EA-Epidemic: An Energy Aware Epidemic-Based Routing Protocol for Delay Tolerant Networks

Bhed B. Bista[1] and Danda B. Rawat[2]
[1] Iwate Prefectural University, Takizawa City, Iwate Ken, 020-0693, Japan
[2] Howard University, Washington, DC 20059, USA
Email: bbb@iwate-pu.ac.jp; db.rawat@ieee.org

Abstract —A Delay Tolerant Network (DTN) is mostly suitable where there is intermittent connection between communicating nodes such as mobile wireless ad hoc network nodes. In general, a message sending node in a DTN copies the message and transmits it to nodes which it encounters. A receiving node, if it is not the destination of the message, stores the message and transmits a copy of the message to nodes it encounters. The process continues until the message reaches its destination or its life time expires. Various DTN routing protocols have been proposed to reduce the number of copies and improve the delivery probability of messages. However, very few of them consider the energy constraint of mobile nodes in routing protocols. Mobile nodes, specially smart phones, tablets, PCs etc. are powered by batteries and energy is limited. It is essential to consider energy constraint also while designing routing protocols for DTNs. In this paper, we propose an Energy Aware Epidemic (EA-Epidemic) routing protocol for DTNs. Our aim is to extend the life expectancy of a DTN by extending lives of nodes in the DTN by reducing energy consumption and at the same time increase the delivery probability of messages. We have achieved this by considering nodes' remaining energy and available free buffer for receiving copies of messages. Only a node with higher energy value than the sending node will receive a copy of the message and store it to send to other nodes or the destination node. The extensive simulation results show that our proposed protocol extends the life of a DTN as well as improve the delivery probability of messages. Moreover, the results also show that the performance of the proposed EA-Epidemic is not significantly affected by the increase in number of nodes in DTNs.

Index Terms—Epidemic routing, energy efficiency, DTN

I. Introduction

Mobile ad hoc networks are wireless networks that are formed by mobile nodes. The assumption of mobile ad hoc networks is that there is end-to-end connection for all nodes. However in reality end-to-end connection is not available all the time since nodes move from one place to another or when nodes density is less in a large geographical area. To overcome the intermittent connectivity problem, a Delay Tolerant Network (DTN) [1], sometimes known as "network of regional networks" is used. A node in DTN essentially stores a message and forwards a copy of it to another node when the connection is available. The process is repeated until the message is relayed to its destination or its life time expires. Since the path from one node to another node is not available due to intermittent connection, traditional routing algorithms for searching a path from a source to a destination cannot be used in DTNs.

There are many routing protocols proposed for DTNs. The major and well known are Epidemic [2], PRoPHET [3], [4] and Spray and Wait [5]. Since the path cannot be found from one node to another, the essential of all the DTN routing protocols is to forward a copy of a message to a node which comes into contact. The node which receives the copy of the message will repeat the process until the message reaches to its destination or the message's life time expires. Although store, copy and forward nature of DTN routing protocols increases the probability of delivering of messages to destination nodes, many copies of messages are stored in many nodes consuming nodes' resources such as buffer, energy and so on. There are other DTN routing protocols such as [6]-[9]. Basically they try to optimize resources consumption of nodes and improve the message delivery probability. However, the majority of well-known DTN routing protocols do not consider energy constraints of mobile nodes in DTNs.

Many mobile nodes such as smart-phones, tablets, PCs and so on have limited energy resources. They use a large amount of energy to transmit and receive messages. Routing protocols that take consideration of energy consumption of mobile nodes are necessary for DTNs also. In this paper, we propose an Energy Aware Epidemic (EA-Epidemic) routing protocol for DTNs. The original Epidemic routing protocol [2] does not take consideration of energy consumption of nodes. It is a simple and effective routing protocol. A node transmits a copy of a message to every node it comes in contact and does not have the message, i.e. same as the epidemic of disease. As a result, a large number of transmission of messages occurs in the network. Furthermore, there are copies of the same message in many nodes. Moreover, when the buffer is full and there is a new message from a neighbor node, old messages are dropped from the buffer to make space for the new message causing more transmission of messages. In our proposal, only a neighbor node which has higher remaining energy than the sender node and has enough available free buffer

Manuscript received January 12, 2017; revised June 20, 2017.
Corresponding author email: bbb@iwate-pu.ac.jp.
doi:10.12720/jcm.12.6.304-311

space for new messages will receive copies of messages because the node will live longer and will have higher chances of delivering the messages to destination nodes. Since the nodes with less energy will not receive copies of messages they will not use their energy faster and will not die early also. As a result, the network life extends longer and delivery probability of messages also becomes higher.

The paper is organized as follows. In section II, we explain the works that are closely related to our work. In section III, we explain our proposed energy aware Epidemic routing protocol. In section IV and section V, we present simulation environment and performance evaluation of our proposed protocol respectively. Finally, we conclude and give the future direction of our work in section VI.

II. Related Work

In order to save energy of nodes, authors in [10], proposed an *n*-Epidemic routing in which a node transmits only when it has *n*-number of neighbors to inhibit the transmission and reduce energy consumption in nodes. Though, the method reduces the number of transmissions, it needs an appropriate value of *n* for its success. However, choosing the value of *n* is difficult because if it is smaller, then there will be many transmissions and the method will not differ from the original Epidemic. If the value of *n* is large, there will be less or no transmissions and there will be less data delivery to the destination.

In [11], authors have proposed three heuristics all based on the dynamic setting of *n* parameters to improve the proposal of [10]. The value of *n* is based on the basis of the current energy level or current neighbor nodes. Unlike [10] where the value of *n* is statically chosen, here the value of *n* is dynamically chosen based on the pre-defined set of thresholds for energy level and its current neighbor nodes. However, the thresholds are fixed and need to be defined. Finding the appropriate pre-defined thresholds is difficult and may not work in all network environments.

In [12], authors take game theoretic approach to minimize total routing and rate allocation cost thereby consuming less energy while transmitting data on the route with rate, buffer and delay constraints. It is a two steps approach; learn the environment and then apply the game. Simulation are performed using 30 nodes in 500m x 500m area. Due to the complexity of the algorithm and the scalability of the scheme (as the simulation is performed with a few nodes in a small area), it may be difficult to use it in a larger area with many nodes.

In [13] and [14], authors propose an optimization strategy based on Bayesian game to be applied to PRoPHET and SimBetTS routing algorithms. The strategy models the message forwarding as a Bayesian game capturing the multi-copy replication decisions, the energy constraints of nodes and the belief about the energy of other nodes and optimizes for longer operation of nodes. However, how the approach will be applied to Epidemic routing is not mentioned.

In [15], authors have mathematically characterized the fundamental trade-off between energy conservation and forwarding efficacy as a heterogeneous dynamic energy-dependent optimal control problem. For optimal solution the range of parameters have to be set.

In our approach, only a node with higher energy than the sending/transmitting node and with enough available free buffer to store the message, receives a copy of the message. This reduces the number of copies of a message in the network as well as number of transmissions of the message, thus reducing the energy consumption of nodes. As a result network life time is extended and delivery probability also improves. Unlike related works above, there is no need to set any pre-defined threshold values or parameters in our proposed protocol. The decision for forwarding a copy of the message is decided dynamically and in distributed manner by each node.

III. Energy Aware Epidemic

A. Message Bundle

Like in any DTN routing and Epidemic mentioned above, each node in EA-Epidemic holds messages it has generated and messages it has received from other nodes destined to some other nodes. Like in Epidemic, each node prepares summary vector (*SV*) and exchanges it with the node it encounters. A node prepares message bundle from its own *SV* and the *SV* of the encountered node. Message bundle contains the message it has but the encountered node does not have. The message bundle is prepared by negating encountered node’s *SV* and logically ANDing it with its own *SV*. For example, let SV_a be summary vector of node *a* and SV_b be summary vector of node *b* as shown below. When node *a* encounters node *b* and after exchanging their *SVs*, node *a* prepares message bundle by $SV_a \wedge SV_b$ operation which gives the message node *a* has, i.e., m1, m3, but the node *b* does not have. Node *b* also performs the similar operation to find out which message it has but node *a* does not have.

SV_a

m1	m2	m3	m4	m5
1	0	1	0	0

SV_b

m1	m2	m3	m4	m5
0	1	0	1	1

$SV_a \wedge SV_b$

m1	m2	m3	m4	m5
1	0	1	0	0

B. EA-Epidemic Routing Algorithms

The most important factor of routing in DTN is to deliver the maximum number of messages to the destination nodes, i.e., maximize the delivery probability of messages. This can be achieved by making robust nodes to store and carry messages. We assume that nodes are powered by batteries and they execute their functions until they are dead, i.e. battery is completely drained out. In this paper, we define two types of robust nodes.

Energy Robust Node: A node is robust in term of energy if its remaining energy is higher than the remaining energy of its neighbor nodes.

Energy and Buffer Robust Node: A node is robust in terms of energy and buffer if its remaining energy and free available buffer are higher than the remaining energy and free available buffer of its neighbor nodes.

A robust node will live longer and hold messages in its buffer longer thereby improving the probability of delivering messages to destination nodes. If messages are forwarded to any nodes, without considering their robustness, messages may be forwarded to a node which has almost zero remaining energy left or almost no free buffer available to store messages. In such case, the node may die early, i.e., will not be able to perform any operation and lose all messages it has or messages will be dropped because of buffer overflow. This causes more frequent message loss reducing the delivery of messages to destination nodes. We propose two routing algorithms; one considering energy robust nodes only and another considering energy and buffer robust nodes.

Here we present the outline of the algorithms considering when node *i* encounters node *j*. We define the following notations for node *i* and node *j* to use in the algorithms.

SV : Summary vector of node *i*.

SV : Summary vector of node *j*.

E : Current energy level of node *i*.

E : Current energy level of node *j*.

FB : Free available buffer of node *i*.

FB_j : Free available buffer of node *j*.

Algorithm 1 When node i encounters node j

```
sendInfo(SV_i, E_i)                     ▷ node i sends its info. to node j
receiveInfo(SV_j, E_j)                  ▷ node i receives node j's info.
MsgBundle = SV_i ∧ ¬SV_j                ▷ node i checks which message node j does not have
if E_j > E_i then
    for each m ∈MsgBundle do
        addMsgSendLst(m)                ▷ node i puts a copy of message m for node j to send list
    end for
    sendMsg()                           ▷ node i sends the message list to node j
else
    recMsg()                            ▷ node i waits to receive messages from node j
end if
```

Algorithm 2 When node i encounters node j

```
sendInfo(SV_i, E_i, FB_i)               ▷ node i sends its info. to node j
receiveInfo(SV_j, E_j, FB_j)            ▷ node i receives node j's info.
MsgBundle = SV_i ∧ ¬SV_j                ▷ node i checks which message node j does not have
if (E_j > E_i) && (FB_j > FB_i) then
    for each m ∈MsgBundle do
        if FB_j > MsgSize(m) then
            addMsgSendLst(m)            ▷ node i puts a copy of message m for node j to send list
        end if
        FB_j = FB_j − MsgSize(m)        ▷ reduce node j's buffer by message size m
    end for
    sendMsg()                           ▷ node i sends the message list to node j
else
    recMsg()                            ▷ node i waits to receive messages from node j
end if
```

In Algorithm 1, we consider energy robust nodes only. The outline of the algorithm is as follows. When a node encounters another node, they exchange their summary vector and the value of remaining energy level to each other. After receiving the summary vector, each node calculates message bundle, i.e., which message it has but the encountered node does not have. Each node compares its remaining energy level with that of the encountered node. If its energy is less than the energy of the encountered node (i.e., the encountered node is more robust in terms of remaining energy) and it has messages which the encountered node does not have, it puts a copy of the message to send list. When the checking is finished it sends the messages in the send list to encountered node, otherwise it waits for messages from the encountered node.

In Algorithm 2, we consider energy and buffer robust nodes only. When nodes encounter each another, along with other information mentioned in Algorithm 1, they exchange value of available free buffer also. Now, the node will put a copy of the message, which it has but the encountered node does not have, to send list if its energy level is less than the encountered node's energy level and its available free buffer is less than the available free buffer of the encountered node and the encountered node has enough free buffer to store the message. Otherwise, it waits to receive messages from the encountered node.

IV. Simulation Environment

We simulated our proposed routing algorithms, original Epidemic routing algorithm [2] and *n*-Epidemic routing algorithm [10] for comparative evaluation.

E-Epidemic represents the proposed routing algorithm (Algorithm1) considering energy robust nodes, EB-Epidemic represents the proposed routing algorithm (Algorithm 2) considering energy and buffer robust nodes, Epidemic represents the original epidemic routing algorithm and 2-Epidemic, 3-Epidemic and 4-Epidemic represents the *n*-Epidemic routing algorithms where value of *n* is set to 2, 3 and 4.We use the well-known DTN protocol simulator called "Opportunistic Network Environment (ONE)" [16], [17]. Simulations were performed for 40~360 nodes. The movement speed of a node was set to 0.5~1.5 m/s to simulate human walking speed. We used the Shortest Path Map-based Movement model for human movement. A node selects a destination randomly in the map and moves to that destination using the shortest path in the map. The movement model used in the simulation reflects the real city environment. The map used in the simulation is Helsinki City map. The rest of the other parameters used in the simulation are shown in Table I and should be self-explanatory.

TABLE I: SIMULATION PARAMETERS.

Parameters	Values
Simulation Area	4500m × 3400m
Number of Nodes	40 ~ 360
Interface	WiFi
Interface Data Rate	2Mbps
Radio Range	100m
Movement Speed	0.5 ~ 1.5m/s
Buffer Size	50MB
Message Size	500KB ~ 1MB
Message Generation Interval	25s ~ 35s
Message TTL	300 minutes (5 hours)
Simulation Time	43200s (12 hours)

Energy parameters of nodes were set as shown in Table II. All nodes have the same initial energy (in units). Scan energy represents the energy for scanning/discovering devices/neighbors. Scan response energy represents the energy consumed while responding the neighbors on discovery. Transmit energy is energy used when transmitting messages and is higher than other values. Base energy is the energy consumed while a node is idle. We assume that when a node's energy is zero it does not execute any functions, i.e. a dead node.

TABLE II: ENERGY SETTINGS

Parameters	Values (units)
Initial Energy	4800
Scan Energy	0.15
Scan Response Energy	0.15
Transmit Energy	0.25
Base Energy	0.12

V. Performance Evaluation

The number of messages created/generated during each simulation is shown in Table III. From the table, we observe that the same number of messages were created for all routing algorithms in each number of nodes simulation showing that each routing algorithms were handing the same number of messages in the network.

We compare energy consumption, number of dead nodes for finding the network life, message delivery probability and overhead ratio of EB-Epidemic, E-Epidemic, 4-Epidemic, 3-Epidemic and 2-Epidemic.

A. Energy Consumption and Network Life

We calculated the average remaining energy of nodes after 8 hours of simulation to find which routing algorithm performs better in terms of energy consumption of nodes. Since all nodes died after 12 hours, which is the end of our simulation time, we took an intermediate 8 hours simulation results.

Fig. 1 shows the average remaining energy of nodes after 8 hours simulation and we see that EB-Epidemic and E-Epidemic perform much better than Epidemic and *n*-Epidemic in terms of energy consumption of nodes. This is more distinct as the number of nodes increases in the network. In EB-Epidemic, the average remaining energy of nodes is almost the same. It does not change according to the number of nodes in the network, but in E-Epidemic, it slowly decreases as the number of nodes increases. In case of Epidemic, the remaining energy of nodes is almost zero because in Epidemic, a node transfers messages to any nodes it encounters and do not have messages it has, consuming a large amount of energy. The remaining energy of nodes in *n*-Epidemic is higher than Epidemic (4-Epidemic being the highest) but it is less than EB-Epidemic and E-Epidemic.

TABLE III: NO. OF MESSAGE CREATED.

No. of Nodes	EB-Epidemic	E-Epidemic	Epidemic	4-Epidemic	3-Epidemic	2-Epidemic
40	1464	1464	1464	1464	1464	1464
120	1460	1460	1460	1460	1460	1460
200	1457	1457	1457	1457	1457	1457
280	1460	1460	1460	1460	1460	1460
360	1466	1466	1466	1466	1466	1466

For the rate of energy consumption of nodes and number of dead nodes, we present the simulation results of 40, 200 and 360 nodes simulations only. Other nodes simulations also have the similar patterns.

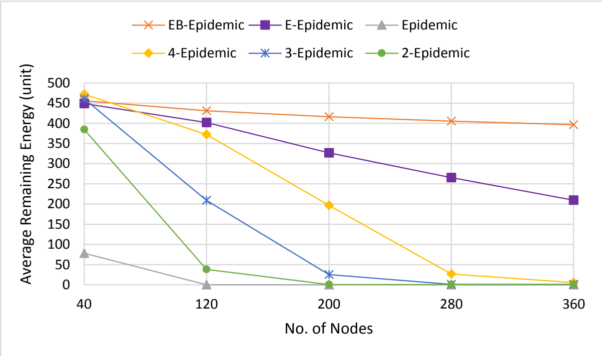

Fig. 1. Average remaining energy of nodes after 8 hours of simulation.

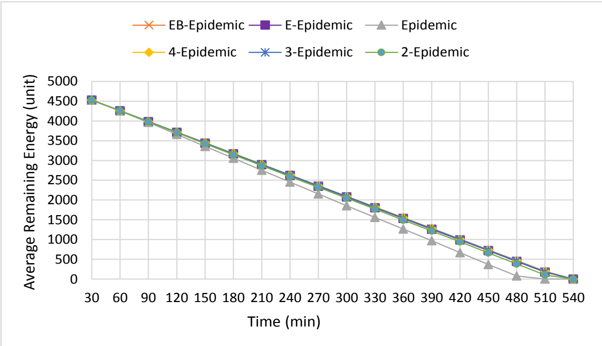

Fig. 2. Average remaining energy of nodes in every 30 minutes (40 nodes simulation).

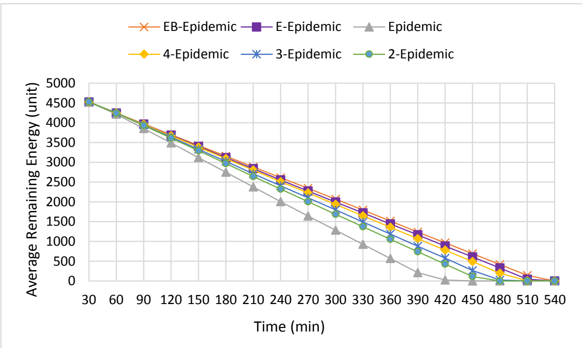

Fig. 3. Average remaining energy of nodes in every 30 minutes (200 nodes simulation).

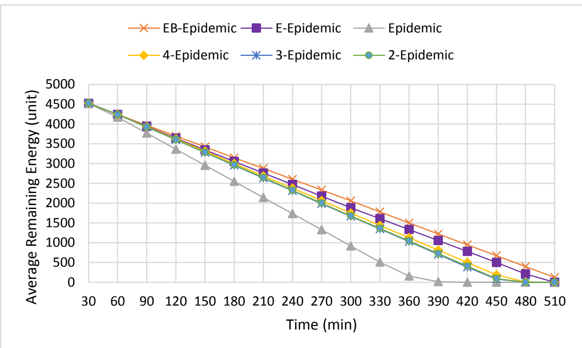

Fig. 4. Average remaining energy of nodes in every 30 minutes (360 nodes simulation).

As we can see from Fig. 3 and Fig. 4, the rate of energy consumption of Epidemic is the highest, the EB-Epidemic is the lowest and E-Epidemic is the second lowest. The rate of energy consumption of *n*-Epidemic is lower than Epidemic. From the figures we see that as the number of nodes increases the rate of energy consumption of nodes in Epidemic, *n*-Epidemic increases faster than E-Epidemic and EB-Epidemic. As a result nodes in Epidemic and *n*-Epidemic consume all energy earlier than nodes in E-Epidemic and EB-Epidemic. However, as shown in Fig. 2, in 40 nodes simulation, there is no significant difference in rate of energy consumption in EB-Epidemic, E-Epidemic and *n*-Epidemic, though they perform better than Epidemic.

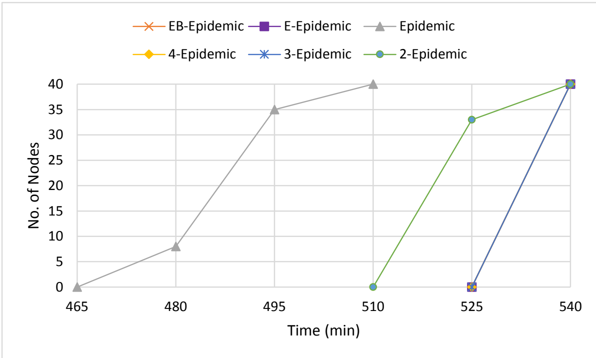

Fig. 5. No. of dead nodes in 40 nodes simulation.

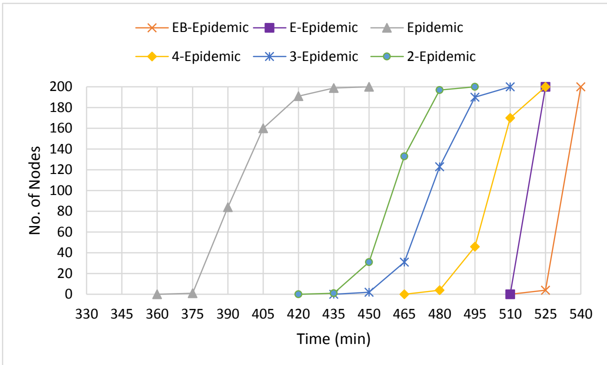

Fig. 6. No. of dead nodes in 200 nodes simulation.

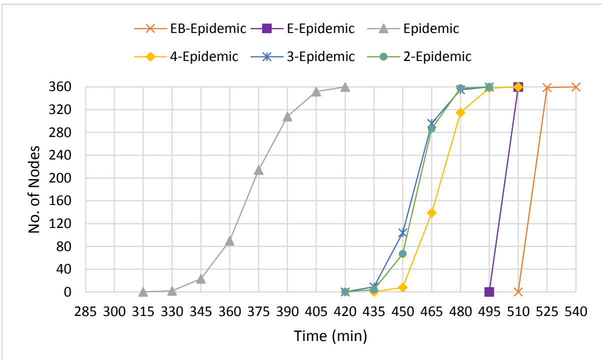

Fig. 7. No. of dead nodes in 360 nodes simulation.

In our simulation, we also checked how fast nodes die and when all nodes die in order to find the life time of the network. When all nodes in the network die, the network also dies. We have shown the results for 40, 200 and 360 nodes simulation which are shown in Fig. 5, Fig. 6 and Fig. 7 respectively.

In 40 nodes simulation, though nodes start dying earlier in 2-Epidemic, all nodes died at the same time, at 540 minutes, in *n*-Epidemic, E-Epidemic and EB-Epidemic, i.e., the network life time remains the same. However, all nodes died at 510 minutes in Epidemic. *n*-Epidemic, E-Epidemic and EB-Epidemic extend network life by 30 minutes compare to Epidemic.

In 200 and 360 nodes simulations, the network life of 4-Epidemic and E-Epidemic is almost the same but EB-Epidemic extends the network life significantly compare to all other routing protocols. EB-Epidemic extends network life by 90, 15, 30 and 45 minutes compare to Epidemic, 4-Epidemic, 3-Epidemic and 2-Epidemic respectively in 200 nodes simulation whereas it expends by 120, 30, 45 and 45 minutes compare to Epidemic, 4-Epidemic, 3-Epidemic and 2-Epidemic respectively in 360 nodes simulation. We see that our proposed routing algorithms extends network life as the number of nodes in the networks increases compare to other routing protocols.

B. Delivery Probability

The delivery probability is defined as shown in Eq. (1).

$$DeliveryProbability = \frac{Total_{msgDeliv}}{Total_{msgGen}} \quad (1)$$

where $Total_{msgDeliv}$ is the total number of messages delivered in the network and $Total_{msgGen}$ is the total number of messages created/generated in the network. If all messages that are generated are delivered to the destination nodes, delivery probability becomes one which is the best scenario of the network. However, due to the resource constraints of nodes or the nature of routing algorithms, some messages are dropped before they are delivered to the destination nodes. It is essential to deliver as many messages as possible and maximize the delivery probability.

As we can see from Fig. 8, EB-Epidemic has the highest delivery probability and Epidemic has the lowest. E-Epidemic performs slightly better than 4-Epidemic, 3-Epidemic and 2-Epidemic. Moreover, in Epidemic, *n*-Epidemic and E-Epidemic, the delivery probability decreases as the number of nodes increases in the network whereas it remains almost the same in EB-Epidemic.

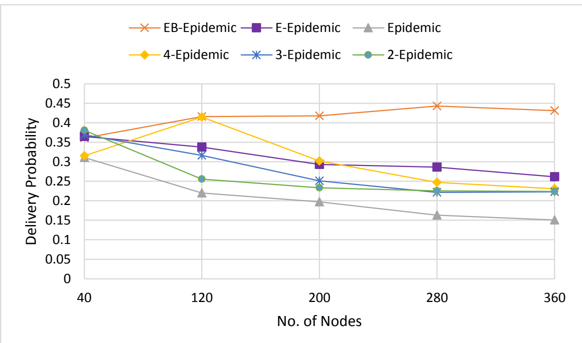

Fig. 8. Deliver probability.

Since nodes in Epidemic consume energy faster, they die earlier. As a result, some destination nodes or nodes that may have a copy of a message may die earlier and the message cannot be delivered. In our proposed EB-Epidemic and E-Epidemic, nodes consume less energy. They die later and message can be delivered even at later time compared to Epidemic and *n*-Epidemic. Furthermore, in Epidemic messages are forwarded to any nodes that do not have messages causing frequent buffer overflow resulting message drop before they are delivered to the destination nodes which subsequently reduces the delivery probability of messages also.

C. Overhead Ratio

The overhead ratio is defined as shown in Eq. (2).

$$OverheadRatio = \frac{Total_{msgFrd} - Total_{msgDeliv}}{Total_{msgDeliv}} \quad (2)$$

where $Total_{msgFrd}$ is the total number of messages forwarded/relayed in the network. $Total_{msgDeliv}$ is as defined in section V.B above. The overhead ratio is essentially the number of copies of messages that are created per delivered message in the network. It can be considered as the assessment of bandwidth efficiency also because if more messages are copied then there will be more transmissions thus consuming more bandwidth. Fig. 9 shows the overhead ratios of EB-Epidemic, E-Epidemic, *n*-Epidemic and Epidemic.

Epidemic has the highest overhead ratio and it increases as the number of nodes in the network increases. It shows that in Epidemic, many copies of messages are created compared to the number of messages delivered and it is affected by the number of nodes in the network also. Overhead ratio of E-Epidemic is less than Epidemic and *n*-Epidemic and it also increases as the number of nodes in the network increases. EB-Epidemic has the lowest and almost constant overhead ratio. Since lower the value better it is, as the less bandwidth is used for message delivery, EB-Epidemic and E-Epidemic perform better than Epidemic especially when number of nodes are 200 or more.

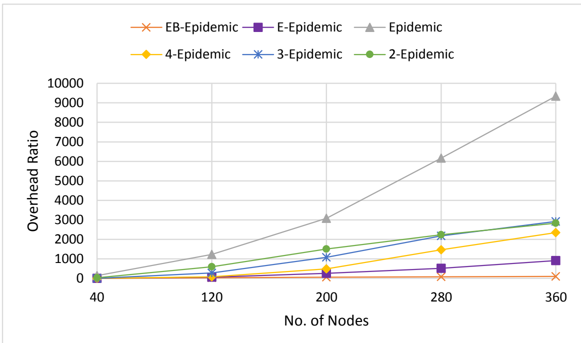

Fig. 9. Overhead ratio.

D. Message Drop and Buffer Time

We calculated average buffering time of message and average number of messages dropped at each node. From

Fig. 10, we see that average buffering time of messages at each node in EB-Epidemic and E-Epidemic is higher than Epidemic and *n*-Epidemic as the number of nodes increases. This is directly related to number of messages dropped at each node which is shown in Fig. 11. Less number of messages dropped in EB-Epidemic and E-Epidemic has increased the probability of messages being delivered to the destination nodes.

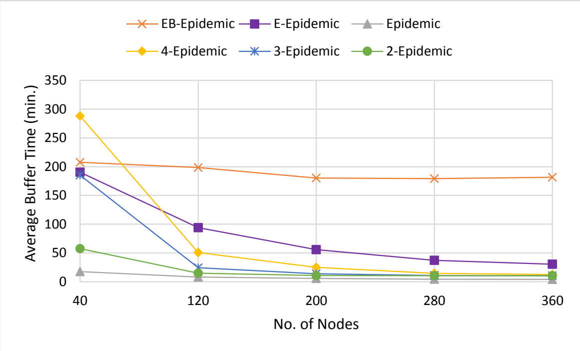

Fig. 10. Average buffering time of message at each node.

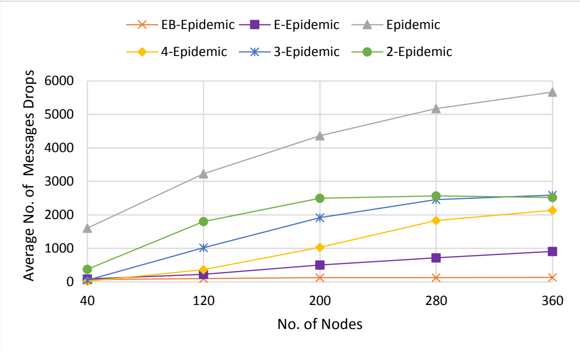

Fig. 11. Average number of message drop at each node.

We have observed that higher buffer time of messages and less number of messages dropped increase delay in message delivery. Since we are considering Delay Tolerant Networks, we do not consider the latency of message delivery to destination nodes. Delivery of delay sensitive messages in DTNs is beyond the scope of this paper.

E. Discussion

Routing protocols for mobile networks which are powered by batteries need to take consideration of energy consumption of network devices in order to extend the network life. In this paper, we defined energy robust nodes and energy and buffer robust nodes with respect to their neighbor nodes for DTN and proposed routing algorithms in which robust nodes are allowed to carry messages. Extensive simulation has shown that robust nodes extend the network life and improve the delivery probability of messages. We have shown that while designing energy efficient routing protocols for DTN, it is essential to consider remaining energy and free available buffer of nodes for making decision to forward messages. Our proposal can be easily incorporated with other decision making parameters of DTN.

VI. Conclusions

We proposed an EA-Epidemic in which we presented two routing algorithms to improve energy efficiency of Epidemic routing in DTNs. The algorithms consider remaining energy and available free buffer of nodes for making decision to forward copies of messages. We simulated our proposed EA-Epidemic, Epidemic and *n*-Epidemic extensively by varying different number of nodes in the network for comparative performance evaluation. The results show that the proposed EA-Epidemic not only extends the network life by making nodes to consume less energy but also increases the delivery of messages in the network. Furthermore, overhead of the network using our routing algorithms is very low. Outperformance of our proposed EA-Epidemic owes to the facts that nodes with higher energy and more available free buffer, i.e., robust nodes in terms of energy and available free buffer, will carry message with them as they will live longer and will have less chances of dropping messages due to buffer overflow. Energy is a very important resource in battery operated mobile devices and available free buffer is very important in nodes in DTNs as they have to store messages. Since we have considered both in our routing algorithms, we believe that our approach used in this paper is applicable to other DTN routing also. Moreover, EA-Epidemic does not need any pre-defined threshold parameters to make message forwarding decision. The message forwarding decision are made dynamically by nodes, thus EA-Epidemic is suitable for all kinds of network scenario. However, further studies in varying message characteristics such, TTL values, message generational interval, message delivery latency and so on may be required in future.

References

[1] K. Fall, “A delay-tolerant network architecture for challenged internets,” in *Proc. Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications*, New York, NY, USA, 2003, pp. 27-34.

[2] A. Vahdat and D. Becker, “Epidemic routing for partially-connected ad hoc networks,” Technical Report, Duke University, April 2000.

[3] A. Lindgren, A. Doria, and O. Schelén, “Probabilistic routing in intermittently connected networks,” *ACM SIGMOBILE Mobile Computing Communications Review*, vol. 7, no. 3, pp. 19-20, July 2003.

[4] A. Lindgren, A. Doria, E. Davies, and S. Grasic. (August 2012). Probabilistic routing protocol for intermittently connected networks. RFC 6693, RFC Editor. [Online]. Available: http://www.rfc-editor.org/rfc/rfc6693.txt

[5] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, “Spray and wait: An efficient routing scheme for intermittently connected mobile networks,” in *Proc. ACM SIGCOMM Workshop on Delay-tolerant Networking*, New York, NY, USA, 2005, pp. 252-259.

[6] E. M. Daly and M. Haahr, “Social network analysis for information flow in disconnected delay-tolerant MANETs,” *IEEE Trans. on Mobile Computing*, vol. 8, no. 5, pp. 606-621, May 2009.
[7] E. Altman, A. P. Azad, T. Basar, and F. De Pellegrini, “Optimal activation and transmission control in delay tolerant networks,” in *Proc. IEEE INFOCOM*, March 2010, pp. 1-5.
[8] E. C. R. De Oliveira and C. V. N. De Albuquerque, “NECTAR: A DTN routing protocol based on neighborhood contact history,” in *Proc. ACM Symposium on Applied Computing*, New York, NY, USA, 2009, pp. 40-46.
[9] S. C. Nelson, M. Bakht, and R. Kravets, “Encounter-based routing in DTNs,” in *Proc. IEEE INFOCOM*, April 2009, pp. 846-854.
[10] X. Lu and P. Hui, “An energy-efficient *n*-epidemic routing protocol for delay tolerant networks,” in *Proc. IEEE Fifth International Conference on Networking, Architecture, and Storage*, July 2010, pp. 341-347.
[11] F. De Rango, S. Amelio, and P. Fazio, “Enhancements of epidemic routing in delay tolerant networks from an energy perspective”, in *Proc. 9th International Wireless Communications and Mobile Computing Conference*, July 2013, pp. 731-735.
[12] Y, Zeng, J. Wu, N. Xiong, and D. Li, “Energy-efficient routing and rate allocation for delay tolerant networks,” in *Proc. 32nd International Conference on Distributed Computing Systems Workshops*, June 2012, pp. 260-266.
[13] S. L. F. Maia, E. R. Silva, and P. R. Guardieiro, “A new optimization strategy proposal for multi-copy forwarding in energy constrained DTNs,” *IEEE Communications Letters*, vol. 18, no. 9, pp. 1623-1626, Sept. 2014.
[14] S. L. F. Maia, E. R. Silva, and P. R. Guardieiro, “A bayesian game based optimization strategy proposal for routing in energy constrained DTNs,” in *Proc. 33th Brazilian Symposium on Computer Networks and Distributed Systems*, May 2015, pp. 1-9.
[15] M. H. R. Khouzani, S. Eshghi, S. Sarkar, N. B. Shroff, and S. S. Venkatesh, “Optimal energy-aware epidemic routing in DTNs,” in *Proc. 13th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, New York, NY, USA, 2012, pp. 175-182.
[16] A. Keränen, J. Ott, and T. Kärkkäinen, “The ONE simulator for DTN protocol evaluation,” in *Proc. 2nd International Conference on Simulation Tools and Techniques*, Brussels, Belgium, 2009, pp. 55:1–55:10.
[17] The ONE. [Online]. Available: https://akeranen.github.io/the-one/

Bhed B. Bista received his Ph.D. degree in Information Science from Tohoku University, Japan. He is currently working as an Associate Professor at Iwate Prefectural University, Japan. His research interests include energy efficient networks, mobile networks, sensor networks, ad hoc networks and cellular networks. He has served as Program Chair, Track Chair and Program Committee Member in various international conferences including IEEE AINA, NBiS and BWCCA.

Danda B. Rawat is an Associate Professor in the Department of Electrical Engineering & Computer Science at Howard University, Washington, DC, USA. Prior to Howard University, he was with the College of Engineering & Information Technology of Georgia Southern University, Statesboro, GA as a faculty member. Dr. Rawat's research focuses on wireless communication networks, cyber security, cyber physical systems, Internet of Things, big data analytics, wireless virtualization, software-defined networks, smart grid systems, wireless sensor networks, and vehicular/wireless ad-hoc networks. His research is supported by US National Science Foundation, University Sponsored Programs and Center for Sustainability grants. Dr. Rawat is the recipient of NSF Faculty Early Career Development (CAREER) Award. Dr. Rawat has published over 100 scientific/technical articles and 8 books. He has been serving as an Editor/Guest Editor for over 15 international journals. He has been in Organizing Committees for several IEEE flagship conferences such as IEEE INFOCOM 2015/2016/2017/2018, IEEE CCNC 2016/2017/2018, IEEE AINA 2015/2016, and so on. He served as a technical program committee (TPC) member for several international conferences including IEEE INFOCOM, IEEE GLOBECOM, IEEE CCNC, IEEE GreenCom, IEEE AINA, IEEE ICC, IEEE WCNC and IEEE VTC conferences. He is the recipient of Outstanding Research Faculty Award (Award for Excellence in Scholarly Activity) 2015, College of Engineering and Information Technology, GSU among others. He is the Founder and Director of the Cyber-security and Wireless Networking Innovations (CWiNs) Research Lab. He received the Ph.D. in Electrical and Computer Engineering from Old Dominion University, Norfolk, Virginia. Dr. Rawat is a Senior Member of IEEE and member of ACM and ASEE. He served as a Vice Chair of the Executive Committee of the IEEE Savannah Section and Webmaster for the section from 2013 to 2017.