4.8 shows the comparison of the delivered packet between ERP and the proposed GT-ERP. As the graph shows more packets were delivered to the destination in GT-ERP than the original ERP within the presence of NNs. This was because the GT-ERP has a cooperative mechanism. In this cooperative mechanism, a node agrees and finds the advantages of cooperation in the game. As shown in the figure, initially there are no NNs in the communication that means all nodes select zero, but the two algorithms have a different number of the delivered packet. This variation occurs was that in the original ERP there is no cooperative mechanism. For example when one hundred numbers of nodes select one that means almost 80% of the node becomes a NN. In the original ERP, the delivered packet was reduced from 1020 to 254 delivered packet. But the GT-ERP has a 955 delivered packet. So there is a big gap between the delivered packets of original ERP and GT-ERP, this implies that the proposed delivers more packets to the destination in the presence of NNs.

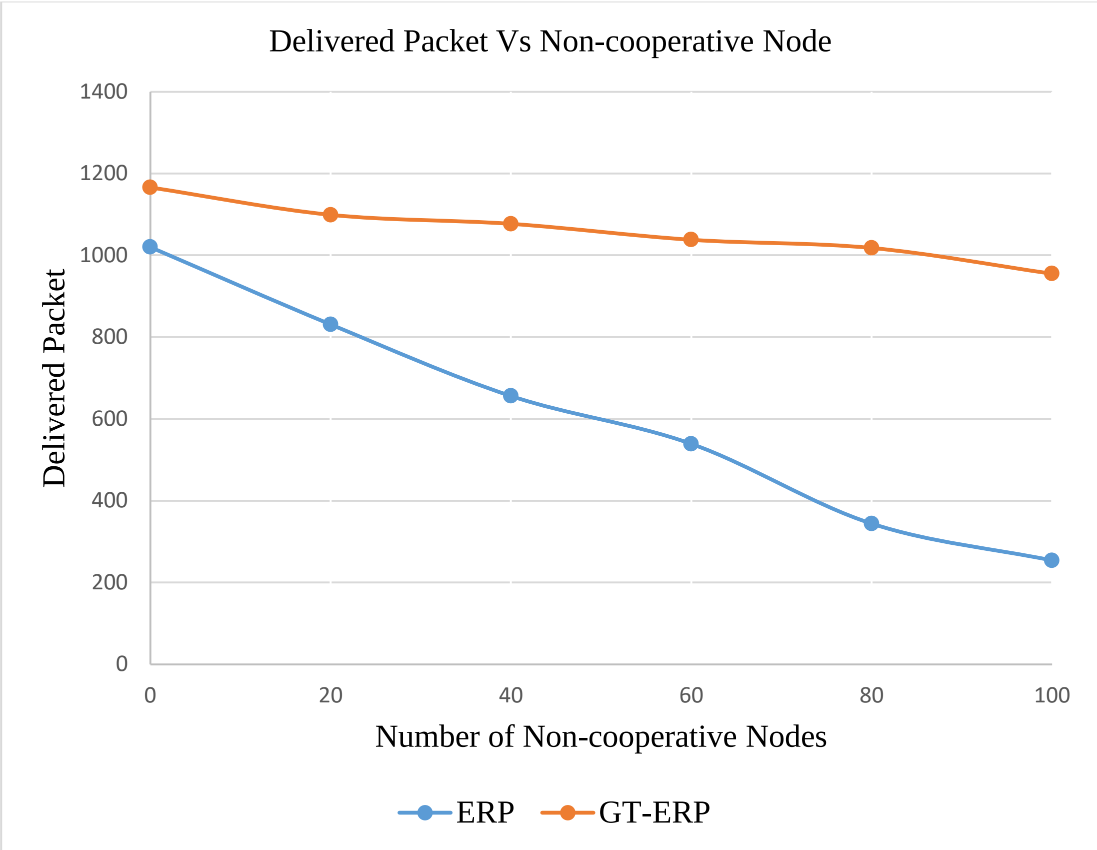


Figure 4.8 Delivered packets Vs Non-cooperative Node

### 4.4.2. Comparison Result in Terms of Dropped Packets

Figure 4.9 shows the comparison of the dropped packet between ERP and GT-ERP. As the graph shows when the number of NNs increases more packet was dropped in the original ERP than the proposed GT-ERP. This was due to in GT-ERP nodes prefer group cooperation rather than having individual benefits. The proposed was more efficient in case of their cooperation among nodes. But also there was a dropped packet in GT-ERP this was the reason for messages TTL reaches. Appendix F shows as the node's packet flow via multiple hops and it has fewer messages TTL.

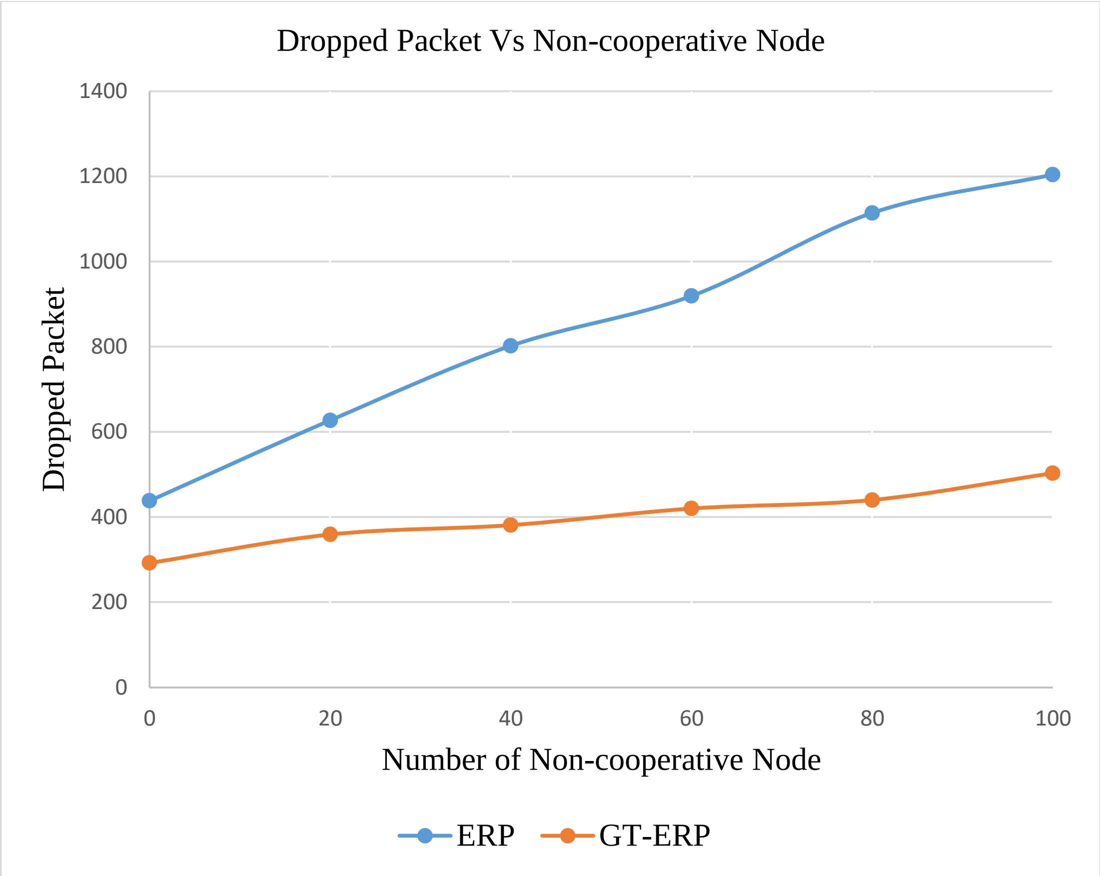


Figure 4.9 Dropped packet Vs Non-cooperative Nodes

### 4.4.3. Comparison Result in Terms of Delivery Ratio

Fig 4.10 shows the simulation results for the packet delivery ratio. The percentage of NNs through the network is varied from [0,100]. It is observed that the packet delivery ratio for ERP is 0.70 and for GT-ERP is 0.80 when none of the nodes select one as acting a NN. Further, the delivery ratio of GT-ERP decreases proportionally when the number of NNs increases. This is happening because, as the number of nodes increases the messages reach TTL. Compared with the original ERP the GT-ERP works better in situations where the NNs increase. For example, when 100 nodes select one, GT-ERP achieves a delivery ratio of about 65.5%, while the original ERP can only have a 17.4% delivery ratio. The proposed GT-ERP was better in these performance metrics.

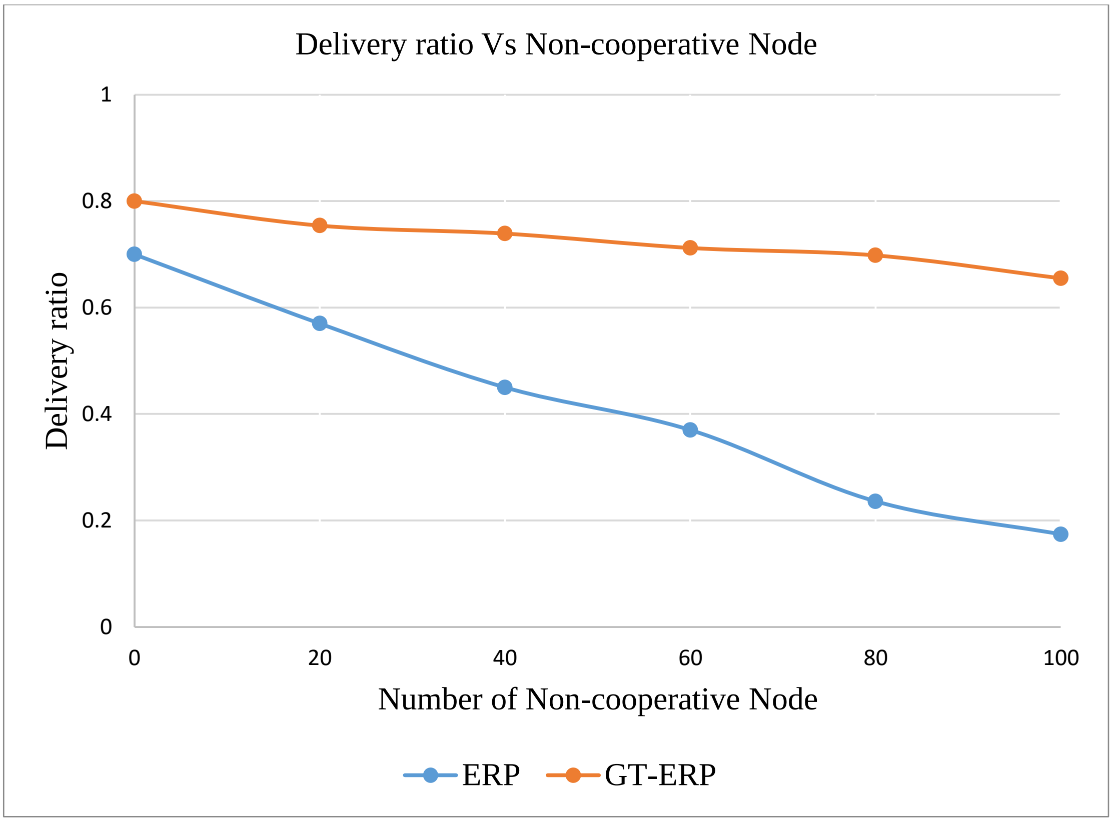


Figure 4.10 Delivery ratio Vs Non-cooperative Nodes

### 4.4.4. Comparison Result in Terms of Overhead Ratio

Figure 4.11 shows the simulation results for the routing overhead ratio of the GT-ERP and the original ERP for the different percentages of NNs. NNs percentage in the network is varied from [0-100] nodes number. It is observed that the routing overhead ratio of the original ERP is 14.05 % and for the GT-ERP it is 13.56% when no node is acting as a NN. The routing overhead ratio for the GT-ERP increases very slowly with the increase of NNs. While the routing overhead ratio for the original ERP increases faster. This is because the number of the delivered packet was less as to the relayed packet. For example, when there are 80% NNs, the overhead ratio for the original ERP increases to 24.58%. While for the GT- ERP, it is only increasing to 15.38%. Since, in the original ERP, the nodes did not implement the cooperation mechanisms.

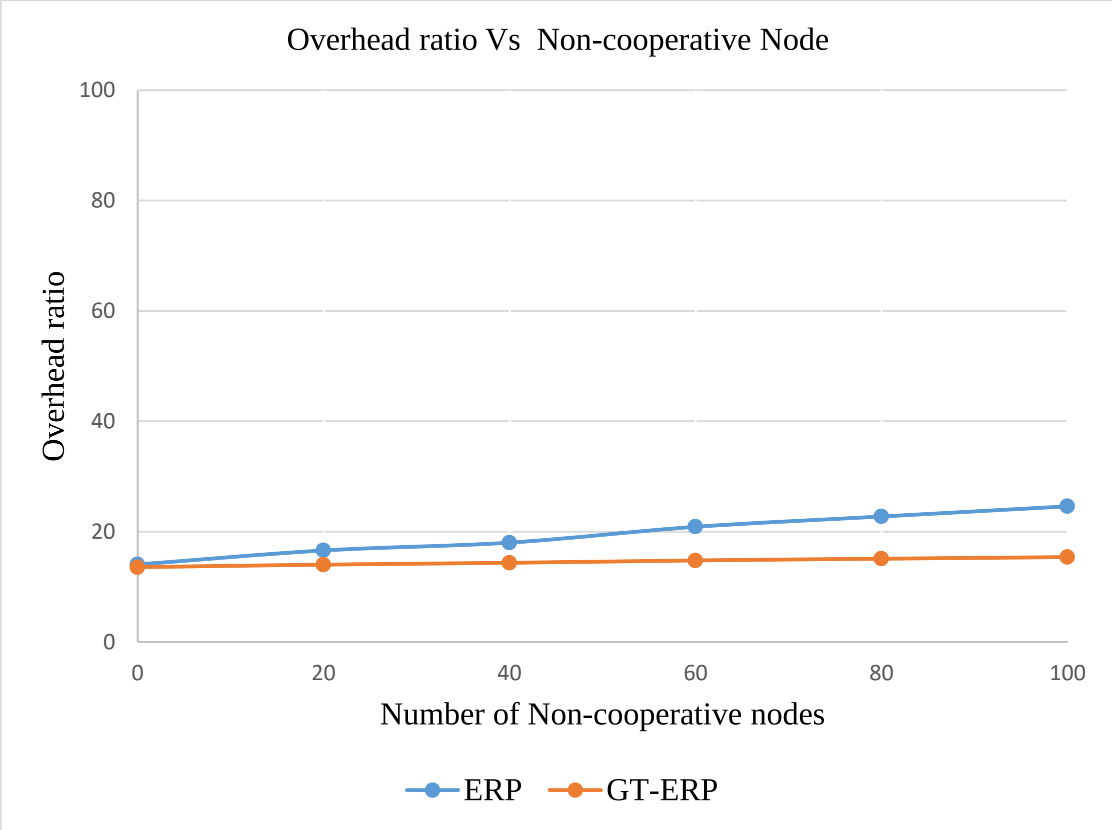


Figure 4.11 Overhead ratio Vs Non-cooperative Nodes

### 4.4.5. Comparison Result in Terms of Average Latency

Figure 4.12 shows the simulation results for the average latency of the GT-ERP and the original ERP for the different percentages of NNs. The average latency was increased in both ERP and GT-ERP. But the increase of delay was proportional to the proposed GT-ERP. In the original ERP as the number of NNs increase, nodes were not willing to forward the packet; in this, the latency was increased. In the case of proposed GT-ERP as nodes number increase the hop count also increased this leads to delays. And the other issue was that in the proposed GT-ERP the nodes select the best strategy during this process proportional latency occurred. But in comparison, the GT-ERP has a proportional increase of latency than the original ERP one.

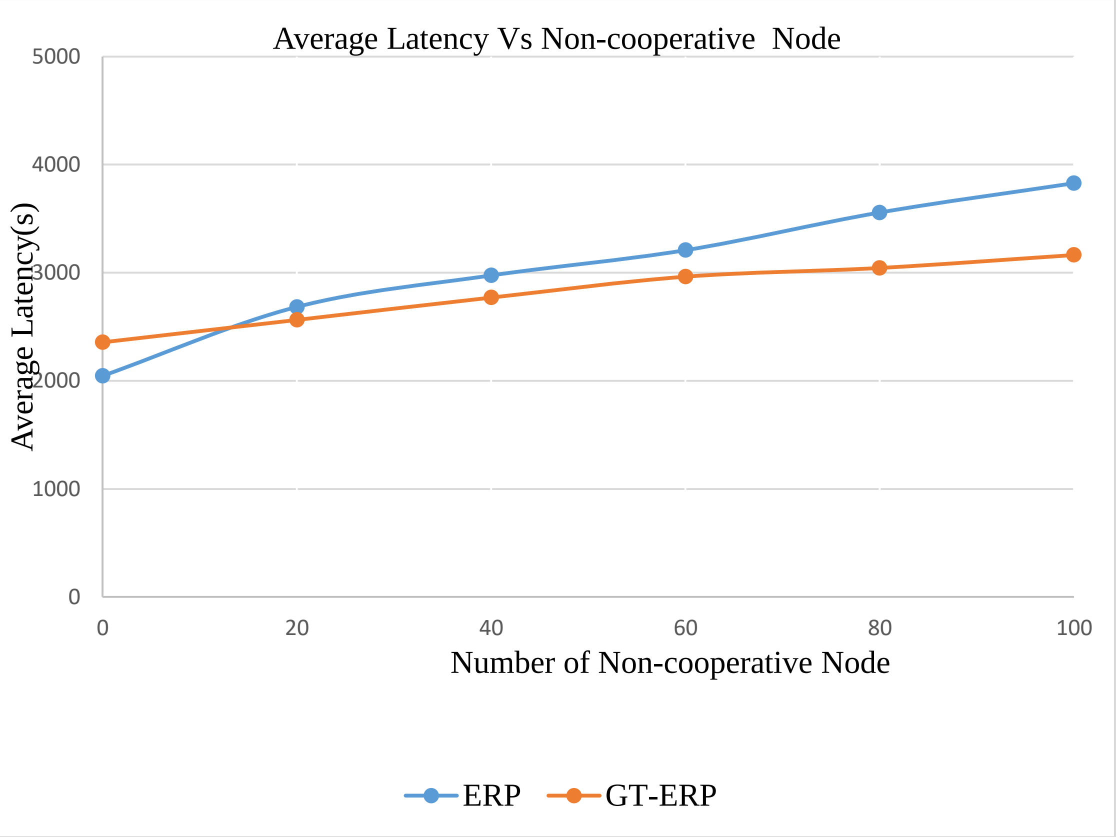


Figure 4.12 Average latency Vs Non-cooperative Nodes

## 4.5. Evaluation Result

The performance evaluation for original ERP and proposed GT-ERP is described generally in table 4.3, and the results are taken by using the average value of each parameter by running the simulation three times. The reason why we take the average value was that as nodes deployed differently and due nodes were mobile; the number of a started packet has varied. The information is taken from the simulation report directory ***E:\the-one-1.6.0\reports*** and event log of GUI. Based on the result it helps to conclude that the proposed GT-ERP improves the original ERP performance by motivating nodes to cooperate among others. The result of all performance metrics is thus proposed GT-ERP enhances the performance of ERP by reducing packet drop, increasing delivered packet, increasing delivery ratio, reducing overhead ratio, and reduce the average latency than the original ERP. The result in table 4.3 was taken as no nodes selecting id 1, which means comparing the original ERP and the proposed GT-ERP without adding a NN. This table showed as GT-ERP is computed in the original ERP, the proposed performs better. This happens due to there was a cooperation mechanism in the proposed algorithm. All those verified the proposed performs better in all measured procedure.

Table 4.3 Reports of simulation

| ***Parameters*** | ***ERP*** | ***GT-ERP*** |
|---|---|---|
| Simulation time | 43200.00 | 43200.00 |
| Created | 1458 | 1458 |
| Started | 11628 | 13553 |
| Relayed | 15351 | 16976 |
| Dropped | 438 | 292 |
| Delivered | 1020 | 1166 |
| Delivery ratio | 0.7 | 0.8 |
| Overhead ratio | 14.05 | 13.56 |
| Average latency | 2045.61 | 2356.21 |

The comparison result of both original ERP and GT-ERP is presented in table 4.5. The Table shows the result of the original ERP with the presence of NN as well as the proposed GT-ERP in the presence of a NN. From the table what we conclude was that as the number of NN increase, the delivery ratio decrease at a high rate in the case of original ERP. Also, the overhead ratio and average latency were increased in this original ERP. These were due to NNs drop message rather than transmitting it. **Appendix C** shows the event log of messages dropped by NNs in the original ERP. In the case of the proposed GT-ERP, as the result shows the presence of NNs did not affect its performance as the original ERP. What we conclude from this result was that as the number of NN increases the GT-ERP has achieved a good delivery ratio than the original ERP. The overhead ratio and average latency of GT-ERP increased proportionally. The latency was occurred due to nodes select the strategy for computing, it takes additional time but this is not as much as the original ERP with NN. The reason for the increased overhead ratio in the proposed GT-ERP was that the existence of a multi-hop path that leads the message expiration time. When the message passes via multiple-path its TTL has decreased that result in nodes to drop the message with TTL less than zero.

The algorithm 4.1 describes how the message dropped when it reaches TTL. The TTL given in the simulation was 300minutes.

Algorithm 4.1 Code of Messages TTL

| ***Messages TTL*** |
|---|
| *dropExpiredMessages()* |
| *Message[] messages = getMessageCollection().toArray(**new** Message[0]);* |
| ***for** (**int** i=0; i<messages.length; i++)* |
| ***int** ttl = messages[i].getTtl();* |
| ***if** (ttl <= 0)* |
| *deleteMessage(messages[i].getId(), **true**);* |

***For example*:** As shown below when the message pass via multiple paths its TTL was reached, which results in message dropping. When we compare M5 and M28, M5 has less TTL because it passes via multiple paths. So M5 expiration time was reached when it's TTL<=0. More of the proposed simulation message report is described in **Appendix F**.

Table 4.4 sample Message Report Status

| ***ID*** | ***From Host*** | ***To Host*** | ***Remaining TTL*** | ***Response Path*** |
|---|---|---|---|---|
| M28 | p13 | w49 | 232 | **p13**->c34->w50->c27->**w49** |
| M207 | c21 | p16 | 195 | **c21**->c29->c21->w46->p15->w41->p9->**p16** |
| M5 | p4 | p1 | 93 | **p4**->w55->p2->w59->w58->p8->w50->p9->p13->w58->p9->p15->**p1** |

Table 4.5 General Results for ERP and GT-ERP

| ***Performance Metrics*** | ***Number of Non-cooperative nodes*** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | 20 | | 40 | | 60 | | 80 | | 100 | |
| | ***ERP*** | ***GT-ERP*** | ***ERP*** | ***GT-ERP*** | ***ERP*** | ***GT-ERP*** | ***ERP*** | ***GT-ERP*** | ***ERP*** | ***GT-ERP*** | ***ERP*** | ***GT-ERP*** |
| Delivered packet | 1020 | 1166 | 831 | 1099 | 656 | 1077 | 539 | 1038 | 344 | 1018 | 254 | 955 |
| Dropped packet | 438 | 292 | 627 | 359 | 802 | 381 | 919 | 420 | 1114 | 440 | 1204 | 503 |
| Delivery Ratio | 0.7 | 0.8 | 0.57 | 0.754 | 0.45 | 0.739 | 0.37 | 0.712 | 0.236 | 0.698 | 0.174 | 0.655 |
| Overhead Ratio | 14.05 | 13.56 | 16.59 | 14.02 | 18.01 | 14.35 | 20.87 | 14.78 | 22.74 | 15.09 | 24.58 | 15.38 |
| Average Latency | 2045.6 | 2356.21 | 2683.4 | 2563.17 | 2974.8 | 2769.52 | 3208.1 | 2963.11 | 3556.8 | 3043.87 | 3827.9 | 3163.35 |

***Result summary***: As described in the above sections both the original ERP and the proposed GT-ERP simulated using a similar environment such as simulation time, number of nodes, movement model, and TTL. The proposed GT-ERP was effective than the original ERP in all measured metrics. When we measure initially without giving id 1 for nodes, the proposed was better. When nodes select id 1 to act as non-cooperative based on different degrees from [0,100] the proposed also gives better performance than the original ERP. In table 4.6 the analyzed percentage gap between both original ERP and proposed GT-ERP was presented. As shown in the table for example the delivery ratio of original ERP was decreased by 13%, when 20 nodes select id 1 to be NN. But in the case of GT-ERP when 20 nodes select id 1 to be NN the delivery ratio was decreased only by 0.046%. This verified us the proposed GT-ERP was effective in the presence of a NN as it creates a cooperative mechanism to reach NE.

Table 4.6 ERP VS GT-ERP

| ***ERP*** | | | | | |
|---|---|---|---|---|---|
| ***Performance Metrics*** | 0-20 | 0-40 | 0-60 | 0-80 | 0-100 |
| Delivery Ratio | ↓13% | ↓25% | ↓33% | ↓46.4% | ↓52.6% |
| Overhead Ratio | ↑ 2.54% | ↑ 3.96% | ↑ 6.82% | ↑ 8.69% | ↑ 10.53% |
| Average Latency(s) | ↑ 637.82 | ↑ 929.21 | ↑ 1162.53 | ↑ 1511.22 | ↑ 1782.37 |
| ***GT-ERP*** | | | | | |
| ***Performance Metrics*** | 0-20 | 0-40 | 0-60 | 0-80 | 0-100 |
| Delivery Ratio | ↓0.046% | ↓0.061% | ↓0.088% | ↓0.102% | ↓0.145% |
| Overhead Ratio | ↑0.46% | ↑0.79% | ↑1.22% | ↑1.53% | ↑1.82% |
| Average Latency(s) | ↑206.59 | ↑413.31 | ↑606.9 | ↑687.66 | ↑807.14 |

Generally, figure 4.12 describes the summarization of the above table values. The graph shows by what percent does original ERP and proposed GT-ERP decreased as the number of NN increases from [0-100]. As the graph shows there was a big difference between the original ERP and the proposed GT-ERP in all performance metrics. The graph describes as more number of NNs added to the communication, the original ERP routing performance was decreased. Those issues were handled by our proposed GT-ERP, in this algorithm nodes want to create cooperation among them. That is as described above nodes want to reach NE, the strategy to reach NE was cooperation. ***Delivery ratio:*** When NN increase from 0-20, the original ERP decreased by 13%, the proposed only by 0.046%, and as more NN existed like 100 NN the original decreased by 52.6% but the proposed only by 0.145%. ***Overhead ratio:*** as NN increase from 0-20, the original ERP decreased by 2.54%, the proposed decreased by 0.46%. And as more NN existed like 100 the original decreased by 10.5% but the proposed only by 1.82%. ***Average latency:*** as NN from 0-20, the original ERP increased by 6.37%, the proposed increased by 2.07%, and as it increases to 100 NN the original increased by 17.82% but the proposed increased only by 8.07%.

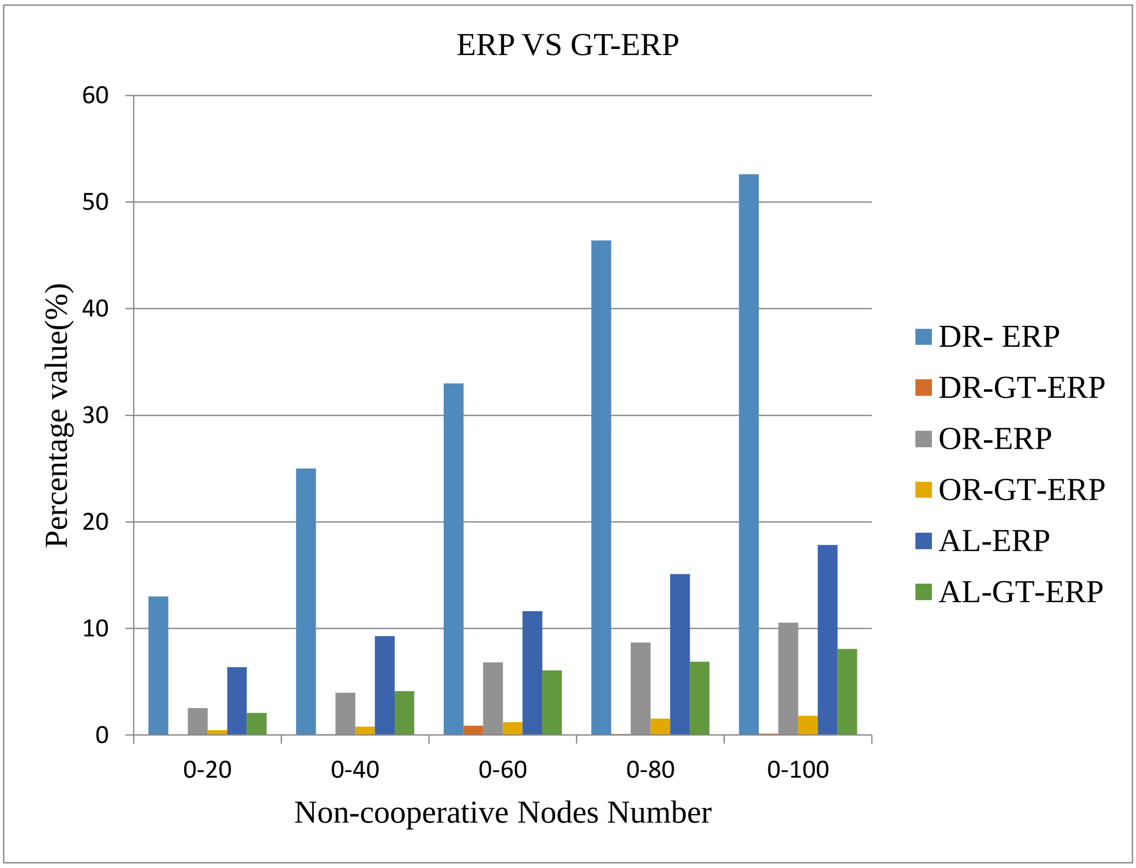


Figure 4.13 Comparison of ERP VS GT-ERP

Form graph **DR**- Delivery Ratio, **OR**- Overhead Ratio, and **AL**- Average Latency.

## 4.6. Discussion

The evaluation of the result simulated on the DTN simulation tool of ONE Simulator that the proposed GT-ERP algorithm is the best method to create a cooperation mechanism for NNs. Since initially it increases the latency due to selecting the strategy for processing. But as more NNs existed in the communication the proposed latency increased proportionally than the original ERP. The evaluation result of performance metrics which are shown in table 4.5 and 4.6 confirms that the proposed GT-ERP has the best result in all measured metrics. The three stated questions in the study were addressed based upon the result, and evaluation metrics have been done. It is discussed as the following:

The first question raises the effect of NN in the performance of ERP routing. As discussed in the related work, the original ERP not considered nodes behavior. But it was affected by the presence of this node. This study was described in section 3.4 by giving id 1 for NNs. When the nodes become NN due to different reasons like battery its performance is degraded because they drop the message rather than forwarding. Due to this the delivered packet and delivery ration decreased, dropped packet, overhead ratio, average latency increased. This affects ERP performance. Therefore, this discussion answers the first research question.

The second raised research question is about building a model to capture NN. As discussed in section 3.6 the game theory proposed to ERP. The game theory is used to create a cooperation mechanism. Here in this study, we have answered this question by proposing game theory within the existing ERP. The improvement of this method is shown in the evaluation section.

The third question raises the comparison of both in routing performance. Here, we have evaluated the performance of the proposed GT-ERP form [0-100] number of NN. As discussed in the subsection of 4.4, we have compared the proposed algorithm with the original ERP.

## 4.7. Summary

In this chapter, the objective of routing has been achieved by applying Game Theory to ERP. It was also applicable to the other DTN routing protocol to improve the performance of routing. The performance of both original ERP and proposed GT-ERP was evaluated with performance metrics of the delivered packet, dropped packet, delivery ratio, overhead ratio, and average latency within the same simulation environment. In the simulation nodes to be a NN, they select id 1 and dropped a message rather than forwarding. The effect of non-cooperativeness was measured from [0-100] NNs number. The behavior of nodes affects the performance of routing in the original ERP. Generally, the effect of the NN in the ERP is conducted by sending a data packet from source to destination, the data received by the destination node within a given time, the number of created messages, the number of relayed messages, number of delivered messages and number of dropped messages by the node.

We have studied how the GT-ERP can help the NN routing to enforce cooperation among NNs. It was that creating cooperation among nodes as they have to reach NE. This solution was advantageous for each node, as nodes are rational they decide the best strategy which helps them to achieve NE. Performance evaluation was conducted by taking simulation results three times and presented using this average value. The proposed GT-ERP shows the NNs effect on the network and creates a cooperation mechanism. So the GT-ERP delivered more packet than the original ERP by decreasing the rate of the dropped message. This improves the performance of the delivery ratio in ERP.

Finally, the proposed GT-ERP algorithm achieves better performance in taken performance metrics.

# CHAPTER FIVE

# 5. CONCLUSIONS AND FUTURE WORK

## 5.1. Conclusions

In our study, the problem of routing performance in ERP due to the presence of the NN that leads to packet dropping, and the latency of the message was solved. Different kinds of literature were reviewed to find a solution for this ERP of NN behavior. To meet our objective, the NN analyzed first and the game theory was proposed to create cooperation among nodes. The proposed GT-ERP helps the NN by creating cooperation among nodes. To create cooperation among NNs, the NE is used; never leaving the NE is the goal of every player because their payoff was increased when they reach NE. The theoretical framework for a rational node; that increases its payoff has been presented. To explore the usability of this GT-ERP, simulations are carried out using ONE Simulator.

The GT-ERP achieves better performance in all measured metrics delivered packet, dropped packet, delivery ratio, overhead ratio, and average latency in the presence of a NN. From the result of the simulation, the following remarks are made: The delivery ratio of GT-ERP decreases proportionally when the nodes number increases. But this issue was not due to NNs. As the nodes number increase, the message passes via multi-hop routing that leads to messages TTL expires.

## 5.2. Output of the Study

The output of this study was in the proposed GT-ERP the routing performance was increased in presence of a NN. First nodes can get a random number from 0 and 1. Based on that number we measure the performance of GT-ERP and original ERP. So the proposed enforces the nodes to cooperate. The proposed GT-ERP creates cooperation within the nodes. In this, the below performance metrics achieved better in all than the original ERP.

***Delivered packet***: The delivered packet was increased in the proposed algorithm

***Dropped packet***: The dropped packet decreased in the proposed algorithm.

***Delivery ratio:*** The delivery ratio was decreased in the original ERP with the presence of a NN. But in the proposed GT-ERP it was achieved by increasing the delivered packet and by reducing dropped packet.

***Overhead ratio:*** The overhead ratio was achieved better by increasing the delivered packet.

***Average latency:*** The average latency was proportional for the proposed GT-ERP, as the delay decreased by creating cooperation.

## 5.3. Future Work

The proposed GT-ERP motivates NNs to cooperate. While the issue in Game Theory was consume additional power in case of selecting their best strategy. So for the future, this issue has to be considered. And also this work was done on simulation so it is better to implement for the real environment for the future.

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**ASTU/SM-R/086/19**

**Adama, Ethiopia**

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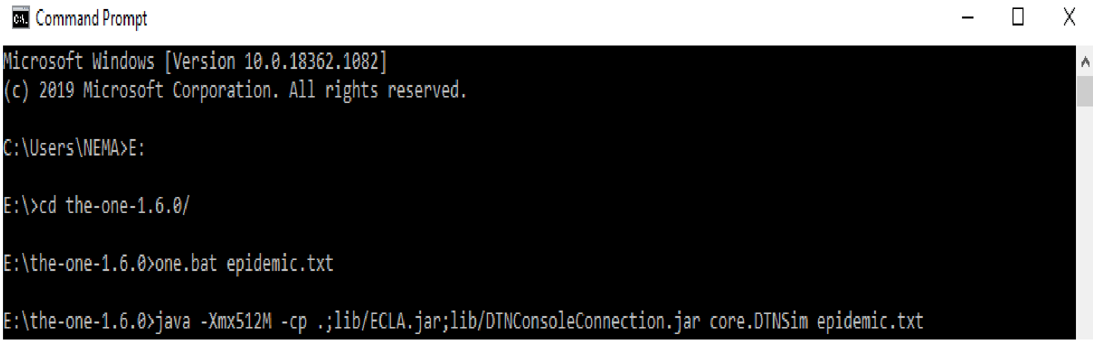
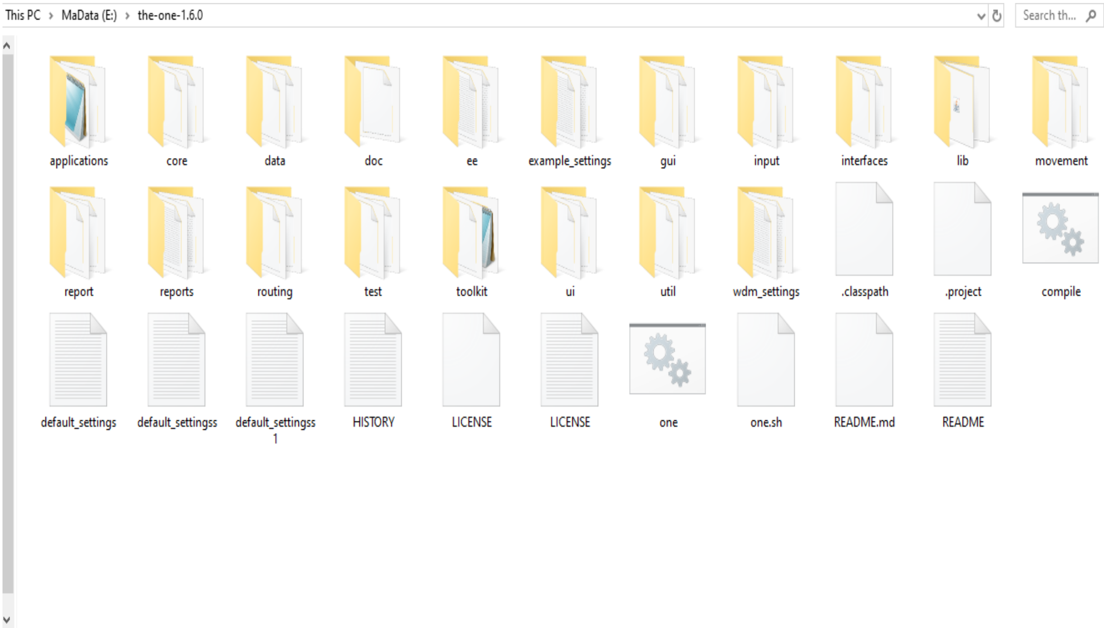
# APPENDIXES

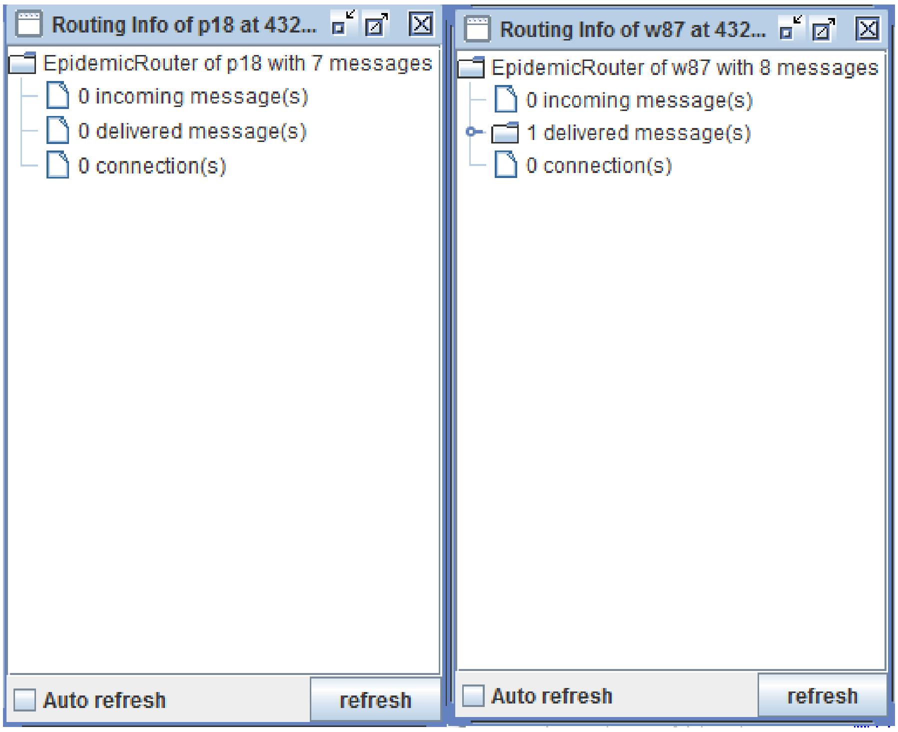
## **Appendix A:** Startup Command Prompt for ONE simulator



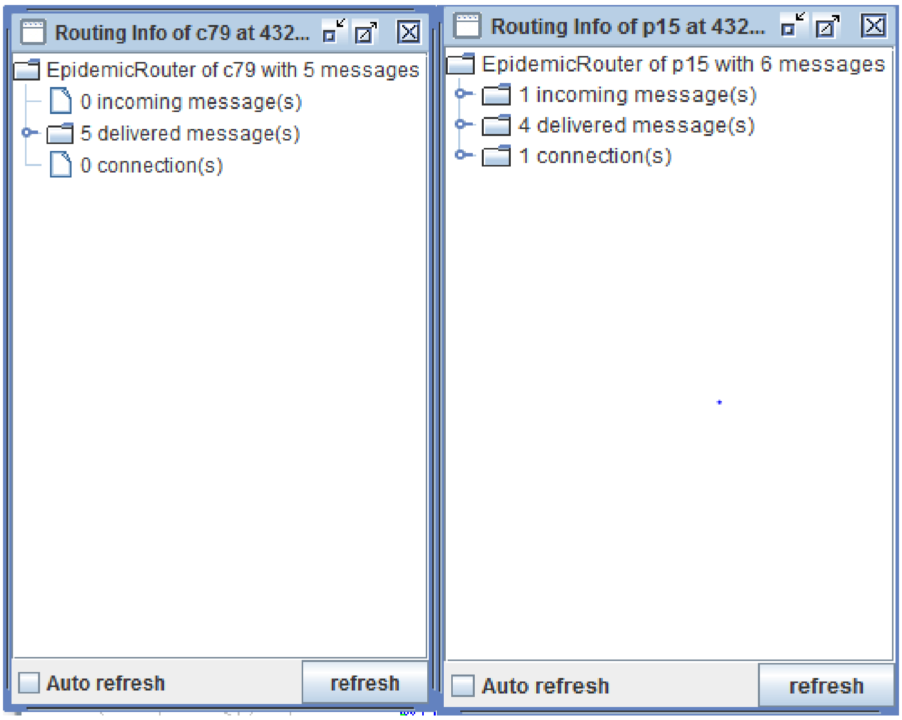

## **Appendix B:** ONE Directory



## **Appendix C:** Sample Routing Information of ERP




## **Appendix D:** Sample Routing Information of GT-ERP



## Appendix E: Message Status Source Code

**MessageStatus.java**

```
public void done() {
write("Message stats for GT-ERP " + getScenarioName() +
             "\nsim_time: " + format(getSimTime()));
double deliveryProb = 0; // delivery ratio
double averagelatencies = 0; // delay
double overHead = Double.NaN;    // overhead ratio

if (this.nrofCreated > 0) {
       deliveryProb = (1.0 * this.nrofDelivered) / this.nrofCreated;
}
if (this.nrofDelivered > 0) {
       overHead = (1.0 * (this.nrofRelayed - this.nrofDelivered)) /
             this.nrofDelivered;
}
if (this.latencies) {
       this.delays.add(getSimTime() - m. getCreationTime());
}
  String statsText = "created: " + this.nrofCreated +

       "\nstarted: " + this.nrofStarted +
       "\nrelayed: " + this.nrofRelayed +
       "\ndropped: " + this.nrofDropped +
       "\ndelivered: " + this.nrofDelivered +
       "\ndelivery_prob: " + format(deliveryProb) +
       "\noverhead_ratio: " + format(overHead) +
       "\nlatency_avg: " + getAverage(this.latencies) +
       ;

write(statsText);
super.done();

}

}
```

**Appendix F:** Delivered Message Report of GT-ERP

# time ID size hop-count delivery-Time from Host to Host remaining-TTL is Response path

445.1000 M10 863541 1 154.1000 p0 c23 297 N p0->c23

813.6000 M12 545086 1 468.6000 c27 c37 292 N c27->c37

1183.2000 M16 875016 3 719.2000 p15 c29 288 N p15->c32->w56->c29

1667.7000 M11 562047 3 1347.7000 w40 p13 277 N w40->w59->w53->p13

2272.7000 M17 790517 4 1774.7000 p2 p3 270 N p2->c26->w51->c23->p3

2336.6000 M78 861599 1 4.6000 c35 c27 299 N c35->c27

2418.9000 M6 661032 1 2248.9000 c33 p15 262 N c33->p15

2515.0000 M7 612010 2 2312.0000 c21 p3 261 N c21->c23->p3

2598.0000 M49 955987 2 1133.0000 p10 c29 281 N p10->w58->c29

2655.2000 M41 838158 3 1439.2000 p6 c21 276 N p6->p2->w59->c21

2903.0000 M76 892737 1 633.0000 w47 p6 289 N w47->p6

3017.9000 M51 797770 1 1489.9000 c30 p3 275 N c30->p3

3536.4000 M92 571438 3 778.4000 c38 c39 287 N c38->p12->p7->c39

3714.9000 M115 591925 1 275.9000 w49 c32 295 N w49->c32

3841.8000 M81 660867 1 1421.8000 w43 c28 276 N w43->c28

4048.6000 M61 640531 2 2222.6000 p19 c29 262 N p19->c20->c29

4050.9000 M59 562758 2 2281.9000 c24 c20 261 N c24->c29->c20

4053.1000 M26 546679 5 3296.1000 c33 c20 245 N c33->w42->c34->p15->c29->c20

4105.6000 M43 596711 5 2824.6000 p2 c29 252 N p2->p6->c32->c30->w46->c29

4171.4000 M135 783655 1 137.4000 c31 c26 297 N c31->c26

4188.0000 M84 745447 1 1686.0000 p4 c25 271 N p4->c25

4250.8000 M39 983915 1 3096.8000 w42 w48 248 N w42->w48

4437.3000 M38 698725 2 3316.3000 p16 c30 244 N p16->w41->c30

4440.4000 M146 807429 1 92.4000 c28 w45 298 N c28->w45

4732.3000 M139 592720 2 583.3000 p14 c21 290 N p14->p15->c21

4803.8000 M142 731013 1 567.8000 c24 c38 290 N c24->c38

4891.3000 M28 627290 4 4073.3000 p13 w49 232 N p13->c34->w50->c27->w49

4913.8000 M111 916898 3 1593.8000 p12 c32 273 N p12->p6->w52->c32

4975.0000 M126 736330 2 1211.0000 w43 c35 279 N w43->p0->c35

5088.5000 M132 591759 2 1148.5000 w45 p9 280 N w45->c34->p9

5104.2000 M21 519301 3 4495.2000 p5 p13 225 N p5->p15->c29->p13

5164.2000 M112 822553 2 1817.2000 p3 p5 269 N p3->w49->p5

5300.0000 M70 766484 3 3209.0000 c24 w49 246 N c24->c29->c33->w49

5673.5000 M29 639593 2 4821.5000 w40 c25 219 N w40->w44->c25

5700.2000 M95 561596 2 2855.2000 c27 c35 252 N c27->w50->c35

5795.9000 M176 736674 1 542.9000 p1 c35 290 N p1->c35

5798.9000 M108 735667 1 2574.9000 p1 c35 257 N p1->c35

5942.5000 M183 540776 1 474.5000 c30 c28 292 N c30->c28

5959.0000 M86 667043 4 3394.0000 w41 c22 243 N w41->w57->p10->c33->c22

5960.6000 M165 827967 1 1037.6000 w42 c29 282 N w42->c29

6053.4000 M123 753044 2 2382.4000 p19 c29 260 N p19->p4->c29

6300.4000 M72 625366 3 4148.4000 p3 w43 230 N p3->c21->c26->w43

6303.0000 M18 640222 8 5780.0000 w40 p15 203 N w40->w59->w53->c21->c28->p2->w59->p11->p15

6427.0000 M205 624107 1 306.0000 w42 c21 294 N w42->c21

6565.9000 M120 653844 2 2979.9000 w42 c32 250 N w42->w48->c32

6824.4000 M196 806351 1 972.4000 p15 p2 283 N p15->p2

6907.2000 M23 555510 2 6238.2000 w40 p14 196 N w40->p17->p14

6998.1000 M118 682174 3 3476.1000 c30 w44 242 N c30->w46->w59->w44

7079.5000 M188 639027 1 1468.5000 c25 p16 275 N c25->p16

7240.8000 M236 521246 1 189.8000 c26 w42 296 N c26->w42

7276.3000 M114 593371 3 3870.3000 c20 c24 235 N c20->c26->w48->c24

7293.6000 M40 572441 2 6109.6000 p1 p14 198 N p1->p3->p14

7377.3000 M197 572874 2 1493.3000 w46 w44 275 N w46->p6->w44

7380.0000 M90 663625 4 4689.0000 w47 w44 221 N w47->p6->w46->p6->w44

7403.9000 M211 658526 1 1103.9000 p7 p0 281 N p7->p0

7950.5000 M241 913264 2 759.5000 c26 p6 287 N c26->p0->p6

8022.1000 M13 693107 3 7643.1000 c21 w48 172 N c21->p18->p13->w48

8554.0000 M259 608758 2 814.0000 p6 p10 286 N p6->c36->p10

8608.6000 M57 601479 2 6901.6000 p18 w46 184 N p18->p13->w46

8674.4000 M237 782615 1 1596.4000 w44 p5 273 N w44->p5

8713.6000 M131 642611 4 4803.6000 c36 p10 219 N c36->c20->p18->c24->p10

8812.7000 M187 879714 3 3234.7000 p16 w47 246 N p16->w53->p17->w47

8830.5000 M83 619743 6 6353.5000 p16 p15 194 N p16->c20->p19->p4->c21->c29->p15

8989.9000 M265 939984 1 1066.9000 c26 w43 282 N c26->w43

9261.1000 M170 782141 2 4186.1000 p16 p5 230 N p16->w52->p5

9407.8000 M157 552730 6 4719.8000 w49 c27 221 N w49->w52->c33->c30->p12->c24->c27

9425.1000 M295 529544 1 640.1000 c21 w46 289 N c21->w46

9592.2000 M266 561949 1 1644.2000 p2 c38 272 N p2->c38

9948.6000 M242 824947 2 2726.6000 w43 p10 254 N w43->w56->p10

10108.4000 M117 500166 4 6611.4000 p18 w41 189 N p18->p13->w46->p15->w41

10145.5000 M223 678819 4 3477.5000 p8 c33 242 N p8->w50->p9->c21->c33

10409.4000 M270 683488 1 2351.4000 p16 c30 260 N p16->c30

10887.0000 M302 783763 2 1883.0000 p5 c27 268 N p5->p1->c27

10911.8000 M44 568074 5 9598.8000 p16 c27 140 N p16->c38->w44->p7->p17->c27

11569.8000 M372 563268 1 480.8000 w43 c39 291 N w43->c39

11572.7000 M200 713084 3 5598.7000 p12 w43 206 N p12->p13->c39->w43

11724.9000 M342 845912 1 1516.9000 p2 p13 274 N p2->p13

11907.2000 M361 672640 1 1134.2000 p16 c28 281 N p16->c28

12085.7000 M340 547278 1 1939.7000 c24 p10 267 N c24->p10

12103.3000 M253 555781 2 4544.3000 c22 c26 224 N c22->c37->c26

12153.3000 M325 714730 3 2467.3000 p2 p19 258 N p2->p5->w43->p19

12473.6000 M207 723620 7 6290.6000 c21 p16 195 N c21->c29->c21->w46->p15->w41->p9->p16

12519.8000 M420 739267 1 4.8000 p5 c38 299 N p5->c38

12554.8000 M299 969156 2 3642.8000 w43 p15 239 N w43->p1->p15

12558.3000 M5 874671 12 12414.3000 p4 p1 93 N p4->w55->p2->w59->w58->p8->w50->p9->p13->w58->p9->p15->p1

12608.4000 M358 668234 3 1930.4000 p4 p7 267 N p4->w52->c26->p7

12750.7000 M159 681657 6 8008.7000 p13 p7 166 N p13->w46->p15->w41->p9->p16->p7

12768.7000 M350 526550 3 2322.7000 c25 p12 261 N c25->p9->p8->p12

12771.3000 M393 645972 1 1065.3000 p12 p8 282 N p12->p8

12800.1000 M22 854050 5 12160.1000 p2 c23 97 N p2->p14->p19->w47->w53->c23

12832.8000 M356 770608 2 2210.8000 p9 c22 263 N p9->p16->c22

12962.7000 M395 762552 2 1199.7000 w45 c31 280 N w45->p18->c31

13075.3000 M262 530322 2 5242.3000 c27 w42 212 N c27->c26->w42

13250.5000 M247 510867 3 5875.5000 c21 c25 202 N c21->c29->c23->c25

13313.6000 M328 888857 5 3533.6000 p9 c23 241 N p9->p15->w41->p9->p16->c23

13336.4000 M443 581539 1 127.4000 c23 c33 297 N c23->c33

13688.9000 M412 891368 1 1410.9000 p10 w48 276 N p10->w48

13835.1000 M386 955676 2 2340.1000 p14 c30 260 N p14->c26->c30

13874.1000 M373 683281 3 2759.1000 c27 p12 254 N c27->w51->c36->p12

14251.0000 M456 642785 1 665.0000 c33 p4 288 N c33->p4

14275.4000 M409 524737 1 2091.4000 c33 c20 265 N c33->c20

14294.8000 M453 936984 2 791.8000 p14 c20 286 N p14->p4->c20

14387.1000 M360 519507 3 3648.1000 p1 c30 239 N p1->p4->c24->c30

14389.7000 M221 655694 5 7779.7000 p15 p19 170 N p15->c33->c23->p15->w49->p19

14484.1000 M436 875534 1 1480.1000 p9 c22 275 N p9->c22

14662.0000 M378 561579 1 3406.0000 c29 c35 243 N c29->c35

14762.1000 M416 699076 1 2375.1000 c37 c36 260 N c37->c36

14811.4000 M392 674102 2 3134.4000 p9 c25 247 N p9->p16->c25

14839.4000 M434 770793 1 1898.4000 c28 p17 268 N c28->p17

14841.5000 M349 522499 5 4422.5000 w40 p17 226 N w40->c36->c29->w47->c28->p17

14843.8000 M343 554839 3 4603.8000 w45 p17 223 N w45->p18->c28->p17

14911.7000 M490 622816 1 344.7000 c38 p5 294 N c38->p5

15013.0000 M462 616438 1 1245.0000 c37 w42 279 N c37->w42

15291.7000 M461 818460 1 1556.7000 c31 p8 274 N c31->p8

15618.3000 M516 531116 1 281.3000 c26 p12 295 N c26->p12

15660.5000 M359 598098 3 4948.5000 p12 c35 217 N p12->p6->p16->c35

15962.8000 M512 674611 2 749.8000 c35 p17 287 N c35->w59->p17

16127.4000 M455 606296 4 2566.4000 c24 c21 257 N c24->w53->w49->c37->c21

16283.2000 M537 622390 1 333.2000 c23 p8 294 N c23->p8

16308.5000 M522 721556 2 790.5000 c27 w44 286 N c27->c28->w44

16602.7000 M515 554773 3 1298.7000 p9 p2 278 N p9->w59->p17->p2

16700.7000 M476 864362 1 2533.7000 c21 c25 257 N c21->c25

16719.9000 M559 503992 1 102.9000 c31 p9 298 N c31->p9

17043.6000 M381 961193 2 5700.6000 c23 c33 204 N c23->c38->c33

17438.2000 M505 523188 1 2432.2000 c20 c32 259 N c20->c32

17670.6000 M548 711075 1 1377.6000 c37 c38 277 N c37->c38

17752.0000 M597 759143 1 9.0000 c36 p1 299 N c36->p1

17754.8000 M550 697484 1 1400.8000 c36 p1 276 N c36->p1

17757.0000 M364 549861 3 6895.0000 w45 c36 185 N w45->p18->p1->c36

18143.8000 M571 625117 1 1170.8000 c31 w41 280 N c31->w41

18166.7000 M503 627072 1 3216.7000 w43 c32 246 N w43->c32

18433.1000 M485 791217 1 4013.1000 c23 w48 233 N c23->w48

18750.3000 M547 709019 3 2487.3000 p9 c24 258 N p9->w42->p5->c24

18881.3000 M487 575094 3 4397.3000 c38 p2 226 N c38->p0->c35->p2

19105.3000 M289 720546 3 10493.3000 w47 p7 125 N w47->w53->c23->p7

19196.5000 M618 720673 1 847.5000 c23 p9 285 N c23->p9

19207.6000 M481 624020 4 4897.6000 p8 c36 218 N p8->w55->c32->c20->c36

19353.5000 M566 874078 2 2519.5000 c27 c25 258 N c27->w50->c25

19406.1000 M573 520893 3 2373.1000 c26 c20 260 N c26->w59->c22->c20

19409.2000 M588 565577 3 1932.2000 c32 c29 267 N c32->c30->p14->c29

19419.0000 M504 638869 4 4441.0000 p10 c28 225 N p10->c25->c31->p5->c28

19471.7000 M611 503655 1 1332.7000 c39 p10 277 N c39->p10

19477.8000 M543 623577 4 3341.8000 c38 p1 244 N c38->w52->p6->p11->p1

19503.4000 M632 764571 2 728.4000 p14 p13 287 N p14->p15->p13

19756.8000 M498 510629 3 4952.8000 w49 p11 217 N w49->p14->c27->p11

20077.2000 M593 546929 1 2455.2000 c31 p1 259 N c31->p1

20119.0000 M634 772807 2 1290.0000 c20 c26 278 N c20->c36->c26

20604.0000 M319 643757 5 11104.0000 w42 p15 114 N w42->c30->c26->w41->c24->p15

20631.1000 M404 603022 4 8600.1000 p9 c24 156 N p9->p12->p11->w54->c24

20650.1000 M555 584862 2 4154.1000 w44 p18 230 N w44->w56->p18

21037.9000 M606 844076 1 3049.9000 p10 p14 249 N p10->p14

21308.1000 M635 596864 3 2448.1000 p13 c26 259 N p13->w53->w57->c26

21430.4000 M713 633958 1 251.4000 c25 p10 295 N c25->p10

21475.4000 M561 608127 5 4793.4000 p9 w49 220 N p9->w42->c38->p12->w52->w49

21656.4000 M712 884716 1 506.4000 w40 c36 291 N w40->c36

21782.0000 M596 696138 1 4070.0000 p0 p9 232 N p0->p9

22120.7000 M711 907619 1 1000.7000 w42 w40 283 N w42->w40

22276.3000 M716 706803 1 1001.3000 w43 c39 283 N w43->c39

22377.0000 M728 662589 1 744.0000 p13 c27 287 N p13->c27

22958.6000 M619 566847 2 4583.6000 w48 c25 223 N w48->c39->c25

23168.6000 M689 703060 1 2700.6000 w44 p18 254 N w44->p18

23439.5000 M735 734920 3 1601.5000 w47 c39 273 N w47->w43->w56->c39

23777.0000 M752 974848 1 1435.0000 p18 c22 276 N p18->c22

23818.5000 M576 778715 4 6703.5000 p13 c21 188 N p13->w53->w57->p17->c21

24006.1000 M337 532282 6 13949.1000 c28 p9 67 N c28->w52->w59->w51->c23->c39->p9

24108.1000 M757 791190 1 1616.1000 c37 w40 273 N c37->w40

24204.3000 M792 834458 1 651.3000 c31 p14 289 N c31->p14

24211.3000 M708 618963 3 3181.3000 w42 c24 246 N w42->w40->p17->c24

24211.8000 M663 891776 1 4520.8000 p16 p11 224 N p16->p11

24460.9000 M721 821376 3 3033.9000 p0 c35 249 N p0->w40->w42->c35

24670.2000 M327 569290 6 14916.2000 p12 w47 51 N p12->p6->c30->w54->w43->c24->w47

24865.1000 M642 946094 2 5798.1000 c22 w41 203 N c22->c38->w41

24918.6000 M500 815315 7 10057.6000 c27 p16 132 N c27->c28->c38->p12->p11->c21->p0->p16

25010.7000 M714 904894 1 3803.7000 c38 w40 236 N c38->w40

25058.0000 M753 682359 3 2686.0000 w40 c24 255 N w40->c28->p19->c24

25088.9000 M793 775343 3 1502.9000 c29 p10 274 N c29->p19->p14->p10

25175.4000 M781 550776 3 1959.4000 p7 p5 267 N p7->w43->c32->p5

25208.8000 M647 522677 4 5985.8000 c36 p17 200 N c36->c22->p7->c25->p17

25353.7000 M736 517962 1 3483.7000 c22 p6 241 N c22->p6

25490.5000 M701 754957 3 4662.5000 c32 c38 222 N c32->p6->p18->c38

25494.8000 M671 714979 3 5556.8000 p19 c26 207 N p19->w57->p5->c26

25570.6000 M802 578368 2 1723.6000 c26 w43 271 N c26->c33->w43

25645.3000 M830 947894 1 922.3000 p19 p1 284 N p19->p1

25762.0000 M556 757669 5 9240.0000 p5 p9 146 N p5->c31->w51->p1->c26->p9

25775.9000 M696 668482 4 5094.9000 p13 c23 215 N p13->c38->p19->w57->c23

25908.5000 M569 670142 6 8991.5000 p2 p12 150 N p2->w53->w57->p17->c21->w41->p12

26003.9000 M810 661408 1 1908.9000 w43 c24 268 N w43->c24

26119.0000 M840 585426 1 1104.0000 p0 c23 281 N p0->c23

26167.2000 M871 715994 1 261.2000 w45 p2 295 N w45->p2

26170.1000 M655 720969 4 6709.1000 p18 p2 188 N p18->p14->c36->w45->p2

26256.7000 M795 684065 2 2611.7000 p10 c29 256 N p10->c30->c29

26353.5000 M883 879107 1 93.5000 c21 c33 298 N c21->c33

26404.0000 M700 535948 5 5609.0000 p9 c20 206 N p9->c29->p15->p2->c24->c20

26855.7000 M837 707819 2 1924.7000 p1 c35 267 N p1->c26->c35

27168.5000 M835 522247 4 2297.5000 c20 p1 261 N c20->p17->c28->p9->p1

27404.1000 M749 995086 1 5148.1000 w48 p12 214 N w48->p12

27597.3000 M776 850655 1 4538.3000 p4 p16 224 N p4->p16

27636.4000 M910 821606 2 597.4000 w48 p4 290 N w48->p12->p4

28261.3000 M882 603939 2 2031.3000 p14 w40 266 N p14->c33->w40

28445.1000 M759 913303 1 5890.1000 c37 c38 201 N c37->c38

28748.7000 M948 892966 2 589.7000 c30 w44 290 N c30->w42->w44

28817.2000 M919 554139 1 1508.2000 c27 w46 274 N c27->w46

28945.5000 M892 781341 1 2435.5000 c37 p9 259 N c37->p9

28974.3000 M870 534184 3 3096.3000 p5 p8 248 N p5->w48->w50->p8

29273.1000 M872 503056 1 3339.1000 c36 p1 244 N c36->p1

29499.5000 M738 541236 3 7572.5000 c22 c35 173 N c22->w46->p15->c35

29731.5000 M688 663004 2 9295.5000 c20 c31 145 N c20->c23->c31

29885.9000 M850 519920 2 4580.9000 c36 p14 223 N c36->w56->p14

30221.6000 M824 610580 2 5699.6000 p5 p6 205 N p5->w48->p6

30711.5000 M944 830606 1 2662.5000 w47 c34 255 N w47->c34

30731.9000 M1004 934398 1 900.9000 p13 c33 284 N p13->c33

30882.7000 M959 863681 2 2406.7000 w48 p8 259 N w48->p6->p8

30904.9000 M772 507255 5 7960.9000 w44 w48 167 N w44->c35->c32->c36->c26->w48

30908.4000 M945 867778 1 2832.4000 w48 c26 252 N w48->c26

31008.9000 M861 606516 5 5391.9000 c24 c39 210 N c24->w53->p7->w40->p12->c39

31339.9000 M502 579959 6 16418.9000 c29 p6 26 N c29->w55->w44->c25->p10->c28->p6

31392.9000 M699 520666 3 10627.9000 c24 c31 122 N c24->p2->c39->c31

31452.0000 M1046 615185 1 379.0000 c27 c35 293 N c27->c35

31700.3000 M927 708896 4 4162.3000 p7 c31 230 N p7->p17->c25->w52->c31

31820.0000 M666 637227 3 12036.0000 w48 c30 99 N w48->p12->w55->c30

31852.4000 M946 557787 2 3751.4000 c28 c39 237 N c28->w55->c39

32183.8000 M1071 530781 2 356.8000 p2 c35 294 N p2->w54->c35

32317.4000 M833 851872 4 7503.4000 c27 c24 174 N c27->w52->w59->w58->c24

32406.5000 M687 756105 2 12001.5000 c37 p11 99 N c37->w58->p11

32449.0000 M1033 662474 1 1753.0000 c32 w40 270 N c32->w40

32638.7000 M797 635332 7 8933.7000 p11 p17 151 N p11->p0->c27->w45->c29->p5->c30->p17

32829.0000 M584 647598 6 15474.0000 w44 w43 42 N w44->w46->w55->w57->c25->c20->w43

32927.7000 M821 750676 7 8499.7000 w41 w40 158 N w41->p12->p0->c27->w45->c31->p15->w40

33062.8000 M965 780054 4 4392.8000 p7 p5 226 N p7->w40->c26->p14->p5

33159.4000 M888 505874 3 6769.4000 p15 p13 187 N p15->c31->c36->p13

33635.5000 M1045 637029 3 2588.5000 c32 w46 256 N c32->w58->c27->w46

33692.6000 M875 726314 4 7667.6000 c24 c37 172 N c24->p11->w53->w54->c37

33725.5000 M1114 795428 1 662.5000 w47 p2 288 N w47->p2

33757.5000 M1091 866071 1 1354.5000 c25 p5 277 N c25->p5

33892.0000 M814 584284 6 9677.0000 c39 c38 138 N c39->w58->p1->c32->c26->p10->c38

34236.0000 M1109 548160 2 1307.0000 w40 p11 278 N w40->c24->p11

34359.9000 M1083 803224 1 2183.9000 c26 p2 263 N c26->p2

34371.5000 M1111 552288 2 1386.5000 p14 c27 276 N p14->p5->c27

34693.7000 M1144 733617 1 762.7000 p12 p6 287 N p12->p6

34982.9000 M1103 713637 2 2219.9000 p16 p5 263 N p16->w40->p5

35166.6000 M1124 526911 1 1807.6000 w46 p7 269 N w46->p7

35542.7000 M807 671353 6 11535.7000 p5 c29 107 N p5->w48->w50->p3->p12->w57->c29

36143.9000 M846 990355 4 10956.9000 p7 c36 117 N p7->c26->w50->w49->c36

36150.3000 M991 525852 4 6699.3000 c29 p17 188 N c29->c25->c23->w53->p17

36200.2000 M1158 996513 1 1858.2000 p10 p17 269 N p10->p17

36806.5000 M977 648063 3 7760.5000 c23 p8 170 N c23->c39->w52->p8

36821.5000 M1085 552572 3 4590.5000 c23 p6 223 N c23->c29->c31->p6

36854.1000 M1047 525013 5 5749.1000 p3 p18 204 N p3->w42->w50->p3->w40->p18

37077.0000 M1209 577625 1 1253.0000 c27 c33 279 N c27->c33

37110.6000 M925 818455 5 9624.6000 w48 p17 139 N w48->w50->w49->p4->p8->p17

37263.4000 M1168 840764 2 2629.4000 p11 c27 256 N p11->c35->c27

37611.4000 M1176 707001 2 2746.4000 p13 p16 254 N p13->w45->p16

37683.5000 M1097 534941 4 5084.5000 p16 p17 215 N p16->w40->p5->w56->p17

37820.0000 M832 590014 9 13035.0000 p3 p16 82 N p3->p10->c33->c23->w57->w51->w58->p11->w43->p16

38186.1000 M1093 562916 6 5720.1000 c25 w49 204 N c25->c23->c32->c33->w56->w42->w49

38499.2000 M1289 582527 1 260.2000 c26 p13 295 N c26->p13

38673.6000 M1296 648740 1 227.6000 c35 c39 296 N c35->c39

38797.5000 M1246 775998 1 1879.5000 c37 w43 268 N c37->w43

38838.9000 M1008 558090 5 8883.9000 w43 p0 151 N w43->c30->c23->w57->c34->p0

38858.0000 M1157 809019 3 4549.0000 c30 c28 224 N c30->w53->w57->c28

38939.5000 M1231 767839 1 2462.5000 p9 c29 258 N p9->c29

39227.2000 M1052 599247 3 7976.2000 c22 c25 167 N c22->c24->p6->c25

39266.8000 M1082 611082 4 7118.8000 c22 c27 181 N c22->c35->p11->w51->c27

39375.5000 M1061 544186 8 7850.5000 p16 p0 169 N p16->w40->p5->w40->p3->p17->w52->w46->p0

39421.9000 M1306 617099 1 670.9000 c32 c28 288 N c32->c28

39498.9000 M1307 856610 1 719.9000 c26 p6 288 N c26->p6

39624.6000 M1160 624686 3 5219.6000 c27 w42 213 N c27->w53->w50->w42

39725.3000 M1332 821319 1 227.3000 p19 c23 296 N p19->c23

39954.4000 M1344 913656 1 121.4000 p15 c26 297 N p15->c26

40136.3000 M1339 648221 1 446.3000 p2 w44 292 N p2->w44

40404.1000 M1362 700817 1 38.1000 c21 p19 299 N c21->p19

40509.4000 M1271 605312 1 2830.4000 p9 c26 252 N p9->c26

40583.9000 M1146 527370 3 6592.9000 c20 c22 190 N c20->p16->c29->c22

40612.1000 M1290 506582 3 2346.1000 w46 c22 260 N w46->p0->c26->c22

40686.2000 M1229 590618 1 4265.2000 w49 c38 228 N w49->c38

41284.1000 M1126 858739 3 7865.1000 p0 c28 168 N p0->p12->p13->c28

41359.8000 M1268 868434 4 3773.8000 c32 p10 237 N c32->w52->w42->w49->p10

41389.4000 M1186 753303 3 6241.4000 p0 c35 195 N p0->p12->p13->c35

41544.5000 M1376 704490 1 761.5000 c35 w48 287 N c35->w48

41655.0000 M1388 918296 1 522.0000 p5 p4 291 N p5->p4

41846.3000 M1243 615461 3 5019.3000 c39 c30 216 N c39->w53->c23->c30

41948.1000 M1145 550915 4 7985.1000 p13 p2 166 N p13->w45->c33->p12->p2

41964.5000 M1298 944472 2 3456.5000 p8 w40 242 N p8->w57->w40

42056.3000 M1260 863405 2 4715.3000 p9 p3 221 N p9->c25->p3

42299.8000 M1282 803507 4 4276.8000 c31 c34 228 N c31->w54->p10->p17->c34

42452.3000 M1273 608474 4 4710.3000 w42 p6 221 N w42->w49->p13->c37->p6

42472.3000 M1034 807481 6 11750.3000 c30 c37 104 N c30->c20->p16->p7->p0->w52->c37

42568.7000 M1391 526666 1 1342.7000 p9 c38 277 N p9->c38

42842.3000 M1328 970948 2 3464.3000 c26 w48 242 N c26->c22->w48

42861.8000 M1425 549783 2 654.8000 w45 w43 289 N w45->p9->w43

43026.9000 M1417 789502 2 1055.9000 w41 p15 282 N w41->w40->p15

43076.9000 M1342 578489 5 3305.9000 c21 c29 244 N c21->w56->w50->p3->p14->c29