Performance assessment of routing protocols for campus area emergency delay-tolerant network

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ABSTRACT

Handheld devices have recently become an indispensable part of our daily lives. These devices always require an end-to-end connection for proper message transmission. Message transmission will be halted if the connection fails. In this case, delay-tolerant networks (DTNs) are preferable. One of the most important applications of DTN is the transmission of emergency messages among rescue personnel in the aftermath of a disaster. Previously, we created a simulation map in the Rajshahi University (RU) campus area of Bangladesh and studied the performance of DTN routing protocols. This paper used our developed simulation map to evaluate the performance of DTN and social-based routing protocols for emergency message circulation in the RU campus area when traditional communication networks are unavailable. We conducted extensive experiments with the opportunistic network environment (ONE) simulator for evaluations. The performance analysis is based on the delivery ratio, average latency, transmission cost, and average hop count of each group when the message size and node density are changed. According to the simulation results, dLife outperforms all other routing protocols in terms of delivery ratio, while the Spray-and-Focus routing protocol outperforms all other performance metrics.

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1. INTRODUCTION

In the context of a highly developed technological epoch, portable energy-limited devices have experienced significant proliferation. The user expresses a strong interest in attaining uninterrupted connectivity and efficient message transmission across various networks. Using traditional networks presents a significant challenge in effectively meeting their requirements [1]. Transmission control protocol/internet protocol (TCP/IP) is commonly utilized in traditional networking systems. This protocol is not applicable in certain communication networks, such as wildlife tracking networks, vehicular networks, and post-disaster scenarios [2], [3], due to mobility, excessive bit error rate, or power conservation schedule. The delay-tolerant network (DTN) is a potential solution to address this particular issue [4], [5]. DTN is an ad-hoc network that operates without requiring a continuous end-to-end connection between nodes to transmit messages successfully. For the exchange of messages, DTN uses a store-carry-forward paradigm. In an ad-hoc network, upon receiving a message, a node employs a routing mechanism to determine the appropriate path for forwarding the message to the next node, notably when it lacks direct connectivity to the intended destination node. In these instances, the message has been transmitted utilizing the DTN paradigm. However, regarding connectivity failure or loss, the messages are not disregarded but stored in a buffer until a connection becomes available. Furthermore, it is advisable to initiate the transfer whenever the connection of the forwarded node is accessible. As a result of this process, the development of DTN routing protocols is becoming increasingly intricate. Several real-world networks adhere to DTN architecture, including vehicular ad-hoc networks, satellite communication systems, wildfire networks [6]–[8], space communication networks [9], [10], and data security [11].

In recent times, a number of social-aware routing protocols have emerged, gaining popularity due to their ability to prioritize social proximity between nodes in DTN. The utilization of routing protocols in social interactions and structures involves the establishment of communication pathways between nodes to enhance the efficiency of message delivery. The transmission of messages between nodes occurs by taking into account the social closeness among nodes and their knowledge of the content [12], [13]. In recent years, several DTN routing schemes that utilize social features have been developed for opportunistic networks, including Scorp [14], dLife, dLifeComm [15], and Bubble Rap [16]. In a previous study, the researchers focused on the development of the Rajshahi University (RU) campus area as a simulation map and conducted an investigation into the performance of DTN protocols [17]. This paper primarily centers on examining the performance of various DTN and social-based routing protocols. The investigation is conducted within the confines of the simulation area depicted in reference [17]. The present simulation incorporates the utilization of the shortest path map-based movement model (SPMBMM), which is assessed based on several evaluation indices, including delivery ratio, average latency, transmission cost, and average hop count.

The present paper is structured in the following manner. Section 2 provides an overview of the relevant literature and previous research in the field. In section 3, we provide a description of DTN and social-based routing protocols. Section 3 explains the methodology for developing the RU campus area map for investigating the performance of different protocols. In the subsequent section, section 4, we will delve into the simulation setup and parameters. The simulation results are presented in section 5. In section 6, a comprehensive summary of this study is presented.

2. LITERATURE REVIEW

This section briefly discusses some previous research works related to this work. At first, the authors Viet *et al.* [18] investigated the performance of the DTN routing protocol by using an opportunistic network environment (ONE) simulator as a simulation tool and the Asia-Afrika and Braga area in Bandung as the simulation area. They found that social-aware content-based opportunistic routing protocol (SCORP) performs better than other protocols. Then, the authors, Khan and Rahim [19], considered the default ONE simulator simulation area to investigate the performance of DTN and social-aware routing protocols. After that, the simulation map was changed to the Tirana city map (Albania) area map to investigate the performance of DTN routing protocols [20]. The author focused on some mobility models and found that the Epidemic protocol performs better than others. Angulakshmi *et al.* [21], considered the Helsinki city map as the simulation map and found that the spray and wait protocol is more effective than others. Agussalim *et al.* [22], proposed a spray and hop distance (SNHD) protocol and investigated its performance by considering the simulation area of the Surabaya map. The results indicated that the SNHD is more efficient than other existing routing protocols. Table 1 summarises the related works.

Table 1. Comparison between our proposal and existing works.

Ref.	Routing protocols	Simulation area	Evaluation matrices	Findings
[18]	Scrop Epidemic Spray and wait	Asia-Afrika and Braga area in Bandung	Buffer size Nodes	SCORP performs better than other protocols
[19]	DTN Social-aware	Default one simulator simulation area	Delivery probability Overhead ratio Average latency	DTN routing protocols perform better than social-aware routing protocols
[20]	DTN	Tirana city map	Average delay	Epidemic protocol shows a high average delay due to ACK packets
[21]	Some routing protocols	Helsinki City Simulation area	Buffer size, nodes Movement ratio Message generation rate	Spray and wait protocol is more effective than others
[22]	SNHD, Epidemic MaxProp, ProphetV2	Surabaya map	Number of delivered messages, average latency, and overhead ratio	SNHD performs better than other existing routing protocols

However, from the above discussion, it is noticeable that one of the most fundamental difficulties in DTN is routing optimization, as the responsibility of data transmission and the whole network performance heavily depends on the routing protocols [23]. Therefore, it is essential to determine the appropriate routing protocols for emergency network connections. However, the simulation area is another critical metric for evaluating network performance. Several researchers investigate the network performance by considering different city areas, such as the Tirana city map (Albania) [20], Helsinki city [21], Surabaya map [22], or simulator default map [19] as the simulation map. In this work, we develop the simulation map of the RU campus area, Bangladesh, one of the most prominent universities in Bangladesh. Hence, in such a big area, we need to choose a proper and efficient routing protocol that will ease communication in such a challenging environment in a timely and economical.

3. DELAY-TOLERANT NETWORK AND SOUTHBOUND ROUTING PROTOCOLS

3.1. Delay-tolerant network routing protocols

3.1.1. Epidemic

The epidemic algorithm was mainly proposed for the synchronization of replica databases. It uses a replication-based approach to forward data in DTN networks. This makes it the first routing protocol of its kind in DTN. The protocol employs unique IDs for each message to ensure the unique identification of messages maintained by nodes using summary vectors. However, this approach requires a vast buffer size and results in a large amount of redundant data in the network [24].

3.1.2. MaxProp

Messages are only forwarded to neighboring nodes if they are likely to be delivered to the destination node. This process involves calculating each neighbor's expected delivery cost based on the likelihood of success. Then, the message is forwarded to the neighbor node to ensure the lowest cost [25].

3.1.3. Spray and wait

This protocol proposed resolving uncontrolled message copies and low resource consumption in the epidemic routing protocol. The protocol consists of two stages. The first stage is called "spraying," during which a predetermined number of information copies are made from the source node and forwarded to the relay or neighboring node. The Wait phase is the second. A certain number of information copies are held in a buffer during the wait phase and await direct transmission to the target node. Utilizing fewer resources and fewer uncontrolled message copies are two benefits of this strategy [26].

3.1.4. Spray and focus

The Spray and focus (SF) protocol proposes a significant improvement over the Spray and wait (SW) protocol by using a sophisticated single-copy scheme for message delivery. It replaces the resource-intensive multi-copy approach of the SW protocol during the waiting phase. This protocol maximizes delivery rate, minimizes resource consumption, and lowers message latency by optimizing the waiting phase through single-copy routing [27].

3.2. Southbound protocols

3.2.1. Scorp

Scorp was the first Southbound (SB) routing protocol. It is intended to improve message delivery in congested networks by considering users' social interactions and interests. By creating duplicates only in nodes interested in the content or by forming strong connections with nodes sharing the same interest, it makes use of social intimacy and content knowledge [14].

3.2.2. dLife

The dLife protocol integrates social interactions and user behavior to improve data delivery. Time-evolving contact duration (TECD) and time-evolving contact duration importance (TECDi), two cutting-edge features, are used to customize delivery routes for maximum effectiveness and success. the TECD function first assists in calculating the average contact period of nodes with other nodes, while the TECDi function considers the changing relevance of a user depending on the level and societal influence of neighbors at various times of the day for improving the effectiveness of the message delivery [15].

3.2.3. dLifeComm

dLifeComm (DLC) is the community-based version of the dLife routing protocol. This protocol utilizes a k-clique algorithm to detect social structure. TECDi is a feature that gives priority to users with higher influence scores when routing messages submitted across communities to their targeted destinations. Throughout the target community, DLC guarantees faster and more dependable message delivery by concentrating on users who demonstrate greater significance [15].

3.2.4. Bubble rap

Bubble Rap considers the centrality of a node within a community and the community structure to make message-forwarding decisions. It considers the node's position in the community and the relationships between nodes to determine the most efficient way to forward messages and improve delivery rates. This protocol follows two assumptions for forwarding the message. First, each node must at least belong to a community. Second, each node has a local and global ranking across its local communities and whole communities [16].

4. METHODOLOGY

This section describes the methodology to develop the RU campus area map as the simulation map and all steps for simulating and collecting data. Detailed step-by-step instructions on how to compare the performance based on different routing protocols with new MAP using ONE simulator are given:

i. Step 1, Create a new map file: we need to follow the following steps to create a new map:
   - Create a new map file in the maps directory of the ONE simulator. The map file should be in the well-known text (WKT) format, which is a text-based format for representing vector data. We can use a tool like OpenJUMP to create a map file in this format. The map file should contain the coordinates of the vertices of the map, the edges that connect the vertices, and the areas that are filled in.
   - Edit the *config.properties* file to add the new map file to the list of maps. The format for the map file entry is
   - Map.*<map name>=<p a t h t o m a p f i l e >*
   - Start the ONE simulator. The new map will be loaded automatically.

ii. Step 2, Configure the ONE simulator: it can be configured using a configuration file that specifies the parameters, such as node number, node density, routing protocol, and map file.

iii. Step 3, Run the simulation: after configuring the simulator, run the simulation for a specified period of time, and collect data for analysis of the performance of the routing protocol.

iv. Step 4, Analyze the results: after the simulation has finished, we need to analyze the results. The results will show how the performance of the routing protocol varies.

v. Step 5, Compare the results: then we compare the results of different routing protocols to observe which protocol performs better under different performance matrices.

vi. Step 6, Repeat the experiment: to get more accurate results, we should repeat the experiment by using different random seeds each time to ensure that the results are not affected by the random placement of the nodes.

vii. Step 7, Draw conclusions: after repeating the experiment multiple times, we can draw conclusions about the performance of different routing protocols. The performances of different routing protocols are compared to see how the performance varies and which protocol is the most efficient.

5. SIMULATION SETUP

5.1. Simulation environment

This paper used ONE simulator for the performance assessment of DTN and SB routing protocols. The primary function of the ONE is to model the node movement, routing and message handling, and internode contacts. The visualization, reports, and post-processing tools of ONE simulator are used to collect and analyze the results. The ONE simulator project page, an accurate simulator description, and the source code are also available [28]. For simulation, we considered the map of the RU campus, Bangladesh, as the simulation map shown in Figure 1. Figure 2 indicates the node position for the simulation area by using the graphical user interface (GUI).

5.2. Simulation parameter

The parameters used to model the simulator for simulation are listed in Table 2 whereas Table 3 describes the parameter for different routing protocols. We have considered the following two different cases for performance investigation. Case 1 is changing the node density of each group and case 2 is changing the message size.

At first, case 1 fixed the message size at 500 KB, simulation duration for 6 hours, message generation rate at 3, the capacity of the buffer is 4 MB, and time-to-live (TTL) is 4 hours by changing the number of nodes per group to 30, 45, 60, 75, 90, 105. Case 2 fixed the node density of each group at 30 and changed the message size of each group from 100 KB to 800 KB. Routing protocols remained the same for both cases. For the evaluation of DTN and SB routing protocols in our developed simulation map, we measured delivery ratio, average latency, transmission cost, and average hop count.

Figure 1. RU map

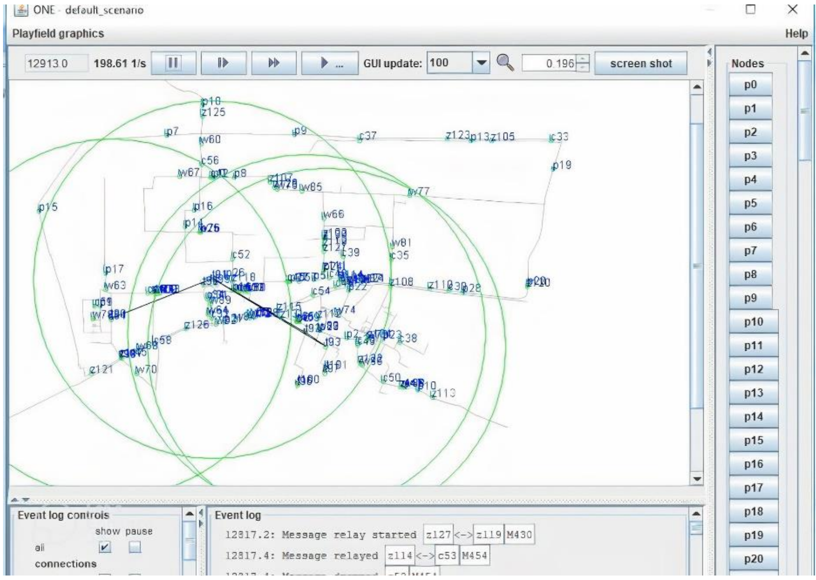

Figure 2. Nodes position in RU map

Table 2. Parameters for simulation setup

Parameters	Value
Simulator	ONE
Simulation map	RU campus, Bangladesh
Simulation time	21600 sec (6 hours)
Update interval	0.1 sec
Nodes in every group	30, 45, 60, 75, 90, 105
Interface type	Bluetooth
Transmission rate	280 kbps
Transmission range	10 m
Protocols	ED, MPP, SW, SF, SC, DL, DLC, BR
Capacity of buffer	4 MB
Message generation rate (per minute)	3
Message TTL	240 min. (4 hours)
Message size (KB)	100, 200, 300, 400, 500, 600, 700, 800
Mobility model	SPMBMM
Simulation area size	3200×3000 m

Table 3. Parameters for different routing protocols

Routing algorithm	Parameters	Value
ED	N/A	N/A
MPP	N/A	N/A
SW	No. Of copies	7
SF	No. Of copies	7
SC	Group of router	Decision engine router
DL	Group of router	Decision engine router
	Decision engine router familiar threshold	700
DLC	Group of router	Decision engine router
	Decision engine router familiar threshold	700
BR	Decision engine router familiar threshold	700

6. SIMULATION RESULTS

This section explores the simulation results that have been obtained using the ONE simulator. The actual campus map of RU in Bangladesh served as the basis for the results. The simulation results offered valuable insights into the performance of the discussed protocols under real-world conditions.

6.1. Simulation results for case 1 (changing node density)

Figure 3 shows the simulation result for case 1, where the x-axis indicates the node number per group and the y-axis indicates the value of different evaluation matrices. At first, Figure 3(a) investigates the influence of the delivery ratio for several protocols where the y-axis indicates the delivery ratio value. It is evident from the simulation result that the delivery ratio of the dLife (DL) protocol shows better performance than the rest of the routing protocols because of its principle to forward the message to the encountered node with substantial social information with greater importance. Moreover, the scorp (SC) protocols show worse performance than other protocols. Therefore, it is concluded that the DL is the best and SC is the worst protocol in the case of delivery ratio. Figure 3(b) depicts the simulation result for average latency, where the y-axis indicates the average latency in minutes. It is observed from this figure that SF protocol has the lowest value than other routing protocols, and DLC protocol has the largest value of average latency. Therefore, we can say that SF is the best protocol because low latency is one of the key features of the 5G communication system, and DLC is the worst protocol for changing the node density of each group. Figure 3(c) illustrates the relationship between the transmission cost with the varying node density of each group. It is observed from the spectra that SF protocol is better for considered simulation setting as it generates only a limited number of messages at the spray phase, and this message does not wait in the focus phase for direct transmission BR has the worst performance as it follows community centrality for forwarding the message which results in the high additional message is required. Similarly, the simulation results of the average hop count are presented in Figure 3(d). It is evident from this figure that epidemic (ED) protocol shows the worst performance as the average hop count value is increased with the increased nodes number per group. In this case, ED protocol requires a huge number of intermediate nodes for delivering information to the proper destination. Moreover, the SF protocol performs best as it requires a small number of intermediate nodes.

Therefore, according to the above discussion, the DL protocol outperforms other routing protocols in terms of delivery ratio. In contrast, the SF protocol conveys excellent performance for other performance metrics. Therefore, it is confirmed from the simulation result for case 1 that the performance of the DTN protocol is better than the SB routing protocol for changing node density for each group.

6.2. Simulation results for case 2 (changing message size)

Figure 4 represents the simulation result for case 2. Figure 4(a) shows the impact of the delivery ratio where the DL protocol exhibits better performance, and the SC protocol provides the worst performance compared to other routing protocols. Figure 4(b) shows the spectra for average latency by varying message size. SF protocol has the lowest average latency value than other routing protocols, as observed for case 1, and DL has an enormous value. Therefore, SF is the best protocol because of low latency, and DL is the worst protocol for message size constraints. The spectra of transmission cost are shown in Figure 4(c). It is noticeable from this figure that the SF protocol shows better performance, and the BR protocol shows worse performance. Figure 4(d) presents the simulation results of average hop count where SF protocol conveys excellent performance, and ED protocol shows the worst performance in the corresponding scenario.

Therefore, it is concluded from the above discussion for case 2 that the DL protocol exhibits better performance in the case of delivery ratio. In contrast, the SF protocol conveys excellent performance for other performance metrics, as we observed from the simulation result for case 1. Therefore, we can say that the DTN routing protocol performs better than social-based routing protocols for changing message size, as obtained from the simulation result for case 1.

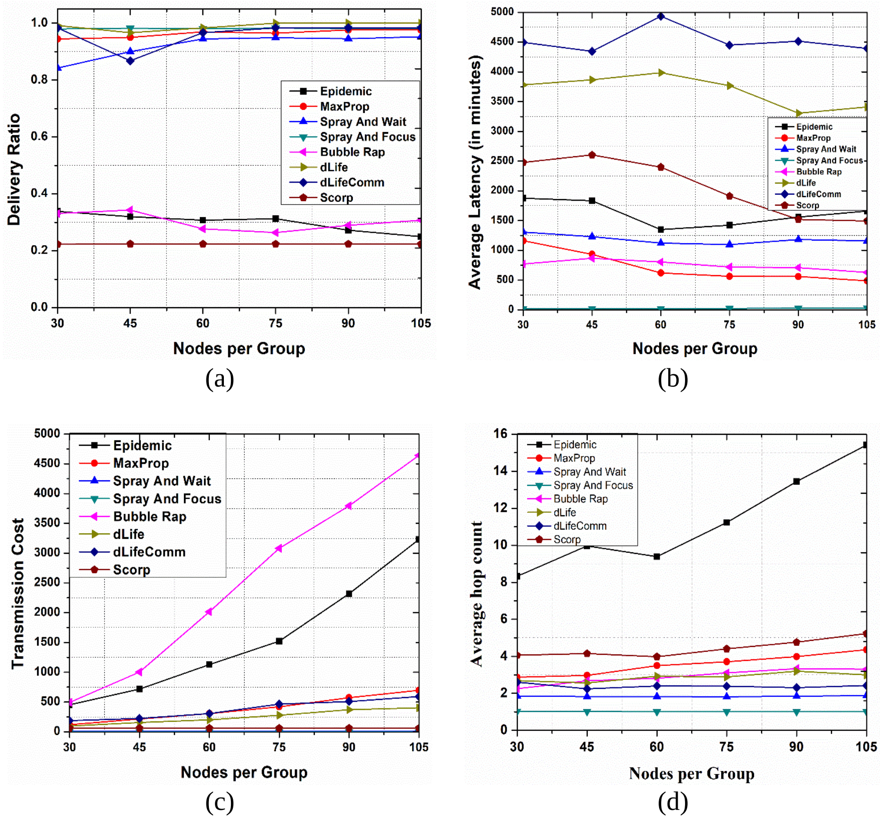

Figure 3. Simulation results for case 1; (a) delivery ratio, (b) average latency, (c) transmission cost, and (d) average hope count

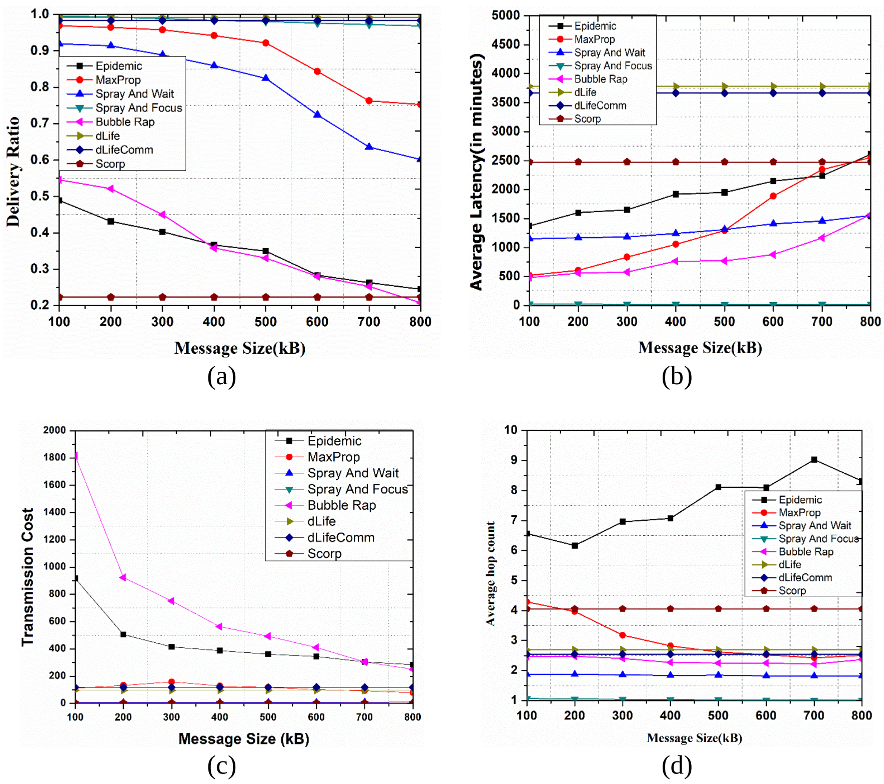

Figure 4. Simulation results for case 2; (a) delivery ratio, (b) average latency, (c) transmission cost, and (d) average hope count

7. CONCLUSION

In this study, we used the RU campus area as the simulation map to assess the efficacy of several conventional DTN and SB routing protocols. We used ONE simulator to evaluate its performance. Moreover, two different cases have been considered for this investigation, where case 1 focuses on changing the node density of each group, and case 2 focuses on changing the message size. For both cases, it is concluded that DTN routing protocols perform better than SB routing protocols under the simulation area of the RU campus, Bangladesh. Moreover, the SF protocol performs excellently except for the delivery ratio, whereas the ED protocol exhibits the worst performance. Therefore, the simulation result confirmed that the DL protocol performs well in terms of delivery ratio while the SF protocol performs well in terms of other performance metrics.

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