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Bridging Health Information Exchange Gaps Among Health Practitioners in Underserved Areas Using Delay-Tolerant Networks

BY

Zekarias Teferi

A THESIS SUBMITTED TO THE DEPARTMENT OF COMPUTING, INSTITUTE OF TECHNOLOGY, JIMMA UNIVERSITY, IN MEETING THE PARTIAL FULFILLMENT FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN COMPUTER NETWORKING.

Principal Advisor: Mr. Dessalegn Mequanint (AAU)

Co-Advisor: Dr. Ramchand Vedaiyan (JU)

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Approval Sheet

This thesis entitled "Bridging Health Information Exchange Gaps Among Health Practitioners in Underserved Areas Using Delay-Tolerant Networks" has been read and approved as meeting the requirements of Department of Computing in partial fulfillment for the award of the degree of Master of Science in Computer Networking, Jimma University, Jimma, Ethiopia.

Principal Advisor ______________________________ ___________________________

Signature Date

Co- Advisor __________________________________ ___________________________

Signature Date

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Contents

List of Figures

List of tables

Acronyms

ANs: Airborne Networks

BP: Bundle Protocol

CLA: Convergence Layer Adaptors

CT: Computerized Tomography

DD: Direct Delivery

DTN: Delay-Tolerant Networks

ERMRRP: Epidemic Routing based on Message Replication Rate Priority

ICMN: Intermittently-Connected Mobile Networks

IP: Internet Protocol

IPN: Interplanetary Internet

ICT: Information Communication Technology

IEEE: Institute of Electrical and Electronics Engineers

JPL: Jet propulsion Laboratory

MULE: Mobile Ubiquitous LAN Extension

ONE: Opportunistic Networking Environment

PSNs: Pocket Switched Networks

TCP: Transmission Control Protocol

TCP/IP: Transmission Control Protocol / Internetworking Protocol

TTL: Time to Live

UWNs: Under Water networks

VANETs: Vehicular Ad hoc NETworks

VDTNs: Vehicular Delay-Tolerant Networks

WKT: Well Known Text

Abstract

The term delay-tolerant networking is invented to describe and encompass all types of long-delay, disconnected, disrupted or intermittently-connected networks, where mobility and outages or scheduled contacts may be experienced. Due to low telecommunication infrastructures coverage in major parts of the country, intermittent connectivity and absence of end-to-end connectivity is the potential problem for the health practitioners in underserved areas to exchange health information among each other in common or with the specialists using communication links. As a result, health practitioners in underserved areas serving the majority of the population are unable to exchange health information in communal and also isolated from specialist support this in turn hampering the health care centers from providing better health care services. The main objective of this study is to bridge the health information exchange gaps among health practitioners in underserved areas using delay-tolerant network mechanisms based on the proposed framework. As health care centers (hospitals) are located sparsely, using flooding-based routing algorithm is the best option in order to achieve high message delivery probability. But the flooding-based routing scheme incurs buffer overflows as a nodes buffer size is limited in reality. Thus, the researcher proposed a buffer management approach named Epidemic Routing based on Message Replication Rate Priority (ERMRRP) to manage the limited buffer space of nodes. For the simulation Opportunistic Network Environment (ONE) Simulator is used. The existing routing algorithm and the proposed routing algorithm approach has been evaluated. They were analyzed on three different metrics namely delivery probability, average latency and overhead ratio. The simulation results obtained in this thesis show that for the proposed routing approach, the message delivery probability is very high, minimum overhead and high average latency (as a tradeoff due to computation at buffer checker in preparing room and priority for transmission) when the nodes buffer get constrained. However, when there is sufficient buffer space, both epidemic and proposed routing approach shows comparable performance in terms of delivery probability and Average latency.

CHAPTER ONE

INTRODUCTION

1.1. Background

Ethiopia is the second most populous country in sub-Saharan Africa, with a population of over 82.8 million people. The country is subdivided in to 9 national regional states and 2 administrative states. The Regional States are administratively divided into 78 Zones and 710 Woredas [1].

According to 2007 census, Ethiopia is among the least urbanized country in the world with 83.6% living in rural areas whilst 16.4% of the total population living in urban areas [2]. With the majority of the population living in underserved areas, the country faces challenges in health care access and quality. There are significant health disparities and access to care issues that are specific to rural populations. Rural and urban areas differ in many ways, including demography, environment, economy, social structure, and availability of resources [3].

Integrating cost effective technologies for exchange of health information among health practitioners will offer tremendous benefits to the underserved areas hospitals, including the prevention of medical errors, a reduction in unnecessary costs, advancement of the exchange of patient-centered medical care, improvements in the efficiency and coordination of care and information exchange among healthcare providers, and facilitating the identification and rapid response to public health threats and emergencies. Such technological integration creates access, enhances quality, improves information exchange and can act as a solution for situations where human resources for health care services are scarce [4]. By doing so, we can address the inadequate access and uneven resource distribution problem of today's health care system of the country. Thus, it is particularly important for the health practitioners working in underserved areas in order to get specialist support from the specialists working at higher level hospitals which in turn will improve health care services in underserved areas.

Better health is a key to individual happiness and a country's development. But there are many factors influencing health care system found in underserved areas, not to provide their service in better way. One of the factors is unbalanced health practitioners especially the proportion of specialist is too small with available health care centers throughout the country. This problem can be addressed if there is technological intervention like internet in order to exchange information among the health practitioners. However, most of the health practitioners working in underserved areas are unable to get support from the specialist and to exchange their need with others due to low telecommunication infrastructures coverage and even no end-to-end connectivity in major parts of underserved areas.

An affordable and reliable Internet is not yet a reality for the majority of people in the world. More focus is needed in bring the economic and social benefits of the Internet to everyone [5]. Ethiopia has the second lowest Internet penetration rate in sub-Saharan Africa (only Sierra Leone's is lower) and is currently attempting a broad expansion of access throughout the country. However, these efforts have been hampered by the largely rural makeup of the population [6]. The rural makeup of the larger population makes the government to invest high costs of network deployment, but with current economic status of the country it is too difficult to achieve in short period of time. Thus it makes the country lags very much behind than other countries in the world in almost all ICT indices.

Particularly health care centers in Ethiopia are currently faced with technological challenges associated with communication (i.e., low bandwidth, low telecommunication infrastructures coverage as well as low access to road networks, intermittent connectivity, high connectivity charges and even no end-to-end connectivity) in order to exchange health information for the provision of better health care services. Because of lack of financial resources and other factors, the above mentioned challenges will not be addressed in a short period of time unless the health centers down the tier can find ways to use cost effective Information and Communication Technology tools to significantly improve information exchange.

Delay-tolerant networking (DTN) are presented as a solution to underserved environments characterized by any or all of the following characteristics: intermittent connectivity, long and/or variable delay, asymmetric data rates, high error rates, and even no end-to-end connectivity [7]. As described in [8], DTNs propose a store-and-forward architecture in which data units, termed bundles, can be temporarily stored at nodes (during network disruptions) until an appropriate next hop can be found. Accordingly, delay-tolerant principles can offer connectivity resilience through store-and-forward in disrupted environments.

1.2. Statement of the problem

Ethiopia is known for the lowest Internet penetration in the world and according to [9], the number of Internet users in 2015 is approximately 3.7% of the population. The reason for the lowest Internet penetration is due to the cost associated with the Internet, low telecommunication infrastructures coverage as well as low access to road networks, intermittent connectivity, high connectivity charges and even no end-to-end connectivity in major parts of the country.

The medical specialists in Ethiopia are few in numbers and also the specialized services are concentrated in higher level of the health service tier. In order to realize the universal health coverage, the government is expected to maximize the number of specialists to serve the majority of the population living in underserved areas. This approach is more supportive but it takes time and requires high resource. The other possible solution is technological intervention for the health practitioners in underserved areas to exchange health information of the patient under treatment with specialists from the remote. Because the advice given by the specialist is very vital for the health practitioners working in underserved areas to treat patients based on the advice they obtained from the specialists. However, due to low telecommunication infrastructures coverage, intermittent connectivity and absence of end-to-end connectivity, most of the health practitioners in underserved areas are unable to exchange health information with the specialists and the inter-communication among the hospitals is very poor. As a result, health practitioners in underserved areas serving the majority of the population are isolated from specialist support and in turn this is hampering the hospitals from providing better health services.

Since establishing the communication link to underserved areas using traditional solution is very expensive due to the cost of trenches, towers, and satellite dishes [10], the alternative ways to use cost effective Information and Communication Technology tools to significantly improve health information exchange is of paramount to the health practitioners in underserved areas. Besides, it is reasonable for the country to provide connectivity with cost effective and alternative approach that will fit with the local context. Accordingly, this study focus on use of delay-tolerant networks for bridging health information exchange gap among health practitioners in underserved areas. DTN mechanism [11] makes a compromise on connectivity to provide cheap access and provision of better services. Thus low cost would be the primary reason of success for any DTN to be deployed in underserved areas.

As the hospitals are located sparsely and there is no end-to-end connectivity in between them, unpredictability in connections and extreme network partition becomes a problem when message is required to be exchange in common. To deal with the stated problem, adopting flooding-based routing (specifically epidemic routing for the proposed framework) is the only means for such scenario to improve the message delivery where the intermediate nodes receives messages, store the messages in their buffers, carries them while moving, and forwards them to other nodes when they encounter each other opportunistically. For the intermediate nodes to cope with long disconnection, it keeps the buffered messages for long period of time and this indicates that the intermediate nodes require sufficient buffer space to store all the messages but the buffer overflows at certain point of time due to the flooding of the messages when the nodes are encounter each other.

In delay tolerant network most of the routing algorithm assume the nodes buffer space as unlimited but is it not the case in reality. As flooding-based routing relies on buffer to have a copy of every message at every node, buffer space has substantial impact on delivery probability. So that it is necessary to understand the influence of buffer space on network performance, as it is limited in reality. Thus, an efficient buffer management technique is required to be introduced to manage the limited buffer space at a point in which the messages stored in the buffer are to be dropped when buffer get overflows to give the room for other new messages to be buffered and also to provide the priority for the messages to be transmit based on the priority criteria when another node encounter. Therefore, this thesis is aimed to consider the buffer problem in to an account and propose a buffer management approach for the considered routing algorithm.

1.3. Objectives of the study

1.3.1. General Objective

The main objective of this study is to bridge the health information exchange gaps among health practitioners in underserved areas using delay-tolerant network mechanisms and to lay foundation for near future implementation in the health care system.

1.3.2. Specific Objectives

To accomplish the above stated general objective, the following specific objectives are developed:

- To explore delay-tolerant networks, its basic features and the reason to use it for the exchange of health information in underserved areas.
- To come up with a framework that is capable to describe the scenario for later implementation.
- To explore the data routing/forwarding algorithms in DTN and then to select the suitable routing algorithm that fit with the proposed framework in terms of message delivery probability.
- To integrate buffer management approach for the selected routing algorithm to manage limited buffer space of the node.
- To evaluate the performance of the considered routing algorithms using the routing metrics in DTNs.

1.4. Methodology

This section directs toward the methodology that is used to conduct the research. So as to achieve the above stated objectives the researcher employed a methodology as described below.

Different related researches and background theory have been revised through literature review in order to have detail understanding of the approaches and methods pertaining to the research under consideration. The review is conducted to assess the basic concepts of delay-tolerant networks and its applications to health practitioners working in the hospitals of underserved areas concerning health information exchange. Data collection, implementation tools, simulation environment setup and data analysis procedures are well described in chapter 3.

1.5. Scope and Limitation of the study

The scope of this study is limited to propose a framework for health care system to bridge the health information exchange gaps among health practitioners in underserved areas using delay-tolerant network mechanisms. The study focus to target the health practitioners involved in the process of patient treatment cases. Accordingly, for the proposed framework the best/suitable routing algorithm has been opted. Therefore, for the chosen routing algorithm, a buffer management approach has been integrated to manage the limited buffer space of the nodes and the approach followed is to improve message delivery probability, reduce overhead and to improve network performance.

1.6. Significance of the study

Health care system can use this findings to improve the universal health coverage and to strengthening the weakened information exchange among health practitioners in the tier of health service arrangement. Appropriate health care support and information exchange empowers health professionals with the required skill and is a cost effective and achievable strategy for sustainable improvement of health care. In general, it can be said that such approach is helpful for physicians, patients and for underserved area community at large. This study is, therefore, a step towards the investigation of such a beneficial approach.

1.7. Thesis Organization

This report document contains six chapters including this chapter which deals with the general overview of the study including background, statement of the problem, objectives and methodology of the research. Chapter two presents review of research works on delay-tolerant network regarding its architecture proposed by various researchers, the area of its application and related works pertaining to the research under consideration. Chapter three describes the methodology employed, the proposed health service tier framework and the proposed buffer management approach to manage limited buffer space of the nodes. Chapter four describes the implementation and the experimentation setup in detail. Chapter five presents the result of the simulation run. Results of the simulation are also analyzed and interpreted in this chapter. The conclusion drawn from the result are briefly explained and future work in the area is presented in the last chapter, chapter six.

CHAPTER TWO
LITERATURE REVIEW

This chapter briefly presents the evolution of the DTN from early inception. The chapter introduces the DTNs application area, routing schemes, its potential benefits, the reason to use it for the exchange of health information among health practitioners in underserved areas. It also introduces the overview of health service delivery arrangement, the current practices of information exchange and the gap in the information exchange that inhibit the health professionals from exchanging the health information in their operation. At last, the chapter presents various approaches proposed by numerous researchers to manage the limited nodes buffer space in the DTNs. Accordingly, in this thesis a buffer management approach is proposed to manage the limited nodes buffer space based on the identified gap from the related works of various researchers which is described in this chapter.

2.1. History of Delay Tolerant Networks (DTNs)

According to [12], the origin of the concepts behind the DTN architecture as it is today came from looking at how to extend the Internet into interplanetary space. This new network paradigm started back in 1994 by the researcher named Vinton Grey (Vint) Cerf, and Adrian Hooke who authored a short, futuristic fantasy tale of 'Internet' communications in 2023 between locations on Earth and other parts of the Solar System. They claim that the study was not an impact in late 1997 and they began thinking about how to extend the Internet into an interplanetary network and use Internet style communications for links to spacecraft.

The first phase of the Interplanetary Internet (IPN) project ran for about four years and its main output was a description of the problems and a proposed architecture for a communications overlay network that would support transmission of messages in the IPN environment. This was published in 2001 as IPN: Architectural Definition [IPNarch00] and set the architectural basis for much of the DTN work that has taken place since that time. The scenarios that the IPN architecture targeted were based on the sorts of extensive delays resulting from interplanetary distances and scheduled communication opportunities that are typical of spacecraft operations.

After the IPN document had been published, researchers began to consider how the architecture could be applied to other situations where communications were subject to delays and disruptions that would make conventional Internet protocols (especially TCP) ineffective.

The architectural work in 2002-3 looked at other scenarios, especially terrestrial wireless networks such as wireless sensor networks and Wi-Fi based local area networks, where communications opportunities were much less predictable. It also provided a framework for dealing with interconnected heterogeneous networks, such as occurs at the gateway between a sensor network which does not usually use IP-based addressing/communications and a conventional IP-based network. By the middle of 2002, when an updated version of the IPN architecture was published [IPNarch01], Kevin Fall of Intel Research had coined the name Delay-Tolerant Networking (giving the initial use of the acronym DTN).

2.2. Delay Tolerant Networks

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 environment, long latency sometimes measured in hours or days is inevitable. Many researches on a delay-tolerant network have been done. According to [13], DTN is defined as a new networking paradigm that allows inter-connection between devices that current networking technology cannot provide. There are a wide variety of networks where an end-to-end connection between a given source and destination may never be present. Consequently, traditional routing protocols cannot be directly applied in these scenarios for delivering data. Traditional networks suppose the existence of some path between endpoints, small end to end round-trip Delay time, and loss ratio. Today, however, new applications, environments and types of devices are challenging these assumptions. In Delay Tolerant Networks, an end-to-end path from source to destination may not exist. Nodes may connect and exchange information in an opportunistic way. DTNs [8] are sometimes also called Intermittently-Connected Mobile Networks (ICMNs). The primary goal in such networks is to get the information from a source to the destination; these networks can tolerate a relatively higher delay. According to [14] Delay-tolerant networking is a term invented to describe and encompass all types of long-delay, disconnected, disrupted or intermittently-connected networks, where mobility and outages or scheduled contacts may be experienced.

The authors in [12] note that DTN serves four critical roles in their wireless networking concept: (i) DTN deals with the reality that mobile edge networks may not have complete source-to-destination paths. It uses opportunistic links, drop boxes, and data MULEs. (ii) DTN allows each hop in the network to be optimized uniquely and individually, which is different from the traditional one where end to end connectivity is expected and hop in the network is not optimized individually. Thus, it deal with latency, congestion, and loss locally, bilaterally and the content cached at each hop (whether encrypted or “clear”). (iii) The DTN bundle is an information interface but not packet interface. Any description of a node is an Address. Nodes supply to and request content from network using same structure - network is aware of information, not just addresses. Cognitive management decides on data storage, replication and other attributes of a router. (iv) DTN hides internal network details (protocols, routing, name services). Allows non-IP networks and DNS dependence

Delay Tolerant Networking is considered as an emerging technology for a new era in interoperable communications [7]. Like IP, DTN operates on top of existing link layer and network protocols and technologies, creating DTN overlay network. The key advantage over IP is that DTN effectively copes with long delays, high error rates and prolonged link disruptions, thus allowing the interconnection of networks with very diverse characteristics.

2.3. DTN Architecture

Delay-Tolerant Networking architecture are designed to support a communications network that can have much longer delays, and hence communication latencies, than is the expectation in the existing Internet, as well as connection disruption.

The DTN architecture was initially proposed as an approach to make the InterPlaNetary Internet [15] a viable networking environment. It was aimed to implement a universal network of networks. Accordingly, more effort was put on interconnection and interoperability issues, the bundle layer and its forwarding capabilities with regard to custody transfers, naming and addressing schemes and store-and-forward capabilities of intermediate nodes.

In an early study [13], the author addresses important issues relating to the design of network protocols for challenged environments, and they propose that the DTN architecture should form an overlay that will embrace all potential challenged environments.

As cited and presented in [16], the authors describe various DTN architecture designed so far with their sole purpose and they laid foundation for the enhancement of DTNs today and for the future. The well-known DTN architecture designed so far includes IPN [15] with the primary goal for space exploration, ZebraNet [17] designed for wildlife tracking for biological interest, DakNet [18] designed for connectivity to developing countries, DieselNet [19] vehicular DTNs for road communications and Haggle [20] designed for social and pocket switched networks.

Heterogeneity drives many of the capabilities of the DTN architecture. The architecture in [7] is designed to support more extensive form of ‘internet’ where the authors use the original meaning of the word that implied an interconnection of networks. The component networks are not expected to have common addressing formats or addressing semantics, and disparate routing methodologies may be employed.

In conventional IP networks, supporting other addressing formats or semantics in conjunction with IP has resulted in the widespread use of overlay networks, where the IP protocol is essentially used as a link layer. The DTN architecture can also be thought of as an (IP) overlay network if the underlying communication uses IP packet encapsulation and protocols, but it is rather different in that the underlying communication may use protocols that are not related to IP at all. Thus, the DTN uses naming, layering, encapsulation and persistent storage to interconnect heterogeneous portions of a larger ‘internet’, irrespective of a formal layering model.

The key services provided by the DTN architecture are in-network data storage, retransmission, custody transfer with authenticated forwarding, and flexible node naming. The structure of DTN architecture that implemented within a single node is shown in figure 1.

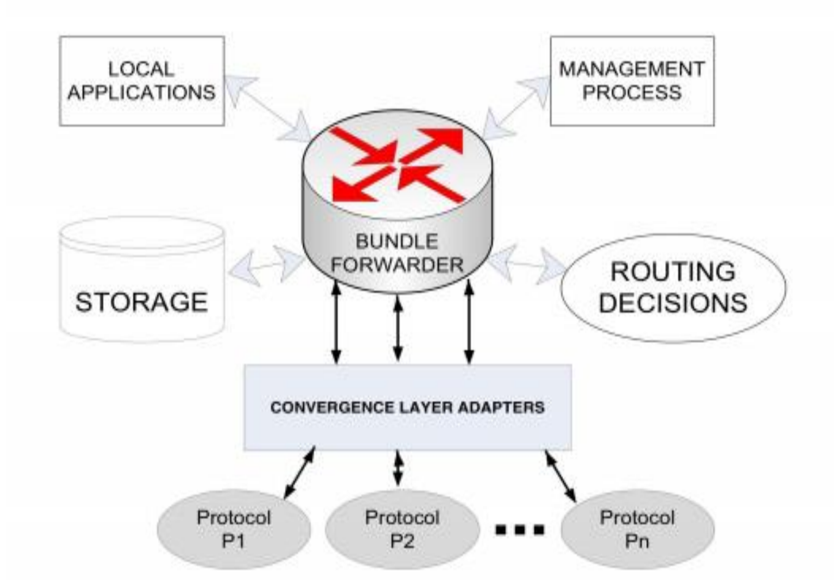

Figure 1: shows how the DTN architecture implemented within a single node

As shown in figure 1 which is referred from [7], bundle forwarder is the core of the mechanism that manages the bundles within the node. During communication the node can connect to other nodes using a multitude of different delivery protocols, including TCP/IP, Bluetooth, Wi-Fi, or hand-carried storage devices. The differing semantics of the various protocols are concealed from the bundle forwarder by a collection of convergence layer adaptors (CLAs) that map the capabilities of the individual protocols to the functions necessary to transfer bundles to a peer node during a communications opportunity.

When a communications opportunity arises, either because it has been scheduled by the node management process or because a peer node has been discovered, typically by some wireless mechanism, the bundle forwarder will initiate and manage a link to the peer node using the appropriate CLA. The link will be used to transfer selected bundles stored on this node to the peer node, in accordance with routing decisions provided by the routing decisions process. If policy requires, the bundle may be encrypted or provided with integrity protection before being forwarded [8].

The Architecture of DTNs has been exploited in many works and its architectural layers compared with the conventional TCP/IP (internet) layers [7], [8]. DTN layers and internet layer are identical except that DTN architecture implements store and forward message switching by overlaying a new protocol layer called bundle layer. It is placed on top of transport layers and it ties together the transport layers and below with application programs to communication across multiple regions. The bundle layer is proposed to function above the existing protocol layers and provide the function of a gateway when two nodes come in contact with each other.

Due to its flexibility, it can be easily linked with the already existing TCP/IP protocol networks or to link two or more networks together. A single bundle layer protocol is used across all networks that make up a DTN. By contrast, the layers below the bundle layer and which is transport layer and below are chosen for their appropriateness to the communication environment of each region. Bundle (message) consists of a source application user data, control information provided by source application and destination application which describes how to process, store, dispose and handle user data and bundle header. Based on this information, a bundle layer may break a whole bundles and into fragments as an IP layer may break a whole datagram into fragments. If bundles are fragmented, the bundle layer at the final destination reassembles them. The difference between TCP/IP layer and DTN layer is shown in figure 2.

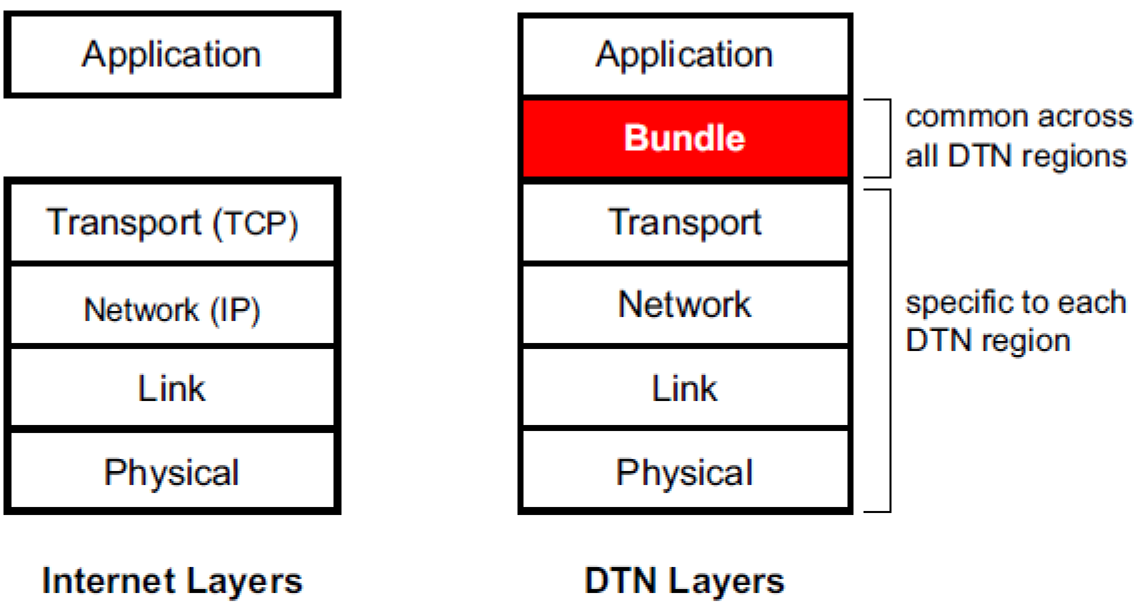

Figure 2: Difference between TCP/IP layers and DTN layers.

2.4. Routing in DTN

In Delay-tolerant networks, at any given time instant, the network may not be connected due to absence of end-to-end connectivity, this makes routing/forwarding decision in DTN is more difficult. However, it allows routing in networks where contemporaneous end-to-end paths are unstable. Unstable paths can be the result of several challenges at the link layer which are high node mobility, low node density, short radio range, intermittent power, environmental interfaces and denial-of -service of attacks.

Routing protocols in DTN has to take more issues in to consideration before making decisions in opposite to traditional networks where the routing protocols has to find the shortest path to the destinations. As it is clearly described in [21] and [22], in conventional ad hoc networks an end-to-end path is assumed to exist before data transmission is started. In contrast, this assumption/rule does not hold in DTNs. As a result, data is delivered in a DTN using a store-carry-forward model. Nodes in the network relay data from source to the destination, where existing nodes in the network relay the data from the source to the destination, in one or more hops, such that each node along the path receives the data from the previous node and stores it locally. This node then carries the data for a while, and upon contact with other nodes, forwards the data. In this way, the data is finally delivered to the destination [23].

A delay-tolerant network requires hardware that can store large amounts of data. Such media must be able to survive extended power loss and system restarts. It must also be immediately accessible at any time. Ideal technologies for this purpose include hard drives and high-volume flash memory. The data stored on these media must be organized and prioritized by software that ensures accurate and reliable store-and-forward functionality.

Store and forward method is an old method similar to that used in the postal network. As cited in [24], with the store and forward method, data is transferred from one node to another node until it reached its destination. The store and forward method in DTN is shown in figure 3.

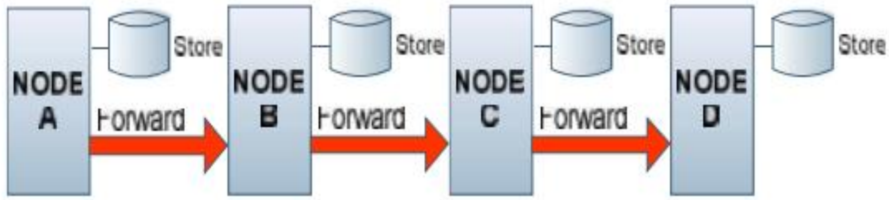

Figure 3: DTN Forward and Store Method

In figure 3 which is referred from [24], each node in DTN must have a storage media such as hard drives to store data before it is moved to another node. Storage at DTN node should be a reliable storage so that the data can be stored for an indefinite period. The main reason why the DTN routers must have a reliable storage are: - i) communication route towards to the next hop may not be available for a long time, ii) one node on the data communication process could send data faster or slower than the other nodes, iii) When data is transmitted, the data should be transmitted usually repeated if there is an error when data is transmitted to the destination or destination reject data that is sent.

The routing of messages in DTN is based on hop by hop, the selection of next hop is done dynamically as per the application scenario as well as the algorithm used. Thus, when a node receives any bundle (or message) then as per the algorithm, that node will search the good relay node to which it can forward the bundle. The transmission of message in DTN can either be done by replicating the message or forwarding it, that depends on the type of algorithm used.

As noted in [16], routing approaches in DTNs can be summarized in to the following three categories. These are: - Flooding or Replication-Based, Probabilistic or History-Based and Knowledge-Based.

i. **Flooding or Replication-Based Routing:** The schemes in this category do not require a node to have knowledge like delivery probability and meeting probability about other nodes. In this approach, nodes in the network opportunistically forward messages to other nodes until messages reach their destinations. The Flooding based routing is further classified into two types [25]. Replication Based: which allows the network nodes to create the replicas of the received message. The maximum number of replicas generated within a network for a particular message could be n-1, where n denotes the number of nodes in the network. Epidemic routing [26] is the representative schemes of this category. Quota Based: in this routing type each message is assigned with fixed quota i.e. the number of replicas for a particular message is limited. Controlled Flooding Schemes [27] and Spray and Wait [28] are the popular representative scheme of this category.

ii. **Probabilistic or History-Based Routing**: This type of routing takes place when nodes have some relevant knowledge about the other nodes in the network. In this scheme no node will generate replicas of the messages, instead they will search for the best suitable relay nodes and forward the message to them based on nodes' encounter history[29], [19], nodes' context information [30], or nodes' location visiting patterns[31]. In addition to this, nodes in this scheme use well known forwarding schemes, such as the Time-to-Live that is by hop-count limit, the Kill Time by amount of time before forwarding is suspended and passive cure (i.e., the method to cure infected nodes and free storage resources). Just to name a few, PROPHET [32], MaxProp [19], Context Aware Routing (CAR) [30] and Most-Social-First [33] are the most popular routing protocols that categorized under history-based scheme.

iii. **Knowledge-Based or Deterministic Routing**: This routing schemes can be efficient in terms of message overhead and buffer consumption. In this routing scheme, the mobile nodes which act as ferries are assumed to reach their destination according to the predefined schedule, this might be difficult in the environment where there is so many constraints that inhibit the mobile nodes from reaching its destination. Therefore, one cannot exclusively rely on such carrier, unless 100% delivery reliability is not required. Also the mobile nodes in this scheme forward messages only to nodes with high delivery probabilities. Thus, it may take the source a long time until if finds a message forwarder with high delivery probability to the destination, which leads to the problem so called slow start problem. Oracle-Based [34], DTN-Multicast [35] and DTN Link State Routing [36] are well known routing algorithms of this scheme.

2.5. Types of Contacts in DTN

DTN architecture defines different types of contacts between network nodes. Request for comments (RFC) of DTN [7] describes five types of contacts, namely, persistent on-demand, intermittent-scheduled, intermittent-opportunistic and intermittent-predicted that may exist in DTN.

2.5.1. Persistent Contacts

Persistent contacts are always available (i.e., no connection initiation action is required to instantiate a persistent contact). An 'always-on' Internet connection such as a DSL or Cable Modem connection would be a representative of this class.

2.5.2. On-Demand Contacts

On-Demand contacts require some action in order to instantiate, but then function as persistent contacts until terminated. A dial-up connection is an example of an On-Demand contact (at least, from the viewpoint of the dialer; it may be viewed as an Opportunistic Contact, below, from the viewpoint of the dial-up service provider).

2.5.3. Intermittent - Scheduled Contacts

A scheduled contact is an agreement to establish a contact at a particular time, for a particular duration. An example of a scheduled contact is a link with a low-earth orbiting satellite. A node's list of contacts with the satellite can be constructed from the satellite's schedule of view times, capacities, and latencies. Note that for networks with substantial delays, the notion of the "particular time" is delay-dependent.

2.5.4. Intermittent - Opportunistic Contacts

Opportunistic contacts are not scheduled, but rather present themselves unexpectedly. A good example for this type of contacts is an unscheduled aircraft flying overhead and beaconing, advertising its availability for communication. Another type of opportunistic contact might be via an infrared or Bluetooth communication link between a personal digital assistant (PDA) and a kiosk in an airport concourse. The opportunistic contact begins as the PDA is brought near the kiosk, lasting an undetermined amount of time (i.e., until the link is lost or terminated).

2.5.5. Intermittent - Predicted Contacts

Predicted contacts are based on no fixed schedule, but rather are predictions of likely contact times and durations based on a history of previously observed contacts or some other information. Given a great enough confidence in a predicted contact, routes may be chosen based on this information.

From the contact types discussed above, the researcher of this study considered the Intermittent-Opportunistic Contacts for the proposed framework.

2.6. DTN Application areas

DTNs span a wide spectrum of application settings. As noted in [12] the study shows that DTNs have been applied to various settings such as interplanetary networks (IPNs), underwater networks, wildlife tracking sensor networks, and networks for developing communities. The application of DTNs which is referred from [37] is shown in figure 4.

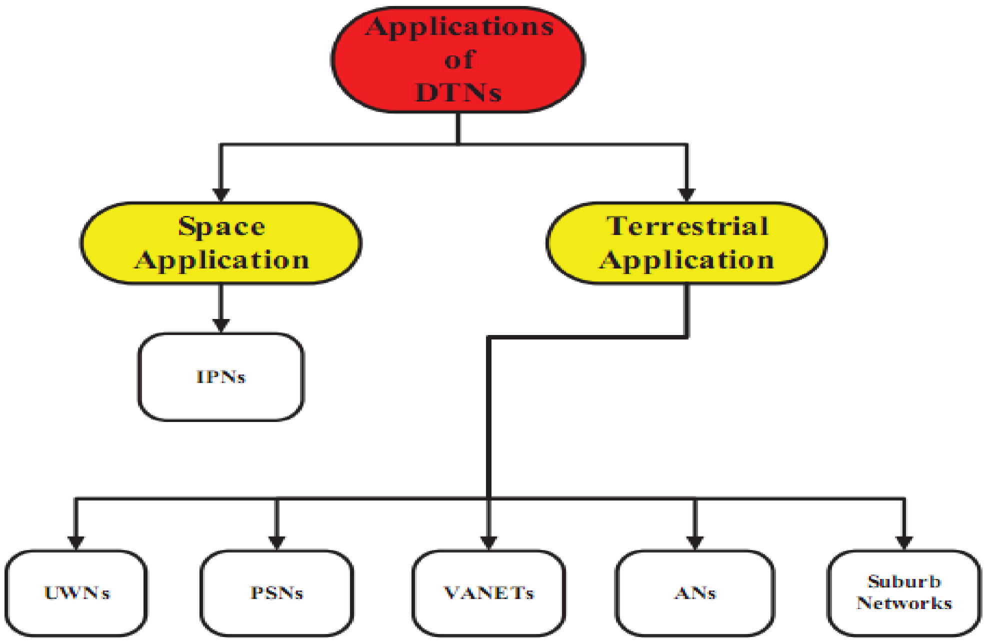

Figure 4: Applications of DTNs

As described in [38], DTN improves network access and the distribution of educational and entertainment content in rural environments, despite the relative underdevelopment of more traditional kinds of infrastructure like roads and electricity. Thus, DTN do compromise network reliability and quality of service by introducing unpredictable delays as data is physically relayed from one wireless device to another.

2.7. Why Delay Tolerant Networks

DTNs introduce store-carry-and-forward functions by overlaying a bundle protocol layer above the transport layer, which provides internetworking on heterogeneous networks (regions) operating on different transmission media [39].The bundle protocol [8] is end-to-end, strongly asynchronous, message (bundle) oriented. The store-carry-and-forward paradigm avoids the need for constant connectivity.

Traditional Internet protocols do not work in DTN environments since they tend to be very “chatty” and exchange many messages between endpoints within a single session. Therefore, the Bundle Protocol was created for DTNs, where the basic message unit is a bundle. The idea is to package all messages from an entire session into a single bundle; this can be sent over the DTN using application specific bundling gateways on both sides of the DTN [40].

Mobile devices are a promising medium for DTN network transmission in underserved areas. DTN has been popularized as a network solution in the event of a disaster scenario, but in underserved areas there are reasons to believe that it may coexist meaningfully with other modes. It may provide a very low-cost complement to traditional infrastructure-heavy forms of network distribution. The DTN mechanisms from the social and economic perspective, as noted in [10], it is a cost effective technology that is well suited to provide network access to people in rural developing regions.

2.8. Overview of Health Service Delivery Arrangement

As described in [2], regarding the health system, Ethiopia implemented a three-tier health service delivery system. The levels of the tier is described below

The first level is Primary Health Care Unit (PHCU), which is composed of a Primary Hospital, Health Center (HC) and five satellites Health Posts (HP). These provide services to 25,000 population altogether. Health Post is staffed with two Health Extension Workers (HEWs). A HC is staffed with an average of 20 staff. It provides both preventive and curative services. It serves as a referral center and practical training institution for HEWs. A Primary Hospital provides inpatient and ambulatory services to an average population of 100,000. It is staffed by an average of 53 persons. It serves as a referral center for HCs under its catchment areas, a practical training center for nurses and other paramedical health professionals.

The second level is General Hospital (Secondary Level Health Care) which provides inpatient and ambulatory services to an average of 1,000,000 people. It is staffed by an average of 234 professionals. It serves as a referral center for primary hospitals. It serves as a training center for health officers, nurses and emergency surgeons categories of health workers.

The third level is a specialized hospital (Tertiary Level Health care) serves an average of five million people. It is staffed by an average of 440 professionals. It serves as a referral general hospital. Figure 5 which is referred from [2], illustrates the tiers in health service delivery system.

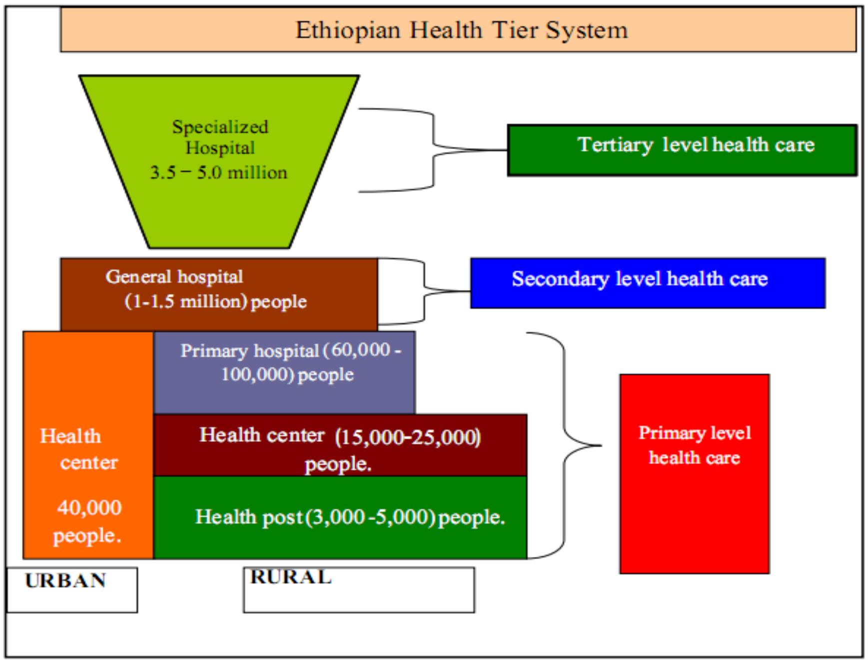

Figure 5: The Tier in Ethiopian Health Service Delivery System

Researches have been conducted on health system using the principle of DTN to improve poor communication among health practitioners that the current networking technology is not adequate. DTN is used over long-delay, disconnected, disrupted or intermittently-connected networks, where mobility and scheduled contacts may be experienced. However, the researcher of this study believe that the health information exchange using the principle of delay tolerant network should be adopted from Ethiopian health service arrangement perspective. Currently, the problem domain in Ethiopian health service arrangement is poor health information exchange among health practitioners due to technological challenges associated with communication and lack of financial resources to establish already the available communication technologies for the health practitioners to exchange health information among health practitioners. As a result, the researcher of this study is motivated to propose a framework that will bridge the health information exchange gaps among the health practitioners in underserved areas based on the DTN principle which complement the challenges faced by current networking.

2.9. Related Research Works

2.9.1. DTN in Health Care System

Many are working to address the issues of poor network problem in underserved areas using the delay tolerant network principle, which is different from the traditional one where end to end connectivity is expected and hop in the network is not optimized individually.

Authors in [41] proposed that a hybrid routing which is persistent, on-demand, scheduled, opportunistic, and predicted routing algorithm, that exploits various types of contacts existing in a partitioned, hybrid, and sparse network. Such networks may be used to provide guidance from the specialist doctors to junior doctors working in primary health centers. They propose it for Uttarakhand state found in the republic of India, the state is situated in the foothills of the Himalayan range, with the most of the villages situated in hilly area. Thus, the state capital has a super specialty hospital, about 12 district level hospitals and 322 state allopathic hospitals or primary health centers located in villages. Due to shortage of trained medical staff at primary health centers, people living in remote villages depend heavily on district level hospitals. Within the state the super specialty hospital and district level hospitals are persistently connected for information exchange with wired networks but there is poor connectivity between district level hospitals and primary health centers in semi-urban and remote villages. Due to physical barriers and lack of economic feasibility, the existence of permanent communication is not suitable. As a result, the authors propose the DTN mechanism which is a feasible solution for providing information connectivity for the regions as shown in figure 6 which is referred from [41]. For information exchange, the smart phones carried by people was used as relay nodes for providing opportunistic and predicted contacts. Also apart from opportunistic contacts, nodes were mounted and set upon ambulances which can act as on-demand contacts.

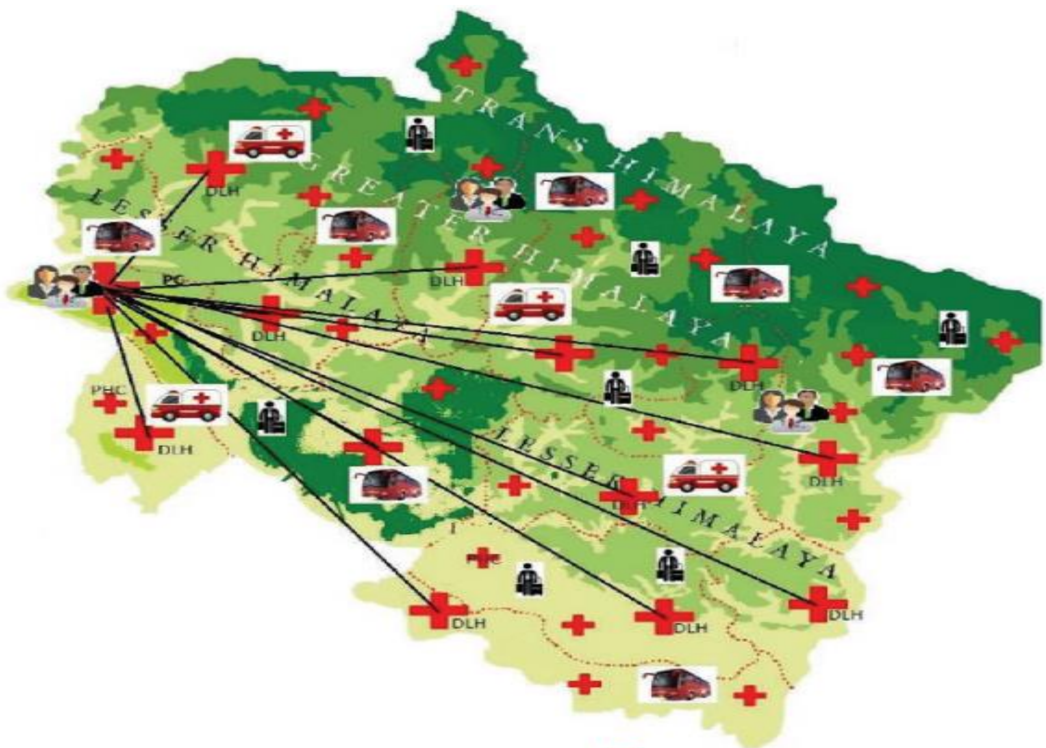

Figure 6: Message transmission between health centers using DTN mechanism

Vehicular delay-tolerant networks (VDTNs) [42] appear as new network architecture based on the concept of DTN. As noted in [39] the paper shows that VDTN allow delay-tolerant data traffic from a variety of vehicular applications to be routed over time, exploiting the physical movement of vehicles and the opportunistic links they establish with each other and with other network nodes. Figure 7 which is referred from [39], shows three possible VDTN node types - terminal nodes, relay nodes, and mobile nodes. Terminal nodes act as access points to the VDTN network providing connection to end-users. Mobile nodes (e.g., vehicles) are responsible for physically carrying data between terminal nodes. Relay nodes are devices with store-and-forward capability allowing bypassing mobile nodes to drop and pickup data bundles. These nodes increase the number of contact opportunities in sparse scenarios, contributing to improve the delivery ratio and decrease the delivery delay [43]. An example of a VDTN network applied to a rural connectivity scenario is shown in Figure 7.

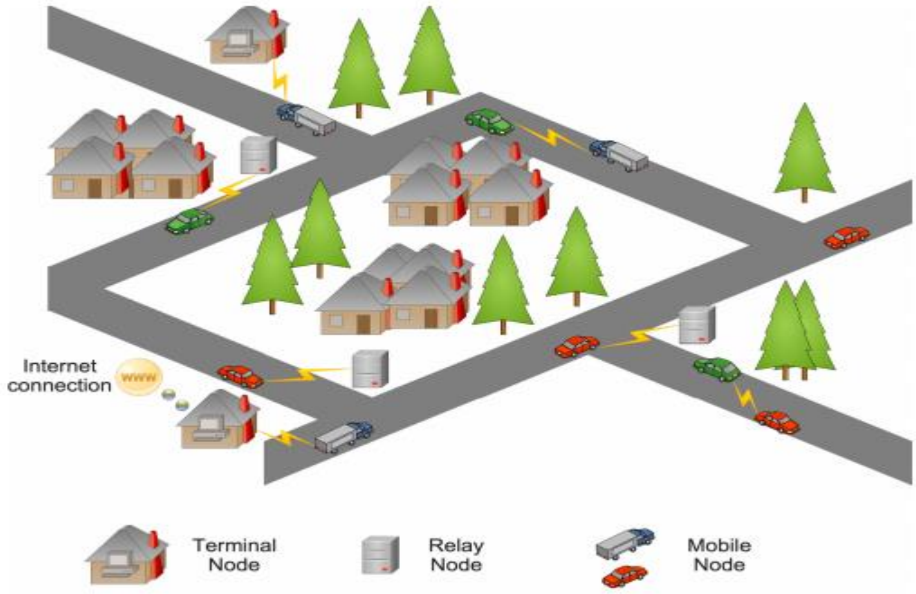

Figure 7: Illustration of a VDTN network

According to [24], DTN technology developed offer a cheap solution, and it can be applied to implement Telemedicine services for the isolated and remote rural areas that cannot be reached by the Internet as shown in figure 8 which is refereed from [24].

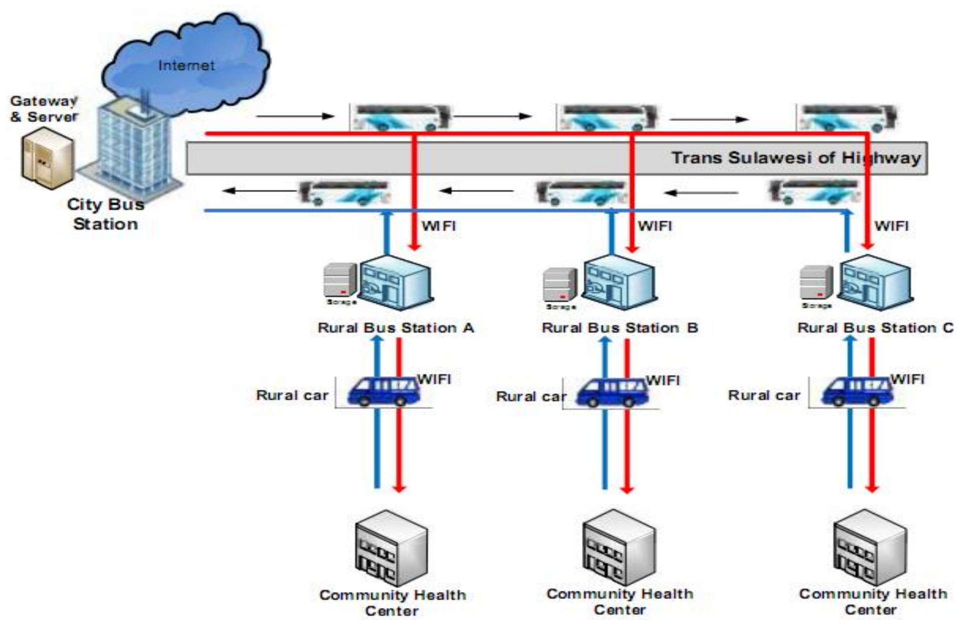

Figure 8: DTN Telemedicine Framework

It can overcome the problem of lack of links for a few days and still be able to provide reliable transfer of data. This is due to the buffering capability at every node. According to proposed method, data services such as health portal news and email was successfully sent and received using the methods and programs are created. But buffering the message for the long period of time introduces the problem as nodes buffer is limited in reality.

2.9.2. Buffer Management Approaches in DTNs

An efficient buffer management techniques is required to be implement in a place where there is limited buffer by making the messages to be dropped when buffer is full and transmit the buffered message to other nodes in prioritized manner to offer a room for the new incoming message in the future communication. There are various bundle (message) forwarding and dropping approaches proposed by researchers. Authors in [44] proposed Drop Old (drop the message from the network with the shorted remaining life time), T-DROP (drop the message having size lie between threshold values), Drop Young (drop the message received recently) and Drop Random (drop the message in random number) to drop messages from the buffer when buffer overflows. Among the above mentioned dropping approaches Drop Old is known by its outstanding performance than the others. In reverse, the forwarding strategies also follows likewise approach based on their integration within the given scenarios. However, all of the approaches mentioned so far provides best effort service. The main drawbacks with the best effort service is its failure to offer any mechanism to prioritize the messages to be dropped.

The drawbacks of best effort service motivates many researchers to propose numerous mechanism that prioritize the message to be dropped and scheduled for transmission in order to manage the limited resources specifically the buffer considered in challenging environment. The following studies are done by various researchers to address this problem and they are more related with the proposed approach in this research work but the methodology followed makes it different from them.

The authors in [45] propose an approach for buffer management as buffer management for preferential delivery in DTN using traffic class and lifetime of the messages for prioritization. They used the bundle processing control flag bit to differentiate the traffic via class-of-service field. Accordingly, the proposed buffer management system comprises bundle classifier to classify bundles based on their flag bit, bundle scheduler to assign priority for the bundles to be transmit when node encounters and bundle dropper to drop the bundle from the buffer when buffer get full based on their bundle class priority. Figure 9 which is referred from [45], illustrates their proposed system.

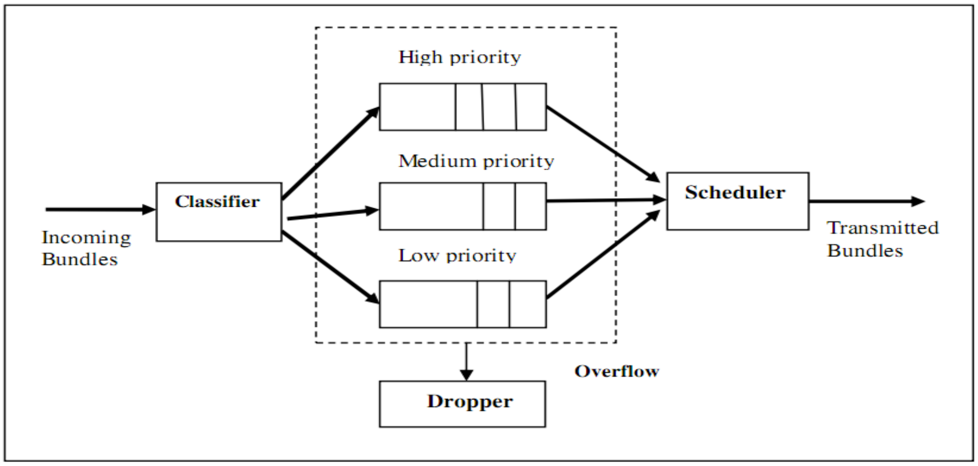

Figure 9: Buffer Management System based on traffic class

The same author in [45] propose another approach in [46] to prioritize the message to be dropped and transmit based on the application and lifetime of the messages. The buffer management system proposed by the authors consist of bundle indexer to assign index for the bundles based on the priority and lifetime, bundle scheduler to schedules the bundles to be forwarded when contact opportunity arise based on indexing and bundle dropper which is to drop the bundle from the buffer when buffer overflows based on the index values. The buffer management system which is referred from [46] is shown in figure 10.

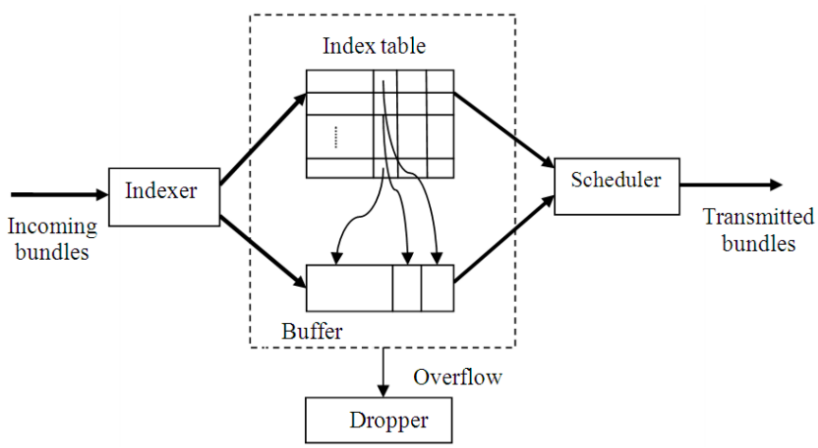

Figure 10: Buffer Management System based on application

Another approach proposed in [47] assign drop and transmit priority for each messages based on hop count. Four inputs namely the current cost to the destination, current cost from source, expiry time and generation time were used for priority function which is slightly dissimilar for transmission and dropping. The authors propose a novel approach named average availability for inter-node computation. Each link's average availability is epidemically distributed to all nodes and with the help of Link State Advertisement (LSA) each node has some knowledge of the network topology. With the help of this knowledge when the buffer get full, the message with large hop count to reach to its destination dropped and the one having small hop count is forwarded. This approach works well for the network with high node density within small area. Because from the result of the study it can be understood that the increasing area makes the connectivity becomes more sparse and increase the level of disruption. So that using this approach we can't obtain good message delivery probability in sparse network since the proposed approach by the stated authors is operate based on the network knowledge.

Authors in [48] proposed a priority order for message transmission based on the hop priority. Their approach is named transmit maximum hop first. The authors target to effectively utilize the network resources by giving priority to message which has the highest priority of hop count will be delivered first. The suitability of this approach is for node-based but not for the scenario which is message-based.

Authors in [49] proposed an approach to drop the message based on their size. According to their approach regardless of other messages attributes, the algorithm drop the message by comparing the size of the message. The message having equal or greater size of the incoming message dropped from the buffer to provide room for the incoming message randomly. This technique can't ensure fair message propagation since it always gives high buffer time to messages with small size.

The metrics used in the work of authors in [50] is almost similar with the proposed approach in prioritizing the message for dropping and forwarding. The reason for using some common metrics is due to the node deployment and resemblance of the considered scenario which mandatorily require the metrics to be used by the node for the decision of dropping and forwarding the message. The authors employs three metrics (replication density, message length and remaining life time) to compute the priority for the messages. In the approach proposed in this thesis, two of them (i.e. the number of replication of the message within the single node and the remaining life time of the messages) is used in assigning priority for the messages to be dropped or forwarded in order to utilize the limited buffer of the node effectively. The novel module introduced in this study is buffer checker to improve the network performance by reducing high overhead and to ensure successful message delivery probability.

All the above mentioned proposed buffer management approaches are unsuccessful in preparing room for the new incoming messages to be buffered before the message transmission start. They are similar in computing the summary vector to notify the message which are not in common and then to exchange them. Beside this, the buffer checking in all the proposed approach begin after computation of summary vector and during the time of message exchange (in the mid of message transmission when buffer overflows). This makes the nodes to get more overhead due to limited buffer during message exchange and it has impact on network performance. The issue above discussed is the motivation for the proposed problem statement.

CHAPTER THREE

PROPOSED APPROACH

This chapter describe the approach proposed in this research. Also the chapter describe the considered scenario, the proposed framework of health care system and the proposed buffer management approach to manage limited buffer space of the node for the proposed framework.

3.1. Method

To achieve the objectives stated in Section 1.3, the researcher made use of the following approach. The idea of this research is to bridge the health information exchange gap among health practitioners in underserved areas using the principle of delay tolerant networks. DTNs introduce store-carry-and-forward functions for connectivity resilience by overlaying a bundle protocol layer above the transport layer, which provides internetworking on heterogeneous networks (regions) operating on different transmission media. Buffer space constraints is well-known problem in DTN due to node's store-carry-and-forward functions. Thus, the researcher proposed a buffer management approach which is suitable for the proposed framework to efficiently utilize the limited buffer space by introducing novel modules in the proposed buffer management approach.

3.2. Data Collection Method

In order to identify and understand the problem of information exchange practices in the level of health care system, primary data collection method is based on the interview and secondary data collection methods such as manual and document analysis have been used. An interview was conducted with the chief executive officer, medical director and health professionals of the Jimma university specialized hospitals physically and through phone and also with other health professionals working at various hospitals, to cross check the structural organization of health service of the country presented in various secondary sources.

The result used for the analysis was collected primarily through reports generated by report modules during the simulation run. During the simulation run, the simulator generates the message statistics file in the report module that gathers statistics of overall performance. In such a way data has been collected for the analysis and discussion purpose.

3.3. The Design Scenario

This section describes the scenario for the proposed framework that styles how health practitioners in underserved areas can exchange health information each another or with the specialists. Hitherto many hospitals in underserved area don't have the specialized staffs or systems necessary to handle a complicated patient cases like Computerized Tomography (CT) scan images and dermatology cases which needs further review by remote specialists (radiologists). The health information created by the specialists are need to be shared for health practitioners working at various hospitals in common to assist the health practitioners in their patient treatment process and to empower them with the required skill in their profession. The primary actors in underserved area hospitals are junior physicians, health officers and nurses. They need support from the specialists to treat the patients locally based on the advice they obtained from the specialists without transfer the patient to the higher specialized hospital unless the patient case is critical or beyond the capability of the local staffs.

But due to absence of cost-effective ICT tools, health practitioners in underserved areas are unable to get already available data created at higher specialized hospital by the specialists or created at any hospital which is required to be shared in common. Therefore, using delay tolerant networks which is cost effective ICT tools and presented as a solution to underserved environments, we can significantly bridge the information exchange gap among health practitioners and in turn to realize quality health care service provision.

3.4. The Proposed Framework

This section describes the framework that is proposed based on the gap identified in previous section of this research work. In Ethiopia, most of the hospitals are located in underserved areas where there is intermittent connectivity or no end-to-end connectivity at all. Also due to their sparse distribution, it is not economical or easy to establish network with infrastructure that can support today's conventional wired and wireless Internet communications. The major challenges in establishing communication networks in underserved areas is related to the economics of the region and the environmental factors. To solve the mentioned problem, a framework is proposed based on the concept of delay tolerant networks principle for health care system as illustrated in figure 11.

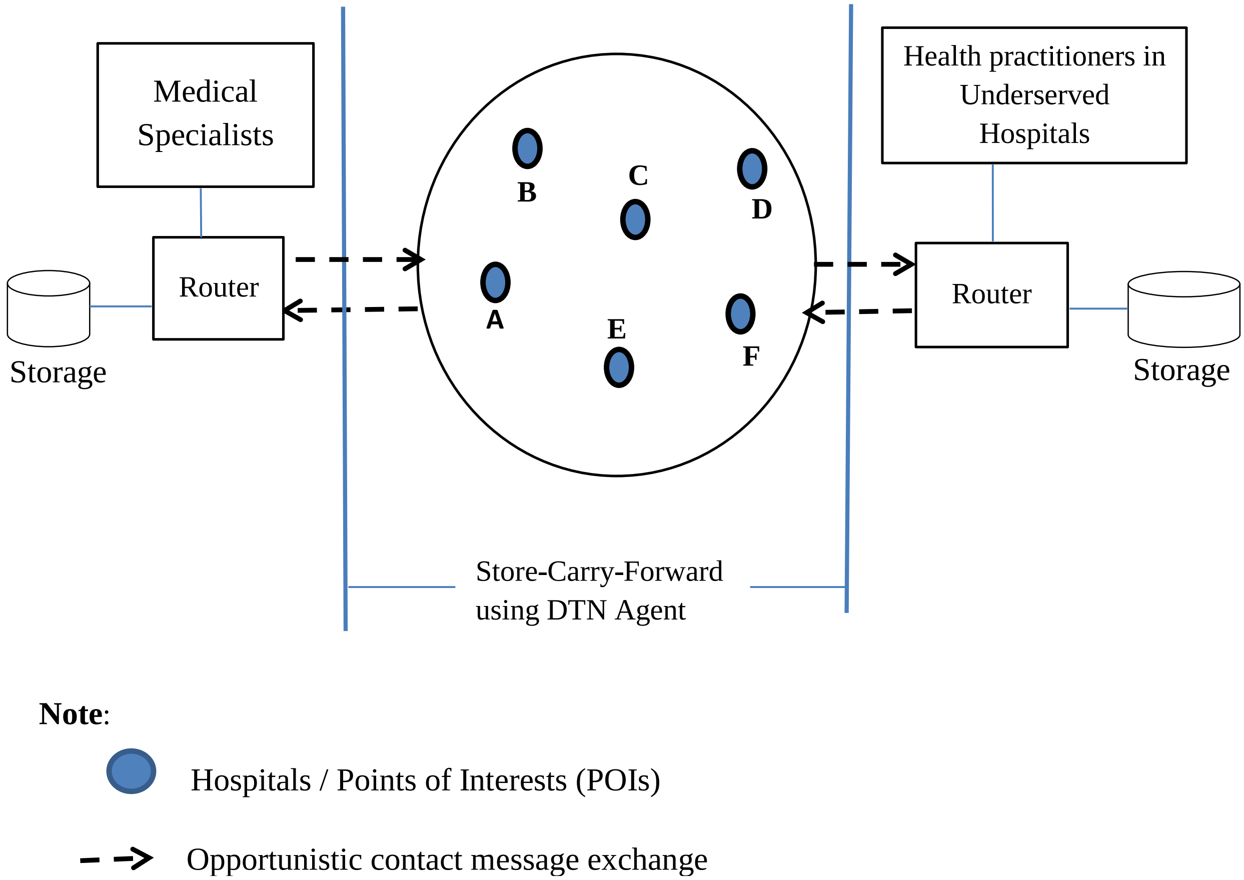

Figure 11: The Proposed Framework for the Health Information Exchange

The framework illustrated in figure 11 describes how health information can be exchanged among health practitioners using delay-tolerant networks in a place where there is no end-to-end connectivity or an intermittent connectivity.

To make the discussion more clear, here after, the term hospital(s) interchangeably used with points of interests (POIs) as they stands to describe the same concept in the proposed framework. According to the health care tier arrangement, advanced services like surgery is carried out at general hospitals, unless the case require physicians in a sub-specialty. Also indeed, some patient cases are not fully clear for the health practitioners working at general hospitals, thus they need specialized physicians in a sub-specialty on the consult. In such case, when they need to exchange the recorded data of the patient among each other, they face a challenge to exchange the existing data due to intermittent connectivity or absence of end-to-end connectivity. Therefore, the researcher consider this problem in to account to select the best routing scheme which is suitable for the proposed framework. The next section briefly describes this in detail.

3.5. Routing Protocol /Algorithm

The selection of routing algorithms is very important and it depends on the network scenario and the application where the network is deployed. In this study, the researcher selected the best routing protocol from the flooding-based routing scheme in DTNs based on its suitability for the proposed framework.

There are various routing protocols available for DTN as it is clearly described in section 2.4. In general, the routing protocols in DTN are differ in the knowledge that they use in making routing decisions and the number of replication they make. Epidemic routing is one of the known routing protocol which grouped under the routing category based on the number of replication it makes. For the proposed approach as the network is sparse and no knowledge about the network is known, epidemic routing is considered as the suitable routing protocol since unlike other protocols, it does not rely on mobility or location information to help in routing decision rather it depends on local information. As the approaches proposed by various researches in section 2.8.1 are unsuccessful in checking the available buffer space before message transmission, the approach proposed in this thesis is designed to address this particular gap.

As epidemic routing is highly enhances the delivery probability of the message among the nodes, it is preferred for the proposed framework. In epidemic routing, the nodes exchange the messages they don't have. The message replication is done after checking the summary vector. The summary vector is maintained at each node that stores the information about all the messages that are passed by that node or currently stored in its buffer. Authors in [26] clearly present how the epidemic routing protocol works. When two nodes come into communication range of one another, the node with the smaller identifier initiates a session with the node having larger identifier. During the session, the two nodes exchange their summary vectors to determine which messages stored remotely have not been seen by the local host. In turn, each node then requests copies of messages that is has not yet seen. Figure 12 illustrates the message exchange in the epidemic routing protocol when two nodes come into transmission range of one another.

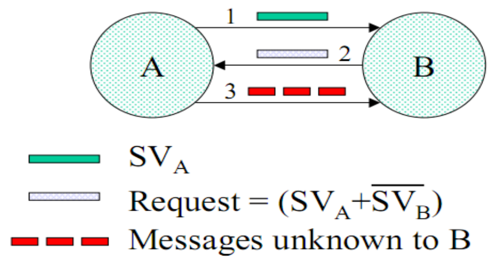

Figure 12: Message exchange in epidemic routing protocol

As shown in figure 12 which is referred from [26], when node A comes into contact with node B it initiates a session and transmit its summary vector to B. summary vector A is a compact representation of all the messages being buffered at A. Then B performs a logical AND operation between the negation of its summary vector and summary vector of A. Accordingly, node B determines the set difference between the messages buffered at A and the messages buffered locally at B. It then transmits a vector requesting these messages from A. In last step, node A transmits the requested messages to B. This process is repeated transitively when B comes into contact with a new neighbor. Given sufficient buffer space and time, these sessions guarantee eventual message delivery through such pair-wise message exchange.

However, epidemic routing results in inefficient use of the network resources such as power, bandwidth, and buffer at each node [51]. It is able to achieve minimum delivery delay at the expense of increased use of resources such as buffer space, bandwidth, and transmission power. In another word, the epidemic routing performs well if network resources are unlimited. In proposed framework, the nodes are assumed to have limited buffer space and sparse in its deployment density. To deal with the shortcomings of the epidemic routing in association to buffer space problem, a buffer management approach for the selected routing protocol has been proposed as described in section 3.6

3.6. Proposed Buffer management approach

From the related work of literature review, it is understood that several research has been done in proposing efficient routing algorithms for epidemic routing to manage the limited buffer of the node using various approach to drop or transmit the message based on some priority mechanism. The scenario considered here is assumed to be consist of network with low node density which is deployed sparsely, limited buffer size and messages with equal degree in importance which is created to be shared in common in the network. A big issue with the considered scenario is

i. To fairly disseminate the message in the network since all messages are considered to be equal in degree of importance.
ii. To assign priority for the message to be transmit when another nodes encounter and drop the buffered message to give room for the new incoming message in selective manner
iii. To make the nodes to compute the required buffer size for the new incoming messages and make a room to accommodate them based on the information obtained from the received meta-messages before message transmission begins. This is to avoid several computation arise in the mid of message transmission by making computation once at the receiving node before message transmission starts.

In order to achieve the above three cases, the buffer of the nodes is required to be managed mandatorily as the considered buffer size is limited. Unless it is difficult to obtain the required message delivery probability. In this study, the metrics named number of message replication or simply message replication rate is proposed to manage the buffer by assigning the priority for the messages to be dropped and transmit. Thus, it is incorporated with epidemic routing due to its matchless delivery probability in DTNs and suitability for the network with low node density. Therefore, the approach is proposed as Epidemic Routing based on Message Replication Rate Priority (ERMRRP). Beside this, a novel module called buffer checker is introduced to check whether the available buffer is sufficient or not to accommodate the new incoming messages before the message transmission begins. Thus, it improves the network performance by increasing delivery probability and reducing more overhead.

In proposed approach, the researcher is addressed to avoid multi-computation (i.e. computation for meta-message and computation for dropping the message when node's buffer overflows in the mid of message transmission phase) because several computation incurs more overhead which arises when two encountered nodes are communicating to each other. In order to avoid several computation at the receiving node, the information enclosed in the meta-messages is adjusted to include the message Id and their size in compact manner and then the buffer checker will get the message stored inside its buffer to jointly compute it to get the message which are not yet buffered along with their size based on the received meta-messages. Soon after this computation, the buffer checker compare the computed size of the new incoming message waiting to be received with the available buffer space.

If the available buffer space is greater than the size of the new incoming messages, the receiving node send request to the node that it is currently connected in order to get the new incoming messages. But if the size of incoming messages (computed size) is greater than the available buffer space, the dropper is invoked by the buffer checker to drop the message(s) from the buffer based on the priority and this process will continue until the buffer space of the receiving node is equal or exceeds the computed size of the new incoming messages. Then after the receiving node send back the request to the connected node having new messages in its buffer about the list of messages Id which are not yet buffed in its memory. Accordingly, the node having new messages in its buffer transfer the messages based on the transmission priority. This approach increase the message delivery probability and reduce more overhead. Beside this, it also enhance successful message transmission. The proposed buffer management approach is shown in figure 13.

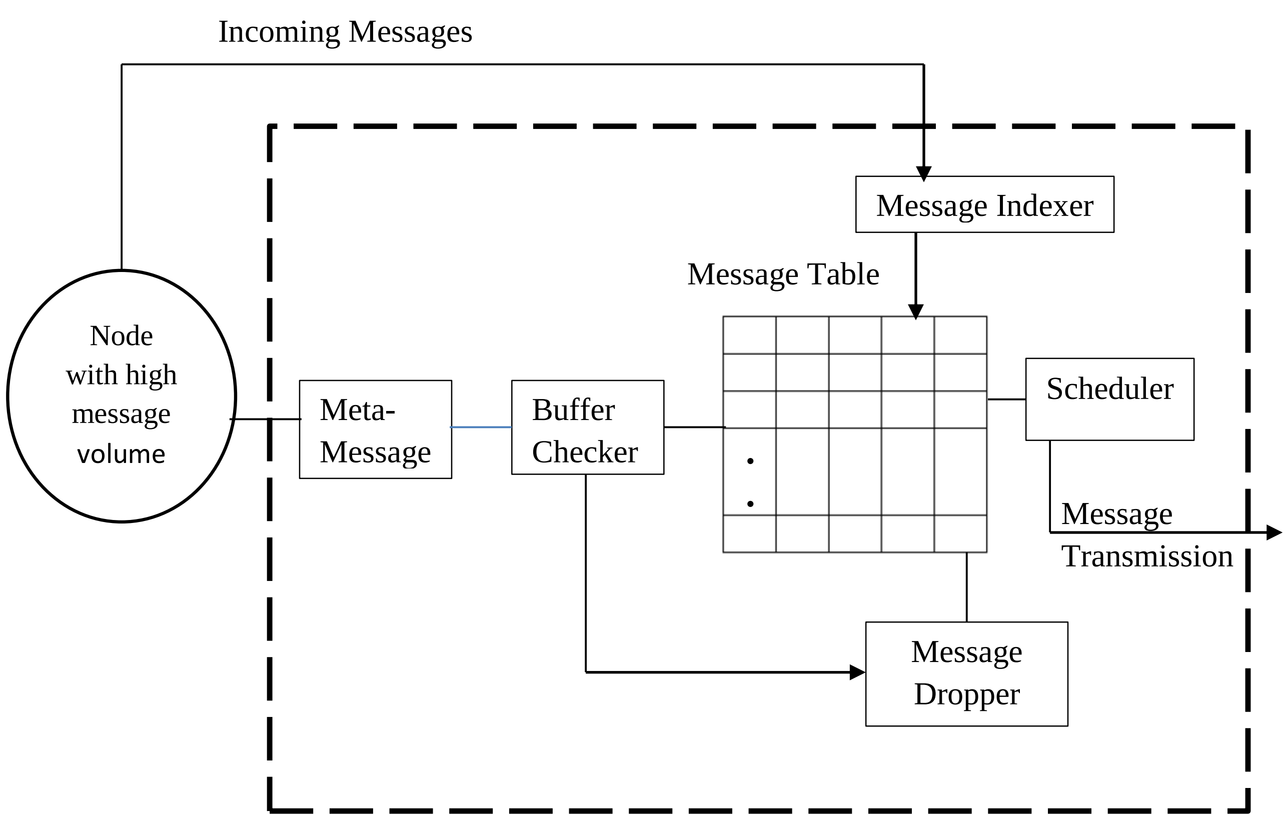

Figure 13: The proposed buffer management approach (ERMRRP)

3.6.1. Meta-Message

In an opportunistic network when two nodes encounter one another, they usually need to exchange some meta-messages to avoid sending duplicate data bundles. Since the considered routing protocol in this study is epidemic routing, the discussion here after is allied to it. In the considered routing, each node's buffer contains messages initiated by the node as well as messages relayed on behalf of other nodes. When two nodes which encounter one another to exchange message stored in their buffer, they first establish a connection between them using three phases (Probing phase, the meta-messages exchange phase and message exchange phase) which is common in opportunistic network.

Probing phase lets the node to broadcast a beacon periodically and listens for the beacons of its neighboring nodes. When two nodes are coming into contact (i.e. in the same radio transmission range), the connection will be established based on the beacons they receive from each other. Then based on the established connection the meta-messages exchange takes place. Meta-message provides information about messages stored in the node's buffer. So that it help each nodes to determine which message it should send, how many messages can send and other important information. Finally after the computation made based on the meta-message, one node sends message to the other node or they exchange messages they don't have in common previously.

In existing epidemic routing, the meta-message is the summary vector and it is encompassed of the identifiers of all the message stored in the node's buffer. Each node carries a fixed length summary vector for the message with ID m and M^{th} bit flag values of the message. Based on the summary vector when two nodes encounter one another, they exchange and compute the received summary vector with their own vector and forward requests to get the message which are not in their buffer. One of the main problem with summary vector is space inefficiency because the size of the summary vector increases with the number of messages. Thus, it suffers high overhead in terms of the transmission energy and time in addition to problem with limited buffer.

In this study, in order to address the shortcomings of summary vector mentioned above which is used in the existing epidemic routing, the meta-message exchange mechanism proposed in [52] is adopted. The authors proposed the approach named known vector which eliminates unnecessary identifiers in summary vector to improve the network performance. In proposed approach the message ID which is uniquely identify the message in the network and the message size which is used by the buffer checker for the computation of a buffer is comprised in meta-message. This approach extends the lifespan of the nodes and enhances the probability of successful message delivery by minimizing the energy usage required by meta-message exchange and the energy used for meta-message computation and also by allowing more time for message transmission. In approach proposed in this thesis, the meta-message comprise only the message Id which to identify the messages uniquely in the network and messages size for computation at buffer checker to make the required room for the incoming messages. Including other identifiers with ID and size of the messages as a meta-message incurs overhead. Therefore, with the precise meta-message exchange, we can achieve high delivery rate and low transmission overhead.

3.6.2. Message Indexer

Message indexer indexes the messages in the message table based on each message replication rate and their remaining lifetime since the proposed routing algorithm rely on local information. The message which are already buffered and replicated to other encountered nodes has value for the replication rate field within the message table along with the remaining lifetime and other identifiers. But for the new incoming message the value for the number of replication is zero (0) until it is replicated to other node. In this case the message indexer consider the remaining lifetime of the incoming message to index them in the message table.

For example if the number of incoming messages will be more than one, they will have the same value which is zero for the replication rate field in the message table as they don’t replicate to any other nodes but their remaining time to live or lifetime varies so the indexer use this information to index them in the message table with others which are buffered earlier. The indexer index the entire message in the table based on each message’s replication rate and remaining lifetime. The message having high number of replication and short remaining life time assigned high index value and in reverse the message having small number of replication and short life time assigned low index value. The index value of the message in message table help the message dropper and scheduler to make decision when they are invoked.

3.6.3. Buffer Checker

By the virtue of the periodical broadcast of the beacon, when two nodes are come into contact, the connection will be established. Based on the established connection, the nodes exchange their meta-messages. Prior to message exchange between the two encountered nodes, the buffer checker compute the meta-message to identify the message which is unknown to the receiving node then the computation of total required size to accommodate them. The total size required to accommodate the incoming message is the sum of each new incoming messages' size which are not yet buffered at the receiving node, identified based on the meta-message computation.

$TS_{incomingMessages}$ = the sum of each messages size unknown to receiving node.

Where TS is total size for the incoming messages.

Once the total size required to accommodate the new incoming messages is known, the buffer checker compares the available buffer size with the computed total size of the incoming messages. If the available buffer space is greater than the computed total size of the incoming messages, the request will be forwarded to the encountered node to get the new (unknown) messages. But if the available buffer size is less than the total size required to accommodate the incoming message, the buffer checker invoke the message dropper to drop the message based on the index value from the message table to offer the room for the incoming messages. At the receiving node the buffer checker execute the following algorithm after computing the total size required to store the incoming messages based on the received meta-message. The algorithmic design of the buffer checker is shown in algorithm 3.1

Notation

N_{ABS} - Available buffer space of the node

$TS_{incomingMessages}$ - Total Size of incoming messages

```
If (N_ABS > TS_incomingMessages)
  {
    Forward request message to get new incoming messages
     Exit buffer checking
   }
  else
    {
      Invoke message dropper
     }
```

Algorithm 3.1: Algorithm for Buffer checker

3.6.4. Message Dropper

The existing work on buffer management used the message (bundle) dropping functionality to manage the limited buffer size of the node based on some priority when the nodes buffer get full. However, simply drop the message based on the buffer status is not efficient because when the messages are dropped in spare network it has direct impact on delivery probability. The message should be dropped if and only if when the new incoming message is required to be accommodate and if the available buffer space is not enough to accommodate the new incoming messages. The message selection for dropping should have to be decided carefully to provide fair chance for the message to be distributed in the network. To do this, the nodes make decision based on network-wide information or Local information.

In proposed approach and considered scenario, due to low node density and the nature of considered routing protocol, the dropper at each node use the local information to drop the messages from the buffer in order to give room for the new incoming message when it is necessary because it is difficult to use the network-wide information in highly sparse network. Two metrics namely messages remaining lifetime and number of replication (replication rate) of each message are considered to drop message from the message table which is indexed based on the mentioned metrics. The message with high index value given high priority to be dropped from the buffer to give a room for the new incoming message. In another word the message which is highly replicated and having small remaining lifetime dropped when the message is required to be dropped from the message table.

Beside this, as stated earlier, each node's buffer contains messages initiated by the node as well as messages relayed on behalf of other nodes. The nodes which initiates the message should keep the message until its lifetime expires because once the time to live (TTL) set for the message expires, the messages is no more useful and it is dropped from the buffer. The reason why the message dropper not to drop the message initiated by the node is to increase the delivery probability of the message. Thus, the message dropper drops the message which are relayed and stored on behalf of others from the buffer when request come from the buffer checker to drop the message and then to give room for the new incoming messages. The following algorithm shows how the message dropper drops the message from the buffer of the node based on the message replication rate and message remaining lifetime. The algorithmic design of the message dropper is shown in algorithm 3.2.

Notation

$M_{indexValue}$ - Index value of the a message

M_T - Message Table

M_{ttl} - Messages remaining lifetime

N_{ABS} - Available buffer space of the node

N_{self} - The node it self

$TS_{incomingMessages}$ - Total Size of incoming messages

If message is initiated by N_{self} && $M_{ttl} > 0$

Move to the next step

While $N_{ABS} < TS_{incomingMessages}$

For each message in M_T **do**

If $M_{indexValue}$ > other messages $M_{indexValue}$ in M_T **then**

Delete message with high index value

End if

End For

End While

Algorithm 3.2: Algorithm for message dropper

3.6.5. Message Scheduler

In order to make fair distribution of message in the network, the messages stored in the nodes buffer should have to be scheduled before transmission start when another node encounter. Thus, in proposed approach the scheduling is done based on the index value of the message. The index value is maintained based on the information of the message stored in the buffer. The indexer use each messages replication rate and remaining life time to maintain the index value as clearly described in section 3.6.2. In reverse to message dropper, the scheduler offer high priority for the message having low index value from the message table.

CHAPTER FOUR
IMPLEMENTATION

4.1. Experimental Environment Setup

The ONE simulator implemented in Java and available as open source has been used to demonstrate the proposed framework. It contributes an environment for generating node movement using different movement models, routing messages between nodes with various DTN routing algorithms, visualizing both mobility and message passing in real time in its graphical user interface [53]. Many of the routing algorithms applicable to DTN environment are pre-implemented in the simulator. In this study, the proposed approach is incorporated to existing epidemic routing algorithm to manage the limited buffer space of the node.

The shortest path map based movement model (the sophisticated version of the map based movement model) provided with the ONE simulator was used and the WKT file of the south western region of Ethiopia illustrated in figure 15, generated using OpenJUMP was used for simulation. OpenJUMP is a Geographical Information System (GIS), which has been developed originally by the two Canadian companies Vivid Solutions and Refractions Research under the name JUMP [54]. The name JUMP is an abbreviation for Unified Mapping Platform. The “J“ points to the used programming language “Java“, “Open“ is for “Open Source“, the quell code is accessible for everybody. Accordingly, the movement model obtains its configuration data using files formatted with a subset of the well-known text format and with the mobility model specified above, the mobile nodes move using roads from the map data.

In the simulation the general hospitals which are grouped under the cluster of Jimma University specialized hospitals are considered as a points of interests. Accordingly, nine stationary nodes and eight mobile nodes which is respective to the eight points of interests were deployed in the simulation. One of the stationary nodes don’t have mobile node as it is a common contact point for the other POIs mobile nodes. The stationary nodes are located at fixed point at each POIs, accessible to mobile nodes (i.e. with store-carry-forward capabilities) and it allows mobile nodes that pass by to collect (pickup) and leave data on them. Also it is assumed that the stationary and mobile nodes in the network used the standard IEEE 802.11b with a data rate of 6 Mbits/s (the approximate throughput according to [55]) but the mobile nodes is configured to have a data rate of 2 Mbits/s in the simulation as DTNs includes various link technologies like Bluetooth and the standard data rate for Bluetooth is also similar with the data rate of the nodes configured for the nodes.

The parameters used for simulation are stationary nodes, mobile nodes which are configured with opportunistic contacts, messages generated, buffer capacity of stationary nodes and mobile nodes, transmission speed of nodes, bit-rates, time to live for the generated messages and simulation time (duration). The detail of various simulation parameters is listed in the table 1.

Figure 15: Simulated Map of south western region of Ethiopia (ONE Simulator)

4.2. The Simulation Scenario

The analysis phase uses the following scenario for describing the proposed framework using the ONE simulator modeling on node movement, inter-node contacts, routing and message handling. The result of the simulation was analyzed based on the metrics described in section 5.1.

In this study, the following points were considered for the simulation scenario. In order to share the created messages in common among all POIs with the help of mobile nodes that store-carry and forward the stored message when the nearby nodes are encountered opportunistically, the scenario was built by defining the simulated nodes and their capabilities. The defined nodes and their capabilities includes the basic parameters such as storage capacity, transmit range, bit-rates, movement and routing models and simulation duration. The scenario consists of stationary nodes and mobile nodes. It is assumed that each stationary nodes at the POIs were having persistent and large storage capacity. But the mobile nodes (intermediate nodes) were having limited buffer space thus, they are prone to buffer overflows at certain point of time due to the flooding of the messages when the nodes are encounter each other. The detail of various simulation parameters for the simulation scenario is shown in table 1.

Simulation Parameters	Values of Simulation Parameter
Simulation Time	36000 Seconds (10 hr.)
Number of Mobile Nodes	8
Number of Stationary Nodes	9
Buffer Size of Mobile Nodes	Limited
Buffer Size of Stationary Nodes	Unlimited
Mobile Node Speed	30-80 km/hr.
Node Movement	Shortest Path Map Based Movement
Interface	High Speed Interface
Transmission Range (meters)	100
Data Rate	2 Mbit/s
Message Size	500kB-2MB
Message Generation Interval (Minutes)	20 -30
Message TTL (time to live)	43200 seconds (12 hr.)

Table 1: Simulation Environment Parameters

4.3. Message Generation

The ONE simulator provides two ways to generate application messages inside the simulation. These are message generators and external event files. The first way of message generation (i.e. message generators) which is built-in in the ONE simulator. It creates messages with a random or fixed source, destination, size, and interval. The second way of message generation is external event files. For the simulation scenario, the message generated by the message generator which is pre-implemented in ONE simulator was used. Message event generator set in such a way that it generates the messages in every 20 to 30 minutes and every time message size can also be varied from 500 Kb to 2Mb.

4.4. The Mobility Model

This section provides the movement models of the node opted in the ONE simulator for node mobility. As DTN networks be contingent greatly on physical movement of devices that can store-carry and forward messages with other DTN devices, the performance of a DTN would seems to depend on the underlying mobility assumed of the vehicles carrying DTN enabled devices. In this study, the mobile nodes mounted on vehicles were considered to buffer and exchange messages with other DTN enabled devices from one point of interest to another nodes in the network.

For the proposed framework, the mobile nodes are assumed to be nodes which are mounted on ambulance, each having Wi-Fi interface to exchange the information when it encounters with other nodes having Wi-Fi interface. The information exchange takes place when the mobile nodes encounters any other mobile nodes in the network opportunistically. The ambulance mobility in which the mobile node mounted on it extend the range of the network, allow data paths to exist over time in networks that suffer from long periods of disconnection. Thus, the mobile nodes act as the communication infrastructure for the network, being opportunistically explored to collect, carry and disseminate data. Once the generated message is delivered to the stationary node, it is assumed that the end user can access the data from the local device through the local router.

In this work, the shortest path map based movement model which is pre-implemented in the ONE simulator is chosen for simulating the node mobility. It is a derivative of the Random Way point model, where at decision point's node choose a random destination and then follow the map-based shortest path to that destination. Since the node configured with the shortest path map based movement models can use the map data that contain the Points of Interest (POIs), the nodes in the simulation follows the deterministic routes according to the configuration files instead of follow any random routes. In the simulation the POIs is a uniform entity (i.e. hospitals), located at various coordinates within the provided map area.

4.5. Reporting and Visualization

This section describes the way how the results of the simulation was visualized. These are through an interactive Graphical User Interface (GUI) and with generated images from the information gathered during the simulation. Figure 16 shows the GUI displaying the simulation in real-time and it has been used for demonstration purposes. In the main window the node locations, current paths, connections between nodes, number of messages carried by a node, etc. are all visualized. Also the GUI produces a filtered log of simulation events, such as contacts and message transfers. While the GUI is good for getting an intuitive over-all picture of what is happening during the simulation, more rigorous ways to visualize node relations, message paths and performance summaries are provided by post processed report files.

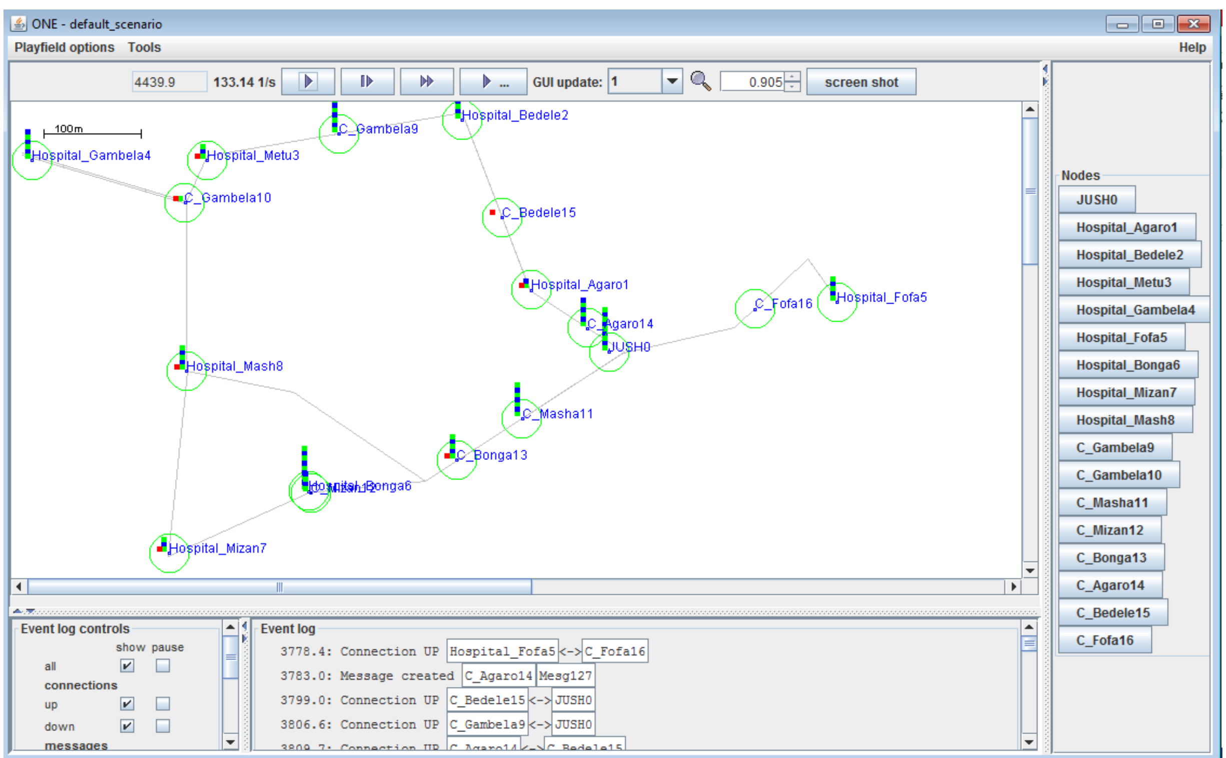

Figure 16: Screenshot of the ONE simulator's GUI

Based on the report file generated by the ONE simulator, the node connections and other reports module files were used for further analysis. Figure 17 shows the node connections and the path that the messages have traveled in the network which is drawn by GVEdit graph file editor based on MessageGraphvizReport file as an input from the ONE simulator reports module.

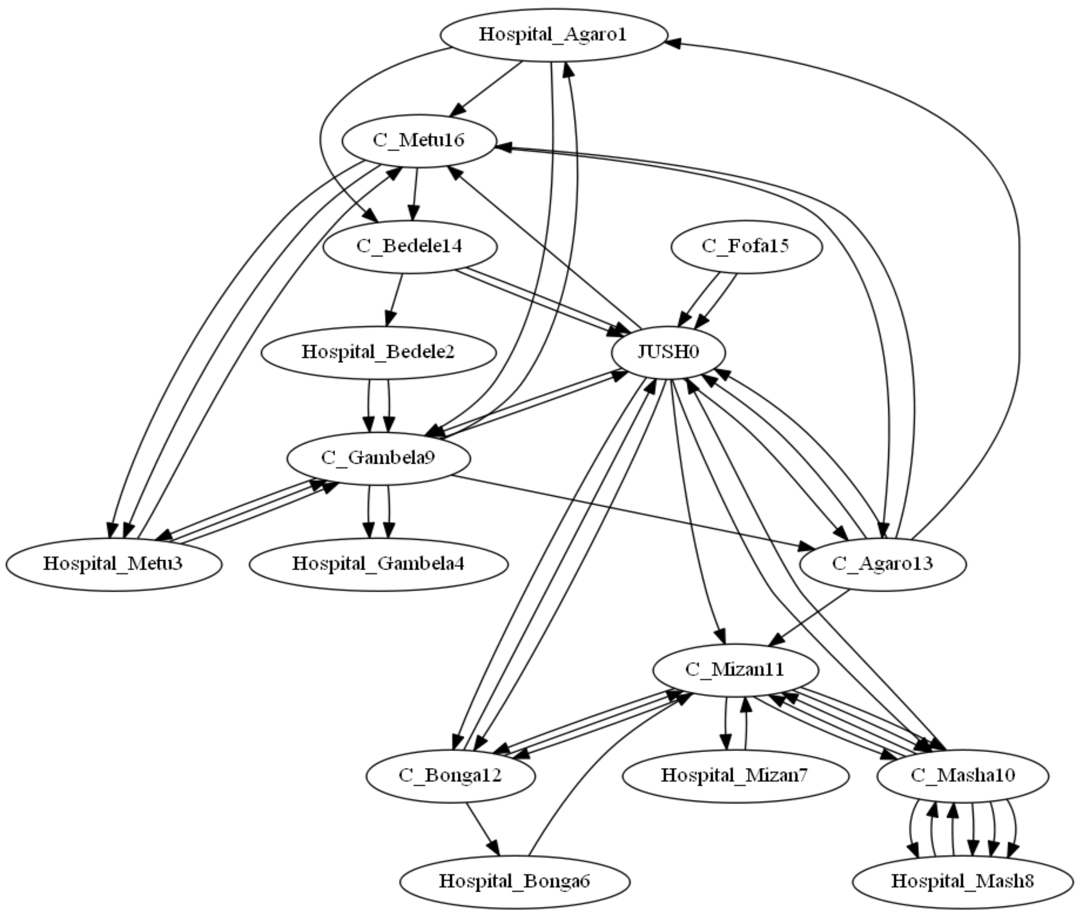

Figure 17: Node connections and the message path in the network

Beside the simulation results of the GUI, the majority of the result used for the analysis was collected primarily through reports generated by report modules during the simulation run. Report modules receive events like message or connectivity events from the simulation engine and generate results based on them [13]. During the simulation run, the simulator generates the message statistics file in the repot module that gathers statistics of overall performance (i.e. the number of created messages, message delivery ratio, how long messages stay in node buffers etc.). Accordingly, the report module's output was used to plot graph for the various message statistics report generated by the ONE simulator as clearly illustrated and discussed in chapter five.

CHAPTER FIVE

RESULT AND DISCUSSION

This chapter describe the results analysis and discussion of the scenarios targeted based on the simulation result. The performance metrics for the designed simulation scenario were briefly described and simulation run with various configuration files based on the predefined parameters was analyzed and discussed.

5.1. Performance Metrics

This section of the chapter describes the metrics adopted for evaluating the considered routing algorithms. Routing in the communication networks depend on the definition of performance indicator called routing metrics. As noted in [56], the popular routing metrics in traditional networks are number of hops, end-to-end delay, delay jitter, route life time and route throughput. However, in delay tolerant networks, these metrics are problematic due to asynchronous specificities. Therefore, DTNs use different routing metrics from the traditional networks as it is clearly defined in [57], [58] and [59]. The routing algorithm considered in this thesis were analyzed based on three routing metrics namely delivery probability, average latency and overhead ratio. Detail description of each metrics is explained as follow:

1. **Delivery Probability**: It is the fraction of generated messages that are correctly delivered to the final destination within given time period. It is defined as

$$\text{Delivery Probability} = \frac{\sum \text{Number of Message delivered}}{\sum \text{Number of Message created}}$$

2. **Average Latency**: It is defined as the average time taken from the source node to transfer the message to the destination node. It is the measure of average time between messages is generated and when it is received by the destination. In other word average latency is the time it takes for a delivered message to reach its destination. Average latency includes all types of delay such as buffer delay, route discovery process, and delay during retransmission of the message, and propagation time etc. The lower value of the end to end delay means better performance of the protocol.
3. **Overhead Ratio**: This metric is used to estimate the extra number of messages needed by the routing protocol for actual delivery of the messages. It is defined as follow

$$\text{Overhead Ratio} = \frac{\sum \text{Number of Messages Relayed} - \sum \text{Number of Messages Delivered}}{\sum \text{Number of Messages Delivered}}$$

It provides an indication of the overhead as transmissions of messages that could not reach their destination are also included. It is deal with the assessment of the bandwidth efficiency. Interpreted as the number of created copies per delivered message. That is, the amount of replicas necessary to perform a successful delivery.

5.2. Performance Evaluation

Often the term performance in networks is used to describe the performance of applications and the impact on end users experience [60]. Likewise in this thesis the network performance is studied from the application performance point of view. For evaluating the performance of the considered routing protocols, the buffer size of the nodes have been used. Based on the buffer size of the nodes, each simulation run generates a trace file containing all the data packets that are sent between the nodes during the course of the simulated scenario. Accordingly, the performance of the considered routing protocols based on different buffer size setting were determined through analysis of the generated trace file of the simulation. The following section of this chapter presents the analysis of simulation result.

5.3. Result Analysis and Discussion

This section presents a detailed analysis of the simulation result using chart based on the generated trace file of the simulation.

Figure 18 shows the reliance of delivery probability on the buffer size of mobile nodes for the epidemic routing algorithm (it is used as it is in ONE simulator) and the proposed algorithm for the epidemic routing based on message replication rate priority (ERMRRP). From the chart it can be noticed that the proposed algorithm has improved the delivery probability of the messages as compared with the epidemic routing algorithm when the buffer size of the nodes becomes limited but both algorithm shows comparable performance when the buffer size of the node is more enough to store the incoming messages.

The delivery probability with the epidemic routing algorithm shows less performance when the nodes buffer get limited due to its incapability to prioritize the messages which is stored in nodes buffer to be dropped or transmit when it is necessary. Thus, the node with epidemic routing lets each node to keeps a copy of each messages in to its buffer until the messages remaining lifetime expires and in turn this introduce the nodes buffer space to be overflowed soon at certain point of time. As the result, the new incoming messages from the new encountered node automatically dropped unless the receiving node provides the room for the incoming messages by dropping the buffered messages from its memory. This drawbacks in epidemic routing results to low message delivery probability in the network when the buffer size of the nodes become limited.

In reverse, the proposed algorithm shows outstanding message delivery probability because of the priority mechanism for the messages stored in the buffer to be dropped when the available buffer space is less than the size of incoming messages and transmitted when the new nodes encounter. From the graph we can easily observe that the node with ERMRRP having a size of 5 MB and 10 MB performs equally with the node running the epidemic routing algorithm having buffer size of 15 MB and 20 MB respectively. This implies that when the nodes buffer becomes constrained, the ERMRRP performs in double as compare with epidemic routing algorithm. From figure 18 we can understood that as the nodes buffer space increases or when the nodes buffer space is greater than the size of messages generated in the network, both algorithms show similar performance. Therefore, we can conclude from the graph that the buffer space has substantial impact on delivery probability.

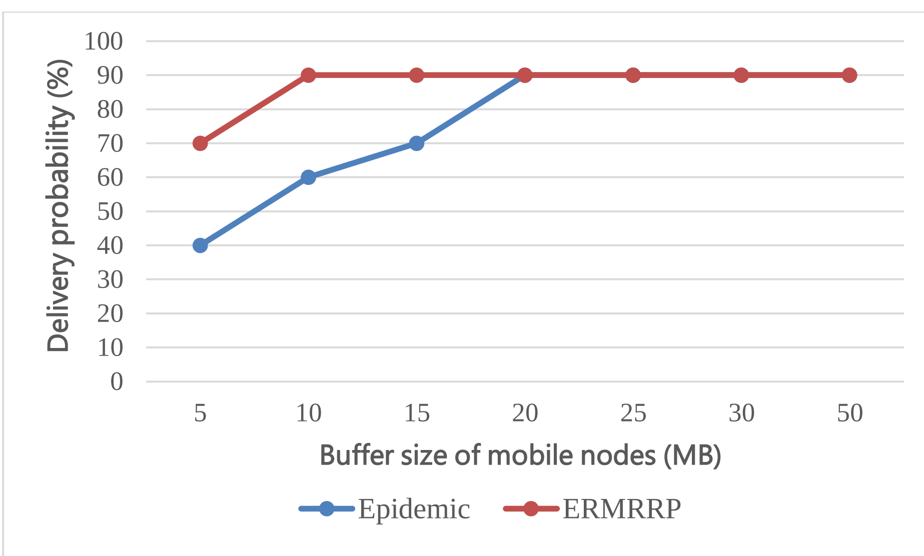

Figure 18: Percentage of delivery probability as function of buffer size

Figure 19 shows the overhead ratio obtained for different buffer sizes for epidemic and proposed routing algorithm. In order to improve message delivery probability and reduce overhead, the proposed routing algorithm removes unnecessary identifiers in the meta-message (message's control information). It is clear that as the number of messages increases, the size of meta-message also increases but in the proposed approach to reduce the size of meta-message only the messages Id and size was comprised as a meta-message. This approach extends the lifetime of the nodes and enhances the probability of successful message delivery by minimizing the energy usage required by meta-message exchange and the energy used for meta-message computation and also by allowing more time for message transmission when the nodes buffer become constrained.

From figure 19 it can be observed that the proposed routing algorithm has less overhead ratio value as compared with the epidemic routing when the nodes buffer is highly constrained. The proposed approach use the priority mechanism for the messages stored in the nodes buffer to be dropped or transmit. In addition to this, it computes the required size and prepare room to accommodate the incoming messages by dropping highly replicated messages from the nodes buffer before incoming message transmission starts. This approach avoids several computation rise in the mid of message transmission so that it reduces more overhead for the nodes and also it improve the network performance.

Even though bandwidth is assumed to be sufficient for the given traffic load, every transmission consumes power. Battery is the major issue in DTNs as many scenarios rely on devices with limited energy supplies and also this problems become amplified when there is more overhead in the network. Therefore, considering the issue of overhead in the algorithm design is paramount and with the proposed approach, we obtained less overhead in addition to managing the nodes limited buffer. The overhead ratio as a function of buffer size is shown in figure 19.

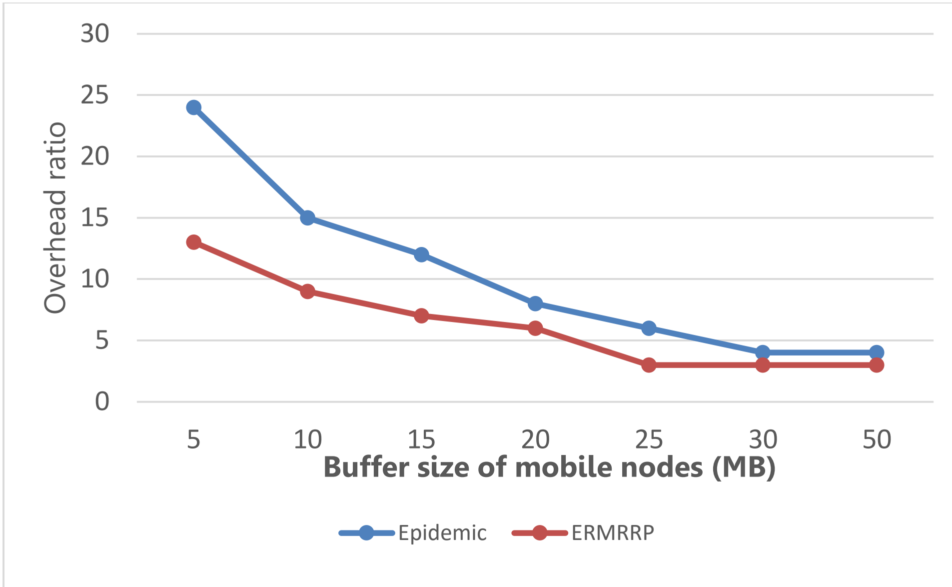

Figure 19: Overhead Ratio as function of buffer size

Figure 20 shows the simulation results for epidemic routing algorithm and proposed routing algorithm with different buffer size as a function with respect to average latency. From the graph it is clear that when the buffer space of the nodes become constrained, the epidemic routing algorithm shows better performance than the proposed algorithm in terms of average latency. But when the nodes buffer is not constrained, they show almost comparable results.

In epidemic routing once the request message is sent from the receiving nodes, the node with high message volume route the message stored in its buffer epidemically until the connection is broken or all the requested messages are routed without any priority. So, the time in which the copies of the messages stay in the nodes buffer is very short. Because in epidemic routing the receiving nodes computes only the summary vector to list out and then to send request to get the messages which is unknown to it based on the computed summary vector without checking its available buffer space. In ERMRRP, the request message is sent to the encountered node if and only if the available buffer space of the receiving node is greater than the total size of the incoming messages. If the receiving nodes available buffer space is less than the total size of incoming messages, the buffer checker invokes message dropper to drop the messages from the nodes buffer until the available buffer space is greater than the total size of incoming messages before request message is sent to the encountered node. This approach realize successful message transmission. However, the integration of buffer checker module in ERMRRP to compute the available buffer space of the node with the total size of the incoming messages after identifying the message which is unknown to the receiving node introduces latency for the nodes during their communication period.

From the graph we can observe that increasing in nodes buffer size in both epidemic and proposed routing algorithm shows reduction in average latency due to absence of computation except computation done at meta-message receiving phase to compute and list out the messages which are unknown to the receiving node. In figure 20 when the nodes buffer space is in between 5 MB and 15 MB, the proposed routing algorithm results in high average latency due to computation done at buffer checker to drop and provide the room for the incoming messages before message transmission begins and the computation done by the scheduler in assigning priority for the messages stored in the nodes buffer to be transmit to the encountered nodes. From the figure 20 we can see that when the nodes buffer space is 15 MB and above, both the epidemic and ERMRRP routing algorithm shows almost similar result in average latency.

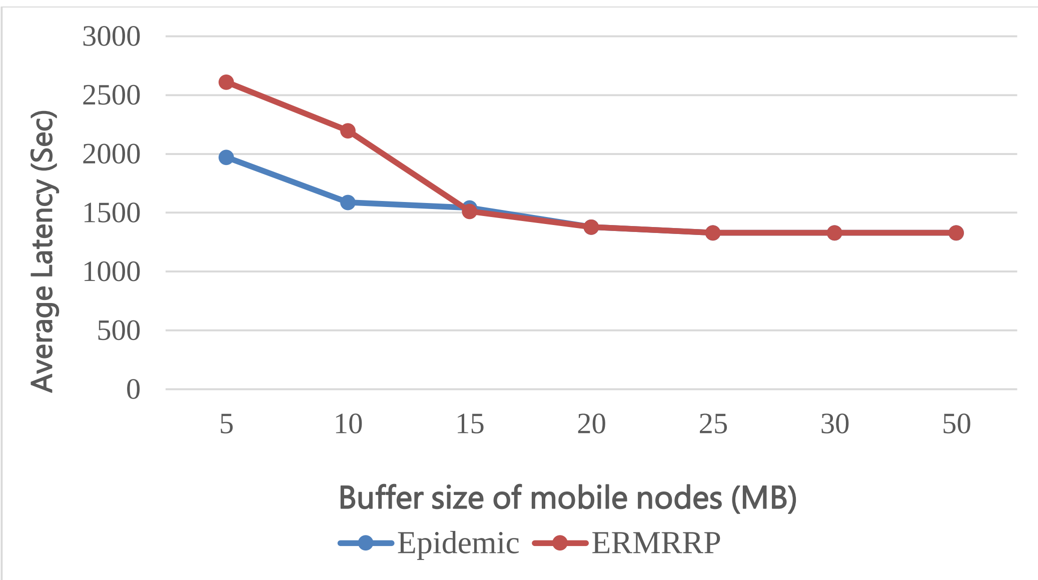

Figure 20: Average Latency as function of buffer size

CHAPTER SIX

CONCLUSIONS AND FUTURE WORK

6.1. Conclusions

The purpose of this study was to explore delay-tolerant networks as an alternative approach in bridging the health information exchange gaps among the health practitioners in underserved areas. In order to understanding the area of the topic, literature was reviewed on delay-tolerant networks, its architecture proposed by various researcher and its application areas. Thus, delay-tolerant networks have the great potential to connecting devices and regions that are being presently under-served by current networks. It address challenging connectivity issues enabling communication on scenarios with sparse and intermittent connectivity, long delay, asymmetric data rate and even with no guarantee of end-to-end connectivity.

In this thesis, the DTN application in the health care system specifically its potential benefit for underserved area health professionals to exchange heath information with their peers in common and with the specialists is explored. The primary reason to choose DTN is its low cost and it is complement to traditional infrastructure-heavy forms of network distribution. Thus, it is a cost effective technology that is well suited to provide network access to health practitioners in underserved areas using mobile nodes as a data carrier in between various points of interests.

Since the density of the nodes is very low in the considered scenario, flooding-based routing scheme specifically epidemic routing is selected to improve message delivery probability. However, due to its flooding nature it makes the nodes to use its limited buffer space inefficiently. Therefore, to address the stated problem, the buffer management approach was proposed and simulated based on the proposed framework. The metrics namely delivery probability, Average latency and the overhead ratio were used to evaluate the considered routing algorithms. To evaluate the performance of the proposed algorithm, the simulation results of existing epidemic routing algorithm was compared with the proposed algorithm. The simulation results obtained in this thesis show that for the proposed routing approach, the message delivery probability is very high, minimum overhead and high average latency (as a tradeoff due to computation at buffer checker for preparing room and priority for transmission) when the nodes buffer become constrained. However, when there is sufficient buffer space, both epidemic and proposed routing algorithm show comparable performance in terms of delivery probability and Average latency. ONE simulator, OpenJUMP, and scripting languages were used as a tools to simulate the proposed framework.

In general, using delay-tolerant networks it is possible to achieve high message delivery for the designed scenario since DTNs compromise network reliability by introducing unpredictable delays as message is physically relayed from one wireless device to another with the help of mobile nodes which was impossible with the traditional routing protocols as they require the existence of some path between endpoints, small end to end round-trip delay time, and loss ratio. Due to its low cost and the above mentioned potential benefits, adopting delay-tolerant networks in the health care system can bridge the communication gaps among the health practitioners immensely and this in turn will improve the health care service provision.

6.2. Future Work

As can be seen in results and discussion of this thesis, the proposed routing approach shows less performance in terms of average latency when the nodes space become constrained due to computation for message priority to be dropped or transmit. Thus, the future research work on the proposed routing approach is to come up with any mechanism to improve the obtained high average latency.

Beside this, another future focus from this research is to apply and test the proposed framework in the health care system. Since the proposed framework is validated with the simulator, it has to be test and validated in the real environment because simulations and analysis can predict trends of performance, but real system expose problems that may not be noticeable on paper.

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