BUFFER ADAPTIVE DISTANCE BASED ROUTING PROTOCOL FOR DTN

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Submitted by:

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CANDIDATE'S DECLARATION

I, Alka Aggarwal, 2K17/ISY/02 student of M.Tech (Information System), hereby declare that the project Dissertation titled "Buffer Adaptive Distance Based routing Protocol For DTN" which is submitted by me to the Department of Information Technology, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation titled "Buffer Adaptive Distance Based routing Protocol For DTN" which is submitted by Alka Aggarwal, 2K17/ISY/02 to Department of Information Technology, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree of Diploma to this University or elsewhere.

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ABSTRACT

Delay Tolerant network has the characteristics of being dynamic, spontaneous and have a number of mobile node. The Delay tolerant network uses the dynamic nature of its mobile nodes to transmit data from one place to another place and to gain access to internet. Epidemic is the simplest routing protocol used in the DTN networks. It floods the bundle (message) to other nodes in its coverage area until it reaches the destination. We have modified the epidemic protocol it will send bundle only to those nodes who have at least two connections, is close to destination and with minimum buffer load. Along with this sending strategy we have implemented and compared buffer strategies in epidemic. As we know that epidemic follows First In First Out algorithm. In this thesis, the implementation and comparison of three more strategies based on the encounter age of the node, first is to delete the bundle whose destination has been encountered by the this node most recently and second is to delete the bundle whose destination has been encountered by the this node least recently and the third one deletes the bundle whose destination is farthest. All three algorithms performed far better than the conventional epidemic protocol.

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LIST OF ABBREVIATIONS

1.	MANET:	Mobile Ad-hoc Network
2.	WSN:	Wireless Sensors Network
3.	DTN:	Delay Tolerant Network
4.	TCP:	Transport Control Protocol
5.	IP:	Internet Protocol
6.	3G:	3rd Generation
7.	TV:	Television
8.	DSL:	Digital Subscriber Line
9.	GPS:	Global Positioning System
10.	DD:	Direct Delivery
11.	ONE:	Opportunistic network
12.	FIFO:	First in First Out

CHAPTER 1

INTRODUCTION

Today, we live in a world where internet access is a must thing. Internet users are increasing day by day. Continues research in the area of communication and network has given rise to many new terms like MANET and WSN. Although they are different from the internet but still they are sort of cousins of the internet. The difference is traditional network and challenged network. In traditional network, the nodes and routers have the information about network topology, route, and distance and have rather a lot resources and end to end connectivity between nodes. They may have multiple paths. But the challenged networks have no such information. They have limited resources. Due to harsh geography in some areas and the sparse connectivity the term “DTN” arise.

In this chapter, we will discuss about DTN, and the need of the DTN (why not traditional internet model), characteristics of DTN, challenges faced by DTN, how routing differs in DTN and traditional networks and applications of the DTN.

1.1 DTN OVERVIEW

The goal [1] of every network is to deliver the message to the destination successfully. Traditional internet model uses a connected graph where there is always a path from a node to every other node. It can have single path or multiple path to a destination. To have access to internet, a device should have connection to at least one element of the internet. If the device have no connection and it sends a message then it will get dropped if either of the source or destination have no connection to internet. As an example, TCP [30] is a widely used connection oriented protocol which means that before starting the conversation, the sender and receiver must establish an end to end connection. TCP [21][26][28][30] sends the data using IP addresses and port numbers of the sender and destination. To send the data TCP uses three way hand shake procedure. The network have continues connectivity, very low packet dropping rate, stable network topology and low packet delivery delay.

Where there is no end to end path and network has intermittent connectivity [21] among nodes. That network is known as DTN. DTN [1][6][10][15] has unstable topology and frequent disruption of the connections. Traditional networks works poorly in these challenged network. DTN may or may not be mobile. DTN can have large and unpredictable delay in delivery of messages. It have very low delivery probability and have limited resources. Some example of DTN are inter-planetary communication, habitat monitoring, rural areas, sub-aquatic exploration, wild-life tracking and military battlefields etc.

Factors that cause the intermittency of contacts are:

- **Sparseness**

  The number of nodes are very few in comparison to the area of the network or we can say that the communication range is too vast while the nodes are few in that range [1][2][21][26][30] .

- **Mobility**

  The nodes keep moving [1][2][7]. They keep moving in or out of the communication range of the other nodes. And obstructions that result in disruption of the connection.

- **Energy**

Nodes have limited source of energy [15]. While sensing, sending and receiving data, they dissipate energy [12]. When all energy of that node is consumed, they died [8]. So all messages to that node get dropped that reduces the delivery probability.

- **Interference**

Interference between nodes causes loss of data packets. It results in disruption of the connection in between the nodes [1][8].

Communication range between the nodes is not long enough to connect all the nodes [1][2][8][13]. Contacts between the nodes are for uncertain and varied durations. So DTN uses the contact between nodes as the opportunity to deliver the messages. DTN network has many routing approaches. Most of them are replication based.

1.2 APPLICATIONS OF DTN

➢ **Zebranet**

Used for wild life tracking [26][27].

- It uses sensor nodes for tracking.
- Used to track the position of animals.
- It replicates the tracked data when animals are in reach of other animals.
- Tracked data can be gathered daily or weekly at a base station.

➢ **Haggle**

Known as “adhoc google” [26].

- It is centred on the social web applications.

- It is push based and data centric.
- Metadata represents the data about an item like, the address of an item, similar attributes between two or more items and representing them using a relation graph. The weight of a relation depends on the number of similar attributes.
- Haggle Applications:
  - PhotoShare: Make photos, tag them, and automatically get other photos according to desired tags.
  - FileDrop: Distribute data in a Haggle network, by moving them into a special folder. Metadata are automatically extracted.
  - MobiClique: Social Network App. Allows adding friends, discussion and file sharing.

➢ **DakNet**

Its goal is to provide access of internet and its applications in rural areas where there exists no infrastructure.

- It was developed by the MIT media lab.
- Its idea is to use the vehicles as data mules to transfer the data.
- Now, in India, the FirstMileSolution is commercializing it.
- When even the wireless radio is not feasible, DakNet can be used.

➢ **OpTraCom**

Its goal is to monitor the pollution in large area.

- It uses public transportation systems and measure the data on vehicles.

- It gathers environmental data.
- It also gathers operating data of the public transportation provider. For example status of rail road's switches, diagnostic data of vehicles).
- Updates public displays and advertisements.

1.3 BENEFITS OF DTN

The network in challenging environment, may or may not have coetaneous connections between the nodes of the network. And even many of the network with challenging environment do not have it. The challenging network cannot guarantee to provide the coetaneous connection [15][18]. But data is needed to get transferred to the destination even when there is, not a single path leading to destination from source. In order to transfer the data, data needs to keep flowing until it reaches the destination. And to keep data flowing nodes need to interact with each other to transfer the data they have to each other [17]. DTN can help in a great and efficient way to keep that data flowing in mobile challenged networks. DTN can provide an opportunistic network with mobile nodes such as a network built of moving sensors on pedestrians, animals and vehicles [8]. Even many of the applications built on DTN like monitoring environment or many other applications do not need the real time data. They can tolerate with the delay and some data loss. So unlike the traditional internet which have very low tolerance to data loss and delay in transferring the data, the applications which are using DTN, most of them are delay and data loss tolerant [7][8]. For an example wildlife monitoring, studying weather, monitoring environment and other statistic and scientific analyses are based on the sensor data that is collected over a long period of time.

CHAPTER 2

LITERATURE REVIEW

2.1 WHY DTN?

There are many communication networks whose environment do not comply with the underlying assumptions of the internet. Some of the characteristics of those environment are as following [7][8][26]:

- **Sporadic connectivity**

  The absence of whole path from source end to destination end is called network partitioning [21]. In such environment TCP/IP protocols does not works.

- **Prolonged or variable delay**

  In addition to sporadic connectivity, prolonged dispensation delay between nodes and unpredictable delays at node causes complete path delay that results defeat of internet protocols [21][4] and other traditional applications that need quick reply or acknowledgements.

- **Uneven data rates**

  The traditional internet supports some amount of asymmetries for users of cable TV or DSL services of bidirectional data rate. But if the data rates vary by a large amount and causes large asymmetries then conversational protocols does not work.

- **High Error Rates**

If there is bit error then it require correction which in turn requires more bits and data processing (increasing overhead) or retransmission of the entire message that result in more network traffic [1][3][6][9]. But such environments needs fewer retransmissions than internet type source end to destination end retransmission for hop by hop retransmission, for a given link-error rate.

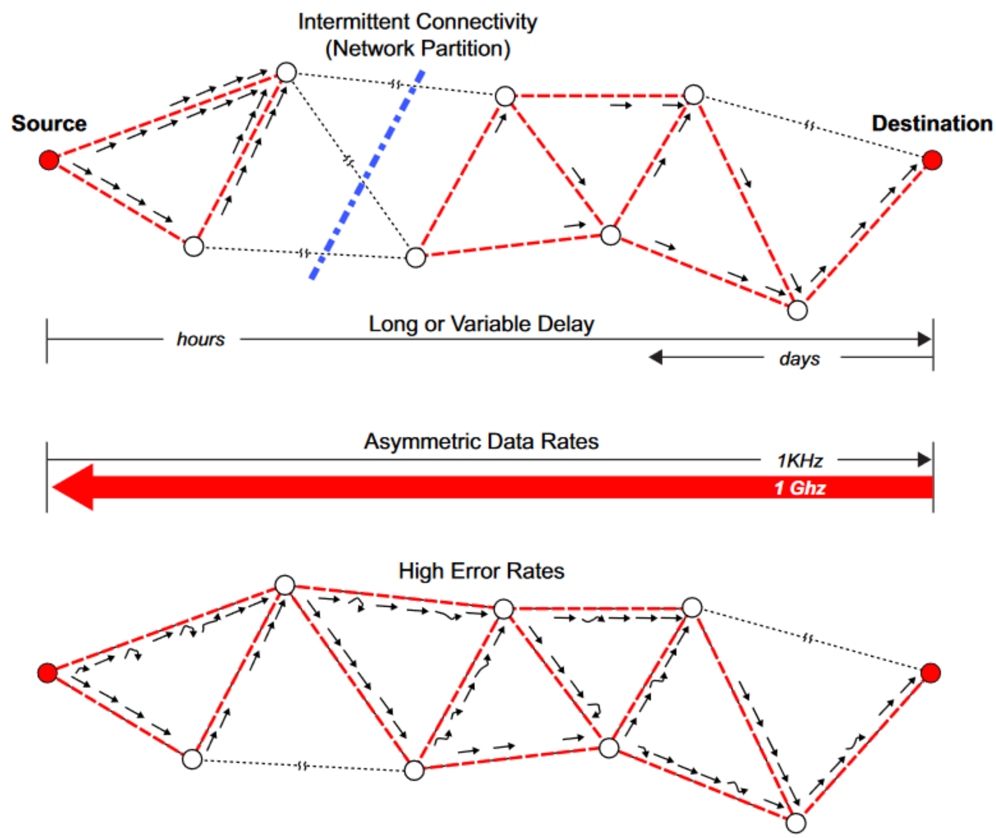

Fig. 2.1 Characteristics of Challenged environment

2.2 DTN ARCHITECTURE

2.2.1 Store-Carry-Forward Message Switching

DTN overcome all the above described problems like sporadic connectivity. Prolonged and unpredictable delays, uneven data rates and high data rates by using Store-Carry-Forward Message Switching [1][3][7]. This an old method, used since ancient times. The whole packet (all complete blocks of application data) or the fragments [21] of these messages are transferred or forwarded from a buffer storage of a node to the buffer storage of another node, on a path that will lastly reach to the destination.

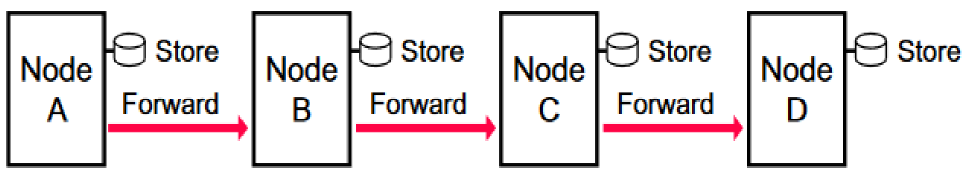

Fig. 2.2 Store-Forward message switching in DTN

In todays' world, this method is used in voicemail or email systems, but these systems are star relays not node to node relays as in shown above figure. In these systems like voicemail or email systems both sender and receiver contact the central storage system independently at center of their links.

The buffer storage can hold messages for an indefinite period of time [21]. These type of storage is called the persistent storage, unlike to temporary or short term storage of provided by memory chips. Other internet routers use those memory chips to store the incoming messages for a few seconds until they are waiting for the information retrieval of their next hop from the routing table and for a routing port available for forwarding.

Persistent storage is needed for DTN because of the following reasons:

- Link for communication to next hop may or may not be accessible or available for a long time.

- Some nodes can be more reliable than other nodes. Some nodes may communicate (send or receive data) much faster or reliably than others.

- A packet may need to be retransmitted even after it has been transmitted once. Because an error could be occurred at source node or a source node can also decline the acceptance of an already forwarded message.

2.2.2 Sporadic Connectivity

It is becoming common with the increasing use of the wireless and mobile communication devices (as an example cell phone) [26][27][28][29][30]. The number communication devices which are in motion and operate on limited power is growing.

Due to motion of the communication nodes, breakage of links can happen because of the interference. Links may get shut down, because of the limited power or preserving secrecy [26][30]. When there is no path from sender to the destination, this condition is known as the network partition.

On internet, sporadic connectivity leads to data loss [21]. If packets could not be forwarded immediately then they will get dropped or TCP may try to resend them by slowing the transmission (by applying some flow control algorithm). And if the packet are dropping too frequently then TCP may end that session which will in turn cause the application to fail.

On other hand, DTN provides the communication between the nodes with random connections by using store-carry –forward mechanism to isolate delay and frequent disruption of the network [21][28]. The sporadic connectivity between the nodes can be opportunistic or scheduled.

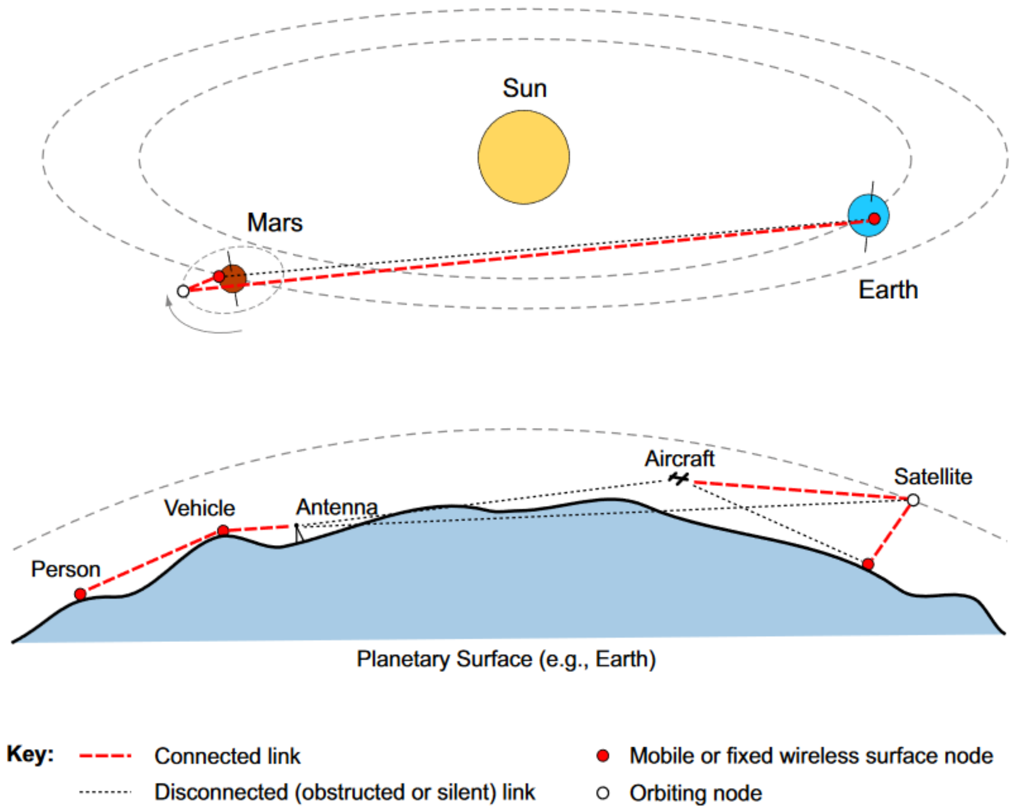

Fig. 2.3 Intermittent connectivity in DTN

2.2.3 Opportunistic Contacts

Due to frequent disruptions of the network, nodes need to communicate during the opportunistic contacts. Opportunistic contacts are the unscheduled contacts [1][13][17][21]. Means, DTN uses this property (mobility) of nodes as an opportunity for delivering messages between source end and the destination end by passing it on to any other nodes that comes within the range of communication of that node [21][28]. The mobile nodes then carry messages to help network to deliver them to destination.

The moving communication devices, people, vehicles, aircrafts or satellites can make contact when they are in communication range or close enough to communicate using the available resources [28]. Everyone in daily life is using this technique as a way to communicate. All of us find the opportunity or a chance to contact or communicate. In similar way, wireless mobile devices make contacts [28]. They are designed to deliver or receive the messages or information when people carrying them come in communication range or when they are carried past an information kiosk.

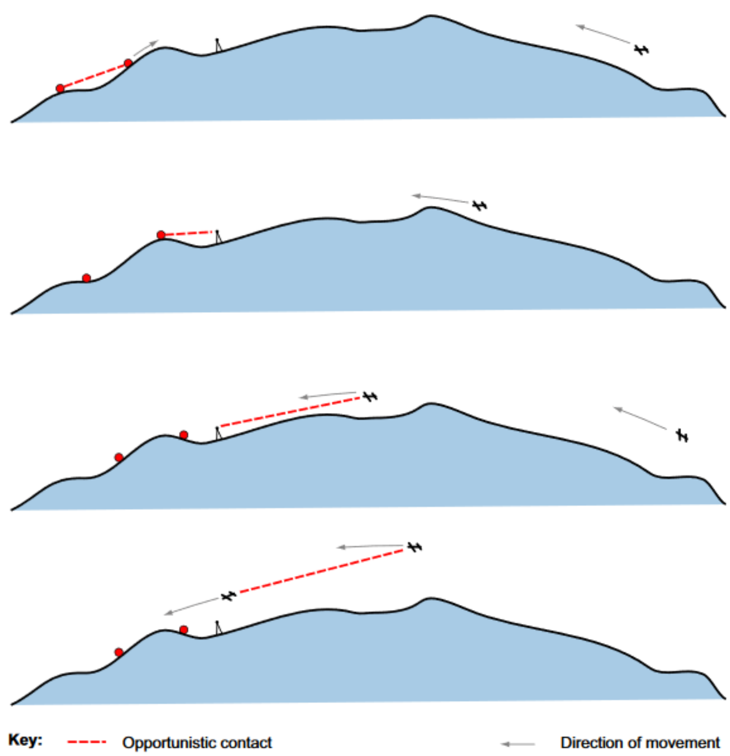

Fig. 2.4 Opportunistic Contacts in DTN

2.2.4 The Bundle Protocol

Below figure shows an overlay structure of the bundle protocol and compares the traditional internet protocol stack with DTN protocol stack.

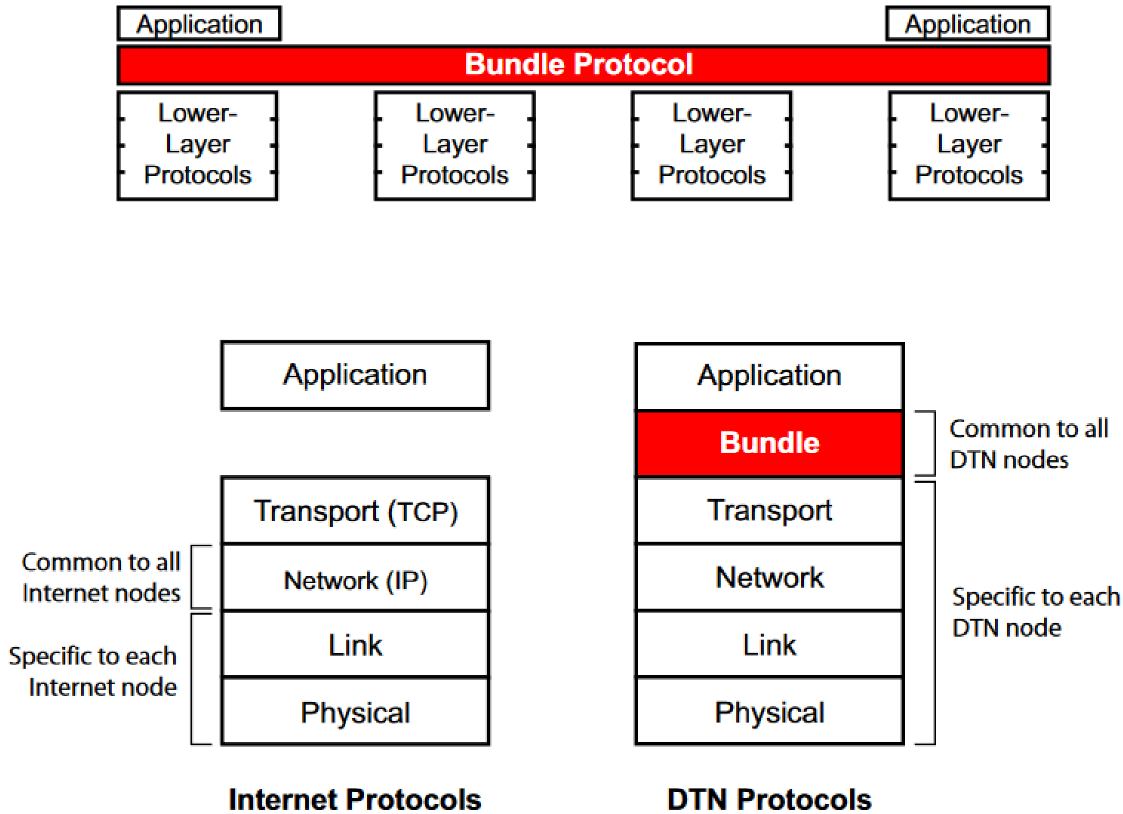

Fig. 2.5 DTN Model

The DTN architecture implements a new protocol that is bundle protocol [21]. This protocol implements the store-forward mechanism of message switching. Bundle protocol is implemented above the lower layer protocols [21][26]. It helps in tying the lower layer protocols together which in turn helps the application layer in communicating across lower layer protocols in a challenged environment.

This protocol stores and forwards the received or generated bundles among nodes. Throughout a DTN, only a single bundle protocol is used. That helps the lower layer protocols to work in each communication environment.

2.2.5 Bundles

A bundle consists:

- A header that may have one or may be more DTN blocks stationed by the bundle-protocol agent

- The user data of a source application describes the destination application about the way in which it should process the data. Even the control information of source application also gives the destination application some instruction on the way it should be processed, stored, disposed of and otherwise the handling of the user data.

- An optional bundle trailer, consists of zero or may be more DTN blocks, set out by the bundle-protocol agent.

Bundles can be of any size. They can be arbitrarily long. The agent can break the bundle into fragments just like the IP protocol breaks the packets into fragments. The destination reassembles the fragmented bundles with the help of the bundle protocol agent.

Bundle protocol encapsulates the data received from the application layer and give it to the lower layers [28]. The figure below describes the encapsulation process performed by the bundle protocol.

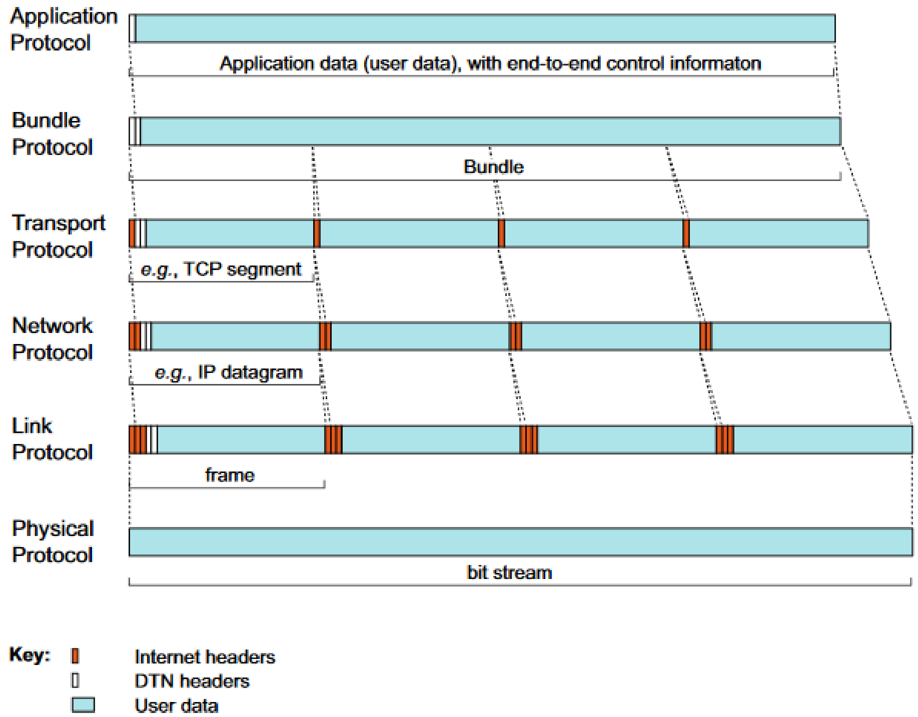

Fig. 2.6 Encapsulation Process in DTN

2.2.6 Non-Conversational protocol

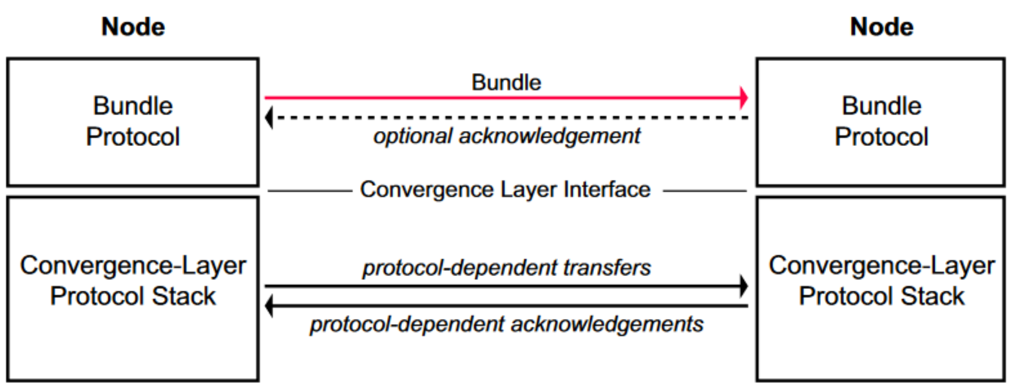

Fig. 2.7 Non conversational Protocol of DTN Architecture

The convergence layer protocol stack sits below the bundle protocol, this layer support exchange of the bundles [21][26][28]. The convergence layer interface is the boundary between the bundle protocol and the lower-layer protocols.

The BP interfaces with different transport protocols through a "convergence layer" adapter. The convergence layer manages the protocol-specific details of interfacing with the underlying protocols and presents a consistent interface to the bundle layer.

2.3 DTN CHALLENGES

There are several challenges in delay tolerant networks. Most of them are caused by the frequent disruption of the network, the isolated nodes and the interference of other particles that causes breakage of the connections [1][2][3][5][8]. Other problems occur because of limited available resources as there are many devices available such as laptop, mobile phones etc.

- **Buffer Size**

  To overcome the issue of the sporadic connectivity, the nodes in the network have to save the messages or data in their buffer space until they find a node to transfer the message to or they find a better node to relay the message to. This delay that occur while nodes are waiting for their next candidate to transfer the messages to can be of few seconds, minutes, hours or days. It means that the nodes of the network needs a large buffer capacity to be able to handle the messages waiting for getting relayed or delivered [3][8][26]. Many routing strategies have been implemented for DTN [3][5][8][13][20][26][29][30], some of them give more priority to available buffer space than the making decision on forwarding while other do not even considers about managing the buffer. It is too difficult to find the ideal buffer size so that no message get dropped. Deciding the perfect buffer size also depends on the rate of messages are generating. It is more difficult to the buffer size that suits for all the applications. So, there are two options left, one is to either consider unlimited buffer space or the second option is to have an application specific buffer size means that suits a particular buffer. One thing to keep in mind is that the unlimited buffer capacity does no ensure the 100% delivery rate because the delivery of the messages depends on other factors too like available bandwidth of the channel, transmission speed and the contact duration of the nodes of the network.

- **Contact Capacity**

Next challenge of the DTN network is the contact capacity, it specifies the data that can be forwarded or exchanged between the nodes during a contact before getting connection down [25][30]. Longer is the contact more data can be exchanged between nodes and shorter is the contact less data would be exchanged or maybe they will not even get a chance to exchange the data before getting the connection down. The duration of the contact between the nodes heavily depends on the application and the medium or the environment. In case of dynamic DTN, usually the duration of contact at each encounter is short and limited [2][30]. On this factor of the network, the performance of network depends largely as there can be scenarios in which the nodes have relatively small data to exchange than the capacity of the network to exchange data during the given or may be average contact phase of that network or nodes may have a large set of data to be exchanged than the capacity of network it can exchange data during the given or may be average contact phase of that network [1]. In past very few researchers have included this as a factor to make forwarding decision on. As it is a good point to make the forwarding decision, researchers can use this factor as a parameter to their routing algorithm.

- **Mobility**

Next issue of the DTN is mobility. In DTN most of the network have dynamic topologies [1][2]. So they mostly have mobile nodes and they exhibits many different mobile patterns. It is a very important factor of the DTN. The mobility of the nodes depends on the application or the environment or say network. The nodes in the network may be mobile or may be static [2][3]. The speed of the nodes with which they are moving may vary with different irregularities. The movement speed can be constant or variable [5][8]. If the environment is highly dynamic then it may cause more frequent disruption of the connections and lower contact capacity than the less dynamic environments. The mobility of the nodes depends on the environment. Many routing protocols have been designed for different types of the mobility. The mobility van be classified into types depending on how predictable it is.

For example, in the interplanetary application, most of the disruption of the connections is caused by the moving objects and their movement is predictable and can be calculated precisely [2]. The predictable movement of the objects helps in making the DTN routing algorithm perform efficiently by creating their schedules. In other instance of mobility is human or bus movements, their overall journey may be regular but their start and end time may vary depending on traffic or other obstructions [24]. The mobility schedule of these type of instances is not precise because of irregular traffic and other conditions. They shows an implicit schedules of activities as there is no rigid time of the arrival of the bus or of a person reaching his office but their schedules are regular [27]. Means the schedules are implicit but regular. So, to improve efficiency of the routing algorithms the mobility of the nodes and the pattern of the regularity of schedules can be observed to make decisions. There are some scenarios in which the mobility of nodes depend on the communication of nodes means they move in accordance to the communication requirements [2][24][27]. These type of mobility is semi predictable and are known as proactive movement.

- **Processing Power and Energy**

There is a large range of devices that can be used in DTN. They can be attached to people, animals or vehicles to transfer the data to their destination or to collect the data for study purpose [27]. Usually these devices are small in size and they have limited power to process data and to gather it. Therefore, the DTN nodes cannot run a complex routing algorithm at each contact especially when the contact duration is short. As complex routing algorithm will consume more energy in processing [24][27]. So it is also an issue or the challenge in DTN. Following are some of activities that consumes energy:

- For transmission of data.
- For receiving data
- For running routing algorithms

2.4 ROUTING IN DTN

Routing is a challenging task to route the data from source end to destination end because of the lack of network topological information. Consequently, store-carry-forward mechanism is used in DTN to help routing in challenging network. Routing algorithms helps the nodes of the network on making the best forwarding decision [1][3][13]. There are some protocols that make simple decision to deliver the data to nodes who are reachable or in communication range for example epidemic, first contact [6][10][9][14]. While other protocols make complex decisions by using the limited information they have it can be distance between nodes, mobility of nodes, energy remaining in the nodes, the buffer space available in the node or the number of copies to replicate. The routing decision may depend on the some kind of spatial or may be temporal conditions [4][5][23]. It has been the one of the main topic that kept research attracting towards it. The performance of a routing algorithm may vary largely by the some factors like the density of the network, mobility of nodes, distance between the source end and the destination end nodes and the amount and quality of information that nodes has. This is the reason that the forwarding strategy of the routing protocols in DTN need to be in accordance to the environment, they need to be adaptive to the requirement of network and should cover all the most possible scenarios that can happen in that environment. Till the date a number of routing protocols have been proposed by different researchers. According to the working of the routing protocols and the information they use foe making decision, they can be classified in two types. The first one is the flooding based routing protocols and the other one is estimation based routing protocols [1][[3][8][5][6][9][14]. The principal of flooding based routing protocols is replicating the messages and forwarding or relaying it to as many nodes or may be all nodes that has been in contact with the node that is carrying the message until the message reaches the destination. Flooding approach increases the chances of message delivery to destination. But it also uses a lot of network resource that causes the wastage of network resources. Estimation based routing protocols [1][3][5][4][12][11][15][19][20][22] used kind of flooding approach but in limited way. These types of protocols try to reduce the flooding in the network by using the available local or global information to select the next best link to relay the message to. Below the detailed information of these types of routing approaches with some example has been given.

2.4.1 Flooding Based Routing Approaches

This flooding type of routing strategy is called replicating type routing strategy or replicating based routing strategy[1][14]. They create multiple copies of the original message and send them to a set of nodes in the network. The node when comes in contact with other nodes, it relay the copy of the message that are stored in its buffer space to all other nodes that are in contact. Different routing protocols vary in terms of how many copies to replicate and on the selection of the next relay agent [1][3]. But in flooding type of routing protocols, most of the protocols assumes unlimited resources such as energy, buffer space, bandwidth and highly random mobility of the nodes of the network. Because the nodes are using all the available opportunities to deliver message to respective destination, these stated assumptions increases the chance of delivery of message to respective destination [13][14][20]. But as these assumptions do not comply with the real world, due to limited resources, the performance of the routing protocols get affected drastically.

- **Direct Delivery Routing Protocol**

  Direct Delivery routing protocol is one of the simplest routing protocol of DTN to send the data from source end to destination end. It is like a debased form of flooding in which the nodes tries to forward the message to minimum number of nodes [1][10]. This routing protocol will forward the message only if the source node and the destination node are in direct contact. Or we can say that the routing the message using Direct delivery routing protocol will be successful only if the source and the destination nodes are neighbours or are only just one-hop away from each other [3]. Direct delivery routing protocol makes no relays because each message is delivered by the source node only. In the pros of this protocol is that it uses minimum amount of resources like buffer, energy and the bandwidth of the network [13]. Because the intermediate nodes are not receiving message from other nodes to deliver them to some other node [10]. So energy used in receiving and transmitting the message to other nodes is saved. And so is the buffer space and the bandwidth. But on other hand while counting for cons, this protocol limits the opportunities to deliver the message to the destination [10][13]. Because this protocol is allowing only the original sender to deliver the message to destination. That cause a large delivery delay, data loss and delivery probability. Mostly Direct delivery protocol is used for comparing the lowest overhead ratio to other more practical routing protocols.

- **First Contact Routing Protocol**

  First Contact routing Protocol is just as simple as the direct delivery routing protocol and in fact it uses the direct delivery strategy for delivering the message [8][13]. The sender node will create only one copy of the message and will relay it to the next node in which it comes in contact with [10]. After that, no other node will replicate or relay the same message. And then this protocol follows the direct delivery strategy to deliver the message to the destination [20]. So if the destination ever comes into the communication range of the relayed node or the sender node then the message will get successfully delivered. This protocol performed better than the direct delivery routing protocol in terms of the delivery probability as it is using more resources than the direct delivery routing protocol [3][10]. Although this protocol makes a successful attempt in increasing the delivery probability while keeping the overhead and the use of resources to limited use, but it still shows a great scope of improvement.

- **Epidemic Routing protocol**

The Epidemic routing protocol is also a simplest but also a fastest routing protocol of DTN. The nodes using this routing protocol replicates the messages and relay them to every node that comes in its path [14]. Likewise, the node that receives that message will exhibit the same behavior [6]. The nodes keeps a summary vector, which helps in discarding the messages that are already stored in the nodes' buffer [9][14]. This protocol follows the pure flooding approach as it is flooding the messages to all the nodes that are in communication range until it gets delivered to the destination. This protocol assumes that the messages are of small size and the network has unlimited resources like buffer capacity, energy and the network bandwidth [3][6][8]. That's why the nodes keep sending their summary vector to other nodes on each contact. This protocol trades the high delivery probability at the cost of nodes and network resources [6][14]. As this protocol is disseminating the messages to all possible paths, it decreases the delay of messages getting delivered to last destination. It also decreases the latency which is the time of a message from getting created at source node to getting delivered to destination node [3][8][13][20]. Even though we say that the protocol keep flooding the message until it reaches the destination but the fact is that the destination node will not relay the message to any other node but the other nodes who still have this message and is not the destination node will keep relaying that message to other nodes until it get dropped from the buffer or get aborted because of some reasons [6][9][14]. It provide the upper bound on delivery probability and delivery delay to compare the performance of other protocols.

- **Spray and Wait routing protocol**

The spray and wait protocol reduces the flooding while using the combination of epidemic and direct delivery routing protocol [9][14]. This protocol replicates a fixed number L, of copies of messages. This protocols have two version of it, vanilla and the binary, they both differ in the way they disperse the L number of copies of the messages in their spray phase. The vanilla version of this protocol disseminates the L copies of the message to first L different nodes that has been encountered while the binary version of this protocol disseminates the half of the L copies of messages to very first encountered node and other copies of the message to very second node that is encountered by the sending node [3][4][8][13][20]. And then the receiving nodes repeats this process until the message reaches to the destination. This is the working of the protocol in its first phase that is spray phase. The second phase of the protocol is wait phase. The working of the both versions of the protocol is same in this phase of the protocol [3][14]. In this phase, when the relaying and the source nodes of the network are left with only one copy of the message then they enter into the wait phase in which the message is transferred by the node by using the direct delivery strategy in which, the node carrying the message will deliver the message to destination by itself only. So the node will carry the message until either it reaches the destination or TTL expires [8][9]. This routing protocol solves the problem of the epidemic routing protocol of unbounded replication of the messages. It also reduces the use of the network bandwidth by L [13][20]. The disadvantage of this routing protocol is the long delivery delays and may be the node to which the message has been relayed may never be able to make it to the destination node.

2.4.2 Estimation Based Routing Approaches

Estimation based routing protocols uses the local and global information of the network to select the nest best candidate to relay the message to, at each contact [4]. It assess the nodes in its communication range and then relay the message to the best candidate who shows the maximum likelihood of delivering the message to destination. The local and the global information stored in the nodes of the network varies from algorithm to algorithm and it depends on the complexity of the protocols [4][7][16[17][18]. The data used as the input also depends on the protocol. This type of protocols, mostly do not replicate the messages but keeps forwarding the single message until it reaches the destination. It limits the flooding of the messages and also limits the usage of the network resources. Below is the some examples of this type of protocols.

- **Location Based Routing Protocol**

  Location based routing protocol is the simplest protocol of estimation based routing strategy of DTN. This protocol gathers an estimate of the location of each node of the routing protocol [1][3][4]. This protocol uses the distance from the source node to the destination node as a metric to deliver the message to destination node successfully. This protocol assumes that the nodes are equipped with the GPS devices and have the information about the position of the other nodes as the GPS coordination. This protocol uses the distance as a metric. The source node uses a distance formula to find the best possible path. The source node computes the cost of all possible paths leading to the destination [13][20]. And finally the message is delivers to the lowest cost path. The disadvantage of this protocol is that may be the distance is shortest leading to destination but it may have maximum disruptions. That may cause high delivery delay or may be message may get dropped due to some reasons related to TTL or buffer space. Another con of this routing protocol is that mostly the DTN have dynamic topology, so the distance may not remain same after sending the message as calculated before sending the message.

- **ProPHET Routing Protocol**

ProPHET uses history of encounters [7] with other nodes to deliver messages to destination. It has statistical property that is used to find the next node to send messages. This protocol uses delivery predictability and transitivity. Each node maintain a delivery probability table that shows the probability of a message to get delivered to destination [7][16][17]. Whenever nodes meet, they exchange their delivery predictability table and update their delivery probability table. Transitivity is, if a node X frequently encounters node Y and node Y frequently encounters node Z then node Z is a good relay to deliver message to node X. As each node calculates the delivery predictability for all known destination nodes where $P(x,y) \in [0,1]$. To calculate delivery predictability where a node encounter other node:

$$P(x,y) = P(x,y)_{old} + (1 - P(x,y)_{old}) \times P_{init} \qquad (2.1)$$

Where P_{init} [2, 3] is initial Predictability and $P_{init} \in [0,1]$. So, whenever node x encounter node y, they exchange their delivery predictability tables to update their delivery predictabilities [7][14]. The recommended value for P_{init} is 0.75.

If node x has not encountered node y for a long time then node x will update its delivery predictability by using following formula:

$$P(x,y) = P(x,y)_{old} \times \gamma^{k} \qquad (2.2)$$

Where γ is aging constant [7] and $\gamma \in [0,1]$ and k is aging factor that depict the time that has been elapsed since the last encounter.

Next equation shows the effect of transitivity on delivery predictability. Transitivity is, if any node x encounters another node y frequently and that node y encounters any other node z frequently [17][18], then node z is a good relay to deliver message to node x. Where $\beta \epsilon [0, 1]$, it is scaling constant that depicts the transitivity impact on delivery predictability.

$$P(x, y) = P(x, y)_{old} + (1 - P(x, y)_{old}) \times P(x, y) \times P(y, z) \times \beta \qquad (2.3)$$

This protocol assumes that the bandwidth is unlimited so time taken to deliver messages is ignored [3][4][7][9][14]. The transitivity property decreases the message dropping rate and it also helps in decreasing the time a message waste in queue of a node. It lowers the load and the pressure of a node.

2.5 ONE SIMULATOR

In this research work, to visualize the movement of the nodes, outcome of the research and to compare them with existing ones, the opportunistic network environment (ONE) simulator has been used to implement the proposed protocol schemes “Optimal hop” routing protocol [1][2].

The ONE simulator is written in java language [1][2] and the selection of ONE simulator for the research work depends on following reasons:

- It has the capability of generating various movement models for node movement in the network [1][2]. Some of the example of those movement models are random, random way point, working day, bus, etc.

- This simulator shows the capability of routing the messages using the already implemented routing algorithms such as Epidemic, Spray and Wait, ProPHET, etc.

- It shows the capability of visualizing mobility of the nodes in the network and the delivery of or relying of the messages to different nodes as it supports graphical user interface, GUI.

- It has the capability of importing real life data traces through an external movement model [1][2].

- This simulator shows the capability to produce various report types after the simulation that can be used for future statistical analysis and performance assessment.

Datasets

In this research work, a basic movement model is used for the simulations. By default, these movement models are present in ONE. The movement model is based on a Helsinki city model with its streets, bus routes, bus stops, tram routes and tram stops. In the research work, ShortestPath movement model will be used.

CHAPTER 3

PROPOSED WORK

It is a challenging task to route the data from source end to destination end because of the lack of network topological information. Consequently, store-carry-forward mechanism is used in DTN to help routing in challenging network [5][15][19][22]. Routing algorithms helps the nodes of the network on making the best forwarding decision. There are some protocols that make simple decision to deliver the data to nodes who are reachable or in communication range for example epidemic, first contact. While other protocols make complex decisions by using the limited information they have it can be distance between nodes, mobility of nodes, energy remaining in the nodes, the buffer space available in the node or the number of copies to replicate [3][4][8][13][20]. The routing decision may depend on the some kind of spatial or may be temporal conditions. It has been the one of the main topic that kept research attracting towards it [22][23]. The performance of a routing algorithm may vary largely by the some factors like the density of the network, mobility of nodes, distance between the source end and the destination end nodes and the amount and quality of information that nodes has.

3.1 PROBLEM STATEMENT

After a comprehensive survey of available routing algorithms, it is found that very less attention has been given to the simplest and fastest routing protocol – Epidemic routing [6]. DTN has the limited buffer space due to which many incoming bundles get dropped which reduces the delivery probability. And flooding is also one of the major problem of the DTN. Due to flooding, consummation of resources get increased [9][14]. To manage the buffer space and simultaneously handling the flooding problem of DTN is the work done in this thesis.

3.2 PROPOSED SCHEME

Epidemic [6] is a very basic example of replication based routing algorithms. Epidemic routing is the simplest routing approach where a node with bundle to send just floods the bundles to all the nodes it is in contact with and then those nodes floods bundles to all other nodes they are in contact with [9][14]. They keep replicating and flooding the bundle until it reaches the destination node or TTL expires.

The performance of routing protocols depends on the information they have like topological information and the replication i.e., how many copies they make. As per [1], there are two types of strategies we can apply on routing protocols.

- Scheduling strategy
- Queue Management strategy

Scheduling strategy is the way of sending bundles that is scheduling bundles and the Queue Management strategy is the way of deleting the bundle from buffer that is scheduling the next bundle to delete [1]. Both of these strategies can impact the performance of a routing protocol in an exceptional way. In this thesis we have worked on these two strategies to implement new protocols.

- **Scheduling strategy**

  As we have seen that epidemic protocol replicates the bundle and floods them in the network. And because of flooding a lot of resources get wasted. It also increases the network overhead. We have tried to reduce the flooding in the network by putting some conditions. If the receiving node satisfy those conditions only then the sender will forward the bundle otherwise it will not forward it.

The first condition is that if the receiving node is not the destination node then it should have at least two connections to forward the bundle further. So that bundle don't have to wait for the further transmission. Many of the bundles get dropped while waiting for a connection to forward the bundle further. If the sending node will first examine the connections of the receiving node then it will reduce the bundle dropping rate. The bundles who get dropped waiting for the other connections. It will reduce the buffer load also. So in this way first condition is managing the buffer also. Because the incoming bundles will get forwarded to other connections as the router will update itself. The router will examine the new up connections and the connections that have gone down then after matching the vector space with available routers it will send the bundles that are not already present on that router. It will directly decrease the bundle dropping rate. But if the receiving node is destination node then it will not check this condition. On destination nodes this condition is not applied. As the destination node does not have the need of forwarding the bundle further, so sending node does not need to check its connections. Even if the destination is isolated and have no connections then too sender node will forward its bundles to that node.

Second condition is that it should be at minimum distance to the sender node and the buffer load should be minimum. So in this way a node will forward the bundle to two best nodes in its communication range. As it is known that shorter is the distance, higher is the delivery probability. In other words delivery probability is inversely proportional of the distance. The sender node will examine the all the connections and then it will choose the closest 2 nodes to forward the bundle. That will in turn increase the delivery probability and reduces the chances of the bundle of getting dropped due to interference in the network. Many bundles get lost even before reaching the receiving intermediate nodes because of the interference in the network. Many objects may come in between the two connected nodes or connection may get lost. Keeping all these things in mind, in this work the proposed approach has taken the nodes whose distance is shortest from the sending node. Because of short distance, the probability of the two nodes going outside their communication range will get reduced. Simultaneously it will reduce the probability of bundle getting dropped. Likewise, lower is the buffer load higher is the chances that the bundle will not get dropped. Many of the bundles get dropped because of the reason that the receiving node has not enough buffer space to accept the incoming bundle. Many routing protocols like Epidemic implement FIFO approach to manage buffer [6][1][3]. In FIFO, the node will drop the oldest bundle even if it has not been forwarded to any other node. So the proposed approach, decreases the dropping of unsent bundles. Combined first and second conditions decreases the unsent bundle dropping rate. Because if a node already have connections with other nodes then that node will immediately forward the bundles on updating the node. If the bundle's dropping chances are less then it will increase the delivery probability. So again, the delivery probability is inversely proportional of the buffer load. So the sender will compute the eligibility of each node in the communication range and will send the bundle to best two routers.

$$Delivery\ probability\ \propto \frac{1}{distance} \tag{3.1}$$

$$Delivery\ probability\ \propto \frac{1}{bufferload} \tag{3.2}$$

$$Eligibility = \frac{1}{distance+1} * \frac{1}{no.of\ bundles+1} \tag{3.3}$$

For the scheduling strategy, the receiving node should have at least 2 connections and should have maximum eligibility ratio. The distance here is the distance between the sending node and the receiving node and the buffer load we have taken as the number of bundles stored in the buffer. The eligibility ratio is calculated by taking the inverse of the distance and the buffer load. As it will define the eligibility of a node to receive the bundles. The sending node will discover the no. of connections its connected nodes have. If those connections are greater or equal to two only then sending node will calculate the eligibility ratio of the receiving node. Then after calculating the eligibility ratio of the connected nodes it will send the bundles to the nodes who have highest eligibility ratio. Higher will be the ratio, if the lower is the distance and the buffer load.

- **Queue Management strategy**

  The Epidemic and many other routing protocols in DTN follows the First In First Out mechanism. So they delete the oldest bundle in stored in the buffer when a new bundle arrives and there is no space of this new bundle. Because of FIFO, the bundles who have not been forwarded to any other node got deleted. To reduce the rate of the bundles dropped before being forwarded to other nodes. The proposed protocol have applied three new strategies to the buffer to delete next bundle and compared them.

  First strategy is to delete the bundle whose destination has been encountered by the node most recently. Because the nodes keep flooding the same bundles until they are in there buffer. It means a node is receiving the same bundles many times it may have forwarded the same bundle to other nodes many times. On each update the nodes floods the bundles present in its buffer to each connection in epidemic protocol. Buffer can have the bundles whose TTL has not expired and are delivered to destination or may be close to destination. FIFO approach not only increases the unsent bundle dropping rate but also increases the flooding and overhead in network. The proposed approach has kept these drawbacks of the FIFO approach in mind and has successfully reduced those effects. So keeping this thing in mind the proposed protocol deleting the bundle whose destination has been encountered by the node most recent and it is observed that it performed far much better than the epidemic routing protocol. It increases the delivery probability by 40% and lowers the overhead to just about 25% of the epidemic routing protocol's overhead.

In proposed second queue management strategy, the nodes will delete the bundle whose destination has been encountered least recently. In this way we are applying the idea that the node will not receive the bundle with destination address which node has encountered least recent anytime soon. So the node will delete that bundle. If there is a situation in which two or more bundle's destination have same encountered age then in that case we are applying the First In First Out strategy in which node deletes the oldest bundle in buffer. So if two bundle's destination have same encountered age then the protocol will delete the older bundle.

The third strategy is to delete the bundle whose destination address is farthest from the node. As earlier said that the delivery probability is inversely proportional to the distance. So we have used the same idea here. If the destination is far away from the node then delivery probability get reduced and as we have limited resources, so protocol will use those resources on those bundles whose probability to get successfully delivered is higher. In this way it will reduce the overhead and simultaneously increases the delivery probability.

CHAPTER 4

SIMULATION AND RESULT

4.1 SIMULATION

For simulation of the DTN, we have used the ONE simulator. Following are the parameters used in the simulation of the routing protocols.

TABLE. 1 Simulation parameters

Parameters	**Values**
Simulation Area	4500*3400
Simulation Time	43200
Mobility Model	ShortestPathMapBasedMovement
TTL	300
Buffer Size	5MB
Transmission Range	10
No. of Nodes	126
Bundle creation rate	25 to 35 seconds
Bundle size	500kB - 1MB

4.2 RESULT

In result, we have compared our implemented routing protocols to epidemic and prophet. And our all three protocols outperformed the epidemic and prophet routing protocol. We compared them on the basis of the delivery probability, overhead and the latency.

The figure below shows the simulation of the network. It shows the movement of nodes and the movement of data from a node to another node.

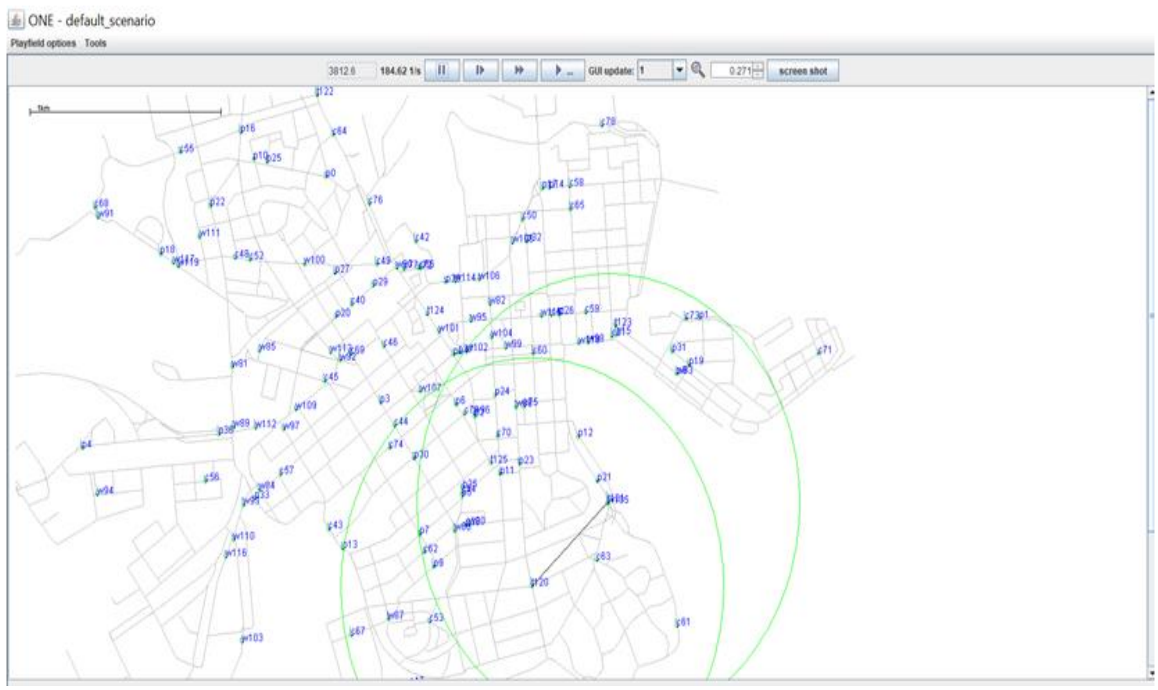

Fig. 4.1 Simulation of protocols

The figure below shows the connections that are made, relayed, movement of bundles, bundles that are dropped, New up connections and aborted connections.

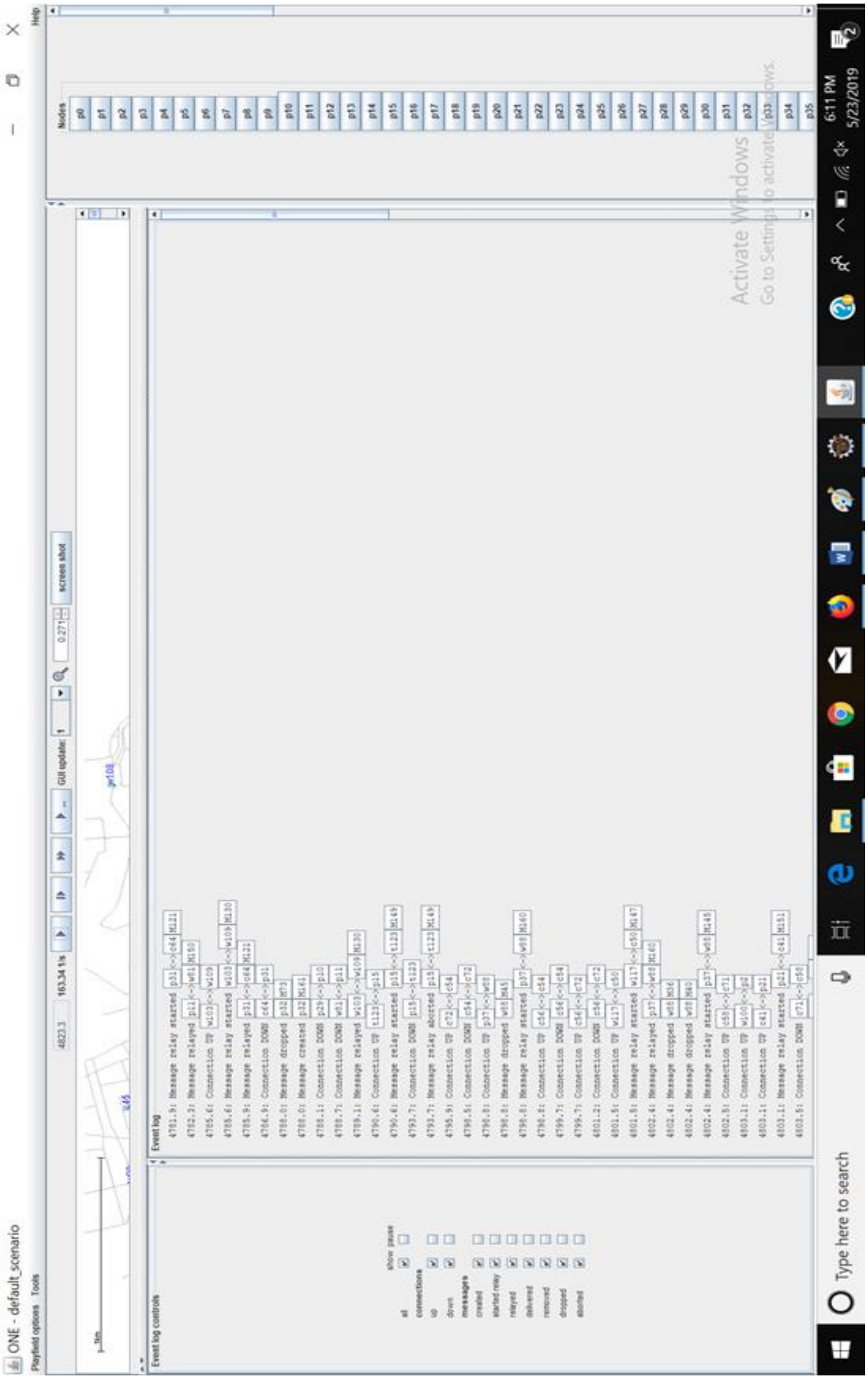

Fig. 4.2 Simulation Events

Most recent epidemic routing, least recent epidemic routing and distance based epidemic, they all shows a much better delivery probability than the epidemic and prophet routing protocols. Because DTN has limited resources. Buffer is one of those resource. DTN needs better strategy to improve the buffer storage. We cannot increase the size of the buffer to a very large value. So we just have to manage the limited size to reduce the bundle dropping before they get delivered to destination.

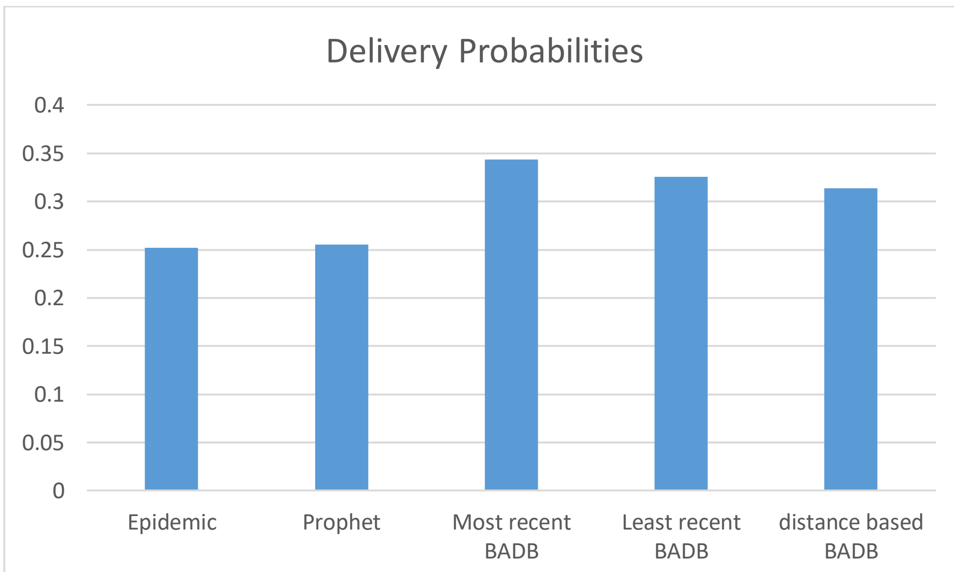

Fig. 4.3 Comparison of Delivery Probability of routing Protocol

There is a need to reduce the flooding in the network. Epidemic has a great speed to deliver the bundle. But it floods the network with bundles that created a lot overhead in the network. It also results in a lot of wastage of the resources of the network. So we saw that Most recent epidemic routing, least recent epidemic routing and distance based epidemic, they all reduce the overhead in the network to 25% (approx.) while increasing the delivery probability.

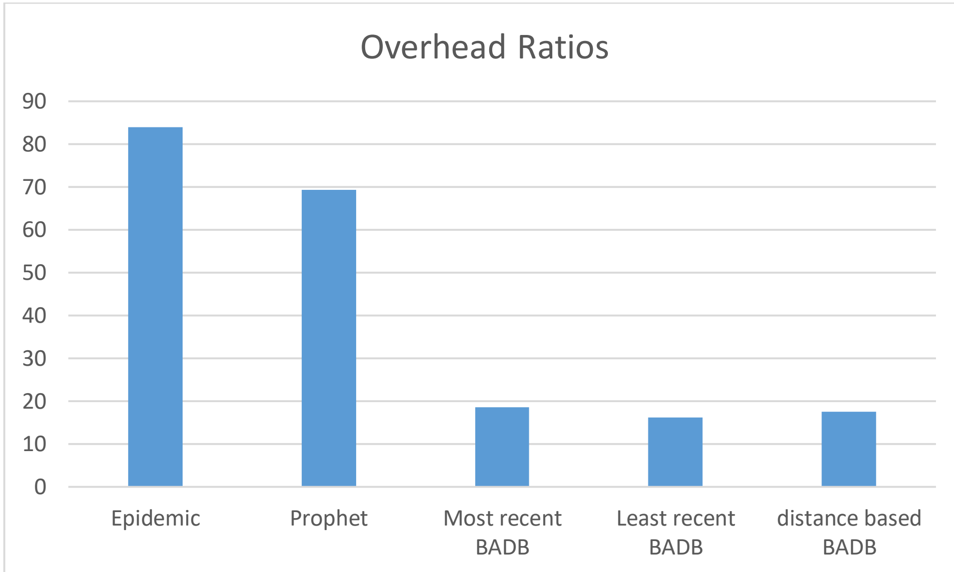

Fig. 4.4 Comparison of overhead caused by routing protocols

Latency is the time from production of bundle to the delivery of the bundle to the destination successfully. So it should be small. But in case of latency Epidemic and prophet routing protocols outperformed our implemented routing protocols.

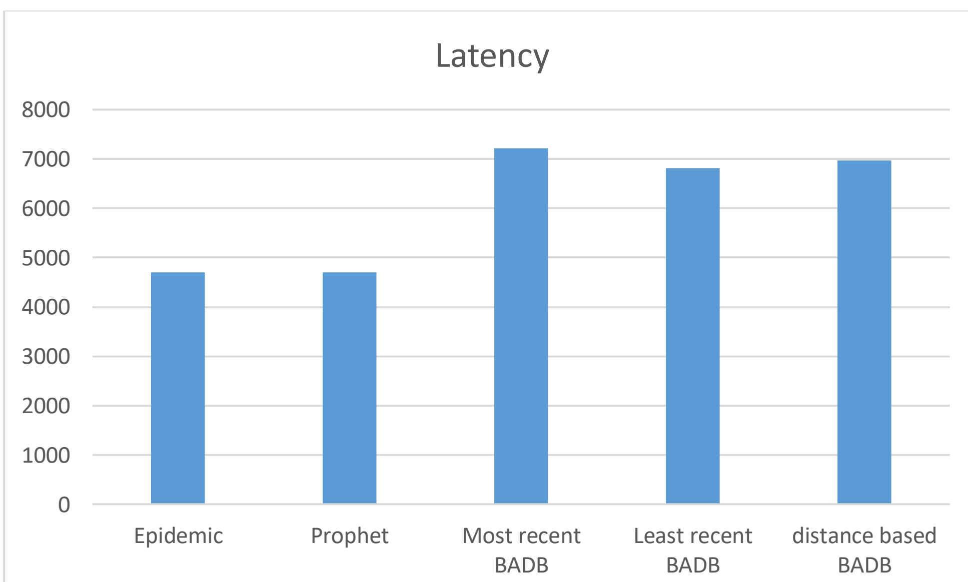

Fig. 4.5 Comparison of latency of each protocol

CHAPTER 5

CONCLUSION AND FUTURE DIRECTION

Resources are the one of the main issue of DTN because DTN's performance depends heavily on these resources. So we need to manage them appropriately. In this thesis, we have tried to manage the some of the resources. And we have seen that we succeed in reducing the overhead in the network and increasing the delivery probability. All the three protocols outperformed the epidemic and prophet routing protocol in terms of delivery probability and network overhead ratio. A lot of work can be done to improve them further. As it is observed that due to calculation to find the next best hop for the bundle, the delay is increasing as it is taking a lot of time to find next best hop. So further work can be done to reduce the delay while keeping the delivery probability and overhead same or better. As the real time systems can't tolerate the delay like VDTN (vehicular delay tolerant network).

REFERENCES

[1] Keränen, Ari, Jörg Ott, and Teemu Kärkkäinen. "The ONE simulator for DTN protocol evaluation." In *Proceedings of the 2nd international conference on simulation tools and techniques*, p. 55. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2009.

[2] Keränen, Ari, Teemu Kärkkäinen, and Jörg Ott. "Simulating Mobility and DTNs with the ONE." *Journal of Communications* 5, no. 2 (2010): 92-105.

[3] Jones, Evan PC, Lily Li, Jakub K. Schmidtke, and Paul AS Ward. "Practical routing in delay-tolerant networks." *IEEE Transactions on Mobile Computing* 6, no. 8 (2007): 943-959.

[4] Musolesi, Mirco, and Cecilia Mascolo. "CAR: Context-aware adaptive routing for delay-tolerant mobile networks." *IEEE Transactions on Mobile Computing* 8, no. 2 (2009): 246-260.

[5] Small, Tara, and Zygmunt J. Haas. "Resource and performance tradeoffs in delay-tolerant wireless networks." In *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*, pp. 260-267. ACM, 2005.

[6] Vahdat, Amin, and David Becker. "Epidemic routing for partially connected ad hoc networks." (2000).

[7] Lindgren, Anders, Avri Doria, and Olov Schelén. "Probabilistic routing in intermittently connected networks." In *ACM International Symposium on Mobilde Ad Hoc Networking and Computing, MobiHoc 2003: 01/06/2003-03/06/2003*. 2003.

[8] Cao, Yue, and Zhili Sun. "Routing in delay/disruption tolerant networks: A taxonomy, survey and challenges." *IEEE Communications surveys & tutorials* 15, no. 2 (2013): 654-677.

[9] Psounis, Konstantinos, and Cauligi S. Raghavendra. *Multiple-copy routing in intermittently connected mobile networks*. Technical report CENG-2004-12, USC, 2004.

[10] Spyropoulos, Thrasyvoulos, Konstantinos Psounis, and Cauligi S. Raghavendra. "Single-copy routing in intermittently connected mobile networks." In *2004 First Annual IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, 2004. IEEE SECON 2004.*, pp. 235-244. IEEE, 2004.

[11] Burgess, John, Brian Gallagher, David D. Jensen, and Brian Neil Levine. "MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks." In *Infocom*, vol. 6. 2006.

[12] Hui, Pan, Jon Crowcroft, and Eiko Yoneki. "Bubble rap: Social-based forwarding in delay-tolerant networks." *IEEE Transactions on Mobile Computing* 10, no. 11 (2011): 1576-1589.

[13] Jain, Sushant, Kevin Fall, and Rabin Patra. *Routing in a delay tolerant network*. Vol. 34, no. 4. ACM, 2004.

[14] Wang, Yu, and Hongyi Wu. "Replication-Based efficient data delivery scheme (RED) for Delay/Fault-Tolerant mobile sensor network (DFT-MSN)." In *Fourth Annual IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOMW'06)*, pp. 5-pp. IEEE, 2006.

[15] Dubois-Ferriere, Henri, Matthias Grossglauser, and Martin Vetterli. "Age matters: efficient route discovery in mobile ad hoc networks using encounter ages." In *Proceedings of the 4th ACM international symposium on Mobile ad hoc networking & computing*, pp. 257-266. ACM, 2003.

[16] Wang, Xingfu, Lei Qina, Pingqing Wei, Fuquan Dai, and Fuyou Miao. "Probabilistic Route Mechanism of Considering Communication Time-PROPHETCCT." In Computer Science and Software Engineering, 2008 International Conference on, vol. 3, pp. 49-52. IEEE, 2008.

[17] Grasic, Samo, Elwyn Davies, Anders Lindgren, and Avri Doria. "The evolution of a DTN routing protocol-PRoPHETv2." In Proceedings of the 6th ACM workshop on Challenged networks, pp. 27-30. ACM, 2011.

[18] Xue, Jingfeng, Jiansheng Li, Yuanda Cao, and Ji Fang. "Advanced PROPHET routing in delay tolerant network." In Communication Software and Networks, 2009. ICCSN'09. International Conference on, pp. 411-413. IEEE, 2009.

[19] Sharma, Deepak K., Sanjay K. Dhurandher, Isaac Woungang, Rohit K. Srivastava, Anhad Mohananey, and Joel JPC Rodrigues. "A Machine Learning-Based Protocol for Efficient Routing in Opportunistic Networks." IEEE Systems Journal (2016).

[20] Yulianti, Deni, Satria Mandala, Dewi Nasien, Asri Ngadi, and Yahaya Coulibaly. "Performance Comparison of Epidemic, PRoPHET, Spray and Wait, Binary Spray and Wait, and PRoPHETv2." Faculty of Computing, Universiti Teknologi Malaysia.

[21] K. Scott, S. Burleigh, "Bundle protocol specification", Internet-Draft, Network Working Group RFC 5050, Nov. 2007, https://tools.ietf.org/html/rfc5050.

[22] D. Pan, Z. Ruan, N. Zhou, X. Liu, Z. Song, "A comprehensive integrated buffer management strategy for opportunistic networks", EURASIP Journal on Wireless Communications and Networking, 2013:103 (2013), http://jwcn.eurasipjournals.com/content/2013/1/103.

[23] M. Xiao, J. Wu, L. Huang, "Community-Aware Opportunistic Routing in Mobile Social Networks", IEEE Transactions on Computers, Vol. 63, No. 7, July 2014, pp. 1682-1695.

[24] A. Chaintreau, P. Hui, J. Crowcroft, C. Diot, R. Gass, J. Scott, "Impact of human mobility on opportunistic forwarding algorithms", IEEE Transactions on Mobile Com-puting, Vol. 6, Issue 6, April 2007, pp. 606-620

[25] McMahon, Alex, and Stephen Farrell. "Delay-and disruption-tolerant networking." *IEEE Internet Computing* 13, no. 6 (2009): 82-87.

[26] Fall, Kevin. "A delay-tolerant network architecture for challenged internets." In *Proceedings of the 2003 conference on Applications, technologies, architectures, and protocols for computer communications*, pp. 27-34. ACM, 2003.

[27] P. Juang, H. Oki, Y. Wang, M. Maronosi, L. Peh, D. Rubenstein, "Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet", Proc. ASPLOS, Oct 2002.

[28] M. Mealling, R. Denenbers, eds., "Report from the Joint W3C/IETF URI Planning Interest Group: Uniform Resource Identifiers (URIs), URLs, and Uniform Resource Names (URNs): Clarifications and Recommendations", Internet RFC 3305, Aug 2002.

[29] J. Sterbenz, et. al., "Survivable Mobile Wireless Networks: Issues, Challenges and Research Directions", WiSe 2002, Sep 2002.

[30] K. Fall, "A Delay-Tolerant Network Architecture for Challenged Internets", Intel Research Technical. Report IRB-TR-03-003, Feb 2003.