The Impact of Node Density and Buffer Size on DTN Routing Protocols with Energy Efficiency: A Comparative Study

Md. Khalid Mahbub Khan, Kawsaruzzaman, Md. Mahbubur Rahman and Al-Imtiaz

Abstract—**Delay Tolerant Network (DTN) architecture comprises of portable devices known as nodes, considered a resource-limited networking system. These nodes in DTN utilize the 'Store Carry and Forward' approach to route data since the end to end connections are absent here due to a large number of constant intermittent connectivity. The energy quantity of nodes is restricted because limited-lifetime rechargeable batteries drive them. Accordingly, energy is an essential resource in DTN scenarios. For efficient network performance, including proper energy usage, nodes need to expense a minimum amount of energy. For this reason, it is essential to select an energy-efficient forwarding strategy and exhibit excellent performance among existent forwarding approaches in the DTN environment for routing messages effectively. In this paper, we have studied the energy efficiency of conventional DTN routing protocols: Epidemic, Spray and Wait, Spray and Focus, MaxProp, and PRoPHET on the impact of varying both buffer size and node density. We analyzed their energy consumption and compared their performance based on five performance metrics: average remaining energy, delivery ratio, average delay, transmission cost, and average hop count, respectively. Using ONE simulator, we performed a simulation with varying node density (while buffer size is fixed) and varying buffer size (while node density is fixed). From the outcomes of simulation, we found that Spray and Wait are the most energy-efficient DTN routing protocols. On the contrary, Spray and Focus possessed as the best performer in terms of average hop count, average delay, delivery ratio and transmission cost among conventional DTN routing protocols.**

Index Terms—**Delay Tolerant Network, ONE Simulator, Buffer Size, Node Density, Routing Protocols, Energy-Efficiency.**

I. INTRODUCTION

The capacity of the network increases simultaneously day by day with the necessity based on their applications. In this era, the communication field is much stronger than the previous day. The increase of communications using several networking devices becomes part of our life. Traditionally, end to end connections is required for propagating messages through the network. However, in many cases in the real world, end-to-end connections cannot afford the continual service for all the time due to the node's movability or the random variations of network architecture. However, people demand more efficient, faster data communication since they want to convey their data faster [1]-[2].

Additionally, unrestricted and unconfined connectivity disrupts the communication in real life as continuous connectivity is desired at moving time too. Within a hectic and unsettled network connection, routing techniques are poorly disrupted. Effective data transmission through an unstable network should require more sophisticated and competent routing techniques that could not be possible in existing TCP/IP architecture. In Delay-Tolerant Network (DTN), intermittent connectedness among nodes is involved in improving data forwarding in such unstable, heterogeneous networks. DTN has a wide range of applications in wireless sensor networks (WSNs), underwater networks, airborne networks, vehicular networks, etc. Data forwarding is performed in DTN architecture following the "Store Carry and Forward" paradigm. Within this model, the message would be temporarily stored by the source node if its connectivity is not available to the other nodes. It will carry a message until the availability of connectedness between the source and other nodes. Whenever the connectivity is employable to another node, the source node will deliver the message to that node [3]-[7].

To route messages efficiently within such a challenging environment like DTN, several forwarding approaches have been proposed. Conventionally, they are sorted into two major categories: first, one is replication-based, where the multiple replicas of message are forwarded by source node towards the neighbors. In this manner, the message will be relayed through the entire network. On the other hand, second group forwarding protocols employ the network's previous knowledge to forward a selected number of message copies towards the elected nodes. These nodes utilize the network's historical knowledge fruitfully in order to transmit a moderated number of messages. All routing approaches in DTN were proposed to improve the success rate of message delivery [8]-[9].

In the DTN environment, node activities are dependent on energy-limited batteries, which are known as "Lithium-ion Batteries". Due to this limited energy reservation capacity, nodes are alive till the end of battery life. However, Bluetooth, Wi-Fi etc. the nodes adopt technologies for the connections. After connecting into the network, nodes have to spend much energy searching the next relay node and then

M. K. M. Khan, Lecturer, Department of CSE, University of Information Technology and Sciences, Bangladesh.
(e-mail: khalid.mahbub@uits.edu.bd)
Kawsaruzzaman, Department of CSE, University of Information Technology and Sciences, Bangladesh.
(e-mail: 16251019@uits.edu.bd)

M. M. Rahman, Assistant Professor, Department of EEE, Jatiya Kabi Kazi Nazrul Islam University, Bangladesh.
(e-mail: mahbubur.ice@gmail.com)
Al-Imtiaz, Assistant Professor, Department of CSE, University of Information Technology and Sciences, Bangladesh.
(e-mail: al.imtiaz@uits.edu.bd)

sending the message to it, receiving the message from the sending node, temporarily storing the message. In such networks, the energy expenditure of the node is considered vital, and energies should be spent efficiently. Less consumption of energy following a controlled and effective usage way is necessary for the better, efficient performance of the network. Thus, forwarding strategies to route messages within DTN need to be energy efficient [10]-[11].

There are many research works have been done in the field of wireless communication [12]-[19] such as in the field of the DTN. In [20], authors have studied the comparative performance analysis of four DTN forwarding strategies: Epidemic, Spray and Wait, Spray and Focus, and MaxProp on applying a new map on behalf of several performance metrics. In that work, they have not considered the energy efficiency of such protocols. Other DTN protocols like PRoPHET etc. are absent on that research. In [21], a performance evaluation of Epidemic, Spray and Wait, PRoPHET and MaxProp have been performed considering the impact of varying buffer size.

Moreover, the impact of varying maximum allowable message copy for Spray and Wait is also considered. In [22]-[23], performance investigation of several forwarding protocols in the DTN environment has been done on behalf of various perspectives. However, energy efficiency is not considered in the mentioned works. The energy efficiency of several routing protocols is considered in some studies in [24]-[28]. Within these researches, "average remaining energy" is also included along with other parameters in performance evaluations for the simulated DTN routing techniques. Moreover, in [26], a new energy-concerned algorithm is proposed and compared with existing DTN protocols based on node density, latency, etc. Although, several aspects are considered these work, the effect of buffer size expansion is not presented in those works. Since energy aspects are closely related to the buffer size. If the node's remaining energy is higher, it would be able to store more messages for a long time. So, the message delivery rate may improve. Similarly, the effect of the node density on existing forwarding techniques with energy consideration is also essential. In this research, we are motivated to study the impact of varying buffer size and node density on several DTN protocols: Epidemic, Spray and Wait, Spray and Focus, MaxProp, and PRoPHET. We will consider overall five performance metrics into our studies, such as average remaining energy, delivery ratio, average delay, transmission cost, and average hop count. The remaining of the paper is consisted as: a brief description of investigated DTN routing techniques are discussed in section II. Then section III explains the simulation environment, and section IV explains the relative comparison and discussion about the outcomes of the simulation. Lastly, section V approaches a conclusion with the future plan of this research.

II. INVESTIGATED DTN ROUTING PROTOCOLS

This section includes a brief discussion of our investigated forwarding techniques. A short explanation of their fundamental routing decisions is provided here. Within our research, we have considered five DTN routing strategies:

Epidemic, Spray and Wait, Spray and Focus, MaxProp, and PRoPHET.

A. Epidemic

Within these selective routing techniques, the Epidemic forwarding approach is the most ancient among other DTN routing techniques that are generally based on message replication. This replication behavior of Epidemic replicates the source's message blindly and then sends the replicated message versions to first encountered nodes. The copies of message relay to the whole network and message congestions can be broken out into the network since the multiple numbers of nodes receive similar message copies. Thus, flooding of the same message copy is caused. However, this routing approach ensures successful message transmission without regarding transmission delay, buffer size, network congestion, etc. It does not have any control method for message flooding while exploiting high energy, buffer space, and pass on network resources for data packets. With this type of conduction in DTN conditions, Epidemic gives the worst data forwarding functionalities, and till it controlled the replication, it will perform the same repeatedly in the network [22]-[23] [29].

B. Spray and Wait

Spray and Wait forwarding strategy ensures the minimum rate of resource usage, and that can be achieved by limiting the replication rate of the message. Instead of blind replication like Epidemic, this strategy adopts controlled forwarding to improve data routing. Within the entire network, there are only L copies of messages can relay where L is the maximum relayed number of message replicas that are allowed to spread. The value of L is depended on the number of nodes and the necessary average time to deliver a message successfully [23]. This forwarding approach is constructed by two steps that are explained as follows [25] [27] [30]:

1) Step 1:

This step is referred as "Spray" where the source node forwards the L copies of the message towards the L numbered distinct relay node. If the absolute target node is not achieved in this step, the next step would proceed.

2) Step 2:

This stage is known as "Wait" stage. Here, L relay nodes those receives L copy of message is waiting until their connectivity with the destination node is available. When the destination node is available message forwarding is performed toward it [28].

C. Spray and Focus

Spray and Focus have improved the single copy strategy that is the sophisticated version of Spray and Wait routing protocols. In this forwarding scheme, the node that received a single copy of the message from a relay would prefer to retransmit that message copy toward the destined node. This routing technique is almost similar to Spray and Wait protocol. The only difference is to the second step, where the first step is similar to both protocols. In Spray and Focus, the second step is known as "Focus" step. In this case, instead of waiting to encounter the destination node, it forwards the message toward the destination node using the utility-driven model and keeps the relay message transmission copy for the

individual message, and it is an instant alternative to the focusing stage [31]-[32].

D. MaxProp

It is a schedule based forwarding technique in which schedule specification and prioritization are considered to forward data packet. Here, two nodes meet each other in order to exchange their values of utility. These values are generally applied to find out the minimal costs. This protocol works through a queue which is ordered. The shortest path is intelligently achievable in MaxProp for those messages that can be delivered to the destination. This forwarding mechanism determines which message would reach the destination with success passing through a minimum count of the hop, minimal delay, etc. Which messages would be dropped when the buffer size runs out of space is also fixed within this forwarding mechanism [20] [24] [27].

E. PRoPHET

Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) can properly use the network resources in the DTN environment. It transmits the messages to the targeted destination maintaining a set probability that helps to identify the targets. This forwarding strategy avoids blind message transmission like Epidemic and uses the possibilities in the real-world encountered node. The message would be sent to that node with the highest probability of delivery and encountered the node first. During the confrontation between source and other nodes, it forwards the message to only those nodes which has higher probabilities. It enhances the delivery probability in the individual node when analogous incidents encounter and stores the delivery predictability for each node particularly [7][23].

III. SIMULATION ENVIRONMENT AND NECESSARY SETTINGS

Within this research, we used the Opportunistic Network Environment (ONE) [33]-[34] simulator that is the Java-based simulator as the source codes are written in Java. The script of the simulation is simply written in plaintext. Moreover, this simulator supports different mobility models, able to visualize the node mobility, capacity to support new maps, etc. This simulator is an ideal tool for simulating DTN forwarding protocols [23] [33]. We also implemented an energy module [34] into the simulator to perform simulations of the Epidemic, Spray and Wait, Spray and Focus, MaxProp, and PRoPHET forwarding approach. Within this work, we are intended to investigate the impact of node density and buffer size on several DTN routing techniques by considering their energy efficiency as well as their performance analysis. First, we varied node density from 40 to 100 by keeping buffer size fixed (5MB) and simulated examined forwarding techniques. Then we increased the buffer size of the node from 5 MB to 50 MB by keeping fixed node density (40). All simulation outcomes is plotted in the graph. Here, in both cases, message Time-To-Live (TTL) was kept 300 minutes. We considered 8 hours for simulation time and used "Shortest Path Map-Based Movement" model as the movement model of nodes. Our entire simulation area is 4500 m × 3400 m. Some parameters that are applied for the simulated forwarding approaches are mentioned in Table I and in Fig.

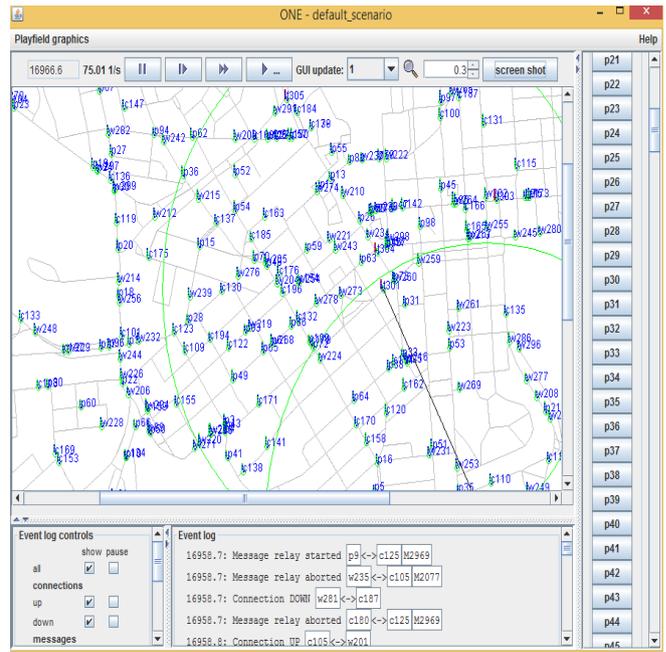1, a screenshot of ONE simulator is displayed.

Fig. 1. A screenshot of ONE simulator

TABLE I: PARAMETERS FOR SIMULATION SETUP

Name of Parameters	Values
Simulation Duration	8 hours
Update Interval	0.1
Node Density	40, 50, 60, 70, 80, 90, 100
Buffer Size	5, 10, 20, 30, 40, 50
Interface	Bluetooth
Interface Type	SimpleBroadcastInterface
Transmission Rate	250kpbs
Transmission Range	10m
Message TTL (in minutes)	300
Message Generation	1
Message Size	500kB – 1MB
Wait Time	0, 120
Movement Model	ShortestPathMapBasedMovement
Mobility	MapRouteMovement
Simulation Area Range	4500m, 3400m

TABLE II: PARAMETERS REGARDING NODE ENERGY

Name of Parameters	Values
Initial Energy (joules)	5000
Scan Energy (mW/s)	0.92
Transmit Energy (mW/s)	0.08
Receive Energy (mW/s)	0.08
Interval of Energy Recharge (seconds)	30000

Energy-related criteria of the node are provided in Table II where the total amount of energy given to each node before the simulation is known as "Initial Energy". When node scans for the next relay among the neighboring nodes transmit or connect, it consumes a given quantity of "Scan Energy," and when the node starts transmitting data to another node it expenses a fixed amount "Transmit Energy". "Receive Energy" is used while receiving time and "Interval of Energy Recharge" is the interval time into that the battery of node can be recharged and in this case, we have fixed it 30000 s that is greater than the overall duration of the simulation (8 hours or 28,800 seconds). It means that the battery of the node is charged a fixed amount of energy before initiating simulation, and it cannot be recharged during simulation is running. Additionally, in Table III, some important parameters for routing techniques are outlined.

Routing Protocols Name	Parameters	Values
Epidemic	N/A	N/A
Spray and Wait	No. of Copies	10
Spray and Focus	No. of Copies	10
MaxProp	N/A	N/A
PRoPHET	Seconds in Time Unit	30

IV. ANALYSIS OF SIMULATION RESULTS

This section delivers an analytical discussion based on the outcomes of simulation that are performed in ONE simulator. The outcomes of simulations are analyzed based on the following performance criteria:

A. Average Remaining Energy:

This metric refers to the average amount of the node's residual energy calculated after the complete simulation. This average value of the node's remaining energy is expected to be high. When the node has higher remaining energy, then it will survive for some extended time. The node can be dead also when their energy level turns into zero.

B. Delivery Ratio:

The ratio of messages that are successfully received in destination to the number of messages sent from the source node is known as a delivery ratio. This success rate required to be high as much as possible. This metric is also related to the node's energy since the dead node fails to forward the message.

C. Average Delay:

This parameter is a delay time between the generation of a message by source and its successful reception in the destination. It is also known as average latency. It should be less for better networking performance.

D. Transmission Cost:

Transmission cost is the value of the total amount of transmitted messages that are relayed unnecessarily to deliver a single message. It is basically used to measure the efficiency of the network. The cost of the transmission is desired to a minimum since the resource is restricted.

E. Average Hop Count:

It is the measure of the average number of intermediary hops used for a message to reach the destination. For the stability of a network, it is assumed to be minimum.

F. Impact of varying node density

To observe the impact of node density on DTN routing protocols, we increased the node density up to 100 from an initial value 40. In such a case, the buffer capacity of the node is fixed in 5 MB. As mentioned earlier, the performance criteria are used to analyze the energy efficiency and performances of simulated forwarding protocols.

Fig. 2 shows that the average remaining energy is decreased with the increasing node density except Spray and Wait. The scanning and transmitting functionalities of nodes are increased when the node density increases. Accordingly, the node consumes more energy as the resultant remaining energy goes to decrease. Fig. 1 shows that the Spray and Wait

routing protocol has the highest amount of average remaining energy among the other routing protocols. Due to this highest energy value, it is the most energy-efficient routing protocol, among others, and the bounded usage of energy at this protocol is possible because of relaying a limited number of message replicas. In opposition, MaxProp experiences minimum remaining energy. So, it can be considered as the lowest energy efficient protocol where Spray and Focus, PRoPHET, and Epidemic show less performance as compared to Spray and Wait with respect to average remaining energy.

Fig. 3 shows the impact on node density on simulated forwarding strategies on behalf of the delivery ratio. Here, with varying node density, Spray and Focus, MaxProp and Spray and Wait graph increase gradually, although the Spray and Focus graph are almost constant. So, Spray and Focus demonstrate the highest delivery ratio than others. Since it exploits the improved limited copy of message forwarding, its success rate of delivering the message is raised. In contrast, Epidemic shows the lowest delivery ratio since the uncontrolled flooding of such a technique reduces the successful reception of messages. MaxProp and Spray and Wait average experience ratio of delivery and PRoPHET strategy shows slightly higher delivery probability than Epidemic.
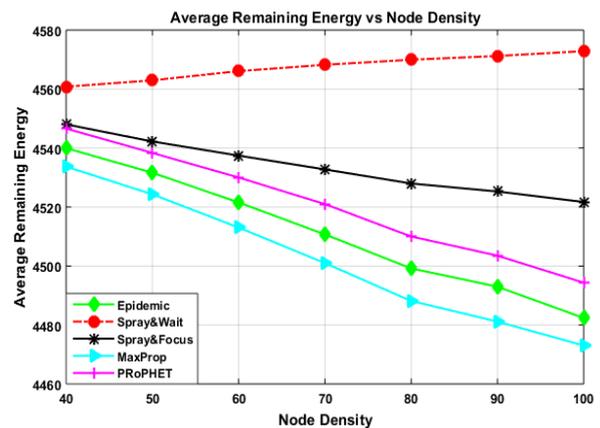

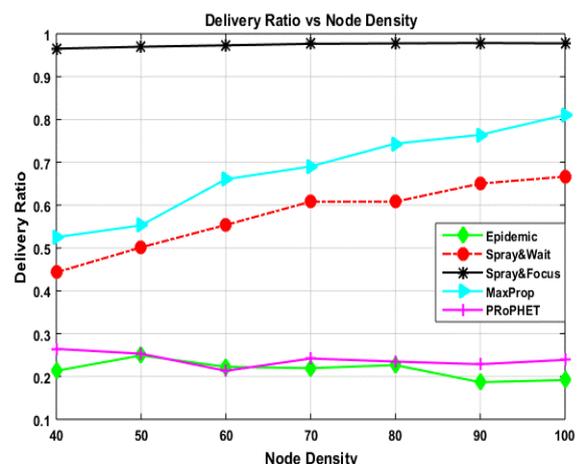Fig. 2. Average Remaining Energy with varying node density

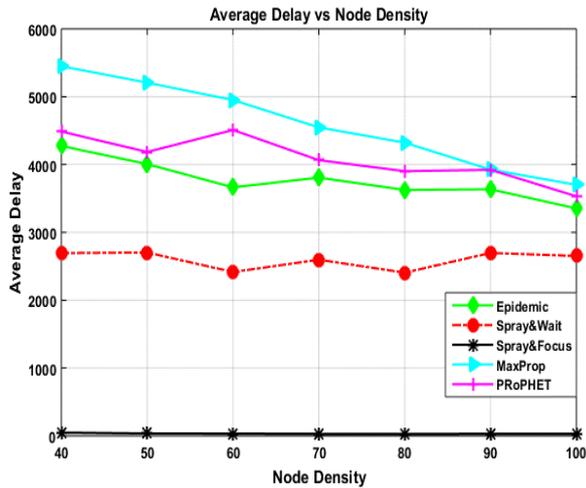
Fig. 3. Delivery ratio with varying node density

Fig. 4. Average delay with varying node density.

Fig. 5. Transmission cost with varying node density.

Fig. 6. Average hop count with varying node density

Average delay variation against the increasing node density is plotted in Fig. 4. From that plot, it is cleared that Spray and Focus have the minimum delay in sending a message successfully toward the destination. Within this routing technique, limited message copies are sent to the next hops, and the number of unwanted copies of the message is reduced. Finally, the allowable number of message copies can reach the destination with minimum delay. Furthermore, the MaxProp protocol experiences the highest delay in this case. As each message will be forwarded according to the schedule into this protocol and message, we need additional time to reach the target for this fixed schedule. So, MaxProp has the minimum performance for the average delay on the impact of node density. PRoPHET, Epidemic, and Spray and Wait provide medium performance between best-performing protocols and worst-performing protocols.

Fig. 5 provides that transmission cost varies with the increase of node density where it is realized that with the increase of node density, the transmission cost of simulated protocols is gradually increasing except both Spray and Focus, therefore Spray and Wait. When more node is employed in the network, sending a single message to the destination will also increase. Among the simulated routing techniques, Spray and Focus have the minimum transmission cost. A selected copy of the message is sent toward selected relays in such protocol, which reduces the transmission cost. So, Spray and Focus have the best performance for transmission cost with the increase of node density. Moreover, Spray and Wait also have minimum propagation cost but much higher than Spray and Focus protocol. This forwarding strategy exhibits second-best performance for such a case where Epidemic has the highest cost for transmitting a single copy of the message toward the target. It blindly replicates the message, so many unnecessary message will be occurred in the network and may waste. For this reason, this protocol has the lowest performance, among others. PRoPhET and MaxProp show the medium performance here.
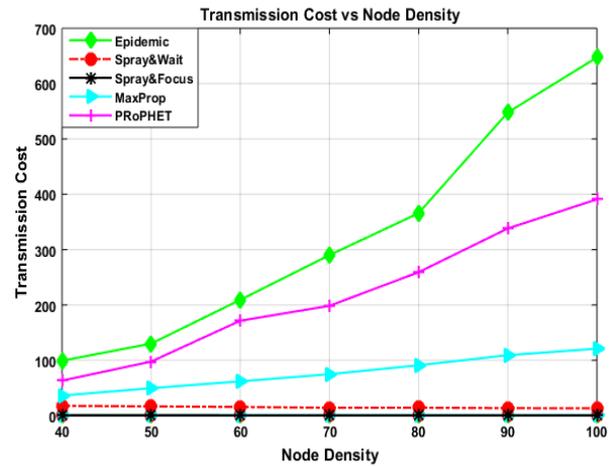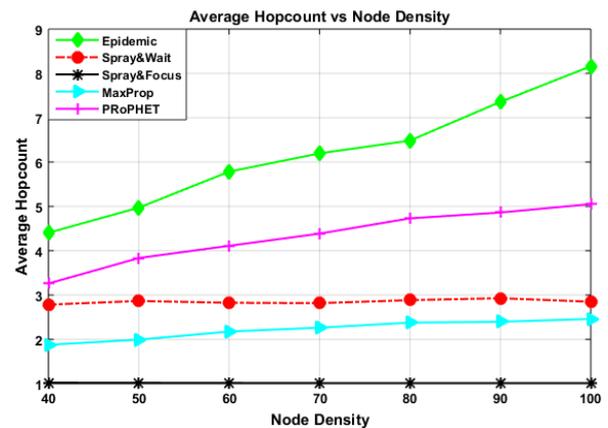
In Fig. 6, the change of average hop count with the accelerating node density is shown. To ensure the stability of a network and avoid discarding messages and collisions, it is necessary to use the minimum number of hop for message routing. From Fig. 5, it is discovered that Spray and Focus have minimum hop count as the graph of it is almost closer to the X-axis. The average hop count can be measured approximately 1 with the variation of node density (starting from 40 to 100). The selected maximum allowable number of message copies are focused and sent to the maximum allowable number relay nodes in this strategy. So, the count of hops is required minimum in Spray and Focus. However, the Epidemic routing technique requires maximum hop count with increasing node density. Because increasing more nodes into the network improves the possibility of using those as relays in the future. The Epidemic is a flooding based forwarding approach, and it requires maximum hops to forward messages. Therefore, Epidemic has the lowest performance for such a parameter. MaxProp, Spray and Wait, PRoPHET demonstrate average performance respectively.

G. Impact of varying buffer size

We increased the buffer size of the node from 5 MB to 50 MB to realize the effect of the buffer capacity of nodes on DTN routing protocols. Here, we kept the fixed node density (actually 40). Above mentioned, five performance metrics are considered to understand the impact of buffer size.

Fig. 7 illustrates how the node's average remaining energy is changed with the increase of buffer size. It can be obtained from Fig. 7 that Spray and Wait has the highest residual

average energy in nodes and it is almost 4558 joules. So, nodes in Spray and Wait can be active more time than other forwarding protocols. Thus, it experiences best performance with respect to buffer size of node. Again, MaxProp as well as Epidemic, has the minimum remaining energy of nodes. But in comparison with MaxProp, Epidemic reveals less performance. When the value of the buffer size is greater than 10 MB, Epidemic's graph will fall behind the MaxProp graph. Limitless replication in such protocol makes it poor candidate for average remaining energy of node.
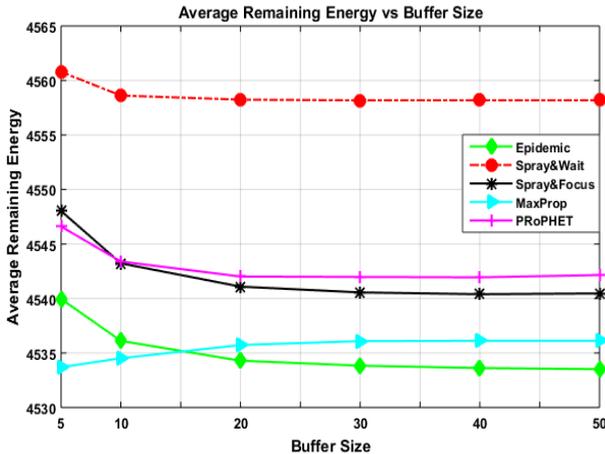

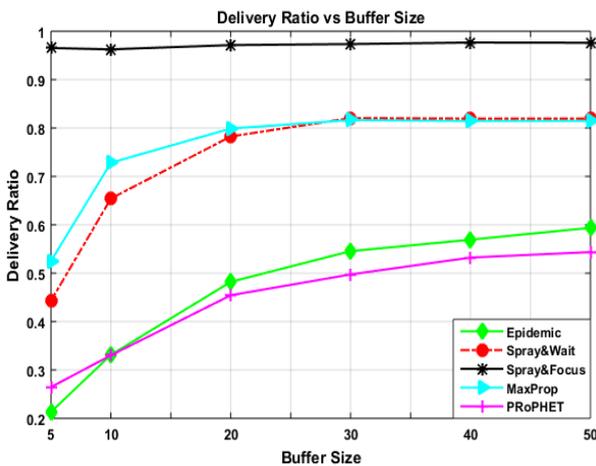Fig. 7. Average remaining energy with varying buffer size.

Fig. 8. Delivery ratio with varying buffer size.

Fig. 8 depicts that the changing of delivery ratio with the increasing of buffer size. Except the Spray and Focus, the delivery probability of other forwarding techniques is increased with the increasing value of buffer size. When the buffering capacity of node is increased, it means that it would able to store more messages to send them toward the destinations. So, the ratio of delivery is increased with buffer size of. In this figure, Spray and Wait has the highest delivery ratio than other protocols and the graph of it is almost constant near the highest value 1. On the contrast, PRoPHET as well as Epidemic show the worst performance for such parameter. Moreover, PRoPHET has the worst performance than other routing approaches since its graph is gone to bellow from Epidemic after the 10 MB buffer size. MaxProp and Spray and Wait exhibit intermediary performance in this case.
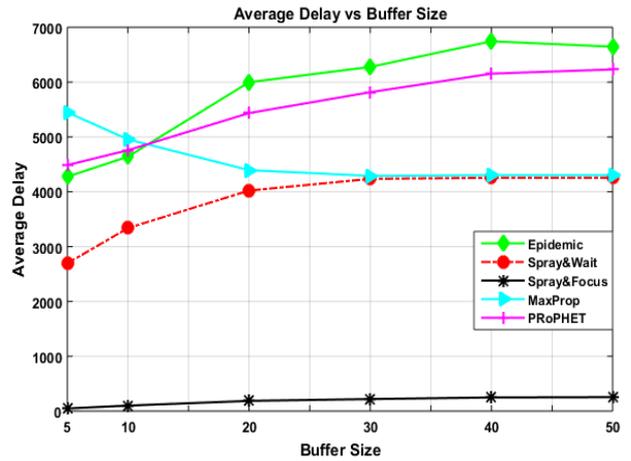

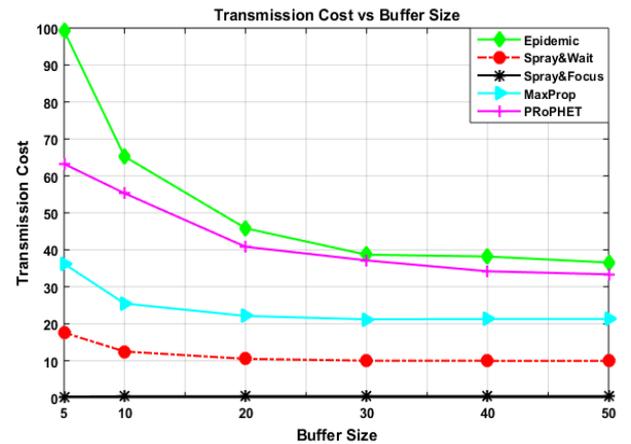Fig. 9. Average delay with varying buffer size.

Fig. 10. Transmission cost with varying buffer size.

The effect of buffer size is quite similar to the effect of node density on average delay parameter. Fig. 9 represents the average delay against the increasing buffer size. As like Fig. 4, from this figure, it is cleared that Spray and Focus have the lowest delay for the successful reception of the message. So, Spray and Focus experienced the best performance for average delay metric with increasing buffer size. However, Epidemic has the highest delay, except on node density effect, where MaxProp has the highest delay. Although the buffer capacity of Epidemic is increased, the possibility of delay in delivering a message on the receiver node is still presented on the network due to the unaware replication of the message. That means, more messages would be stored for a long time in an extended buffer place.
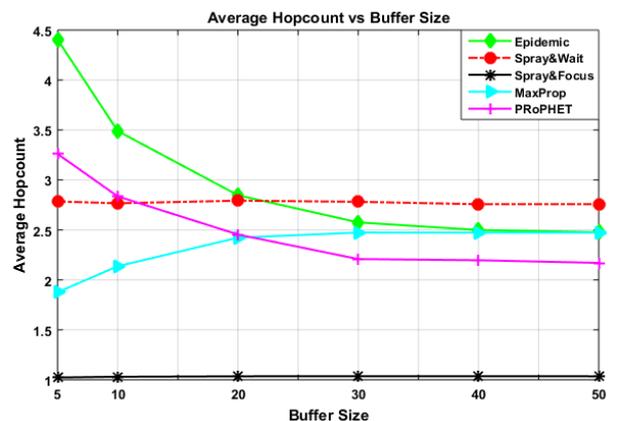

Fig. 11. Average hop count with varying buffer size.

In Fig. 10, we can see that the transmission cost is plotted with varying buffer sizes. In that figure, it is observed that the cost of transmitting a single message in Spray and Focus is minimum among the other investigated protocols. Hence, for the transmission cost, the impact of buffer size is similar to the impact of node density, which proves Spray and Focus as a sophisticated forwarding approach for DTN scenarios. Conversely, Epidemic protocol exposed the highest value of transmission cost. It has the worst performance in this scenario for both buffer size and node density effects evaluations. Unnecessary packet relaying within this protocol makes this a poor choice for DTN architecture. Here, PRoPHET, MaxProp, and Spray and Wait display the intermediary performance between best (Spray and Focus) and worst (Epidemic) performed protocols.

The change of average hop count with the increase of buffer size is demonstrated in Fig. 11. The minimum hop count is desired for stable and efficient networking performance. Spray and Focus protocol has the minimum hop count and best performance with an increasing buffer size of the node. On the contrary. Epidemic, Spray and Wait both protocols expose the maximum hop count. But the Epidemic graph starts from a high value 4.5 and gradually decreases whereas the Spray and Wait graph are almost constant with X-axis, and its value is within 3 hop count. So, here it can be revealed that Epidemic represents the lowest performance as compared to the other routing strategies.

V. Conclusions and Future Endeavors

Within this research, we have considered these DTN routing techniques in our investigation and to simulate in ONE simulator: Epidemic, Spray and Wait, Spray and Focus, MaxProp, and PRoPHET. We investigated the impact of both node density and buffer size expansions with energy efficiency on the simulated forwarding protocols. We also explored the performance comparison of such investigated and simulated routing protocols. We evaluated energy efficiency and performance of simulated protocols by considering the increase of node density and also buffer size based on five performance metrics: average remaining energy, delivery ratio, average delay, transmission cost, and average hop count. From all the outcomes in our investigation, it can be concluded that Spray and Wait is the most energy-efficient forwarding technique among our considered techniques for both node density and buffer size expansion. So, to perform data delivery in an energy-efficient network, Spray and Wait can be a perfect option for implementation. Additionally, Spray and Focus undoubtedly perform the best performance regarding delivery ratio, average delay, transmission cost, and average hop count. This consensus is adopted for the effect of both cases (node density and buffer size). With the increase of node density on the simulated scenario, MaxProp is the worst for average remaining energy and average delay metrics where Epidemic experiences minimum performance with respect to delivery ratio, transmission cost, and average hop count. Oppositely, Epidemic also shows the least performance for average remaining energy, average delay, transmission cost, and average hop count with the variation of buffer size, and only PRoPHET demonstrates the worst performance for delivery

ratio in such case.

We will also involve other aspects like message generation rate, message size, nobility models, etc. The impact of different mobility models on different maps would be our next endeavor. Besides this, energy efficiency evaluation on social-aware forwarding strategies is another future motivation. Finally, to design a novel energy-efficient forwarding strategy in DTN environments for improved and successful message delivery is our future endeavors.

References

[1] J. Wu, Y. Guo, H. Zhou, L. Shen, and L. Liu, "Vehicular Delay Tolerant Network Routing Algorithm Based on Bayesian Network," IEEE Access, vol. 8, pp. 18727-18740, 2020.

[2] R. I. Ciobanu, C. Dobre and V. Cristea, "SPRINT: Social prediction-based opportunistic routing," 2013 IEEE 14th International Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM), pp. 1-7, Madrid, 2013.

[3] M. Musolesi and C. Mascolo, "CAR: Context-Aware Adaptive Routing for Delay-Tolerant Mobile Networks," IEEE Transactions on Mobile Computing, vol. 8, no. 2, pp. 246-260, Feb. 2009.

[4] C. C. Sobin, V. Raychoudhury, G. Marfia, and A. Singla, "A survey of routing and data dissemination in delay tolerant networks," *Journal of Network and Computer Applications*, vol. 67, pp. 128-146, 2016.

[5] Y. Cao and Z. Sun, "Routing in Delay/Disruption Tolerant Networks: A Taxonomy, Survey and Challenges," IEEE Communications Surveys & Tutorials, vol. 15, no. 2, pp. 654-677, 2013.

[6] E. F. Silva, E. C. R. Oliveira, C. V. N. de Albuquerque and D. Muchaluat-Saade, "Context adaptation in delay and disruption tolerant networks," 2012 Global Information Infrastructure and Networking Symposium (GIIS), pp. 1-6, 2012.

[7] K. Massri, A. Vitaletti, A. Vernata, and I. Chatzigiannakis, "Routing protocols for delay tolerant networks: a reference architecture and a thorough quantitative evaluation," Journal of Sensor and Actuator Networks, vol. 5, no. 2, 2016.

[8] M. M. Qirtas, Y. Faheem, and M. H. Rehmani, "A cooperative mobile throwbox-based routing protocol for social-aware delay tolerant networks," Wireless Networks, vol. 26, pp. 1-13, 2020.

[9] D. Vardalis, and V. Tsaoussidis, "Exploiting the potential of DTN for energy-efficient internetworking," Journal of Systems and Software, vol. 90, pp. 91-103, 2014.

[10] M. Ababou, and M. Bellafkih, "Energy Efficient Routing Protocol for Delay Tolerant Network Based on Fuzzy Logic and Ant Colony," International Journal of Intelligent Systems & Applications, vol. 10, no. 1, 2018.

[11] A. Thakur, R. Sathiyanarayanan, and C. Hota, "STEEP: Speed and time-based energy efficient neighbor discovery in opportunistic networks," Wireless Networks, vol. 25, no. 6, pp. 3275-3296, 2019.

[12] M. A. Islam, R. U. Mondal and M. Z. Hasan, "Performance Evaluation of WiMAX Physical Layer under Adaptive Modulation Techniques and Communication Channels", International Journal of Computer Science and Information Security (IJCSIS), Vol. 5, No. 1, pp. 111-114, September 2009.

[13] M. A. Islam and A.Z.M. Touhidul Islam, "Performance of WiMAX Physical Layer with Variations in Channel Coding and Digital Modulation Under Realistic Channel Conditions", International Journal of Information Sciences and Techniques (IJIST), Vol. 2, pp. 39-47, No. 4, July 2012.

[14] N. T. Aown, M. A. Islam, M. M. Rahman and A.Z.M. Touhidul Islam, "Effect of AWGN & Fading (Rayleigh & Rician) channels on BER performance of a WiMAX communication System", International Journal of Computer Science and Information Security (IJCSIS), Vol. 10, No. 8, August 2012.

[15] M. A. Halim, M. A. Islam, T. Islam, H. Homyara and M. Zaman, "Performance Analysis of Cyclic Redundancy Check(CRC) encoded Fixed WiMAX Wireless Communication System under Implementation of M-ary Quadrature Amplitude Modulation(QAM) Technique", International Journal of Engineering Research and Applications (IJERA), Vol. 2, No. 5, pp. 1056-1062, 2012.

[16] M. A. Islam and A. Z. M. Touhidul Islam, "Secure Wireless Text Message Transmission with the Implementation of RSA Cryptographic Algorithm", International Journal of Computer Networks and Communications Security, VOL. 2, NO. 5, pp:146–151, May 2014.

[17] M. A. Islam, D. Das, H. Homyara and A. Z. M. Touhidul Islam, "BER Performance of CRC Coded LTE System for Various Modulation

Schemes and Channel Conditions", Scientific Research Journal (Scirj), Volume II, Issue V, pp: 6-10, May 2014.

[18] M. A. Islam, M. M. Rahman, F. Enam and H. Homyara, "Analysis the Effect of Spectral Efficiency on Digitally Modulated OFDM Communication System over Realistic Channel Condition", International Journal of Scientific & Engineering Research, Volume 7, Issue 1, pp: 1019-1024, January 2016.

[19] M. P. Tai, M. A. Islam, F. Enam and M. A. Rahman, "Secure Color Image Transmission Over WIMAX Communication System", Journal of Multidisciplinary Engineering Science and Technology (JMEST), Vol. 3 Issue 6, pp: 5040-5047, June 2016.

[20] S. C. Roy, M. A. Islam, and M. S. Rahim. "A Study on the Performance of Delay-Tolerant Network Routing Protocols in the Campus Area of Rajshahi University, Bangladesh." In *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)*, pp. 1-6. IEEE, 2019.

[21] A. Mehto, and M. Chawla, "Comparing delay tolerant network routing protocols for optimizing L-copies in spray and wait routing for minimum delay," Proceedings of the conference on advances in communication and control systems-2013, Atlantis Press, 2013.

[22] E. A. A. Alaoui, S. Agoujil, M. Hajar, and Y. Qaraai, "The performance of DTN routing protocols: a comparative study," WSEAS Transactions on Communications, vol. 14, pp. 121-130, 2015.

[23] M. K. M. Khan, and M. S. Rahim, "Performance analysis of social-aware routing protocols in delay tolerant networks, 2018 International Conference on Computer, Communication, Chemical, Material and Electronic Engineering (IC4ME2), pp. 1-4, Rajshahi, Bangladesh, 2018.

[24] R. A. Cabacas, H. Nakamura, and In-Ho Ra, "Energy consumption analysis of delay tolerant network routing protocols," International Journal of Software Engineering and Its Applications, vol. 8, no. 2, pp. 1-10.

[25] E. A. A. Alaoui, H. Zekkori, and S. Agoujil, "Hybrid delay tolerant network routing protocol for heterogeneous networks," Journal of Network and Computer Applications, vol. 48, 2019.

[26] M. Ababou, R. El Kouch, M. Bellafkih and N. Ababou, "Energy-efficient routing in Delay-Tolerant Networks," 2015 Third International Workshop on RFID and Adaptive Wireless Sensor Networks (RAWSN), pp. 1-5, 2015.

[27] A. Socievole and S. Marano, "Evaluating the impact of energy consumption on routing performance in delay tolerant networks," 2012 8th International Wireless Communications and Mobile Computing Conference (IWCMC), pp. 481-486, Limassol, 2012.

[28] B. B. Bista and D. B. Rawat, "Energy Consumption and Performance of Delay Tolerant Network Routing Protocols under Different Mobility Models," 2016 7th International Conference on Intelligent Systems, Modelling and Simulation (ISMS), pp. 325-330, Bangkok, 2016.

[29] Sujan Chandra Roy, Farhana Enam, and Md. Ashraful Islam, "Performance Evaluation of Social Routing Protocols Based on the E ffect of Delivery Ratio and Average Hop Count in Delay-tolerant Networks (DTN)", European Journal of Engineering Research and Science (EJERS), Vol. 4, No. 12, December 2019. Belgium. Doi: 10.24018/ejers.2019.4.12.1696

[30] S. Kumar, M. A. Islam, M. F. Ahmed and M. M. Rahman, "Effect of the Number of Messages on the Performance of Delay Tolerant Networks for Few Mobility Models", American Journal of Engineering Research (AJER), Vol-7, Issue-3, pp:200-205, March 2018.

[31] S. C. Roy, M. M. Ali and M. A. Islam, "Analysis the Effect of Transmission Cost on TTL and Number of Nodes in Social Aware Routing Protocols", International Journal of Scientific & Engineering Research, Vol-10, Issue-9, Sep. 2019. doi: 10.14299/ijser.2019.09.06

[32] T. Spyropoulos, K. Psounis and C. S. Raghavendra, "Spray and Focus: Efficient Mobility-Assisted Routing for Heterogeneous and Correlated Mobility," Fifth Annual IEEE International Conference on Pervasive Computing and Communications Workshops (PerComW'07), pp. 79-85, White Plains, NY, 2007.

[33] A. Keränen, J. Ott, and T. Kärkkäinen, "The ONE simulator for DTN protocol evaluation," Proceedings of the 2nd international conference on simulation tools and techniques, pp. 1-10, 2009.

[34] Opportunistic Network Environment (ONE) simulator project page, https://www.netlab.tkk.fi/tutkimus/dtn/theone, (Accessed: July 1, 2020.