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Thesis Title: "A Centrality Based Routing With a Message Relay Control Mechanism in Opportunistic networks"

Submitted by

ABINEZA Claudia

College of Science and Technology

School of Information and Communication Technology (SoICT)

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Thesis Title: "A Centrality Based Routing With a Message Relay Control Mechanism in Opportunistic networks"

By

Name: ABINEZA Claudia

Registration Number: 216349869

A dissertation submitted in partial fulfillment of the requirements for the degree of

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Supervisor: Professor Santhi KUMARAN

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Declaration

I declare that this Dissertation contains my own work and the references were provided where applicable.

Student Name and Number

ABINEZA Claudia

216349869

Signed………………………………………..

Date…………………………………………..

Research and Postgraduate studies

(RPGS)Unit

Certificate

This is to certify that the project work entitled "A Centrality Based Routing With a Message Relay Control Mechanism in Opportunistic networks" is a record of original work done by ABINEZA Claudia with Reg no: 216349869 in partial fulfillment of the requirement for the award Masters of Science in ICT:Operational Communication of College of Science and Technology, University of Rwanda during the academic year 2015-2016.

Professor Santhi KUMARAN	**Mr. HENRY Kirya**
……………………….. …………	**…………………..**
Supervisor	**Head of IT Department**

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Finally, I would like to dedicate my work to my loving family.

May god bless you all !!!

ABSTRACT

Opportunistic networks are a subclass of delay tolerant networks that aims at transmitting messages by exploiting direct contacts among nodes, without the need of a predefined infrastructure. Typical characteristics of Opportunistic networks include high mobility, short radio range, intermittent links, unstable topology, sparse connectivity, to name a few.

In such situations, the nodes might still copy and forward messages to nodes that are more likely to meet the destination. As such, the challenge routing in such networks is to design a routing protocol that offers the best tradeoff between cost (number of message replicas) and rate of successful message delivery.

This thesis addresses this problem on using the concept of Google Pagerank like centrality to rank nodes in a network using social information. Unlike other nodes in the network, central nodes are more likely to act as communication hubs to facilitate the message forwarding. Furthermore a mechanism of message relay control is designed to overcome and keep the network overhead ratio low.

In this thesis, a Centrality Based Routing with a Message Relay Control Mechanism is designed. The proposed CBRWMRCM is evaluated by simulations using the ONE simulator, showing performance compared to other typical routing protocols.

List of Acronyms

CBRWMRCM: Based Routing with a Message Relay Control Mechanism

ONE: opportunistic Network environment

DTN: Delay Tolerant Network

OppNets: Opportunistic network

3G: third Generation

DV: distance vector

LS: link state

MANETs: Mobile Ad-hoc Network

SnW: Spray and Wait

PRoPHET: the Probabilistic Routing Protocol using History of Encounters and Transitivity

RAPID: Resource Allocation Routing for DTN Paradigm

OMN: Opportunistic Mobile Network

MAP: mobile access points

DTWiki: a Wiki system operating in DTNs

MIME: Multipurpose Internet Mail Extensions

GUI: Graphical user interface

WSN: wireless sensor network

TTL: Time To live

GPS: Global Positioning System

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CHAPTER I: GENERAL INTRODUCTION

1.1 INTRODUCTION

In recent years, incoming of smartphones and advent of wireless technologies make a seemless and cheaper communication between wireless devices anytime and anywhere. In this setting, Opportunistic networks (OppNets) are considered as specialized ad hoc networks , characterized by frequently intermittent connections, which operate without any assistance to any infrastructure such as access point, routers. Communication in this type of network is made possible by "mobile self-configurable devices, with no infrastructure assistance" feature, exploiting direct contacts among nodes with a message store –carry and forward way and incentive way to make information exchange guaranteed as some nodes in a network tend to refuse to share their private resources such as buffer space. Summarily network topology is not known a-priori, at the message sending.

So routing protocols in such environment, rely much on network assumptions such as mobility patterns, node capacity, scheduling knowledge, estimation and on prediction on the likelihood of future network topology.

So, most routing protocols for OppNets rely on partial knowledge and the prediction of future contacts based on historical contact information. They also rely on social-metrics, which themselves are dependent on the past information of nodes.

Centrality is one way, among other routing prototocol metrics used to forward the message in social opportunistic network. As the name expresses, centrality relates to action to identify central nodes in a network, thus centrality definition should derive from various means, including social criteria. Due to the dynamics of node mobility, the influence that a node may have over the spread of information in relation to how many other nodes (encounters) this node may have been in contact with, is defined as centrality metric, in this work.

Based on this definition, each node in a network is assigned a centrality value using Google Pagerank like algorithm entitled " A Centrality Based Routing with a Message Relay Control

Mechanism" and nodes with highest centrality values, are more likely to act as the best messages forwarder.

1.2 BACKGROUND

A delay-tolerant network is a network designed to operate effectively over extreme distances such as those encountered in space communications or on an interplanetary scale. In such an environment, long latency , sometimes measured in hours or days is inevitable. However, similar problems can also occur over more modest distances when interference is extreme or network resources are severely overburdened.

Communication in DTN, where network is infractureless, is called opportunistic network. Basically, routing in such network use a store carry and forward mechanism, where a message is replicated between contacted nodes, in expecting it to deliver to a destination. This replication of message occupy buffer of nodes and may cause congestion, and network overhead. So the message forwarding strategy is a key issue in such dynamic and intermittently disconnected networks.

This operational mode imposes a new model for routing, based on the current connectivity information and the prediction of a future connectivity.

Various routing schemes in oppNets evolve[1]. However mostly, two main routing schemes are more noticeable: flooding based and knowledge based. In the latter, the knowledge of the context in which nodes operate is used to determine the best next hop of a given node .This includes node position, its movement path and its neighbors to name a few.

On one hand, due to the lack of sufficient knowledge on network topology, OppNets routing exploits both mobility and social context of a node, to determine who can communicate with whom.

On other hand, it should be noted that for many proposed routing which replicate the message, some of which don't establish the way to stop spreading the same message, after the delivery of message.

This urges in establishing a mechanism for acknowledgement of a delivered message. This work thus alleviates this challenge by establishing a message acknowledgement upon receiving the message by a destination.

This concludes to the development of " A Centrality Based Routing With a Message Relay Control Mechanism in Opportunistic networks" which belongs to a context aware routing category by exploiting social attributes of a node.

1.3 STATEMENT OF THE PROBLEM

In particular types of Delay-Tolerant Networks (DTN) such as Opportunistic Mobile Networks that rely on the store-carry-and-forward paradigm, using contacts between nodes to opportunistically transfer data, traditional routing mechanisms are no longer suitable.

New approaches use social relations between mobile users as additional criterion for the routing process to increase the message delivery. Among them, Centrality is mentioned. Centrality is defined as an identification of nodes in a network, that could act as bridge nodes, which are capable to retransmit and transfer the message among disconnected nodes[2] .It should be clearly noted here that centrality can be defined according to any criteria.

Commonly used centrality metrics, include degree centrality [3] - which measures the number of direct ties maintained by this node with other nodes, closeness centrality [4] which is derived from the shortest path between a node and other reachable nodes, betweenness centrality[5] which measures how often a node belongs to the route that links other nodes , to name a few.

While the above-mentioned centrality based forwarding consist on forward messages ,where the social information is known a-priori, this work uses a distributed algorithm to dynamically ranking a node in a network upon meeting another node, inferred an implicit social node. This makes the proposed algorithm feasible in dynamic mobile wireless environments.

The approach proposed here ,which takes inspiration from Google Pagerank, computes for each node probability to be used as carrier for random messages traversing the network, using the concept of centrality of the node in a network. The centrality, here was inferred from how popular a node is in a social network, expressed implicitly by a social attribute of a node:” the number of encounters.”

1.4 OBJECTIVES OF THE PROJECT

1.4.1 GENERAL OBJECTIVE

To design a routing protocol for opportunistic network operation, that reduces network overhead by exploiting social information as criteria to select a next hop.

1.4.2 SPECIFIC OBJECTIVES

- Investigate characteristics and technologies of an opportunistic network, as well as apply them for routing in such networks.
- Develop a model for a benchmark resulted from node centrality metric, to use in a forwarding routing in DTN.
- To Design CBRWMRCM routing protocol

1.5 SCOPE AND LIMITATION OF THE PROJECT

Mostly routing protocols in opportunistic network are context-based, meaning classified in mobility-based routing protocols, and social context-based routing schemes. The routing protocol proposed in this work is a hybrid protocol that exploits both node mobility and social attribute.

1.6 JUSTIFICATION OF STUDY

The rapid proliferation of small wireless devices (e.g., smart phones) creates ample opportunity for novel applications, as well as for extending the realm of existing ones [6]. Opportunistic networking is a new networking paradigm that is envisioned to complement and extend existing wireless infrastructure such as 3G and WiFi: Mobile devices exploit communication opportunities by exchanging data whenever they are within mutual wireless transmission range (in contact). Furthermore algorithms and protocols (e.g., routing protocols) for opportunistic networks were originally largely based on random decisions, then further improve by using context of nodes such as mobility and social context.

So the interest in designing a routing protocol for opportunistic network is as following:

- To get up-to-date and acquire skills in designing today technologies.

- To contribute to design of technology in opportunistic network.

- To use social characteristic of a node in a network, to design a model that can be used in routing to complement with the existing technologies.

1.7 ORGANIZATION OF THE PROJECT

This project is organized into six chapters:

The first chapter is general introduction which contains the background, statement of the problem, project objectives, scope of the project ,interests of project and organization of the project.

- The second chapter deals with literature review.
- The third chapter describes the methodology used in developing CBRWMRCM routing protocol.
- The fourth chapter will be the CBRWMRCM protocol analysis and design
- The fifth chapter consists of implementation of CBRWMRCM protocol , results and discussions.
- The sixth chapter consists of conclusion and recommendation.

1.8 CONCLUSION

This chapter described the research problem about the routing in opportunistic network, as a subclass of Delay Tolerant Network, the objective of the project and about the scope and limitations of the study.

CHAPTER II: LITERATURE REVIEW

2.1 INTRODUCTION

The literature review consists of concepts and technologies used in the design of "Centrality Based Routing with Message Relay Control Mechanism." Thus it discusses the main characteristics of opportunistic networks along with routing in such networks and the related work to this research.

2.2 NETWORK TOPOLOGY

As stated earlier, an opportunistic network is a kind of challenged mobile multi-hop ad hoc network characterized by unpredictable topology, prolonged disconnections and partitions. This is due to some reasons such as having intensive number of nodes in a small area or when a node density is sparse, and high mobility of nodes, to name a few .So the successful establishment of an end-to-end path between a source and destination node is not guaranteed .An example of architecture of such a network is a network formed by a group of people equipped with smart devices such as PDA, cell phones. It is noticed well that such network can grow or reduced both in time and space as people can move at anytime and to anywhere [7]. Thus a dynamically network with uncontrolled network links may be resulted. The most thing to notice here is intermittent network topology due to above mentioned reasons, wherein the old ad hoc routing protocols could no longer be applied, as long as the network topology is not always predetermined and guaranteed.

2.3 DATA DISSEMINATION

Opportunistic networks use human mobility and consequent wireless contacts between mobile devices to disseminate data in a peer-to-peer manner. Due to node mobility, nodes can connect and disconnect since they move in and out of their communication range.

As such a node is expected to be a router for another node, thus store, carry and forward a message for another node, in expecting to meet the node or another selected node with a high rank, expressed as capability to reach a message destination.

Mostly routing in this communication paradigm, rely on identifying what would be the best message forwarder, in terms of capability of battery power, position in a network, history of contacts of nodes, social behavior of nodes etc or simply by exploiting when physical proximity arises and then forward a message[8].

2.4 ROUTING PROTOCOLS FOR OPPORTUNISTIC NETWORK

The fundamental goal of any communication network is to have the messages delivered to their corresponding destinations, meaning there should be an optimum path, along with a message should follow in order to reach a destination. Identifying such an optimum path is the role of routing protocols.

Traditional networks and the Internet assume that a network, even if is sparse, is connected and that a path between a source and destination always exists. In general, one may group the routing protocols into two broad categories: distance vector (DV) and link state (LS). Although similar routing algorithms have been used in MANETs, such approaches become difficult in DTNs. This is due not only to highly dynamic, but also DTN exhibits high degree of network partitioning. Consequently, a message is carried by replicating it among meeting nodes, under a store and carry message mechanism. This requirement raises the challenges in this type of network of dealing with specifying and selecting a best message forwarder, for a message delivery success and with fewer networks overhead consumed.

To overcome such issues and constraints, several schemes have been proposed in the literature to achieve efficient routing in DTNs/OppNets. However, a common characteristic of all these routing protocols is that they are replication-based. So the efficiency of any protocol relies much on what extent the protocol restricts message replication.

When looking over the network architecture and a metric used for measuring performance routing and strategy for restricting a message relay in OppNets:

Two main categories are distinguished: routing protocols designed for infrastructure-based and infrastructure-less opportunistic network. In the latter, most routing protocols are context-aware routing protocols, where the knowledge of the context in which nodes operate is used to identify the best next hop of a given node. Context aware based routing are in turn, classified into mobility-based routing protocols, and social context-based routing schemes [9], [10]. So The CBRWRMCM protocol to design in this work is a social context-based by exploiting mobility of nodes.

Mostly in DTN applications, such as mobile social networks and vehicular networks, the most of mobile devices are carried by humans. Consequently their behaviors patterns are described by social models and helped in better forwarding decision .So various social-based routing protocols have been proposed [11], [12], exploiting various social characteristics, like community and centrality.

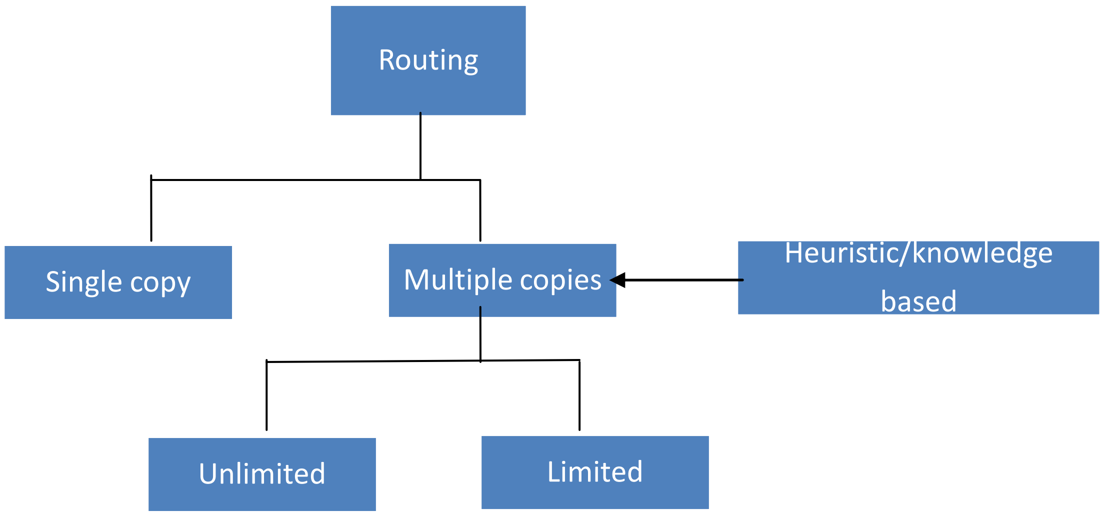

Figure 2.1: Routing categories in DTNs

A brief look at some of the well-known routing protocols used in DTNs.

Epidemic routing

Vahdat and Becker [13] proposed the epidemic routing protocol for ad hoc networks with high network partitions. The epidemic routing protocol is flooding-based in nature, as nodes continuously replicate and transmit messages to newly discovered contacts. Now, when a node comes in contact with another node not having that message, the former node transmits a message to the latter . Then eventually, after replicating the same message to multiple nodes in the network, the message reaches to its destination.

The goal of the epidemic routing protocol has been to maximize the chances of message delivery ratio and minimize latency while minimizing the aggregate resource consumption (for example, bandwidth and energy) in the network .

Spray and Wait

Spyropoulos et al. [14] proposed the Spray and Wait (SnW) routing protocol, which imposes a maximum limit on the number of possible replications of a message. The SnW protocol is composed of two phases: the spray phase and the wait phase. When a new message is created in the system, a number L is attached to that message indicating the maximum allowable copies of the message in the network: in the spray phase, a particular message is spread to at most *L* different relay nodes. Such spraying begins with the source node, i.e., the node that created the message. Any node receiving such a message can, in turn, engage in spraying.

In Wait phase: if the destination node was not encountered with during the spray phase, the intermediate nodes carrying a copy of the message perform a direct delivery when they come in contact with the corresponding destination of the message.

PRoPHET

Lindgren et al. [15] proposed the probabilistic routing protocol using history of encounters and transitivity (PRoPHET). PRoPHET, the probabilistic Routing Protocol using History of Encounters and Transitivity ,is a greedy algorithm, that attempts to exploit the non randomness of real world encounters by maintaining a set of probabilities for successful delivery to known destinations in the DTN(delivery predictabilities) and replicating messages during opportunistic encounters only if the latter node has a greater chance of encountering the destination of the message than the former itself.

MaxProp

MaxProp [16] is flooding-based in nature, in that if a contact is discovered, all messages not held by the contact will attempt to be replicated and transferred. The intelligence of MaxProp relies in determining which messages should be transmitted first and which messages should be dropped first. Thus MaxProp maintains an ordered-queue based on the destination of each message, ordered by the estimated likehood of a future transitive path to that destination.

RAPID

The rapid [17] protocol is based around the concept of utility function. To achieve this RAPID used an inband control channel to exchange various metadata including expected contact time with other nodes, list of messages delivered, and average size of past transfer events. Based on the information in utility function, Rapid replicates packets first that locally result in the highest increase in utility.

Bubble Rap

With knowledge of interactions among people, Bubble Rap determines and predicts how a message from a person passes on to a different person. Hui et al. [18] studied the social structures of the between devices and leverage them in the design of forwarding algorithms termed as Bubble.

The Bubble algorithm assumes that every people in the OppNet belong to at least one community. Moreover, each node has two rankings associated with themselves. The first ranking is a local ranking, where a node is assigned a relative rank in its own community. The other one is the global ranking, which is valid across the entire OMN.

Message forwarding using Bubble essentially involves climbing or *bubbling* up the hierarchical ranking tree. Initially, a message is replicated by the nodes using their relative global ranking until the message reaches to a node that belongs to the same community as the destination of the node. Once a member of the desired community receives the message, it uses local ranking of the other nodes in the community to further disseminate it until the message reaches to its corresponding destination node.

2.5 APPLICATIONS AND SERVICES

OppNets can be deployed for several types of applications, including wireless and underwater sensor networks, day-to-day scenarios, smart homes. Few opportunistic networks case studies and architectures are described in the following:

DakNet

The DakNet project [19] has been developed at MIT Media Lab. It combines asynchronous services together with wireless mode of communication to connect remote villages with towns and cities. DakNet consists of kiosks, mobile access points (MAPs) equipped with portable storage devices and internet access points or hubs. The MAPs are mounted on and powered by vehicles such as bus or motorcycle. Whenever such a MAP comes within the proximity of a kiosk, data are transferred between them. Subsequently, when a MAP comes near a hub (possibly in the town or city), data from the kiosks are synchronized with the internet. The MAPs, therefore, essentially act as data mules. DakNet has been deployed in the villages of India and Cambodia.

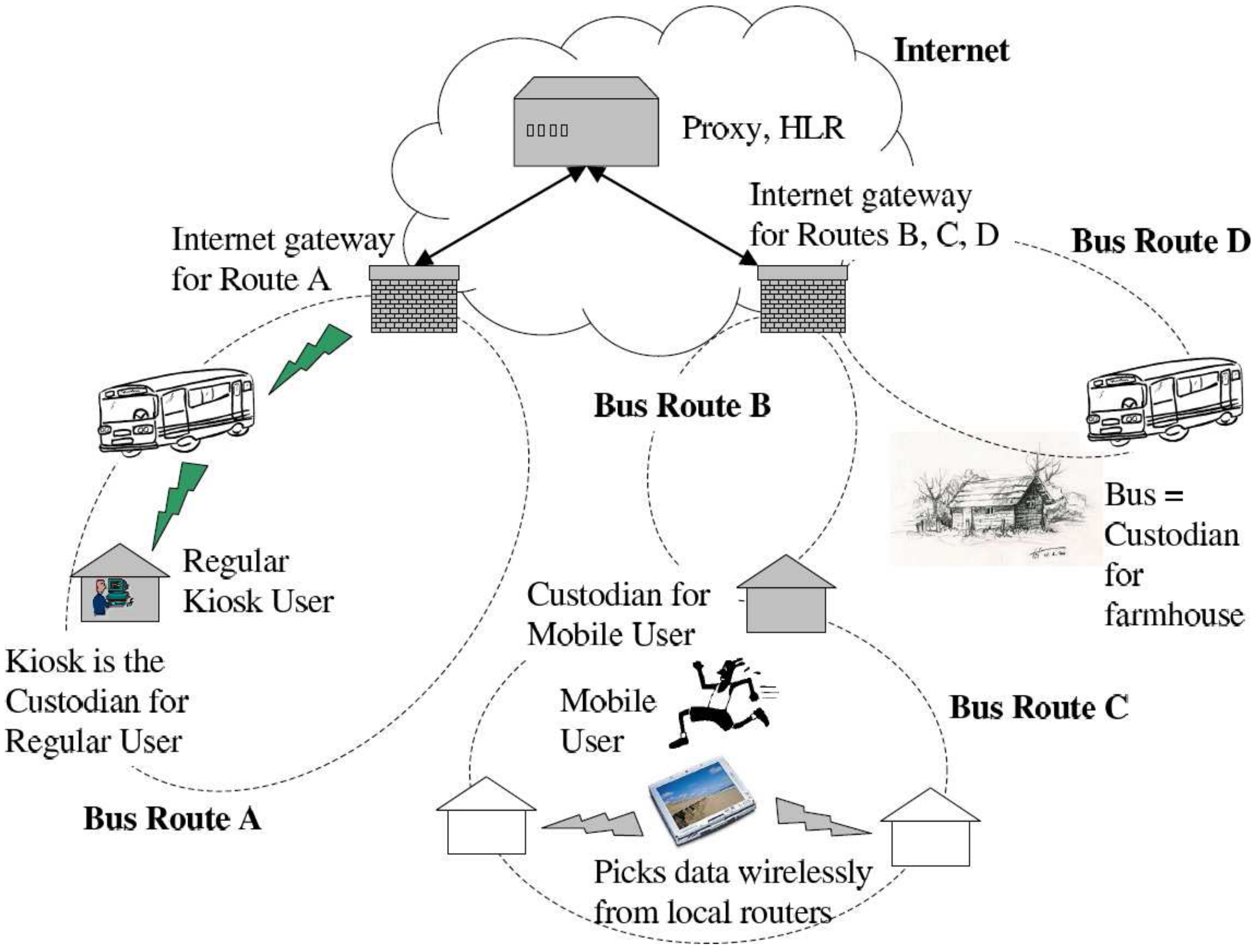

Figure 2.2: Sample KioskNet architecture , reproduced from [19]

Bytewalla

Ntareme et al. [20] developed Bytewalla, an android application to enable delay tolerant networking. With Bytewalla a user can specify where to store the bundles as well as how much memory to be used. It has provision for sending emails via DTN, which is useful in rural areas with no internet connectivity. A DTN server receiving such an email converts it into a bundle, and are forwarded to other smartphones using the application. On the other hand, a server extracts the email from a bundle before delivering it to a client. Bytewalla consists of two networks which can be deployed to interoperate from two separate remote locations.

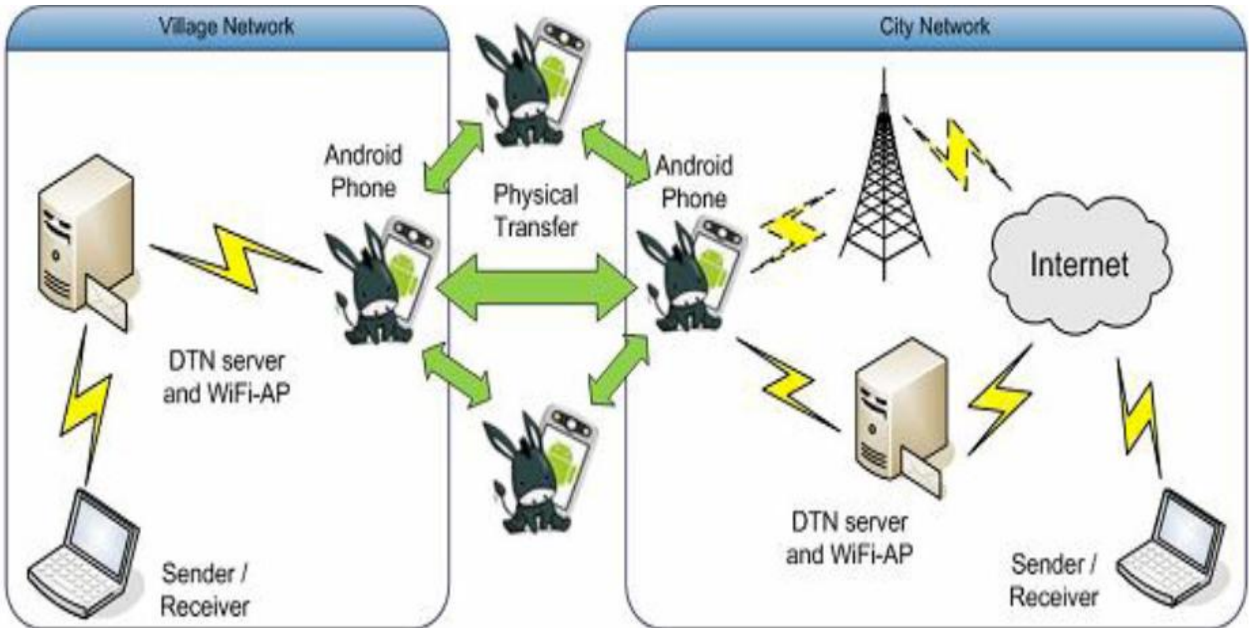

Figure 2.3: Bytewalla Network Architecture

DTWiki

Du and Brewer [21] implemented a Wiki system operating in DTNs with intermittent connectivity. The DTWiki application runs on the top of TierStore, a distributed file system used to manage file replication, synchronization, and consistency. The backend of DTWiki is not a simple relational database, but consists of several components to ensure data consistency under intermittent connectivity. The data back end stores pages and their revisions with related metadata, user account information, attachments (for example, images and videos) contained in the pages, discussion pages for coordination among the users, facility for searching and indexing content, and mechanism for sharing. Such features help in providing robustness and scalability in the face of frequent network partitions and intermittent connectivity

DT-Talkie

Islam et al. [22] developed DT-Talkie. At a high level, DT-Talkie consists of five modules. The first module, audio capture and play, is responsible for capturing the input voice message at the sender's side and storing the encoded voice message inthe local file system. At the receiver's end, this module plays a received voice message.

The MIME (Multipurpose Internet Mail Extensions) create and parse module creates multipart MIME message at the sender's side containing the encoded voice message and sender's information. At the receiver's end, this module is responsible for parsing the appropriate data from the received bundle. There is also a bundle send and receive module for creating, sending, and receiving a bundle; a GUI module to let the user interact with the application. Finally, the DTN daemon runs in the background providing necessary service for operations with bundles. Apart from one-to-one "conversations," DT-Talkie also allows group-based communication.

ZebraNet

The ZebraNet [23] project was aimed at monitoring the movement and activity of zebras at the Mpala Research Center,Kenya. Such wildlife movement spanned over a large terrain size and a long temporal scale. Although ZebraNet can be considered as a typical project on ad hoc WSNs, it exhibited several challenging requirements. For example, the size and weight of the collars could not be large so that they do not inhibit the movement of the zebras. On the other hand, with collars attached to the necks of zebras, a sparse network topology is created with lower chances of communication.

Moreover, since the tracking devices, equipped with GPS sensors, were required to operate over long periods of time without human intervention, relying only on battery sources for power was not feasible. These factors led toward the design of custom-made hardware for the collars. However, from the perspective of network communications, a more stringent requirement was that the base station, which itself was mobile, should receive almost all the tracking data gathered as close to 100% as possible. The delay in obtaining all such data was not critical. In other words, the ZebraNet project exhibited delay-tolerant characteristics, where eventual delivery of messages was acceptable. The collars attached to the zebras would normally transfer data in peer-to-peer fashion. Subsequently, the base station received data from the zebras when they came within proximity.

Other related application includes Web searching from buses and Twimight, a Twitter client for disaster mode etc. So more similar applications are expected to come up and used in the future

2.6 FRAMEWORK OF SOCIAL BASED ROUTING AND CENTRALITY

When analyzing human behavior, it is found out that nowadays people carry several electronic devices that could be a part of the network e.g. notebooks, smart phones, e-book readers, multimedia players etc [24].

Social routing is based on communication in DTN wireless ad-hoc mesh network created by those personal devices. Clearly, node mobility relies on the behavior of the user in this type of network, as the device is owned and often carried by the user. Thus several solutions have been proposed that exploit the interplay between the structural properties of social networks, mobility aspects, and information diffusion. Few social based forwarding are pointed out : (SimBet) [25] that uses social network properties such as betweenness centrality and social similarity to inform the routing strategy and (BUBBLE Rap) that targets nodes with high centrality as well as members of the communities, yielding delivery ratios similar to flooding approaches with lower resource utilization, to name a few.

2.6.1 SOCIAL PROPERTIES USED IN DTN SOCIAL BASED FORWARDING

a) Community

A community can be seen as a group of interacting people occupying the same geographical area [26]. Thus communities naturally reflect social relationship among people, as a member of a given community is more likely to interact with another member of the same community. So the community can be detected and used for routing forwarding in an OppNet.

b) *Centrality*

In the context of network graph, a central node, typically, has a stronger capability of connecting other nodes in the graph. Thus quantifying centrality metric can be used for routing forwarding in an OppNet.

c) Similarity

Similarity is a measure to calculate how different two nodes are and what their degree of separation is. So it can be delivered if two nodes have a common neighbor, their probability of getting connected is quite high. Similarity can also be found on different contexts such as having common neighbors or on the other basis such as of common interests [27] and locations [28]. So , Similarity can be seen as a metric for routing forwarding in an OppNet

d) Friendship

In sociology, friendship describes close personal relationship such as sharing common interests. In this context , two nodes are considered friends, when their contact are regular or lasts long. So friendship can be used for social based routing forwarding in an Oppnet [29].

2.6.2 THE CONCEPT OF NETWORK GRAPH

By the definition**,** Graph G is 2-tuple (V, E) where, V is the set of nodes (or vertices) and E is the set of edges (or links) connecting a pair of nodes, therefore, a graph can be directed or undirected where an edge between two nodes is either non-mutual or symmetric. Also a graph can be weighted or unweighted. See the below figure

The connections among nodes, in case of mobile ad-hoc networks are varying over time and exhibit a time-evolving graph. Simply in network graph structure, the mobile nodes can be presented as vertices and opportunistic contact between nodes as an edge. The graph network model, has been used in different approaches to routing as it can be seen in [30]- [33] to capture and represent network characteristics such as duration of contact, inter contact time, repeated contact, etc.

This work computes for node rank in an OppNet over an imaginary social graph, to alleviate and address the problem of frequent network disconnection, as it is stated later in subsection of analysis of the proposed system. Summarily there should be at least an optimum path along with a message should follow from a source up to a destination.

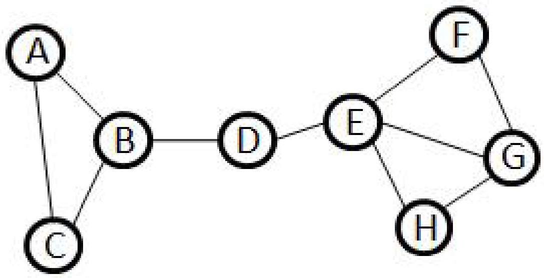

Figure 2.4: A network graph

2.6.3 THE CONCEPT OF CENTRALITY

Centrality is a network metric which identifies important node in a network and centrality measures quantify the role of the node from different perspectives. It has been an age since various research on network centralities in different domains , such as in sociology, biology, physics, applied mathematics and computer science, see [34]- [38]. The computations of centrality in a DTN social network forwarding , the idea is related [39], [41]. For example, when calculating the betweeness and closeness centralities of all the vertices in a graph involves calculating the shortest paths between all pairs of vertices. So many algorithms evolved to calculate the betweenness centrality, including Floyd-Warshall algorithm [42], Johnson's algorithm [43] and Brandes' algorithm [44]. However, when investigating into the above centrality computing algorithms, are centralized and rely on global information of the network.

Recently, distributed algorithms have been proposed in [45], [46] for computing the betweenness and closeness centralities to adapt the algorithm to dynamic characteristics of mobile wireless network.

Different approaches were adopted for computing Pagerank like centrality in mobile wireless environments, namely eigenvector centralities[47] and peoplerank algorithm[48].The latter computes centrality inspired from Google pagerank[49], both in a centralized and distributed way.

Motivated by the above mentioned works , this work proposes incremental algorithms to distributedly compute the centrality adapted to Google Pagerank concept and opportunistic mobile network dynamics.

By the proposed algorithm, through this work , every node computes its own measure with only local interaction and without any centralized coordination, meaning at the sending a message, network is unaware of the network toplogy and node neighbors. Consequently, this suits well the opportunistic networks characteristics where network topology is frequently intermittent and change. Furthermore a new feature added, comparing to Peoplerank algorithm is an acknowledgement of a sent message.

2.7 CONCLUSION

In this chapter, a detailed research was done on a large number of routing and message forwarding techniques which are related to routing in opportunistic network. Furthermore, publicly available implementations and Characteristics of a DTN/OppNet network were analyzed throughout this chapter. Finally, a framework for social based routing and centrality was explained, along with the motivation and interest of this work.

CHAPTER III: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter shows how the research will be conducted in order to achieve the stated objectives. It will indicate the research motivation and procedures, which include method for data collection and CBRWMRCM protocol design requirements. Finally to derive an approach to follow for assessment of the protocol performance.

3.2 PROJECT MOTIVATION AND DATA COLLECTION METHODS

Currently, there is not a one approach that fits all opportunistic routing protocols in an opportunistic network. However it is time to start to give a model, under which the CBRWMRCM protocol could be designed. Many routing protocols in opportunistic network were investigated in literature review such as ones which use a node context information to forward and select a next hop, while others use social based information to know who is communicating with whom. Originally, routing protocol originally were largely based on random decisions, such as epidemic routing protocol, which forward a message to any encountered node, without any type of computation.

Deriving from the literature review, it is clearly noted that the problem of intermittent disconnection among nodes in an opportunistic network, is always dealt from every research conducted on routing in such types of network. It is in this regard a model should be imagined, established and suggested to overcome the problem of frequent disconnection to be able to transmit a message up to a destination, without any break of network linkage.

On one hand, this raises a need to propose and follow a model that guarantee a permanent link existence among network nodes. The model chosen, to accomplish this work, was a contact time-evolving social graph, that should be imagined and implicitly inferred upon nodes contacts, thus constructed dynamically through each encountered nodes 'encounters (predecessors and successors).

On another hand, when reading through existing routing protocols, some of them manage on how to reduce network overhead and message replicas in a network while others don't. This raises a need to increase the performance of a proposed protocol, by adding it with a mechanism of message acknowledgement, upon a message receiving. This will prevent spreading extra copies of the same message in a network. Thus reducing network overhead and unnecessary copies of a delivered message.

3.3 RESEARCH GOALS AND REQUIREMENTS

The development of a routing protocol which exploits both mobility and social node characteristics is the motivation behind the Centrality based Routing With a Message Relay Control Mechanism.

The algorithm is defined by the following developmental guidelines, upon a contact:

1. Update node encounters and centrality data structures. And implicitly derive from this meeting event, a newly added social encounter for each node.
2. Check if a message to forward is not owned by encounter node or is not acknowledged from encounter node's buffer.
3. Finally compare node centrality to determine whether to transfer a message or not.

To accomplish the previous goals, "Centrality Based Routing With Message relay Control Mechanism" should be designed and project requirements were derived such as:

- First establishing nodes data structures .
- Secondly, developing an algorithm to follow.
- Thirdly use a tool for simulation, ONE(Opportunistic Network Environment) simulator and eclipse software development editor, are used for this project.
- Finally, doing an assessment of CBRWMRCM protocol, through simulation.

3.4 RESEARCH METHODOLOGY OVERVIEW

First, existing opportunistic routing protocols were studied to better understand the OppNets problem and to determine which of the existing protocols should be used to compare with CBRWMRCM protocol.

Once the OppNets problem and existing solutions were better understood, a preliminary version of the CBRWMRCM algorithm was developed, tested (by simulation) and the results compared with comparison protocol results (using the same values for simulation parameters).

As problems and glaring inefficiencies with the CBRWMRCM algorithm were discovered, they were studied, fixed and the algorithm was modified, tested and the results compared again. This refinement process involved in doing much more research related to routing in opportunistic network and tweaking the social graph model upon which CBRWMRCM algorithm is based.The entire process of testing, comparing and refining was repeated over several iterations until the final version of the CBRWMRCM algorithm was created.

Once a CBRWMRCM algorithm was developed, assessing the protocol with testing began. Testing involved a very specific network simulation where the only changes made between runs were the routing protocol, the number of nodes and message time to live(TTL). The key comparison results were chosen to be delivery ratio CBRWMRCM (messagesdelivered/messagessent) and network overhead().

Finally a table containing report on different simulation run is shown, to compare CBRWMRCM protocol with other typical routing protocol in opportunistic network.

3.5 CONCLUSION

This chapter covered the approach followed while carrying out this work. The approach includes methods of data collection, its analysis and the processes to be undertaken when designing CBRWMRCM protocol. It should be noted that data was collected and analyzed through observation and documentation method, and the model followed is prototyping by developing a CBRWMRCM algorithm model . By this stated methodology, data structures and the algorithm for CBRWMRCM protocol simulation are going to be modeled and addressed.

CHAPTER IV: CBRWMRCM PROTOCOL ANALYSIS AND DESIGN

4.1 INTRODUCTION

To analyse and design the CBRWMRCM protocol, Prototyping as software development life-cycle was used as prescribed in chapter III of the research methodology.

The main idea in Prototype model is that instead of freezing the requirements before a design or coding can proceed, a throwaway prototype is built to understand the requirements. So, by using this prototype, the client can get an actual feel of the system, since the interactions with prototype can enable the client to better understand the requirements of the desired system.

4.2 ANALYSIS OF THE CBRWMRCM ROUTING PROTOCOL

4.2.1 ANALYSIS OF TECHNIQUE USED

Google pagerank algorithm[50].

Google search engine uses Pagerank algorithm to know which page from a list of pages, to be shown first to the user.

The engine uses probabilistic distribution over the World Wide Web graph, where the nodes are pages, and the edges are links between pages .It computes for the likelihood that a person randomly clicking on links will arrive at any particular page. The Pagerank is recalculated every time the search engine crawls the web.

It is given by

$PR(A) = (1-d) + d\,(PR(T1)/C(T1) + ... + PR(Tn)/C(Tn))$

where

- PR(A) is the PageRank of page A,
- PR(Ti) is the PageRank of pages Ti which link to page A,
- C(Ti) is the number of outbound links on page Ti and
- d is a damping factor which can be set between 0 and 1.

It is well seen from above formula that pagerank uses not only the concept of link popularity, rather a page is in fact considered the more important when the more other pages link to it. Furthermore, the pagerank does not compute for web sites rank as a whole, rather is determined for each page individually, and the pagerank of a page A is recursively determined by the pageranks of those pages which link to page A.

Within the PageRank algorithm, the PageRank of a page A is always weighted by the number of outbound links C(T) on page T. This means that the more outbound links a page T has, the less will page A benefit from a link to it on page T.

Finally computing for rank of a page A from links to it, it is equally adding up their pageranks, multiplied by a dumping factor d.

"d" is set between 0 and 1, and it gives the probability distribution used to represent the likelihood that a person randomly clicking on a link will arrive at any particular page. Thus (1-d) the probability of the same person to remain on that page.

Dumping factor when applied to mobile wireless network, it expresses how much social a network is tied, thus can be set according to a type of network environment.

4.2.2 ANALYSIS OF THE CBRWMRCM PROTOCOL

The CBRWMRCM protocol is shown in subsection 4.3.3. A model of an imaginary social graph is adopted, where a node itself in a network forms a graph vertex, and its predecessors and successors are its encounters. Extracting from meeting event, implicit social node attributes such as sharing common interests, being friends, the protocol aggregates this imaginary node's social attributes into a contact graph. Obviously in a daily life, friends and people sharing the common interest like students in a campus meet more frequently. Thus The CBRWMRCM protocol computes for popularity of each node in a network, based on number of its encounters, inferred social nodes.

The Google pagerank algorithm, is then applied as following: When two nodes meet, one is considered as forming an incoming link to another node, and the nodes' encounters as forming outbound links on the involved nodes. Then, the meeting nodes calculate and update its newly computed pagerank like centrality, upon a contact.

Clearly, upon each contact, the imaginary social graph is dynamically constructed as a node is linked to predecessors and successors, which are here node encounters, of another social node when the nodes meet, then node centrality value is updated every time the nodes meet. The higher ranked node is chosen to be the best message forwarder.

Furthermore, this protocol developed a mechanism for message acknowledgement to keep network overhead low, where a transferred message is marked acknowledged, from the destination's buffer, thus prevented from spreading to any encountered node.

Summary, Google pagerank like technique, for ranking the most popular websites as more important was adapted to compute for node's rank/score in a network, then to compare nodes ranks to select the best relay node, among other nodes in a network.

4.3 CBRWMRCM PROTOCOL DESIGN

The CBRWMRCM protocol design is described through the following flowchart, algorithm and data structures described in the following:

4.3.1 CBRWMRCM PROTOCOL DATA STRUCTURES

A data structure table which records how many times a node meets other nodes, with a record in a form <HostID,#encounters> . Table 4.1 shows an example of encounters table.

Table 4.1. Encounters table of a node

HOST ID	Number of encounters
A1	23
C4	12
H8	7
A3	53
E5	4

In addition to encounters table, A Centrality table is maintained, which records the centrality of nodes encounters, which have met sofar in the form <Host ID,Centrality >. Table 4.2 shows an example of centrality table .

Table 4.2: Centrality table of a node

HOST ID	Centrality
B3	0.2
A5	0.05
H6	0.1
A2	0.33
B2	0.02

The CBRWMRCM protocol works as follows: When two nodes meet, both their tables are updated: encounters table whose the current number of encounters is increased of one and their centrality table get updated with new calculated pagerank like centrality .The pagerank like centrality is calculated according to the following equation:

$C(i) = (1-d) + d\,(C(j)/(Tj))$, which was derivered from Google pagerank, as it has been described in subsection 4.2.1

Where C(i) is centrality of current node ,C(j) Centrality of encountered node and Tj is a number of a node Tj encounters, d which depend on how much the social relationship between nodes can help improving their centrality values.

It is clearly noted that Centrality in the network, is calculated dynamically in time and in space, using a distributed algorithm, for which the total number of nodes cannot be initially known, thus much suitable to our wireless mobile environment.

For simulation purpose, d has been set to 0.86.

Finally, a message is delivered from node i to node j, if the centrality value of j is greater than or equal to that of i or j is the destination node.

Finally each node maintains an acknowledgement table in the form <Message ID, Source ID, Destination ID>, that contains information on message delivered to destination and that should be flooded among nodes in network. In fact, when two nodes meet, they should check for, if any new acknowledged messages are in acknowledgement table of the encountered node, then update their buffer by removing a copy of it and update their acknowledgement table to spread the information to other nodes in network.

4.3.2 FLOWCHART FOR THE CBRWMRCM PROTOCOL

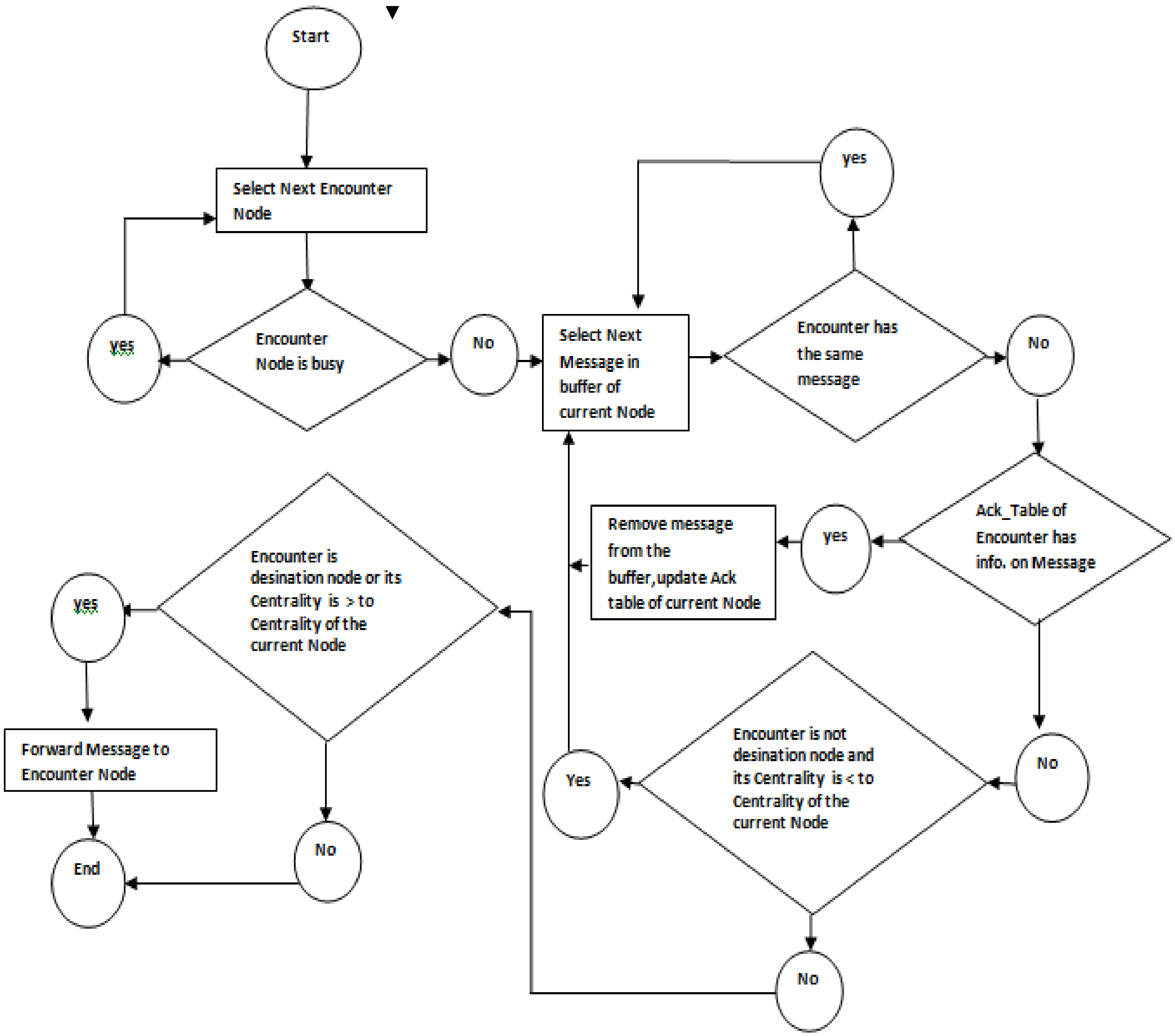

Figure 4.1: Flowchart for the CBRWMRCM protocol

4.3.3 ALGORITHM FOR CBRWMRCM PROTOCOL

Notations:

- E(i): number of encounters of current node i
- C_i: Centrality value of node i
- Buffer(i): the buffer at node i
- M:Message currently being sent
- DN: Destination node

If E(i)>=0 //Require: E(i)>=0

While i is in contact with another node j do// Step 1

update (C_i,E(i)) && (C_j, E(j)) // Step 2

If j is busy

Select next node j=j+1// Go to step 1 to select the next Encounter node j

End if

While M ϵ buffer(i) do//repeat all messages (M) of current node i// Step 3

3.a :if j has M then go to step3

3.b : check Ack_table of j for M

If Ack_Table of j has M then

Remove M from buffer of i

Update Ack_table of j

Go to step3 for next M

End if

End if

```
    If cj >=Ci or j is equal to DN then// Step 4
            Forward M to j
     End if
  End while
 End while
End if
```

4.4 CONCLUSION

In this chapter CBRWMRCM protocol has been analyzed and designed which results in a model (algorithm and its corresponding flowchart) that can be followed for the flow of a message in an OppNet network. This will be taken as input to the fifth chapter for implementation and testing of CBRWMRCM algorithm.

CHAPTER V: IMPLEMENTATION AND RESULTS DISCUSSION

In this Chapter, the proposed protocol CBRWMRCM is evaluated by Random Scenario simulations and compared against the standard routing algorithms including : Epidemic : due to its potentially high overhead , PRoPHET due to its probabilistic routing and MaxProp due to its predictability routing with acknowledgement. The simulations focused on the performance metrics: Delivery Probability and Overhead Ratio. The simulator used is the Opportunistic Networking Environment (ONE) [51] version 1.6.

5.1 THE ONE SIMULATOR

The java-based (ONE) simulator specifically designed for evaluating DTN routing and application protocols has been used. It allows users to create scenarios based upon different synthetic movement models and real-world traces and offers a framework for implementing routing and application protocols. Interactive visualization and post-processing tools support the result visualization through a GUI and the reporting. Finally a report is collected, on the statistics of simulation performance such as overhead ratio, delivery ratio, latency average, etc.

With ONE simulator, nodes can be created, placed within a blank or elaborate map, then translated according to many different movement models. RandomWayPoint movement model was used during this work.

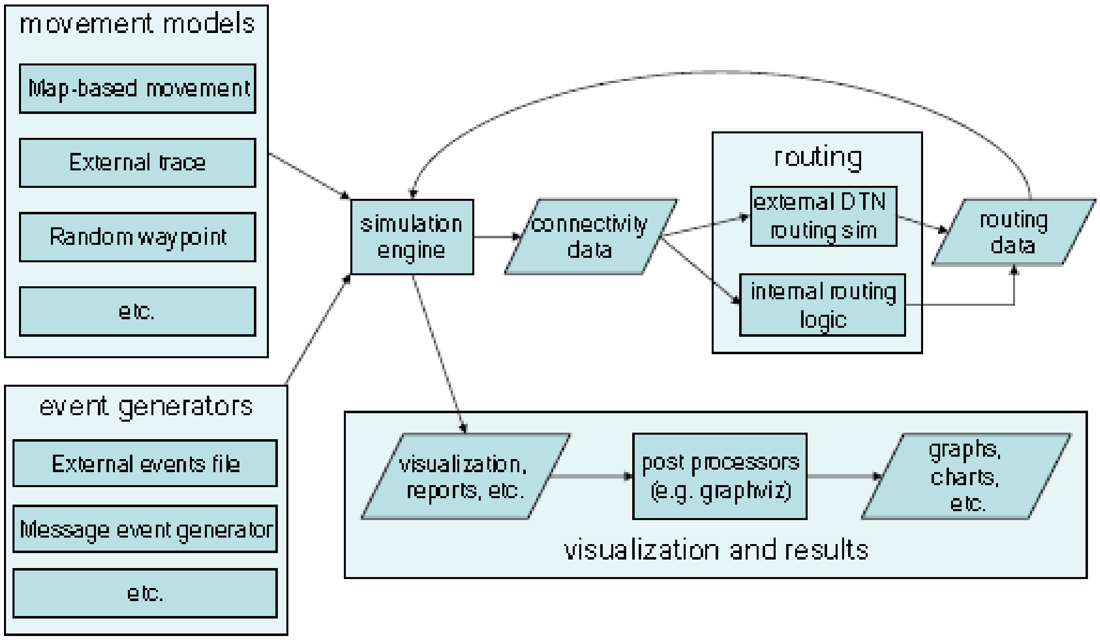

Figure 5.1: Overview of the ONE

The ONE can be run in two different modes: batch and GUI. The GUI mode is especially useful for testing, debugging and demonstration purposes and the batch mode can be used for running large amount of simulations with different set of parameters. Both modes can include any number of report modules which produce statistics of the simulation. These statistics can be further analyzed with post-processing tools to create different kind of summaries, graphs and plots.

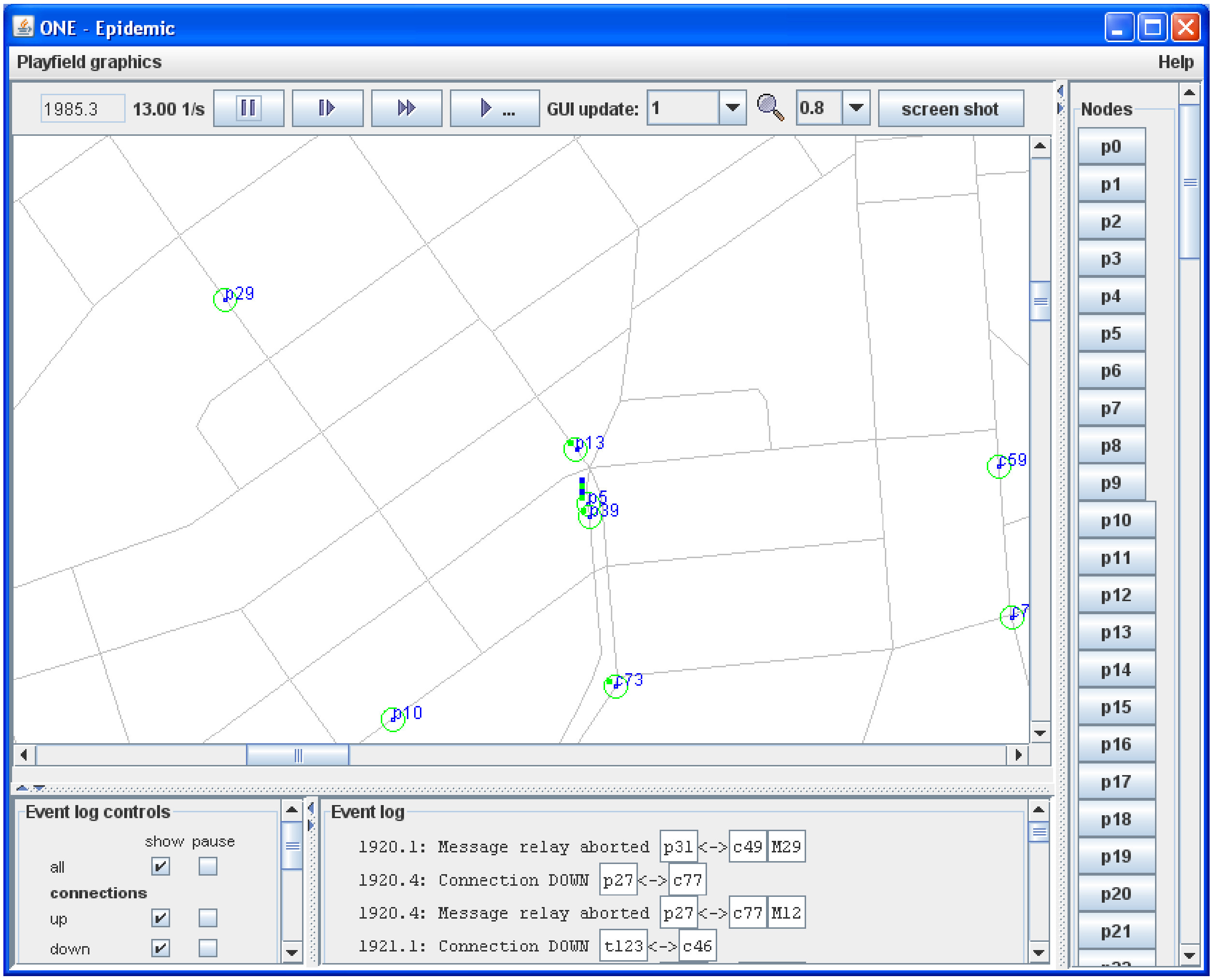

Figure 5.2: Screenshot of the ONE simulator's GUI

5.2 PERFORMANCE METRICS

The performance metrics used to evaluate the developed protocols are:

- Delivery probability is defined as the number of successfully delivered messages divided by the number of created messages .

$$Delivery\ probability = \frac{\text{Total number of packets received by destination}}{\text{Total number of packets sent by the source}}$$

- Overhead ratio: This is a metric used to estimate the extra number of packets needed by the routing protocol for actual delivery of the data packets. It can be defined as:

$$Overhead\ ratio = \frac{\text{Number of packets relayed} - \text{Number of packets delivered}}{\text{Number of packets delivered}}$$

5.3 SIMULATION

5.3.1 SIMULATION SETUP

Step 1: Setup a scenario for simulation(Name, time and nodes group)

Step 2: specify the Network Interface (Bluetooth interface)

Step 3: Specify group of nodes, TTL of message, Buffersize at each node

Step 4: Mobility model setting

Step 5: time for message creation

Step 6: Reports creation setting

Step 7: GUI settings(image is set where nodes move)

Some simulation parameters used are shown in the following table:

Table 5.1: Simulation parameters

Simulation parameter	Value
Routing Protocol	CBRWMRCM,Epidemic,Prophet,Maxprop
Number of nodes	variable
Mobility Model	RandomWaypoint
Simulation Time	43200 secs
Simulation Area	(4500X3500)m
TTL	variable
Node speed	0.5-1.5(meters/sec)

5.3.2 SIMULATION RUNNING:

- We have 15 scenario for each router(CBRWMRCM,EPIDEMIC and PROPHET) combined with each variable number of hosts/ each variable message TTL, to compute for message delivery ratio.
- We have 15 scenario for each router(CBRWMRCM,EPIDEMIC and MaxProp) combined with each variable number of hosts/ each variable message TTL, to compute for network overhead ratio.
- Their reports are generated in the reports folder.
- Now for the above two metrics, we have to compare for 3 routing protocols.
- Each simulation includes 15 scenario, run for once and under the same values for parameters. After the simulation was complete, 15 MessageStarReport.txt files were generated ,that generate the overall network statistics. Each file includes the Message Delivery Ratio, Average Latency, the Average Number of Duplicate Messages, and many other network statistics. The results from each scenario were extracted and imported to an excel spread sheet. The use of a spreadsheet aided with the evaluation as to which routing algorithm has the best performance

5.4 REPORTING

The ONE simulator offers many reporting tools that are engaged by simply adding the report name to the parameter configuration file. Detailed here are the couple reports used to produce the results discussed in this work.

The Message statics report, as shown in tables, containing a summary report of all nodes for each 15 scenario simulation: one to compute for message delivery ratio and another to compute for overhead ratio. It contains the standard results used to produce the following plots :

- Plots of message delivery ratio as a function number of nodes

- Plots of message delivery ratio as a function message TTL

- Plots of network overhead ratio as a function of number of nodes

- Plots of network overhead ratio as a function message TTL

A) Analyzing about Delivery ratio: (what about overhead)

When comparing CBRWMRCM to Prophet and Epidemic, it is clearly seen on the figure , that CBRWMRCM is much comparable to a flooded based Epidemic, whereas outperforms a probabilistic Prophet.

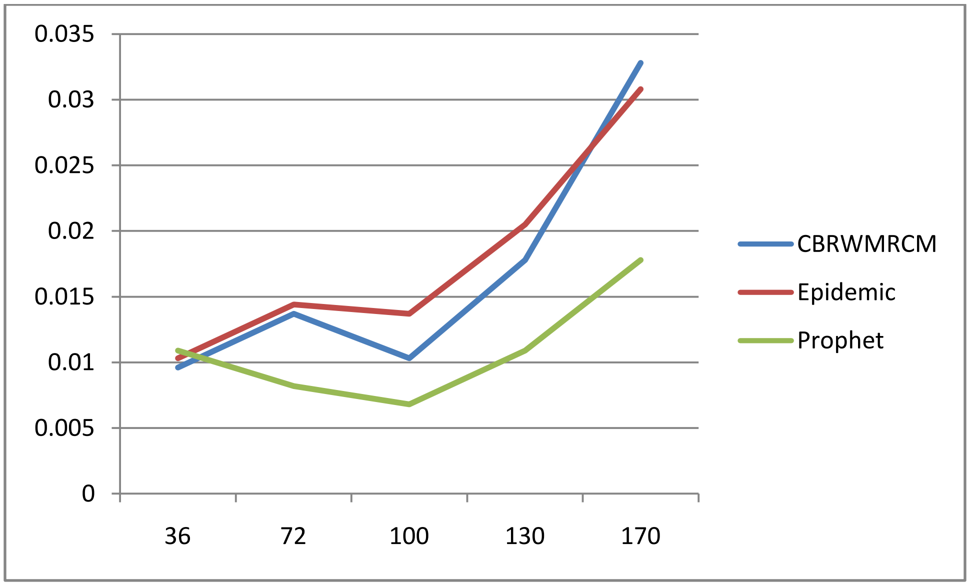

Figure 5.3: Comparison of CBRWMRCM, Epidemic and Prophet for varying number of nodes

Table 5.2: Message statics report 1, for delivery ratio

Nof_Node / Router	36	72	100	130	170
CBRWMRCM	0.0096	0.0137	0.0103	0.0178	0.0328
Epidemic	0.0103	0.0144	0.0137	0.0205	0.0308
Prophet	0.0109	0.0082	0.0068	0.0109	0.0178

As the number of nodes increases, delivery ratio increases, meaning there may be more relayed messages, thus a high chance to reach the destination, the same for TTL when increases, messages dropped are less, thus delivery ratio increases

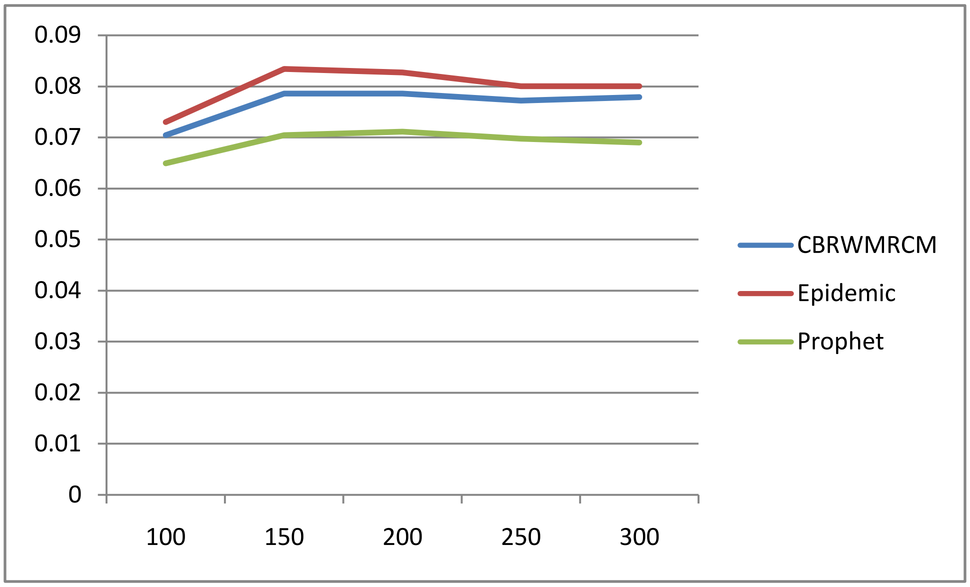

Figure 5.4: Comparison of CBRWMRCM, Epidemic and Prophet for varying message TTL

Table 5.3: Message statics report 2 , for delivery ratio

TTL / Router	100	150	200	250	300
CBRWMRCM	0.0704	0.0786	0.0786	0.0772	0.0779
Epidemic	0.0730	0.0834	0.0827	0.0800	0.0800
Prophet	0.0649	0.0704	0.0711	0.0697	0.0690

B) Analyzing about overhead ratio:

When comparing CBRWMRCM to Maxprop and Epidemic, it is clearly seen on the figure that CBRWMRCM outperforms both a predictability based Maxprop with acknowledgement, and a flooded based Epidemic. This is due to that MaxProp and Epidemic are both flooded based with over buffers.

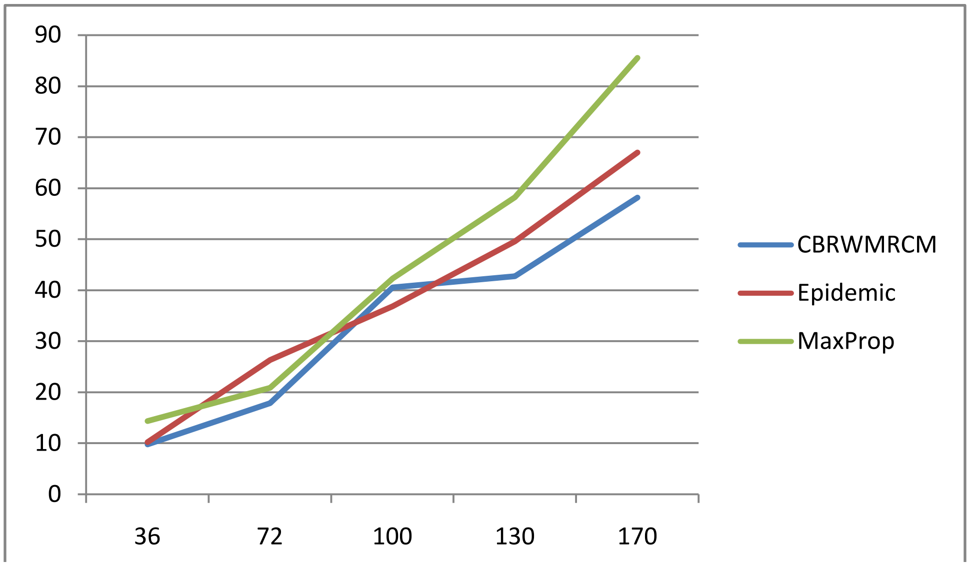

Figure 5.5: Comparison of CBRWMRCM, Epidemic and MaxProp for varying number of nodes

Table 5.4: Message statics report 1 , for overhead ratio

Nof node / Router	36	72	100	130	170
CBRWMRCM	9.777	17.846	40.5263	42.7059	58.1395
Epidemic	10.2222	26.3478	36.8387	49.5455	66.9836
MaxProp	14.3571	20.8621	42.2963	58.1944	85.500

As number of nodes increases, overhead ratio decreases. This is due to more messages are delivered

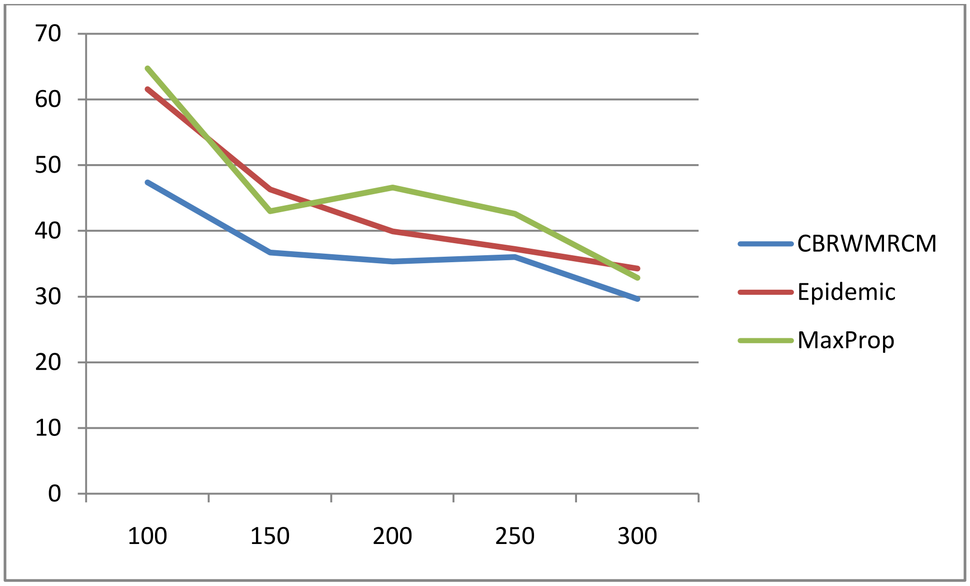

Figure 5.6: Comparison of CBRWMRCM, Epidemic and MaxProp for varying message TTL

Table 5.5: Message statics report 2 , for overhead ratio

Router \ TTL	100	150	200	250	300
CBRWMRCM	47.3529	36.7037	35.3548	36.0000	29.6500
Epidemic	61.5263	46.2963	39.9063	37.2353	34.2432
MaxProp	64.7222	42.9667	46.6071	42.6129	32.8500

As TTL increases, overhead ratio decreases, meaning that message remains for a long period in buffer, thus are not dropped on the way to its destination and consequently no need to be replicated which results to a low overhead ratio.

5.5 CONCLUSION

This chapter analyzes the simulations done for our CBRWMRCM protocol, when comparing to other known protocols. It gives what scenarios have been run, and in what conditions. It should be noted well that all the comparison done among protocols, are conducted through similar conditions.

CHAPTER VI: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

In this Thesis, a "Centrality Based Routing With a Message Relay Control Mechanism" has been designed and implemented through random simulations, then tested and evaluated successfully. All the simulations focused on Delivery Probability and Overhead Ratio performance metrics: proved that CBRWMRCM protocol outperforms other compared protocols, under the same experimental conditions. So a developed model could be a choice, to follow for a message forwarding in opportunistic networks.

6.2 RECOMMENDATION

In this thesis, a CBRWMRCM protocol for OppNets has been developed which uses the Centrality concept for the message forwarding process. Simulation results on the performance of CBRWMRCM in comparison with Epidemic, Prophet and MaxProp, has revealed improvement that cannot be ignored, both in terms of a message delivery ratio and overhead ratio. However, as for recommendation, two things are mentioned.

On one hand the tested performed here were limited to the random scenario simulation as the Randomwaypoint movement model of nodes was used. Due to this, it can be recommended to test the developed protocol under human scenarios and other recurring pattern based structures to explicitily show how well CBRWMRCM routes message under realistic mobility scenarios.

On other hand, the developed CBRWMRCM protocol can be enhanced with new capabilities that deserve attention in a network routing such as security, energy, to name a few.

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APPENDIX

Configuration file when varying number of hosts

```
#Something behind a "#", is a comment
# Default settings for the simulation
## Scenario settings
Scenario.name = %%Group.router%%_%%Group.nrofHosts%%
Scenario.simulateConnections = true
Scenario.updateInterval = 0.1
# 43200s == 12h
Scenario.endTime =43200

## Interface-specific settings:
# type : which interface class the interface belongs to
# For different types, the sub-parameters are interface-specific
# For SimpleBroadcastInterface, the parameters are:
# transmitSpeed : transmit speed of the interface (bytes per second)
# transmitRange : range of the interface (meters)

# "Bluetooth" interface for all nodes
btInterface.type = SimpleBroadcastInterface
# Transmit speed of 2 Mbps = 250kBps
btInterface.transmitSpeed = 250k
btInterface.transmitRange = 10
```

```
## Group-specific settings:
# groupID : Group's identifier. Used as the prefix of host names
# nrofHosts: number of hosts in the group
# movementModel: movement model of the hosts (valid class name from movement package)
# waitTime: minimum and maximum wait times (seconds) after reaching destination
# speed: minimum and maximum speeds (m/s) when moving on a path
# bufferSize: size of the message buffer (bytes)
# router: router used to route messages (valid class name from routing package)
# msgTtl : TTL (minutes) of the messages created by this host group, default=infinite


# Common settings for all groups
Scenario.nrofHostGroups = 1
Group.movementModel =RandomWaypoint
Group.router = [CBRWMRCM; EpidemicRouter; ProphetRouter]
Group.bufferSize = 5M

# All nodes have the bluetooth interface
Group.nrofInterfaces = 1
Group.interface1 = btInterface
# Walking speeds
Group.speed = 0.5, 1.5
# Message TTL of 300 minutes (5 hours)
Group.msgTtl=300
Group.nrofHosts = [36; 72; 100; 130; 170]
Group.groupID = n
```

```
## Movement model settings
# seed for movement models' pseudo random number generator (default = 0)
MovementModel.rngSeed = 1
# World's size for Movement Models without implicit size (width, height; meters)
MovementModel.worldSize = 4500,3400
# How long time to move hosts in the world before real simulation
MovementModel.warmup=1000

## Message creation parameters
# How many event generators
Events.nrof = 1
# Class of the first event generator
Events1.class = MessageEventGenerator
# (following settings are specific for the MessageEventGenerator class)
# Creation interval in seconds (one new message every 25 to 35 seconds)
Events1.interval = 25,35
# Message sizes (500kB - 1MB)
Events1.size = 500k,1M
# range of message source/destination addresses
Events1.hosts = 0,35
# Message ID prefix
Events1.prefix = M
```

```
#Default settings for some routers
ProphetRouter.secondsInTimeUnit = 10


## Reports - all report names have to be valid report classes
# how many reports to load
Report.nrofReports = 15
Report.reportDir                                              =
reports/ok_%%Group.router%%_%%Group.nrofHosts%%
# Report classes to load
Report.report1 = MessageStatsReport
Report.report2 = MessageStatsReport
Report.report3 = MessageStatsReport
Report.report4 = MessageStatsReport
Report.report5 = MessageStatsReport
Report.report6 = MessageStatsReport
Report.report7 = MessageStatsReport
Report.report8 = MessageStatsReport
Report.report9 = MessageStatsReport
Report.report10 = MessageStatsReport
Report.report11 = MessageStatsReport
Report.report12 = MessageStatsReport
Report.report13 = MessageStatsReport
Report.report14 = MessageStatsReport
Report.report15 = MessageStatsReport


##  Optimization  settings  --  these  affect  the  speed  of  the
simulation
## see World class for details.
Optimization.cellSizeMult = 5
Optimization.randomizeUpdateOrder = true
```

Configuration file when varying message time to live

```
# Default settings for the simulation
#

## Scenario settings
Scenario.name = %%Group.router%%_%%Group.msgTtl%%
#
Scenario.simulateConnections = true
Scenario.updateInterval = 0.1
# 43200s == 12h
Scenario.endTime =43200

## Interface-specific settings:
# type : which interface class the interface belongs to
# For different types, the sub-parameters are interface-specific
# For SimpleBroadcastInterface, the parameters are:
# transmitSpeed : transmit speed of the interface (bytes per second)
# transmitRange : range of the interface (meters)

# "Bluetooth" interface for all nodes
btInterface.type = SimpleBroadcastInterface
# Transmit speed of 2 Mbps = 250kBps
btInterface.transmitSpeed = 250k
btInterface.transmitRange = 10


## Group-specific settings:
```

```
# groupID : Group's identifier. Used as the prefix of host names
# nrofHosts: number of hosts in the group
# movementModel: movement model of the hosts (valid class name from movement package)
# waitTime: minimum and maximum wait times (seconds) after reaching destination
# speed: minimum and maximum speeds (m/s) when moving on a path
# bufferSize: size of the message buffer (bytes)
# router: router used to route messages (valid class name from routing package)
# msgTtl : TTL (minutes) of the messages created by this host group, default=infinite

# Common settings for all groups

Scenario.nrofHostGroups = 1

Group.movementModel =RandomWaypoint
Group.router = [CBRWMRCM; EpidemicRouter; MaxPropRouter;]
Group.bufferSize = 5M

# All nodes have the bluetooth interface
Group.nrofInterfaces = 1
Group.interface1 = btInterface
# Walking speeds
Group.speed = 0.5, 1.5
# Message TTL of 300 minutes (5 hours)
Group.msgTtl=300
Group.msgTtl = [100; 150; 200; 250; 300;]
Group.nrofHosts=100
Group.groupID = n
```

```
## Movement model settings
# seed for movement models' pseudo random number generator
(default = 0)
MovementModel.rngSeed = 1
# World's size for Movement Models without implicit size (width,
height; meters)
MovementModel.worldSize = 4500,3400
# How long time to move hosts in the world before real
simulation
MovementModel.warmup=1000

## Message creation parameters
# How many event generators
Events.nrof = 1
# Class of the first event generator
Events1.class = MessageEventGenerator
# (following settings are specific for the MessageEventGenerator
class)
# Creation interval in seconds (one new message every 25 to 35
seconds)
Events1.interval = 25,35
# Message sizes (500kB - 1MB)
Events1.size = 500k,1M
# range of message source/destination addresses
Events1.hosts = 0,100
# Message ID prefix
Events1.prefix = M

#Default settings for some routers
ProphetRouter.secondsInTimeUnit = 10
```

```
## Reports - all report names have to be valid report classes
# how many reports to load
Report.nrofReports = 15
#Report.reportDir = reports/
#Report.reportDir                                                    =
reports/Max_reports_nrofHosts_world_sizelarge/%%Group.router%%_%
%Group.nrofHosts%%
Report.reportDir                                                     =
reports/MAx_ok_100hosts%%Group.router%%_%%Group.msgTtl%%
# Report classes to load
Report.report1 = MessageStatsReport
Report.report2 = MessageStatsReport
Report.report3 = MessageStatsReport
Report.report4 = MessageStatsReport
Report.report5 = MessageStatsReport
Report.report6 = MessageStatsReport
Report.report7 = MessageStatsReport
Report.report8 = MessageStatsReport
Report.report9 = MessageStatsReport
Report.report10 = MessageStatsReport
Report.report11 = MessageStatsReport
Report.report12 = MessageStatsReport
Report.report13 = MessageStatsReport
Report.report14 = MessageStatsReport
Report.report15 = MessageStatsReport


## Optimization settings -- these affect the speed of the
simulation
## see World class for details.
Optimization.cellSizeMult = 5
Optimization.randomizeUpdateOrder = true
```