ISLAMIC UNIVERSITY OF TECHNOLOGY

Effective Data Routing in Delay Tolerant Network Using Game Theory.

by

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Md. Rifat Hossain (092424) &

Zahidul Islam (092459)

A thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical & Electronic Engineering.

Academic Year: 2012-2013

Department of Electrical and Electronic Engineering

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Declaration of Authorship

We, Rumman Raihan (092476), Md Rifat Hossain (092424), Zahidul Islam (092459) declare that this thesis titled **"Effective Data Routing in Delay Tolerant Network Using Game Theory"** and the works presented in it are our own. We confirm that

- This work has been done for the partial fulfillment of BSc. in EEE.
- Any part of this thesis has not been submitted anywhere else for obtaining degree.

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Abstract

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This paper explores the theoretical approach to improve existing Delay and Disruption Tolerant Networking routing algorithms using Game Theory. Game Theory is a systematic study of strategic interaction among rational individuals. DTN deals with networks in challenged environment. DTN focuses on deep space to a broader class of heterogeneous networks that may suffer disruptions, affected by design decisions such as naming and addressing, message formats, data encoding methods, routing, congestion management and security. DTN is part of the Inter Planetary Internet with primary application being deep space networks. The hypothesis behind modeling DTN routing as a game is based on understanding that routing is also a strategic interaction between the DTN nodes. This brings cognitive abilities leading to automated routing decisions.

Summary

The DTN architecture aims to provide interoperable communications between a wide range of networks which may have exceptionally poor and disparate performance characteristics. The design embraces the notion of messages witching with in-network storage and retransmission, late-binding of names, and routing tolerant of network partitioning to construct a system better suited to operations in challenged environments than most other existing network architectures, particularly today's TCP/IP based Internet.

The proposed DTN architecture advocates a change to the basic service model and system interface most Internet-style applications have become accustomed to, motivated by the exceptionally poor performance present in some networks. This is a comparatively radical approach; other approaches aim to "repair" underlying link performance problems or alter limited portions of the Internet architecture, such as routing, with additional protocols in an effort to keep the current service model and existing TCP/IP based protocols constant. Because it provides a different type of network service than Internet, the DTN design makes a different set of choices in the architectural design space: messages versus packets, a form of hop-by-hop reliability and security versus end-to-end, name based routing versus address based routing, and a routing abstraction of partially-connected rather than fully-connected network graph. Interestingly, DTN can be overlaid upon the TCP/IP based Internet easily, and therefore remains compatible. This is not the most interesting case, however, as its strength lies in its ability to tie together dramatically different types of networks with unusual connectivity properties. As such, in some ways it makes more limited assumptions on the underlying protocol layers than IP does upon its underlying link layers.

Keywords: DTN - Delay and Disruption Tolerant Networking, BRG – Bundle Routing Game, PRoPHET – Probabilistic Routing Protocol using History of Encounters and Transitivity, Game Theory, Nash Equilibrium,BENEFIT,

CONTENTS

Chapter -1

Introduction

Data routing signifies the ability to transport data from a source to a destination and is the fundamental ability for any communication system. Effective data routing means the ability to transport or route data from a source to a desired destination under various challenged environments. The next few paragraphs in this chapter will show the basic needs of delay tolerant network, perspectives of game theory and basic summary of the simulations included in the study.

1.1 Networks and Routing

Effective data routing deals with the process of selecting the best path for various conditions in a network along which to send network traffic. Routing is performed for many kinds of networks, including the telephone network (circuit switching), electronic data networks (such as the Internet), transportation network, Delay tolerant network etc. The routing procedure of data is effective, if it can transmit data withstanding the various challenged conditions, such as lack of instantaneous end-to-end connections, distance, natural calamities, wiring effects etc. Let us first see various networks and their routing protocols.

1.1.1 Telephone Network

A **Telephone Network** is a telecommunication network used for telephone calls between two or more parties.

There are a number of different protocols used for telephone network:

- A fixed line protocol is one, where the telephones must be directly wired into a single telephone exchange. This is known as the Public Switched Telephone Network or PSTN.
- In the case of wireless network the telephones are mobile and can move around anywhere within the coverage areas.

- A private network is mainly used by closed groups where the telephones are connected primarily to each other and use a gateway to reach the outside world. This is usually used inside companies and call-centers and is called private Branch Exchange (PBX).

Public telephone operators (PTOs) own and build networks of the first two types and provide services to the public under license from the national government. Virtual Network Operators (VNOs) lease capacity wholesale from the PTOs and sell on Telephony service to the public directly.

1.1.2 Electronic Data Network

An **Electronic Data Network** or **Computer Network** is the form of telecommunication network which allows computers to transmit data or to route data from one to another. In computer networks, networked computing devices or network nodes pass data to each other along data routes. The connections or the links between nodes are established using either cable wires or wireless media. The most popular and most used computer network is the Internet.

Networking nodes can be defined as the networking devices that originate, route and terminate the data. Nodes include various electric devices, i.e. hosts such as servers and personal computers, as well as networking hardware. Two nodes are said to be connected when each device is able to exchange information with another device.

Various applications are supported by Computer networks. One of the most popular applications supported by computer networks is the World Wide Web. Other supported applications are such as shared use of application and storage servers, printers, and fax machines, and use of email and instant messaging applications.

For data routing the networking nodes must be linked with each other. The device or equipment used to link the networking nodes to form a computer network is called the communication media. The communication media can be of two types. Either there can be a wired connection between the two nodes or the connection can be wireless. For the wired connection the mostly used communication medias are twisted pair cable, coaxial cable, ITU-T G.hn, optical fiber etc. Wireless technology mainly uses terrestrial microwave, communications satellites, Cellular and PCS systems, radio and spread spectrum technologies, infrared communications, global area network (GAN) etc.

1.1.3 Transport Network

A **transport network** or **flow network** can be called the network of nodes, streets, pipes, aqueducts, power lines, or nearly any structure that permits either vehicular movement or flow of some commodity.

The analysis of the transport network can be used to determine the flow of vehicles or people through a transport network. Mathematical graph theory is commonly used to calculate the desired result . Different modes of transport can be combined using this theory, for example, walking and car, to model multi-modal journeys. Transport engineering mainly deals with the transport network analysis.

In graph theory, a transportation network or flow network is a directed graph where each edge receives its flow and have a capacity. The amount of flow should not exceed the capacity of the edge. Often in Operations Research, a network is the directed graph, the vertices are the nodes and the edges are called arcs. A flow must satisfy the restriction that the amount of flow into a node equals the amount of flow out of it, except when it is a source, which has more outgoing flow, or sink, which has more incoming flow. A network can be used to model traffic in a road system, fluids in pipes, currents in an electrical circuit, or anything similar in which something travels through a network of nodes.

1.2 Delay Tolerant Network (DTN)

Delay tolerant networks are characterized by the lack of instantaneous **end-to-end** connectivity. Popular ad hoc routing protocols such as Ad hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR) fails to establish connection if it does not get a instantaneous end-to-end connection between the two networking nodes. These protocols first try to establish a complete route and then, after establishing the complete route forward the actual data to the destination. In the case of discontinuous end-to-end connection routing protocols can't follow maximize the probability of successful data transfer, the common technique is to send several copies of the transmitted data among the network. AOVS or DSR. It must take a 'store and forward' mechanism in order to withstand the discontinuity. It is the protocol of Delay Tolerant Network. The store and forward technique can be defined as the technique, where data is incrementally moved and stored throughout the network in hopes that it will eventually reach its destination by creative successive links between the nodes. To

1.3 History

The first step to begin the research of the field which is known today as Delay Tolerant Network was taken by United States government grants as projects relating to the necessity of networking technologies that can sustain the significant delays and packet corruption of space travel. It was initially developed for short range data transmission.

Advanced Research Projects Agency (ARPA), known today as Defense Advanced Research Projects Agency or DARPA issued a numerous government grants to both academic institution and industries to research technical details of communication between Earth and an orbiting satellite. With the exclusion of Earth-based communication to space, there was little research in the 1980s and early 1990s in communication with the presence of a delay or disruption in the communicating field. In the recent periods of time the study of data routing with frequent delay and discontinuity is becoming more and more popular for its usefulness in the case of effective data routing.

1.4 DTN and Game Theory

Effective data routing in the presence of discontinuity or delay can be achieved by using delay tolerant networking protocol. In the 'store and forward' mechanism the transmitter sends the data to a node and the node stores this data until it can successfully pass the data to a subsequent node, the next node does the same until the data is sent to the desired location. In order to create successful links among the nodes various connecting protocols can be used. The definition of game theory deals with strategic decision-making of two individuals; for our study we can say decision-making of two nodes. Especially the concept of nash equilibrium in game theory is extensively used to influence the decision of individual nodes. Nash equilibrium, named after John Forbes Nash Jr. is the solution concept of non-cooperative interactions involving two or more individuals. For data routing through nodes the cooperation of nodes is the key parameter for increased efficiency. In order to gain the cooperative behavior of nodes the concept of game theory and Nash equilibrium is used.

The earlier fields of application of game theory are economics, political science, and psychology. But now-a-days this theory finds its application in the fields of logic, biology as well as telecommunication. In 1713,the first discussion of game theory was found in a letter by James Waldegrave. In 1838, Antoine Augustin Cournot presented a restricted version of the game theory. This theory was developed extensively in the 1950s by many scholars.

1.5 Simulation

The simulation profile of data routing under various conditions is established in the study using the software 'Netlogo'. This software is mainly used for designing social and natural activities and to show the change in the environment by changing various parameters. Various results in various perspectives can also be calculated by use of proper codes. Codes allow us to place the elements which are to interact in the experimenting environment. The elements interact with time. They will act in normal and changed conditions according to the coding involved regarding their properties. Each element can be considered individually in the modeling procedure.

The coding procedure involves two parts. One deals with the designing of the environments. This involves placement of objects, shape and size of objects, types of objects and initial values of different parameters. Second part is the main part; it deals with the nature or behavior of objects with time. It contains coding regarding the running procedure, interacting procedure, change in properties. In a nutshell we can say it defines the logic of the objects.

Chapter – 2

Delay Tolerant Network

Today's Internet may operate poorly in some environments which is stated as *'challenged networ*ks' although the architecture and protocols of Internet is highly successful and effective. So under this kind of environments we have to look for alternative communication architecture rather than the Internet for a successful communication between or among the networks and nodes. Such an communication network can be **Delay Tolerant Network (DTN).**

2.1 Internet and Challenged Networks

The existing Internet service of our generation is based on TCP/IP model. It can provide good end to end inter-process communication although several key assumptions are to be followed regarding the overall performance characteristics. These are : existence of an end to end connection between the source and sink, end to end data drop probability is less, round trip delay time is not large. The data communication in environments which follow these conditions can be simply done by Internet. But several '*challenged networks'* violating one or all the assumptions cannot use Internet as they might not be well served by the existing TCP/IP model.

At a glance, challenged networks can be characterized by very long delays and no end to end connection. End nodes with limited power and memory storages make the problem more complex. The path and link characteristic of challenged networks are stated below :

- **High latency** : Disregarding the processing and queuing delays , the transmisson and propagation delays of a link may be comparataively large (minutes, hours in some case even days) .

- **Low data rate** : For some challenged networks data transmission rates may be very poor. Besides, data rates of uplink and downlink may be highly asymmetric.The worst case can be if there is no return channel available.

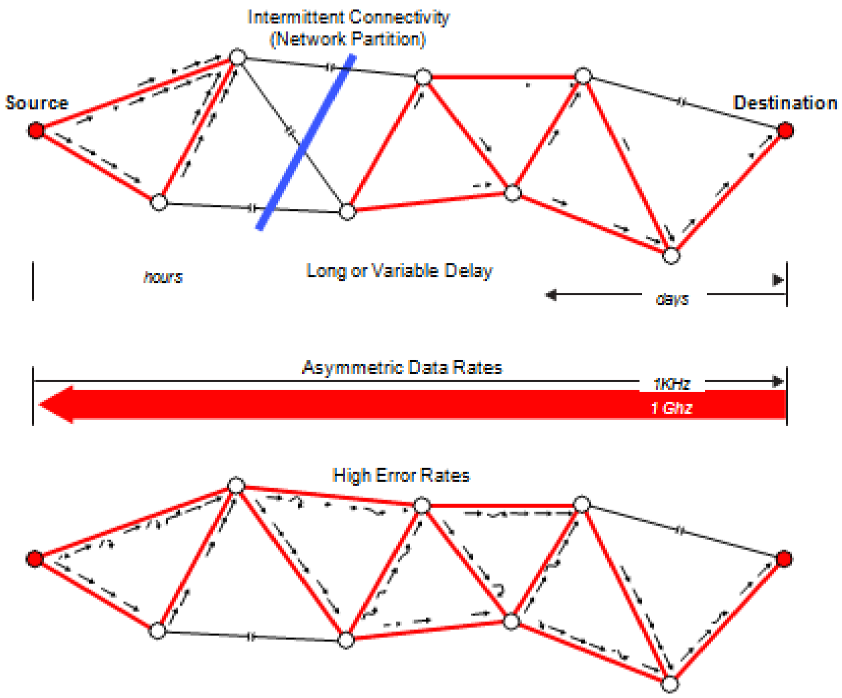


Fig 2.1: challanged networks characteristics

- **End to end disconnection** : Due to faults or not in most of the challanged networks end to end disconnection is rather common than the end to end connection. In the wireless environments disconnection can ocuur due to the mobility and limited energy sources of the interconnecting nodes. In our work we considered the movement of the nodes random but yet predictable(orbiting sats, routes of vehicles acting as a DTN node) while the low duty cycle is very common in DTN nodes .

- **Long queuing time and high error rates**: In comparisons to other networks the queuing time of some challanged networks may be extremely large specially when no end to end connection is available as well as the error rate.

Some of such network is terrestrial mobile networks, military Ad-hoc network, sensor or actuator network, exotic media network and so on.

2.2 Motivation of DTN

Some of the problems posed by challenged internetworks can be dealt by proxies, PEPs and electronic mail but yet they do not provide a complete solution. Disconnected paths, limited capability or longevity end devices and unusual routing may pose some difficulties for the direct use of IP's addressing and routing features. Besides, the packets are dropped if a next hop route is not immediately available which may result in data loss and no communication between the nodes/networks. For reliable and effective data delivery , Internet's idea of fate sharing suggests that per connection state should remain only on end- stations because a failure of one of them would render the data connection useless. But in many challenged networks this does not happen because it may be quite useful to allow a node to 'hand off' its end –node connection state if it has other tasks to perform specially for devices which possess limited power and memory. This will not endanger fate sharing entirely but would represent a different fate sharing behavior than the current Internet.

Moreover, applications designed with assumptions of low delay can also cause problems in case of operation over challenged networks. Indeed it may be advantageous to provide applications with a direct indication as to expect ordinary or extraordinary delays and allow them to customize their tasks accordingly.

Given the assumptions, the most desirable framework for supporting challenged internets would appear to be a network service and API providing a sort of least common denominator interface: non-interactive messaging. Based on experience with the Internet, we conclude such a system should combine some overlay routing capability such as is present in peer-to-peer systems with the delay-tolerant and disconnection-tolerant properties of electronic mail. If implemented at the application layer (in the form of a proxy), such a system could conceivably provide a gateway function between radically dissimilar networks. These considerations together motivate the articulation of a new architecture, which is Delay Tolerant Network (DTN).

2.3 Basic Architecture of DTN

The architecture proposed for interoperability between and among challenged networks is called the *Delay Tolerant Networking* architecture (DTN). It is based on an abstraction of message switching. Message aggregates are known as "bundles". The routers that handle them are called "bundle forwarders" or DTN gateways.

2.3.1 Concept of DTN

A delay-tolerant network (DTN) is a network of regional networks. It is an overlay on top of regional networks, including the Internet. DTNs support interoperability of regional networks as it can accommodate long and variable delays between and within regional networks, and can translate between regional network communication characteristics. In addition to providing these functions, DTNs accommodate the mobility and limited power of evolving wireless communication devices.

The wireless DTN technologies may be diverse, which includes not only radio frequency (RF) but also ultra-wide band (UWB), free-space optical, and acoustic (sonar or ultrasonic) technologies.

2.3.2 DTN Regions and Gateways

Mainly because of the fact that DTN is an "overlay" architecture, it is intended to operate above the existing protocol stacks in various network architectures and provide a '*store-and forward'* gateway function between them when a node physically touches two or more networks which may be dissimilar. A simple example of various dissimilar networks and interoperability between them is given below:

Within the Internet the overlay may operate over TCP/IP, for deep space links it may provide a gateway service to CFDP, and in delay-tolerant sensor/actuator networks it may provide interconnection with some sensor transport protocol. Each of these networking environments stated above have their own specialized protocol stacks and naming semantics developed for their particular application domain . Interoperability between them is accomplished by special DTN gateways located at their interconnection points.

The DTN architecture includes the concepts of regions and DTN gateways as showed in the following figure :

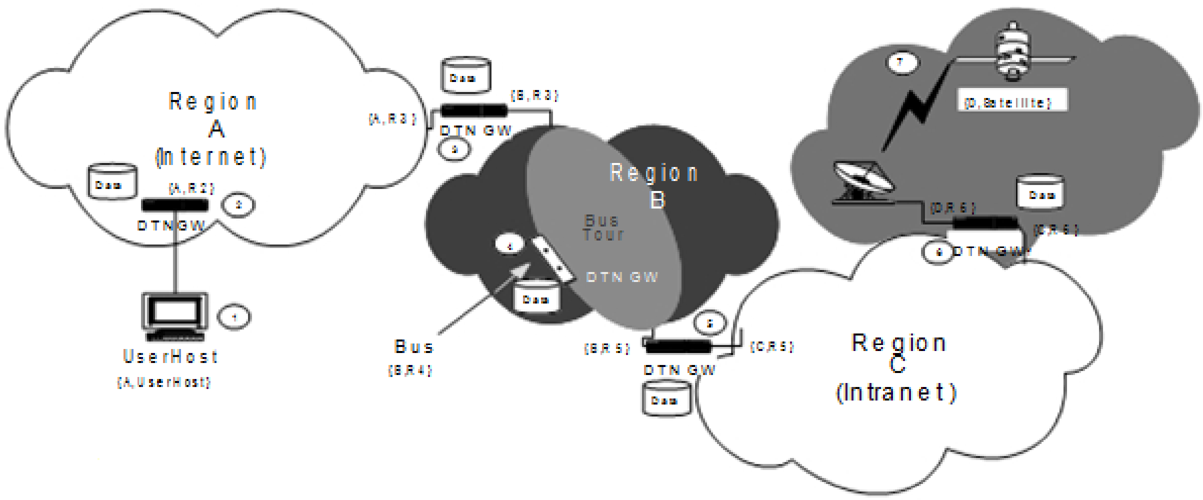


Fig 2.2: DTN gateways interconnected regions

Each region has a unique region ID which is knowable among all regions of the DTN and is part of each node's name. DTN gateways have membership in two or more regions and are the only means of moving messages between regions.

Region boundaries are used as interconnection points between dissimilar network protocol and addressing families. More formally, two nodes are in the same region if they can communicate without using DTN gateways.

DTN gateways are focused on reliable message routing instead of best-effort packet switching. DTN gateways are responsible for storing messages in nonvolatile storage when reliable delivery is required and mapping between differing transports by resolving globally significant name tuples to locally resolvable names for traffic destined internally to an adjacent region.

2.3.3 Names and Addresses

For routing of DTN messages, we elect to use identifiers for objects or groups of objects called 'name tuples' which comprises two variable length portions. In figure 2.2, the DTN name tuple(s)for each end point and each router "half" is illustrated in curly braces. The general form of name tuple is

{Region Name, Entity Name}.

The first portion is a globally-unique, hierarchically structured region name. DTN gateways interpret it to find the path(s) to one or more DTN gateways at the edge of the specified region.

The second portion identifies a name which is resolvable within the specified region and it does not need to be unique outside the region.

For example, in case of the Internet, the tuple may be like following: *{internet.icann.int, "http://www.ietf.org/oview.html"}.*

This tuple would refer to the Internet region along with an Internet-specific local identifier(URI). As a message transits across a collection of regions, only its region identifier is used for routing. After reaching the edge of the destination region, the entity name information is locally-interpreted, and translated if necessary, into a protocol-standard name (or address) appropriate to the containing region.

This method of resolving names results in a form of late binding for tuples in which only the portion of the tuple (the region portion) immediately needed for message forwarding is used by DTN gateways. By not imposing any particular fixed structure on the second portion of a tuple, any reasonable naming scheme can be easily accommodated, even unusual ones.

For challenged networks, the need to consult a name-to-address mapping that may be resident only in the destination region seems impractical given potentially large end-to-end delays.

2.3.4 Selection of Paths and Schedule

The DTN architecture is applied at networks where an end-to-end routing path does not exist. Rather, routes are comprised of a cascade of time-dependent contacts (communication opportunities) used to move messages from their origins toward their destinations. Contacts are parameterized by their start and end times (relative to the source), capacity, latency, endpoints, and direction. Contacts might be of two types.

- **Opportunistic contacts** : Network nodes may need to communicate during opportunistic contacts, in which a sender and receiver make contact at an unscheduled time. Moving people, vehicles, aircraft, or satellites may make contact and exchange information when they happen to be within line-of-sight , within range of transmissoin and close enough to communicate using their available (often limited) power.

  All of us use opportunistic contacts for communication: when we happen by chance, to meet certain people with whom we wish to talk, we talk. This same model can apply to electronic communication. For example, wireless Personal Digital Assistants (PDAs) can be designed and programmed to send or receive information when certain people carrying the PDAs come within communication range.

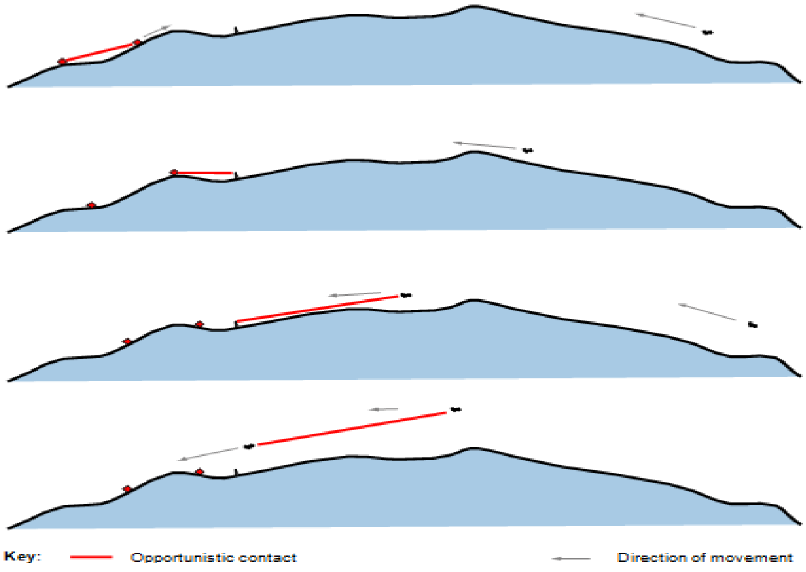


Fig 2.3 : opportunistic contacts

- **Scheduled Contacts** : Scheduled contacts may involve message-sending between nodes that are not in direct contact. If potentially communicating nodes move along predictable paths, they can predict or receive time schedules of their future positions and thereby arrange their future communication sessions.

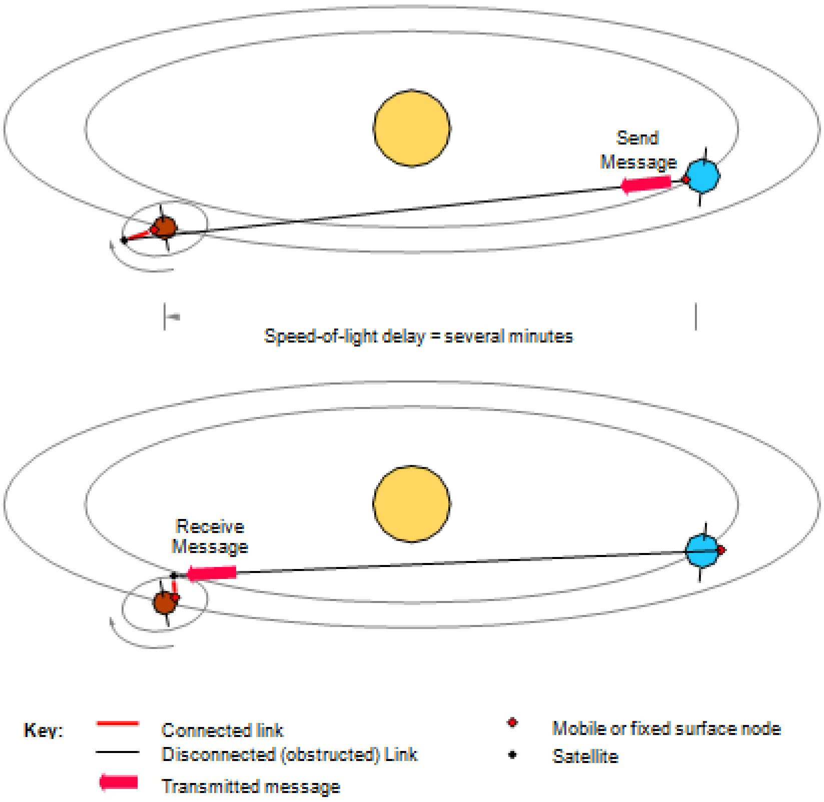


Fig 2.4: scheduled contacts

They may also involve storing information until it can be forwarded, or until the receiving application can catch up with the sender's data rate. Scheduled contacts require time-synchronization throughout the DTN.

2.3.5 Custody Transfer and Reliability

A custody transfer refers to the acknowledged delivery of a message from one DTN hop to the next and the corresponding passing of reliable delivery responsibility.

The DTN architecture includes two distinct types of message routing nodes: persistent and non-persistent. Persistent nodes are assumed to contain nontrivial amounts of permanent message store, and non-persistent nodes might not. Unless they are unable or unwilling to store a particular message, persistent nodes generally participate in '*custody transfer*' using the appropriate transport protocols of the containing region as they have the space to store a message or data for an indefinite time until another node takes the custody or expiration of the bundle's time-to-live, which is intended to be much longer than a custodian's time-to-acknowledge. However, the time-to-acknowledge should be large enough to give the underlying transport protocols every opportunity to complete reliable transmission.

Custody transfers do not provide guaranteed end-to-end reliability. This can only be done if a source requests both custody transfer and return receipt. In that case, the source must retain a copy of the bundle until receiving a return receipt, and it will retransmit if it does not receive the return receipt.

2.4 'Store and Forward' Message Switching

By using 'store-and-forward' message switching DTNs overcome the problems associated with intermittent connectivity, long or variable delay, asymmetric data rates, and high error rates. This is an old method, used by pony-express and postal systems since ancient times. Whole messages (entire blocks of application program user data)—or pieces (fragments) of such messages—are moved (forwarded) from a storage place on one node (switch intersection) to a storage place on another node, along a path that eventually reaches the destination.

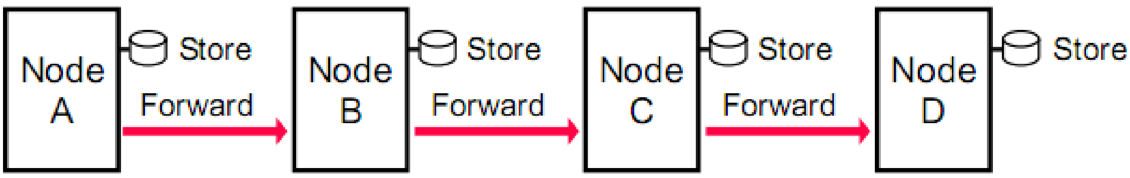


Fig 2.5 : ‘Store and forward’ method

Today’s voicemail and email systems also use Store-and-forwarding methods although these systems are not one-way relays (as shown above) but rather star relays where both the source and destination independently contact a central storage device at the center of the links.

The storage places (such as hard disk) can hold messages indefinitely. They are called persistent storage (as stated before) as opposed to very short-term storage provided by memory chips.

The reasons for which DTN routers need persistent storage for their queues are stated below:

- A communication link to the next hop may not be available for a long time.
- One node in a communicating pair may send or receive data much faster or
  more reliably than the other node.
- A message, once transmitted, may need to be retransmitted if an error oc-
  curs.

By moving whole messages (or fragments) in a single transfer, the message-switching technique provides network nodes with immediate knowledge of the size of messages, and therefore the requirements for intermediate storage space and retransmission bandwidth.

2.5 The Bundle Layer

The DTN architecture implements store-and-forward message switching by overlaying a new protocol layer which is called the bundle layer. It is implemented on top of heterogeneous region-specific lower layers. The bundle layer ties together the region-specific lower layers so that application programs can communicate across multiple regions.

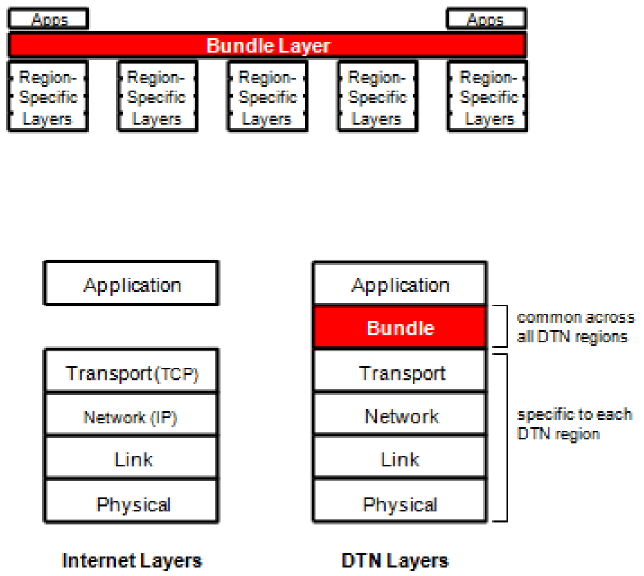


Fig 2.6 : DTN and Internet protocol layers comparison

The figure above illustrates the bundle overlay (top) and compares Internet protocol layers with DTN protocol layers (bottom).

Bundles are also called messages. The bundle layer stores and forwards entire bundles (or bundle fragments) between nodes. A single bundle layer protocol is used across all networks (regions) that make up a DTN. By contrast, the layers below the bundle layer (the transport layer and others) are chosen for their appropriateness to the communication environment of each region.

2.6 DTN Nodes

In a DTN, a node is an entity with a bundle layer. DTN nodes are the main media to transfer data. Any wireless device, sensor/actuator or other devices capable of transmitting and receiving data as well as storing them in a persistent storage can be considered as a node. A node may be a host, router, or gateway (or some combination).Node may act as a source, destination, or forwarder of bundles.

Host: Sends and/or receives bundles, but does not forward them. A host can be a source or destination of a bundle transfer. The bundle layers of hosts that operate over long-delay links require persistent storage in which to queue bundles until outbound links are available. Hosts may optionally support custody transfers.

Router: Forwards bundles within a single DTN region and may optionally be a host. The bundle layers of routers that operate over long-delay links require persistent storage in which to queue bundles until outbound links are available. Routers may optionally support custody transfers.

Gateway: Forwards bundles between two or more DTN regions and may optionally be a host. The bundle layers of gateways must have persistent storage and support custody transfers. Gateways provide conversions between the lower-layer protocols of the regions they span.

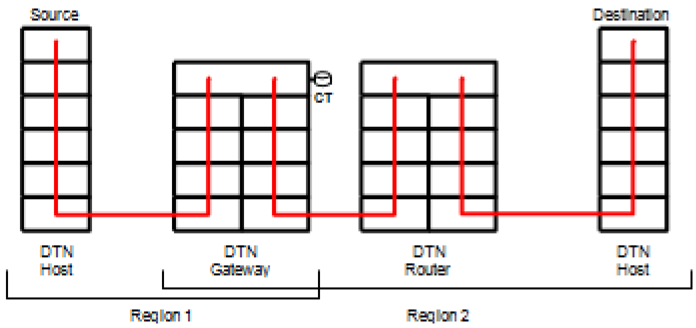


Fig 2.7 : DTN Nodes specified in protocol layers

2.7 Network Application Interface

As we already know the DTN architecture is implemented as an overlay network using messages as the primary unit of data interchange. Applications making use of the architecture must be careful not to expect timely responses and must generally be capable of operating in a regime where a request/response turn-around time exceeds the expected longevity of the client and server processes as the very network is called *'Delay Tolerant Network'*.

Moreover, applications must be prepared to handle the creation and manipulation of name tuples and their registrations , class of service specifiers, and authentication information. The application interface is non-blocking, and callback registrations are persistent. Generally speaking, all DTN applications should be structured to continue operating in the face of reboots or network partitioning as much as possible.

Chapter 3

Game Theory

3.1 Overview of Game Theory

Humans cannot survive without interacting with other humans, and ironically, it sometimes seems that we have survived despite those interactions. Production and exchange require cooperation between individuals at some level but the same interactions may also lead to disastrous confrontations. Human history is as much a history of fights and wars as it is a history of successful cooperation. Many human interactions carry the potentials of cooperation and harmony as well as conflict and disaster. Examples are abounding: relationships among couples, siblings, countries, management and labor unions, neighbors, students and professors, and so on. One can argue that the increasingly complex technologies, institutions, and cultural norms that have existed in human societies have been there in order to facilitate and regulate these interactions. For example, internet technology greatly facilitates buyer-seller transactions, but also complicates them further by increasing opportunities for cheating and fraud. Workers and managers have usually opposing interests when it comes to wages and working conditions, and labor unions as well as labor law provide channels and rules through which any potential conflict between them can be addressed.

Similarly, several cultural and religious norms, such as altruism or reciprocity, bring some order to potentially dangerous interactions between individuals. All these norms and institutions constantly evolve as the nature of the underlying interactions keep changing. In this sense, understanding human behavior in its social and institutional context requires a proper understanding of human interaction. Economics, sociology, psychology, and political science are all devoted to studying human behavior in different realms of social life.

However, in many instances they treat individuals in isolation, for convenience if not for anything else. In other words, they assume that to understand one individual's behavior it is safe to assume that her behavior does not have a significant effect on other individuals. In some cases, and depending upon the question one is asking, this assumption may be warranted. For example, what a small farmer in a local market, say in Montana, and charges for wheat is not likely to have an effect on the world wheat prices.

Similarly, the probability that my vote will change the outcome of the U.S. presidential elections is negligibly small. So, if we are interested in the world wheat price or the result of the presidential elections, we may safely assume that one individual acts as if her behavior will not affect the outcome.

In many cases, however, this assumption may lead to wrong conclusions. For example, how much our farmer in Montana charges, compared to the other farmers in Montana, certainly affects how much she and other farmers make? If our farmer sets a price that is lower than the prices set by the other farmers in the local market, she would sell more than the others, and vice versa. Therefore, if we assume that they determine their prices without taking this effect into account, we are not likely to get anywhere near understanding their behavior. Similarly, the vote of one individual may radically change the outcome of voting in small committees and assuming that they vote in ignorance of that fact is likely to be misleading. The subject matter of game theory is exactly those interactions within a group of individuals (or governments, firms, etc.) where the actions of each individual have an effect on the outcome that is of interest to all.

Yet, this is not enough for a situation to be a proper subject of game theory: The Game theory studies strategic interactions way that individuals act has to be strategic, i.e., they should be aware of the fact that their actions affect others. The fact that my actions have an effect on the outcome does not necessitate strategic behavior, if I am not aware of that fact. Therefore, we say that game theory studies strategic interaction within a group of individuals. By strategic interaction we mean that individuals know that their actions will have an effect on the outcome and act accordingly. Like any other theory, the objective of game theory is to organize our knowledge and increase our understanding of the outside world. A scientific theory tries to abstract the most essential aspects of a given situation, analyze them using certain assumptions and procedures, and at the end derive some general principles and predictions that can be applied to individual instances. For it to have any predictive power, game theory has to postulate some rules according to which individuals act. If we do not describe how individuals behave, what their objectives are and how rules of the game they try to achieve those objectives we cannot derive any predictions at all in a given situation.

The most important, and maybe one of the most controversial, assumption of game theory which brings about this discipline is that individuals are rational. An individual is rational if she has well-defined objectives (or preferences) over the set of possible outcomes and she implements the best available strategy to pursue them. Rationality implies that individuals know the strategies available to each individual, have complete and consistent preferences over possible outcomes, and they are aware of those preferences. Furthermore, they can determine the best strategy for themselves and flawlessly implement it. If taken literally, the assumption of rationality is certainly an unrealistic one, and if applied to particular cases it may produce results that are at odds with reality.

We should first note that game theorists are aware of the limitations imposed by this assumption and there is an active research area studying the implications of less demanding forms of rationality, called bounded rationality. The term strategic interaction is actually more loaded than it is alluded to above. It is not enough that I know that my actions, as well as yours, affect the outcome, but I must also know that you know this fact.

Take the example of two wheat farmers. Suppose both farmer A and B know that their respective choices of prices will affect their profits for the day. But suppose, A does not know that B knows this. Now, from the perspective of farmer A, farmer B is completely ignorant of what is going on in the market and hence farmer B might set any price. This makes farmer A's decision quite uninteresting itself. To model the situation more realistically, we then have to assume that they both know that they know that their prices will affect their profits. One actually has to continue in this fashion and assume that the rules of the game, including how actions affect the participants and individuals' rationality, are common knowledge. A fact X is common knowledge if everybody knows it, if everybody knows that everybody knows it and so on. This has some philosophical implications and is subject to a lot of controversy, but for the most part we will avoid those discussions and take it as given. In sum, we may define game theory as follows:

Game theory is a systematic study of strategic interaction among rational individuals. Its limitations aside, game theory has been fruitfully applied to many situations in the realm of economics, political science, biology, law, etc. This paper attempts to apply game theory to data routing too.

There are **four** elements to describe a game:

1. players;

2. rules: when each player moves, what are the possible moves, what is known to each player before moving;

3. outcomes of the moves;

4. payoffs of each possible outcome: how much money each player receive for any specific outcome.

3.2 Game Forms

The Games are analyzed along 2 different dimensions:

1. Order of Moves

2. Information

This leads to **four** general forms of game namely:

1. Strategic Form Games with Complete Information and Simultaneous moves

2. Bayesian Games with Incomplete Information and Simultaneous moves

3. Extensive form Games with Complete Information and Sequential Moves

4. Extensive form Games with Incomplete Information and Sequential Moves.

The success of this problem description lies with the seamless co-relation of the DTN node behavior to the players of the Game. It is perfectly acceptable to have a game based on machine or automated decisions as well. Such a game fits into one of the 4 game forms depending on the parameters that are considered to make the routing decision. In the following paragraphs, a brief treatment of DTN routing with each of the Game forms is discussed.

TABLE 3,1: Game Forms.

		Information	
		Complete	Incomplete
Moves	Simultaneous	Strategic Form Games with Complete Information	Bayesian Games
	Sequential	Extensive Form Games with Complete Information	Extensive Form Games with Incomplete Information

3.3 Nash Equilibrium

The most commonly used solution concept in game theory is that of Nash equilibrium. This notion captures a steady state of the play of a strategic game in which each player holds the correct expectation about the other players' behavior and acts rationally. It does not attempt to examine the process by which a steady state is reached. The solution (routing decision) of the game (of forwarding bundles) in this case is based on Nash Equilibrium. The solution theory has two components.

1. Each Node chooses its action according to the model of rational choice, given its belief about the other Nodes' actions.

2. Every Nodes' belief about the other Node's action is incorrect.

These two components are embodied in the definition-

A Nash equilibrium is an action profile a* with the property that no player i can do better by choosing an action different from ai*, given that every other player j adheres to aj*.

In other words, the players (Nodes) act in accordance with the theory of rational choice (of forwarding), given their beliefs about the other players (Nodes) actions, and these beliefs are correct. In the idealized setting in which the players (Nodes) in any given play (of forwarding bundles) are drawn from a collection of population (of Nodes), a Nash Equilibrium corresponds to a steady state. If, whenever the game is played, the action profile is the same Nash equilibrium a*, then no player has a reason to choose any action different from its component of a*; there is no pressure on the action profile to change. Expressed differently, a Nash equilibrium embodies a stable "social norm": if everyone else adheres to it, no individual wishes to deviate from it.

The second component of the theory of Nash Equilibrium – that the players' beliefs about each other's actions are correct – implies, in particular, that the two players' belief about a third player's action is the same. For this reason, the condition is sometime referred to as the requirement that the player's "expectations are coordinated". The situations to which Nash Equilibrium is applied may not apply to idealized scenario only. Nash Equilibrium depends on the Best Response Function of the Game. The Best Response function of a Game in which each player (Node) has only a few actions (Generate, Receive or Forward the Bundle) is found by examining each action profile in turn to see if it indeed satisfied the conditions for equilibrium. In more complicated Games (Routing decisions), it have been observed to be better to work with the players' (Nodes') "Best response functions". All games need not necessarily have Nash equilibrium. Example is matching penny which does not have Nash Equilibrium.

3.4 An Instructive Example

One way to describe a game is by listing the players (or individuals) participating in the game, and for each player, listing the alternative choices (called actions or strategies) available to that player. In the case of a two-player game, the actions of the first player form the rows , and the actions of the second player the columns, of a matrix. The entries in the matrix are two numbers representing the utility or payoff to the first and second player respectively. A very famous game is the Prisoner's Dilemma game. In this game the two players are partners in a crime who have been captured by the police. Each suspect is placed in a separate cell, and offered the opportunity to confess to the crime. The game can be represented by the following matrix of payoffs

	Person 2		
Person 1		not confess	confess
	not confess	5,5	20,0
	confess	0,20	10,10

Note that lower numbers are better (more utility). If neither suspect confesses, they get jail for 5 years each. However, if one prisoner confesses and the other does not, the prisoner who confesses testifies against the other in exchange for going free while the prisoner who did not confess goes to prison for 20 years. If both prisoners confess, then both get jail for 5 years: better than having the other prisoner confess, but not so good as going free.

This game has fascinated game theorists for a variety of reasons.

First, it is a simple representation of a variety of important situations. For example, instead of confess/not confess we could label the strategies "contribute to the common good" or "behave selfishly." This captures a variety of situations economists describe as public goods problems.

An example is the construction of a bridge. It is best for everyone if the bridge is built, but best for each individual if someone else builds the bridge. This is sometimes referred to in economics as an externality. Similarly this game could describe the alternative of two firms competing in the same market, and instead of confess/not confess we could label the strategies "set a high price" and "set a low price." Naturally it is best for both firms if they both set high prices, but best for each individual firm to set a low price while the opposition sets a high price.

A second feature of this game , is that it is self-evident how an intelligent individual should behave. No matter what a suspect believes his partner is going to do, it is always best to confess. If the partner in the other cell is not confessing, it is possible to get 0 instead of 5. If the partner in the other cell is confessing, it is possible to get 10 instead of 20.

A third feature of this game is that it changes in a very significant way if the game is repeated, or if the players will interact with each other again in the future. Suppose for example that after this game is over, and the suspects either are freed or are released from jail they will commit another crime and the game will be played again. In this case in the first period the suspects may reason that they should not confess because if they do not their partner will not confess in the second game. Strictly speaking, this conclusion is not valid, since in the second game both suspects will confess no matter what happened in the first game.

However, repetition opens up the possibility of being rewarded or punished in the future for current behavior, and game theorists have provided a number of theories to explain the obvious intuition that if the game is repeated often enough, the suspects ought to cooperate.

3.5 Step by step procedure to find Nash equilibrium of a payoff matrix

Step 1 look at the payoff matrix and figure out whose payoff's are whose

	Person 2		
Person 1		not confess	confess
	not confess	5,5	20,0
	confess	0,20	10,10

Step 2 figure out person 1's best response to all of person 2's actions

	Person 2		
Person 1		not confess	confess
	not confess	5,5	20,0
	confess	**0**,20	**10**,10

Step 3 similarly figure out person 2’s best response to all person 1’s actions

	Person 2		
Person 1		not confess	confess
	not confess	5,5	20,**0**
	confess	**0**,20	**10**,**10**

Step 4 Nash Equilibrium exists where person 1’s best response stays with person 2’s best response.

So both persons will confess. This is the Nash Equilibrium.

Chapter – 4

4.1 Application of Game Theory in Routing

4.1.1 Implementation of Game Theory in Data Routing

A node can perform **four** job. It can

1. Generate
2. Store
3. Receive or/and
4. Forward

any data. And the payoff matrix of this situation will look like

<table>
<tr><td></td><td colspan="3">Node 2</td></tr>
<tr><td rowspan="3">Node 1</td><td></td><td>Strategy 1</td><td>Strategy 2</td></tr>
<tr><td>Strategy 1</td><td>(generate + forward),
(generate + forward)</td><td>(Generate + forward),
(Generate + forward+ Receive +store +forward)</td></tr>
<tr><td>Strategy 2</td><td>(Generate +forward+ Receive + store + forward),
(Generate + forward)</td><td>(Generate + forward+ Receive + store + forward),
(Generate + forward+ Receive +store +forward)</td></tr>
</table>

4.1.2 Calculation of Nash Equilibrium

Any task performed by a node causes its battery energy consumption. So we considered the payoff in a common unit, Energy loss.

For easier calculation we assumed:

GENERATE (G) →-1 unit

STORE(S) → -1 unit

RECEIVE (R) → -1 unit

FORWARD (F) →-1 unit

This unit can be any energy unit like electron volt (eV), Joule (J), kilojoule (kJ)

So strategies available for any node-

Strategy 1→ generate + forward = (-2)

Strategy 2→ generate + forward + receive + store + forward = (-5)

So payoff matrix will be-

	Node 2		
Node 1		Strategy 1	Strategy 2
	Strategy 1	(-2),(-2)	(-2),(-5)
	Strategy 2	(-5),(-2)	(-5),(-5)

Here both player's best strategy is the strategy 1 since the Nash equilibrium point is in the 1st box. So all nodes will act selfish. But selfish is not desirable. So we have to motivate them to co-operate. Benefit is a concept which will be used to motivate them by moving the Nash equilibrium to 4th box.

4.2 What is Benefit

Benefit is an extra payoff given to any node in order to motivate them to co-operate. Nodes act selfish because of their limited energy. So we will allow them to recharge if they co-operate. For a single co-operation a nodes payoff value will increase (shown in the following payoff).

At a point, nodes can use this payoff values for recharge when it needs.

Scenario 1 when Benefit is less than 5(total energy loss), i.e 2

Strategy 1→ generate + forward = (-2)

Strategy 2→ generate + forward + receive + store + forward (-5) + BENEFIT (2) = (-3)

	Node 2		
Node 1		Strategy 1	Strategy 2
	Strategy 1	(-2),(-2)	(-2),(-3)
	Strategy 2	(-3),(-2)	(-3),(-3)

Yet now the Nash Equilibrium point is in the 1st box. So if BENEFIT is less than total energy loss, selfish routing will occur.

Scenario 2 when Benefit is greater than 5(total energy loss), i.e 7

Strategy 1→generate + forward (-2)

Strategy 2→ generate + forward + receive + store + forward (-5) + BENEFIT (7)

= (2)

	Node 2		
		Strategy 1	Strategy 2
Node 1	Strategy 1	(-2),(-2)	(-2),(2)
	Strategy 2	(2),(-2)	(2),(2)

4.3 Desired Criterion of Benefit

To motivate the nodes to co-operate, the minimum value of Benefit will have to be at least greater than the summation of the payoffs of receive +store + forward.

We can express it in a conditional statement-

Receive + Store + Forward < Benefit

Chapter – 5

Simulation and Results

This chapter begins by giving some generalized idea about the simulation software ‘NetLogo’. NetLogo is the programmable modeling software which can be used to design various social and natural phenomena and to calculate any desired result. NetLogo is particularly well suited for modeling complex systems developing over time. This software differs from various other simulating software such as “MATLAB” which uses the ‘simulink’ code to show simulation of any experiment in a way that, each objects in the experimenting environments are to be create separately. Their logic input is to be done by coding. The logic of running and interacting is be given separately and in order to specify the changes due to interaction proper coding is to be there.

5.1Features of “NetLogo”

The simulation of any environment can be done by use of button in the interface portion. Proper coding relevant to each buttons is necessary for the proper work of the model. Not only buttons but also various other parameter controlling systems are used to make the model more flexible. Here we discuss some features of “NetLogo” regarding various parameter controlling and changing system.

Button:

It is like the push-and-go mechanism. By clicking the button, the model will run the codes associated with the button. The button can be either ‘run-forever’ or ‘run-once’ type. The run once type will execute the codes once from top-to-bottom. On the other hand ‘run-forever’ means to execute the codes continuously until a ‘stop’ code is executed or the user pushes the button again.

Slider:

It is used to change the value of a parameter inside a coding. Such as the speed of an object can be controlled using speed slider. If the slider is moved to the left side, the speed will be lower and if it is taken to the right side, the speed will be higher.

Switch:

Switches and sliders give you access to a model's settings. A switch has two states, either 'ON' or 'OFF'. In the 'ON' state, the model will run the simulation acknowledging the codes regarding that switch. While in the 'OFF' state, the model will simulate without considering the codes regarding that switch.

Chooser:

It is used to choose among various experimenting environments. A single experiment can be done in various environments. By the help of chooser, we choose the suitable environment and simulate the model accordingly. Things must be kept in mind that each environment must have its associated coding to run the simulation.

Input:

The numerical value of the inputs can be seen. A input monitor should be associated with only one input terminal.

Monitor:

It is a mean of displaying information from a model. Numerical values regarding objects and model environment are given in the continuous experimenting period. It provides good numerical results for data plotting or future predicting.

Plot:

It is used to plot the result in a definite time scale. Values of different parameters can be plotted in a graph, which are changing with time. Various results can be plotted in a same time scale, at the same time by using different color lines. Comparison between two or more results can be visualized by using plots.

Output:

The numerical value at various output terminals can be seen. A output monitor should be associated with only one output terminal.

Note:

In order to write any useful information in the interface or any experimental notification Note is used. It only shows the lines or words written in the note window.

There are three tabs associated with the modeling of any phenomenon in NetLogo. First is the interface tab, where the visualization of the coding is seen. All the buttons and other parameter controlling and changing features are located. The model runs in the interface according to the codes given by coder. Second is the Info tab. Basic information and understanding about the model is provided here. The enquiry of user regarding the model can be satisfied through this tab. Third and the most important part is Code. The logics behind the running the model is to be given here. The interface tab is the mere visualization, where code forms the basic layout of the model and the protocol is to be used by each objects.

5.2 Simulation profiles, results and assumptions :

The simulation profile established to simulate the result regarding the timing of data routing is explained first. Next we consider another model to show the effectiveness regarding data routing with or without the application of game theory.

Model Scenarios:

There are two different model to visualize the two key features of this study.First model is the model of data transmission from source to destination along various nodes with or without discontinuity. Second model deals with use of game theory in effective data transmission.

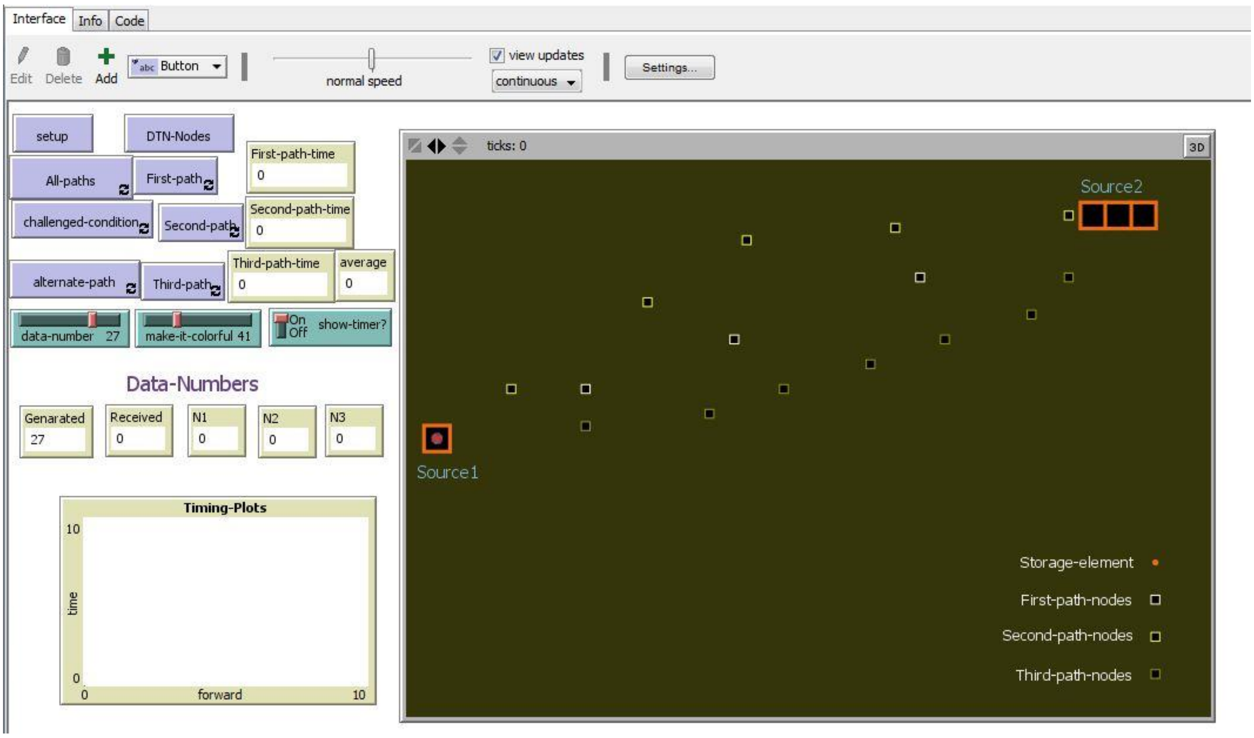
First experimental environment considers data routing :

- Along multiple paths.

- In the presence of discontinuity and a possible solution of it.

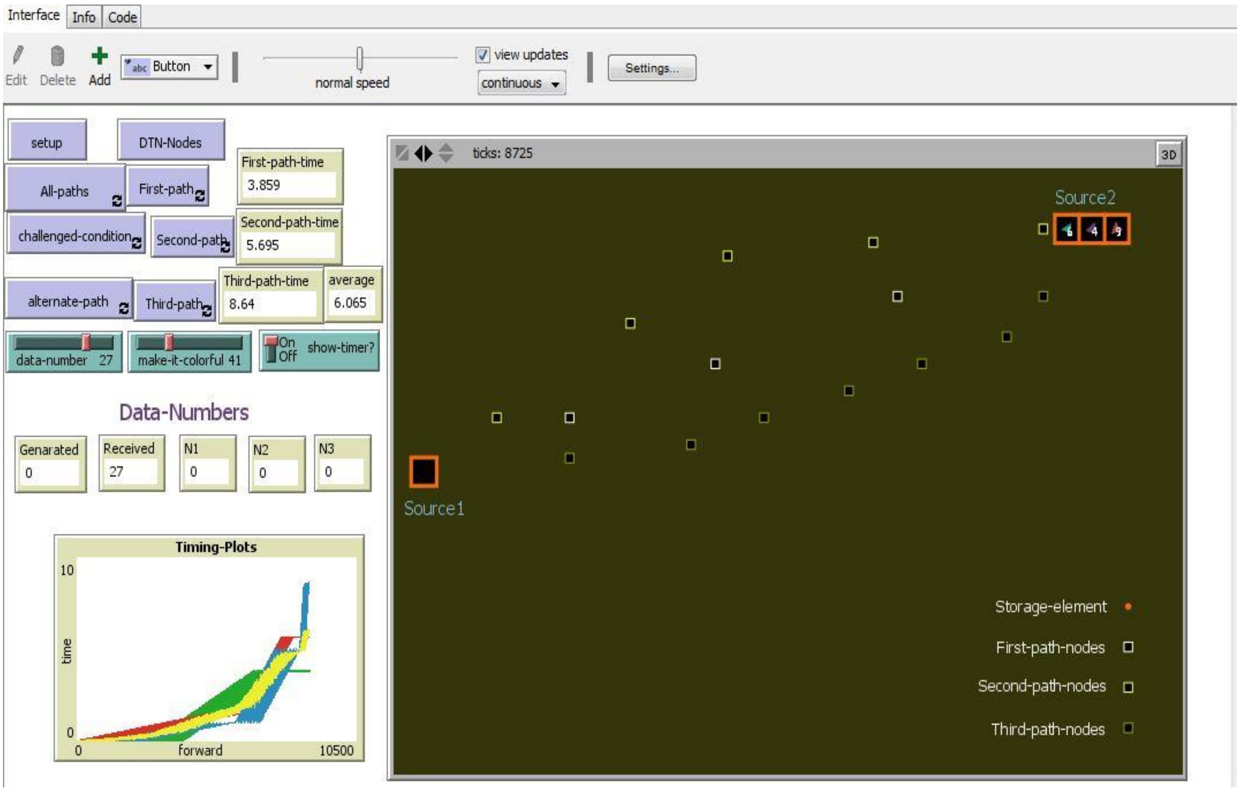
Along multiply paths:

A. Initial scenario :



The initial interface of the model. Here all the parameters are at their initial value and all the datas are confined to the source (source1). In this case the data number is given 27, which is shown using the monitor generated data number. The tick counter above showns that time is zero, that means the experiment is at initial stage. The source is visualized by one orange box at the left side as all the datas were generated at the same point. Similarly the destination is visualized by three orange boxes, as datas are being routed through three different paths. Various networking nodes through which data will be transmitted from source to destination, are shown by smaller boxes in the scenario.

B. Data transmitted along various paths from source to destination :



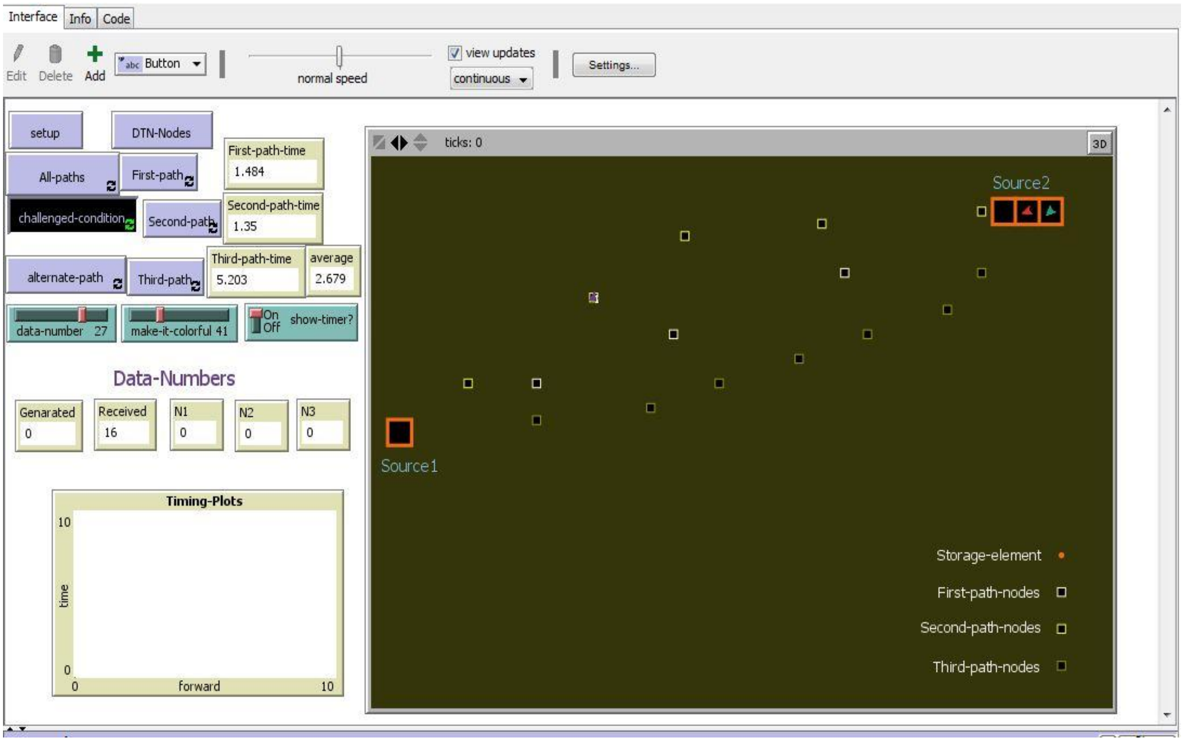
The interface of the model after the simulation is done is shown next. Data have been passed to destination (source2) by following any of the three possible routes and as the show-time switch is on, each data shows the time associated with routing.

First path, second path and third path timings are shows in the monitor, which are **3.85s, 5.69s, 8.64s** respectively. Average of the three timings is also shown in the average monitor, which is **6.06s**. Data number at source is **0** and at destination or receiver is **27**. So we can say, all the data were successfully transmitted from source to destination.

In order to transmit the whole data, this system requires 6.06s. We assumed that nodes are always end-to-end connected. The timing plot shows the various times required for different routes. The presence of noise makes the plot scattered.

In the presence of discontinuity and a possible solution of it

A. Discontinuous end-to-end-connection



In this case, data had been transmitted successfully along two paths. But discontinuity is occurred in a third path. A networking node fails to establish continuous connection due to challenged conditions.

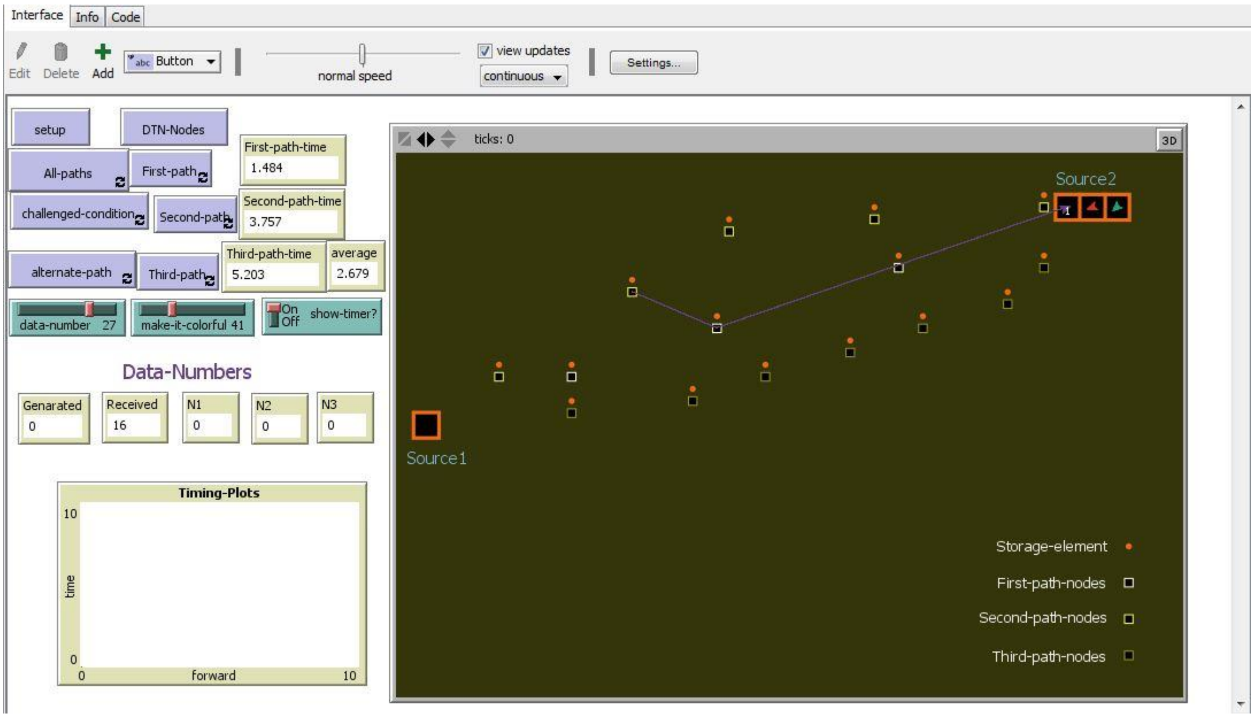
Data number at source is **0** it signifies all the data had been transmitted from the source. Data number at receiver is 16; which signifies that all the data were not successfully transmitted to the receiver. Path timing for the disconnected network is infinity, as the disconnected device loses the data when it fails to establish a continuous end-to-end connection.

It has been assumed that data was transmitted randomly along different paths and the discontinuity is occurred in a random transmission path.

B. The possible solution:

A possible solution of discontinuity is alternate data routing. If the nodes follow the store and forward protocol then successful data routing can be achieved.

Alternate data routing



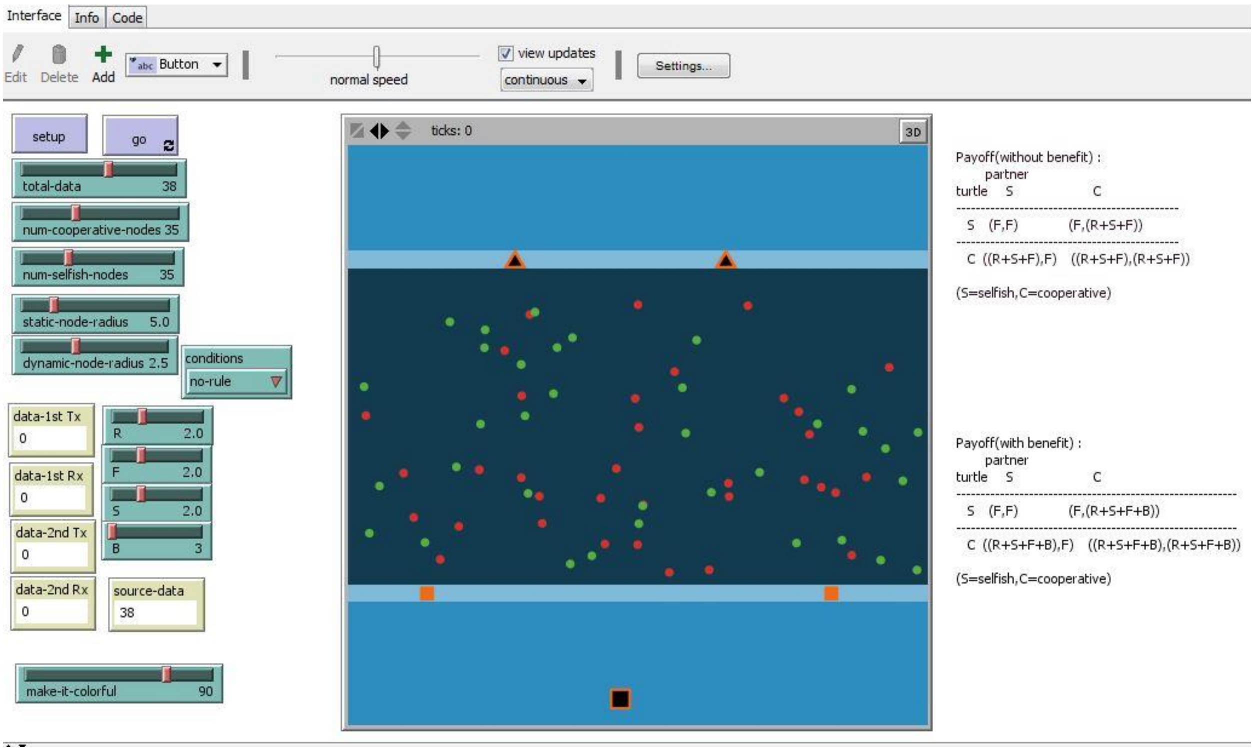
An alternate path is shown here, where the disconnected node supplies the data to any available node, which then transmit the data to another node to reach destination. The storage element is shown by small circles above each nodes. The 'storage and forward' protocol is used by the nodes. The disconnected node stores the data until it can make successful link with another node and in our scenario the disconnected node passes the data to a node of first path. By following this procedure all the transmitted data complete their path.

In this model we assumed that all the nodes have infinite memory for storing data and infinite charge to remain connected.

In this mechanism, in order to route the whole data, each node which transmit the data must be cooperative, i.e. should be willing to receive data from the disconnected node. The behavior of nodes is the main concern for the second model.

Second experimental environment deals with the behavior of nodes under various conditions. First we show the case of data routing without the application of game theory. Then we considered the application of game theory.

Initial stage:

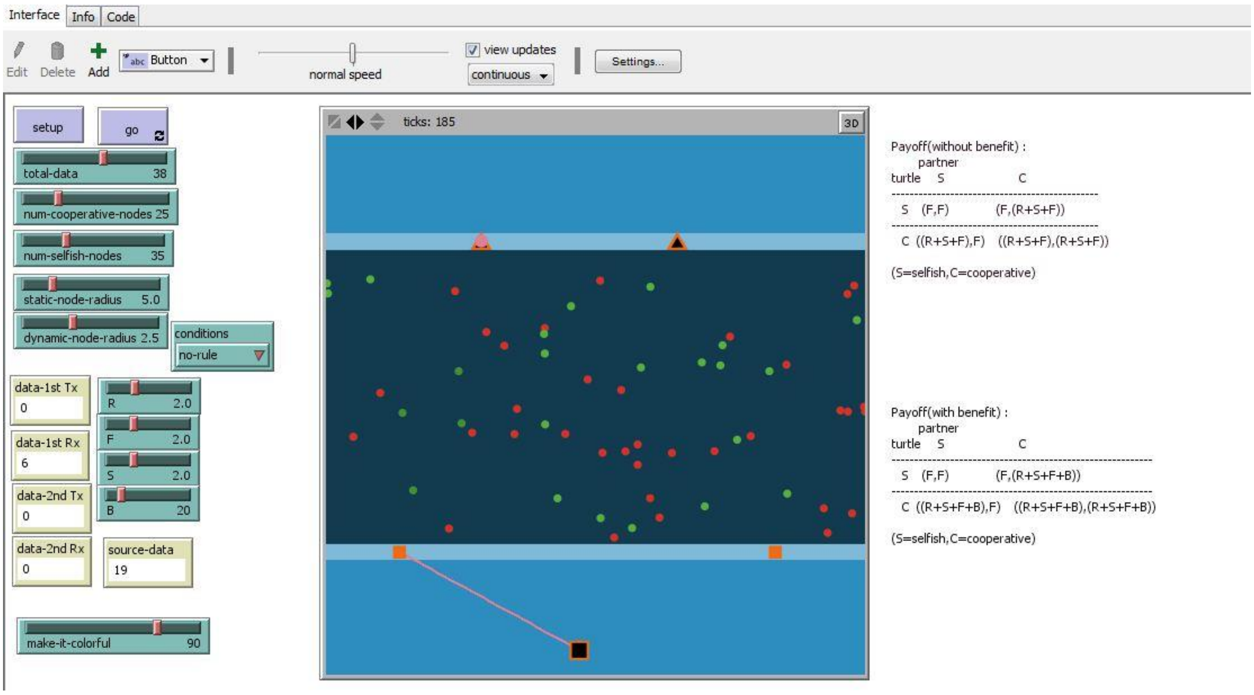


The source is shown by the black box in the lower middle portion of the scenario. Nodes can be either static or dynamic. Static nodes, receiver and dynamic nodes are shown by orange squares, triangle and circles respectively. All the data is confined to source, which is 38 given by the slider, total-data. Nodes can randomly be either selfish or cooperative. Number of selfish and cooperative codes can be changed using sliders, which will allow us to visualize various experimenting scenario. Two conditions are considered here and the associated payoffs are given in notes beside the model. The value of the payoffs can be changed by using sliders.

The condition 'no-rule' implies data routing without the application of game theory. Data can't be transmitted through a node which exhibit selfish behavior. Only cooperative nodes will transmit the data. If the number of cooperative nodes is less then effective data routing will be questioned. Moreover there can be intolerable delay in data routing and whole data may not be transmitted.

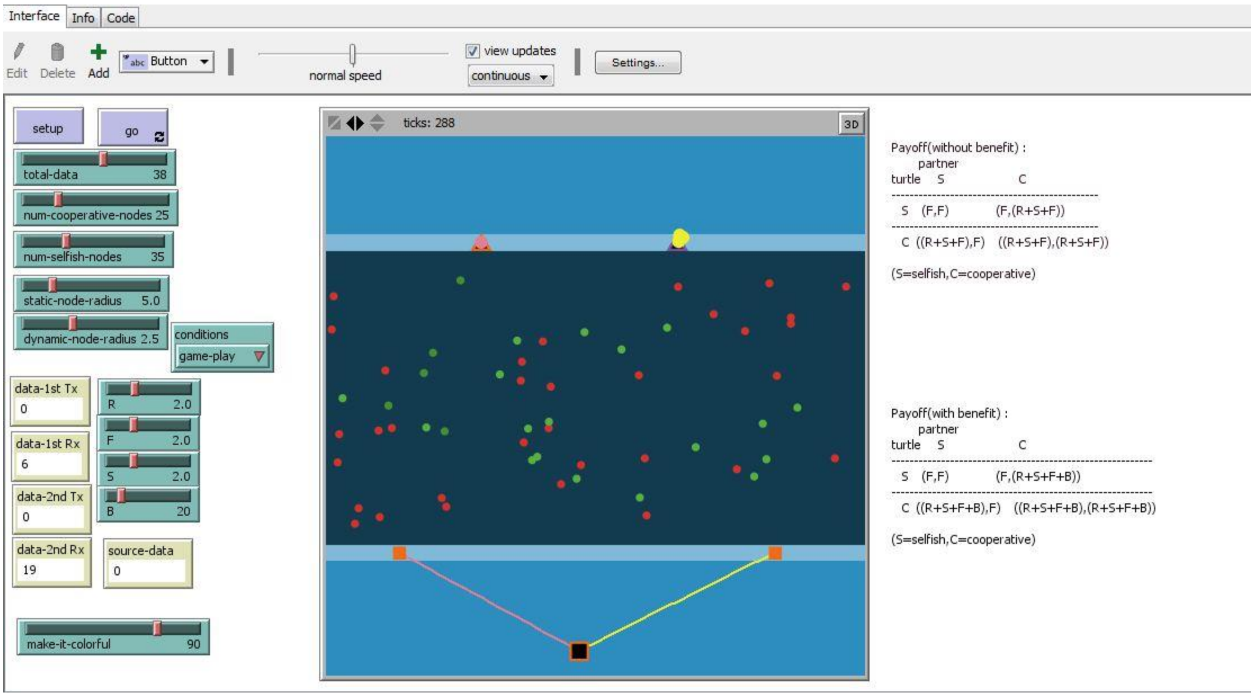
The condition 'game-play' implies data routing by applying the game theory. In order to change the Nash equilibrium a new term 'benefit' is added to the payoff. From the simulation we can visualize data transmission among the nodes for various values of benefit. This model mainly works when the value of benefit is greater than the value of the summed losses due to store and forward protocol. When benefit is greater than associated losses, then high speed data transmission can be visualized from the simulation. When benefit is lower than the losses then data are transferred with slow rate. Increasing the benefit much higher results in higher speedy data transmission. But it also corresponds to higher resource consumption.

Without the application of game theory:



Data number at source is 19 as half of the data is transferred through the system which do not apply game theory for effective data routing. Data number at destination is 6; which signifies data loss in the system. In the experiment it is assumed that, three nodes are required to transmit the whole data. From the results we can say only one node was successful to create a complete path.

With the application of game theory:



Data number at the source is 0, so all the data are now transmitted. The rest half is transmitted using the system which applies game theory. All the data transmitted using this route completed the path. Data number at the receiver is 19. So data loss is occurred in this case. It is achieved by the use of the addition feature 'benefit' in the payoff.

Chapter – 6

Conclusion and Future Work

6.1 Conclusion

Delay Tolerant Network has the ability to interconnect devices in regions current or normal networking technology fails or cannot reach which is normally when the end to end connection is unavailable.

Now in such cases communications is possible by the suggestion of DTN in which the NODES take the custody of data transfer and forward the data whenever the connection is possible. In such a case the nodes may not always be static rather it can be mobile.

In our work we introduced 'GAME THEORY' between the nodes. A node may be any kind of wireless device which has a persistent storage and capable of forwarding data. The nodes in DTN which may be referred to as DTN NODES works on a "Store and Forward" method. The nodes have limited power and storage.

However we most importantly focused on the data routing scenario which is our main concern. To realize the DTN vision, data routing must be effective over a thousands of unreliable, intermittently connected, temporary or permanent networking devices. We've had considered each device as a single node which can operate on the basic of DTN technology .

Mainly because of the fact that DTN enables communication between a wide range of devices, there may occur various problems and according to those problems routing strategies need to be changed. The primary problems are contact schedule, contact capacity, limited power and storage.

Thus these factors can greatly impact in DTN routing. But it can be effectively minimized by the influence of offering some benefits in the economical point of view to the nodes for a single exchange of information. This may seem costly at a first look but considering it as a trade-off between cost and performance it can be effective. For these very reason we implied a theory based on economics ' GAME THEORY' between the DTN nodes for better routing efficiency.

In our work we introduced the term ‘BENEFIT’. Primarily, we considered the ‘BENEFIT’ as to provide power for those DTN nodes which participate in data forwarding . In this way, our prediction of improving the routing efficiency was proved to be correct by the simulation.

6.2 Future Work

We propose the following to be continued as future work-

1. A optimum value for **Benefit** is to be calculated.
2. In our scenario we assigned our losses and benefit in terms of energy. Some other type of benefit such as time delay, data rate etc. can also be used.
3. Payoff matrix under each-node-generation scenario is to be calculated.
4. Detailed analysis of DTN routing with respect to each game form. For instance, a node may have positive payoff on receiving a new bundle. However, the same node will suffer a negative payoff when it tries to receive the same bundle again as it is a duplicate.
5. Experimentation and subsequent implementation of the same in DTN bundles.
6. The implementation may require changes to the Bundles in way of maintaining history or signaling which may be necessitated by the Game theory itself.
7. Analysis of BRG using Gambit to compute its Nash Equilibrium and other solutions.

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- Routing Problems in Stochastic Time-Dependent Networks with Applications in Dynamic Traffic Assignment

11. **S. Burleigh**

- Delay-Tolerant Networking: An Approach to Interplanetary Internet

12. **S. Jain**

- Routing in Delay Tolerant Network

13. **M. Musolesi**

- Adaptive Routing for Intermittently Connected Mobile Ad Hoc Networks

14. **Jones, Li, and Ward**

- Practical Routing for Delay Tolerant Networks

15. **Jones, Li, and Ward**

- Practical Routing for Delay Tolerant Networks