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Socially-Aware Adaptive DTN Routing Protocol

by

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Socially-Aware Adaptive DTN Routing Protocol

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Dedicated to my loving parents and to my advisor from whom I have learned so much

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Abstract

In infrastructure-less dynamic environment, no end-to-end path exists between a source node and destination node due to network partitioning, node disconnectivity and other related issues which results in high latency and highly repetitive link disruption. In such enviornment, routing a message towards a destination node is a challenge which leads to a new paradigm termed as Delay Tolerant Networks (DTNs). DTNs provide an environment in which messages can be forwarded in a store-carry-forward fashion. Some recently proposed DTN routing protocols either use a single or combination of multiple social metrics to identify the suitable forwarder node. However, these existing DTN routing protocols do not use some of available social attributes keeping in mind the randomness and the nature of message. The existing routing scheme produced results at the expense of community formation cost and over utilization of network resources. Therefore, there is a need to devise a mechanism that can take advantages of social metrics to select more appropriate forwarder node which can deliver more packets with low overhead.

This thesis attempts to address these issues by proposing Socially-Aware Adaptive DTN (SAAD) routing scheme which exploits a social attribute known as Degree Centrality. In this scheme, each node calculates and shares its Degree Centrality with other nodes at regular intervals. A forwarder node disseminates message to the most influential node possessing highest Degree Centrality. This process continues till the message reached to the destination node. This thesis also examines the impact of changing the number of nodes on the delivery ratio, overhead and latency. Hence, another scalable routing scheme is proposed in which we increase the number of nodes and run the simulations using different number of nodes. For evaluation, we keep all the parameter values same as used for SAAD except the number of nodes. The simulation results using different number of nodes also improve the packet delivery ratio, reduce overhead, hop-count at the cost of delay which ensures that the proposed routing scheme is scalable.

To further ensure the scalability, we exploit multiple social metrics (i.e., Degree Centrality, Random Walk Encounter and Social Activeness) in the proposed routing

scheme. In this scalable routing scheme, each node calculates its social rank (SR) using Degree Centrality, Random Walk Encounter and Social Activeness. A source node selects the forwarder node possessing highest SR value. In addition, our proposed algorithm will also ensure the adaptive routing keeping in mind the nature of message.

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Abbreviations

DTN	Delay Tolerant Network
SR	Social Rank
NR	Node Rank
DC	Degree Centrality
RWE	Random Walk Encounter
SA	Social Activeness
NW	Normalized Wieght
DD	Direct Delivery
MADM	Multiple Attributes Decision Making
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution

Symbols

S_n	Source Node
D_n	Destination node
V	Velocity
$N - list$	Neighbor list
$F - list$	Final list
$sort - F - list$	Sorted Final list
$NR - list$	Node Rank list
NW_{DC}	Normalized Weight of DC
NW_{SA}	Normalized Weight of SA
NW_{RWE}	Normalized Weight of RWE
BS_{Ni}	Best Solution of node i
WS_{Ni}	Worst Solution of node i
$P.S_{Ni}$	Point Score of node i

Chapter 1

Introduction

1.1 Overview

Traditional Computer networks are considered to be high speed networks due to the provisioning of guided media. In wired communication environment, data is transmitted over a cable-based communication technology. Wired networks are comparatively given more preference just because of their high upload/download speed, lack of interference, long distance system connectivity and high security [1][2][3]. Although, the traditional networks ultimately provide high throughput and low latency but have few associated limitations in terms of expensive cabling and mobility. To overcome the cost of cabling and more importantly the provision of mobility, in recent times, wireless networks have been preferred. Although, the wireless medium (unguided) is more error-prone and suffers unreliable low speed connectivity but accessibility and ease of use appeals users to use wireless internet.

Moreover, disconnectivity among wireless devices is common due to obstacles, such as walls, doors, high buildings, and sparseness etc. Wireless networks are of different types and concerning mobility, wireless networks covers the entire spectrum of mobility from very low to very high as shown in Figure 1.1. Figure 1.1 demonstrates that different wireless networks including Wireless Sensor Networks (WSNs) with limited mobility, Mobile ad-hoc Networks (MANETs) [4]with moderate and Vehicular ad-hoc Networks (VANETs) [5][6][7][8]with high mobility.

FIGURE 1.1: Spectrum of Mobility in Wireless Networks

However, various deployments of wireless networks have to face extreme environments where continuous connectivity is challenging. In these networks, link disruptions are common and depend on the severity of the operating environment. Wireless networks are subject to high propagation delays, frequent disruptions and high error rate due to dynamic topology and high mobility. These limitations affect the performance of routing protocols. It is further deteriorated in sparse and intermittent wireless environment which is known as Intermittent Connected Networks (ICNs) [9].

An ICN is an infrastructure-less wireless network that facilitates various wireless applications to operate in a challenging wireless environment [9], where no end-to-end paths exist which results in high latency and highly repetitive link disruptions [10][11]. These networks lack network state information (i.e., network topology and knowledge about other nodes in an entire network, etc.) and thus have to take decisions at their own using criteria to find the relay node to disseminate the message from source node to destination node in an opportunistic way. In an Opportunistic network, a node possessed data packets and forwards it, whenever it comes in contact with a required relay node. Moreover, if a node fails to locate the most appropriate intermediate influential node to forward a message, then this node has to buffer that message and carry till it finds the desired node which leads to another paradigm called as Delay Tolerant Networks (DTNs) [12][13][14][15][16].

1.2 Delay Tolerant Networks

Networks in which nodes are interconnected intermittently are termed as DTNs. A DTN is an overlay network of ICN. The DTN architecture provides a promising

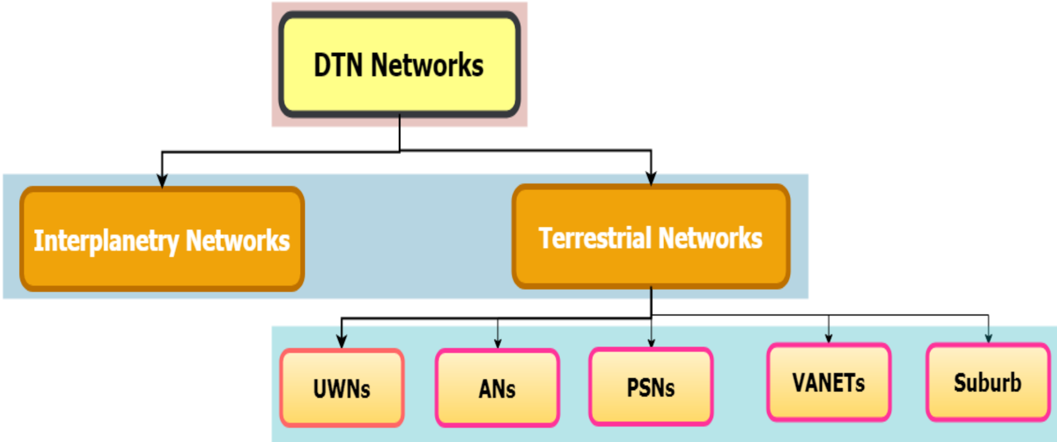


FIGURE 1.2: DTN networks

platform which improves the efficiency of routing data forwarding either in partitioned opportunistic networks (i.e.; Mobile Adhoc Networks (MANETs), deep space, Vehicular Adhoc Networks (VANETs)) or sparse network where no end-to-end path exists between source and destination to deliver a message. Hence, there is a need to exploit DTNs in which message is disseminated to the destination in a store-carry-forward fashion [17][18].

In DTN environment, no direct link exists between sender and receiver [19][20]. Therefore, when a sender node fails to relay a message, it stores the message in its custody [11] until it finds an appropriate relay node to forward the message. Due to dynamic topology and network partitioning, DTN may be used in a variety of applications. It can be implemented to deal with post-disaster situations e.g. earthquakes, flood affected areas and emergency/rescue scenarios, where traditional networks fail to provide reliable communication between nodes, mostly because the infrastructure is itself destroyed.

Delay tolerance tries to address the issue of high error rate within communication networks. It is normally assumed that communication will occur without errors, however in intermittent networks and increasing use of the spectrum results in high error rate. Delay tolerance is also capable to cope with the problem of long or variable delay within networks. It is normally assumed that propagation delays are relatively homogeneous within networks, however in long intermittent connections, and high error rates this is not always the case. It may take longer for the transmission of data successfully.

The DTN protocol suite can operate with the terrestrial IP suite or it can operate independently. DTN provides assured delivery of data using store-and-forward mechanisms.

In DTN, each node forwards a received packet to one hop node because no end-to-end path exists between a source and destination node. When a source node or intermediate node fails to find the appropriate node, source/intermediate node buffers the message and carry it until it encounters the suitable relay node in a store-carry-forward fashion.

As a result, only the next hop needs to be available when using DTN.

1.2.1 Characteristics of DTN

1.2.1.1 Improved Operations and Situational Awareness

The DTN provides store-carry-and-forward mechanism which have more insight into events while transmitting data that occur as result of relay and poor atmospheric conditions. This characteristic overcome the requirement to schedule ground stations for data transmission.

1.2.1.2 Interoperability and Reuse

A DTN protocol suite provides interoperability of ground stations and spacecraft operated by any space agency or private entity with space assets. It also allows NASA to use the same communication protocols for future missions (low-Earth orbit, near-Earth orbit or deep space).

1.2.1.3 Space Link Efficiency, Utilization and Robustness

DTN enables reliable data transmissions which utilizes maximum use of bandwidth. DTN also improves link reliability by having multiple network paths and assets for potential communication hops.

1.2.1.4 Security

The DTN Bundle Protocol Security allows for integrity checks, authentication and encryption, even on links where not previously used.

1.2.1.5 Quality-of-Service

The DTN protocol suite deals with different priority levels to be set for different data types, so that high priority data can be received earlier than low priority data based on the set priority.

DTN networks are categorized into two groups, Interplanetary Networks and Terrestrial Networks. Interplanetary Networks include artificial satellite communication while Terrestrial Networks include networks like Under Water Networks (UWNs), Pocket Switched Networks (PSNs), Vehicular Ad hoc Networks (VANETs), Airborne Networks (ANs) and Suburb Networks for developing region shown in Figure 1.2.

Major DTN applications are Wildlife Tracking (e.g. ZebraNet, SWIM), Village Communication applications (e.g. DakNet), VANETs (e.g. CarTel) and Healthcare services applications (e.g. Telemedicine System).

1.2.2 Challenges in DTN

In any ICN particularly DTNs, no end-to-end path exists between a source node and destination node due to network partitioning, node disconnectivity etc [21]. However, there is only a DTN environment in which a message is conveyed to other members in an opportunistic way using store-carry-forward fashion. Therefore, DTN-based routing protocols are required to deal with the following challenges [22]:

- Dynamic topology
- Intermittent connectivity

- Network partitioning
- Long delays
- No end-to-end path exists
- Sparse density
- Frequent packet drops
- Data dissemination in congestion-free route
- Security provisioning
- Routing in DTN

Moreover, traditionally, a message is transmitted using typical internet protocol (IP) but there is a problem to transmit data from one region to another region through reputable gateways. In order to resolve bandwidth mismatch, propagation delay and queuing overhead between terrestrial and extra-terrestrial networks, the prime requirement is to design a new protocol framework for DTN applications. In 2007, a new protocol for DTN applications called as bundle protocol was introduced.

Bundle protocol connects multiple subnets into a single network, assemble data blocks into bundles and then transmit them using a store and forward technique [6]. In DTN, bundles assumed to be traversed in specific heterogeneous networks, where disruption connection is observed. In these scenarios, it becomes hard to transmit the complete bundle. Hence, bundle is fragmented for the successful transmission especially when contacts are short as compare to propagation delays.

The bundle protocol stores data for a long time and provides a custody-based gathered retransmission generic. When a source node or intermediate node unable to forward a bundle to next hop due to the intermittent and sparse network, it stores the bundle in its custody until, it finds the opportunity to forward it to the next relay node. This protocol is more capable to cope with breakups and bandwidth delay issues related with internet connectivity. Internet Engineering Task Force (IETF) standard protocols along with bundle protocol are used to

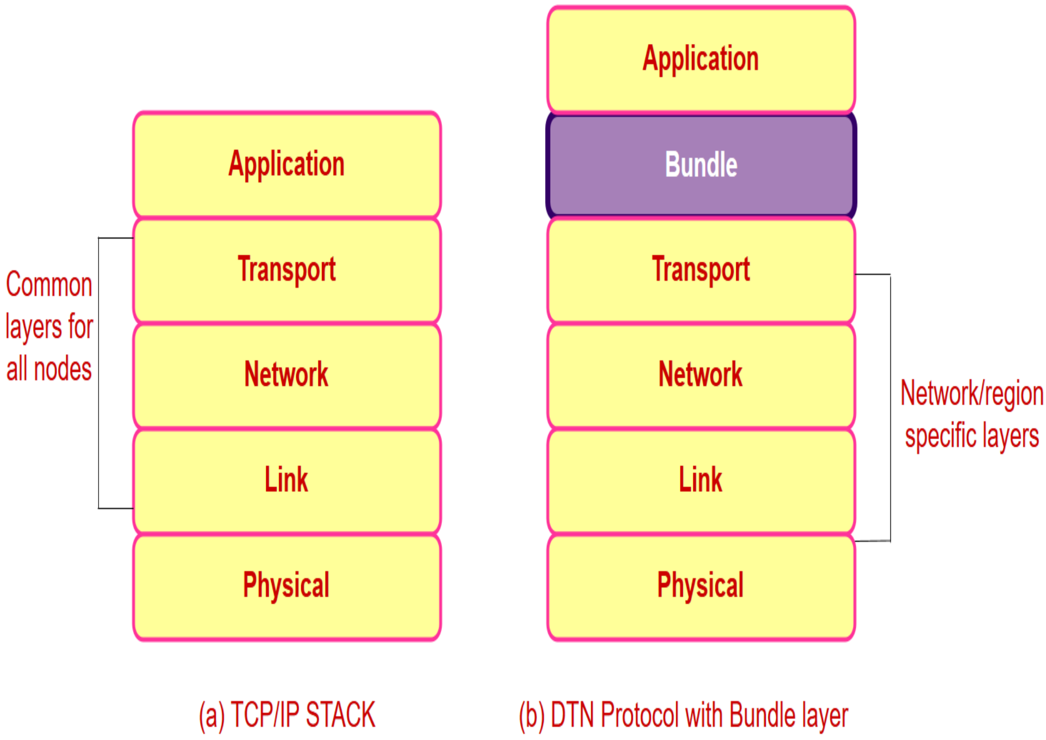


FIGURE 1.3: Bundle protocol

ensure security and congestion control. Bundles are transmitted between nodes in a store-and-forward fashion using bundle layer over network transport technologies. The interface between a bundle layer and inter network protocol suit is known as the convergence layer adapter. However, to ensure the data delivery in DTN environments, a typical TCP/IP protocol stack design is changed to a new modified protocol stack having bundle layer in between application layer and transport layer as shown in Figure 1.3.

1.3 Motivation

A world has become a global village because of the provision of internet connectivity in almost every part of the world. This internet connectivity is possible just because of the Network. This increases the significance of network in global communication. In my MSCS, I started my research in routing in Vehicular Ad-hoc Network. During the literature review, I came to know that people or vehicles can also communicate with one an other to share data even in disaster areas even there is no end-to-end path exists between a source and a destination. This motivates me to carry on research in this area as my PhD research.

When we started my research, we came to know that research community is already working in this area and had designed many routing protocols which could be implemented in Wireless Sensor Networks, Mobile Ad-hoc Networks, Vehicular Ad-hoc Networks and Delay Tolerant Networks. These routing protocols were designed based on replication or forwarding based on some criteria. Initially, protocols were designed based on location, distance etc. Later, social attributes among the people are considered to be more reliable. These protocols either used single social metric or combination of social metrics to design routing protocols. Then we thought that we should also design a routing scheme based on multiple more appropriate social metrics which can deliver more messages than existing routing approaches with low overhead. we also consider the disaster scenario in which urgent messages must be reached on priority basis and speedily. hence, I researched in Delay Tolerant Network and successfully introduced a scalable and adaptive routing scheme.

1.4 Routing

Routing is the fundamental issue in DTN environment to disseminate the message more efficiently[23][9][24][20][25][26] [27] [28] [2] [29] [30]. In DTNs, upon receiving a message, DTN nodes seems hard to find the next intermediate node to forward a message. Therefore, the node is capable to store a message in its local buffer and forward it when it finds the appropriate node. Figure 1.4 demonstrates time evolving DTN in which no end-to-end path exists between a source node (S) and a destination node (D). When a node wants to send message to an other node which is not in its neighbors. A message can be forwarded to the next relay node which may carry a message and passed it to the next intermediate node. This process will continue till the message reached to the destination. At time t0, the source node generates a message destined for node D. Furthermore, a message can not be sent to the destination node directly as there is no end-to-end path exists between source node and destination node. Therefore, source node attempts to contact with

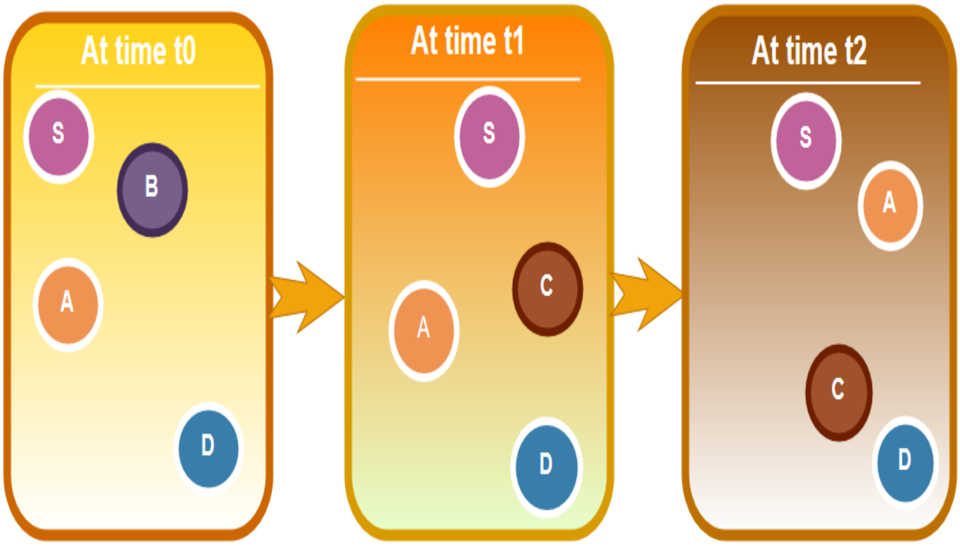


FIGURE 1.4: Time evolving DTN

both nodes A and B as both are in the radio range of source node. Source node forwards message to node A based on some criteria, which stores the message in its buffer. At time t1 (t1 > t0), A enters in radio range of node C, A will forward packet to C. Node C store the received packet in its buffer and at time t2 (t2 > t1), C will enter into direct communication range of destination node and hence, node C will successfully delivers the message to destination node.

However, selection of a most suitable relay node and when to transmit a message is still a challenge. Inspite of location, speed and other attributes, social ties and behavior [31] [32] [33] among nodes tend to be more stable over time which are more helpful in identifying the most appropriate relay node. To address these issues, there is need to have a plenty of information about the dynamic network (i.e. location information, encounter information and traffic information) and network knowledge (i.e; social relation among nodes) to support diverse range of applications in various extreme environments. Considering different opportunities, a number of routing protocols have been proposed in literature that consider different metrics to find the most influential node to disseminate the message.

The existing routing protocols (i.e.; GPSR [34], AODV [35] etc.) have been developed to deal with above-mentioned situations. However, recent research has proved that social relations among nodes become stable after certain period which showed better delivery of packets in DTNs. Figure 1.5 represents the taxonomy of the DTN routing protocols.

In disaster scenarios, where intermittent connectivity is observed and other means of communication are unavailable [36][37], the provisioning of wireless adhoc [18] [38]networks also called as DTNs is required on urgent basis. The characteristics of DTNs ensure the probability of message delivery using store-carry-forward mechanism in disconnected networks. The fundamental challenge in these types of networks is routing. Moreover, the probability of message delivery in DTN network is based on the availability and selection of opportunistic intermediate node which itself is a challenge [17][39]. Due to above-mentioned reasons, we are proposing a Socially-Aware Adaptive DTN Routing Protocol (SAAD) to deal with the above-mentioned challenges in DTN environments.

Moreover, in some DTN scenario, messages which need to be forwarded can be urgent or general message. Therefore, the proposed routing protocol forwards message adaptively according to the nature of message.

1.4.1 Research Problem

Network partitioning and node disconnectivity results in high latency and frequent link disruption in DTNs. Several DTN routing schemes have been introduced in this regard. However, these DTN routing protocols do not use some of available social attribute to identify a n influential forwarder node in DTN environment and produced results at the expense of over utilization of network resources (i.e. buffer, bandwidth etc.). The existing DTN routing schemes deliver messages to the desired destination node by exploiting high network resources. In recent times, social attribute-based routing protocols have shown better results as compare to those routing schemes which used attributes like distance, location etc. The existing routing schemes do not use some of available social attributes. Considering the importance of social attributes (i.e.; Degree Centrality, Random Walk, Social Activeness etc.), we are interested to contribute in DTN routing domain to further improve the performance of DTN. Therefore, there is a need to introduce a DTN

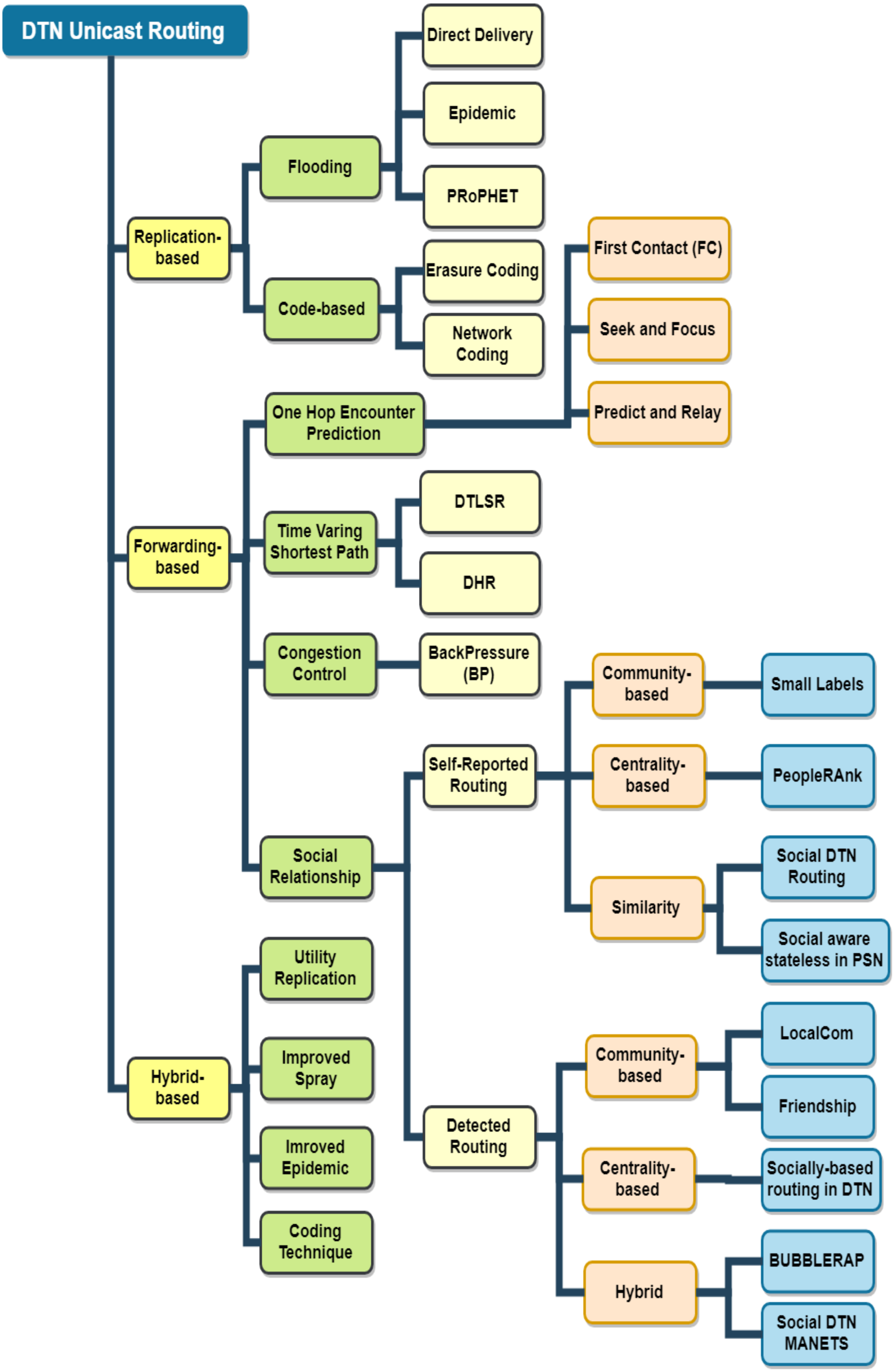


Figure 1.5: Taxonomy of DTN Routing Protocol

routing scheme either using a single social attribute or combination of social attributes which not only improves the message delivery ratio but also uses low resources.

1.5 Research Objectives and Significance

The proposed approach aims to disseminate data efficiently with improved packet delivery ratio, overhead, hop-count and reduced end-to-end delay in infrastructure-less DTN environment. The proposed algorithm is designed to identify the appropriate social metrics for routing messages in DTN environment. This also aims to improve the performance of DTN routing through social-aware adaptiveness (while considering the significant social-aware routing metrics) and to find the most appropriate relay node for message dissemination based on social metrics.

1.6 Research Questions

In order to resolve the above-mentioned problem statement, we devised the following research questions.

1. Which of the social routing metric is more suitable for DTN routing?
2. How Social-Aware adaptiveness improves the performance of DTN routing?
3. How aggregation of significant social routing metrics improves the performance in terms of packet delivery ratio?

1.7 Research Contribution

1.7.1 Socially-Aware Adaptive DTN Routing Protocol (SAAD)

In proposed routing schemes, Socially-Aware Adaptive DTN (SAAD) routing protocol, exploits social attributes known as Degree Centrality, Random Walk

Encounter and Social Activeness. Two of the social are already used in DTN routing while keeping in mind the random movement in DTN routing, we introduced a new social metric Random Walk Encounter (RWE) which is calculated by each node during its walk during a simulation.

In first routing scheme, we used Degree Centrality to calculate the popular node in the network as a forwarder node. In this routing scheme, each node calculates and shares its Degree Centrality with other nodes whenever a node joins a network. A forwarder/source node selects the nodes possessing Degree Centrality more than the set criteria and then forwards message to all shortlisted nodes. The same technique for forwarding message is repeated till the message (s) reached to the desired destination.

To evaluate the performance of SAAD, number of simulations have been performed while taking into account disaster scenario. We used ONE (Opportunistic Network Environment) simulator and Random Waypoint mobility model for our proposed routing scheme. We also examine the impact of changing number of nodes on the delivery ratio, overhead and latency. keeping in mind the simulation results taken in literature, we also run five simulations each time and then calculate the average value as a final value which is later used in selecting the forwarder node to disseminate the message towards the destination node.

In this scalable routing scheme, we increase the number of nodes and run the simulations using different scenarios (i.e.; node-50 scenario, node-100 scenario, node-150 scenario). We keep all the parameter values same as used for SAAD except number of nodes. This scheme exploits the same social attribute known as Degree Centrality.

To evaluate the performance of this scalable routing technique, number of simulations have been performed while taking into account disaster scenario. We also simulated our proposed routing scheme "Socially-aware Adaptive DTN routing protocol" with Random Walk Encounter and Social Activeness. The simulation results demonstrate that routing scheme with Random Walk Encounter produced better results than routing schemes with Degree Centrality and Social Activeness.

1.7.2 Socially-Aware Adaptive Routing Protocol (SR-SAAD)

Socially-Aware Adaptive Routing Protocol, exploits social attributes known as Degree Centrality, Social Activeness and Random Walk. In this scheme, each node calculates its Social Rank (SR) based on three social attributes and shares its SR with other nodes at regular intervals. A forwarder node disseminates message to the most influential node possessing highest SR value. To evaluate the performance of SR-SAAD, number of simulations have been performed while taking into account disaster scenario. To evaluate the performance of SR-SAAD, We used ONE (Opportunistic Network Environment) simulator and Random Waypoint mobility model along with other set parameters. To further check the scalability of SR-SAAD, we use a technique which uses the same attributes (i.e.; Degree Centrality, Social Activeness and Random Walk Encounter) but in this routing technique, each node calculate its Social Rank (SR) by combining the attribute score of all three social attributes and share its Social Rank with neighboring nodes at regular intervals. A forwarder node forwards message to the most influential node possessing highest SR value. To evaluate the performance, number of simulations have been performed while taking into account disaster scenario. To evaluate the performance of SAAD-SR, We used ONE (Opportunistic Network Environment) simulator and Random Waypoint mobility model along with other set parameters.

1.8 Organization of the Thesis

The rest of the thesis is organized as follows:
Chapter 2 - Literature Review:
This chapter explained the existing protocols related to our research areas; it explained routing protocols based on replication and forwarding strategy. Then, it shows the most relevant social metric-based research protocols implemented in DTN.

Chapter 3 - Proposed routing scheme (SAAD)
This chapter discusses the methodology of our proposed routing scheme. This chapter covers the flow operation of SAAD, details the algorithms associated with

the proposed strategies to implement routing scheme. This also covers proposed routing scheme using MADM. This chapter also covers the detail of simulation setup which includes the simulator, use of mobility model, interface, speed of nodes, warm up time, transmission range, transmission speed etc.

Chapter 4 - Experimental setup:
This chapter elaborates the establishment of the scenario in which routing schemes are run to evaluate their performance. To evaluate the performance of SAAD, We used ONE (Opportunistic Network Environment) simulator, Random Waypoint model and set values for different parameters.

Chapter 5 - Results and Discussion:
This chapter presents, in detail, the simulation results in form of graphs along with their detailed description. The simulation results are compared with three existing routing schemes Epidemic, PRoPHET and PRoPHETv2. The results are evaluated in terms of packet delivery ratio, overhead, hop-count and Average end-to-end delay.

Chapter 6 - Conclusion and Future Work:
Finally, this chapter concludes this thesis by discussing its major contributions, its main limitations, and well as a selection of future research directions.

Chapter 2

Literature Review

2.1 Overview

In this chapter, we have explained the working principle, classification and associated shortcomings of different state-of-the-art DTN routing protocols. Considering distinct characteristics of dynamic environment (i.e., network partitioning, high mobility, dynamic topology changes, etc.), a number of routing metrics (either individual or in combination) have been exploited to enable efficient route finding in DTN. Section 2.1 provides the basic principles and taxonomy of DTN routing. Section 2.2 presents the Principle of DTN Routing. Section 2.2.1 describes replication-based DTN routing protocols and shows their comparative summary. Section 2.2.2 includes the working details of various state-of-the-arts proposed Forwarding-based DTN routing protocols belong to each class. Section 2.2.3 presents details about the hybrid-based DTN routing protocols.

2.2 Principle and Taxonomy of DTN Routing Protocols

The fundamental principle of DTN routing is based on store-carry-forward paradigm in an opportunistic way as already explained in Chapter 1. Data dissemination is one of the main challenge in highly dynamic and intermittently connected environment as in DTN. In these scenarios, a message is delivered either directly or using an intermediate potential node to its unique destination. Recently many routing protocols [17][40][21][41][42][29] [43] [44][45]utilize social relations among nodes to determine when and where to forward messages. These protocols are commonly known as socially-aware routing protocols.

In DTN routing, the relay node is selected based on some criteria either distance, location or some social- based metrics etc. Each node in DTN is responsible to calculate metrics value based on distance, location or social ties between nodes. Moreover, nodes in DTN exchange these metric values with each other on encounter. In order to forward message towards the destination node, forwarder nodes will be selected whose metric value is above than defined threshold value [46]. This approach will be continued till the message received by the destination node. In DTNs, three approaches are mostly followed to design routing protocols. Firstly, a flooding technique named as "Naive Replication" in which multiple copies are sent to all encountered nodes. The second approach is named as "Utility Forwarding", in which a message is sent to other nodes based on some criteria to achieve an efficient forwarding. The third approach named as "Hybrid" is utilized by many researchers to take benefit of both the above-mentioned approaches.

2.2.1 Naive Replication-based Routing

Replication-based algorithms are designed based on flooding with and without coding technique. In flooding strategy [2][22], a source node sends copies of a message to all encountered nodes which ensures the successful delivery of a message to the destination. A comparative study and overall performance of flooding-based routing protocols can be viewed in Table 2.1 which presents that the delivery ratio increases at the cost of latency. Therefore, it can be concluded that flooding is reliable but not the fairest one. However, there are certain issues associated with the flooding strategy, are mentioned below in Table2.1. The large number of copies needs to generate for a single message which consumes more bandwidth and other network resources. The second issue related to replication is that the number of copies of a message to be transmitted to a node upon each contact opportunity.

The examples of flooding strategies are Direct Delivery, Two-Hop Relay, Epidemic, Spray and Wait etc. Moreover, to compensate the shortcomings of DTN routing protocol, coding-based algorithms are designed e.g. erasure coding-based routing protocol, network coding-based routing protocol etc. In Erasure coding, only source node split and encode the entire message into smaller chunks and the receiving node, decode the encrypted message upon receiving a portion of the sent message. In Network coding, transmitted data is ciphered and deciphered to enhance the performance in terms of latency and throughput. Brief description of few replication-based routing protocols is given below.

M. Grossglauser and D. Tse presented the Direct Delivery (DD) [40] routing technique in which a source node keeps the message in its custody till it encounters with the destination node and delivers the message directly. In Two-Hop-Relay routing [46], a source node transmits a message to neighboring N nodes, which keep the message in their custody until they come in contact with the destination node and deliver the message directly which reduces delay to some extent.

In [22], Vahdat and Becker proposed Epidemic Routing to reduce delay and to increase packet delivery ratio. Pair-wise messages are exchanged to deliver a message where no end-to-end path exists between source and destination. In this technique, when a node encounters any other node, it forwards its summary vector to the neighboring nodes. The neighboring nodes then request the source node to forward only those messages which they don't already possess in their buffer. Then the sender node transmits the messages requested by the receiving node. Each intermediate node will follow the same procedure till the message is received by the destination node. Simulation results showed high message delivery at the cost of consuming large network resources (i.e., bandwidth, buffer and power).

Moreover, Spray and Wait [39] technique combines the speed of Epidemic routing in a simplest form and thriftiness of direct transmission. In this routing scheme, the message is delivered in two phases. Firstly, half of the copies of the message are sent to entire network and half remained in the custody of forwarder node and wait till one of that node interacts with the destination node. This process continue till sender node left with only one copy, which it delivers to the destination in a direct mode. Experiment-based results demonstrate that Spray and Wait scheme performs better than all existing schemes in terms of number of transmissions and latency.

The routing scheme [47] for DTN, is actually a modified form of existing Spray and Wait. The core objective of this technique is to improve the performance of DTN by making a slight change in the existing approach. In existing approach, when a node encounters another node, it transfer half copies to the node and keep half of the copies with itself. While in this routing technique, we forwarded 70% and 80% of the copies to the encountered node. Therefore, more number of copies are sprayed in the entire network which will increase the more probability to deliver a message.

The procedure of forwarding 70% or 80 % copies of each message to the neighboring nodes continues till that node holds only a single copy which will be delivered directly to the destination node. The overall performance of the existing DTN routingschemes is evaluated using the evaluation parameters delivery ratio overhead ratio etc. The simulation results in high delivery probability with less no of copies and save buffer memory. Brief comparison summary of replication-based DTN routing protocols are mentioned in Table 2.1.

2.2.2 Criteria-based Forwarding Strategy

In Utility Forwarding strategy, a message is sent from a source node to the destination node based on the network knowledge [11]. In this strategy, the main challenge is to find the appropriate next hop for data dissemination based on some metrics, which may also benefit from social attributes. The examples of forwarding-based

Table 2.1: Summary of Forwarding Strategy-based DTN routing protocols

Approach	Forwarding Strategy	Strengths	Weaknesses
Direct Contact [40]	Source to Destination	Low buffer usage, Low bandwidth usage	Low delivery ratio, High latency
Two-Hop Relay [46]	Partial replication	Better buffer and bandwidth utilization than Direct Contact	High latency
Epidemic [22]	Flooding	Efficient message delivery	High resource consumption, High overhead
Spray and Wait [39]	Copies (50%)to encountered nodes	Reduced no. of transmissions, Reduce delay, Scalable	High delay, Random movement, Utilize high bandwidth and network resources
Adaptive Spray [47]	70% and 80% per copies to nodes	High delivery probability with less no of message copies, require less memory	Utilize high bandwidth and network resources

routing are One Hop Encounter Prediction-based routing (i.e. First Contact, Seek and Focus, MOVE, PER etc.), Time Varying Shortest Path-based routing (i.e. Delay Tolerant Link State Routing and DTN Hierarchical Routing), Congestion Control-based routing (i.e. Backpressure[48]), Social relationship-based routing (i.e. SimBet, BubbleRap etc.). Now, we discuss some of the utility forwarding-based routing schemes available in the literature.

In One Hop Encounter Prediction-based routing, the messages are forwarded to only one hop node based on prediction. First Contact, Seek and Focus and Motion Vector are considered as One Hop Encounter Prediction-based routing. In First Contact (FC), a source node forwards a message to the first encountered node. FC is regarded as one-hop encounter prediction-based algorithm in which a message is forwarded to the destination node via a set of relaying nodes. However, Seek and Focus exploited random forwarding in seek phase and utility forwarding in focus phase considering the latest interaction time. Motion Vector, in addition to consider distance, utilizes the moving direction to calculate a new metric (geometry) value to forward a message to filter the selection process of appropriate relay node.

In Time Varying Shortest Path Based routing protocols, messages are relayed to the shortest path with respect to time. Delay Tolerant Link State Routing (DTLSR) [30] constructs a path from source to the destination with respect to time based on minimum estimated expected delay. DTLSR considers that encountered nodes are also capable of being members of the selected path. Another Time Varying algorithm is DTN Hierarchical Routing (DHR) [16], which considers hierarchical routing in a scenario in which nodes are in stationary mode as well as in mobility mode. The limitation of this approach is to manage a plenty of time varying information.

In Congestion Control, messages are transmitted keeping in mind the network load. In end-to-end connectivity based environment, routing protocols exchange the acknowledgements. Therefore, messages can be successfully received in time but it is hard to control the traffic in dynamic or hop-by-hop environment. Moreover, in order to increase the throughput, one of the congestion control-based routing protocols, e.g. BackPressure (BP) [48] made the routing decisions independently by calculating BP weight, based on link state information and local queue size. Brief comparison summary of Forwarding-based DTN routing protocols are mentioned in Table 2.2.

Despite appealing interests (i.e., location information, traffic information, moving direction, trajectory-based information), currently, DTN routing protocols prefers to exploit social-network information to find more appropriate forwarder nodes. One of the reasons is that social relationships are more stable than other measures. Therefore, in this work, we are interested to propose routing protocols that would utilize social relationships among mobile nodes within DTN. Before the discussions related to the proposal of our proposed protocol, we discuss the general principle of social-aware routing protocols, significance of different social measures, and

Table 2.2: Summary of Criteria-based DTN routing protocols

Approach	Forwarding Strategy	Strengths	Weaknesses
First Contact [19]	Routing loop	Node does not accept the already possessed message	Low scalable
Seek and Focus[19]	Random forwarding and utility forwarding	Reduce time for messages to get stuck	Low scalable
DTLSR [30]	Constructed path with respect to time	System operates effectively	Long delays
DHR [16]	Hierarchical routing	Improve delay and hop-count	Manage time varying information
BackPressure [48]	BP weight	Increase the throughput, improves the energy consumption	Low delivery ratio

available state-of-the-art Social-Aware routing protocols.

2.2.3 Principle of Social-Aware DTN Routing

In Social-Aware DTN routing, social relationships between nodes are exploited to deal with the problems related to the selection of suitable forwarder node to enroute packets from source to destination within a DTN network. In social-aware DTN routing, each node calculates social measures (i.e., centrality, similarity, etc.) based on social ties and behaviors between nodes which tend to be more stable over a time[49]. Each node in social-aware DTN network exchanges these social values with each other whenever they encounter.

In order to forward message towards the destination node, those forwarder nodes will be selected whose social value is above certain threshold [41][50]. This approach will be continued till the message received by the destination node. However, the basic challenge associated with these approaches is to calculate different centrality and similarity measures locally. Socially-aware DTN routing is based either on Self-reported Routing or Detected Routing.

In Self-reported social-aware routing, the details about social relationships between the encountered nodes are collected off line (using questionnaire) and online from different social networks such as Facebook, Twitter, and Google Plus etc. The social relations among the nodes are collected explicitly using a web crawler called as Spider which automatically go through the web pages and extract the relevant links. The limitation of crawling technique is that some online social networks do not allow to collect personal data at a large scale due to privacy. On the other hand, in Detected social-aware routing, information about the social ties among the nodes are collected implicitly through mobility traces, call records, location-based services etc.

In Socially-aware environment, each node is able to dynamically calculate and shares social metric value (i.e., Degree Centrality, Social Activeness, Interest, Friendship etc.). On the basis of calculated social value, the sender node selects appropriate next hops or forwarders, whose social value is higher than the defined thresh- old value in the network. Details regarding associated detected approach (with centrality-based, similarity-based and hybrid approach) for DTN routing are provided next.

2.2.4 Centrality-based Social-Aware Routing

In Centrality-based routing, each node shares its own calculated centrality (i.e., Degree Centrality). On the basis of shared calculated centrality, the sender/intermediate node selects next hops whose centrality is higher than the other nodes in a social network. Details regarding associated protocols with centrality-based routing are provided next.

In Peoplerank [46], social relationship is used to assign rank to the nodes. Whenever two nodes encounter in a social network, they share two types of information with each other, i.e. own Peoplerank value and their neighbor's People rank value. A node which is socially connected with other high ranked nodes in a network is considered as high Peoplerank node. Messages are propagated from a low Peoplerank node to high Peoplerank node till the message reaches to the destination. It has been evaluated that Peoplerank algorithm achieves successful delivery rate close to the epidemic and reduced up to 50% retransmissions.

In a socially-based routing protocol for delay tolerant networks [51], a social-based routing scheme is used to solve limited storage space and power issues. Traditional routing protocols are failed to route a message in such intermittent networks where no end-to-end path exists. So, DTN routing protocol is required for such environment. Simple DTN routing protocols flood multiple copies of messages to increase the probability to reach a message on destination which utilize more system resources e.g. bandwidth, power, buffer etc.

This routing scheme exploits social criteria to select a relay node to decrease the no of copies and retransmissions. When the nodes interact with each other, they update degree of connectivity and exchange data packets which they don't possess in their buffer. The simulation results demonstrate that this routing technique significantly reduces number of transmissions which saves network resources while maintaining same or high delivery ratio.

Borrego et al. [52] introduced a new technique to deliver messages to high influential node. Influential node is considered as high central node possessing special characteristics e.g. high reputation, truthfulness, and credibility. The proposed technique uses optimal stopping statistics to choose high ranked central node among neighboring nodes. However, in an opportunistic network, choosing a most appropriate node is still a challenging task. Especially in an emergency situation, trustful information needs to be conveyed to the victim community. An influential node is calculated based on physical interaction also known as electronic centrality and virtual interaction also known as virtual centrality (i.e; messages exchanged between nodes).

A message is delivered in two phases, explore phase and wait phase. In explore phase, a messages is sent from one node to another node during this phase, only a node which receives maximum value for virtual centrality is kept in the message but message is not delivered. In wait phase, the message is delivered to the first node which is more suitable node than others in terms of virtual centrality. Our technique proves better results than the state of the art routing protocols in terms of latency, delivery ratio and overhead.

In EpSoc [41], authors introduced a hybrid approach which uses the flooding strategy and utilizes a significant social feature called degree centrality. EpSoc exploits two approaches to increase the performance of a routing in the opportunistic mobile social network (OMSN). Firstly, the TTL value of a message is adjusted according to the degree centrality of nodes, and the replication is controlled using blocking mechanism. Simulation results demonstrate that EpSoc enhances the delivery ratio, reduces the overhead ratio, average latency and hop counts as compared to Epidemic and Bubble Rap.

2.2.5 Similarity-based Social Routing

In [53], Matthias proposed a Social-based Relaying Strategy (SRS) where social metrics information is utilized to select a suitable forwarder node. SRS exploits Localized Clustering Co-efficient (LCC) and lobby index to target the most active node having high degree of centrality in order to increase the coverage of Service Channel (SCH). Author proposed to distribute the load fairly on service channels to maximize the throughput in highly mobile multi-channel network. To achieve this objective, author proposed an adaptive multi-channel (AMC) allocation algorithm based on space and time. A node having high lobby index value has more potential to find the central node and the nodes on the border of sub graphs. For each area, the best relay nodes are selected to rebroadcast the SCH state lists between neighbors. Simulation results using NS-3 demonstrate that Multi-channel social based routing outperforms GPSR-MA in terms of network throughput.

Li and Wu [54]exploit similarity properties to illustrate the relationship between neighboring pair of nodes using temporal and spatial information. This local information is used to form the community having strong intra community connections and controllable diameter. A node computes the average separation period of the encountered neighboring nodes using length and frequency to depict the closeness in the relationship. Shorter average separation duration represents a stronger relationship. A gateway, a node that has at least one edge in the neighboring graph is exploited for inter community packet forwarding. Authors also presented two fold schemes: 1) select the gateways 2) prune them to connect communities to reduce redundancy and support inter-community packet forwarding. The tradeoff between packet delivery ratio, latency and redundancy can be obtained by setting suitable pruning criteria.

[55] proposed an improved Spray and Wait routing technique in DTN which is using social attributes of a node. This routing technique messages by considering the following factors in mind. Firstly, in Spray stage, messages are relayed between two nodes dynamically and keep the record of social relationship between a node and its circle nodes. Secondly, they used non-social of a node which is basically a nodes's activity and its delivery predictability. Finally, copies of messages are sent to a node which has the better ability to deliver by using the the proportion of both spcial and non-social value. The simulation results demonstrate that the proposed routing technique increase the delivery rate with low overhead as compared to Direct Delivery, Epidemic, PRoPHET and Spray and Wait.

In Friendship [17], authors are convinced that friends are far better choice to select a forwarder node. Therefore, they suggested a new attribute known as Social Pressure Metric (SPM), which is used to measure direct friendship based on node's history. In this technique (SPM), the link qualities between nodes are supposed to be analyzed accurately. Three sub social metrics (i.e., encounter frequency, longevity and regularity) are exploited to analyze and compute a route to transmit a message towards the destined node.

In [56], authors are motivated to use different physical attributes of mobile nodes and their positional attributes using node's TTL value and routing hops. The main objective of the routing technique is to increase the delivery rate of messages by keeping a balance between overhead and hop-count. This technique forwards the message based on the predicted path which is calculated using parameters like bandwidth, nodes buffer, power etc. They also consider other factors like transmission range, distance between a source and destination, TTL value of a message etc. The simulation results show that the proposed routing technique maintains high delivery probability while balancing overhead ratio and average hop count.

They also proposed Conditional Social Pressure Metric (CSPM) value of its friends to find indirect friendship relationship. Once a node constructed its friendship community at a given interval, the message is transmitted using a forwarder node which must be a part of the friendship community of the destination node. The results demonstrated that the proposed scheme provides better delivery but at the cost of community formation overhead.

2.2.6 Hybrid-based Social Routing

In hybrid-based social routing, researchers exploited different combinations of centrality measures with different similar social metrics proposed to form the community. The rapid increase in exploiting smart devices with numerous networking functionalities opens the door to transmit data packets in an ad hoc manner. Previous methods relied on building and updating routing tables to cope with dynamic network conditions. While social information which is considered as more stable over a time, has become an key metric for developing forwarding algorithms for adhoc-based networks. Details of some hybrid-based socially-aware routing protocols are as under.

In Bubble Rap algorithm [50], two social metrics (i.e.; centrality and community) are used to select the most influential relay node which enhances delivery performance. Community value is calculated using both methods, K- clique and Weighted

Network Analysis (WNA). Although WNA directly computes weighted graphs without threshold but unable to find overlapping communities. On the other hand, K-clique is designed for binary graphs and has the capability to detect overlapped communities using threshold value of the edges of the contacts used in mobility traces. Betweenness centrality is calculated of the people in the entire network.

The proposed algorithm works in two fold. First, we develop and evaluate the proposed routing protocol, which uses the community and centrality attributes to improve delivery performance. Secondly, we show that BUBBLE can also improve forwarding performance as compare to existing algorithms including social-based forwarding SimBet algorithm and PROPHET algorithm. Simulation results show that it has similar delivery ratio to, but much lower resource utilization than flooding, control flooding, PROPHET, and SimBet.

In SimBet Routing [31], two social attributes (i.e.; betweenness centrality and similarity) are exploited to find a forwarder node. In this routing technique, if the destination node is unknown to the sending node or intermediate nodes, the message is routed to a more central node. Simulations using real trace data showed delivery performance close to Epidemic Routing but with reduced overhead. Additionally, SimBet routing outperforms PRoPHET routing, particularly when the sending and receiving nodes have low connectivity.

In Socially-aware Routing Protocol based on Fuzzy Logic (FCSA) [40], the authors exploited three social features (i.e. Similarity, Activeness and Centrality) to find the high priority neighboring node as a next-hop. Each node calculates the priority of its neighbor node using Fuzzy logic instead of utility function. The numeric value of these three social metrics (i.e. Centrality, Similarity and Activeness) is converted into fuzzy value to calculate the priority of its neighbor node. FCSA improved delivery ratio and reduce end-to-end delay than the existing routing protocols but they use social attributes partially only on intersections.

In Figure 2.1,the numeric value of these three social metrics (Centrality, Similarity and Activeness) is converted into fuzzy value using fuzzy membership function.

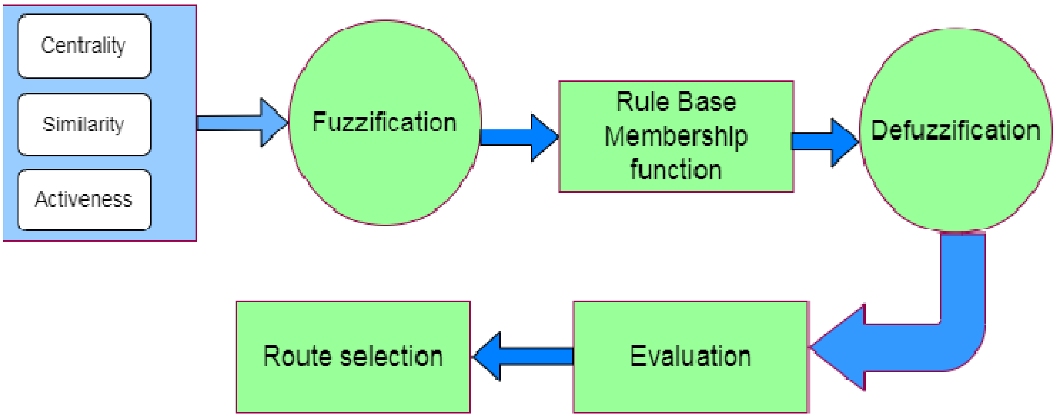


FIGURE 2.1: Fuzzy logic approach to find next forwarder node

The membership function uses rule base to find the node priority by exploiting different combinations of rank variables i.e., low, middle and high. Finally, output of the membership function (fuzzy value) is again converted back to numeric value us- ing centroid method. FCSA improved a delivery ratio and reduce end-to-end delay than the existing routing protocols.

In Social Acquaintance-based Routing Protocol (SARP) [57], the global and local community acquaintance of nodes are considered to overcome the shortcomings of conventional routing protocols. SARP calculates the priority value of a node by combining all three social attributes (i.e. social acquaintance, social activeness, and degree centrality). However, members having global knowledge of community are far better in intercommunity communication. For message dissemination, an intermediate node is selected based on local and global knowledge of a community member. Secondly, along with community acquaintance, a member's activeness and similarity will also be considered.

However, members having global knowledge of community are far better in inter-community communication. For message dissemination, an intermediate node is selected based on local and global knowledge/experience of a community member as shown in Figure 2.2. Secondly, along with community acquaintance, a members activeness and similarity will also be considered. SARP not only uses three social metrics (i.e., Community Acquaintance, Centrality and Activeness) but also considers the historical values for decision making to find the next hop as a relay

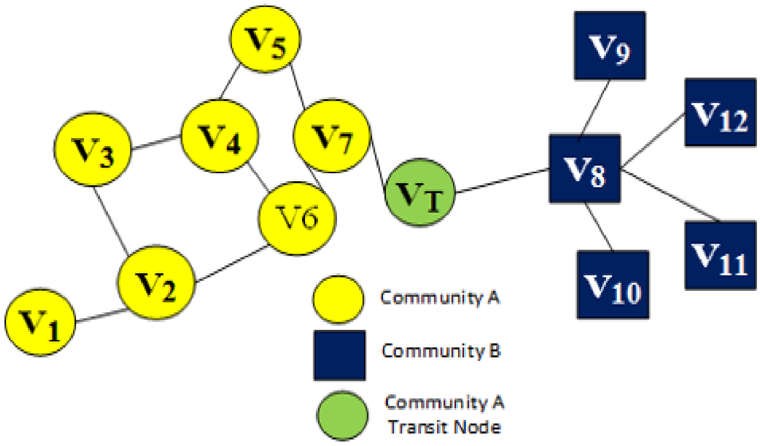


FIGURE 2.2: Community Acquaintance

node which makes it more flexible and reliable. The performance of the SARP is compared with two traditional routing protocols i.e., AODV and GPSR and outperforms the both protocols in terms of Packet Delivery Ratio and end-to-end delay.

Chang et al. [58] proposed a Socially-Aware Trajectory-based Routing (SATR) protocol which analyzes node trajectories and social relationships at different time intervals. This protocol designs two graphs to improve the performance of packet forwarding. At first, it designs the node encounter graph and then based on this node encounter graph; construct the packet relay path graph. SATR splits a day into several time intervals and to deduce their social relationship, constructs node encounter graph by analyzing moving trajectories of nodes in the past. SATR can predict future locations to encounter nodes by comparing node encounter graph.

SATR calculates popularity values of all locations based on trajectory information. In contrast, throw box is deployed on the public location having high popularity. Throw-boxes are deployed on populated intersections having high popularity as shown in Figure 2.3 which increases number of routes to forward a packet, increase delivery ratio and reduce forwarding delay.

The summary of social metrics-based DTN routing protocols are mentioned in Table 2.3.

Table 2.3: Summary of social metrics-based routing protocols

Approach	Social Ties	Forward Strategy	Simulation results
PeopleRank [46]	Centrality	High Ranked Node	Reduce 50% message retransmissions
Hey! Influencer [52]	Virtual Centrality and Electronic Centrality	Explored phase and Wait phase	Improved delivery ratio and Latency
Socially-based DTN [51]	Degree of connectivity	High degree of connectivity	Improve delivery ratio Reduce no of transmissions
SUDS [10]	Zone-based forwarder V2V or V2I	Better data dissemination. Zone formation overhead	
Friendship [17]	Friendship based community	Direct friend or indirect friend	Better delivery rate
SimBet [31]	Egocentric Betweenness and Similarity	Forwards to more central node	Delivery performance is close to Epidemic with low overhead
BubbleRap [50]	Centrality and Community	High centrality and community value	Minimum resource utilization
FCSA [40]	Degree centrality, Similarity, Activeness	Selection of High Priority node based on Fuzzy value	Reduce end-to-end delay and improve delivery ratio
SARP [55]	Community knowledge, Activeness, Degree Centrality	A node having high social probability	Improve delivery ratio and reduce cost

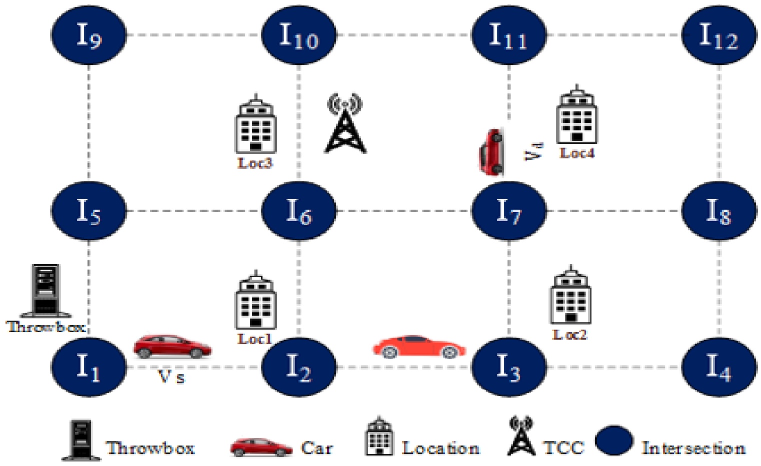


FIGURE 2.3: Social Vehicular Network Environments

The following routing protocols control the replication to a great extent by utilizing some criteria. Following are the brief details of the routing protocols with which we compare our simulation results.(i.e. PRoPHET and PRoPHETv2).

In [59], a bundle is forwarded by selecting an intermediate node based on criteria in contrast with Epidemic routing in which messages are flooded which consumes more network resources. The proposed routing protocol exploited delivery predictability (i.e.; history information of the encountered nodes) and the transitivity to select and forward bundles to the next hop regardless to the distance. Each node calculates its delivery predictability with its neighboring nodes. A node having high delivery predictability will be considered the most appropriate forwarder node.

In PRoPHET approach, data is disseminated into two phases. In first phase, the neighboring nodes sync their summary vector using a control packet and update their internal delivery predictability vector. In second phase, bundles are forwarded based on the information exchanged in first phase. Transitivity is also an important factor in selecting the forwarder node.A node having larger delivery predictability will be selected as an intermediate node to transmit data packets. Experimental results demonstrate that the pro- posed PRoPHET protocol has shown improvement in delivery ratio and latency.

In simple PRoPHET approach, an intermediate node is selected based on the de- livery predictability and transitivity. When a source node encountered more than one nodes having same value of delivery predictability located at different

Table 2.4: Criteria-based Comparison

Approach	Forwarding Strategy	Strengths	Weaknesses
PRoPHET [57]	History of node and transitivity	Lower overhead than Epidemic, Receives more messages	When two or more nodes with equal DP
DiPRoPHET [58]	Distance + History of node and transitivity	Better delivery ratio	Delivery ratio increase at the cost of high network resources utilization. Additional calculation of Distance
PRoPHETv2 [59]	History of node encounters and transitivity	High delivery ratio than PRoPHET	Low scalable, using only 18 nodes for simulation

positions, may result in high delay and low delivery ratio. In order to resolve this issue, Sok et al. [60] proposed a Distance-based routing protocol in DTN which utilizes a distance metric along with delivery predictability and transitivity.Each node maintained a distance table to keep the distance of the encountered nodes using shared registry. Whenever a node comes in the range of another node, they exchange distance information through a Hello message. Later, this distance information is used to calculate the delivery predictability.Simulation results proved that the modified PRoPHET protocol not only decreases delay but also increase the delivery ratio. In addition to these, DiPRoPHET can also determine the directions of encountered nodes which will help in reducing delay while routing.

PRoPHETv2 [61] is the updated version of the old PRoPHET in which minor modifications are made in the metric calculation. Based on evaluations of PRoPHET, we realized the need for the protocol to evolve to meet new challenges and improve its performance. The main objective of this routing scheme is to improve the performance of existing PRoPHET. They proposed an refined protocol as PRoPHETv2 and evaluate its performance against the original PRoPHET. Brief comparison summary of Hybrid-based DTN routing protocols are given below in Table 2.4.

Chapter 3

Proposed Methodology and Techniques

3.1 Overview

The objective of our proposed Socially-Aware Adaptive DTN (SAAD) routing protocol is to minimize the resource utilization and increase packet delivery in DTN by using the appropriate forwarder node. The proposed routing scheme exploits significant social attributes, (i.e., Degree Centrality, Random Walk Encounter and Social Activeness), to find the most popular and central node.

In recent few years, a number of social-aware routing protocols [42][29][10][51][47] [18][13][52]have been proposed to enhance the performance of different social networks in terms of maximizing the packet delivery ratio and to minimize overhead, hop-count and end-to-end delay. Considering the importance of social aspects connected with DTN in future, we are interested to contribute in DTN routing domain to achieve the following objectives:

1. To identify the more significant social metrics for routing in DTN
2. To improve the performance of DTN routing through social-aware adaptiveness (while considering the significant social-aware routing metric)

3. To select appropriate relay nodes for efficient message dissemination based on social metrics using Multiple Attributes Decision Making (MADM) approach.

3.1.1 Methodology to Find the Best Social Attribute

In order to find out the more significant social attribute (i.e., Degree Centrality, Random Walk Encounter and Social Activeness) within the context of DTN routing, we are intended to perform simulation-based analysis in an infrastructure-less scenario. We run the simulations with all above-mentioned social attributes. The simulation results demonstrate that a routing scheme using Random Walk Encounter produced better packet delivery ratio than a routing schemes using Degree Centrality and Social Activeness because a node having higher Random Walk Encounter value is proved to be more influential social node and results in higher packet delivery ratio. The flow diagram and algorithm can be seen on page 47 and 48 and the results can be seen on page 75.

3.1.2 Methodology to Know the Performance Improvement by Aggregation of All Three Social Attributes

To achieve second objective, we are intended to propose Socially-Aware Adaptive DTN (SAAD) routing technique that will address the application-oriented data dissemination problems in infrastructure-less scenario which ultimately improve the performance to a significant level in terms of maximizing packet delivery ratio and minimizing overhead, hop-count and end-to-end delay. Our proposed routing scheme will be able to disseminate the message adaptively keeping in mind the nature of the message. When an urgent message need to send, the proposed routing technique forwards message to all short listed nodes while if a message is normal then a message is sent to only one node possessing highest Degree Centrality to reduce overhead. The flow diagram and algorithm can be seen on page 50 and 51. The results can be seen on page 126.

3.1.3 Methodology to Know the Performance Improvement by Forwarding Messages Adaptively

To forward messages adaptively, we created 10% urgent messages and 90% normal messages. Urgent messages are broadcasted to all neighboring nodes sothat urgent messages must reach to all on immediate basis while a normal is disseminated based on unicast. Normal message is sent to a single node possessing highest SR value. The flow diagram and algorithm can be seen on page 50 and 51. The results can be seen on page 126.

Our proposed routing scheme will be able to disseminate the message adaptively keeping in mind the nature of the message. When an urgent message need to send, the proposed routing technique forwards message to all short listed nodes while if a message is normal then a message is send to only one node possessing highest Degree Centrality to reduce overhead. To understand the heterogeneous nature of social attributes in combination, we are intended to exploit different Centrality and Similarity based measures through MADM [62][63][64][65][66] approach to find the most appropriate forwarder to disseminate message in an efficient way. The proposed methodology is shown in Figure 3.1.

3.2 Phases Detail Involved in Proposed Research Operational Framework

Phase 1 Understanding of DTN Routing Principle

Phase 2 Taxonomy of DTN Routing

Phase 3 Problem Investigation

Phase 4 Description of Social Metrics

Phase 5 Design of Social-Aware Adaptive DTN (SAAD) Routing Technique

Phase 6 Performance Metrics

Phase 7 Simulation Setup and Evaluation

Phase 8 Results and Discussion

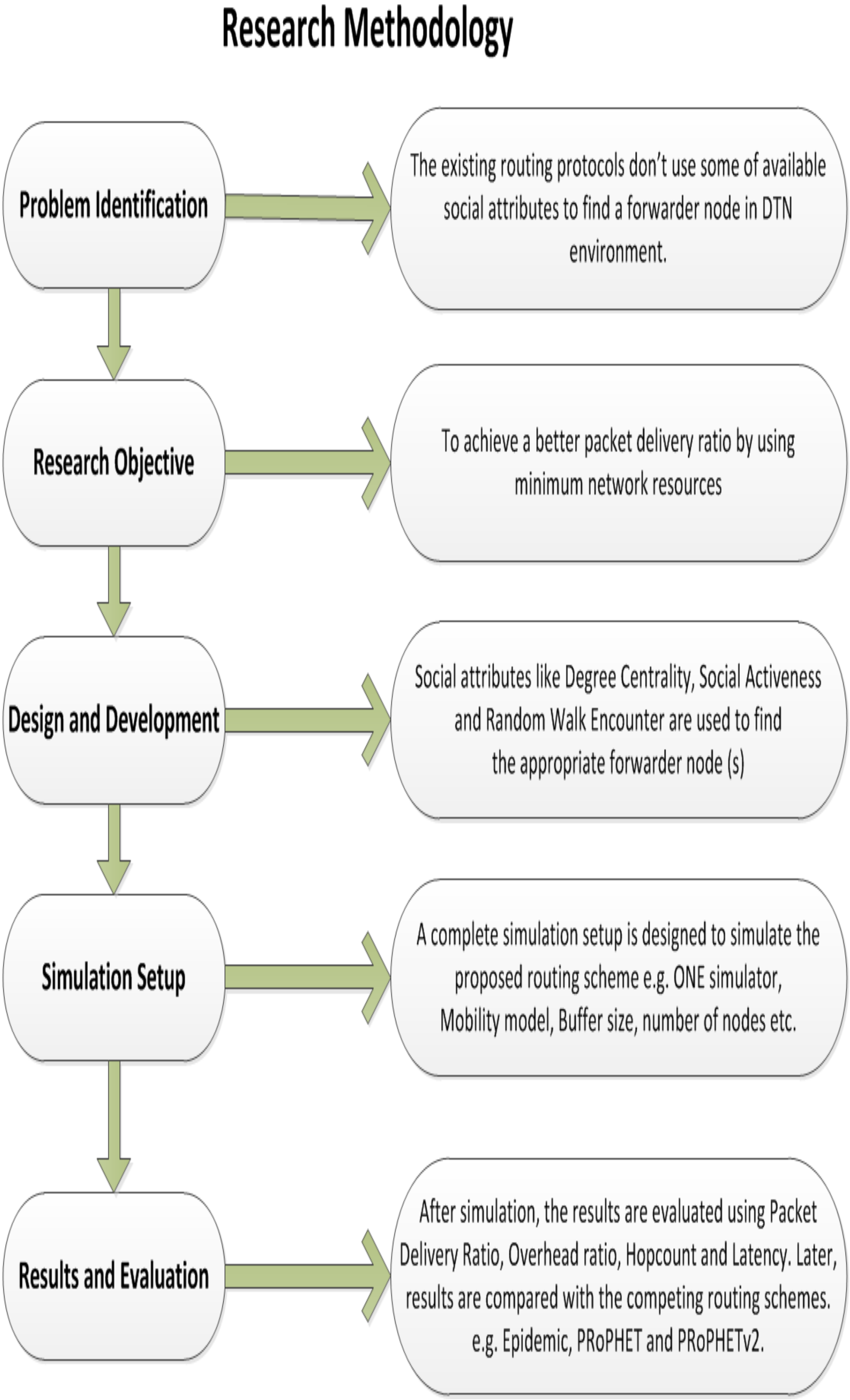


Figure 3.1: Research Methodology

3.2.1 DTN Routing Principles

The basic principle of DTN routing is based on store-carry-forward fashion in an opportunistic way. The details about the DTN routing principle is already discussed in Section 1.2.

3.2.2 Taxonomy of DTN Routing

The fundamental phenomenon of DTN routing (i.e., selection of appropriate relay nodes) is further classified into three categories i.e., Replication- based, Forwarding-based and Hybrid. The detailed taxonomy of DTN routing protocols is discussed in Section 2.2.

3.2.3 Problem Investigation

Although, the existing MANET routing protocols reduce end-to-end delay and improve packet delivery ratio but still these routing protocols are insufficient to route a message towards the destination in dynamic and intermittently connected environment. In recent years, few researchers have proposed DTN routing protocols using either a single social metric or combination of social metrics.

The existing approaches have used various ranking mechanisms to identify the suitable forwarder nodes to carry messages towards the intended destination.

Therefore, there is a need to devise a mechanism that can take advantages of maximum available ranking metrics in such a way that the selection of forwarder node becomes more appropriate and adaptive while considering the challenges of DTN scenarios (i.e., intermittent connectivity, decentralized control, selfishness etc.).

The routing-related social metrics (i.e., Degree Centrality, Random Walk , Social Activeness etc.), will be provided to MADM that ultimately provides the next-hop nodes rank.

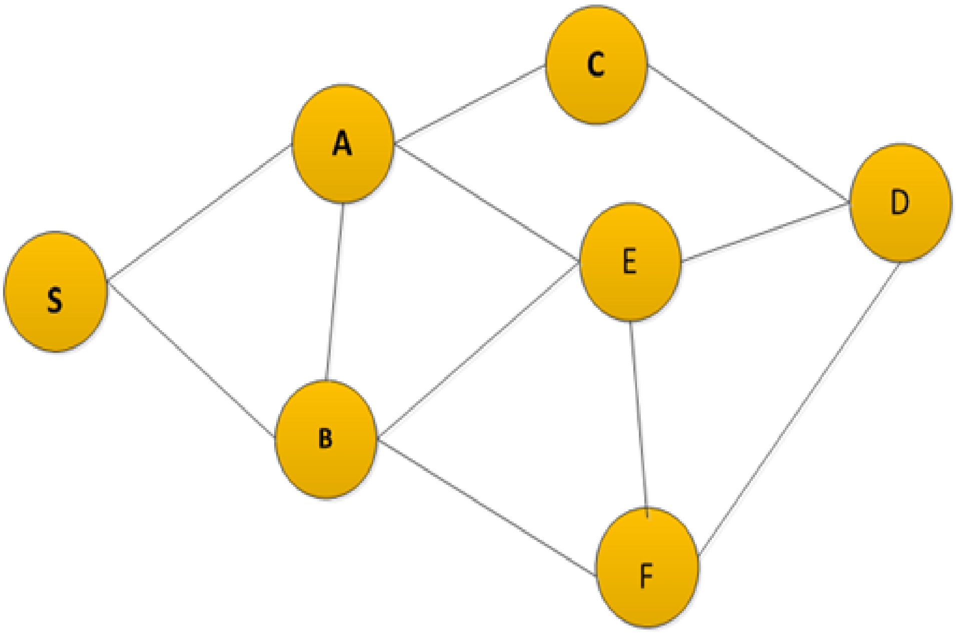


FIGURE 3.2: Degree Centrality

3.2.4 Description of Social Metrics

In designing of Socially-Aware DTN routing protocols, many researchers exploited the following social metrics either as individual or in combination of social metrics. Brief description of these social metrics is given below.

3.2.4.1 Degree Centrality

Degree Centrality [41] [67] [19][68] is calculated based on the direct links of a node in its transmission range as shown in Figure 3.2 and the score of the given Figure is shown in Table 3.1. A node having high Degree Centrality will be selected as more appropriate node to disseminate message towards the destination. Degree Centrality of the nodes is calculated using the following equation 3.1.

$$DC_i(t) = \sum_{j=1}^{N} (C_{ij}) \tag{3.1}$$

Where $C_{i,j} = 1$ means node$_i$ and node$_j$ have direct communication link with each other. Degree Centrality is also updated periodically.

TABLE 3.1: Degree Centrality Score

Parameters	**Value**
S	2
A	4
B	4
C	2
E	4
F	3
D	3

3.2.4.2 Random Walk Encounter (RWE)

Random walk Encounter (RWE) is calculated whenever a node encounters another node during a random walk. RWE value keeps on incrementing throughout the simulation time whenever a node encounters any other node in the network. This attribute calculates RWE value while nodes are continuously moving randomly in a specific bounded area [69][70]using the following equation 3.2.

$$RWE_i(t) = \sum_{j=1}^{N}(R_{ij}) \tag{3.2}$$

3.2.4.3 Social Activeness

The node which meets with more nodes frequently or with members of different communities will be considered as more active or high ranked node [40][57]. So, this active/high ranked node will be selected as a more influential forwarder node to transmit the message towards the destination. The following equation 3.3 calculates the Social Activeness of a node.

$$SA_n(t) = 1 - \frac{N(t - \triangle t) \cap N(t)}{N(t - \triangle t) \cup N(t)} \tag{3.3}$$

where N(t) denotes that node N at time t encounters the number of current neighbors and N(t -△ t) denotes the previous number of neighbors of node N at time t - △ t respectively. Value of △ t is variable, depends upon the current and previous value of t at which the SA value of n at time t is calculated using equation 3.3.

We modified the existing equation to calculate the Social Activeness of a node in a dynamic environment for the following reasons. When a node encounters the same set of nodes currently as it encountered previously, the existing formula id producing Social Activeness of that node = 0 even though it is encountering a set of nodes. Secondly if a node encounters a single new node even currently which was not encountered previously, the existing formula is producing Social Activeness of a node '1' even it encounters either a single new node or multiple new nodes. Therefore, we modified the existing formula by taking the 80% value of the existing formula and 20% of the new formula as described below in equation 3.4.

$$SA_n(t) = 80\% of 1 - \frac{N(t - \triangle t) \cap N(t)}{N(t - \triangle t) \cup N(t)} and 20\% of \frac{Number of current nodes}{total number of nodes} \tag{3.4}$$

Finally, we are also proposing a routing scheme which selects a forwarder node based on the Social Rank (SR) which is being calculated by combining the social attribute score of Degree Centrality, Random Walk Encounter and Social Activeness. First, we normalize the score of Degree Centrality and Random Walk Encounter using the following equation 3.5.

$$SA_n(t) = \frac{ownscore - minscore}{maxscore - minscore} \tag{3.5}$$

We also assign weights to all these social attributes based on the performance of individual score like RWE = 0.4, DC = 0.34 and SA = 0.26.. We see the results based on each social attribute then we also analysis manually the output of their score individually. A Social Rank of a node is calculated based on the following equation 3.6.

$$SR_i = DC_i + RWE_i + SA_i \tag{3.6}$$

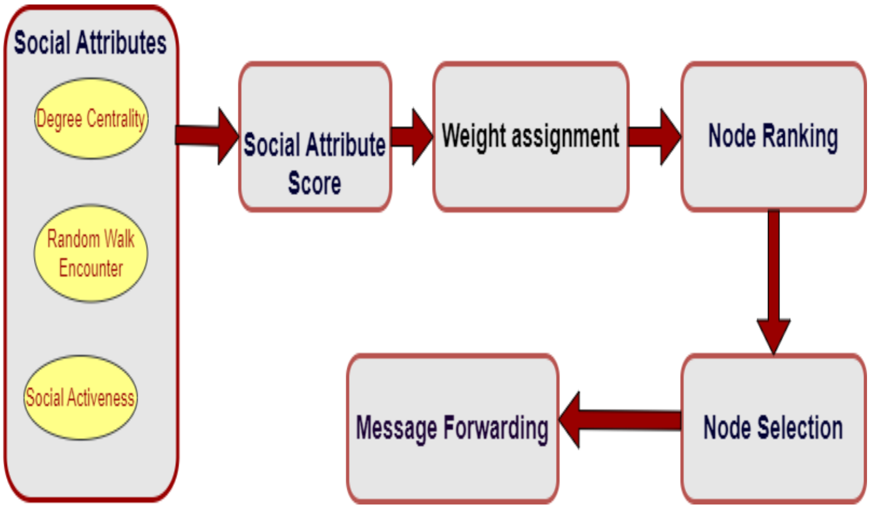


FIGURE 3.3: Proposed Methodology

3.2.5 Design of Proposed Socially-Aware Adaptive DTN Routing Techniques

In our proposed schemes, we have selected three distinct social categories (i.e., Centrality, Similarity and Ranking). Our proposed social-aware routing approach will be able to perform its functionality adaptively in three steps. First step is related to routing messages using individual social attribute (i.e., Degree Centrality, Random Walk Encounter, and Social Activeness), which is based on simulation-based experiments. Secondly, our proposed algorithm will be able to dynamically adapt the routing approach while considering the nature of received message either an urgent message or a normal message. Thirdly, we calculate the social rank of each node by combining three social attributes to discover the next forwarder hop on the basis of Social Rank as shown in Figure 3.3.

The process of selecting the most appropriate forwarder node is shown in Figure 3.4.

Figure 3.4 demonstrates that in DTN environment, source node wants to send a message to a destination node. Each node's DC is calculated whenever a new node joins the network and shortlists (f-list) the nodes possessing DC value greater than the source node and threshold value in descending order. Then from the sorted shortlist (sort-f-list) selects the relay node having highest DC and forwards

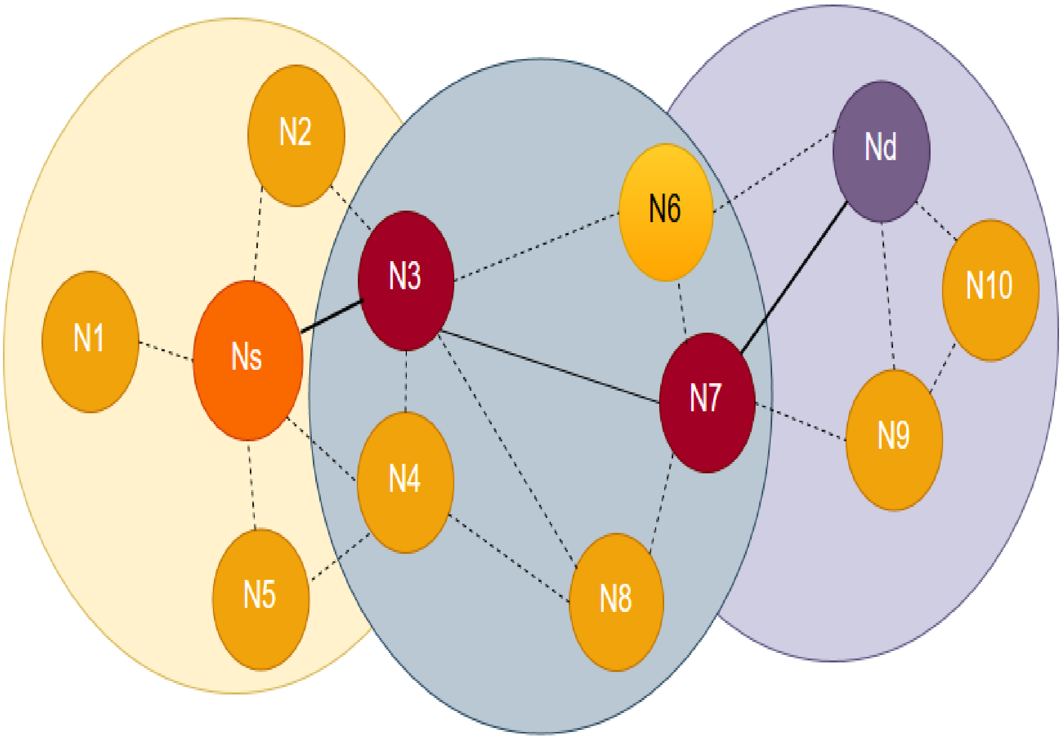


FIGURE 3.4: Appropriate Forwarder Node Selection

the messages to node N_3 which possesses highest DC. The same process will be followed by node N_3 and forwards messages towards the node N_7.

Finally, destination node is in radio range of N_7, so N_7 directly forwards message to destination node. The flow of selecting a forwarder node is also shown below in Figure 3.4.

3.3 Socially-Aware Adaptive Delay Tolerant Network Routing Protocol (SAAD)

3.3.1 Overview

The objective of our proposed SAAD routing protocol is to find the more appropriate forwarder nodes which minimizes the resource utilization in DTN. In SAAD, the process of routing a message is divided into two phases i.e. calculation of DC and message forwarding. In first phase, whenever a node joins the network, its DC (the total number of connected nodes) is calculated. This DC value of a node can be increased or decreased due to the joining/leaving nodes in the network due to high mobility in DTN. This DC will be used in the next phase for the selection of the forwarder node.

In second phase, source node will compare its DC value with all other nodes which lies in the transmission range. Only those nodes will be short listed which has higher DC as compared to source node's DC and also greater than threshold value (which is discussed in the following paragraph). Short listed nodes are sorted in the descending order with respect to their DC.

After that, source node selects a node from the sorted list which possess highest DC and forwards message to the selected node. This process will continue till the message reaches to the destination. At the end of simulation period, a statistical report is generated which contains message delivery, overhead ratio, hop count etc.

3.3.2 System Architecture

Whenever a node joins the network, the new node and only those nodes which come in its range will recalculate their DC values according to the node connectivity.

A source node which has a message to be sent, will share its DC value with its neighboring nodes and will obtain DC values of its neighboring nodes. Source node will check the DC value of all its neighboring nodes. For each neighbor node, two conditions will be checked. First, DC of selected node should be greater than source node. Second, DC of selected node should also be greater than threshold value.

Only those nodes will be shortlisted (f_list) which meet both conditions. If f_list is not empty, f_list is sorted in descending order according to their DC values (sorted_f_list) and source node forwards the message to the first node from sorted_f_list. However, if f_list is empty, then source node will carry message itself as shown in Figure 3.5.

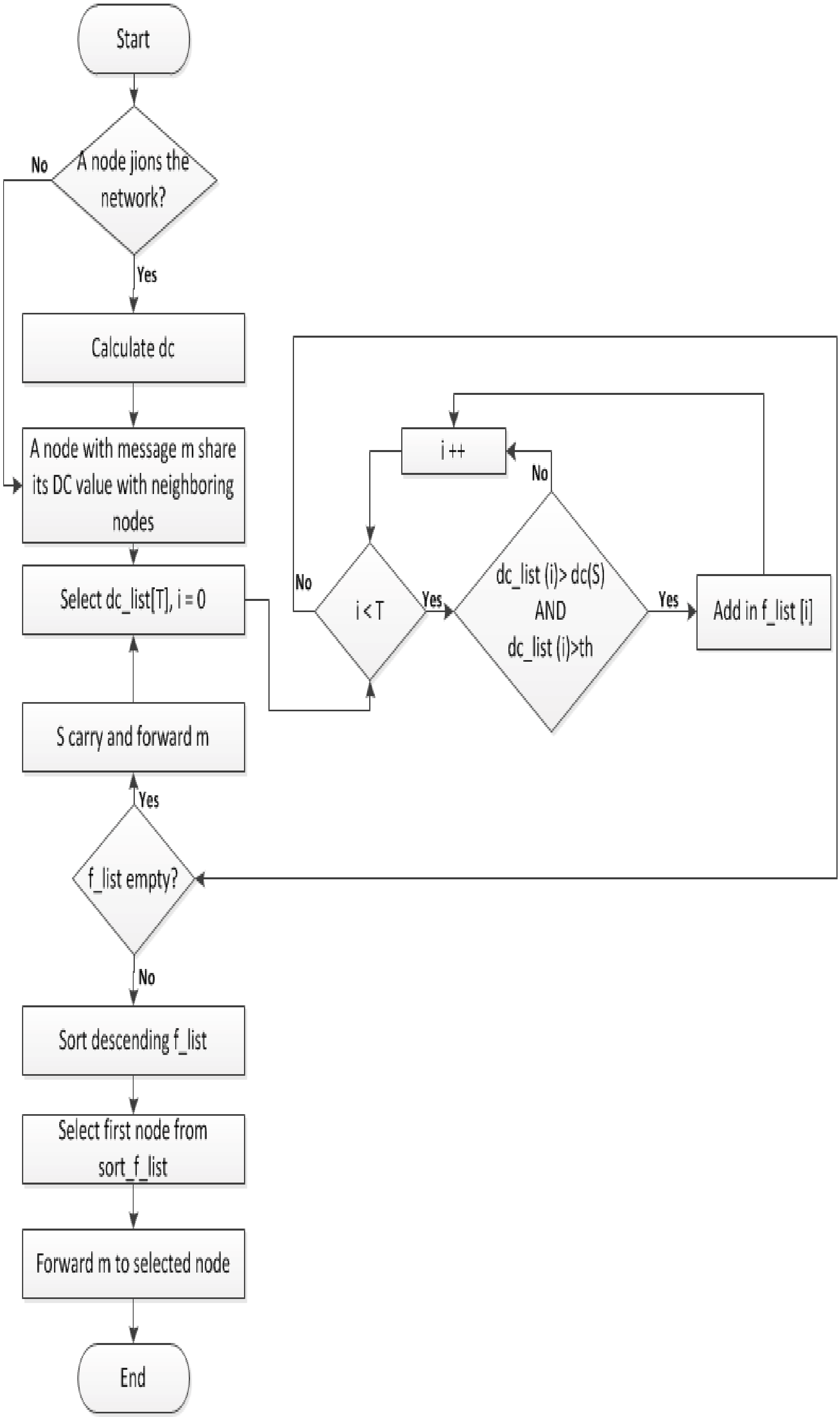


Figure 3.5: Operation Flow of SAAD Routing Scheme

3.3.3 Algorithm

```
void MessageForward (S, m, D)
if node = up then
    int DC = Calculate_DegreeCentrality ( )
end
A node with message m
share_list [ ] = Share (DC)
f_list [ ] = GetForwarderNode (share_list [ ], S)
GetForwarderNode (sorted_share_list [ ], S)
for each (neighbor_node in share_list [ ]) do
    if neighbor_node (DC) > S (DC) AND neighbor_node (DC) > Th) then
        f_list [ ].add (neighbor_node)
    end
end
if IsEmpty (f_list [ ]) then
    Return S
else
    Return f_list [ ]
    sorted_list [ ] = SortDesc (f_list [ ])
    select first node from sorted_list [ ]
    forward m to selected node
end
```

To ensure the scalability of our proposed routing scheme, we run the simulations with different number of nodes. In this routing scheme, we keep the all the parameter values same as used for SAAD except the number of nodes.

To ensure the scalability, we run the simulation with 50 nodes, then with 100 and 150 nodes. The simulation results demonstrates that scalable routing scheme also showed improvement in terms of delivery ratio, overhead, hop-count at the cost of average end-to-end delay.

3.4 Socially-Aware Adaptive DTN Routing Scheme (SR-SAAD)

3.4.1 Overview

The objective of our proposed routing protocol is to find the more appropriate forwarder node(s) which minimizes the resource utilization in DTN. In this routing technique, the process of routing a message from source node to destination node is categorized into three steps. In first step, each node in the network is required to compute its social rank (SR) based on different social attributes. When nodes encountered each other, they exchange SR using Hello message. This SR value of a node can be increased or decreased due to the joining/leaving nodes in the network due to high mobility in DTN. This SR will be used in the next phase for the selection of the forwarder node.

In second step, source node S check the destination node D in its radio range, if D exists, S directly forward message m to D. Otherwise, upon receiving list of sorted ranked nodes, S check for their SR value should be greater than S as well as threshold value (Th). In third step, If the message is urgent, then message m will be forwarded to all short listed nodes, otherwise, message m will be forwarded to a node possessing highest social rank (SR). This process will continue for a given time period t. At the end of simulation period, a statistical report is generated which contains message delivery, overhead ratio, hop count etc.

The proposed approach will also consider the type of message so that routing scheme can forward the message adaptively depending on the nature of message either the message is urgent or normal. SAAD routing scheme is exploiting the more significant social attributes (i.e., Degree Centrality, Random Walk Encounter and Social Activeness) to calculate the SR of encountered nodes using the following equation 3.6.

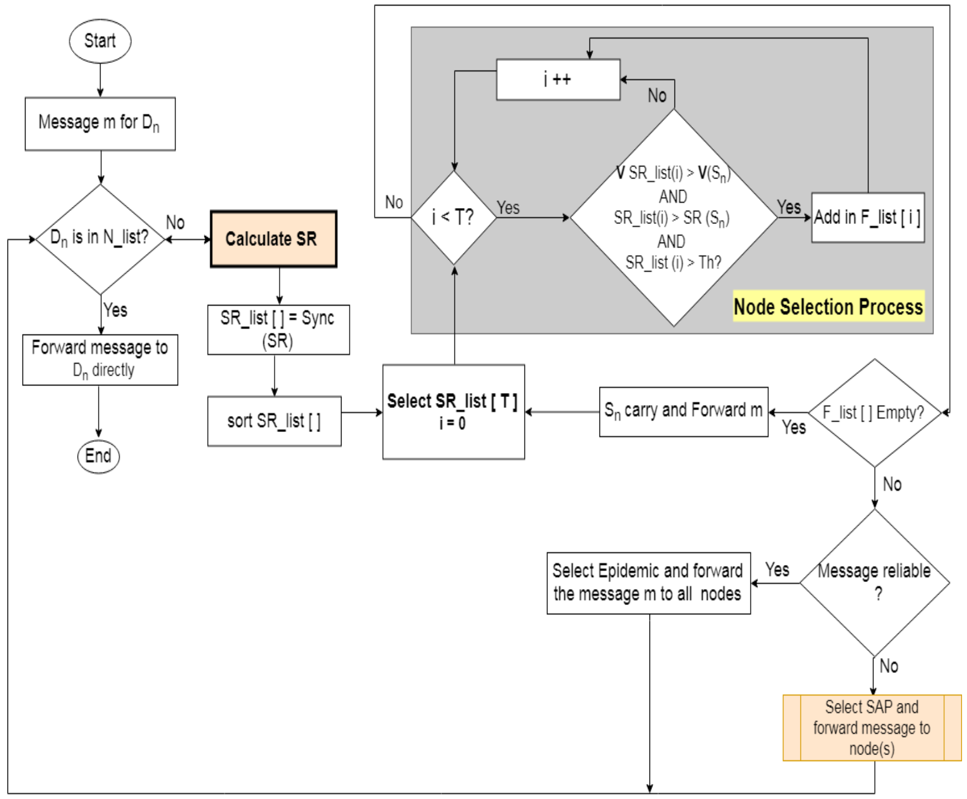


FIGURE 3.6: Operation Flow of Proposed SAAD Routing Protocol using Social Rank

3.4.2 System Architecture

Whenever a node needs to send a message to another node, it will first check the destination node in its surroundings. If it is found, then a source node forwards the message to the destination node directly, but if not then, only those nodes which come in its range will recalculate their SR values according to the node connectivity. A source node which has a message to be sent, will share its SR value with its neighboring nodes and will obtain SR values of its neighboring nodes. Source node will check the SR value of all its neighboring nodes. For each neighbor node, two conditions will be checked. First, SR of selected node should be greater than source node. Second, SR of selected node should also be greater than threshold value. Only those nodes will be short listed (f_list) which meet both conditions. If f_list is not empty, then the nature of message is checked. If a message is urgent, then message will be sent to all short listed nodes otherwise message will be sent to a node possessing highest SR. However, if f_list is empty, then source node will carry message itself as shown in Figure 3.6.

3.4.3 Algorithm (SR-SAAD)

```
void MessageForward (Sn, m, Dn)
if Dn is in range then
    Send m to Dn
else
    Float SR = Calculate_SR ( )
    share_list [ ] = Share (SR)
    sorted_list [ ] = Sort (share_list [ ])
    f_list [ ] = GetDestinationNode (sorted_shared_list [ ], Sn)
    if (Ishighpriority (m)) then
        SendUsingFlist (m, f_list [ ])
    else
        SendUsingFriendship (m, f_list [ ])
    end
end
GetDestinationNode (sorted_share_list [ ], Sn)
for each (neighbor_node in sorted_share_list [ ]) do
    if neighbor_node (SR) > Sn (SR) AND neighbor_node (SR) > Th) then
        f_list [ ].add (neighbor_node)
    end
end
if IsEmpty (f_list [ ]) then
    Return Sn
else
    Return f_list [ ]
end
Calculate_SR (dc, rwe, sa)
DC_i(t) = Σ_{j=1}^{N} (C_ij)
dc = DC_i(t)
rwe_i(t) = Σ_{j=1}^{N} (R_ij)
SA_i(t) = 1- (N (t - Δ t)∩ N(t))/(N (t - Δ t) ∪ N(t))
sa = β SA_N (t - Δ t) + (1-β) SA_N (t)
SR = dc*.34+rwe*.4+sa*.26
return SR
```

Table 3.2: Social Attribute Score of each node

Nodes/Attributes	DC	RWE	SA
N1	0.5	0.43	0.5
N2	0.40	0.73	0.32
N3	0.35	0.26	0.41
N4	0.25	0	0.26
N5	0.34	0.076	0.38

3.5 Proposed SAAD Routing Protocol using TOPSIS (TOPSIS- SAAD)

3.5.1 Overview

The objective of our proposed routing protocol is to find the most appropriate forwarder node(s) by exploiting MADM based approach TOPSIS (Technique for order Preference by similarity to ideal solution) [71][72] [73] [74] [75]to compute NodeRank using social attributes (i.e., Degree Centrality, Random Walk Encounter and Social Activeness). The proposed scheme considers message nature to adaptively follow suitable social attributes. According to the best of our knowledge, no protocol exists in DTN environment which selects the highest ranked forwarder node according to the nature of message. In order to calculate NodeRank, the whole process is divided into different phases. In first phase, each node in the network is required to compute its social attribute score. To illustrate the TOPSIS technique, we took the vales for Degree Centrality (DC), Random Walk Encounter (RWE) and Social Activeness (SA) based on the output of individual attribute score as shown in Table 3.2.

In second phase, TOPSIS calculates the NodeRank based on the provided combinations of the social attributes score in the following steps. In first step, the social attribute score is normalized using the following equations 3.7 and 3.8.

Table 3.3: Normalized Attribute Score

Nodes/Attributes	N_{DC}	N_{RWE}	N_{SA}
N1	0.71	0.41	0.31
N2	0.57	0.30	0.44
N3	0.5	0.50	0.44
N4	0.35	0.41	0.57
N5	0.48	0.55	0.44

$$DC_{total} = \sqrt{\sum_{i=1}^{i=n} (DC_i)^2} \tag{3.7}$$

$DC_{total} = (0.5^2 + 0.40^2 + 0.35^2 + 0.25^2 + 0.34^2)^1/2 = 0.7$

$$N_{DCi} = \frac{DC_i}{DC_{total}} \tag{3.8}$$

$N_{DC_{Ni}}$= 0.5/7, 0.40/7, 0.35/7, 0.25/7, 0.34/7

= 0.71, 0.57, 0.5, 0.35, 0.48

The normalized score of N_i is shown in Table 3.3.

In second step, weight of each social attribute is assigned, based on initial experimental results as well as by reviewing manually the score or contribution in the message dissemination of each social attribute. The normalized weighted score is computed using the following equation.

$$NW_{DC} = N_{DC_{Ni}} * W_{DC} \tag{3.9}$$

e.g. W_{DC} = 0.340, W_{RWE} = 0.4, W_{SA} = 0.26 The normalized weighted score is shown below in Table 3.4.

In third step, calculate the best solution and the worst solution using the following equations 3.10and 3.11.

Table 3.4: Normalized Weighted Score

Nodes/Attributes	N_{DC}	N_{RWE}	N_{SA}
N1	0.241	0.164	0.08
N2	0.193	0.12	0.114
N3	0.17	0.2	0.114
N4	0.119	0.164	0.148
N5	0.163	0.22	0.114

Table 3.5: Best and Worst Score of Nodes

Nodes/Attributes	NW_{DC}	BS_{Ni}	WS_{Ni}
N1	0.284	0.6204	0.1862
N2	0.228	0.0031	0.0077
N3	0.200	0.0070	0.0036
N4	0.140	0.0207	0.0000
N5	0.192	0.0084	0.0027

$$BS_{Ni} = \sqrt{\sum_{j=1}^{m}(N_{ij} - N_j+)^2} \tag{3.10}$$

$BS_{Ni} = ((0.284 - 0.284)^2 + (0.228 - 0.284)^2 + (0.200 - 0.284)^2 + (0.140 - 0.284)^2) + (0.192 - 0.284)^2)^1/2$

$BS_{Ni} = 0.6204$

$$WS_{Ni} = \sqrt{\sum_{j=1}^{m}(N_{ij} - N_j-)^2} \tag{3.11}$$

$WS_{Ni} = ((0.284 - 0.140)^2 + (0.228 - 0.140)^2 + (0.200 - 0.140)^2 + ((.140 - 0.140)^2) + (0.192 - 0.140)^2)^1/2$

$WS_{Ni} = 0.1862$

The result of the best solution and the worst solution is shown in Table 3.5.

Table 3.6: Node Rank based on Performance Score

Nodes/Attributes	BS_{Ni}	P.S	R
N1	0.6204	0.2308	5
N2	0.0031	0.7023	2
N3	0.0070	0.4212	4
N4	0.0207	0.5201	3
N5	0.0084	0.8104	1

In last step, performance score of each node is calculated using the following equation 3.12 and then rank them according to the final performance score as shown in Table 3.6.

$$P.S_{Ni} = \frac{WS}{(WS + BS)} \tag{3.12}$$

In last phase, the nodes from the node list according to their ranking order are selected and checked for its NodeRank must be higher than source/relay node and threshold value. The successful nodes will be added to the directed list and message will be forwarded to the nodes in the directed list. This process will continue till the destination node is found. The operation flow of the SAAD (MADM) is shown below in Figure 3.7.

3.5.2 System Architecture

Whenever a node needs to send a message to another node, it will first check the destination node in its surroundings. If it is found, then a source node forwards the message to the destination node directly, but if not then, only those nodes which come in its range will recalculate their NodeRank value using TOPSIS, based on node's calculated values of Degree Centrality, Random Walk and Social Activeness. A source node which has a message to be sent, will share its NodeRank value with its neighboring nodes and will obtain SR values of its neighboring nodes. Source node will check the SR value of all its neighboring nodes. For each neighbor node, two conditions will be checked. First, SR of selected node should be greater than source node. Second, SR of selected node should also be greater than threshold value. Only those nodes will be shortlisted (f_list) which meet both conditions. If f_list is not empty,

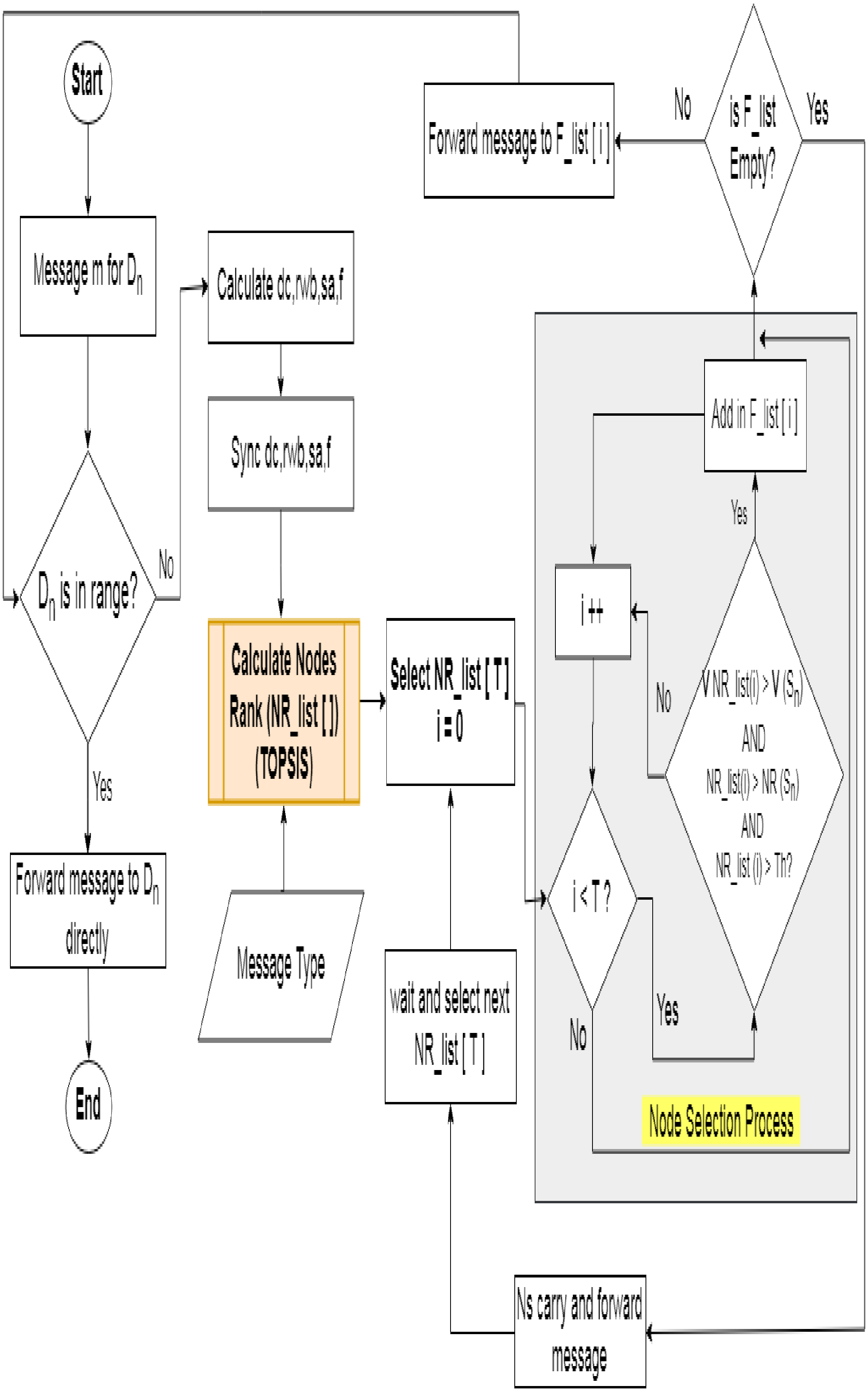


FIGURE 3.7: Operation Flow Diagram of SAAD (TOPSIS)

then the nature of message is checked. If a message is urgent, then message is sent to all shortlisted nodes otherwise message is sent to a node possessing highest Social Rank (SR). However, if f_list is empty, then source node will carry message itself.

3.5.3 Algorithm

Algorithm 1: SAAD Algorithm (TOPSIS)

```
void MessageDissiminate (Sn, m, Dn)

if D_n is in range then
    Send m to D_n

else
    float NR_list [ ] = Topsis_NR ( )

    Sorted_NR_list [ ] = Sort (NR_list [ ])

    f_list [ ] = GetDestinationNode (sorted_NR_list [ ], S_n)

    GetDestinationNode (sorted_NR_list[ ], S_n)

    for each (neighbor_node in sorted_NR_list [ ]) do
        if neighbor_node (NR) > S_n (NR) AND neighbor_node (NR) > Th)

         then
            f_list [ ].add (neighbor_node)

        end

    end

    if IsEmpty (f_list [ ]) then
        Return S_n

    else
        Return f_list [ ]

    end

    Forward m to f_list [ ]

end
```

Algorithm 2: Topsis-NR

Topsis_NR ()

$DC_i(t) = \sum_{j=1}^{N}(C_{ij})$

dc = DC_i (t) β DC_i (t) + (1 - β)DC_i (t - Δ t)

$rwe_i = \frac{\sum RW(i)}{n-1}$

$SA_i(t)$ = 1 - (N (t - Δt)$\cap$ N(t))/(N (t - Δt) $\cup$ N(t))

sa = βSA_N (t - Δ t) + (1 - β) SA_N (t)

for *each (N_i in N_list [ ])* **do**

  share_list [ ] = share (Sn_id, dc, rwe, sa)

  if *IsMessageHighPriority(m)* **then**

    $dc_{total} = \sqrt{\sum_{i=1}^{n}(dc(Ni))^2}$

    $rwe_{total} = \sqrt{\sum_{i=1}^{n}(rw(Ni))^2}$

    $sa_{total} = \sqrt{\sum_{i=1}^{n}(sa(Ni))^2}$

    $N_{(dc(Ni))} = dc_{Ni}/dc_{total}$

    $N_{rwe(Ni)} = rwe_{Ni}/rwe_{total}$

    $N_{(sa(Ni))} = sa_{Ni}/sa_{total}$

    $W_{dc} = 0.34$, $W_{rwe} = 0.4$, $W_{sa} = 0.26$

    $NW_{dc} = N_{dc(Ni)} * W_{dc}$

    $NW_{rwe} = N_{rwe(Ni)} * W_{rwe}$

    $NW_{sa} = N_{sa(Ni)} * W_{sa}$

    $BS_{Ni} = \sqrt{\sum_{j=1}^{m}((N_{ij} - N_j)^2)}$

    $WS_{Ni} = \sqrt{\sum_{j=1}^{m}((N_{ij} - N_j)^2)}$

    P.SNi = WS/(WS+BS)

    NR_list [ ] = Sort (P.SNi)

    return NR_list [ ]

  else

  end

end

Chapter 4

Experiments and Simulation Setup

To evaluate the performance of our proposed routing schemes, number of simulations have been performed while taking into account disaster scenario. The description of the simulator, mobility models and other important parameters used for the simulation of the proposed routing schemes is as follows:

4.1 ONE Simulator

Opportunistic Networking Environment (ONE) simulator is designed to evaluate the performance of DTN routing protocols [76] [77]. The ONE provides an environment in which nodes are moved using different movement models. ONE can import mobility data from real-world traces or other mobility generators. It allows a user to create scenarios based upon different synthetic movement models and real-world traces. The ONE simulator has become part of a real-world DTN testbed because of its interactive visualization, post-processing tools and an emulation mode. The graphical user interface is shown in Figure 4.1. The interface demonstrates that a user can view the number of nodes, their initial placement, event log control which can be set by the user before the simulation actually starts.

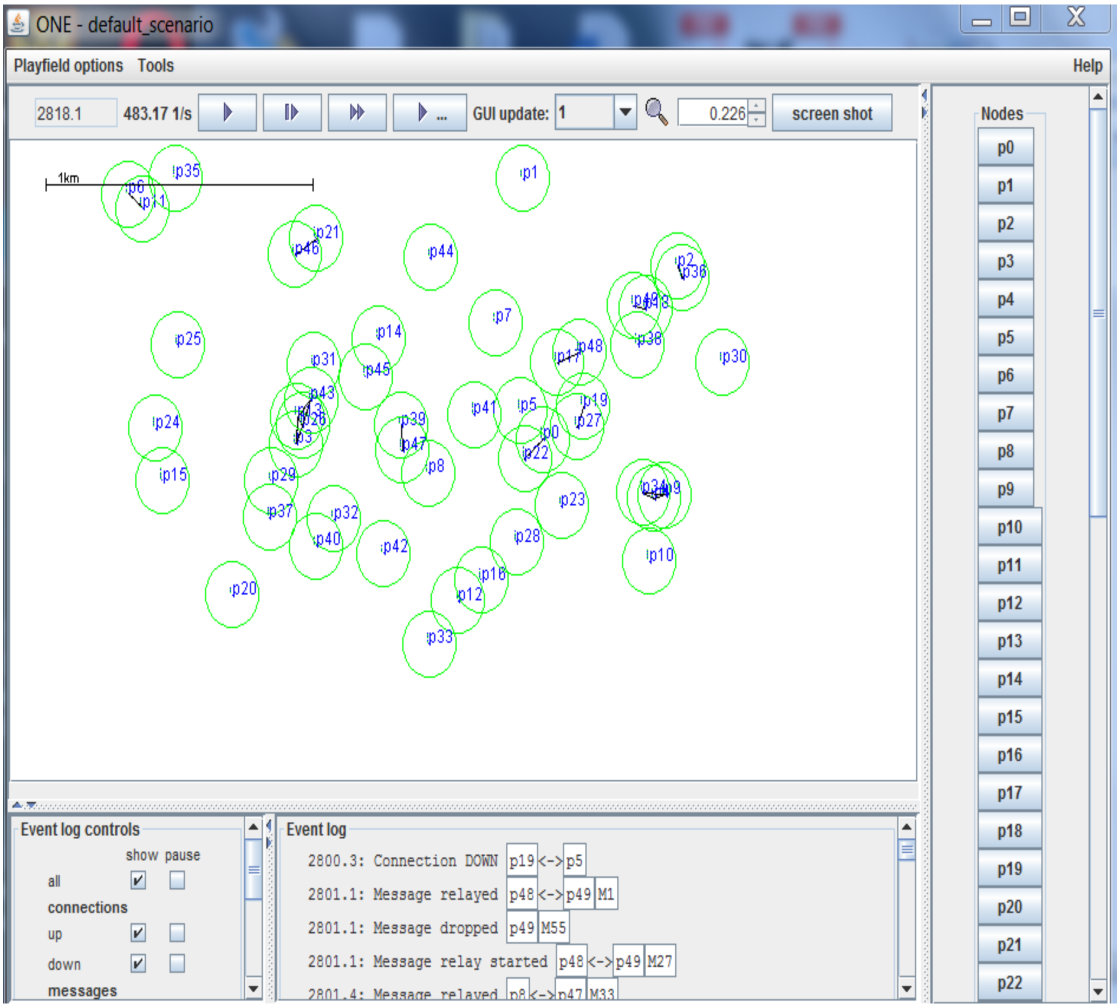


FIGURE 4.1: Graphical User Interface of ONE Simulator

ONE simulator supports many built in mobility models like Random Waypoint, ShortestPathMapBased movement model, MapBased movement model, Working-Day movement model etc. ONE also provides few built in routing schemes, a researcher can compare its proposed routing scheme results with these built-in routing schemes for evaluation. ONE simulator is very much flexible that a researcher can set different values of the simulation parameters and can produce results. For example, a researcher can change the number of nodes, can set transmission range and transmission speed, can set different values of random seed valued to produce random results. It also provides the possibility to divide the nodes in different groups and can set different values of parameters for different groups, e.g. in one simulation, few nodes can be considered as pedestrians, few can be considered as cars and few can be considered as train etc. It also provides both Bluetooth interface and high speed interface for either same simulation or can be used as individual for two different simulations. ONE simulator provides different buffer sizes and TTL (time to live) values. It also provides some warmup time which is time nodes can move around within the limited area before the actual simulation starts.

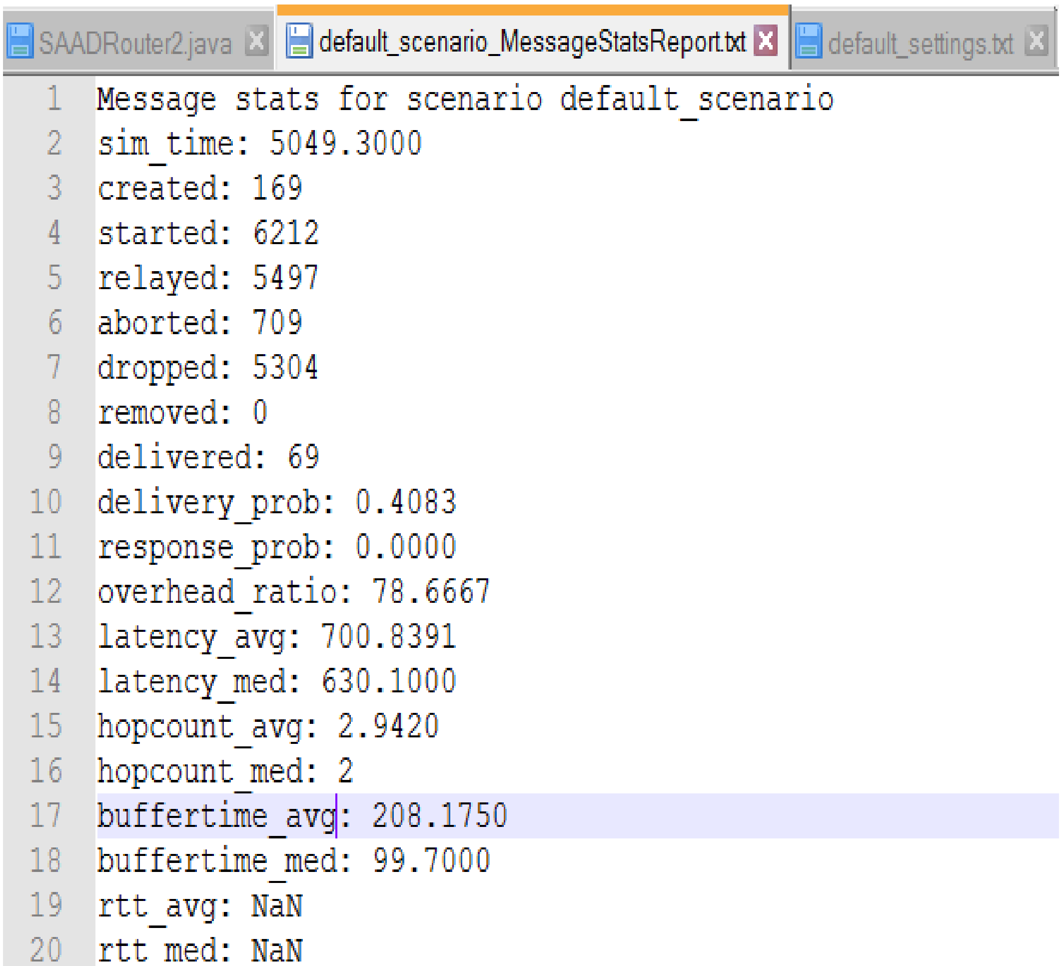
It allows a user to create scenarios based upon different synthetic movement models and real-world traces. The ONE simulator has become part of a real-world DTN testbed because of its interactive visualization, post-processing tools and an emulation mode. The graphical user interface is shown in Figure 4.1. The interface demonstrates that a user can view the number of nodes, their initial placement, event log control which can be set by the user before the simulation actually starts. A user can view the status of nodes either they are down or up, either message is relayed, message dropped or message delivered etc. Finally, it provides built in reports after each simulation which demonstrate the packet delivery, overhead ratio, average hop count and latency etc. as shown in Figure 4.2

We used ONE (Opportunistic Network Environment) simulator for our proposed routing schemes. For simulation scenario, we assumed an area of 3000 x 1500 m^2 in disaster site. We consider the Random Waypoint model to track the pedestrians as this mobility model is commonly used in evaluations of DTN routing schemes. In these models, each node selects a random destination and starts its movement. When a node reaches at the destination, the node pause for a while and then selects a new destination. This process continues till the simulation time ends.

4.2 Mobility Models

4.2.1 Random Waypoint Mobility Model (RWP)

The Random Waypoint mobility model was first proposed by Johnson and Maltz. RWP is commonly used mobility model to evaluate routing protocols [3] [78][79][24]. It includes random pause time after finishing each movement segment in the random



SAADRouter2.java | default_scenario_MessageStatsReport.txt | default_settings.txt

```
Message stats for scenario default_scenario
sim_time: 5049.3000
created: 169
started: 6212
relayed: 5497
aborted: 709
dropped: 5304
removed: 0
delivered: 69
delivery_prob: 0.4083
response_prob: 0.0000
overhead_ratio: 78.6667
latency_avg: 700.8391
latency_med: 630.1000
hopcount_avg: 2.9420
hopcount_med: 2
buffertime_avg: 208.1750
buffertime_med: 99.7000
rtt_avg: NaN
rtt_med: NaN
```

FIGURE 4.2: Stats Report generated by ONE simulator after simulation

walk. In Random Waypoint mobility model, direction angles, speeds and pauses are sampled from a uniform distribution. In this mobility model, the mobile nodes move directly to the specified destination at a constant speed, stay there for few moments and then acquire a new random destination.

4.2.2 Shortest Path-Based Map Mobility Model (SPBMM)

Shortest Path-Based Map Mobility model is the improved version of Map-based Mobility model. In this mobility model, initially nodes are placed on Map and started their move [79][80]. After reaching on the destination, they wait for a while and then select a new destination. Map data has point of interest (POI). POI has advantage for modeling places where people tend together like restaurant and tourist place. This mobility model does not ensure the inter connect time and contact time distributions that match real data traces when small no of nodes are used in simulation.

4.2.3 Map-Based Mobility Model (MBM)

In this mobility model, nodes move randomly in predefined directions and roads following the map. [81][79][82]. Nodes move onward until they touch the end of road and turn back or end up in an intersection. At intersection, node selects a new direction randomly but does not return back where they come from. When a node has traveled a configurable distance, it stops for a while then continues its journey.

4.2.4 Working Day Mobility Model (WDM)

Working Day Mobility Model is more realistic as it demonstrates the daily routine of human beings like sleeping at home, working in office, visit some tourist place with friends etc [79][83]. [84] In this mobility model, three different transport models are presented like node can move alone, in groups or by car. Nodes can move either alone or in groups at different speed which increases heterogeneity. The concept of communities and social relationships included in WDM which are not usually considers in Random WayPoint Mobility Model. This mobility model provides inter-contact time and contact time distribution which follow closely the ones found in traces from real worlds.

4.3 Description of other Parameters Used in Simulation

We uses various values for the parameters (e.g. speed, time to live (TTL), buffer size etc.) to get random results of the simulation. We use TTL value so that a packet should not move infinite time in the network. In literature, TTL value is used in minutes as well as number of hops. However, ONE used TTL value in minutes. After each update interval, TTL value is reduced.

When TTL value reaches to '0'. Nodes which possess this packet will discard it immediately. We use various buffer sizes (i.e; 5MB, 10MB, 15MB, 20MB and 25MB) and random seed values (i.e; 30, 50, 100, 150 and 200). As we increase buffer size, the more messages can reside in buffer long enough to be delivered to the destination.

The ratio of drop packets also decreases as packets drop at smaller queue size. A warm up period of some seconds can also be set that the process of calculating Degree Centrality initializes before any message is generated. A source or intermediate node can transmit a message in a defined transmission range and with defined transmission speed.

We analyzed the existing DTN routing schemes and list down the simulation parameters used by these existing DTN routing schemes. For example, the simulator which they have used for simulation, the routing schemes with which they compared their own results.

We also considers the mobility models or traces which they have used for the simulation.Finally, we identify the evaluation metrics which they used to evaluate the performance of their routing schemes. The summary of the above-mentioned parameters used by these routing schemes is shown in Table 4.1.

To ensure further the validity and authenticity of the proposed routing scheme, we also analyzed the parameter values used by DTN existing routing schemes as shown in Table 4.2.

Table 4.2 presents the comparative analysis of existing DTN routing protocols with respect to parameter values used in simulation. The most commonly used simulation parameters in ONE simulator are area, simulation time, no of nodes, mobility model, buffer size, Time to live (TTL), transmission range, transmission speed etc. Each existing DTN routing protocol has its own set of simulation parameter values.

TABLE 4.1: Research articles, their mobility models and performance evaluation metrics

Approach	Compare with	Mobility model/traces	Evaluation metrics
PRoPHET [2003]	Epidemic	Random WayPoint	Packet delivery ratio, delivery delay Overhead Avg hop-count
PRoPHETv2 [2011]	PRoPHET, Spray and Wait	Working Day Movement, N4C traces	delivery rate Overhead
EPSOC [2018]	Epidemic, BubbleRap	Real trace data (Cambridge)	Packet delivery ratio, latency Overhead Avg hop-count
FCSA [2010]	GPSR, BAGH	VANET MobiSim	Packet delivery ratio, delivery delay
Hye Influencer [2019]	First Contact, Random Virtual Centrality	Info5, Cambridge, Taxis	Packet delivery ratio, Latency Overhead

TABLE 4.2: Parameter values used by routing algorithms using ONE simulator

Parameter	PRoPHETv2	PRoPHET	SAAD
Simulator	ONE	ONE	ONE
No of nodes	500	50	50
Area	1500 * 3000 m^2	1500 * 3000 m^2	1500 * 3000 m^2
Mobility model	Working Day Movement	Random WayPoint	Random WayPoint
Buffer size	100 MB	20 - 200 (MB)	5, 10, 15, 20, 25 (MB)

This Table presents the comparison of parameters used by Epsoc [41],SARP [55], PRoPHETv2 [59], PRoPHET [57] and SAAD. For example, all above-mentioned DTN routing protocols used ONE simulator for simulation except SARP (NS2.34). Similarly, different parameter values are used by different DTN routing protocols as mentioned in Table 4.2.

4.4 Simulation Environment for Socially-Aware Adaptive DTN Routing Protocol (SAAD)

To evaluate the performance of SAAD, we run the simulations five times and then take an average of the five simulation while taking into account disaster scenario. We used ONE (Opportunistic Network Environment) simulator and simulation area of 3000 x 1500 m^2 in disaster site. We consider the Random WayPoint mobility model in which each node calculates its Degree Centrality, Random Walk, Social Activeness and shares with one-hop nodes. Then the source (forwarder) node selects the intermediate node (s) possessing the higher Degree Centrality, Random Walk, Social Activeness and sends the messages to the selected nodes. The details about the other important parameters is given below in Table 4.1.

To evaluate the performance, we run the simulations five times and then take an average of the five simulation while taking into account disaster scenario. We used ONE (Opportunistic Network Environment) simulator and simulation area of 3000 x 1500 m^2 in disaster site. We uses different number of nodes, first we take 50 nodes, run the simulations and note down the results. Then we used 100 nodes and 150 nodes, run the simulations and note down the results. In this routing scheme, each node calculates its Degree Centrality and shares with one-hop nodes. Then the source (forwarder) node selects the intermediate node possessing the highest Degree Centrality and sends the message. For implementation and simulation of our scheme, we assume that all nodes are fully cooperative for simplicity purposes. The following table 4.3 shows the simulation parameters set for SAAD.

Table 4.3 describes the simulation parameters used by the proposed routing scheme. SAAD used ONE Simulator for the simulation. In proposed routing technique, any node can select a destination node randomly.

The results are produced by running the simulation for 12 hours and the total number of nodes used in this simulation are 50. We used Random Waypoint mobility model. We set different buffer size and speed of nodes vary from 0 to 20 m/sec as mentioned in Table 4.3. A source or intermediate node can transmit a message upto 100 m with 2Mbps speed.

4.5 Performance Evaluation Metrics

The performance of the proposed SAAD routing scheme is evaluated by comparing its results with other routing schemes based on varying random seed and buffer size of nodes. Brief description of the performance evaluation metrics is given below:

4.5.1 Packet Delivery Ratio (PDR)

Packet delivery ratio is calculated by computing the number of successfully received packets to the total number of packets sent by source. The higher delivery probability means more messages will be delivered successfully. This is the most important metric to evaluate the routing performance.

4.5.2 Overhead Ratio

Overhead is calculated by measuring the ratio between total number of message transmission required for delivery and total number of messages delivered. The lower overhead means less utilization of network resources e.g. storage space, bandwidth etc.

4.5.3 Average Hop Count

Hop count is the total number of intermediate devices such as routers through which a message is transmitted from a source to destination. Low average hop count probably increase the message delivery which overcome the network overhead.

4.5.4 Average end-to-end Delay

The average time used to successfully deliver all messages from source to destination. Low average end-to-end delay shows better routing performance.

TABLE 4.3: Simulation parameters (SAAD)

Parameter	**Value**
Network Simulator	ONE
Simulation time	12 hrs
No of nodes	50
Simulation area	3000 x 1500 m^2
Traffic source, destination	Random Selection
Mobility model	Random Waypoint
Buffer size	5MB, 10MB, 15MB, 20MB, 25MB
Speed	0 m/sec, 20 m/sec
TTL	300 mins
Transmit range	100 m
Transmit speed	2 Mbps

4.6 Comparison with Routing Schemes

We selected the following routing algorithms to compare the results of our proposed routing scheme. The following routing schemes are available in ONE simulator.

4.6.1 Epidemic Routing

This routing scheme used a flooding technique in which a message is sent to all neighboring nodes. This process continues till the message reached to the destination. This technique uses more network resources because of flooding. However, this routing scheme is considered to be the most important flooding technique in DTN.

4.6.2 PRoPHET

A routing scheme PRoPHET is introduced in which a message is forwarded to an intermediate node which is selected based on some criteria (i.e.; delivery predictability and transitivity). This routing technique exploited delivery predictability (i.e.; history information of the encountered nodes) and the transitivity as a criteria to select and forward messages to the next-hop regardless of the distance. Each node calculates its delivery predictability and share with its neighboring nodes. A node having high delivery predictability will be considered the most appropriate forwarder node. In this routing scheme, the message can be sent to more than one node having the same delivery predictability.

4.6.3 PRoPHETv2

This is the updated version of the old PRoPHET in which minor modifications are made in the metric (i.e.; delivery predictability (DP)) calculation. The main objective of this routing scheme is to improve the performance of existing PRoPHET. The problem in the previous transitive equation was that as long as beta > 0, the DP for every known node k will increase regardless of whether any node in the network has recently met node k or not. In this routing technique, delivery predictability and transitivity is measure efficiently.

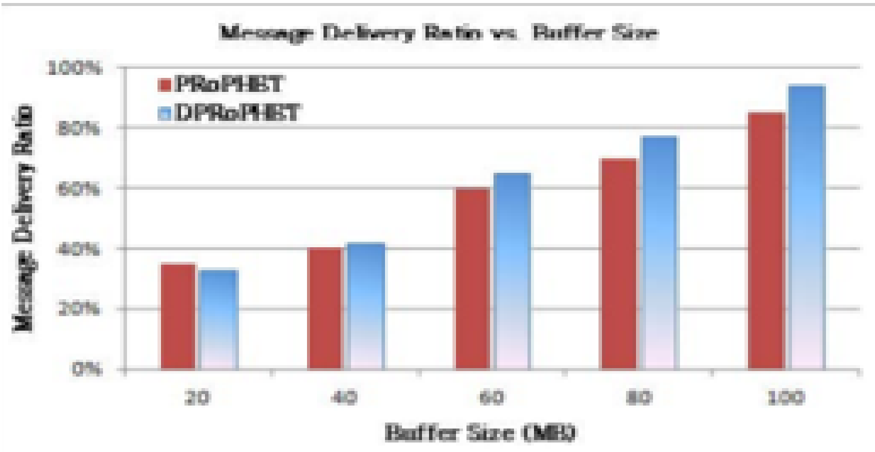


FIGURE 4.3: Message Delivery Ratio with PRoPHET and DiPRoPHET

4.7 Comparison:PRoPHET, DiPRoPHET and PRoPHETv2

PRoPHET routing algorithm is the first criteria-based routing technique in which a forwarder node is selected based on some criteria. The simulation results of PRoPHET are compared by many routing algorithms (i.e.; DiPRoPHET, PROPHETv2, INBAR, Friendship etc.). In DiPRoPHET [60], PRoPHET is producing delivery ratio upto 32% while DiPRoPHET is producing delivery ratio upto 30% which increases later by increasing the buffer size. While in PRoPHETv2, PRoPHET is producing delivery ratio upto 20% while PRoPHETv2 is producing delivery ratio upto 25%. We also evaluate the performance of these routing schemes by running the same default setting file with old version ONE simulator 1.4 and then run with ONE simulator 1.6. We observed that when we set buffer size 5MB, 10MB, 15MB, Epidemic and PRoPHET are producing almost the same number of packets while we increase the buffer size from 20MB to 25MB, ONE simulator 1.4 forwards 10 to 15 more packets than ONE simulator 1.6. Therefore, we evaluated based on all above-mentioned observations that we produced the simulation results of SAAD and other routing techniques using ONE simulator 1.6, which are reliable and proved as shown in Figures. 4.3 and 4.4.

To further ensure the validity of our simulation, we do simulation with a set of defined parameters using both versions of ONE simulator. We run simulations with

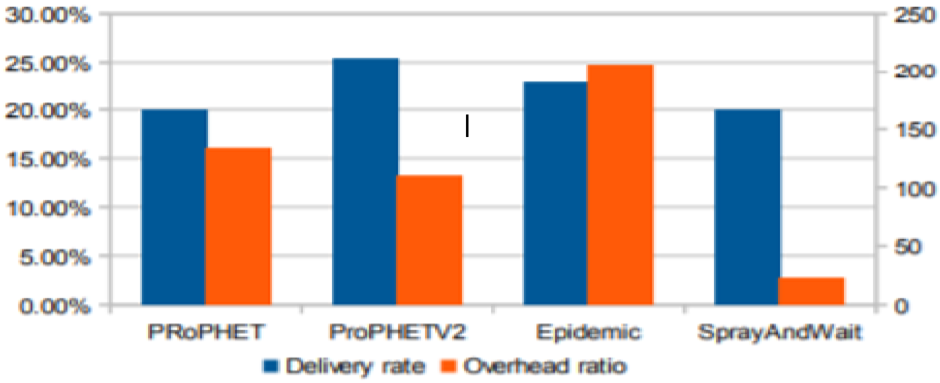


FIGURE 4.4: Message Delivery Ratio and Overhead Ratio with PRoPHET and PRoPHETv2

TABLE 4.4: Epidemic results of Simulator ONE 1.4v and ONE 1.6v in terms of PDR

Buffer size (MB)	ONE 1.4v	ONE 1.6v
5	515	517
10	518	519
15	643	638

TABLE 4.5: PRoPHET results of Simulator ONE 1.4v and ONE 1.6v in terms of PDR

Buffer size (MB)	ONE 1.4v	ONE 1.6v
5	318	318
10	360	359
15	400	389

using ONE 1.4 as well as ONE 1.6 simulator. We run the simulation with flooding technique Epidemic router as well as a criteria based routing algorithm PRoPHET. First, we run the simulations with Epidemic, with buffer size 5MB, 10MB and 15MB and record the results presented by statistical report after successful simulations as shown in Table 4.4. Secondly, we run the simulations with PRoPHET, with buffer size 5MB, 10MB and 15MB and record the results presented by statistical report after successful simulations as shown in Table 4.5. The simulation results demonstrate that both versions of ONE simulator (i.e.; ONE 1.4 and ONE 1.6) are performing almost the same in terms of Packet delivery ratio.

Chapter 5

Results and Discussion

With the help of simulation setup mentioned-above, simulations have been performed for SAAD and three other routing schemes (i.e., Epidemic, PRoPHET and PRoPHETv2) because most of the recent DTN routing schemes which are using social attributes for message delivery are comparing their results with Epidemic, PRoPHET and PRoPHETv2. This section discusses the results of the proposed routing scheme and above-mentioned routing techniques. We presented the comparison of the results of SAAD and other routing techniques using graphs. Results are compared in terms of evaluation metrics mentioned in chapter-4. We have considered that all nodes are fully cooperative to forward messages to one another in an entire network.

5.1 Results of Socially-Aware Adaptive DTN Routing Protocol (SAAD)

5.1.1 Packet Delivery Ratio

Packet delivery ratio (PDR) is calculated based on the results produced by the simulation as shown in Figure 5.1 to Figure 5.5. We uses various buffer sizes for the simulation (i.e.; 5MB, 10MB, 15MB,20MB and 25MB). For each

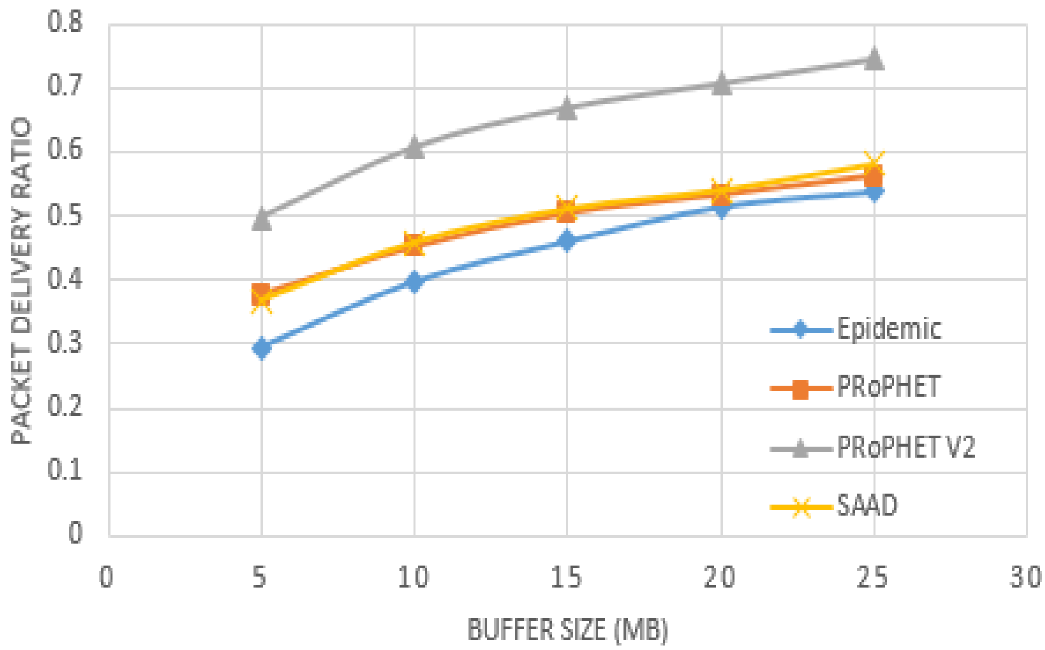


FIGURE 5.1: Packet Delivery Ratio with different buffer capacity and Degree Centrality (threshold = 0)

buffer size (5MB), each simulation is run for 12 hours, this process is repeated five times by using different values of random seed and then average of the five simulations is taken as a final value. We uses different values of Degree Centrality as a threshold so that only those nodes can be selected as relay nodes which meet the given threshold.

We start simulation with threshold value = 0 so that a node even if it has a single neighbor node, can participate in the message forwarding process. When we use threshold value 0, our proposed scheme (SAAD) performs better than Epidemic and PRoPHET. However, performed bit lower than PRoPHETv2 as shown in Figure 5.1 because large number of nodes are initially short listed which reduces the performance of SAAD in terms of message delivery.

It is also obvious that as far as number of nodes will be higher in a specific area, lower the packet delivery ratio while on the other hand, as far as number of nodes are lower and highly influntial, packet delivery ratio will be higher.

Figure 5.1 shows that Epidemic routing technique performs very low amongst all

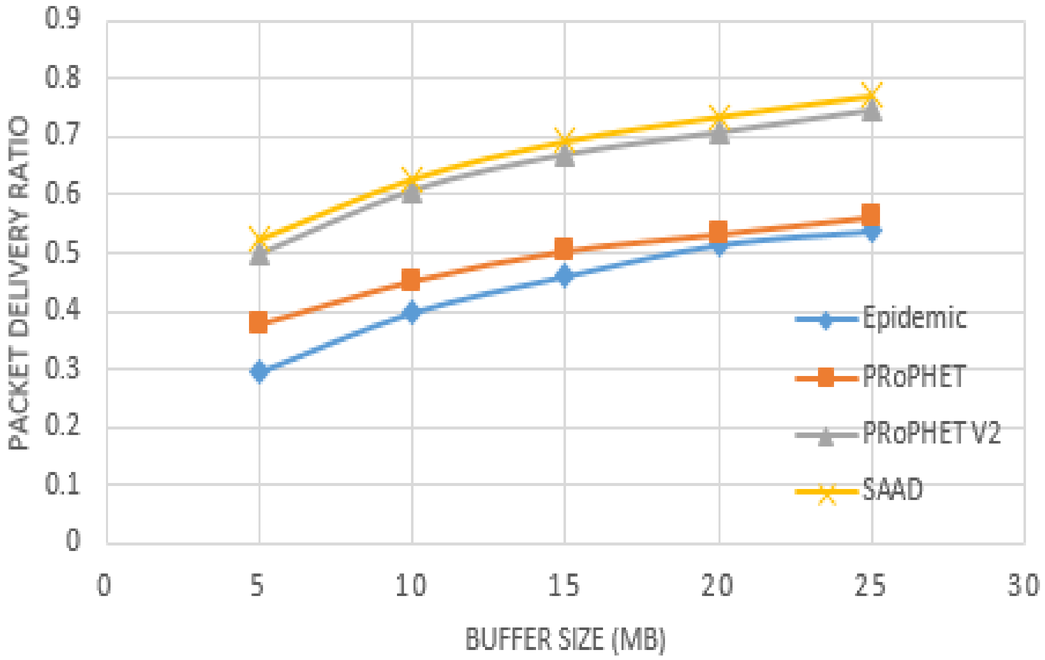


FIGURE 5.2: Packet Delivery Ratio with different buffer capacity and Degree Centrality (threshold = 1)

competitive routing schemes because Epidemic broadcasts the messages to all its neighboring nodes. Hence, large number of messages are relayed in the network which utilized lot of network resources and reduced the packet delivery ratio. On the other hand, PRoPHET showed low PDR than PRoPHETv2. However, PRoPHET showed better PDR than Epidemic because in PRoPHET, messages are sent to either one or more nodes having same delivery predictability. PRoPHETv2 is the refined routing technique of PRoPHET and make better use of transitivity and delivery predictability.

In this routing technique, less number of messages are relayed as compared to PRoPHET. Hence, more messages are delivered as compared to Epidemic, PRoPHET. The proposed routing scheme has shown improvement in terms of packet delivery ratio as compared to Epidemic, PRoPHET and PRoPHETv2 as shown in Figure 5.1. SAAD forwards message to only one node possessing highest Degree Centrality. Therefore, SAAD routing scheme is very efficient and relayed very less number of messages in the network. As a result, SAAD not only improve the PDR but also reduce the overhead.

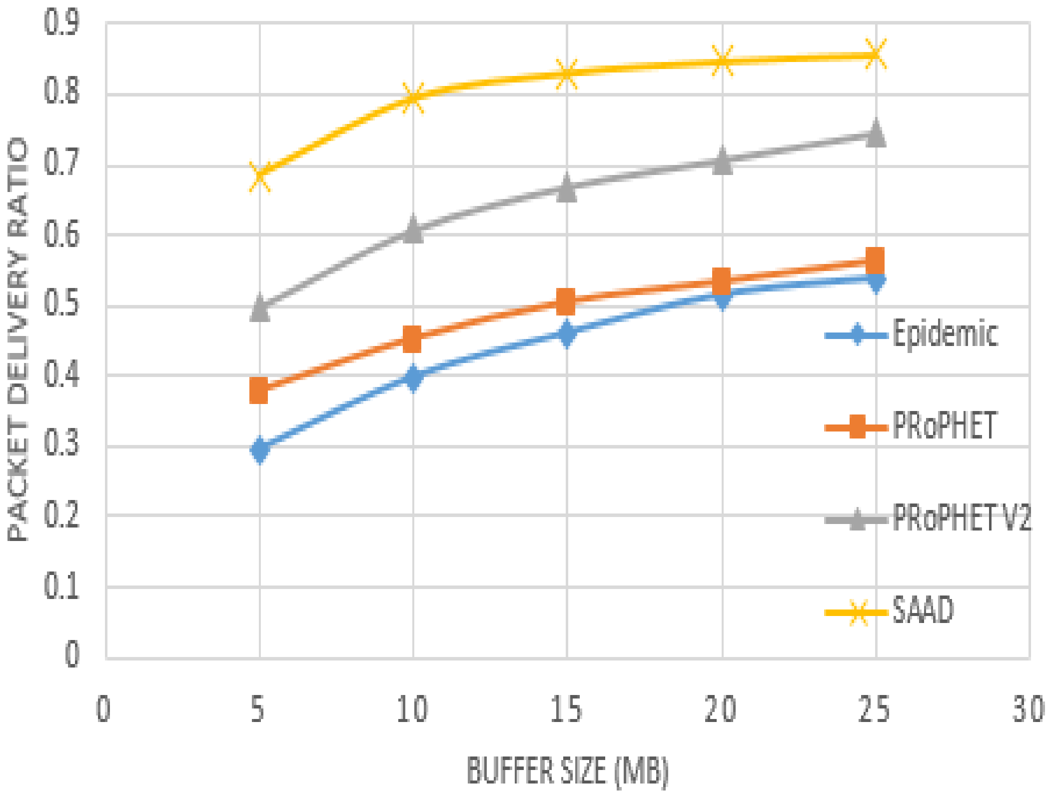


FIGURE 5.3: Packet Delivery Ratio with different buffer capacity and Degree Centrality (threshold = 2)

In Figure 5.2, when we use threshold = 1, all nodes that have Degree Centrality (DC) value greater than 1, are considered to be relay nodes. In this scenario, less number of nodes are initially short listed as compared to the previous scenario when threshold was 0, because only those nodes are short listed which have two or more Degree Centrality. The increase in threshold, increases the performance of SAAD to some extent in terms of message delivery. Therefore, as we increase the threshold value to 2, 3 and 4 respectively, message delivery increases.

When we use threshold = 3, SAAD showed an improvement in terms of PDR as compared to the previous scenarios(i.e.; threshold = 0, 1 and 2) because now all the nodes which has DC value either 3 or more are short listed for forwarding process. In this scenario, less nodes are short listed as compared to the previous scenarios. This increases the performance of proposed routing scheme. On the other hand, when we use buffer size of 5MB, SAAD's PDR is 0.62 while when we use buffer size of 10MB, SAAD showed a better improvement in terms of PDR

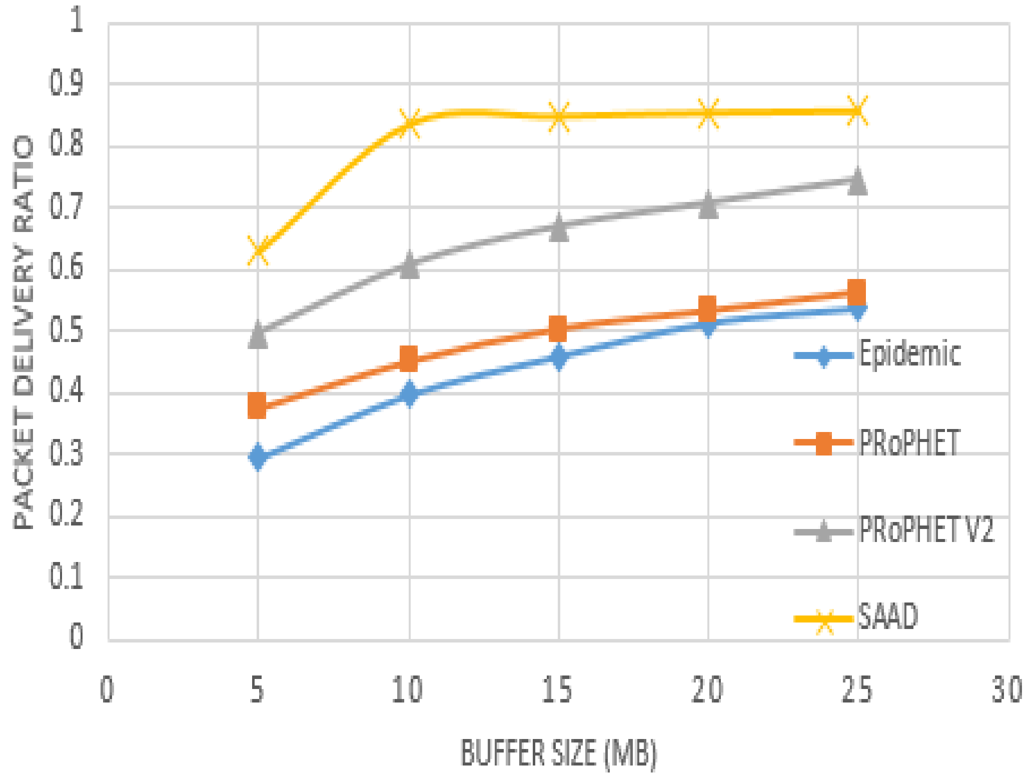


FIGURE 5.4: Packet Delivery Ratio with different buffer capacity and Degree Centrality (threshold = 3)

from 0.62 to 0.84. When we use buffer size of 15MB, a minor improvement in PDR is observed which is 0.86 as shown in Figure 5.4.

Similarly, when we use buffer size of 20MB and 25MB, SAAD showed almost the same PDR as it produced with buffer size of 15MB. Therefore, we can conclude that when we use buffer size 5MB, 10MB and 15MB, PDR increases gradually but with buffer size 20MB and 25MB, almost the same number of nodes are short listed as with of 15MB because of high threshold.

When we use threshold = 4,all neighboring nodes having Degree Centrality value 5 or more are considered to be relay nodes. When we use buffer size 5MB, initially the proposed routing scheme showed more PDR which is 0.71 as shown in Figure 5.5 which is higher than PDR showed with 5MB when threshold was 3. With buffer size 10MB, SAAD delivers more messages with PDR 0.84 because more messages can reside in buffer as shown in Figure 5.5 but when we use buffer size 15MB, 20MB and 25MB, SAAD showed almost

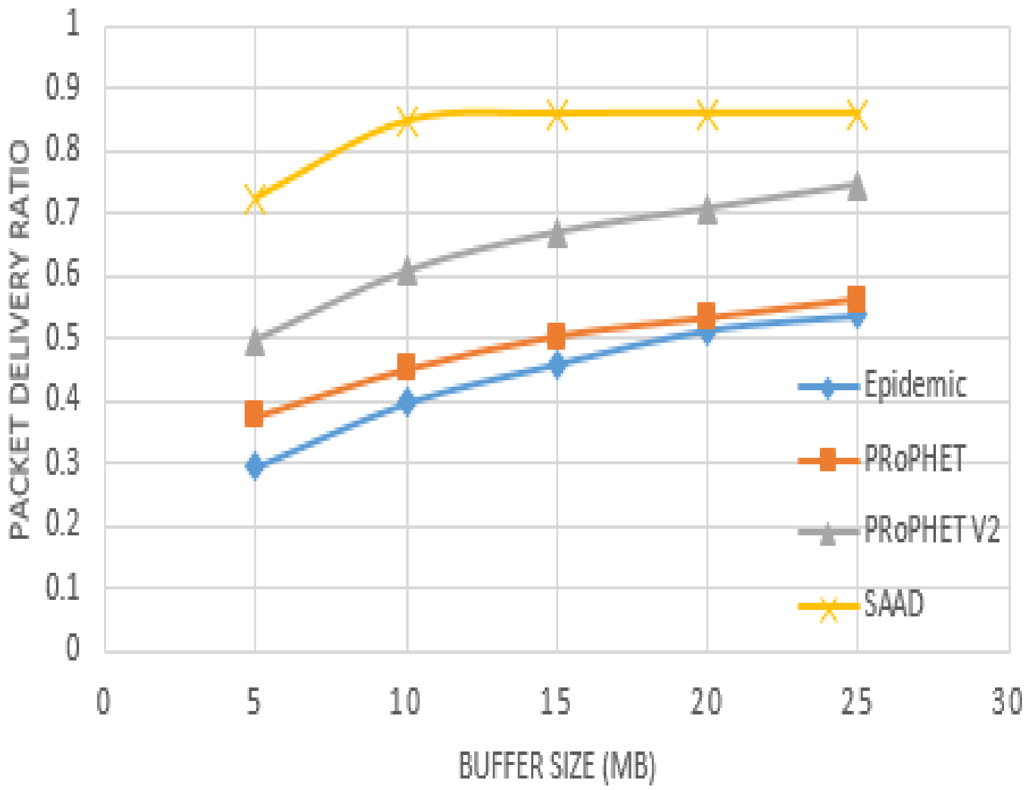


FIGURE 5.5: Packet Delivery Ratio with different buffer capacity and Degree Centrality (threshold = 4)

the same PDR value 0.86 even though more messages can reside in 15MB, 20MB and 25MB as compared to 5MB, and 10MB.

We analyzed the impact of buffer capacity on the simulation results, resultantly, as we increase the buffer capacity (i.e; 5MB, 10MB, 15MB, 20MB, 25MB, etc.); the delivery ratio and average packet delay are also increased. The proposed routing scheme has shown a significant improvement in packet delivery ratio as well as in overhead at the cost of longer delays.

5.1.2 Overhead Ratio

We run the simulations using different threshold values (i.e.; 0, 1, 2, 3 and 4) and different buffer sizes, we observed that Epidemic routing technique showed high overhead as compared to the other routing techniques because it floods the message to all its neighboring nodes which results in utilization of high bandwidth. On the other hand, it can also be observed that with increase of buffer size, the overhead

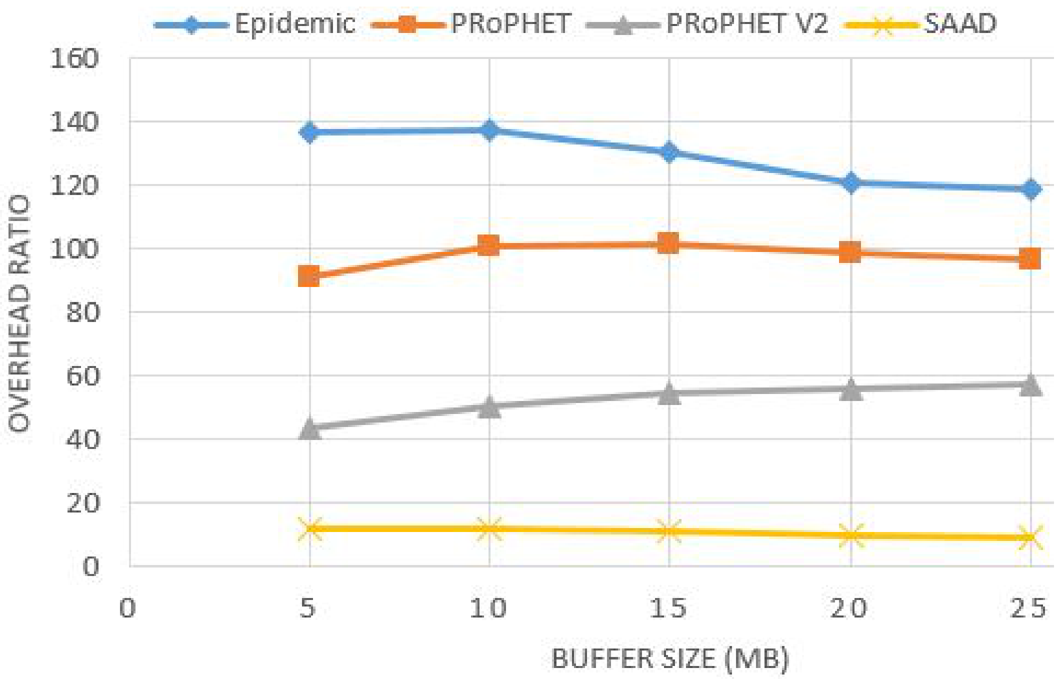


FIGURE 5.6: Overhead Ratio with different buffer capacity and Degree Centrality (threshold = 0)

gradually decreases from 138 to 120 because as far as we increase the buffer size, a node can carry more messages which not only increase packet delivery ratio but also decrease overhead ratio. PRoPHET showed low overhead than Epidemic but high overhead than PRoPHETv2 and SAAD. Unlike Epidemic, PRoPHET routing technique forwards message to one or more number of nodes which meet the given criteria. Hence, nodes utilize less bandwidth than Epidemic and more bandwidth than PRoPHETv2 and SAAD.

PRoPHETv2 has shown lower overhead than Epidemic and PRoPHET because it relayed less number of messages in the network which results in low utilization of network resources. While with threshold = 0, the proposed routing scheme show high overhead than PRoPHETv2 with buffer size 5MB, 10MB and 15MB but showed lower overhead than PRoPHETv2 with buffer size 20MB and 25MB because more messages can reside with buffer size 20MB and 25MB than buffer size 5MB, 10MB and 15MB.

However, SAAD showed less overhead than Epidemic and PRoPHET because all nodes having even a DC value '1' or more, are initially short listed.

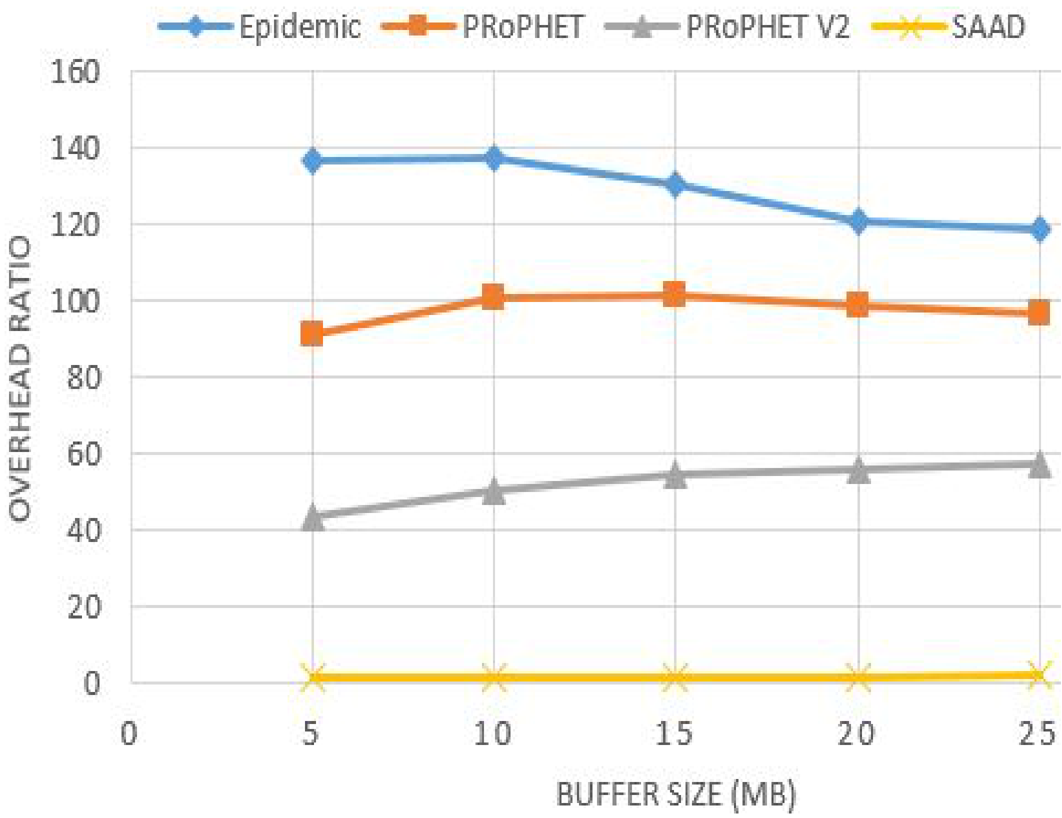


FIGURE 5.7: Overhead Ratio with different buffer capacity and Degree Centrality (threshold = 1)

Hence, large number of short listed nodes utilized more bandwidth which results in high overhead.

When we use threshold =1, it can be seen in Figure 5.7 that SAAD showed lowest overhead than Epidemic, PRoPHET and PRoPHETv2. Overhead is further decreasing gradually with increase in buffer size (i.e.; overhead between 0 and 20) because with threshold = 1, less number of nodes are short listed which results in low overhead than with threshold = 0.

Figure 5.8 demonstrates that when we use threshold = 2, SAAD showed the lowest overhead than Epidemic, PRoPHET and PRoPHETv2 which is almost 0 because less number of nodes are short listed. Due to high threshold (3), few messages are relayed which results in low overhead as compared to the previous situations in which threshold was 0 and 1.

With threshold = 3, SAAD produces low overhead as compared to Epidemic, PRoPHET and PRoPHETv2 because with increase in threshold, less number of

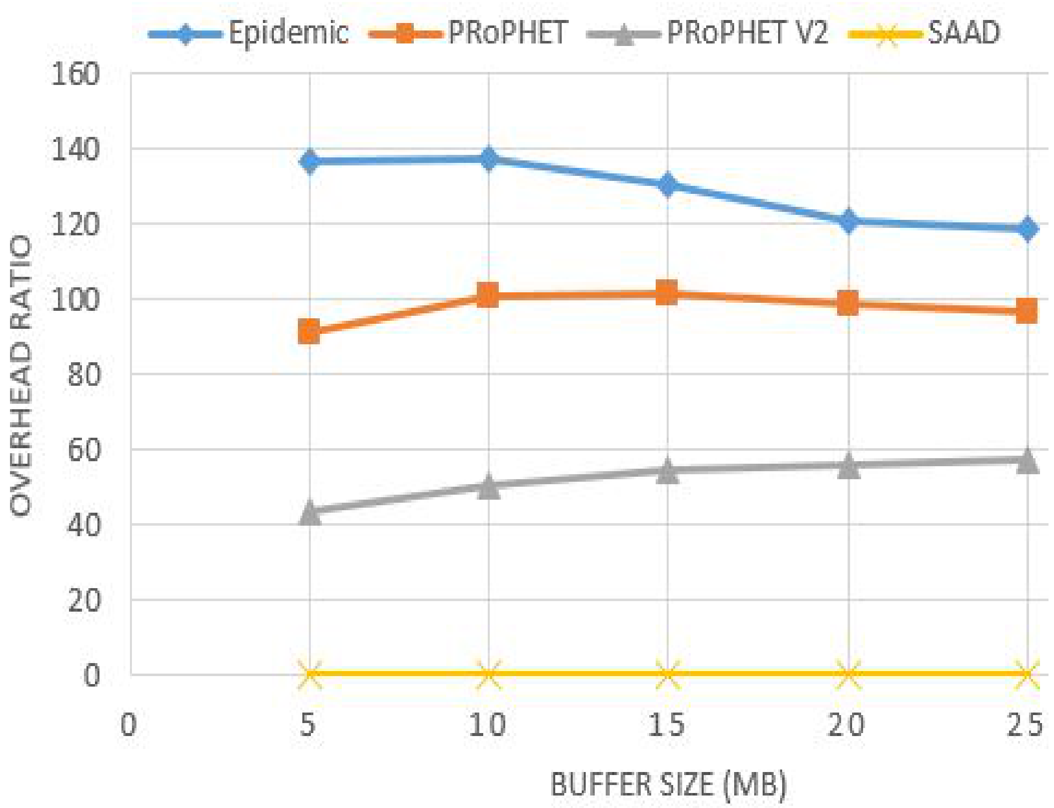


FIGURE 5.8: Overhead Ratio with different buffer capacity and Degree Centrality (threshold = 2)

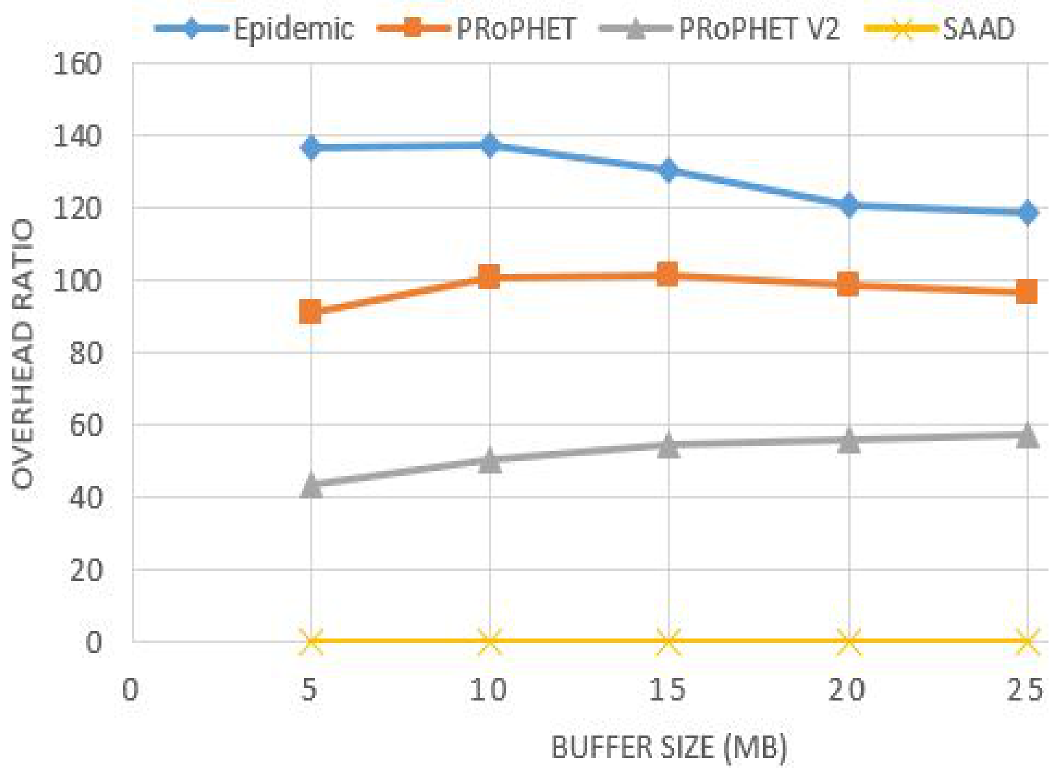


FIGURE 5.9: Overhead Ratio with different buffer capacity and Degree Centrality (threshold = 3)

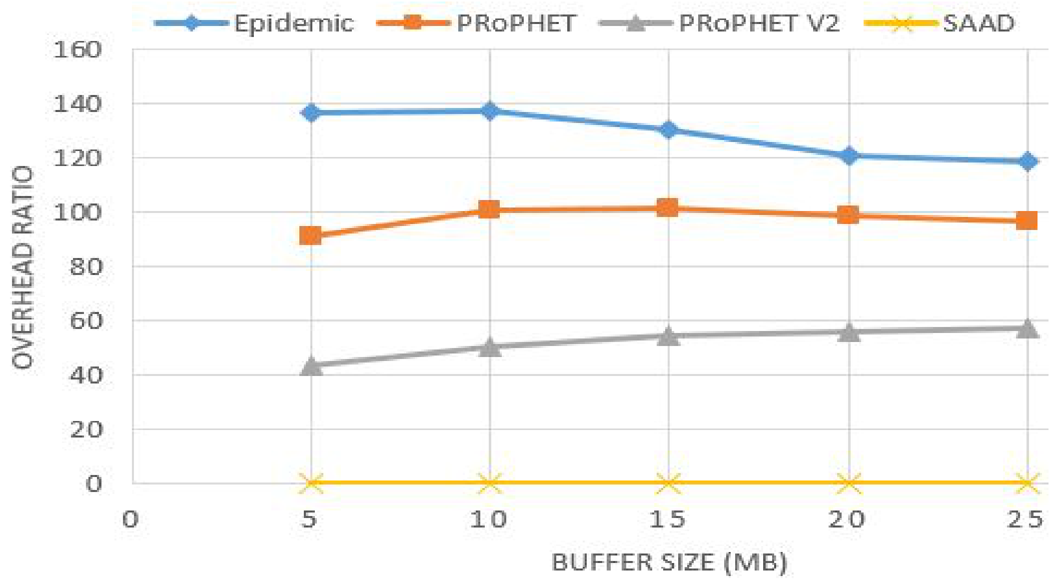


FIGURE 5.10: Overhead Ratio with different buffer capacity and Degree Centrality (threshold = 4)

nodes are short listed which decreases the overhead to a great extent. While With threshold = 3, SAAD produces slightly more overhead than with threshold 2 as shown in Figure 5.9 and Figure 5.10.

With threshold = 4, SAAD produces low overhead not only as compared to Epidemic, PRoPHET and PRoPHETv2 but also with threshold 3 because with increase in threshold, very few nodes are selected as relay nodes which can take part in message forwarding process. Due to less number of nodes being short listed, less number of messages are relayed in the network which results in low overhead. An other reason of producing low overhead is that our proposed routing technique is that it forwards the message to only one hop node possessing highest Degree Centrality.

5.1.3 Average Hop-count

The simulation results demonstrates that Epidemic routing technique encounters more number of average hops to send a message from a source node to a destination node as compared to PRoPHET, PRoPHETv2 and SAAD because it broadcasts the message to all its neighboring nodes and all nodes participate in the forwarding process. Hence, Epidemic encounters large number of hops as shown

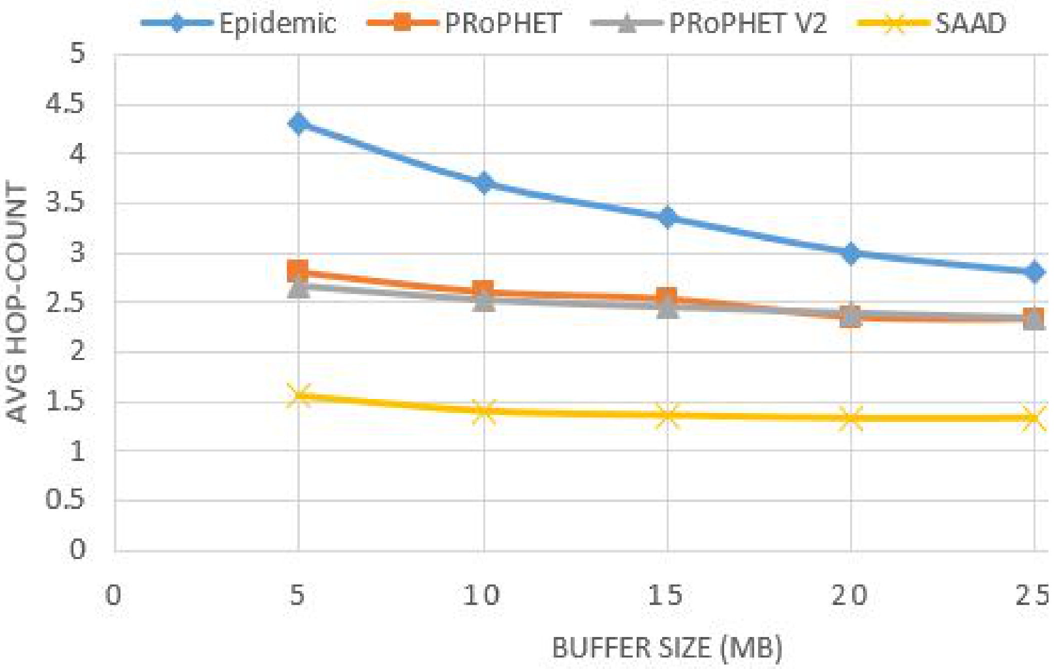


FIGURE 5.11: Average Hop-count with different buffer capacity and Degree Centrality (threshold = 0)

in Figure 5.11. While PRoPHET encounters less number of nodes because unlike Epidemic, PRoPHET forwards message to either a single node or more than one node which meet the given criteria but encounters slightly more number of nodes than PRoPHETv2 .

PRoPHETv2 routing technique encounters less number of nodes as compared to Epidemic and PRoPHET but encounters more number of nodes than SAAD. On the other hand, it can be observed that with increase of buffer size, the number of hops gradually decreases in all routing schemes because with more buffer size, more message can be carried which results in packet delivery using low number of hops.

It can be seen in the Figure 5.11 to Figure 5.15 that SAAD is encountering less number of hops to deliver the packets from the source node to the destination node as compared to Epidemic, PRoPHET and PRoPHETv2. When we use threshold value = 0, SAAD encounters less average hop-count from 1.5 to 2.3 as compared to Epidemic, PRoPHET and PRoPHETv2. However, when we increase buffer sizes from 5MB to 25MB, the number of average hop-count decreases gradually from

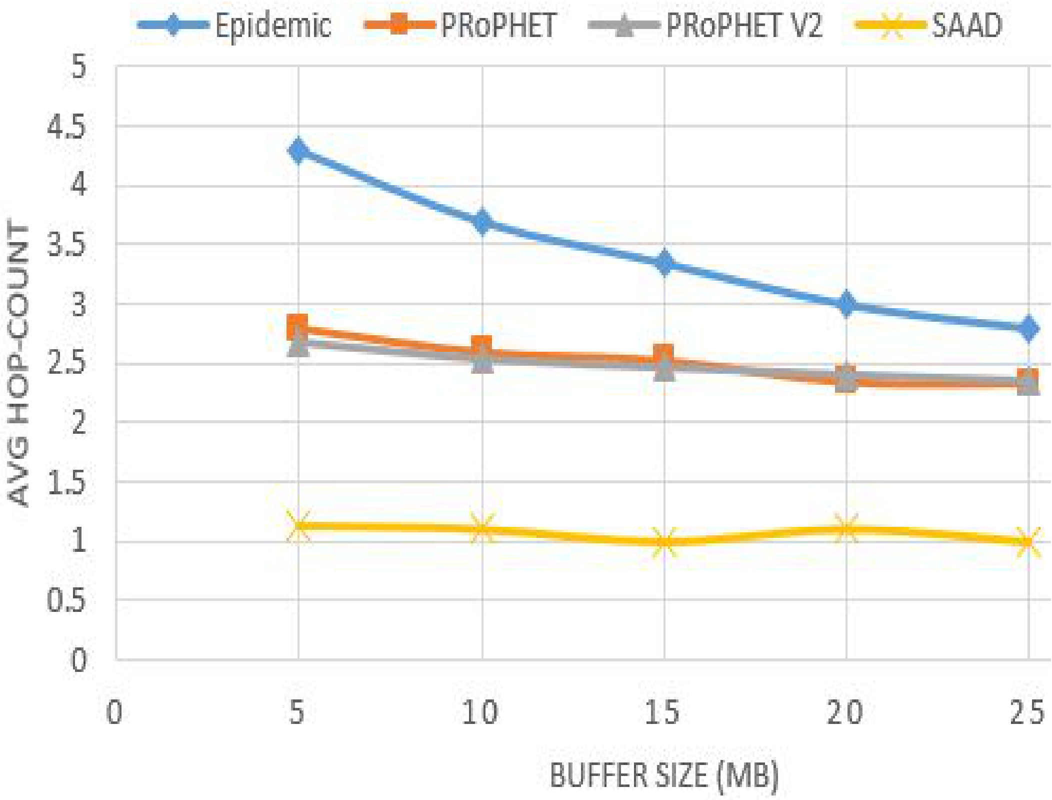


FIGURE 5.12: Average Hop-count with different buffer capacity and Degree Centrality (threshold = 1)

2.3 to 1.75.

While when we use threshold value = 1, SAAD encounters average hop-count 1.3 to 1.6 as shown in Figure 5.12. When we use buffer size 5MB, SAAD encounters almost 2.3 average hop-count but as we increase the buffer size from 10 MB to 25 MB, the average hop-count gradually decrease from 2.3 to almost 1.8 as shown in Figure 5.12.

With threshold value = 2, SAAD encounters less number of hops to deliver packets from a source node to the destination node because with threshold 2, less number of nodes are qualified for the selection of relay nodes.

Due to less no of nodes participating in the message forwarding process, the encounter ratio decreases and packet drop ratio also decreases which results in less number of average hop-count to delivery messages successfully towards the destination. SAAD encounters almost average hop-count 1.3 to 1.6. When we use

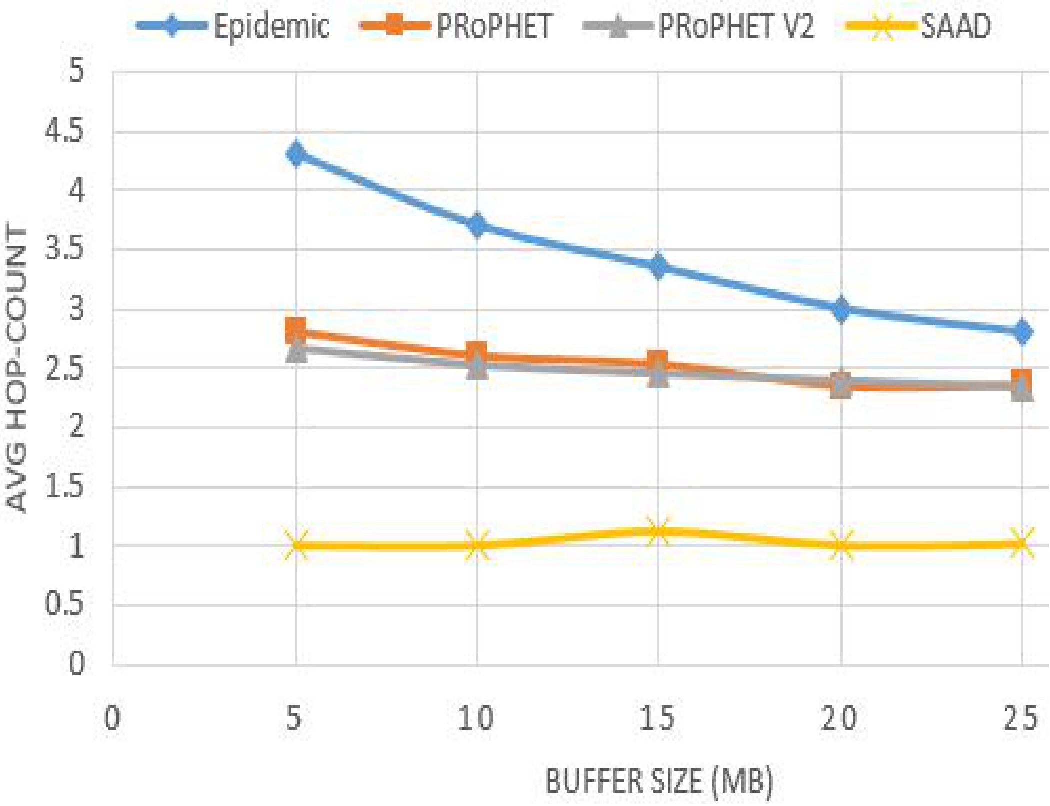


FIGURE 5.13: Average Hop-count with different buffer capacity and Degree Centrality (threshold = 2)

buffer size of 5MB 10MB, 15MB, 20MB and 25MB, average hop-count gradually decreases from 1.6 to 1.3.

With threshold value = 3, SAAD has shown improvement in terms of exploiting number of hops to forward packets and encountering less number of hops to deliver the packets from the source node to the destination node as compared to Epidemic, PRoPHET and PRoPHETv2 as shown in Figure 5.13.

With threshold value = 3, Epidemic encounters large number of nodes to deliver message while SAAD with all buffer sizes, encounters almost 1 as an average hop count because with high threshold, less number of nodes are considered as forwarder nodes. Consequently, source node or intermediate node encounters less no of hops to deliver message successfully.

With threshold value = 4, SAAD utilized less number of hops to relay messages towards the destination. Our proposed routing scheme forwards the message to a more central and social node which has highest Degree Centrality. Our

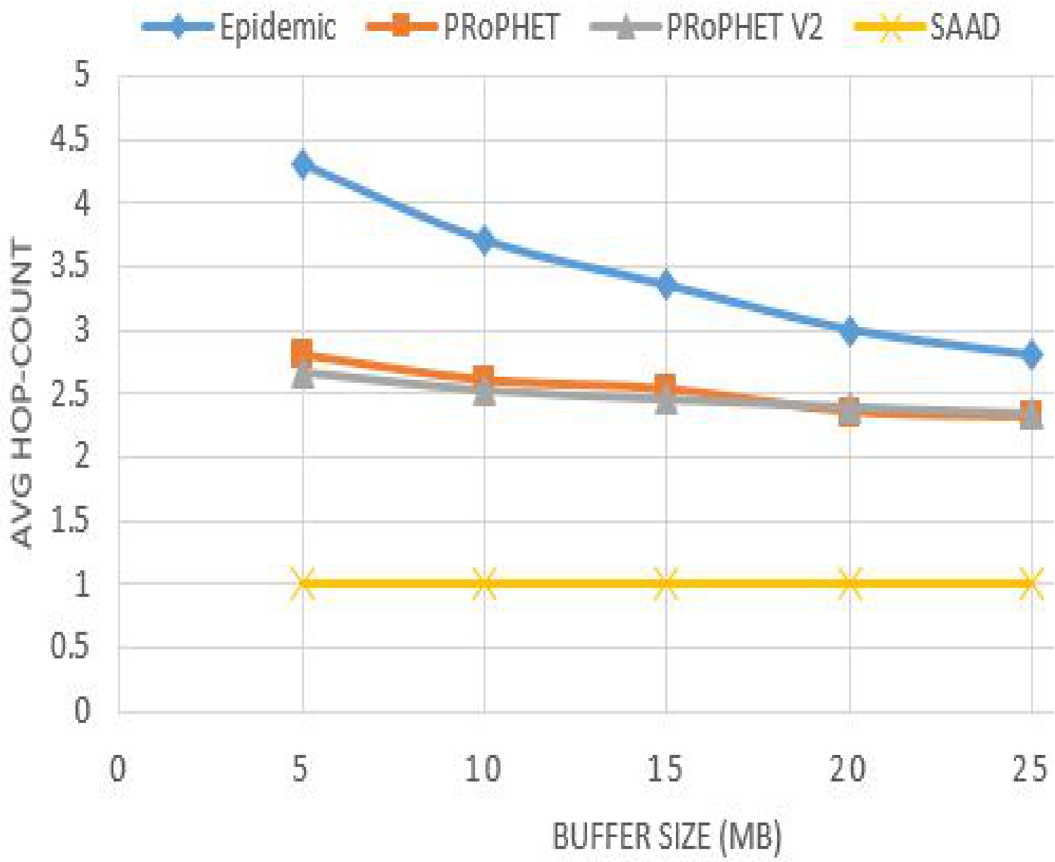


FIGURE 5.14: Average Hop-count with different buffer capacity and Degree Centrality (threshold = 3)

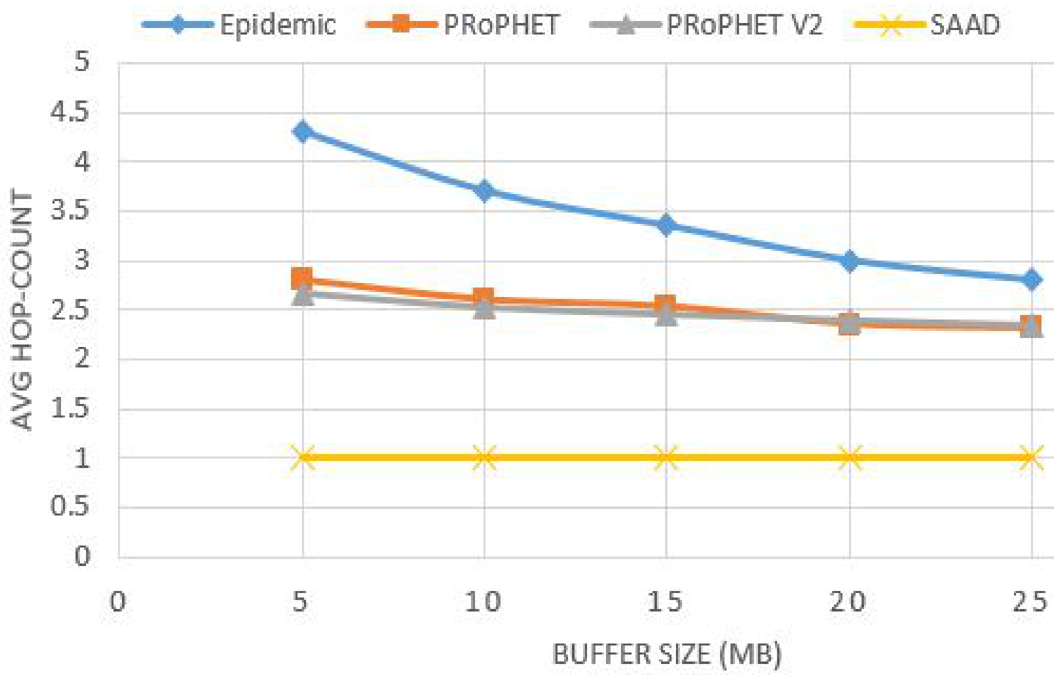


FIGURE 5.15: Average Hop-count with different buffer capacity and Degree Centrality (threshold = 4)

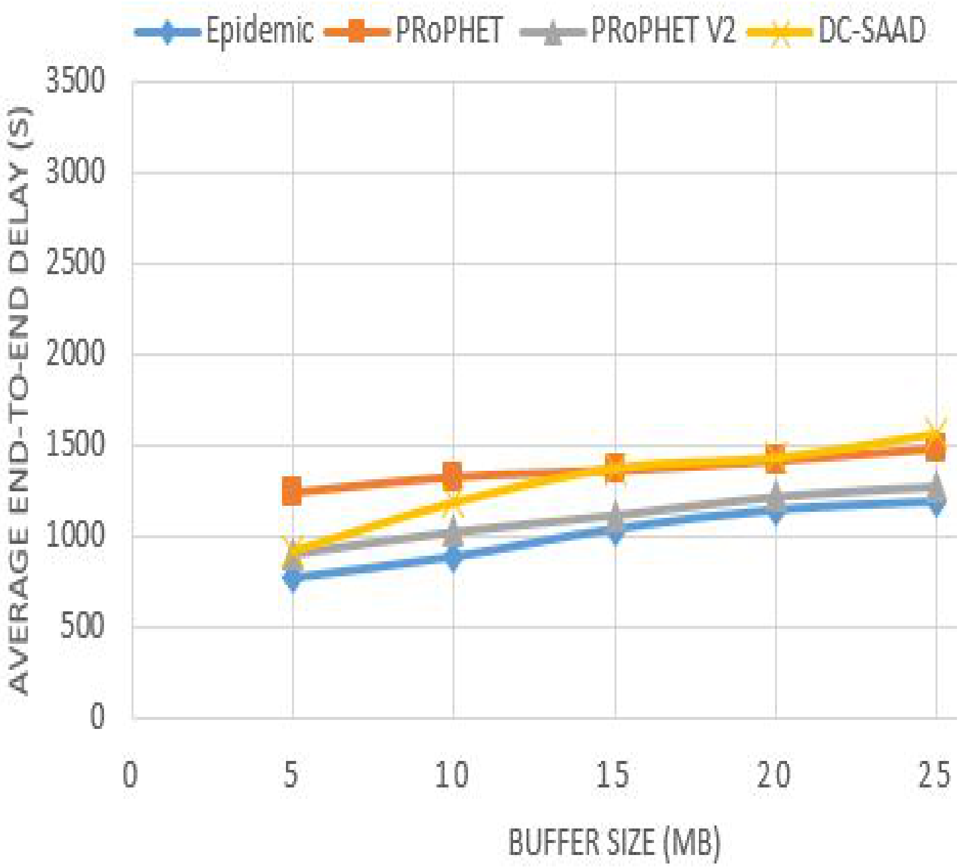


FIGURE 5.16: Average end-to-end delay with different buffer capacity and Degree Centrality (threshold = 0)

proposed routing scheme encounters less number of nodes as compared to Epidemic, PRoPHET and PRoPHETv2 and delivered messages to the destination successfully as shown in Figure 5.15.

5.1.4 Average end-to-end Delay

It can also be seen in the Figure 5.16 to Figure 5.20 that SAAD improve the packet delivery ratio, reduce the overhead and hop-count as compared to Epidemic, PRoPHET and PRoPHETv2 but at the expense of higher average end-to-end delay. When we use threshold = 0 (which means even if a node has a single connected node, can participate in forwarding process). Epidemic routing scheme produces the lowest delay because Epidemic broadcasts the message and takes less time to reach the destination node as the delivery probability is maximum in broadcast delivery. PRoPHET produces higher delay than Epidemic and PRoPHETv2.

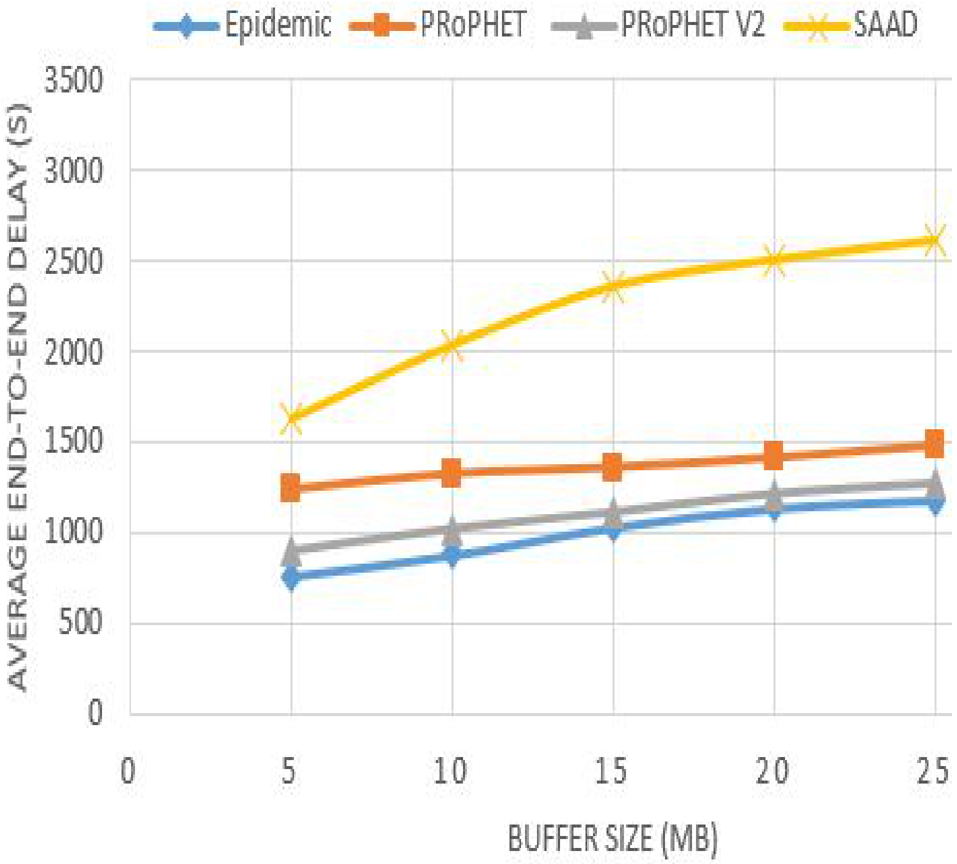


FIGURE 5.17: Average end-to-end delay with different buffer capacity and Degree Centrality (threshold = 1)

On the other hand, Epidemic produces very low average end-to-end delay than all other routing schemes because Epidemic routing scheme broadcast the message to all neighboring nodes without any selection criteria which increases the delivery probability in less time which results in low latency. Unlike Epidemic, PRoPHET routing technique forwards message to more than one hop nodes which meet the delivery predictability. As a result, PRoPHET routing scheme take more time deliver all the message to the destination.

When we use threshold value = 1, SAAD has produced more delay than with threshold = 0. With threshold = 2, SAAD produces more delay as compared to threshold 0 and 1. However, SAAD with buffer size of 5MB, initially produces almost 2300 delay but when we increase buffer size to 10MB, it produces almost 3000 delay while with buffer size of 15MB, 20MB and 25MB, average end-to-end delay increases gradually as shown in Figures 5.17, and 5.18.

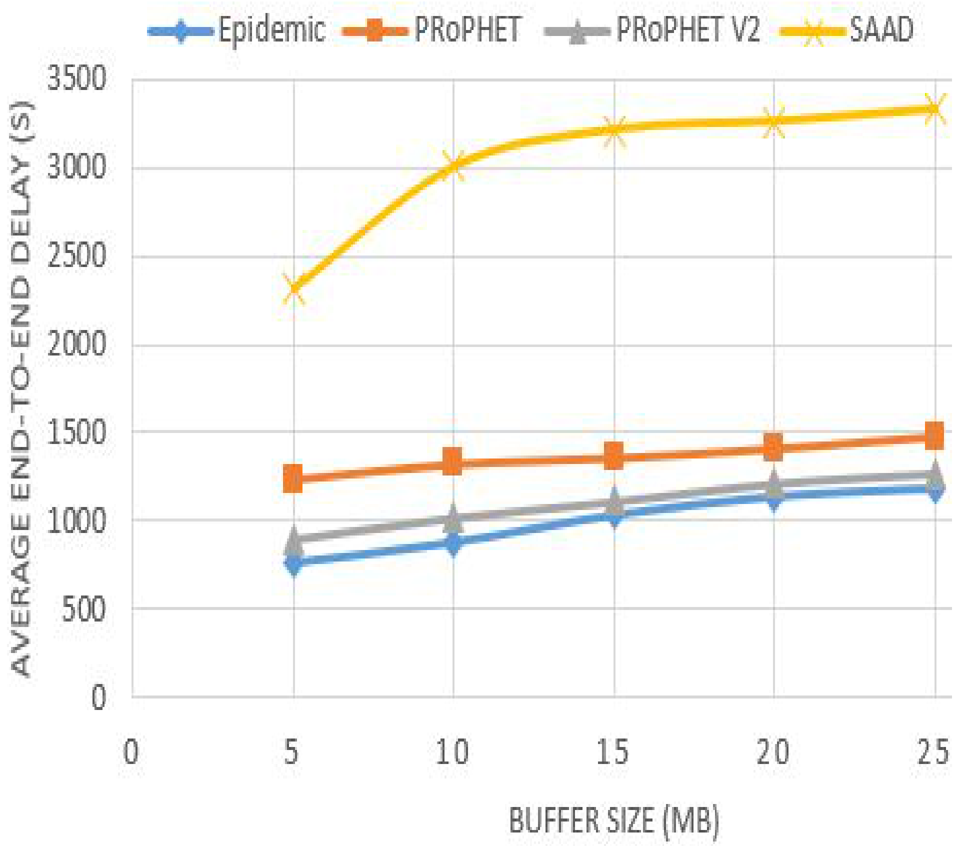


FIGURE 5.18: Average end-to-end delay with different buffer capacity and Degree Centrality (threshold = 2)

With high threshold, less number of nodes meet the threshold and selected as relay nodes. Although in this situation nodes uses less number of hops to forwards messages to the destination but take long to transmit all messages to the destination node successfully.

However, SAAD initially produces low delay than PRoPHET with buffer size 5MB and 10MB, almost the same delay with buffer size 15MB and 20MB but, produces higher delay than even PRoPHET when we use buffer size 25MB as shown in Figure 5.16. When we use threshold 1, 2, 3 and 4, SAAD produces higher delay than Epidemic, PRoPHET and PRoPHETv2 with all buffer sizes (i.e.; 5MB, 10MB, 15MB, 20MB and 25MB) as shown in Fig. 5.19 and Fig. 5.20.

With threshold value = 3, SAAD has produced more delay than with threshold

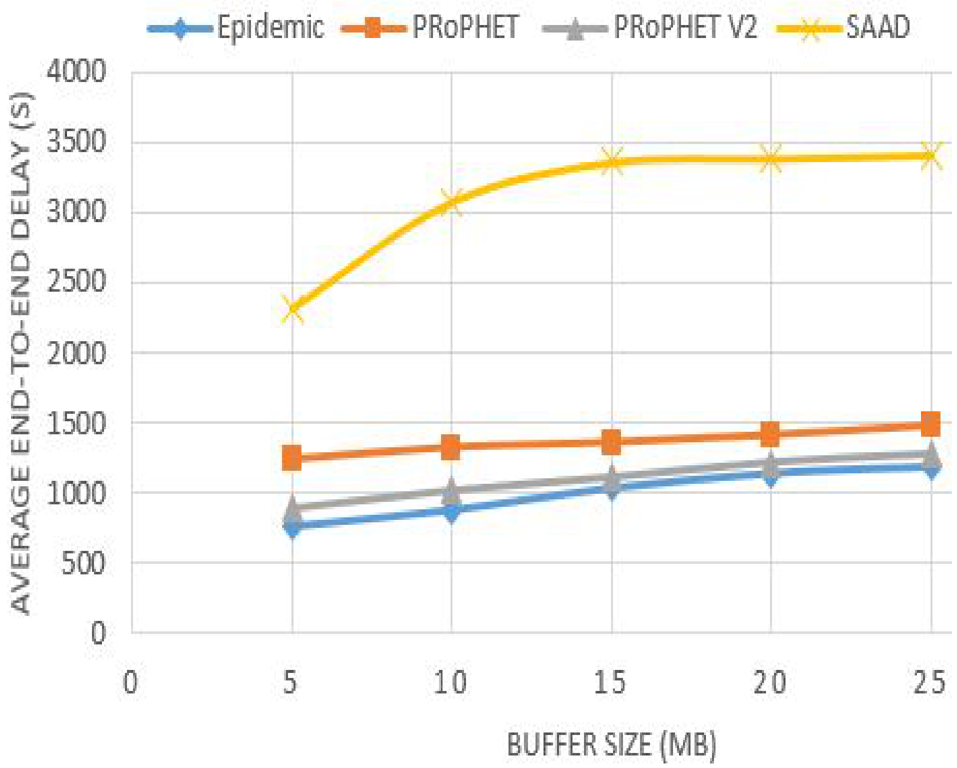


FIGURE 5.19: Average end-to-end delay with different buffer capacity and Degree Centrality (threshold = 3)

= 0, 1 and 2. With threshold = 3, SAAD produces more delay than Epidemic, PRoPHET and PRoPHETv2. With threshold 3, less number of nodes qualified to be selected as forwarder/intermediate nodes which can take part in message forwarding process. Consequently, less number of nodes take long time to forwards all messages from source to the destination which results in high average end-to-end delay. With high threshold, the node's encounter ratio decreases as compared to threshold 0, 1 and 2.

However, SAAD with buffer size of 5MB, initially produces almost 2500 average end-to-end delay but when we increase buffer size to 10MB, it produces almost 3700 average end-to-end delay while with buffer size of 15MB, 20MB and 25MB, average end-to-end delay remains the same as shown in Figure 5.18.

With threshold = 4, SAAD produces more delay than Epidemic, PRoPHET and PRoPHETv2. With threshold value = 4, SAAD has produced more average end-to-end delay than with threshold = 0, 1, 2 and 3. With threshold 4, only few

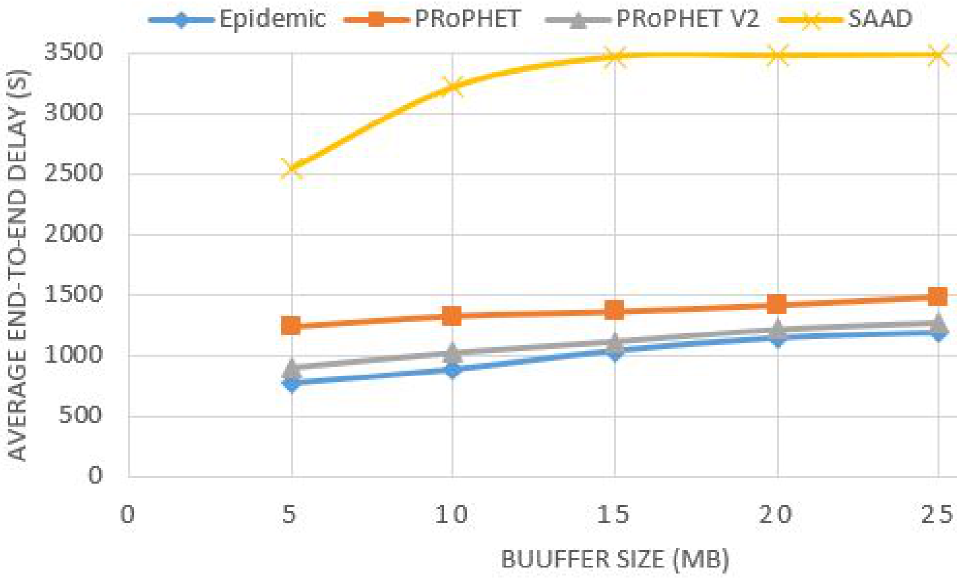


FIGURE 5.20: Average end-to-end delay with different buffer capacity and Degree Centrality (threshold = 4)

number of nodes are short listed as forwarder nodes which results in high average end-to-end delay to forward all messages from a source node to the destination node.

With high threshold, less number of nodes meet the threshold and selected as relay nodes. Although in this situation nodes uses less number of hops to forwards messages to the destination but take long to transmit all messages to the destination node successfully.

Finally, it can be said that SAAD has shown improvement as compared to Epidemic, PRoPHET and PRoPHETv2 in terms of delivery ratio, overhead and hop-count but at the cost of higher average end-to-end delay which can be tolerated in DTN.

5.2 Results of Scalable Routing Scheme (Scalable-SAAD)

To ensure the scalability of our proposed routing scheme SAAD, we run the simulations with different number of nodes (i.e.; Node-50, Node-100 and Node-150) keeping all other parameters vale same as we have in SAAD. We run the simulations by using Epidemic routing scheme, PRoPHET, PRoPHETv2 and SAAD. We have run simulations successfully with different number of nodes and has shown the improvement in Packet delivery ratio, overhead ratio and hop-count at the cost of long delays which a DTN has potential to cope with delays. We observed that In node-100 scenario and node-150 scenario, PRoPHET can run the simulation with only buffer size 5MB, 10MB and 15MB but not with 20MB and 25MB. We also used different random seed values for each simulation to get different results each time.The description of results along with graphs is as follows:

5.2.1 Packet Delivery Ratio

We run the simulations and records the results presented in statistical repot by ONE simulator. In statistical report, the number of packets delivered are shown, later we calculate the packet delivery ratio with the help of formula mentioned in chapter 3. The following graphs shown in Figures 5.21 5.22 5.57 show the message delivery ratio. We uses various buffer sizes for the simulation (i.e.; 5MB, 10MB, 15MB,20MB and 25MB). For each buffer size, each simulation has been run for 12 hours, this process repeated for five times and then average of the five simulations is taken as a final value. We do simulations using different number of nodes (i.e; Node-50 scenario, Node-100 scenario and Node-150 scenario). We also uses different threshold values e.g. 0, 2, and 4. We start simulation with threshold value = '0', so that a node even if it has a single neighbor node, can participate in the message forwarding process.

Epidemic routing scheme broadcasts the packets to its neighbors. Consequently, a large number of packets are relayed in the network which results in high packet drop ratio. Unlike Epidemic, PRoPHET forwards packet to those neighboring nodes (may be more than one if they have the same predictability) which meet the given criteria. Therefore, this routing scheme relayed less number of packets as compared to Epidemic. PRoPHETv2 routing scheme refines the predictability formula of PRoPHET to select the popular nodes to forward the packet to the

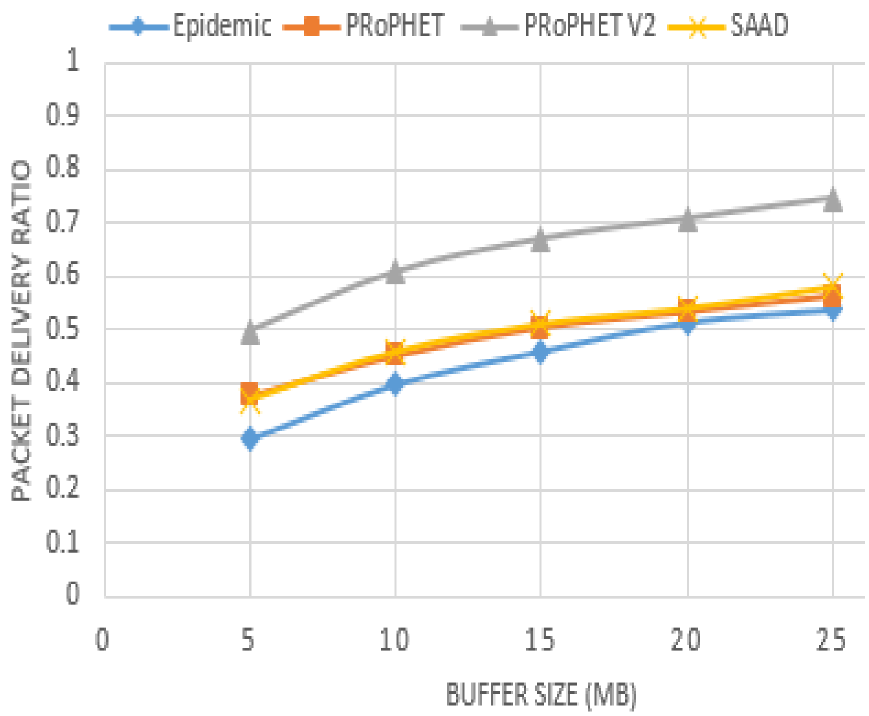


FIGURE 5.21: Packet Delivery Ratio with 50-nodes and Degree Centrality (threshold = 0)

next hop. This routing scheme relayed less number of packets as compared to PRoPHET and Epidemic. However, SAAD forwards packet to only one neighbor node which possesses highest Degree Centrality. Therefore, our proposed routing scheme relayed very less number of packets which results in high packet delivery ratio.

In Node-50 scenario, with threshold value = 0, Scalable-SAAD delivered more packets than Epidemic and PRoPHET. However, it has shown bit lower performance than PRoPHETv2 because large number of nodes are initially short listed and more messages are relayed in network which also increase the packet drop ratio. This reduces the performance of Scalable-SAAD in terms of packet delivery. We have also observed that increase in buffer size, increases the packet delivery ratio as with increase in buffer size, more messages can reside in a buffer which in result increase the PDR.

In Node-100 scenario, with threshold value = 0, Scalable-SAAD performs better

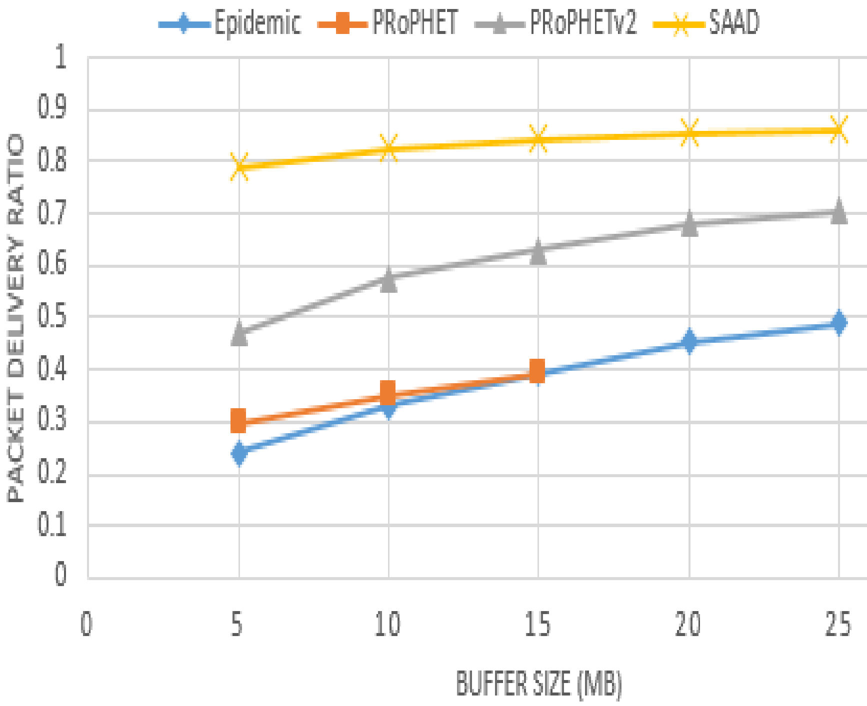


FIGURE 5.22: Packet Delivery Ratio with 100-nodes and Degree Centrality (threshold = 0)

than Epidemic, PRoPHET and PRoPHETv2. However, with buffer size 5MB, the proposed routing scheme produces almost 0.8 PDR, while with buffer size 10MB, PDR value is almost 0.82 which further increases gradually with the gradual increase in buffer size as shown in Figure 5.22.

In Node-150 scenario, with threshold value = 0, Scalable-SAAD performs better than Epidemic, PRoPHET and PRoPHETv2 because more nodes in the network increase the packet delivery probability. However, the PDR value is lower than Node-100 scenario. In this scenario, packet delivery ratio increases with the gradual increase in buffer size as shown in Figure 5.57.

With threshold value = 2, all nodes that have a Degree Centrality value greater than 2, are considered to be relay nodes. with threshold 2, less number of nodes are initially short listed as compared to the previous scenario in which threshold was 0 which increases the performance of Scalable-SAAD to some extent in terms of packet delivery ratio (PDR) as shown in Figures 5.24, 5.25 and 5.26. When we increase the threshold value to 2, PDR increases in all three scenarios (i.e; Node-50

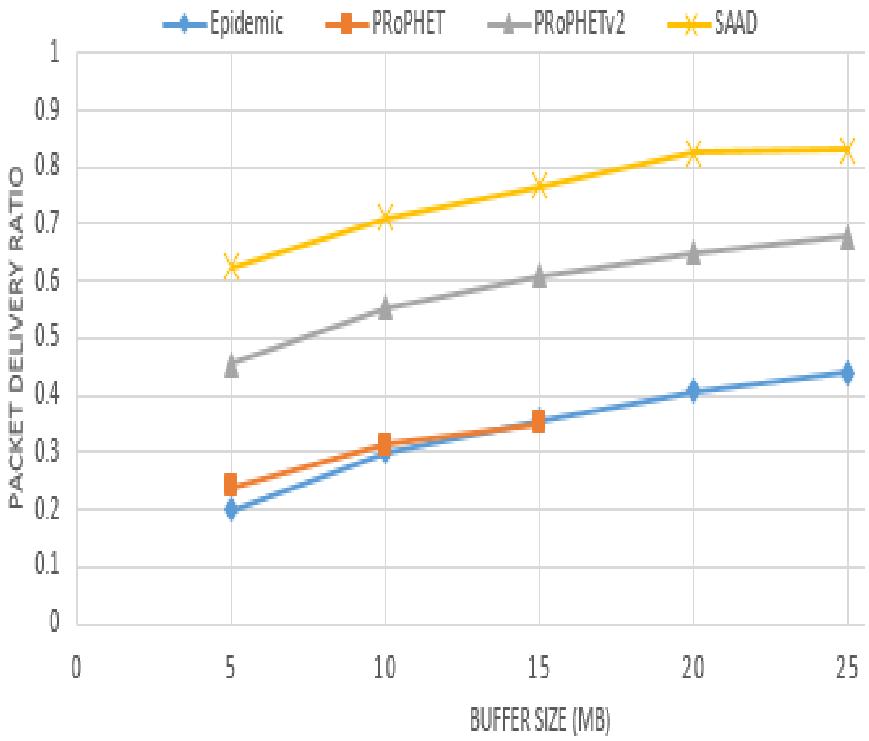


FIGURE 5.23: Packet Delivery Ratio with 150-nodes and Degree Centrality (threshold = 0)

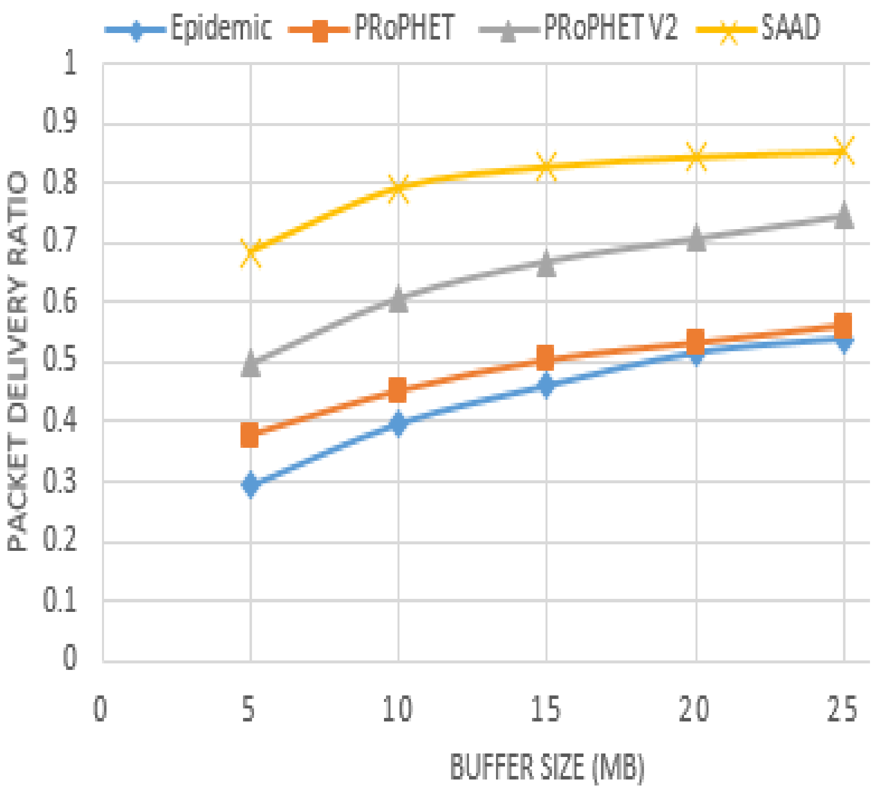


FIGURE 5.24: Packet Delivery Ratio with 50-nodes and Degree Centrality (threshold = 2)

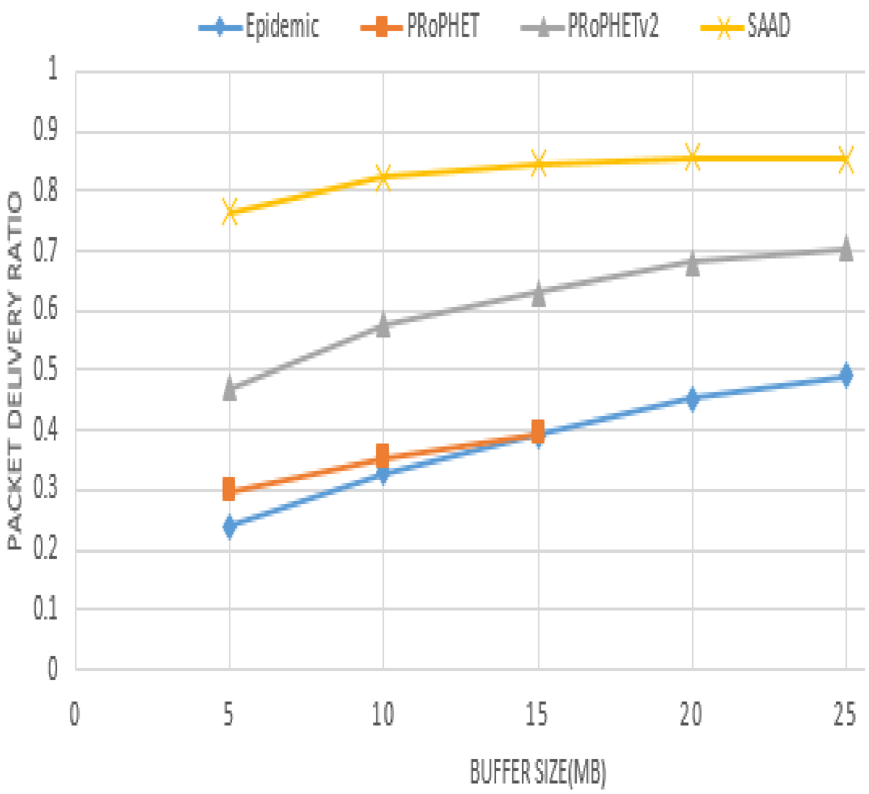


FIGURE 5.25: Packet Delivery Ratio with 100-nodes and Degree Centrality (threshold = 2)

scenario, Node-100 scenario and Node-150 scenario) because with high threshold, less number of nodes are short listed which relayed less number of messages in the network. The PDR increases because packet drop ratio decreases.

In Node-50 scenario with threshold value = 2, Scalable-SAAD delivered more packets than Epidemic, PRoPHET and PRoPHETv2. While, with Node-100, Scalable-SAAD not only delivered more packets than three other routing schemes but also delivered more packets than Node-50 scenario. When we use threshold value = 2. Scalable-SAAD has shown better performance in all three scenarios as compared to Epidemic, PRoPHET and PRoPHETv2. However, it has been observed that when we increase the buffer size (i.e; 5MB, 10MB, 15MB, 20MB, and 25MB), PDR increases gradually as shown in Figures 5.24, 5.25 and 5.26 because more messages can reside in buffer.

With threshold value = 4, Scalable-SAAD delivered more packets than Epidemic, PRoPHET and PRoPHETv2 in all three scenarios. In Node-50 scenario with

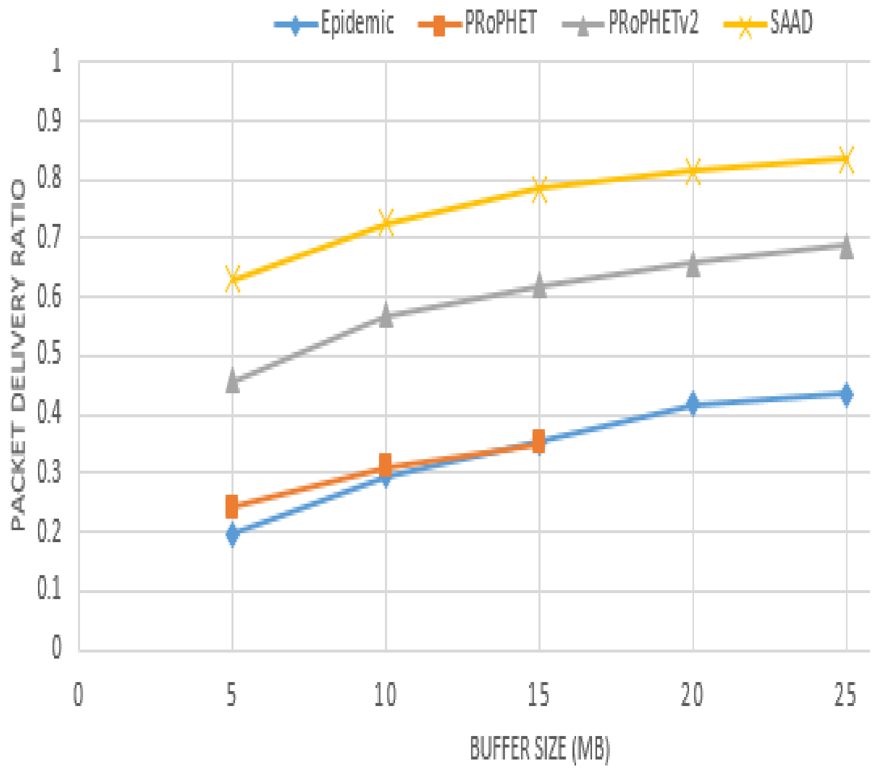


FIGURE 5.26: Packet Delivery Ratio with 150-nodes and Degree Centrality (threshold = 2)

buffer size 5MB, the proposed routing scheme delivered packets with PDR 0.72 while when we increase buffer size to 10MB, the proposed routing scheme delivered packets with PDR 0.82 as shown in Figures 5.27, 5.28 and 5.29. After that with buffer size 15MB, 20MB and 25MB, PDR almost remains the same, a slight gradual increase can be observed. While in Node-100 scenario with threshold 4, it has been observed that Epidemic, PRoPHET and PRoPHETv2 delivered slightly less number of packets than Node-50 scenario in which we have less number of nodes in the network.

Hence, Large number of nodes decreases their performance because large number of nodes relayed more message in the network, packet drop ratio increases which results in low packet delivery.

Scalable-SAAD with Node-100, initially delivered more packets than Node-100 scenario with buffer size 5 MB but after that gradual increase is observed with gradual increase in buffer size. On the other hand, Node-150 scenario delivered less number of packets than Node-100 scenario because large number of nodes in

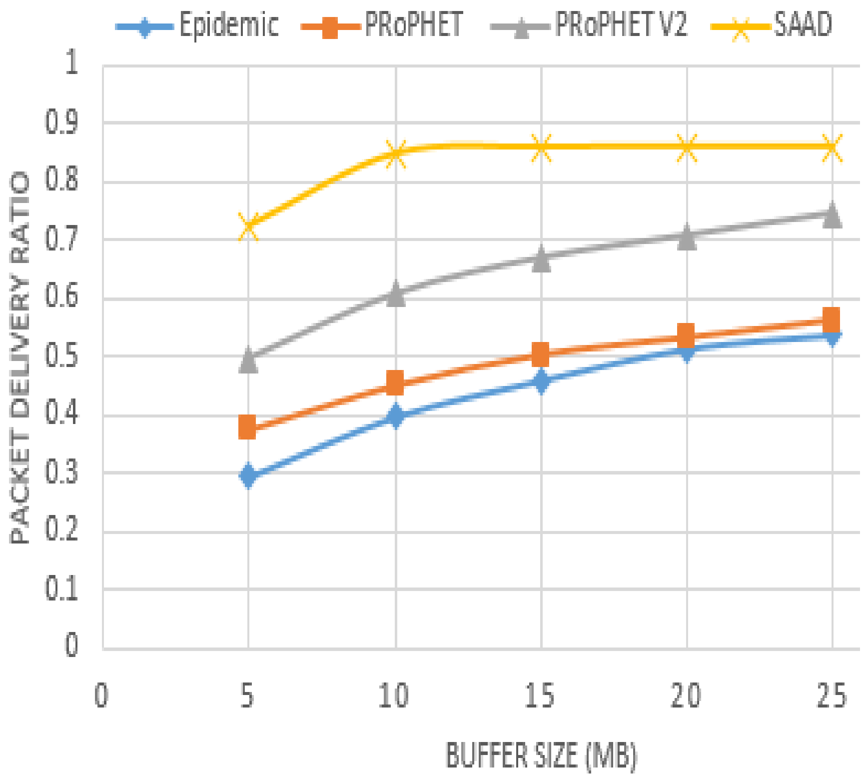


FIGURE 5.27: Packet Delivery Ratio with 50-nodes and Degree Centrality (threshold = 4)

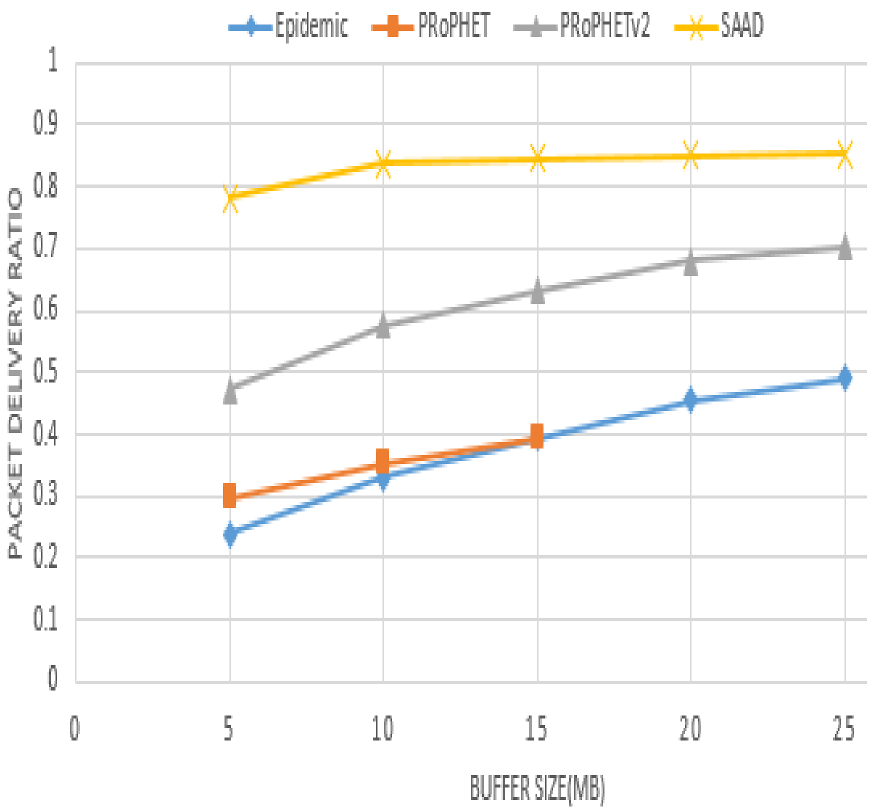


FIGURE 5.28: Packet Delivery Ratio with 100-nodes and Degree Centrality (threshold = 4)

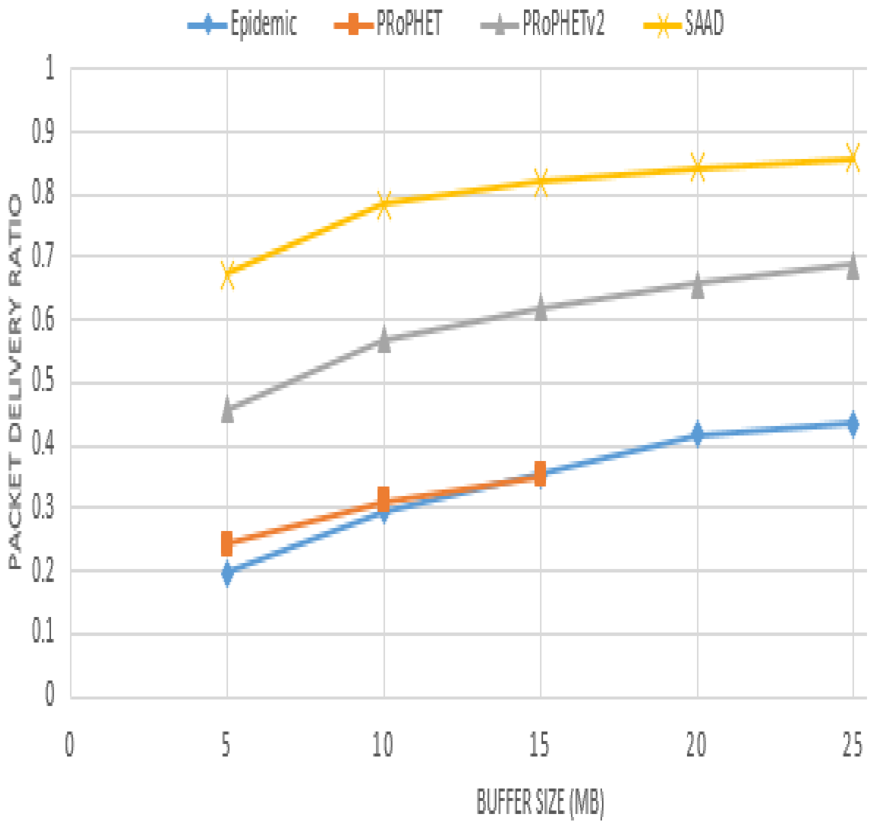


FIGURE 5.29: Packet Delivery Ratio with 150-nodes and Degree Centrality (threshold = 4)

the network relayed more packets, increase the packet drop ratio which ultimately decreases the packet delivery ratio. However, with gradual increase in the buffer size, packet delivery increases because more messages can reside in memory which decreases the packet drop ratio as shown in Figures 5.27, 5.28 and 5.29.

5.2.2 Overhead Ratio

When we run the simulation using different threshold values (i.e.; 0, 2, and 4) and different buffer sizes, it can be seen in the Figures 5.30 5.31 5.32 that Scalable-SAAD is delivering more messages than Epidemic, PRoPHET and PRoPHETv2 with lower overhead. We observed that Epidemic routing technique showed high overhead as compared to the other routing techniques because it floods the message to all its neighboring nodes which results in utilization of high bandwidth.

On the other hand, it can also be observed that with increase of buffer size,

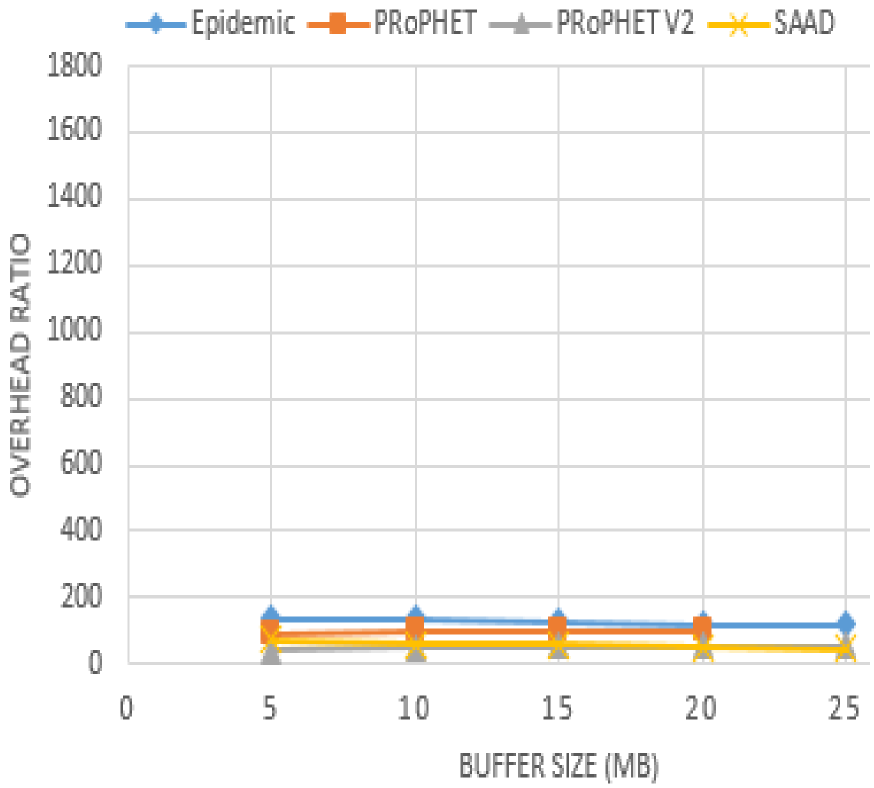


FIGURE 5.30: Overhead Ratio with 50-nodes and Degree Centrality (threshold = 0)

the overhead gradually decreases . PRoPHET showed low overhead than Epidemic but high overhead than PRoPHETv2 and Scalable-SAAD. Unlike Epidemic, PRoPHET routing technique forwards message to one or more number of nodes which meet the given criteria. Hence, nodes utilize less bandwidth than Epidemic and more bandwidth than PRoPHETv2 and Scalable-SAAD.

Node-50 scenario with threshold value = 0, initially Scalable-SAAD has lower overhead ratio than Epidemic and PRoPHET but higher overhead ratio than PRoPHETv2. However, when we increase the buffer size, the overhead ratio gradually decreases than PRoPHETv2. When we increase the threshold value to 2, and 4 respectively, Scalable-SAAD uses very less bandwidth and has shown lower overhead as compared to Epidemic, PRoPHET and PRoPHETv2 because with increase in threshold, less number of nodes are short listed, less number of packets are relayed in network, decrease the packet drop ratio which results in high packet delivery.

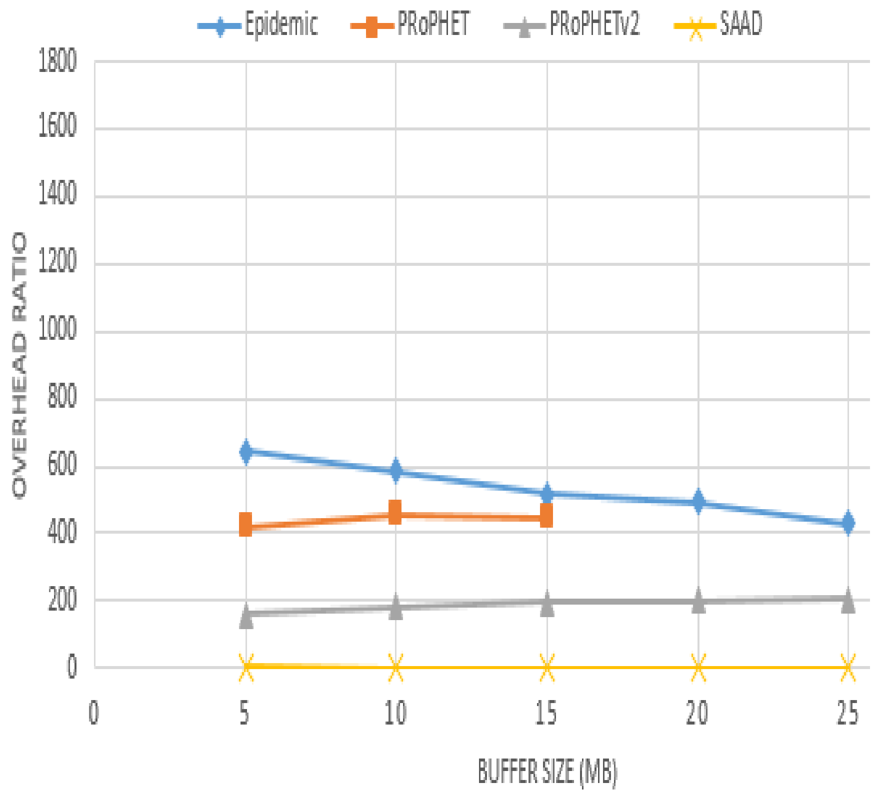


FIGURE 5.31: Overhead Ratio with 100-nodes and Degree Centrality (threshold = 0)

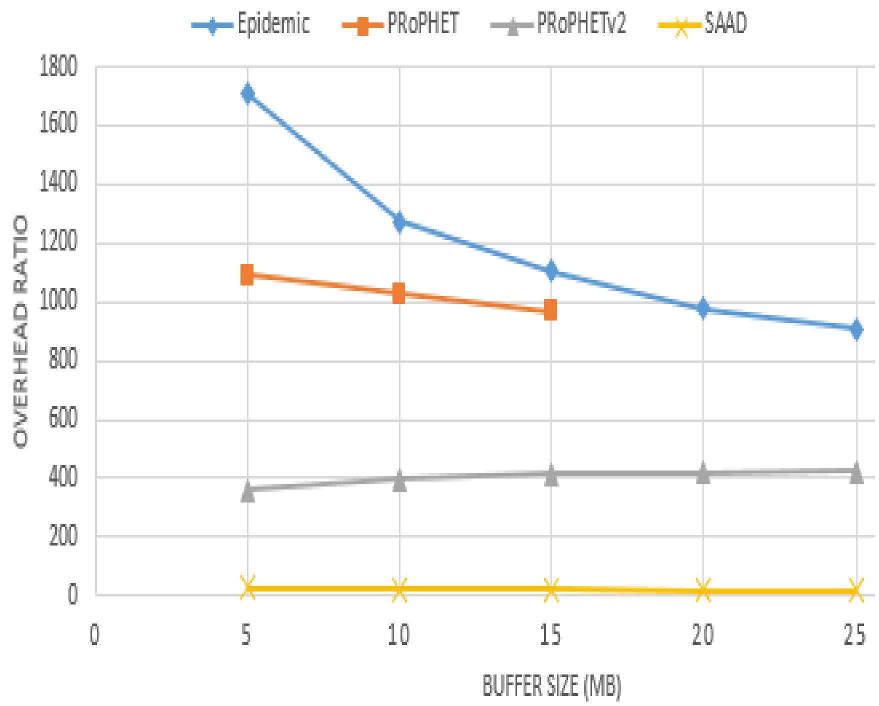


FIGURE 5.32: Overhead Ratio with 150-nodes and Degree Centrality (threshold = 0)

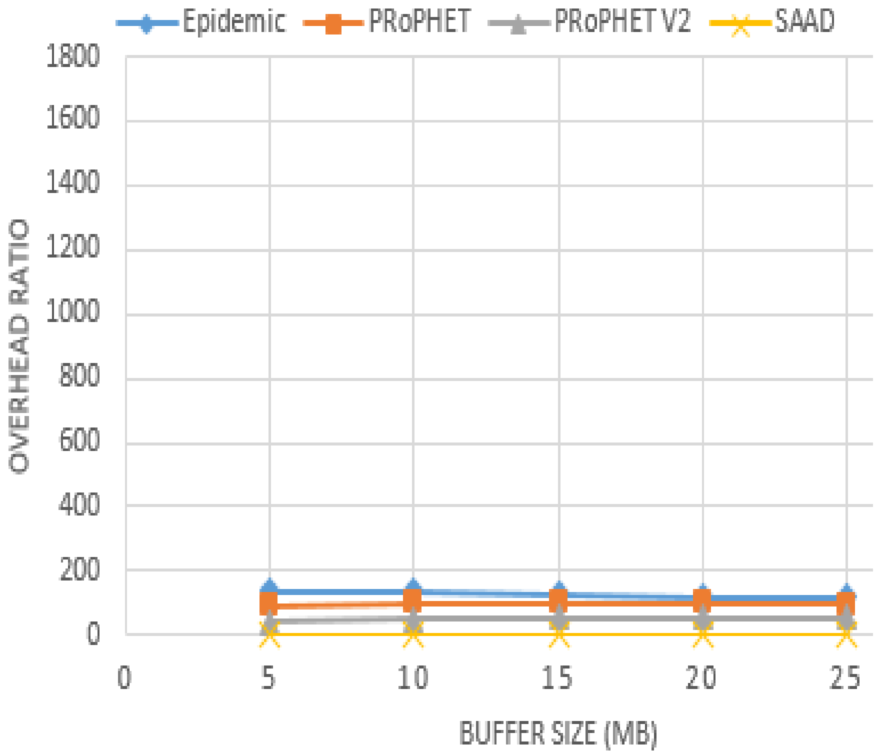


FIGURE 5.33: Overhead Ratio with 50-nodes and Degree Centrality (threshold = 2)

On the other hand, in Node-100 scenario with threshold value = 0, the proposed routing scheme produced low overhead as compared to Epidemic, PRoPHET and PRoPHETv2. However, in Node-50 scenario, Scalable-SAAD overhead ratio remains from 50 to 100, while in Node-100, overhead remains very low. It has been observed that when we use threshold 2, 3, 4 respectfully, the overhead remains very low in all three scenarios from 0 to 1 only as shown in Figures 5.30, 5.31 and 5.32. It means that Scalable-SAAD is using very less bandwidth and other system resources in all three scenarios while disseminating more packets than Epidemic, PRoPHET and PRoPHETv2.

It has also been observed that Epidemic routing scheme produces less overhead in Node-50 scenario as compared to Node-100 and Node-150 scenarios. However, as we increase the buffer sizes from 5MB to 10MB, 15MB, 20MB and 25MB, overhead gradually decreases in all three scenarios because large number of messages can reside in buffer which results in low packet drop ratio. It has also been observed that Node-100 scenario produced more overhead than Node-50 scenario and produced less overhead than Node-150 scenario.

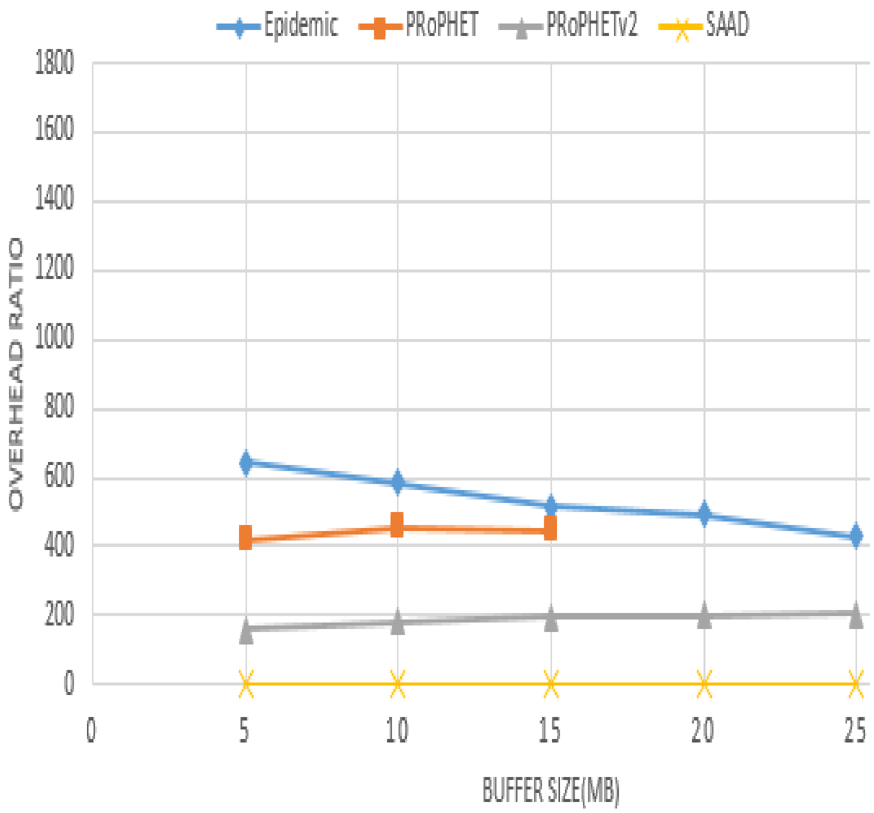


FIGURE 5.34: Overhead Ratio with 100-nodes and Degree Centrality (threshold = 2)

Therefore, we can conclude that as we increase the number of nodes from 50 to 100 and 150, the overhead gradually increases as shown in Figures 5.33, 5.34 and 5.35. On the other hand, in PRoPHET, as we increase the buffer sizes from 5MB to 10MB and 15MB, overhead increases gradually in both Node-50 and Node-100 scenarios while in Node-150 scenario, overhead gradually decreases with increase in buffer sizes from 5MB to 10MB, 15MB, 20MB and 25MB. PRoPHETv2 produces less overhead than Epidemic and PRoPHET but more overhead than Scalable-SAAD.

Node-50 scenario with threshold = 2, Scalable-SAAD produces less overhead as compared to Epidemic, PRoPHET and PRoPHETv2 because with increase in threshold, less number of nodes are short listed which decreases the overhead to a great extent. However, it has been observed that with increase in number of nodes increase the overhead ratio because more nodes in the network utilizes more network resources like bandwidth which results in producing high overhead.

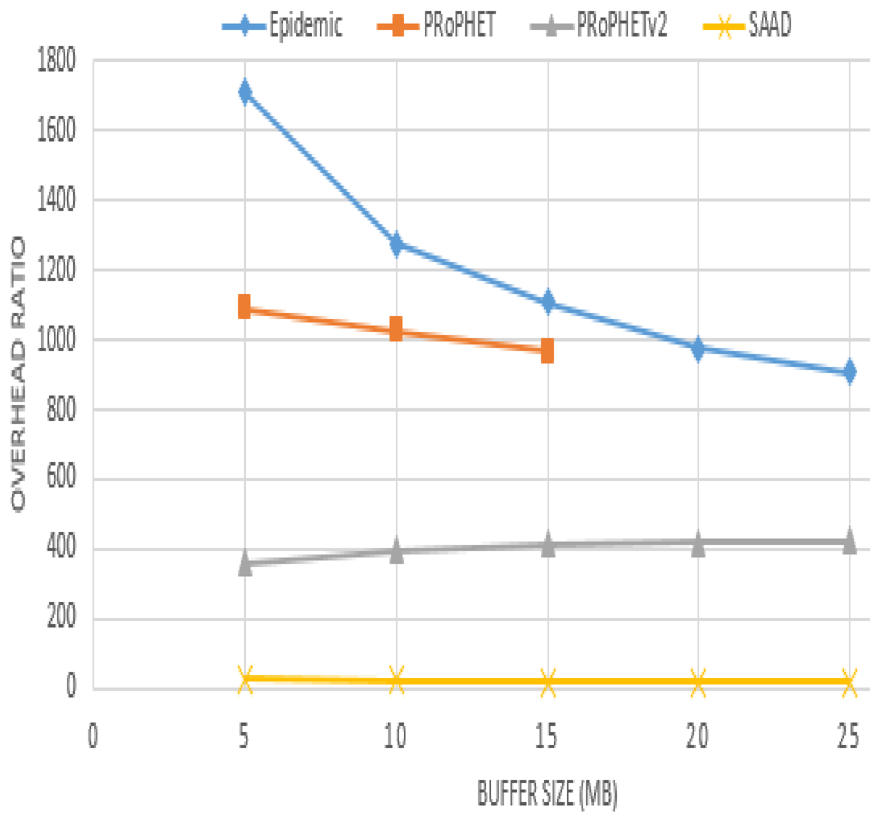


FIGURE 5.35: Overhead Ratio with 150-nodes and Degree Centrality (threshold = 2)

However Node-100 scenario with threshold = 2, overhead of all routing schemes increases because large number of nodes in the network utilizes more network resources, consequently, increases the overhead.. However, the same behavior is observed as we see with threshold 0 that even number of nodes are increased but still Epidemic overhead decreases gradually with gradual increase in buffer size while PRoPHET and PRoPHETv2 overhead increases with increase in buffer size.

While Node-150 scenario with threshold 2, Epidemic produces very high overhead than Node-50 scenario and Node-100 scenario because increase in number of nodes also increases the complexity and high use of network resources which results in high overhead. However, with increase in buffer size, overhead decreases gradually because more packets can reside in memory which results in low packet drop ratio. Node-150 scenario with threshold '2', the proposed routing scheme produces very low overhead as compare to Epidemic, PRoPHET and PRoPHETv2 because Scalable-SAAD forwards packet to only one node in its neighbor which possesses the highest Degree Centrality value as shown in Figures 5.33, 5.34 and 5.35.

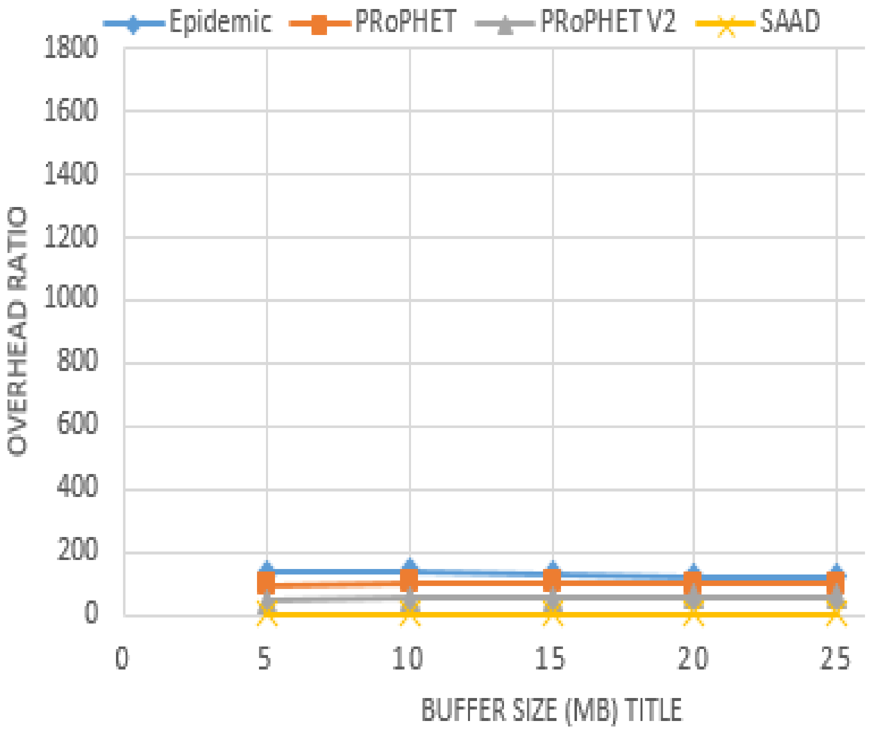


FIGURE 5.36: Overhead Ratio with 50-nodes and Degree Centrality (threshold = 4)

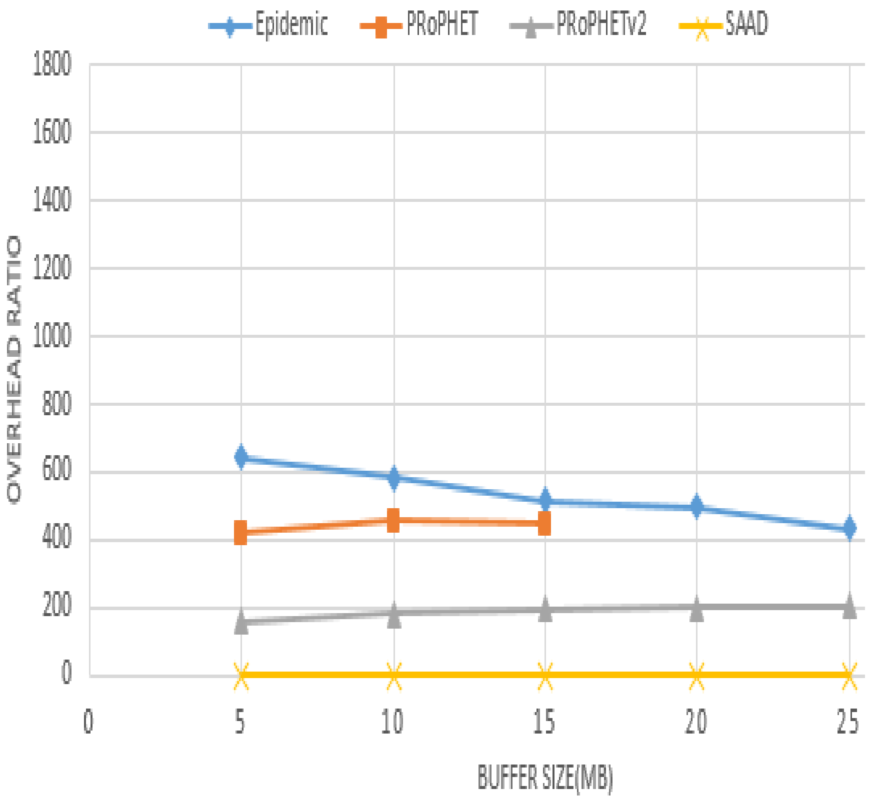


FIGURE 5.37: Overhead Ratio with 100-nodes and Degree Centrality (threshold = 4)

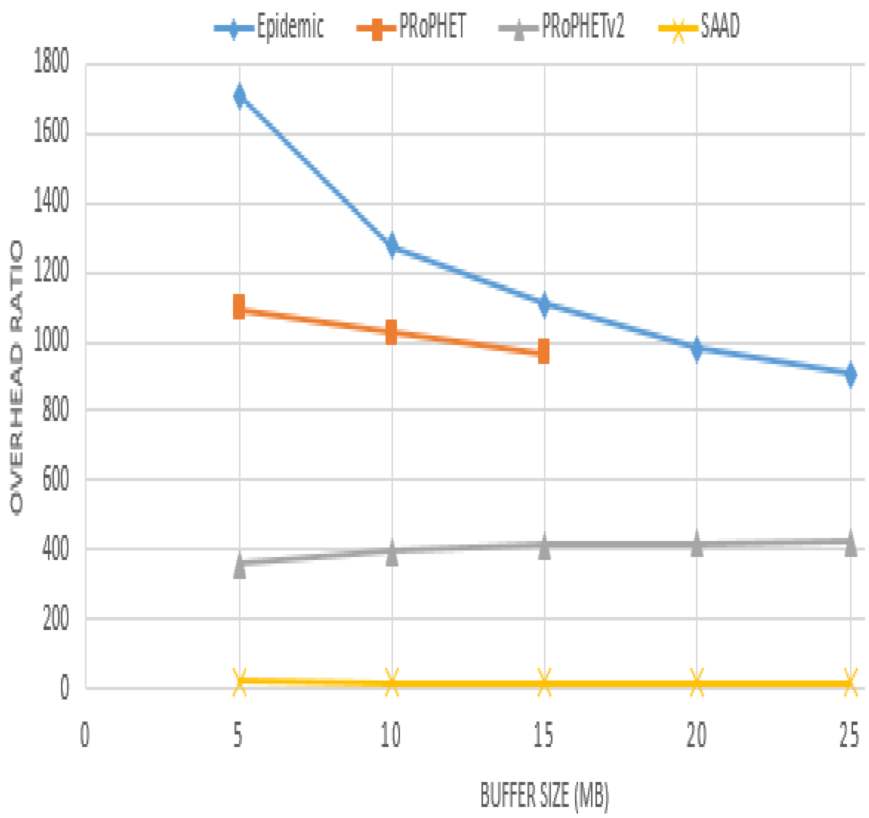


FIGURE 5.38: Overhead Ratio with 150-nodes and Degree Centrality (threshold = 4)

Node-50 scenario with threshold = 4, Scalable-SAAD produces less overhead as compared to Epidemic, PRoPHET and PRoPHETv2 because with high threshold, only few nodes in the network have more than 4 Degree Centrality. With increase in threshold, decrease the number of short listed nodes which results in low overhead. However, it has been observed that with increase in number of nodes increase the overhead ratio because more nodes in the network utilizes more network resources like bandwidth which results in producing high overhead in all three scenarios (i.e.; Node-50, Node-100 and Node-150) as shown in Figures 5.36, 5.37 and 5.38.

5.2.3 Average Hop-count

Graphs shown in Figures 5.39, 5.40, 5.41 show the average hop-count encountered by the nodes to deliver packets from source nodes to destination nodes in all three scenarios (i.e.; Node-50, Node-100 and Node-150). It can be clearly seen in graphs that the proposed routing scheme encounters less number of hops to

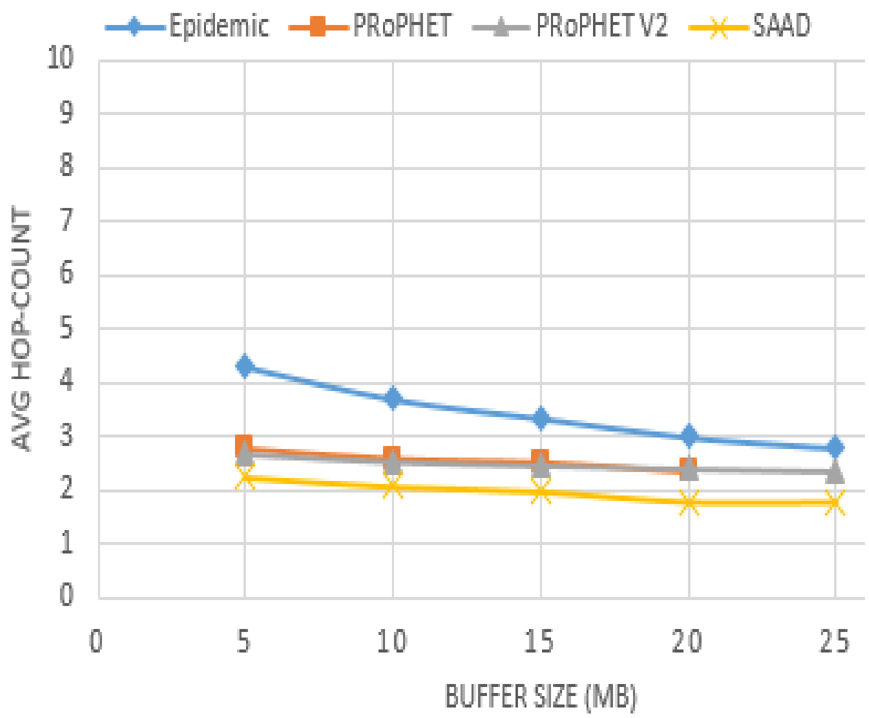


FIGURE 5.39: Average Hop-count with 50-nodes and Degree Centrality (threshold = 0)

deliver the messages towards the destination as compared to Epidemic, PRoPHET and PRoPHETv2 because as for as we increase the buffer size, a node can carry more messages which results in low hop-count. While, Epidemic encounters more average hop-count than other competitive routing techniques (i.e.; PRoPHET, PROpHETv2 and Scalable-SAAD) because it broadcasts the message to all its neighboring nodes and all nodes participate in the forwarding process. Hence, Epidemic encounters large number of hops.

PRoPHET encounters less number of average hop-count than Epidemic because unlike Epidemic, PRoPHET forwards message to either a single node or more than one node which meet the given criteria but encounters more number of average hop-count to delivered messages towards the destination than PRoPHETv2. PRoPHETv2 also encounters less number of average hop-count than Epidemic and PRoPHET but still encounter more number of average hop-count than Scalable-SAAD. On the other hand, it can be observed that with increase of buffer size, the number of encounter nodes gradually decreases in all routing schemes.

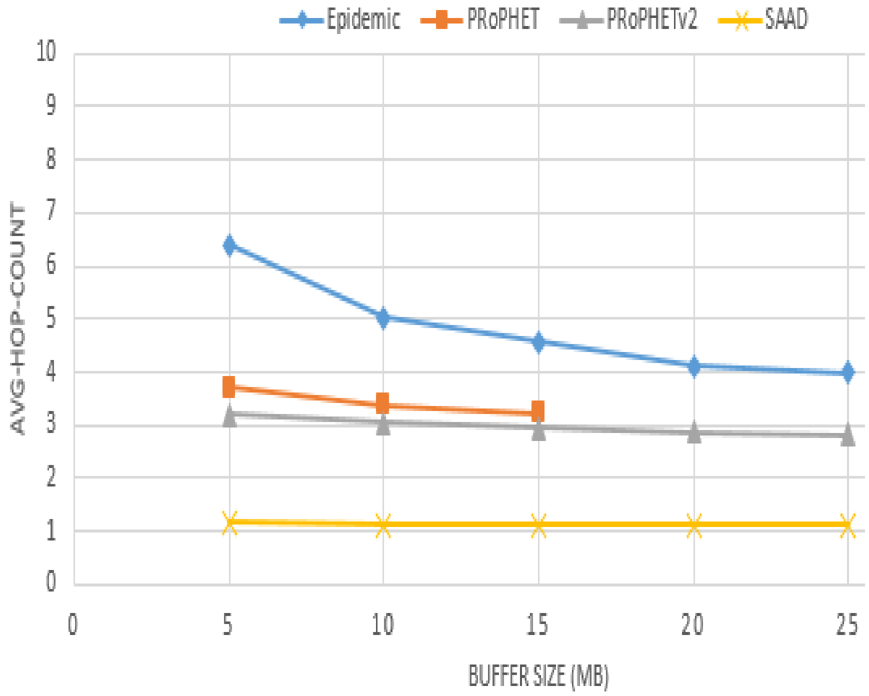


FIGURE 5.40: Average Hop-count with 100-nodes and Degree Centrality (threshold = 0)

Scalable-SAAD has shown improvement in terms of exploiting number of hops to forward packets and encountering less number of hops to deliver the packets from the source node to the destination node as compared to Epidemic, PRoPHET and PRoPHETv2 in all three scenarios. With threshold value = '0', initially Scalable-SAAD encounters average hop-count 1.5 to 2.3 in Node-50 scenario. However, when we increase buffer sizes from 5MB to 25MB, the number of average hop-count decreases gradually from 2.3 to 1.75 because now more messages can reside in memory and packet drop ratio, consequently, encounters less number of hops to deliver the message to the destination. With threshold value = 0, Epidemic, PRoPHET and PRoPHETv2 gradually encounters average less number of nodes with increase in buffer size because packet drop ratio decreases with increase in gradual buffer size.

While in Node-100 scenario with threshold = 0, Epidemic, PRoPHET and PRoPHETv2 encounters more number of average hops because now we have more nodes in the network. While the proposed routing scheme encounters less number of nodes

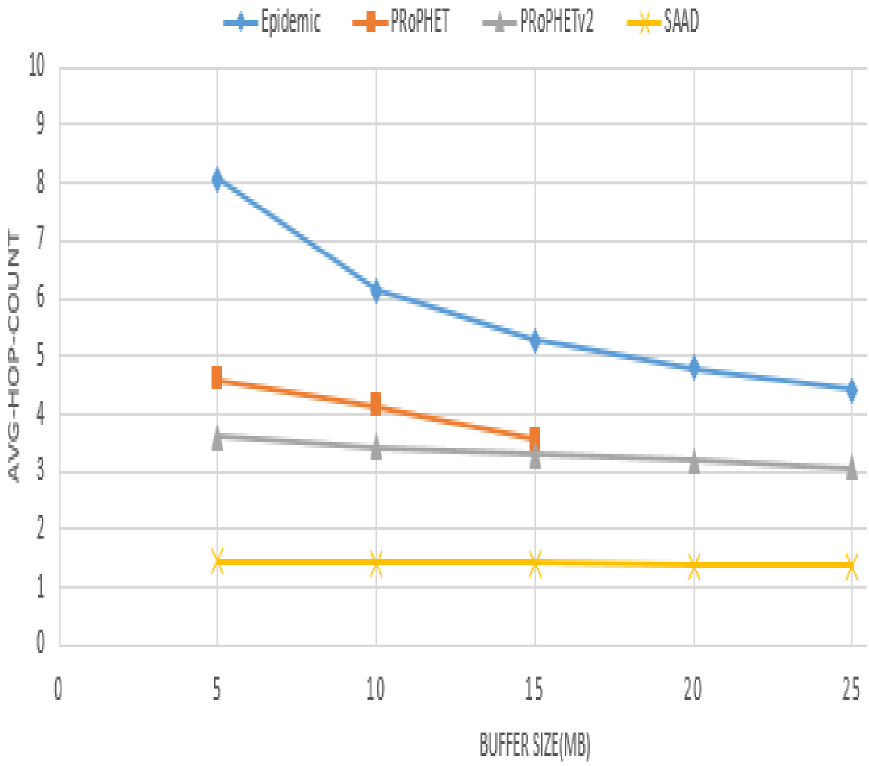


FIGURE 5.41: Average Hop-count with 150-nodes and Degree Centrality (threshold = 0)

to deliver messages to the destination as compared to the previous scenario (i.e.; Node-50 scenario) because the proposed routing scheme only forwards the message to a more social node possessing highest Degree Centrality as shown in Figures 5.39, 5.40 and 5.41. It has also been observed that Node-100 scenario encounters less number of average hop-count as compared to Node-50 scenario because now more number of nodes are involved in the forwarding process as compared to the Node-50 scenario. Node-100 scenario with buffer size of 5MB, initially encounters 1.2 average hop-count. However, as we increase the buffer sizes from 10MB to 25MB, the number of average hop-count decreases gradually from 1.2 to almost 1.

On the other hand, in Node-150 scenario with threshold = 0, Epidemic, PRoPHET and PRoPHETv2 encounters even more number of average hops to deliver messages to the destination node because more nodes in the network results in congestion and encounter rates increases which consequently, increases the average hop count for all routing techniques. However, gradual increase in buffer size decreases the number of encounters for all routing schemes because messages can reside in memory for

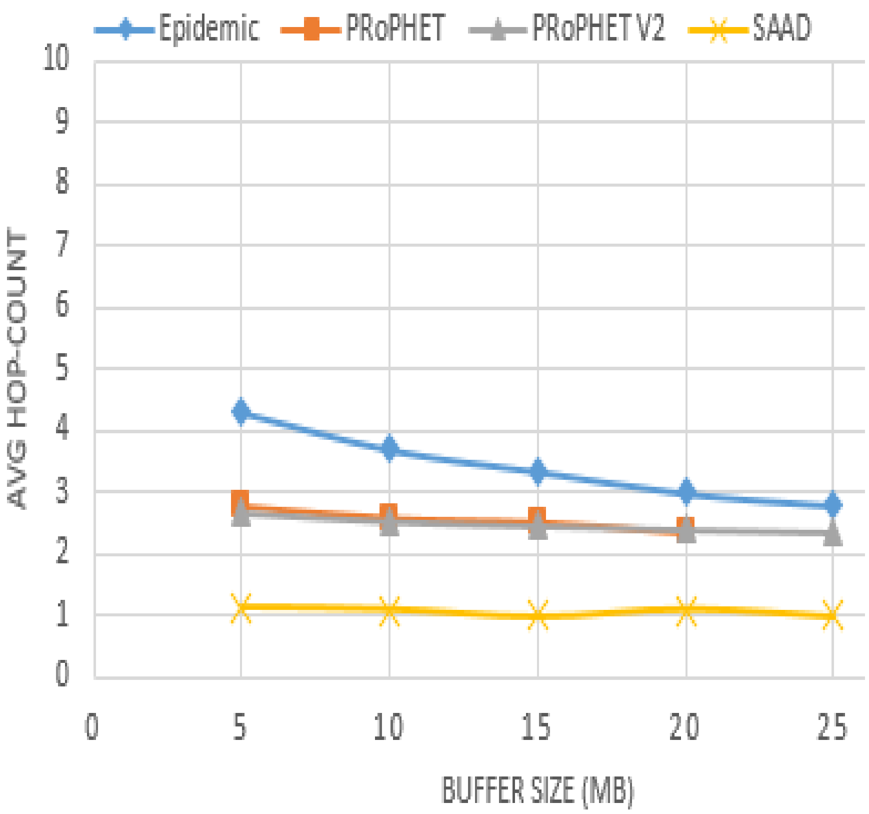


FIGURE 5.42: Average Hop-count with 50-nodes and Degree Centrality (threshold = 2)

longer as DTN provides store-carry and forward opportunity. Nodes keep the messages in their buffer until they encounter a highest social node in its one hop. Node-150 scenario with buffer size 5MB, initially encounters 1.4 average hop-count. The number of average hop-count gradually decreases when we increase buffer sizes from 5MB to 25MB as shown in Figures 5.39, 5.40 and 5.41.

Node-50 scenario with threshold value = 2, Scalable-SAAD encounters average hop-count 1.5 to 2.3 in Node-50 scenario. However, when we increase buffer sizes from 5MB to 25MB, the number of average hop-count decreases gradually from 2.3 to 1.75 because now more messages can reside in memory and packet drop ratio, consequently, encounters less number of hops to deliver the message to the destination. With threshold value = 0, Epidemic, PRoPHET and PRoPHETv2 gradually encounters average less number of nodes with increase in buffer size because packet drop ratio decreases with increase in gradual buffer size.

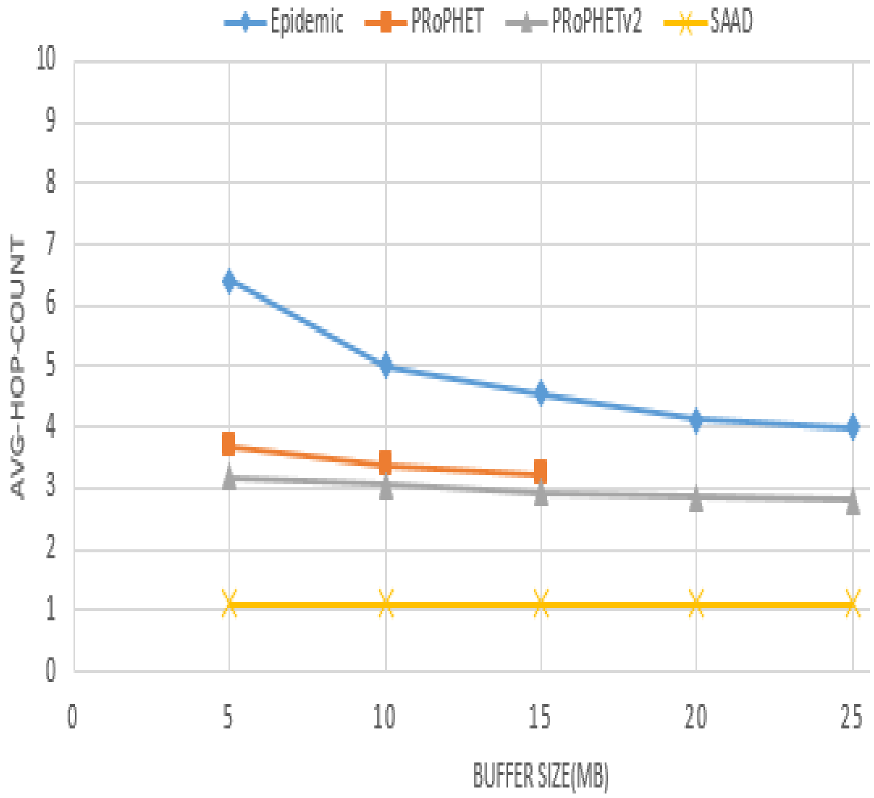


FIGURE 5.43: Average Hop-count with 100-nodes and Degree Centrality (threshold = 2)

Node-50 scenario with threshold = 2, has shown some improvement and encounters less number of average hop-count than Node-50 scenario with threshold = 0. However, with the increase of buffer sizes from 5MB to 25MB, the number of average hop-count decreases from 1.5 to 1.2'. Node-50 scenario with threshold = 2, has shown some improvement and encounters less number of average hop-count than Node-50 scenario with threshold = 0 as shown in Figures 5.42, 5.43 and 5.44.

In Node-100 scenario with threshold value = 2, Scalable-SAAD encounters less number of average hop-count as compared to Epidemic, PRoPHET and PRoPHETv2 because the proposed routing scheme forwards message to the node which have highest Degree Centrality and with threshold 2, only those nodes are short listed which have Degree Centrality value greater than 2. the proposed routing scheme almost encounter 1 node as an average to deliver a message. On the other hand, Epidemic, PRoPHET and PRoPHETv2 performs

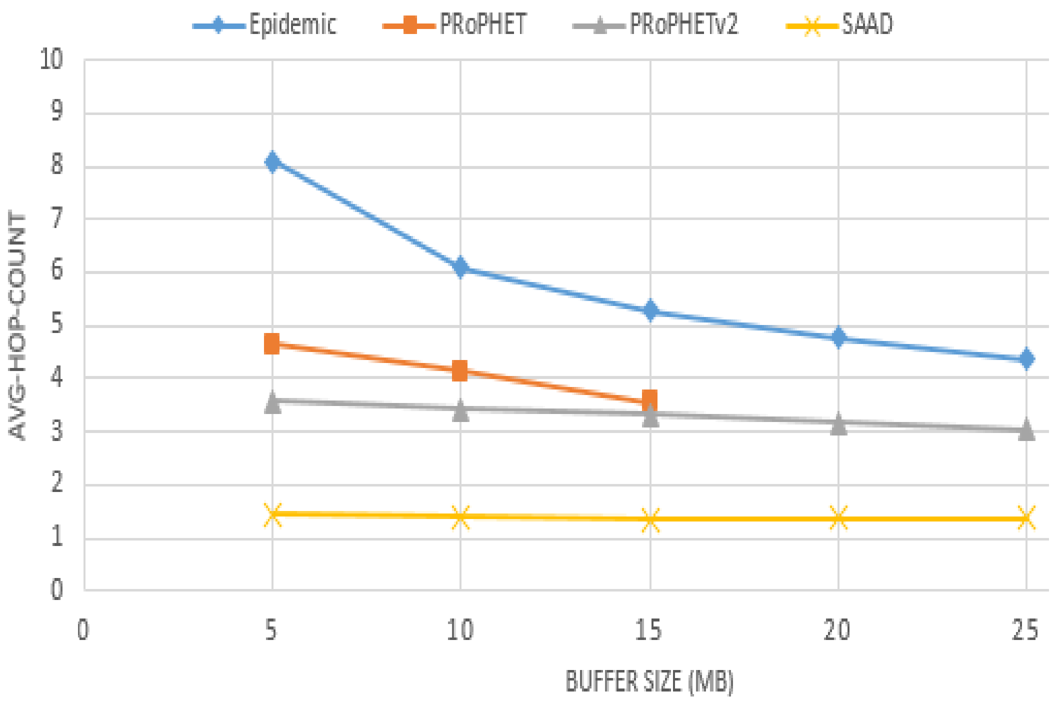


FIGURE 5.44: Average Hop-count with 150-nodes and Degree Centrality (threshold = 2)

the same as they performed with threshold 0 because threshold criteria only effects the performance of Scalable-SAAD.

In Node-150 scenario with threshold value = 2, all routing schemes are encountering more average hop counts to deliver a message to the destination because large number of nodes in a certain area increases the congestion which results in more number of encounter among the nodes. The increase number of nodes increases the probability of encounter amongst the nodes. Scalable-SAAD encounters less number of average hop-count as compared to Epidemic, PRoPHET and PRoPHETv2 because the proposed routing scheme forwards message to the node which have highest Degree Centrality and with threshold 2, only those nodes are short listed which have Degree Centrality value greater than 2. The proposed routing scheme almost encounter 1 node as an average to deliver a message as shown in Figures 5.42, 5.43 and 5.44.

Node-50 scenario with threshold = 4, has shown a slight improvement as compared

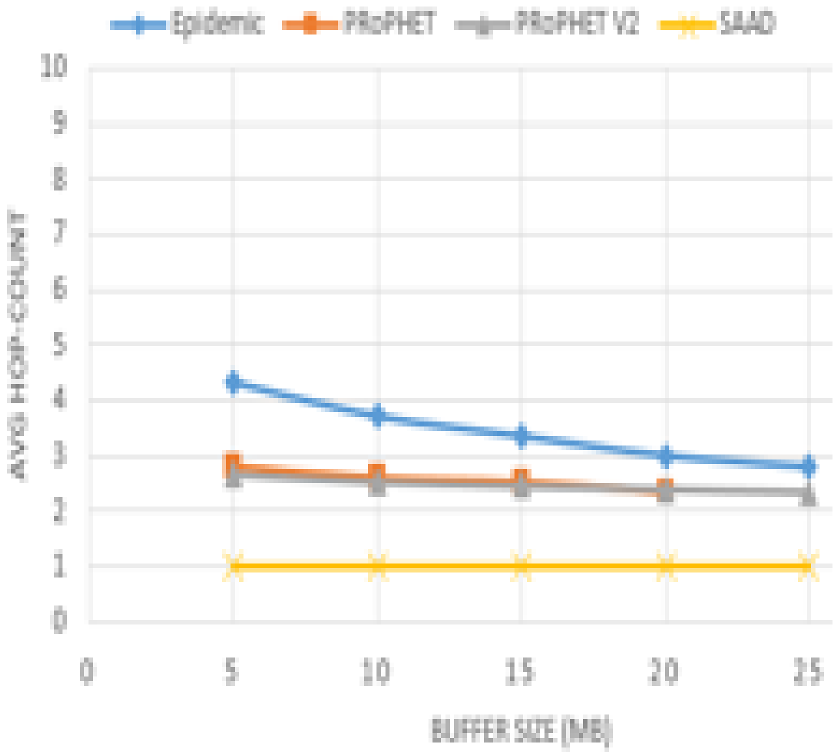


Figure 5.45: Average Hop-count with 50-nodes and Degree Centrality (threshold = 4)

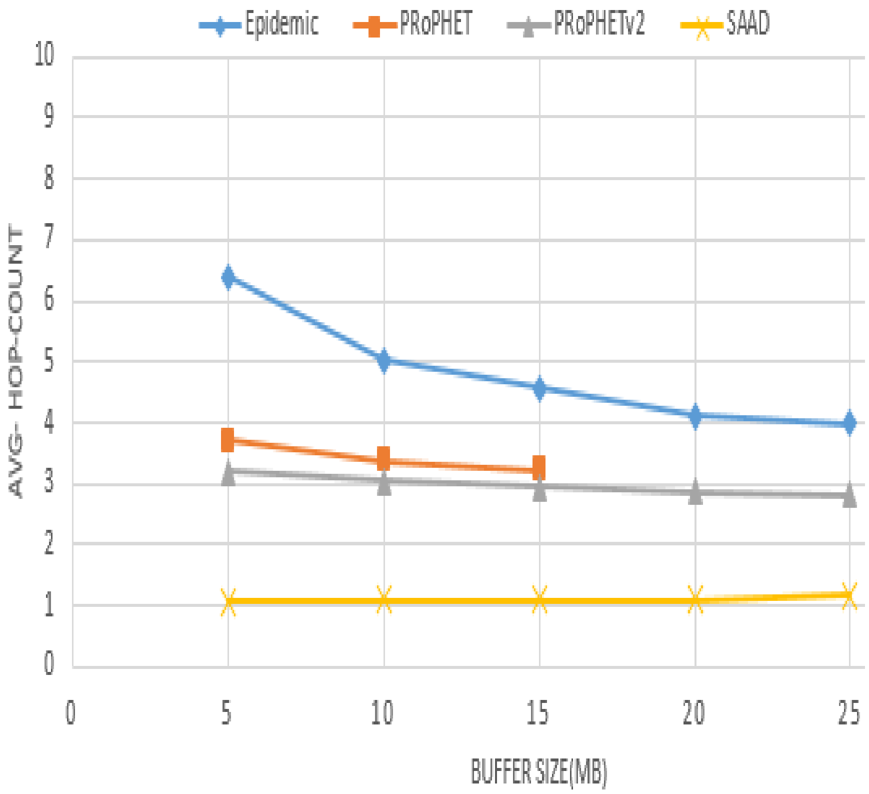


Figure 5.46: Average Hop-count with 100-nodes and Degree Centrality (threshold = 4)

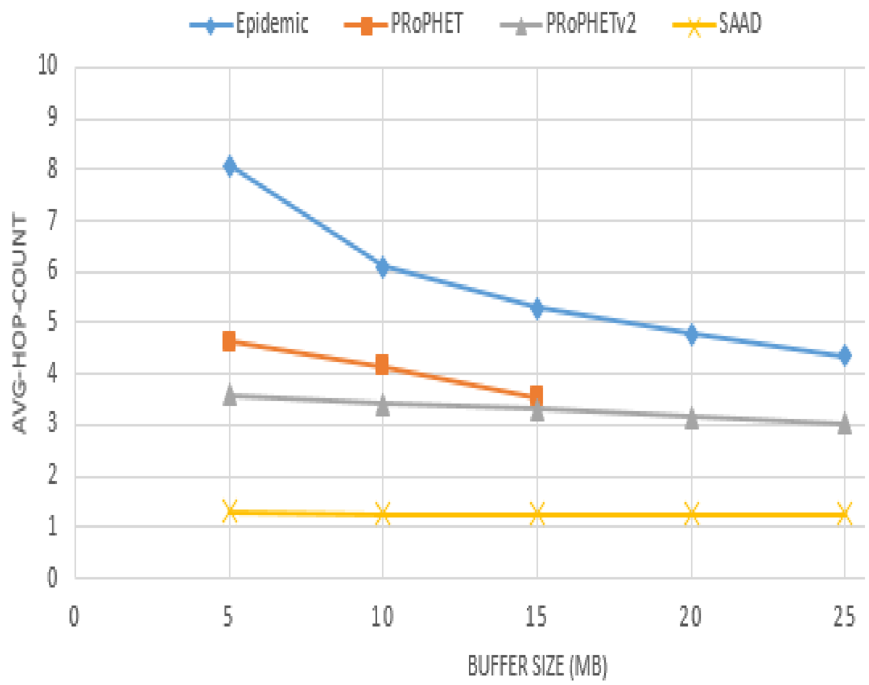


FIGURE 5.47: Average Hop-count with 150-nodes and Degree Centrality (threshold = 4)

to the previous scenario when threshold was 2. In Node-100 scenario and NOde-150 scenario, Epidemic PRoPHET and PRoPHETv2 encounter average more number of hops to deliver messages from source node to the destination node.

While the proposed routing scheme encounters average 1 node to deliver messages because with threshold 4, few number of nodes qualify to be selected as relay nodes and participate in the process of message forwarding and messages are forwarded only to the high social node which possesses the highest Degree Centrality as shown in Figures 5.45, 5.46 and 5.47.

5.2.4 Average end-to-end Delay

Graphs shown in Figures 5.48, 5.49, 5.50 show the average end-to-end delay produced by the nodes to deliver packets from source nodes to destination nodes in all three scenarios (i.e.; Node-50, Node-100 and Node-150). When we use threshold value = 0, It can be clearly seen that PRoPHET produces more average

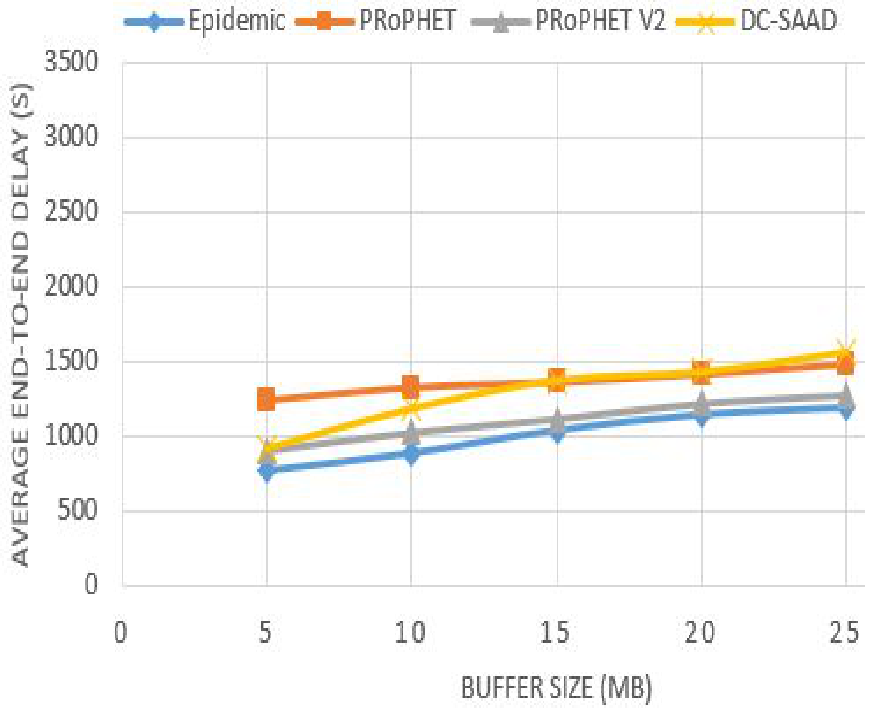


FIGURE 5.48: Average end-to-end Delay with 50-nodes and Degree Centrality (threshold = 0)

end-to-end delay in Node-50 scenario than other routing techniques (i.e.; Epidemic, PROpHETv2 and Scalable-SAAD). However, Scalable-SAAD produces more average end-to-end delay in Node-100 and Node-150 scenarios than all other routing schemes. Node-100 scenario even produces more average end-to-end delay than Node-150 scenario. When we increase the buffer sizes from 5MB to 25MB, the average end-to-end delay gradually increases.

On the other hand, Epidemic produces very low average end-to-end delay than all other routing schemes because Epidemic routing scheme broadcast the message to all neighboring nodes without any selection criteria which increases the delivery probability in less time which results in low latency. Unlike Epidemic, PRoPHET routing technique forwards message to more than one hop nodes which meet the delivery predictability. As a result, PRoPHET routing scheme take more time deliver all the message to the destination.

In NOde-50 scenario with threshold value = 2, Scalable-SAAD produced initially

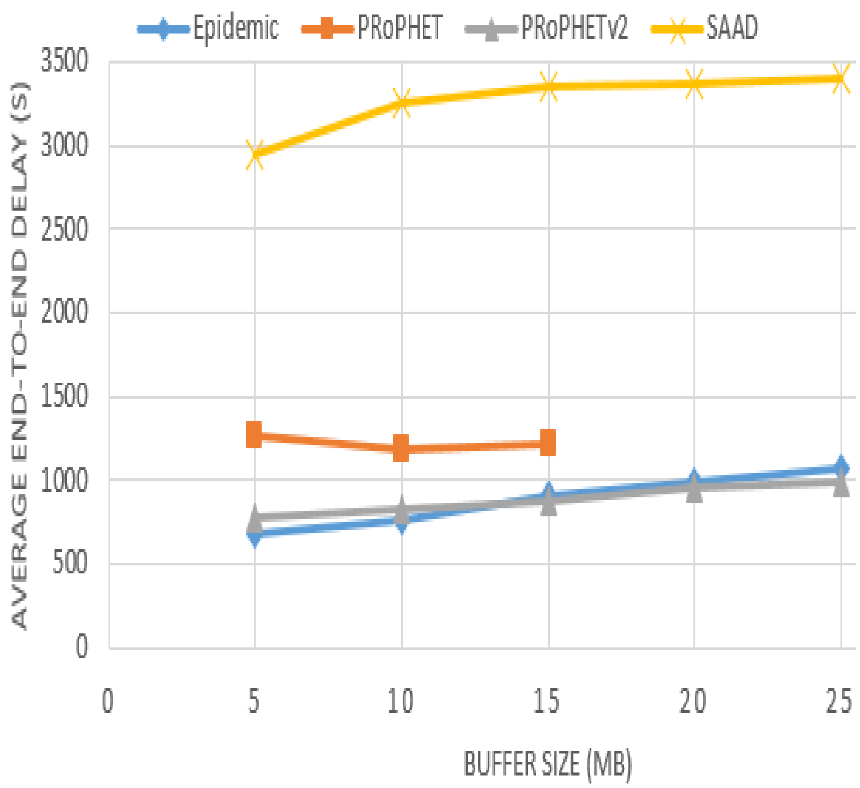


FIGURE 5.49: Average end-to-end Delay with 100-nodes and Degree Centrality (threshold = 0)

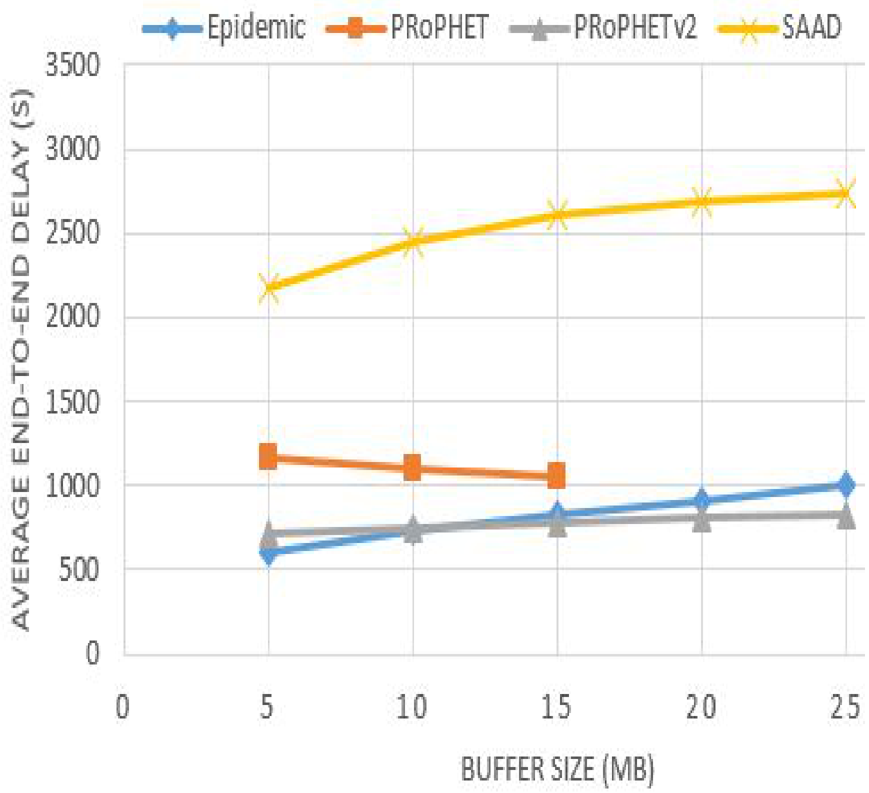


FIGURE 5.50: Average end-to-end Delay with 150-nodes and Degree Centrality (threshold = 0)

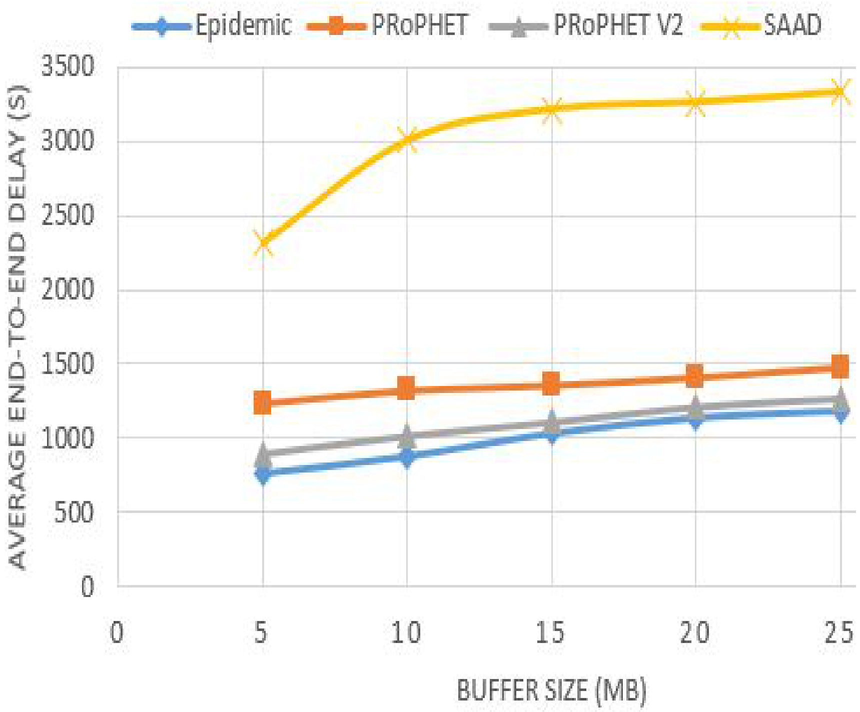


FIGURE 5.51: Average end-to-end Delay with 50-nodes and Degree Centrality (threshold = 2)

with buffer size 5MB and 10MB, less average end-to-end delay as compared to Node-50 scenario because with threshold 2, less number of nodes are short listed which can participate in message forwarding process. Consequently, less number of nodes move around the network, decrease the packet drop ratio and take less time to deliver messages towards the destination. After that with gradual increase in buffer size to 15MB, 20MB and 25MB, a gradual increase in delay occurs to disseminate the messages to the destination.

In Node-100 scenario with threshold 2, the proposed routing scheme producing high average end-to-end delay not only than other routing schemes but also produced high latency than Node-50 scenario because now with threshold 2, more number of nodes are selected as relay nodes. High number of nodes encounters frequently results in increase the packet drop ratio as well more intermediate hop nodes are used to deliver messages towards the destination which ultimately took long to deliver messages as shown in Figures 5.51, 5.52, 5.53.

In Node-150 scenario with threshold 2, the proposed routing scheme producing high

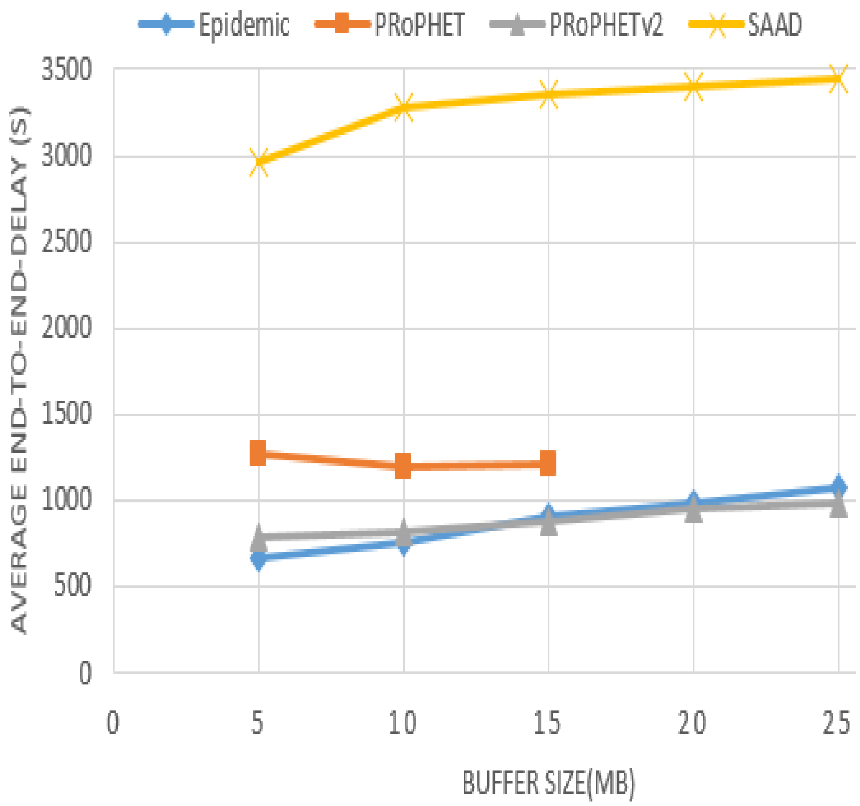


FIGURE 5.52: Average end-to-end Delay with 100-nodes and Degree Centrality (threshold = 2)

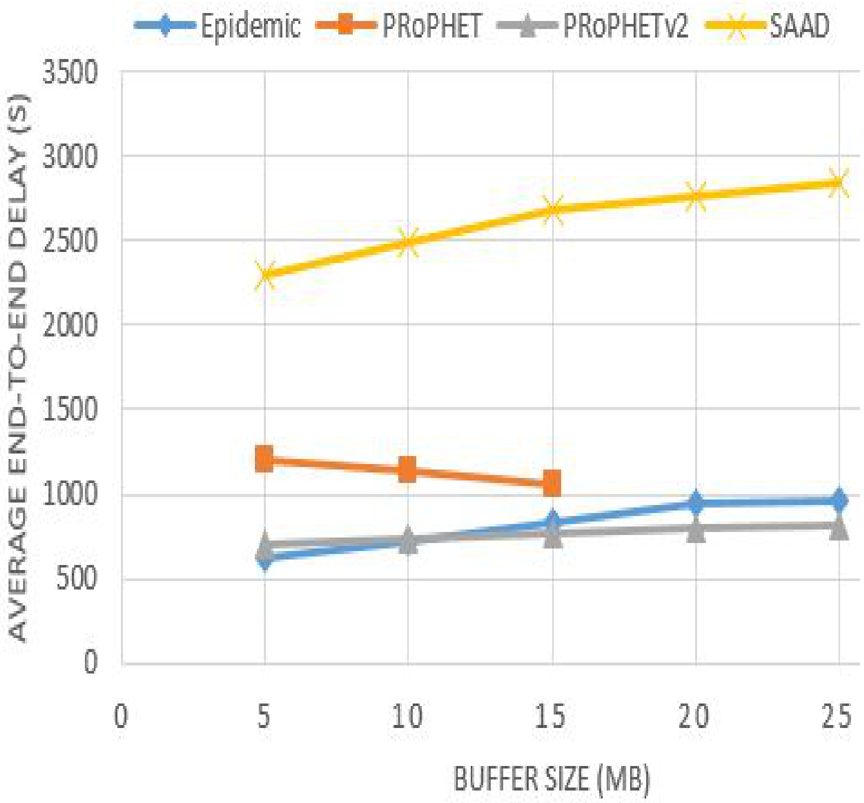


FIGURE 5.53: Average end-to-end Delay with 150-nodes and Degree Centrality (threshold = 2)

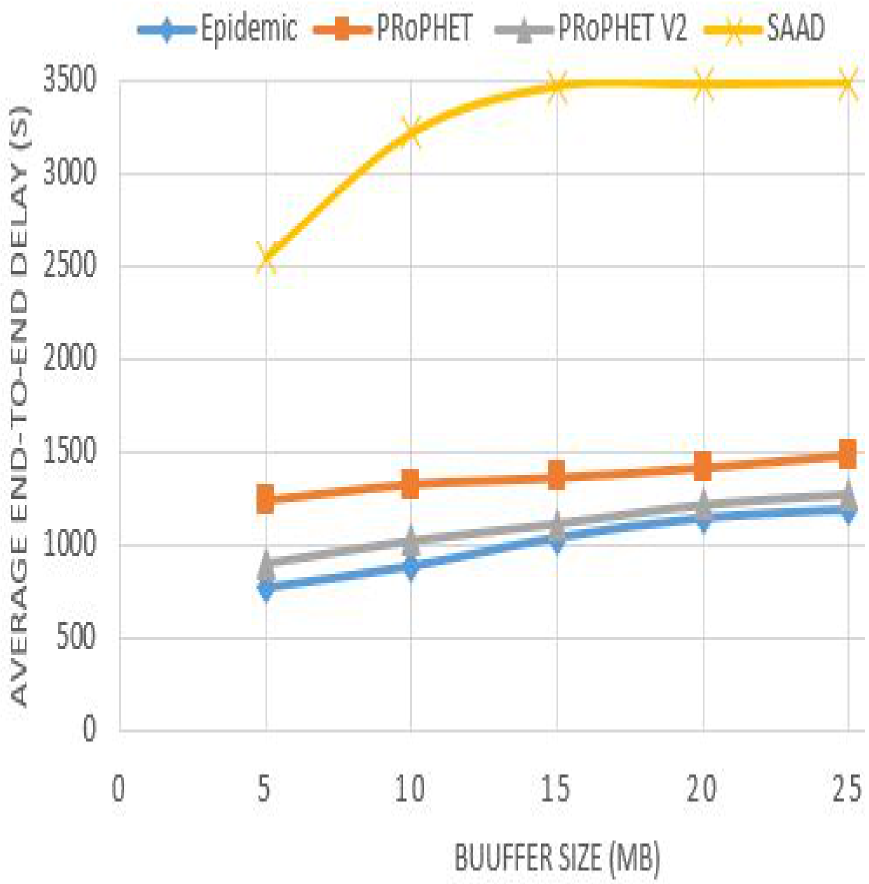


FIGURE 5.54: Average end-to-end Delay with 50-nodes and Degree Centrality (threshold = 4)

average end-to-end delay than Epidemic, PRoPHET and PRoPHETv2. Initially, with buffer size 5MB, Scalable-SAAD produces less average end-to-end delay but after that with gradual increase in buffer size, average end-to-end delay increases gradually because nodes have now more capacity to hold messages which results in high latency.

In Node-50 scenario with threshold value = 4, Scalable-SAAD produced more average end-to-end delay than Epidemic, PRoPHET and PRoPHETv2. However, the proposed routing scheme produces low average end-to-end delay with buffer size 5MB which is almost 2500, while with buffer size 10MB, average end-to-end delay reached to 3200 but after that gradual increase in latency is observed with gradual increase in buffer size. With increase in threshold, reduce the number of short listed forwarder nodes which results in low overhead comparatively as shown in Figures 5.54, 5.55, 5.56.

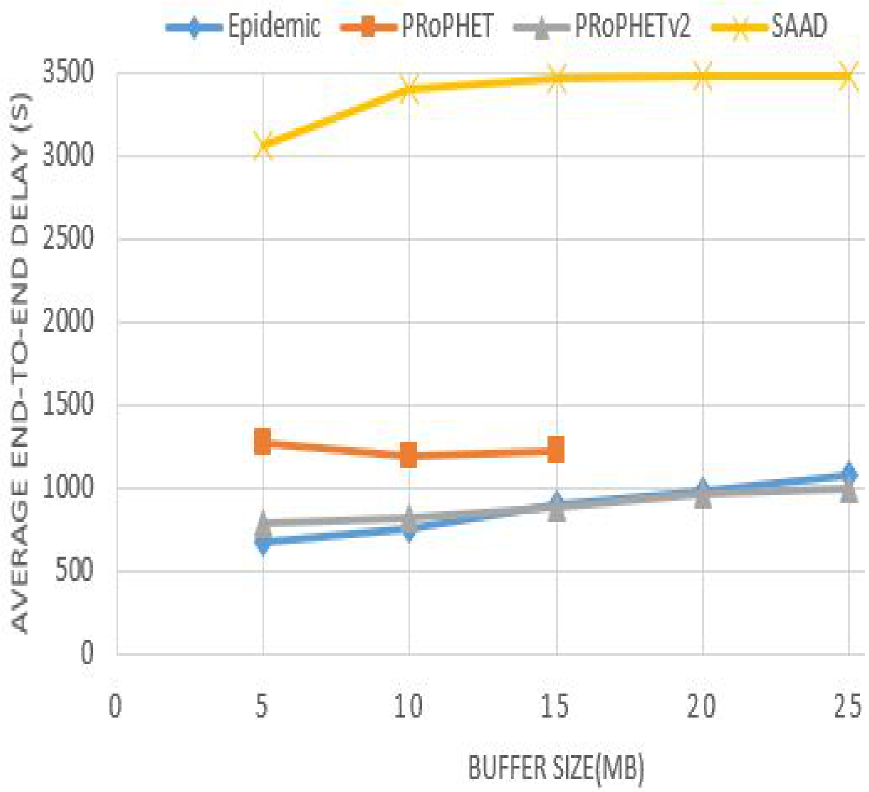


FIGURE 5.55: Average end-to-end Delay with 100-nodes and Degree Centrality (threshold = 4)

In Node-100 scenario with threshold 4, the proposed routing scheme producing high average end-to-end delay than Epidemic, PRoPHET and PRoPHETv2. This scenario producing more average end-to-end delay because large number of nodes are in network which increase the encounter ratio and results in high delay as compared to Node-50 scenario. With buffer size 5MB, Scalable-SAAD produces almost 3000 average end-to-end delay but after that latency gradually increases with gradual increase in buffer size.

In Node-150 scenario with threshold value = 4, Scalable-SAAD produced more average end-to-end delay than Epidemic, PRoPHET and PRoPHETv2. However, the proposed routing scheme produces low average end-to-end delay with buffer size 5MB which is almost 2500, while with buffer size 10MB, average end-to-end delay reached to 3200 but after that gradual increase in latency is observed with gradual increase in buffer size. With increase in threshold, reduce the number of short listed forwarder nodes which results in low average end-to-end delay as shown in Figures 5.54, 5.55, 5.56.

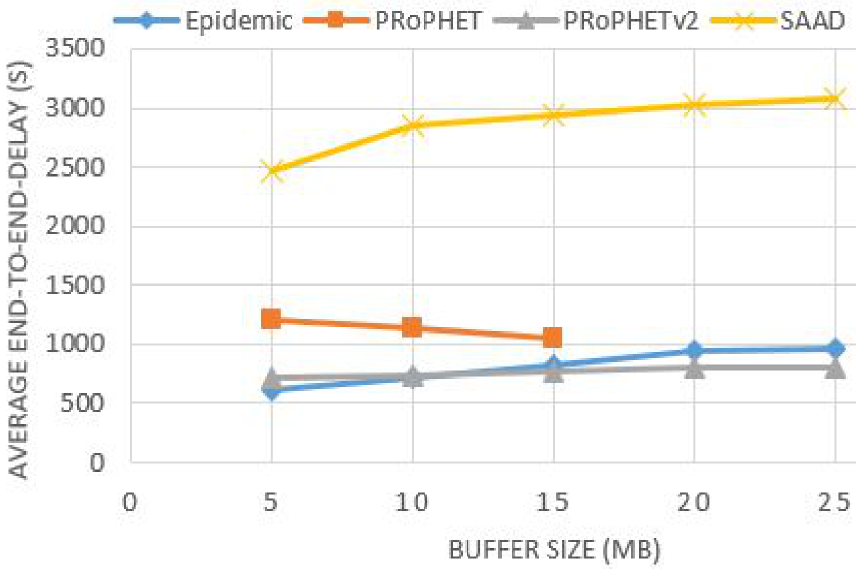


FIGURE 5.56: Average end-to-end Delay with 150-nodes and Degree Centrality (threshold = 4)

Finally, it can be said that SAAD has shown improvement as compared to Epidemic, PRoPHET and PRoPHETv2 in terms of packet delivery ratio, overhead and hop-count but at the cost of high average end-to-end delay which can be tolerated to some extent in DTN.

5.2.5 Packet Delivery Ratio using Random Walk Encounter

Our proposed routing protocol using a social metric named as" Random Walk Encounter" produced better results than PRoPHET, PRoPHETv2 and our own proposed routing scheme using social attribute named as "Degree Centrality" as shown in Figure 5.57

5.2.6 Adaptive Routing

In order to address third research question, our proposed routing technique delivered messages keeping in mind the nature of message. If a message is urgent, proposed routing technique floods the message to all neigboring nodes without any criteria because urgent message need to be delivered speedily otherwise, a message will be

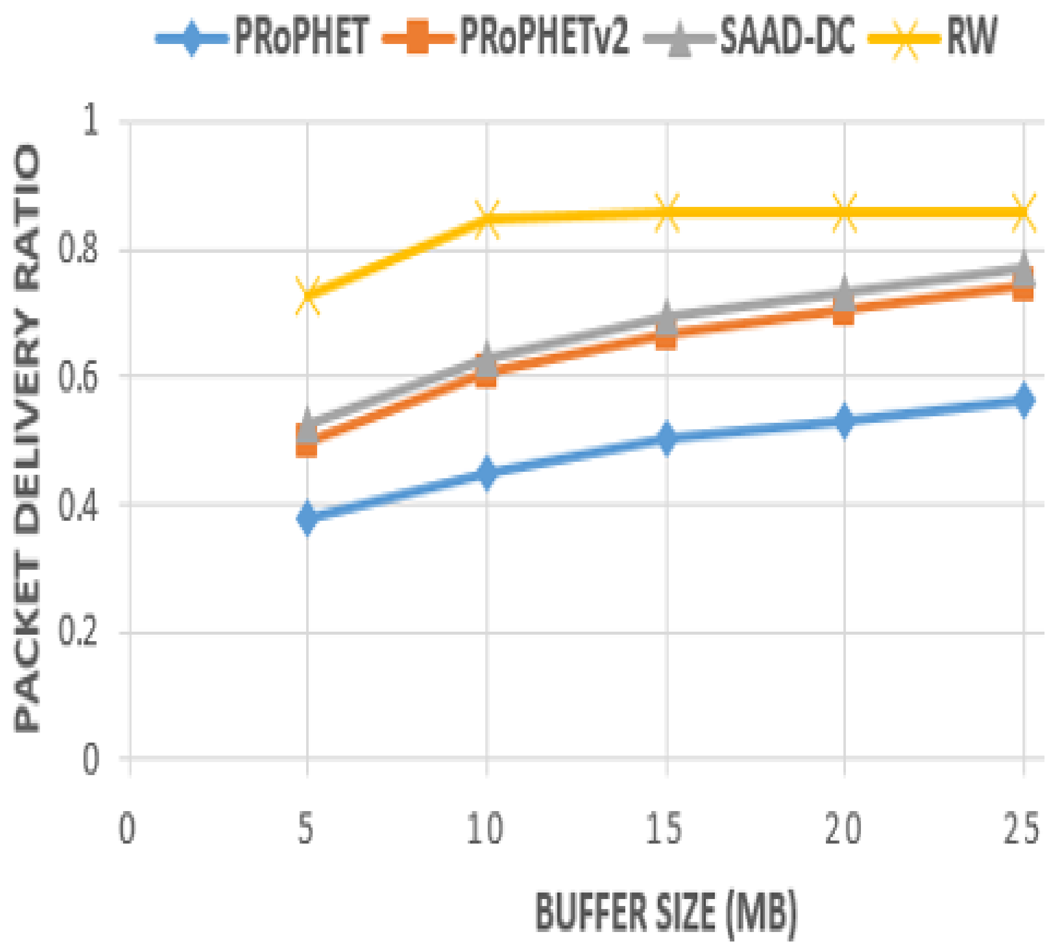


FIGURE 5.57: Packet Delivery Ratio using Random Walk Encounter)

delivered using unicast method as proposed routing technique is delivering normally either based on Random Encounter value or Social Rank value. The simulation results showed that Adaptive routing is delivering more messages than a normal proposed technique as shown in Figure 5.58.

5.2.7 Refined Social Activeness vs Existing Social Activeness

After having a thorough literature, we came to know that the existing equation which is being used in literature[40],[57] is considering the social activeness value when a node tends to encounter new nodes but if a node encounters a set of same nodes which it had encountered previously, the existing equation produced 0 social activeness although it may encounter a large number of nodes. Secondly, the

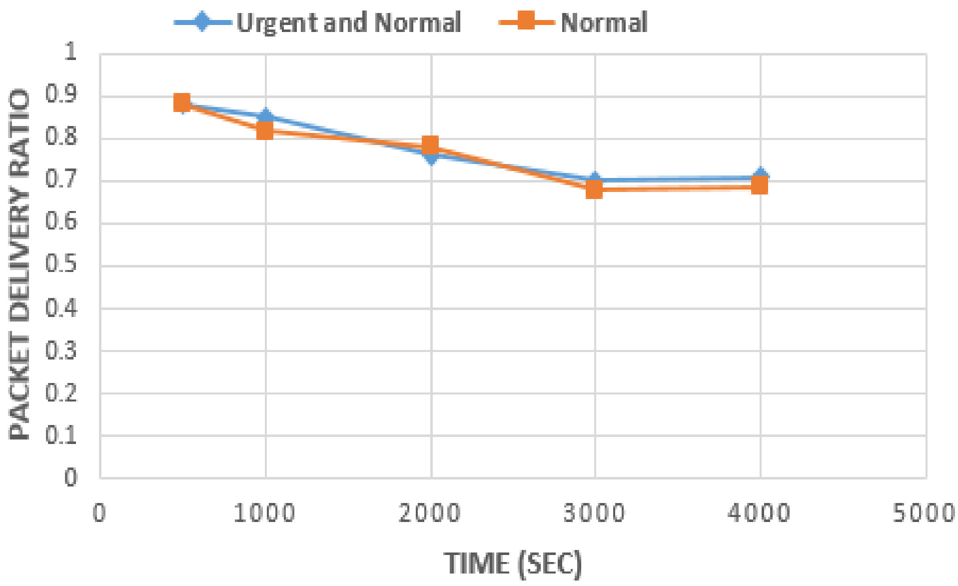


FIGURE 5.58: Packet Delivery Ratio using Adaptive Routing)

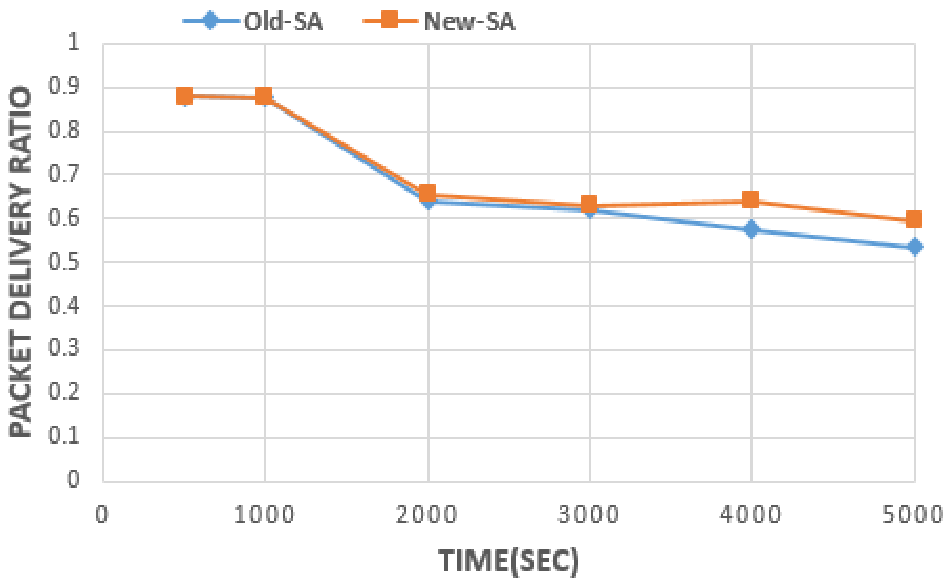


FIGURE 5.59: Packet Delivery Ratio using Refined formula of Social Activeness

existing social activeness formula is producing social activeness value as 1 even if it encounters only one new node which was not encountered previously. To address these two shortcomings in the existing formula, we introduced a new formula calculate the social activeness of a node which keeps the utility of existing formula and also deals the worse cases mentioned above using the equation3.4 mentioned in section 3 and the our refined formula of Social Activeness is producing better packet delivery than existing formula of Social Activeness as can be seen in Figure 5.59.

Chapter 6

Conclusion and Future Work

Delay Tolerant Network can be used to deal with post-disaster situations e.g. earthquakes, flood affected areas, rescue scenarios etc. where traditional networks fail to provide reliable communication between nodes, mostly because the infrastructure is itself destroyed. In this thesis, we proposed SAAD routing scheme which uses social attributes (i.e. Degree Centrality, Random Walk Encounter and Social Activeness) to calculate social rank of each node. The simulation results indicate that SAAD has improved the delivery ratio, has reduced the overhead and hop-count on the expense of delay as compared to Epidemic, PRoPHET and PRoPHETv2. To ensure the scalability of our proposed routing scheme, we run the simulations with different number of nodes. The simulation results demonstrates that scalable routing scheme also showed improvement in terms of delivery ratio, overhead, hop-count at the cost of average end-to-end delay.

Furthermore, we exploit multiple social metrics (i.e., Degree Centrality, Random Walk Encounter and Social Activeness). In this scalable routing scheme, each node calculates its social rank (SR) using Degree Centrality, Random Walk Encounter and Social Activeness. A source node selects the forwarder node possessing highest SR value.

In addition, our proposed algorithm also deal with the types of a message. As we have discussed earlier that our proposed routing scheme is designed to perform in disaster scenarios where an urgent message need to be sent on priority and speedily. Therefore, the proposed routing scheme ensures the adaptive routing keeping in mind the nature of message.

The simulation results indicate that SAAD has improved the selection of best forwarder node. The proposed routing scheme increase the packet delivery ratio, reduce overhead ratio, reduce hop-count at the cost of long delay as compared to Epidemic, PRoPHET and PRoPHETv2.

Future work

This work can be extended by exploiting combination of social metrics along with transitivity to find the more popular forwarder node to transmit packets to the destination node. The proposed routing schemes can be run using synthesis traces rather than built in mobility models as the infrastructure totally destroyed due to disaster. This may improve the results in terms of delivery ratio, overhead, hop-count and average end-to-end delay.

The existing routing techniques can be extended by utilizing more than one mobility models, separate mobility models for vehicles and pedestrians. For vehicles, either Map-Based mobility model or ShortestPathMap based mobility model can be used while a Random Waypoint, Disaster Mobility model or WorkDayMobility model can be used for pedestrians. Social Rank of nodes can also be calculated using TOPSIS to select an influential forwarder node which may improve the performance of DTN routing schemes becuase TOPSIS is considered a popular method to calculate the highest rank based on multiple social attributes values.

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