EFFICIENT INCENTIVE-BASED ROUTING IN DTN USING COALITIONAL GAME THEORY

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of degree of

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in

COMPUTER SCIENCE & ENGINEERING

By

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Declaration

I declare that the work presented in this dissertation with title, "**Efficient Incentive-Based Routing in DTN Using Coalitional Game Theory**", towards the fulfillment of the requirements for award of the degree of **Master of Technology** in **Computer Science & Engineering**, submitted to the **Department of Computer Science and Engineering**, **Indian Institute of Technology-Roorkee**, India, is an authentic record of my own work carried out during the period from **June 2015 to May 2016** under the guidance of **Dr. Vaskar Raychoudhury**, Assistant Professor, Department of Computer Science and Engineering, Indian Institute of Technology, Roorkee.

The matter presented in this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

Date:

Place: Roorkee **(Deepak S)**

Certificate

This is to certify that the statement made by the candidate in the declaration is correct to the best of my knowledge and belief.

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Place: Roorkee

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ABSTRACT

Delay Tolerant Networks(DTNs) differ from the traditional Ad-hoc networks in its main characteristic function. DTNs are opportunistic networks in which there exists no complete end to end paths between the nodes. In view of the limited connectivity, DTNs rely upon the store carry and forward approach for communication. DTN is a well researched topic and finds large number of applications in daily life. The applications of DTN vary from space communication, smart city application to wildlife study. With the need of a working robust and efficient communication network in areas of limited connectivity, DTNs belong to the most sought and researched topic in networks.

The study of behaviour of DTN nodes has been considered as a good area in DTNs by many of the researchers. Nodes may not always behave rationally and in a cooperative manner for network efficiency. Some of the network nodes may act selfishly to spend its resources such as buffer space or energy, for message transfer. These unwanted activities of the nodes hamper the smooth working of the network. With appropriate incentive, Tit-For-Tat (TFT) and game theoretic approaches these negative aspects of DTN nodes could be nullified. In this work, focus has been given to present a protocol based on coalitional game theory. Selfishness are induced on the basis of message drop, hence buffer space of a node plays as a good parameter in efficiency.

Game theory has been identified and applied as a potential conflict resolution candidate in communication networks. Coalition game theory targets those problems in which the players of

the game group together, achieve the intended aim and share the reward points among themselves. Among different solutions existing in coalitional game theory for the reward division, the *Shapley value concept* emerges as a plausible concept providing appropriate shares to the players. In the proposed research work, coaltion game formation with shapley value credit division is implemented. Also the idea of grand coalition is discussed and simulated for comparison.

A new routing protocol incorporating the idea of encounter history, named as *Encounter protocol*, is proposed. Relay selection is based upon the coalition game theory and the credit division, for avoiding selfishness, is implemented according to Shapley value. Extensive simulations have been performed as a part of the work. Comparisons have been made to existing benchmark algorithms which throw light upon the protcol's efficiency. Also by simulating two selfishness based protocols, the proposed work shows better efficiency and implementation capability in the current scenario. To provide a better comparison covering wider aspects, a less used comparison criteria, energy dissipation, is also included as a part of the research work.

Acknowledgements

I would never have been able to complete my dissertation without the guidance of my supervisor, help from friends, and support from my family.

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CHAPTER 1

INTRODUCTION

Delay Tolerant Networks or Disruption Tolerant Networks(DTNs) [1] are adhoc networks which provides communication in highly stressed and disconnected environment where a dedicated path between all the nodes is unavailable . The intermediate nodes will store the received message, carry it with them and finally forward to other DTN nodes so that they are successfully delivered in such networks. They provide a provision for communication in the absence of network infrastructure. The characteristic features of DTN are low delivery ratio, high delivery delay and large periods of network disconnection. The use of DTNs in metro cities has been of recent attention. In future, smart cities may be realized with new technologies under the DTN platform. The use of portable smart devices prove to be a deciding factor in the usage of DTN in an urban environment. They are also widely used in space communication, vehicular communication, mobile adhoc networks, wildlife traffic, etc. All these applications make DTN a good candidate for extensive research study to work upon the various challenges faced in implementing it with ease. Among different challenges, the work deals with node selfishness and irrational behaviour and ways to minimise or mitigate the negative effects. Game theoretic approaches have been found to be applied in different areas of wireless sensor networks and other mobile adhoc applications. The work intends to study in detail coalitional game theory and induce cooperation among the DTN nodes to achieve better efficiency in terms of higher delivery, lower latency and lower energy consumption.

1.1 Delay Tolerant Networks

DTNs are also called opportunistic networks in which message forwarding takes place according to the opportunity available to the network nodes. It does not follow the traditional routing protocols and is based on "*store carry and forward"* approach. The intermediate nodes in the network store the messages till it finds an opportunity to forward the message in the network path. With respect to MANETs, DTNs share a lot of comparisons such as infrastructure unavailability, resource constraints etc. MANETs communicates using TCP/IP protocol whereas DTNs communicate using application bundle layer protocols. These bundle layer protocol span across network and transport layers. The nodes contain buffer space required for storing messages, which may be required for a long time till the apt relay node is selected. As DTNs use bundle layer, the messages can also be referred to as bundles. Therefore, the terms bundle, data, message and packet are used interchangeably in this dissertation. Fig 1.1 shows the snapshot of DTN at three different times t1, t2, t3. As inferred from the figure, there exists no complete path between the source node and destination. A node may suffer from large delay while sending message to another node in the network. The pair of nodes transferring data needs to be in communication range with each other. In a DTN there exists no guarantee that the two nodes will be in communication range permanently.

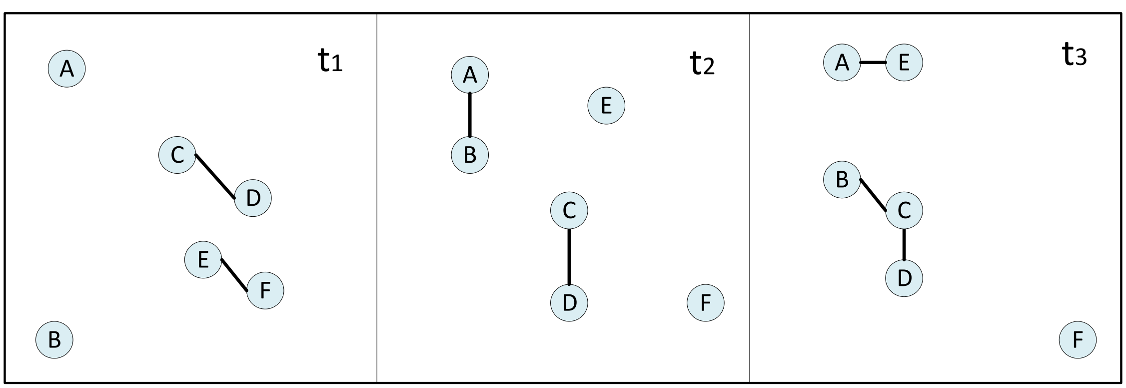


FIGURE 1-1 DTN ROUTING SCENARIO

DTN routing protocols may be classified based on how these protocols replicate messages, those that do not replicate messages may be classified as forwarding based whereas those that do as replication based. Forwarding message based protocols although utilises and conserves network resources is inefficient as it does not provide necessary message delivery rates whereas replication based protocols do the opposite. There are various replication based protocols such as epidemic routing [2], PRoPHET [3],Spray and Wait [5], MaxProp[4] , RAPID [7] and BubbleRap [6].

DTNs are meant for challenging environments which are characterized by high latency, bandwidth limitation with large error probability and path instability. Queuing times are large comparatively with conventional networks where it rarely exceeds a second. As such routers are required to store messages over a long period. In such an environment the link capacity is always of importance and hence the appropriate security for usage of link should be provided.

- Performance Metrics of DTN

    - Delivery Ratio : It is defined as the total number of messages delivered to total number of messages generated at the nodes. The efficiency of a forwarding scheme is determined by this metric. High delivery ratio implies good relay selection and maintenance of ample copies of messages in the network.

$$\text{Delivery ratio} = \frac{\text{No.of msgs delivered}}{No.\ of\ msgs\ generated}$$

    - Delivery latency : It is defined as the average time taken to deliver a message from the source to destination. It measures efficiently how the intermediate paths are selected from source to destination. Delivery latency can be low if the relay node selection is efficient.

    - Overhead Ratio : It is defined as the ratio of difference between the total number of relayed nodes and delivered messages to the total number of delivered messages.

$$\text{Overhead ratio} = \frac{\text{No.of relayed msgs} - \text{No.of delivered msgs}}{\text{No.of delivered msgs}}$$

    - Energy dissipation : Energy as a metric is not usually considered in most of the research works . But in the new era of low power consumption, the metric is pretty useful in comparison. Energy dissipation is defined as the amount of energy dissipated per unit message delivered.

$$\text{Energy dissipated} = \frac{\text{Total energy dissipated}}{\text{No.of delivered msgs}}$$

DTNs find variety of applications ranging from space communication, smart cities, crisis management, wildlife etc. Some of the important applications of DTN are as follows:

- DakNet [8]:- The project is developed by MIT media lab aimed at providing energy efficient facilities at low cost. It's successfully deployed in the areas of India and Cambodia. The project is based upon wireless communication with asynchronous services to connect a particular remote village to nearby towns or cities. It consists of kiosks, MAPs (Mobile Access Points) with portable storage and facilities for internet access. MAPs are mounted on top of vehicles- bus,cars,bicycles. MAP transports data from a hub to rural kiosks and vice versa (non real time internet access). MAP on reaching with proximity with the kiosk, transfers data to them. Also when MAP comes within contact with the hub it transfers the data to hub installed in the town. Thus these MAPs act as data mules in the whole network.

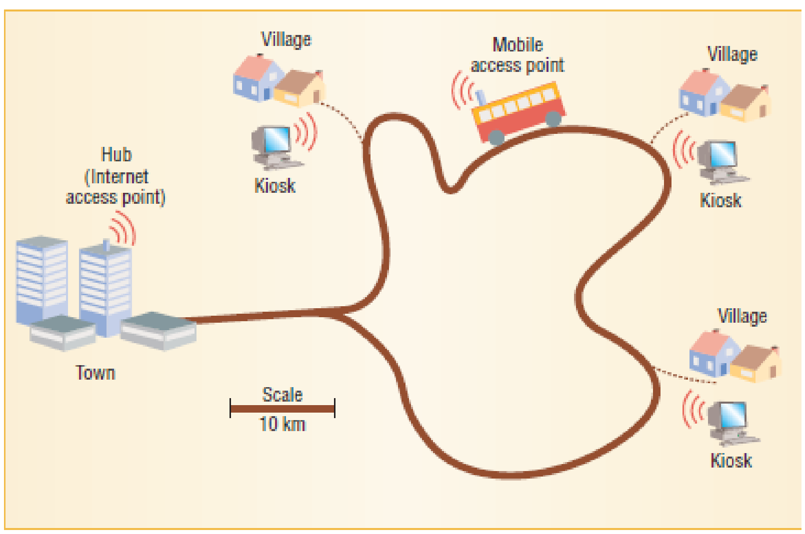


FIGURE 1-2 DAKNET WORKFLOW

- ByteWalla [9]:- Its an android application which implements DTN. It can send or receive data bundles. Users have the provision for specifying the amount of memory to be set aside for the work. Users are able to send emails via DTN through this app which helps them in rural areas. The email upon acknowledgement from the DTN server is converted to a bundle form and transferred over other smartphones or devices in the network. The server on the other side of the application extracts the bundle and converts it to the message form prior to delivering it to the client.

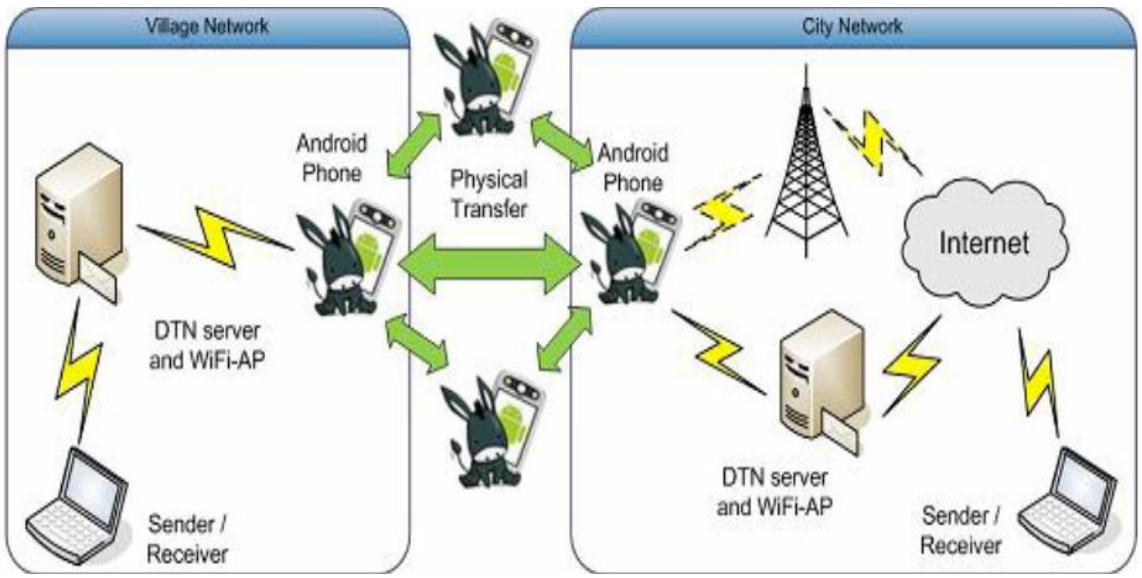


FIGURE 1-3 FLOWCHART OF BYTEWALLA APP

- ZebraNet [10]:- In the area of wildlife tracking, a very good example of DTN is the ZebraNet. It is used to track the mobility patterns of zebras in wild areas. It was implemented at the Mpala Research Center in Kenya. It works around the attachment of a device alongwith a collar on the necks of zebras. So it creates a sparse network scenario, the project could be implemented as an adhoc Wireless Sensor Network (WSN) , limited connectivity leads it to be implemented in a DTN scenario. Another strict version is making the base station to receive all the tracking signals. The delay in receiving such signals was not a critical criteria. The collars around the zebras operate in a peer-peer fashion.

- DTWiki [11]:- It's a wiki system operating in DTN. The system runs on top of *TierStore*- a distributed file system. Also the backend of the system is not a simple database system and is powered to ensure consistency, concurrency under limited connectivity. It stores pages and the related information with the required metadata, account information, attachments, discussion pages etc.

1.2 Scope of Game Theory

The study of game theory is assumed to be started with the publication from Von Neumann in 1944. The publication " *Theory of Games and Economic Behaviour* " presents a mathematical approach to game theory. Game theory attempted to describe mathematically several problems in economics. The very basic concept lies in the player's attempt to maximize its gain or minimise loss. But with this game theory differs little from many of the other approaches in the field. What makes game theory different is the fact that the decision made by a player depends not only on what it plans to achieve but also on what other players decide on. Thus it studies what may be referred to as the conflict of interest between different players in the game.

In such scenarios where different players have different interests, traditional optimization techniques do not provide good results. Thus in problems with conflicts of interests, probability theory or other techniques cannot be used. Game theory understands and tries to resolve problems with such selfish individuals in different contexts. Such characteristic of game theory enables it to be used not only in economics, but political science, military affairs, communication networks etc. Thus Game theory has been used widely in computer networking with large applications in wireless sensor networks, mobile adhoc networks etc.

Game theory can be used to analyse system operations in decentralised and self organising networks. The players in the game, in this case networks may be either cooperative or selfish in nature. There are different methods in game theory which includes cooperative, non cooperative, coalitional, repeated, Bayesian, evolutionary, bargaining etc. The games may also be classified as transferrable utility game (TU) and non transferrable utility game (NTU). Among these coalitional game theory aims to provide a solution based on the group effort of a particular number of nodes. Also with appropriate credit schemes the ill effects of a misbehaving or selfish node could be avoided. The branch of problem solving, Game Theory, hence provides large help in the area of network applications.

1.3 Motivation

The performance of DTNs depend on the selection of intermediate relay nodes. These relay nodes in turn may have their own self interests while forwarding.Thus the nodes may be cooperative or selfish in nature. If a node is selfish it may be reluctant to forward messages wasting its own resources such as energy, buffer space etc. This selfish behaviour of nodes may cause the nodes to behave irrational and cause negative impact on the network performance in entirety. To make the nodes behave in a cooperative manner different schemes are employed. Most of these schemes aims at providing incentives or credits upon delivery of message. These schemes aims at equality of cost allocation whereas equality does not guarantee justice to all nodes. Certain nodes in the network may be highly efficient and active participant in the network and thus allocation of credits should be larger to these nodes. If credits are divided equally to all the connected nodes at a time then the node with higher probability of delivery is bound to suffer loss of reward. Thus the work aims at providing unique distribution of pay off using coalitional game theory.

Game theory provides us with different mathematical tools and enables us to perform an analytic approach towards complex interactions or games among players. There has been a significant growth in game theory applications in the field of communications and computer networks. It is mainly due to the need for an autonomous, distributed network system where network devices can make decisions. Coalitional game theory is a powerful tool for designing efficient strategies in a network. Vast research works are available on non cooperative game theory in the field of communication but very less on cooperative game theory owing to the fact of sparse literature available in the field.

Among the different concepts applied to the coalitional game theory, the core is an important concept. But certain drawbacks of the core prompts us to look for other solutions in the area. The core may be empty, large and rather unfair to some of the players in the game. Thus in the research work shapley value concept is applied inorder for credit distribution. By providing effective credit distribution the relay nodes may be motivated to work cooperatively rather than remaining selfish. Thus with good relay selection, the work aims at better delivery ratio, less overhead and less delivery latency. With a comparative study on the existing energy reduction schemes the proposed routing protocol can be judged on how it fares in energy consumption.

1.4 Problem Statement

Assume a network with *N* nodes with source *S* and destination *D* and a number of relay nodes in between. All nodes are assumed to be selfish in nature to forward message *M* to another node in the network. We assume all nodes in the network are selfish in nature, with following constraints:

- Buffer space : A network node may become selfish on storage of incoming message upon finding out that its buffer space is full.
- Contact duration between nodes T, which is bounded, chosen randomly, unknown in advance and unrelated to M.
- Bandwidth
- Energy

The objectives of the proposed work are as follows :

- Study of cooperative game theory in DTNs and the outcome of its usage in a rational network environment.
- A routing protocol which selects relay nodes based on the past encounter history and provides an option for multi copy sending of messages rather than a single copy.
- A novel routing protocol which aims at providing rational, efficient and network node friendly division of credits such that the relay selection is efficient and all relay nodes behave cooperatively.

1.5 Contributions

With the above presented views and observations, the following contributions are provided to the DTN community through this work:

- We provide an encounter history based relay selection technique which maintains in each node the past history of encounter with other nodes in the network.
- We propose a credit division scheme using coalitional game theory to provide better support for the nodes that have higher chances of delivery than its peers and compared the same with

grand coalition method and existing benchmark methods. The results are in favour of the proposed approach.

- We have induced selfishness into the epidemic system and compared the results with the proposed scheme and found out the latter to fare better.

- Extensive simulations have been performed on different research works and the current work is compared with the same.

1.6 Dissertation Overview

The dissertation comprises of five chapters:

- Chapter 1 introduces Delay Tolerant Networks, their performance metrices and applications. A brief problem statement , the motivation of work and the different contributions made is also discussed.

- Chapter 2 reviews the work related mainly to the different selfish behaviour modelling techniques and the game theoretic works done so far. Different works related to energy module is also reviewed. We also brief about the ONE simulator we have used for our performance analysis in this chapter.

- Chapter 3 comprises of the novel application of coaltional game theory model in our work It also discusses the shapley value concept being applied in credit division.

- Chapter 4 introduces a novel routing protocol based on the encounter history and the overall working of the model from start to end. It provides a description about the usage of encounter history, relay node selection and the message drop policy. Simulation results of comparisn with different existing methods are provided.

CHAPTER 2

RELATED WORKS

RESEARCH on DTNs have been conducted for many years. Many routing strategies have been proposed over the years and different enhancements proposed. It has been found in research that all the nodes in a system may not behave equally. Some of these nodes may promote its own interests. Among different areas studied, DTN node behaviour and conduct in a network has been a well researched topic. Selfishness and behaviour modelling techniques with the sole aim of making the nodes cooperate has been done by many researchers. A brief description of different techniques used for mitigating the effect of selfishness is also included in the section. Game theory has been for the past decade a major contributor in the field of behaviour modelling. Non cooperative and cooperative game theoretic applications has been studied and widely applied in communication networks. The section deals with various routing theory in the field of DTNs, the effect and mitigation of selfish nodes in DTN, the need of cooperation among nodes for avoiding selfish behaviour etc. It also provides a study on the coalitional game theoretic model and the effect of its application in DTN environment. ONE simulator[12] has been used for extensive simulations in the work and hence a brief description of ONE simulator and its working is also provided.

2.1 Routing in DTNs

Traditional ad-hoc routing protocols fail when they come to deal with delay tolerant networks attributed to the fact that these protocols first aim to establish a path for message transfer between the source and the destination. DTN protocols are based on store carry and forward approach where the messages or data packets move in an incremental manner . A most common technique employed is to replicate as many messages as possible to flood the network so that eventually one of them may reach the destination. Also encounter history based prediction techniques, flooding to a limited number of nodes has also been good routing techniques. DTN is an area with rich amount of work done especially in the area of routing and relay selection. Most of these works are based on pure oppurtunistic in which packets are routed based on the temporary connection made available.

There are many different characteristics which are taken under consideration for routing in DTNs. First, the information of the nodes to forward the message should be available. For example, in disaster affected areas, the information on future contacts is not available. Another consideration is the mobility model. The way in which the nodes are moving, random or not, whether all nodes are mobile etc. Lastly, the availability of network resources. Mobile phones may have limited resources in terms of energy and storage space. These conditions lay down the structure and properties of different routing techniques. A large number of algorithms have been devised by varying one or more of these characteristic properties.

Routing protocols may be classified based on how the operations are carried out. Fig 2.1 shows the layered structure of DTN routing techniques. The lowest layer determines the number of replicas to be produced for a DTN message to maximize the delivery opportunity. Although a single copy may only be necessary for delivery, different researchers opt for multiple copies of the message for guarenteed delivery to the destination. One extreme of multi-copy routing is Epidemic flooding where at every intermediate relay node, the message is forwarded to all neighbor nodes but the source. After being injected into the network from the source, packets are relayed by other nodes following unicast, multicast, or anycast communication strategies based on the number of receivers. The top layer determines the strategies to be adopted for forwarding data packets using either social or pure oppurtunistic contacts.

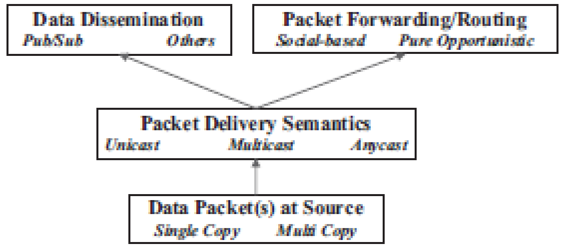


FIGURE 2-1 LAYERED STRUCTURE OF DTN ROUTING

Accordingly the different important routing strategies and their description are as follows:

PROTOCOL	DESCRIPTION	YEAR
Epidemic Protocol [2]	Flooding based, messages are continuously replicated and forewarded to newly discovered contacts	2000
PROPHET Protocol [3]	Nodes use encounter history and delivery predictability to select the relay for message transfer	2003
Spray and Wait [5]	The algorithm aims to make use of the benefits from both replication based routing and forwarding based routing. The protocol constraints upon the number of copies of message to be transferred to the network.	2005
MaxProp [4]	Flooding based in nature.The messages which are not held by the contact node will be forwarded.	2006
RAPID [7]	Utility of nodes is calculated based on the routing metric to be optimized. The node with higher utility is selected as the relay.	2007

TABLE 2-1 ROUTING TECHNIQUES AND DESCRIPTION

2.2 Selfishness and behaviour modelling in DTNs

DTNs differ from the other ad-hoc networks in the unavailability of dedicated path between source and destination at any point of time. The messages or data packets are oppurtunistically routed through the use of temporary connection. The network conditions being highly variable, mobility patterns being difficult to predict and the delays in feedback makes DTN different from traditional networks. DTN nodes in control of rational entities which may be either people , network devices or organizations may behave selfishly trying to maximize their individual benefits without considering the benefits of the whole system as a single unit. There are a large number of routing protocols proposed in the area of DTNs but these do not consider the node's willingness to transfer the message. A node or user which is selfish [19] may drop messages of others and replicate excessively its own messages or of those in favour of the node. These actions degrade the performance of other nodes in the network. The previous algorithms devised does not work in such an environment where the nodes are selfish in nature hence the problem of starvation may also occur. However the removal of such selfish nodes is not a good alternative because the DTN in itself is made up of sparse number of nodes and limited connectivity. Thus by simply removal of nodes may lead to performance penalty. Thus it is necessary to devise design techniques to deal with such selfish nodes to take full advantage of the limited nodes and connectivity available.

Selfishness may be defined to be of two types:

- **Social Selfishness:** Nodes forward the messages only to those individuals:
    - who are friends
    - having similar interests or
    - in same community
- **Individual Selfishness:** Node is unwilling to relay and store messages because:
    - no storage space left
    - remaining battery power is less
    - computational power has become limited

In DTN all the routing techniques have considered the network to be either completely devoid of selfish nodes or are fully selfish. These oppurtunistic algorithms do not consider the real world scenario that the nodes in the network may be partially selfish. Thus the routing algorithms may be classified as follows:

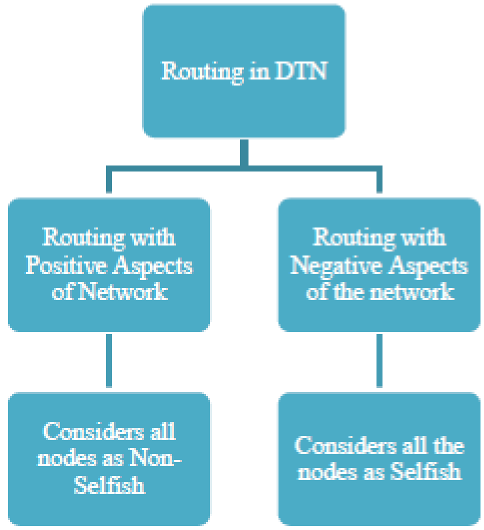


FIGURE 2-2 ROUTING TECHNIQUES WITH SELFISH NODES

Inorder to nullify the negative aspects of selfishness, the nodes should cooperate with each other. There has been extensive study in the area of cooperation among nodes in communication networks particularly mobile ad-hoc, wireless sensor, and Delay Tolerant Networks. These research works fall into the following categories:

- Isolating the misbehaving nodes from the system. The protocols make use of trusted nodes to find out the misbehaving nodes and preventing them in participating in network activities. Fear of punishment motivates the nodes to cooperate and foreward data packets in the network.
- Credits: Nodes earn payments in the form of credits for forwarding packets.These credits can in turn be used for obtaining message transfer service from other nodes in the system. However to ensure transparency , these protocols need to implemented with trusted centralized bank system or dedicated and secure hardware.
- Tit for Tat (TFT): A node blacklists and avoids the service to another if it detects misbehaviour from any node in the network. Conversely full cooperation is guaranteed if no misbehaviour is detected.
- Game theoretic approach: Game theory can be applied to the area of DTNs in which the nodes may be assumed as players. At any moment if we consider three nodes in the

network, A ,B and C as in the following figure. The packet received by node B can either be forwarded or dropped as decided by B. A keeps track of B's activities for the packet through acknowledgements and if B forwards the packet then A gains α (packet value) utility units. B loses β (packet cost) units as it loses its resources. The traffic is assumed to be such that the relationship between A and B is reciprocal. Thus it can be modelled into a strategy game where each player strategically determines whether to drop the opponent's packet or not. The game becomes equivalent to prisoner's dilemma if packet value becomes greater than packet cost. Thus individual selfishness may lead to zero throughput. Cooperation emerges under repeated playing of the game under certain conditions.

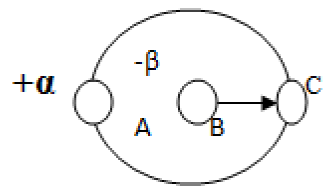


FIGURE 2-3 GAME SCENARIO WITH TWO PLAYERS

2.3 Game theoretic applications in DTN

Game theory in the field of communication networks has been early identified as a potential research area and there has been considerate work in the field. The starting work can be identified back to early 2000's in which revenue division amongst internet service providers was considered as a research problem. In DTNs, the studies based on node's selfishness and the requirement of profit division among the players for transfer services lead researchers to the usage of game theory due to its popularity of application in economics. This section deals with the enumeration and detailed description of various game theoretic works in the field of delay tolerant networks.

In the research work [19] proposed by Zhang et.al, an incentive aware routing technique was proposed. The researchers found the existence of selfishness in networks without appropriate incentive mechanisms to be harmful and hampering the entire system. They proposed an incentive aware routing protocol with Tit For Tat (TFT) mechanism that allows the nodes to fare better with the incentives provided to them.The authors found the existing TFT mechanisms to face bootstrapping problems and made the TFT mechanisms to be generous in the matter. The delivery ratio of the system without incentive mechanism was found out to decrease by 20% whereas with the incentive criteria the delivery ratio increased by an amount of 60%. The routing protocol comprises of the following components: link state exchange between the nodes, forwarding route computation using the link state values and finally the destination responds to the packet received with ACK allowing the source to adjust the TFT constraints. The incentive aware routing protocol was tested with both synthetic and real test beds and found to be effective in imparting cooperation in the network.

In 2009, Saad et.al [15] in their work, studied the application and scope of coalitional game theory in the field of communication networks. For this purpose they grouped coalitional game theory into the following: 1) canonical games 2) coalition formation games 3) coalition graph games. The coalition games are mainly in characteristic form in which the total value of the coalition depends on the contribution of the members. There exists another form which depends on how the coalition is formed namely the partition form. The work as a tutorial provides a comprehensive overview of coalitional game theory in wireless communication networks. It explains in detail the three groups identified, their fundamental properties, solution concepts and the application of methodologies in communication networks. The tutorial also highlights on the usage of the coalition games as analytical tools in future works.

A work on coalitional game theory in the area of DTNs was done by Niyato et.al [13] in 2010. The work proposed develops an analytical model to find out the effect of cooperation among nodes in DTN. A stable coalitional structure where no individual member can improve its individual payoff by changing the coalition structure is proposed. A study on performance of the coalitional model is done and the ways in which the cooperation costs can be mitigated is performed. In this work, players form coalition if its payoff in forming coalition is larger. A unique payoff model is also formulated using game theoretic approach. The work concluded that indeed coalitional structures improve the performance of DTN nodes in a selfishness based environment.

In 2011, Kazemeyni et.al [17] identified the potential usage of coalitional game theory in their work for energy conservation. The replacement of a dead or used out mobile or node in a network system (wireless system network) is difficult and costly. The major part of power consumption occurs in transmission and if the nodes could be made to cooperate in transmission process, it could result in energy conservation. Thus in their work, the authors propose an algorithm allowing nodes to choose the group their range which is suitable for them for power conservation. The researchers use Maude model for analysing the protocol for possible failures of the sensor nodes. The results prove that the grouping of nodes are done correctly and show significant improvement in terms of power efficiency.

Omar et.al [14] in their research work proposed the usage of coalitional game theory as a mean of incentive mechanism for content caching in DTNs. The network resource constraints such as relay buffer, energy and packet life time are considered for conservation. The nodes are organized so as to balance the reward scheme and constraints. The reward scheme in the work is such that the first node to deliver the message to the intendent destination receives the credit or reward. The nodes which form coalition and help in the forwarding will not receive the reward but will lose some of its energy and resources in the play. The messages nearing the ttl value are given priority while forwarding by a node. The rewards get distributed according to shapley value. The investigators evaluated the performance of the nodes regarding cooperation using the "*Imitative Boltzmann-Gibbs*" learning algorithm. The algorithm also aims to learn about Nash

Equilibrium with the help of network nodes. Accordingly the results of the simulations showed that the performance of the system improves with coalition formation.

2.4 Opportunistic Network Environment (ONE) Simulator

ONE or Opportunistic Network Environment [12] is a DTN simulator created on Java platform entirely for its research and for Opportunistic Mobile Networks(OMNs). The simulator helps users in simulating various scenarios useful for their research in quick and flexible manner. The platform also helps in generating statistics from the performed simulations. The software can be run on windows, linux or other operating systems supporting java platform. The software is a widely used one in the research field. Well known protocols such as Epidemic routing, PROPHET, MaxProp etc are pre installed in ONE simulator. Real world traces can also be run on the simulator and results collected. The overall visualization and post processing tools make it highly interactive and easy.

In DTN, the focus is mainly on the routing behaviour and the working of application protocols. The simulations consider network as sparse and avoid considering the wireless link characteristics. The nodes communicate with each other when they come in range of one another. Thus the evaluation of DTN protocols becomes one of the main aspects in the network study. The engine updates modules to implement the main functions of the simulation at each step. Node movement modelling, inter-node contacts, message handling and routing are some of the characteristic functions of ONE simulator. Results are collected and evaluated through visualization and reports. Various post processing tools in the simulator makes the presentation of the reports in an apt and standard manner. Movement models in the simulator decide the node movement. These models may be either synthetic or real world traces. Location, bit rate and the communication range decides the connectivity between the nodes. Routing modules decide which message to dorward through the existing contacts. Event generators generate the messages and are always unicast inside the simulation environment.

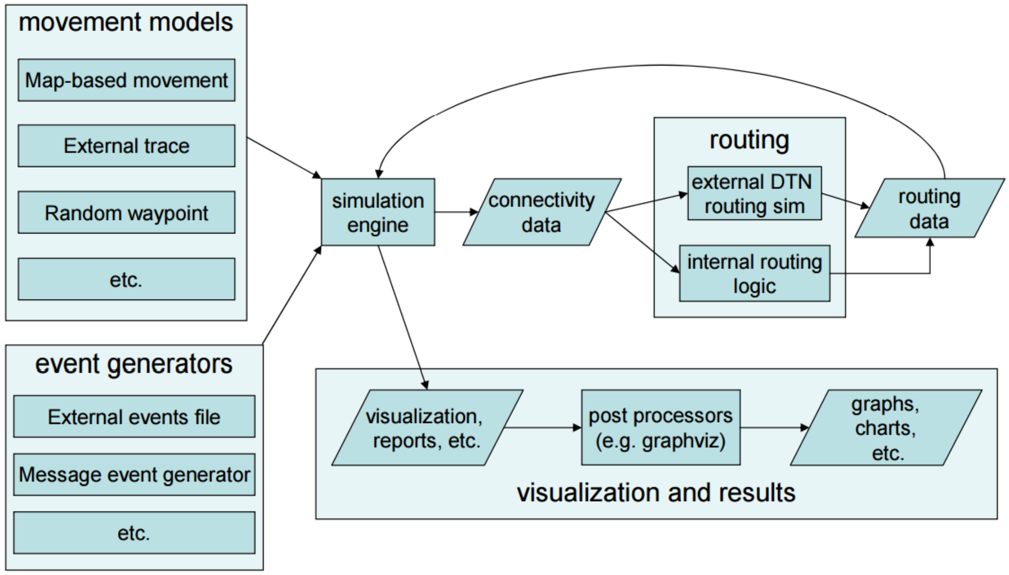


FIGURE 2-4 STRUCTURE OF ONE SIMULATOR

There are different configuration files in the simulator which decide upon various settings for the protocol simulation. These perform the same function as TCL scripts in NS-2. There exists a *default_settings.txt* file which is used in every simulation. In every run of the simulator, this file is read and thus every different run of the protocol requires modifying this file. However a complex scenario would require a modular approach having multiple configuration files. Imagine a group of nodes using different protocols for such a complex scenario. The various steps in performing simulation are as follows:

1. Default_settings.txt file is modified specifying the different requirements.
2. Network interfaces of the nodes are specified.
3. Groups of nodes are created.
4. Motion and traffic patterns are specified.
5. The number and type of reports to be generated are specified.

After all these settings are specified, the simulations are performed.

2.5 Summary

In this chapter, we reviewed different types of routing schemes existing in DTNs. These techniques vary from the simple flooding technique, the prediction technique to different variety of other ideas. A very brief idea about the different benchmark protocols is discussed. Selfishness, the way in which it harms the network performance, different types of selfishness is also discussed. Different methods are employed in DTN to mitigate the effects of selfishness and to impart cooperation. These include avoidance of selfish nodes, credit based system , tit for tat approaches and game theoretic models. Game theoretic models has been applied largely in the area of communication networks. Since the work concentrates on the use of coalitional game theory in DTNs, a brief survey on the use of the same in networks including wireless sensor networks is discussed. In our work simulations are carried out using Oppurtunistic Network Environment (ONE) simulator. A brief description about its overall structure and way of working is also provided.

The next chapter concentrates in detail coalitional game theory, credit division among the players in coalition and the application of the same in our protocol to mitigate the selfishness of DTN nodes.

CHAPTER 3

COALITIONAL GAME THEORY BASED INCENTIVE DIVISION

IN DTN, selection of relay nodes as well as the cooperation of the nodes with the source node is important for message transfer and delivery. With cooperation among the relay nodes, the data delivery performance can be improved. But with cooperation and willingness of the nodes to relay messages comes the additional cost of energy and space usage. Assuming the nodes being rational in behaviour, the nodes will try to maximize individual benefits. Thus there is a need to select the optimal cooperation decision to maximize benefits and minimize costs.

3.1 Coalitional Game Theory Scheme

Game theoretical techniques have recently been increasingly used in the communication field of engineering applications. Game theory in the past has been largely applied in the field of economics, politics, engineering and psychology. The idea to decentralize the decisions taken in a mobile network has led researchers to look for methods to provide autonomy, control and decision making policies to the individual players in the network.Cooperation among the players in a communicaton network is the new term that is increasingly used to improve the performance of a network. It has been understood that the cooperation among nodes significantly improve the performance of the network.

A coalition is basically a subset of players formed to coordinate activities and strategies and to decide upon how to divide the total payoff received among themselves [15]. In general, coalitional games involve a group of players, say **N={1,...,N}**, who form a group or coalition to act as a single user having a unique function. In politics, individual members may form groups to improve their vote count. Similarly in a network, individual nodes may form group with the function to deliver messages. Coalitional games may be profit games or cost games. In profit games, players choose to form coalition inorder to increase its individual benefits under a group. A characteristic function $\mathbf{v : 2^N \rightarrow R}$ defines the mapping from the set of all possible coalitions of players to the set of payments that satisfies $V(\phi) = 0$.

Similarly, a coalition game can also be defined as the characteristic function $\mathbf{c : 2^N \rightarrow R}$ with $C(\phi) = 0$. In this type, the players cost of accomplishing the task is provided by the function c. A profit game can also be converted to the cost function.

There are several characteristic properties associated with a cooperative game. These are: 1) SuperAdditivity: Characteristic functions of a game are always assumed to be superadditive. i.e the value obtained by the sum total of all disjoint groups is always greater than the sum of individual coalitions.

$$\mathbf{v(SUT) \geq v(S) + v(T)\ ;\ S,T \subseteq N\ ,\ S \cap T = \phi} \qquad \text{(i)}$$

2) Monotonicity: The large the coalition the large will be the gain.

$$\mathbf{S \subseteq T \rightarrow v(S) \leq v(T)} \qquad \text{(ii)}$$

The formation of grand coalition is considered to be one of the main event or factor in cooperative game theory. Payoff among the players is allocated in a rational manner. Solution to the problem is a vector $x \in R^N$ which provides the player's allocation. There exists various solution concepts based on the fairness of solution. In all these solution concepts, the properties to look for are:

- Efficiency: the vector should split the whole value.

$$\Sigma\, x = v(N)$$

- Individual rationality. Every member receives a payoff than what it could acquire acting upon its own.
- Existence: There always exists a solution for any game V.
- Uniqueness: Solutions are always unique for any game V.
- Computational ease: Solution can be calculated with efficiency.
- Symmetry: The solution allocates payment equally as $x_i = x_j$
- Additivity: The allocation of individual games can be added up to provide the cost of a player for two games.
- Null players: they are given zero allocation.

With respect to the above properties , there are different solution concepts proposed. These include:

- **The stable set** : if there are two payoff vectors x and y. If some coalition ($\neq \phi$) satisfies $x_i > y_i \ \forall i \in S$ and $\Sigma_{i \in S} x_i \leq v(S)$, then x is said to dominate y. Players may prefer x to y and leave the grand coalition if payment is more in x.
- **The core** : It refers to a set of vectors in which value of the coalition is provided in such a way that the value is not greater than the sum of its individual members payoffs.
- **Shapley value** A unique payoff vector satisfying the properties of efficiency, symmetry, additivity and allocation of zero payoff to dummy players.
- **The kernel** : it refers to a concept in which no player has bargaining power over other.
- **The nucleolus:** Let (N,v) be a transferrable utility game, $C \subseteq N$ be the coalition and let x be the payoff distribution over N. Then the excess e(C,x) of coalition C is called as the excess function and is defined as $e(C,x) = v(C) – x(C)$. A positive excess shows dissatisfaction over the credit division, Then the core of the game may be defined as $Core(N,v) = x \in R^N$ where x is an imputation and $e(C,x) \leq 0$.

In this work, since cutoff of reward points is the main aim ***shapley value*** is the solution concept used. The next part deals with Grand coalition and the drawbacks it may cause. The need of an optimal solution other than the grand coalition is also discussed.

3.2 Coalition selection by DTN nodes

A coalitional game model is formulated to study and analyze the decisions made by communities to cooperate and forward the packets for other nodes and thereby reap the benefits of attaining credits. These credits may be used later by a node for starting a message of its own. This section deals with how coalitions are formed and DTN nodes cooperate to transfer messages.

Consider a community of rational players C, where players decide upon the interested coalitions to join. The grand coalition in this set is thus represented by {C}.The model maps to a non-transferrable utility and the value of credit or reward is given by a unique payoff vector. Reward points are given only when the ultimate goal of message transfer is completed. Ex: If there are 4 players in the game then the structure of coalitions which may be formed are as follows:

State	Structure	State	Structure
C_1	{{1},{2},{3},{4}}	C_8	{{1},{2},{3,4}}
C_2	{{1,2},{3},{4}}	C_9	{{1,2,3},{4}}
C_3	{{1},{2,3},{4}}	C_{10}	{{1,3,4},{2}}
C_4	{{1},{2},{3,4}}	C_{11}	{{1,2,4},{3}}
C_5	{{1,3},{2},{4}}	C_{12}	{{1},{2,3,4}}
C_6	{{1,4},{2},{3}}	C_{13}	{{1,2},{3,4}}
C_7	{{1},{2,4},{3}}	C_{14}	{{1,4},{2,3}}
		C_{15}	{1,2,3,4}

TABLE 3-1 POSSIBLE STRUCTURE OF COALITIONS

3.3 Grand coalition of dtn nodes

Grand coalition in game theory refers to the addition or coalition of all players available in a selection group. In the proposed work, forwarding of messages to all connected nodes in the network comes under grand coalition. The main idea is "why not include all the players?". Although it may seem to be a good idea to include all players in a game , its observed that there are shortcomings to this approach. These are:

- Equal credit distribution to players do not guarantee justice but equality
- Unnecessary forwardings to nodes.
- Large overhead ratio of messages
- Larger drop of messages
- Wastage of energy in nodes.

Hence with all these drawbacks, there exists a need to find a subset and optimal structure from the available set of players. In this work, the solution concept of *shapley value* is used as a cost function and is described next.

3.4 Shapley value and Cost calculation

Shapley value, introduced in 1953, is a solution concept named in honour of Lloyd Shapley in cooperative game theory. A unique distribution of the total reward points generated by the coalition is asigned to its members. The brief idea of shapley value concept is as follows: players group themselves or form coalition to obtain a utility gain or overall profit to system. Since certain players may be contributing more to the coalition, equal payoff may not provide justice or be optimal. Hence how important is a particular member to the coalition and how much cost should be allocated to him is an answer provided by shapley value concept.

In a cooperative game, if S is a set of players in coalition v(S) is called the worth of coaliton S. Worth describes the total expected payoffs of members in S. By shapley value the solution to a game may be defined as:

$$\phi_i(v) = \Sigma_{S \subseteq N \setminus \{i\}} \frac{|S|!\,(n - |S| - 1)!}{n!} (v(S \cup \{i\}) - v(S)) \qquad \text{(iii)}$$

The equation can be described as: assume each coalition being formed as one player at a time, then the payoff demanded by them is the total gain acquired by the coalition with the addition of the particular player to the team. The payoff provided to the player is the average of his contribution over all permutation in which the coalition can be formed.

Another formula for the same shapley value can be written as:

$$\phi_i(v) = \frac{1}{n!}\Sigma_R \left[v(P_i^R \cup \{i\}) - v(P_i^R)\right] \quad \text{(iv)}$$

where P_i is the set of players preceding the involvement of the current player i in the order given by R.

Example:

Consider a game of three players having different gloves in their hand. Suppose player 1 and 2 have right hand gloves and player 3 has left hand glove. The utility fuction of the game is to form pair of gloves.

The value of this coalitional game is as follows:

$v(S) = 1$ if $S \in \{\{2,3\},\{1,3\}, \{1,2,3\}\}$, 0 otherwise;

The following table describes the contributions of the player 1 towards coalition formation.

ORDER OF ADDITION R	CONTRIBUTION
P_1,P_2,P_3	$v(\{P_1\}) - v(\phi) = 0 - 0 = 0$
P_1,P_3,P_2	$v(\{P_1\}) - v(\phi) = 0 - 0 = 0$
P_2,P_1,P_3	$v(\{P_1,P_2\}) - v(P_2) = 0 - 0 = 0$
P_2,P_3,P_1	$v(\{P_1,P_2,P_3\}) - v(P_2,P_3) = 1 - 1 = 0$
P_3,P_1,P_2	$v(\{P_1,P_3\}) - v(P_3) = 1 - 0 = 1$

P_3,P_2,P_1	$v(\{P_1,P_2,P_3\}) – v(P_2,P_3) = 1 – 1 = 0$

TABLE 3-2 COST CALCULATION OF PLAYER 1

Therefore the cost of player 1 is : $\phi_1(v) = 1/6$. $\phi_2(v) = 1/6$ and since the game is super additive the gain or cost of player 3 is $\phi_3(v) = 4/6$.

Shapley value in general has the following properties:

1) Efficiency: The gains are distributed.

$$\Sigma_{i \in N} \phi_i(v) = v(N)$$

2) Symmetry : if i and j are two players then

$$v(S \cup \{i\}) = v(S \cup \{j\})$$

3) Linearity : $\phi_i(v) + \phi_i(w) = \phi_i(v+w)$
4) Zero player: the value of a null player game is zero.

3.5 Reward point calculation in proposed protocol

In the proposed routing protocol, the main utility is to achieve greater average or mean of delivery predictability. From a given cluster of players, the adjacent group. those players with less standard deviation, with larger mean of predictability are selected for transmission. Hence the utility function for the calculation is larger average or standard mean of delivery predictability. The average of a null player or zero player is 0.

Suppose there are three players with the delivery predictability as follows: Player 1→ 0.6 , player 2→0.5 , player 3→0.7 . Value of coalitional game is the standard mean. A player gains entry to the coalition if it could offer a higher average with minimum standard deviation of delivery ratio to the coalition formed.Therefore the table with the individual contribution of players is as follows:

ORDER OF ADDITION R	CONTRIBUTION OF PLAYER 1	CONTRIBUTION OF PLAYER 2	CONTRIBUTION OF PLAYER 3
P_1,P_2,P_3	$v(\{P_1\}) – v(\{\phi\}) = 0.6$	$v(\{P_1,P_2\}) – v(\{P_1\}) = -0.05$	$v(\{P_1,P_2,P_3\}) – v(\{P_1,P_2\}) = 0.05$
P_1,P_3,P_2	$v(\{P_1\}) – v(\{\phi\}) = 0.6$	$v(\{P_1,P_2,P_3\}) – v(\{P_1,P_3\}) = -0.05$	$v(\{P_1,P_3\}) – v(\{P_1\}) = 0.05$
P_2,P_1,P_3	$v(\{P_1,P_2\}) – v(\{P_1\}) = 0.05$	$v(\{P_2\}) – v(\{\phi\}) = 0.5$	$v(\{P_1,P_2,P_3\}) – v(\{P_1,P_2\}) = 0.05$
P_2,P_3,P_1	$v(\{P_1,P_2,P_3\}) – v(\{P_2,P_3\}) = 0$	$v(\{P_2\}) – v(\{\phi\}) = 0.5$	$v(\{P_2,P_3\}) – v(\{P_2\}) = 0.1$
P_3,P_1,P_2	$v(\{P_1,P_3\}) – v(\{P_3\}) = -0.05$	$v(\{P_1,P_2,P_3\}) – v(\{P_1,P_3\}) = -0.05$	$v(\{P_3\}) – v(\{\phi\}) = 0.7$
P_3,P_2,P_1	$v(\{P_1,P_2,P_3\}) – v(\{P_1\}) = 0$	$v(\{P_2,P_3\}) – v(\{P_3\}) = -0.05$	$v(\{P_3\}) – v(\{\phi\}) = 0.7$
Total	**1.2**	**0.8**	**1.65**

TABLE 3-3 COST CALCULATION OF INDIVIDUAL NODES

The shapley value of each player is then calculated as:

$\phi_i(P_1) = Total_1/ n! = 1.2/6 = 0.2.$

$\phi_i(P_2) = Total_2/ n! = 0.8/6 = 0.133.$

$\phi_i(P_3)$ = $Total_3$/ n! = 1.65/6 = 0.275.

Total mean of delivery predictability of three players, v(N) = (0.6+0.5+0.7)/3 = 0.6.

$\phi_i(P_1) + \phi_i(P_2) + \phi_i(P_3) = v(N)$. Hence the shapley value concept applied is efficient. Similarly the solution satisfies all the properties of shapley value concept.

Suppose the total credit obtained for forwarding the message is 30. Then the cut off of each player is calculated as follows:

Cutoff of player 1 = {$\phi_i(P_1)$/0.6 } * total_credit = (0.2/0.6) * 30 = 10.

Cutoff of player 2 = {$\phi_i(P_2)$/0.6 } * total_credit = (0.133/0.6) * 30 = 6.65.

Cutoff of player 3 = {$\phi_i(P_3)$/0.6 } * total_credit = (0.275/0.6) * 30 = 13.75.

Thus it can be inferred that the credits or reward points are uniquely distributed according to the contribution made by individual players to the coalition.

3.6 Summary

In this chapter, we described cooperative game theory in general. The very basic idea of grand coalition and the different shortcomings it may experience is also discussed. The need of a suboptimal structure of players and unique, rational distribution of credits to all players leads to the usage of any of the solution concepts of coalitional game theory. Thus shapley value comes into picture and the division of credits are thus discussed. In the following chapter the entire routing protocol is discussed along with the discussion of simulation results.

CHAPTER 4

AN ENCOUNTER HISTORY BASED ROUTING PROTOCOL

THE following section deals with the description and working of the new encounter history based routing protocol used in the work. The underlying communication paradigm of this algorithm is unicast, i.e. it considers a single source S, having a message M to be delivered to a single destination node D. Multiple copies of the message are send to relay nodes which ensure guaranteed delivery to the destination whereas in traditional networks a single copy is send to relay nodes which ensure guaranteed delivery to the destination. This characteristic of the protocol ensures high delivery ratio and low delivery delay. But since multiple copies are made into the network the overhead ratio is bound to go high. This could be mitigated with proper relay selection and forwarding. With appropriate drop policy in the buffer, the individual gain of the players or nodes in the network is also maintained. With extensive simlations on existing two benchmark protocols as well as on two selfishness induced protocols, the proposed Encounter protocol bests the existing protocols and outperforms the selfish modelled ones.

4.1 The Encounter Protocol

The protocol model along with different assumptions made are discussed in this section in detail.

4.1.1 Model

The DTN network is considered with Random Way Point mobility model. There are around 100 nodes assumed in total which belong to different communities of pedestrians, automobiles, tram vehicles and stationary equipments. The inter encounter rate between different nodes are asuumed to be exponential. Each data packet or message has a time to live (ttl) associated with it. These messages are unusable if they are not delivered on time. Each relay node has to decide whether to store and forward the message or drop it according to the incentives offered and the resource usage it may incur.

4.1.2 Encounter history and delivery predictability

The protocol uses the past history of encounter between nodes inorder to provide a better decision for relay selection. These data are stored by the node. In this work, ONE simulator is being used with the backend language Java, hence the data are stored in a linked HashMap. The HashMap contains entry for all the remaining nodes in the network and increases the count of each node on encounter. Delivery predictability is calculated based on the encounter history. Upon each encounter, the delivery predictability gets changed as:

$$Pred_{A\_new} = \alpha * Pred_{A\_old} + (1-\alpha) * Pred_{init} \qquad \text{(i)}$$

The value of α is set to be 0.75 which provides the necessary aging factor for delivery predictability and $Pred_{init}$ value is taken as 1. The value of α is obtained from the usage of delivery predictability in Prophet routing.

4.1.3 Forwarding strategy

The selection of the relay nodes form an important part of the proposed work. The forwarding of a message from a source node to the destination takes place according to the following points:

- Based upon the delivery predictability of the connected nodes to the destination, the nodes form coalitions among themselves to attain the forwarding message to deliver.
- With the single aim of increasing the utility function of coalition, all the combinations of coalitions are considered and the best suitable coalition with large mean of delivery predictability and minimum standard deviation is selected.
- Since the nodes are selfish in nature, the credits are divided according to the shapley value.
- The nodes in their individual behaviour transfer messages which at last provide them with larger credit gain.

4.1.4 The overall pseudocode of Encounter Protocol

The section provides with the overall detail of the protocol implemented from the DTN node point of view. The following are the main functions used by the active router at the source in forwarding.

```
1:  Message msg = createMessage()
2:  List<Connection> con=getConnectedNodes()
3:  for i = 1 to con.size()
        a. updateDeliveryPredictability(con.get(i))
        b. if (canAddConnection(con.get(i))
              i. calculateMean(ref, con.get(i))
             ii. addConnection(ref, con.get(i))
        c. end if
4:  end for
5:  /* calculating the credit division */
6:  Permute(ref,to,arr,0,vec)
7:  /* vec now contains the required credit division to all the individual nodes for forwarding
    message */
8:  for i = 1 to ref.size()
        a. startTransfer(msg,vec[i])
9:  end for
```

The sub functions used in the above pseudocode are as follows:

- **createMessage()** : creates a new message including the ids of the source and the destination. Assigns a minimum credit (*say* 30) used for starting the transfer of message. Decreases the credit count of the sender.

- **getConnectedNodes()** : returns the list of the nodes currently connected to the node under consideration.
- **updateDeliveryPredictability()** : updates the encounter history and thereby the delivery predictability of the connected nodes with the current node.
- **canAddConnection()** : the boolean function decides whether the connection under scrutiny should be added to the final set of connected nodes so that the standard mean of delivery probability will be increased. The pseudocode of the function is as follows:

1. canAddConnection(Connection con)
2. **for** i = 0 to ref.size()
    a. sum+= getDeliveryPredictability(ref.get(i))
3. **end for**
4. sum+= getDeliveryPredictability(con)
5. **double** mean = sum/(ref.size()+1)
6. **if** *mean > threshold*
    a. **if** *standard_dev < 0.3*
        i. **return** true
    b. **return** false
7. **end if**
8. **return** false

- **startTransfer()** : the function checks whether the message transfer can be initiated. Checks for the following conditions:
    - Message is not already delivered.
    - Destination and the connected node is the same
    - if transfer possible increases the credit for the transferring node
- **permute()** : Generates all the possible permutation of the connected nodes required for shapley value calculation.

4.2 Simulation Results and Discussions

The proposed Encounter protocol is simulated on the ONE (Opportunistic Network Environment) Simulator, which is a well-known DTN simulator. The results are compared with two existing benchmark algorithms Prophet and Epidemic routing. But since the work studies selfishness, we have induced selfishness into epidemic routing for comparisn. Also the grand coalition method is also studied and compared with the proposed work. The following table shows the settings file being used for a simulation run.

Scenario end time	**43200 sec**
Number of host groups	6
Group number of hosts	200
Movement model	Random WayPoint model
Buffer space	2,3,4,5,6,7 (in Mb)
Group message ttl (time to live)	300 minutes
Group initial energy	4000 mAh
Scan energy	1 mAh
Receive energy	3 mAh
Transmit energy	4 mAh

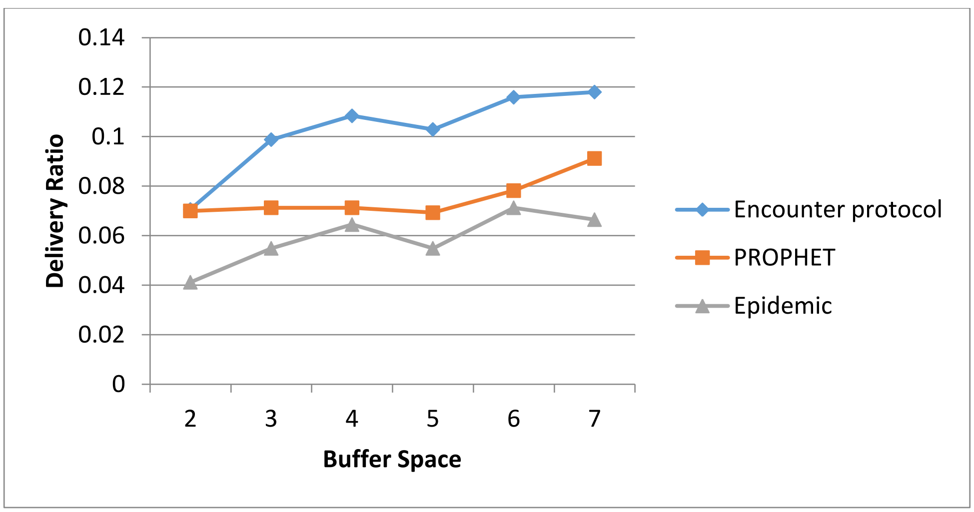
TABLE 4-1 TYPICAL SIMULATION SETTINGS

Various parameters by which the protocols are evaluated are as follows:

- Delivery ratio: "The ratio of number of messages delivered to the number of messages generated." High delivery ratio, the better.

- Overhead ratio: "It is defined as the ratio of difference between the total number of relay nodes and delivered messages to the total number of delivered messages". Less overhead ratio is always considered the best.
- Delivery delay: "Average delay in delivery of the message, the lower the better".
- Energy dissipated: "Amount of energy dissipated per unit message. Low energy dissipation for higher efficiency".

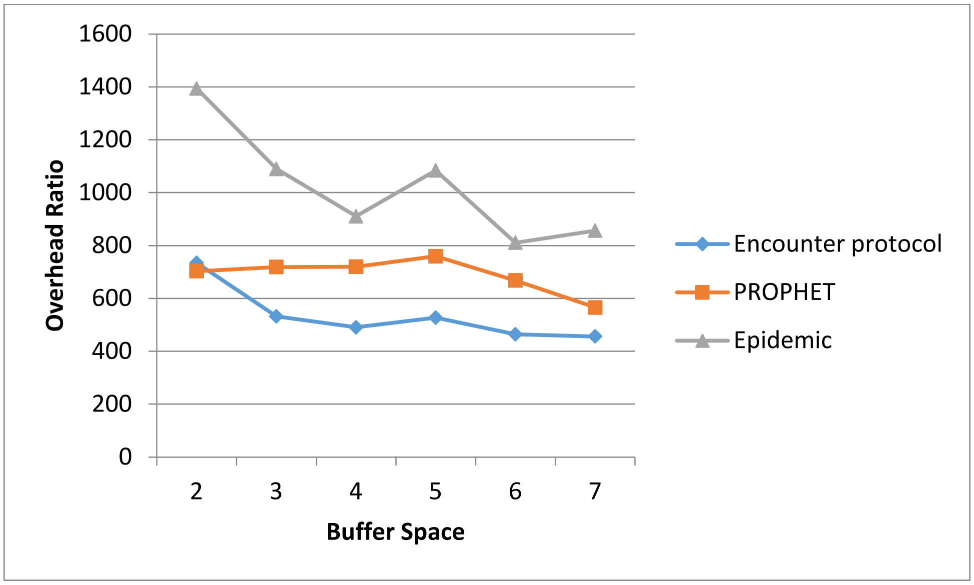
The following graphs show the comparison of the work proposed with the existing benchmark protocols. Since selfishness is induced on the basis of message drop from buffer, variations in buffer space is considered to be the main parameter in understanding the variations between the different protocols. Although, node count, time to live (ttl) etc may be taken as valid variation parameters, the intended difference in results with respect to selfishness could only be observed by varying the buffer size.



(a)

<u>Observations:</u>

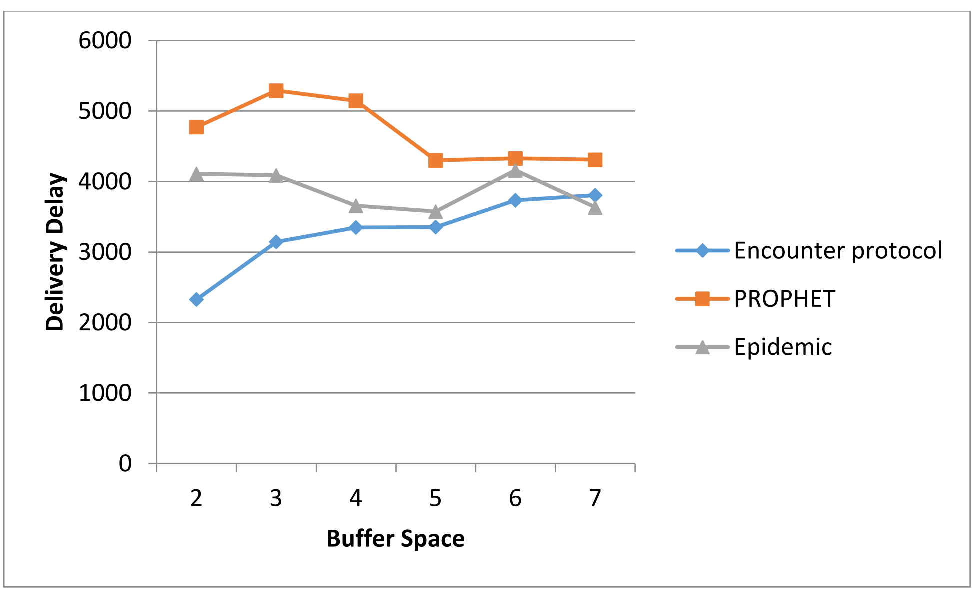
- Simple flooding of messages to all the connected nodes does not guarantee high delivery ratio.
- With appropriate relay selection and coalition formation the proposed protocol, encounter protocol provides high delivery ratio as compared to the benchmark algorithms.



(b)

<u>Observations:</u>

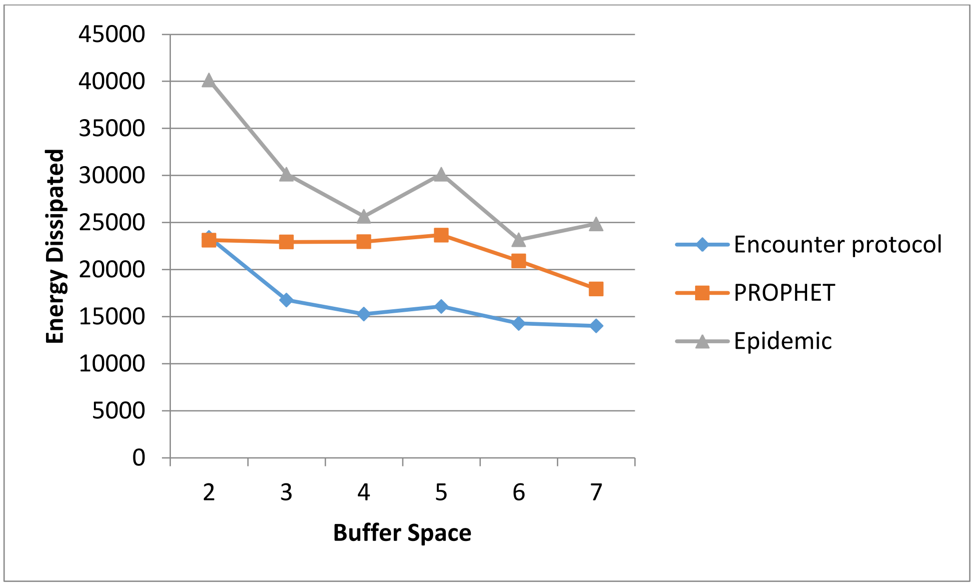
- Encounter protocol achieves large reduction in overhead ratio because of its proper relay selection and coalition formation. No nodes with low delivery predictability to the message destination are expected to carry messages ,which in fact is the reason for large overhead.



(c)

Observations:

- In PROPHET, a single relay with high delivery predictability for destination is chosen and the packets are forewarded. Since the message delivery depends on the contact between the nodes carrying packets, delivery delay is expected to be high.
- Although flooding appears to be the best candidate for reducing delivery delay, large flooding may result in message drops and hence is suboptimal.
- Encounter protocol with appropriate grouping techniques overcome the limitations of both PROPHET and Epidemic based routing.



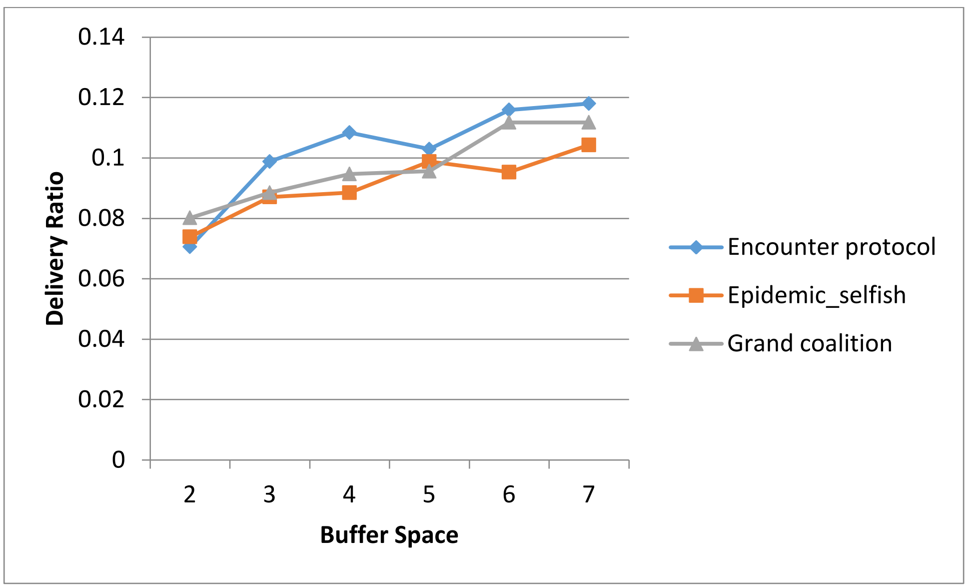
(d)

FIGURE 4.1 GRAPHICAL RESULTS OF COMPARISN WITH BENCHMARK ALGORITHMS

Observations:

- With every message forwarding transmission cost or power dissipation increases. Thus flooding technique comes out to be least favourable.
- In such a case, PROPHET may seem to be the ideal candidate with single forwarding. Surprisingly Encounter protocol achieves low dissipation in energy also. This could be attributed to other factors in energy usage such as scan and receive energy.

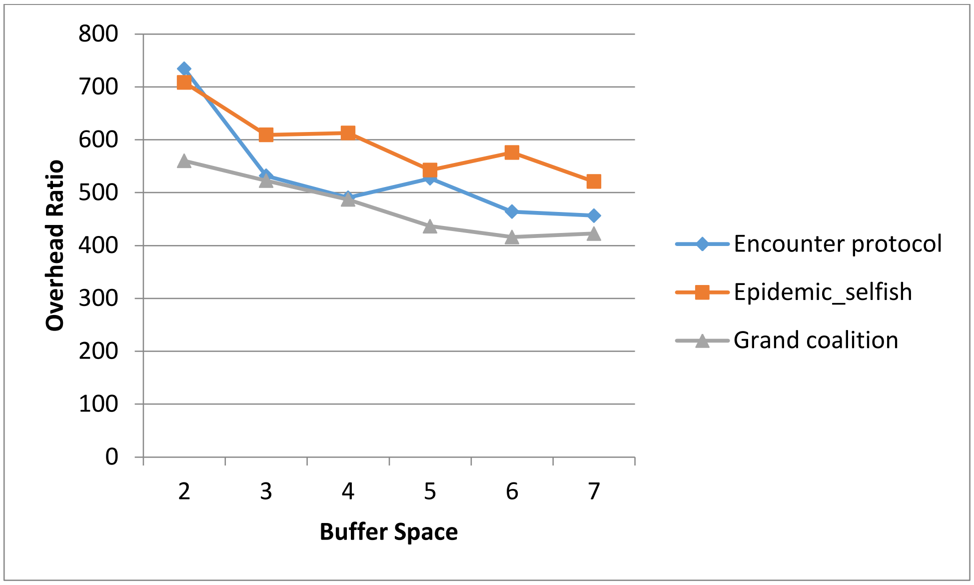
The above graphs represent the comparisn of the proposed protocol with existing benchmark algorithms. This does not provide a clear idea of the protocol efficiency as the idea is to study reduction in selfishness. As such to provide a better comparative study selfishness in the form of message drop is induced or imparted into the existing Epidemic algorithm. Epidemic protocol is chosen because it is mainly a flooding based technique and magnifies the benefits of the usage of a group or coalition in the proposed protocol. The following graph represents the comparisn between the proposed work and the selfishness induced Epidemic routing and Grand Coalition method.



(a)

<u>Observations:</u>

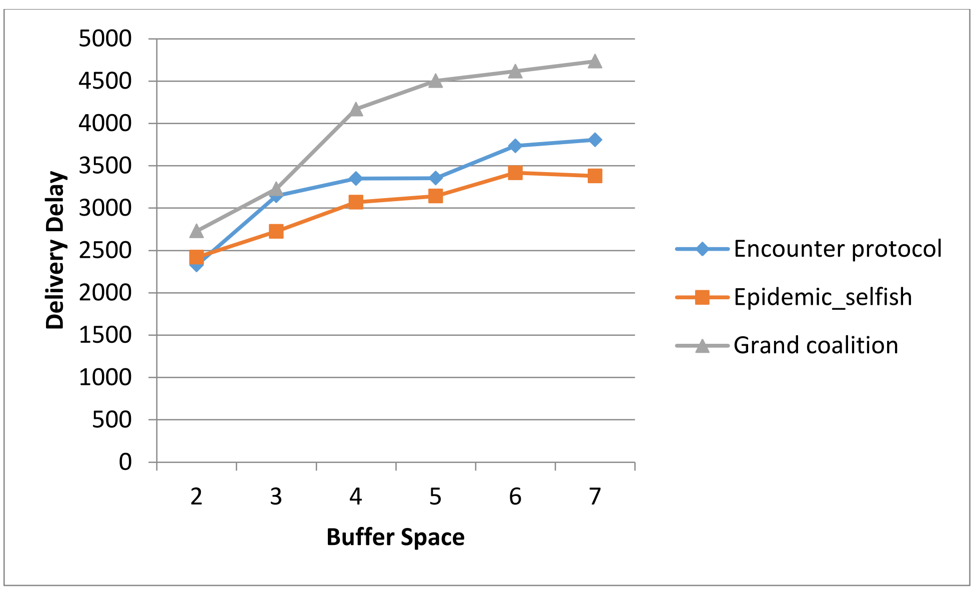
- In comparisn with the grand coalition and epidemic routing, with induced selfishness, the proposed game theoretic approach achieves better delivery ratio.
- As expected grand coalition technique has proved to be not the best or optimal idea in solving conflict based problems or selection problems.



(b)

<u>Observations:</u>

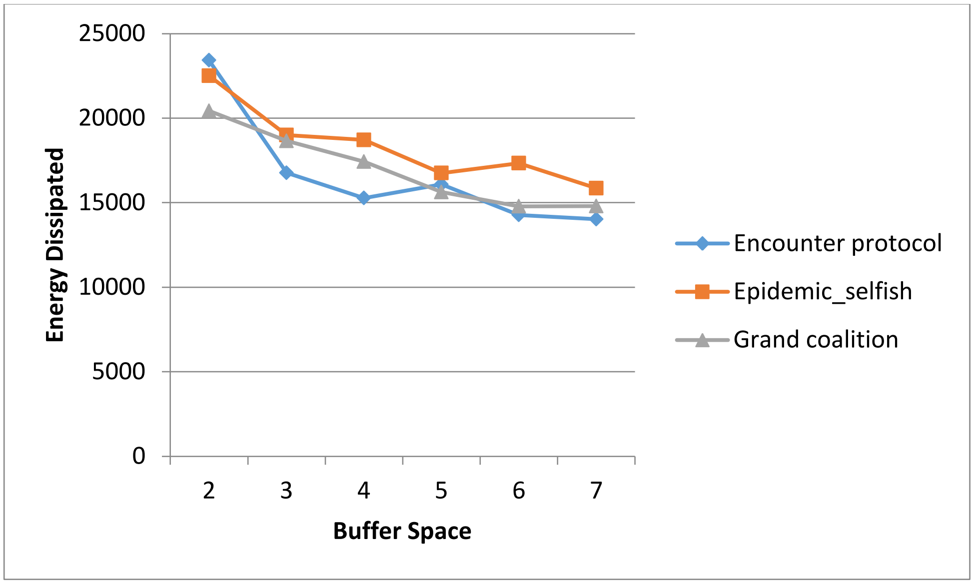
- Although the proposed protocol does not provide an efficient result in terms of overhead ratio, it is comparable and in par with the other two protocols compared.
- Lower overhead ratio in grand coalition may be attributed to the fact that the movement model used assumes source and destination to be nearer and in the same group of nodes.



(c)

Observations:

- Encounter protocol achieves lower delivery delay than the conventional grand coalition method.
- Selfishness induced Epidemic protocol achieves lower delay in message delivery due to its flooding based message forewarding technique.



(d)

FIGURE 4.2 GRAPHICAL RESULTS OF COMPARISN WITH SELFISHNESS BASED PROTOCOLS

Observations:

- Encounter protocol achieves lower energy dissipation and is hence suitable for application in areas requiring low energy dissipation and green energy criteria.

4.3 Summary

In this chapter, the overall working of the protocol is explained in detail. The usage of encounter history and delivery predictability, how coalitional game theory gets used in relay selection, shapley solution concept based cost division and how it mitigates selfishness behaviour has been discussed. Since selfishness occurs in terms of message drop policy, buffer space is the parameter taken under consideration for simulation. Extensive simulations have been performed comparing the research work with the existing benchmark protocols. Since the work focusses on game theoretic approach and selfishness, two subsidiary simulations on basic flooding based Epidemic routing and the trivial Grand Coalition method has been executed. Also the work adds an extra parameter as a performance metric: energy dissipated. The research work has been found to increase its efficiency in comparisn with the existing benchmark algorithms. Also in respect with the coalitional game theory, grand coalition method has been outperformed by the routing technique. The application of shapley solution concept has also been a unique part of the work.

CHAPTER 5

SUMMARY AND FUTURE WORK

The research work has mainly focussed upon the applications of game theoretical methods in Delay Tolerant networks. With focus on the coalition games the research work aims at non conventional or not so eyed upon area of game theory. Also cooperative game theory has been a less researched topic. The work also considers energy module as a parameter which has been a less concentrated parameter in the researches done on DTN. The work as an application of coalitional game theory in DTN achieves good result in the area of behaviour modelling of DTN nodes and selfishness avoidance. With the results comparing the existing benchmark algorithm, high delivery ratio, less overhead delay, delivery delay and energy dissipation becomes characteristic feature of the protocol. There exists different areas in which the work proposed can be improved and extended to. These areas include:

1. **Parameters of efficiency:** The work concentrated only on four parameters for efficiency measure namely delivery ratio, overhead ratio, delivery delay and energy dissipation. Different other characteristic like delivery deadline as a quality measurement could also be included in the work.

2. **Hardware or software credit system:** The work includes the usage of credits or reward points for message transfer initiation and forewarding. Without the existence of a centralised

credit bank either in hardware or software form challenges the credibility of the work. But concentrating on this aspect would make the intended thesis to divert from the main aim and problem statement. As a future work, credit banks could be integrated with the work for a more robust and credible system.

3. **Detection of selfish nodes:** The work is implemented with the assumption that all nodes in the network are selfish and hence require appropriate credits for message transfer. In real world scenario, all nodes are not selfish. Some nodes may be selfish and others may be cooperating to the transfer process from the beginning. Detecting the selfish nodes from the non selfish could provide enough information to the node transferring message so that it could target the selfish nodes with the incentive methods.

4. **Real test-bed experiments:** The simulations are carried out in synthetic test beds. However real traces can be of no extra use without the knowledge of the selfishness of different nodes in the network. The work could be extended to real test bed for more clarity on its efficiency.

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