Energy Efficient Multi-Objectives Optimized Routing for Opportunistic Networks

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ICC 2021 - IEEE International Conference on Communications | 978-1-7281-7122-7/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICC42927.2021.9500645

***Abstract*—This paper proposes a novel routing protocol for Opportunistic networks called Energy Efficient Multi-Objectives Optimized Routing (E^2MOOR), which uses a multi-objectives weight function for efficient routing. The proposed protocol is energy efficient and predicts the next optimal forwarder based on four objectives, which consists of hop encounter, distance between the source/intermediate and destination, delivery probability, and node's energy consumption, as context information. The pareto optimal solutions set is extracted through the Naive and Slow algorithm. The nodes in the set are further used for forwarding the data packets to the destination node. The proposed protocol is evaluated considering the double, triple, and quadruple objective functions, when the predefined threshold values are varied. Simulations results show that the proposed E^2MOOR scheme outperforms the E-Epidemic, E-PRoPHET, and E-EDR chosen as benchmarks routing protocols.**

***Index Terms*—Opportunistic Networks, Energy Consumption, Multi-Objectives Techniques, Routing.**

I. Introduction

Opportunistic Networks (OppNets) [1] are a subclass of wireless networks consisting of mobile nodes having opportunistic connections which are discontinuous. The challenges encountered when designing a routing protocol for OppNets [2] include high latency, low data rate, high waiting time in buffers of nodes, poor delivery ratio and high consumption of resources. Due to limited energy constraint, the challenge is to control the consumption of energy of nodes in the network.

Energy is a crucial aspect of the deployment and performance of modern communication systems [3] . Currently, all the smart phones are becoming the leading platform for communication and computing. These all are furnished with communication abilities like WiFi, Bluetooth, and other applications as well, which authorize them for transmitting information in OppNets. In these networks, the quantity of the node's energy is contemplated as a chief aspect in communication and delivering the information. However, most of the modern smart phones run on lithium-ion batteries and in this way supply limited energy and enough attempts have been made to increase the amount of node energy which can lead to life extension of batteries.

The proposed E^2MOOR leads us to enquire about the consumption of the node's energy in such network environment. For highly parametric hardware, it is crucial to consider the remaining energy of a node in the determination of whether to exchange data during node encounter. However, unusually few researches have directed this problem. To investigate the node energy expenditures [4], we will carry an energy-based performance evaluation of OppNets with some specific objectives [5], to find out the most efficient combination for optimized routing. The objectives are listed as hop encounters, delivery probability, distance between initial and final destination, and node energy consumption. This paper reports on the feasibility of an optimization problem, by proposing an energy-efficient multi-objectives optimization technique for optimized routing in OppNets. To find the node's next forwarder, we depend upon the optimization and designing of the weighing function. We decide to maximize the hop encounter *(HE)*, maximize the delivery probability *(DP)*, the distance between the source/intermediate and destination *(SD)*, and to minimize the energy consumption of nodes *(EC)* in the topology. Assigning to the scheme, a pareto optimal solutions set (non-dominated solution set) is derived through the Naive and Slow algorithm technique [6] to transmit the data packets to the final node.

The paper is organized into the following sections. The related work is presented in Section II. Section III gives a detailed description of the proposed E^2MOOR protocol and simulation results are presented in Section IV. Finally, The conclusion is discussed in Section V.

II. Related Work

In this section, various research papers, factors, and routing protocols for OppNets are discussed. Most prominent ones are as follows: In [7], A multi-objectives optimization of data-dissemination in delay tolerant networks (DTNs) is presented. It presents the data routing limitations in DTNs with a multi-objectives genetic algorithm approach towards the optimization problem. It weighted three optimizing metrics which were cost delivery, latency, and hit rate

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for the optimization of the algorithm. To formulate the forwarding probability, they focused on parameters like friendship, social strength, trust, similarity, and centrality. To obtain the sets of non-dominated solutions for the multi-objectives optimization problem, the authors developed pareto fronts, which indicated that the hit rate metric in the optimizing genetic algorithm does not change drastically, with latency and cost being counterbalanced. The limitation of this approach was that the decision tree mechanism could have been more improved to enhance the variable-selection, which had more influence on the performance parameters.

In [8], an energy-efficient history-based routing scheme for opportunistic networks has been proposed. This research is an improved version of, that protocol by making it more energy-efficient. The improvement factors in the HBPR scheme were introduced in its energy related version HBPR. In this scheme, various components were added to improve its energy-consumption performance. But more constraints can be added to further improve its energy-efficiency mechanism.

In [9], an energy-efficient routing protocol for opportunistic networks is presented, in which a genetic algorithm is utilized to forward copies of data between the source and destined node. In this strategy, the node table and the grouped data on the source locations interaction are utilized in the genetic algorithm for selecting the hop. The shortcomings of this work were that, it lacks efficiency in different opportunistic network topological scenarios.

In [10], the authors argued that in such strategies, a node with significant increasing social popularity will rapidly consume its energy measures and because of that, it might be reluctant to get involved in the routing process. Based on this fact, they introduce energy surveillance as a vital procedure in routing and they presented a socially driven solution for routing in OppNets, which uses energy as a key criterion in the routing decision. They argued that if consumption of energy is considered in socially drive routing, then popular nodes will get confined and their resources will get evacuated, and this will cause the desired nodes to become unavailable, especially when there are amendments in the battery lifetime. Thee limitations of this scheme is that the average latency and hop count performance are less-efficient.

In [11], an energy-efficient n-epidemic protocol for DTNs is presented. In that paper, a comparison between epidemic and n-epidemic schemes is performed using a real-life experimental dataset. Considering the energy consumption with every transportation, the merits of broadcasting in the wireless medium were adopted, which limited the quantity of relaying packets because the relay nodes could not forward the information whenever there was an interaction with other nodes. These nodes had to wait for the neighbors to transmit the data packets to a greater number of neighbors.

A. Motivation

Many protocols for opportunistic networks take under consideration the information like *HE*, *SD*, and *DP* in some rules for a node to follow for the selection of the next suitable hop. These rules are often derived based on unique or multiple constraints. For instance, the EDR protocol concentrates on dual constraints, like maximizing the nodes encounters and minimizing the distance between nodes; the routing strategy presented in [12], focusses on attaining the minimum energy consumption while utilizing the node's history; In [6], the authors have used three constraints which are maximizing the number of node encounters, minimizing the distance between the source and destination, and maximizing the delivery probability.

None of these earlier work discusses the consideration of consumption of energy using the optimized message routing and a multi-objectives approach. In this research, another objective of energy consumption is included to make it a quadruple objective optimized message routing, namely maximizing *HE*, minimizing *SD*, maximizing *DP*, and minimizing *EC*. This has been the motivation for the authors to design and present the E^2MOOR scheme.

III. Proposed Energy Efficient Multi-Objectives Optimized Routing

It is assumed that the OppNet environment consists of *L* moving nodes considered to be mutual with one another, each of which has enough energy capacity to get involved in the transportation of data. It is also assumed that the hops will have enough buffer spaces to store their respective information and will not behave abnormally. Based on these assumptions, it is generally accepted that the context data of a node, which are: number of hops with the destination node, residual energy, delivery probability, to name a few, be valid parameters that can be utilized to determine or select the next best hop for a given node. According to these parameters and the desired combination of target objectives (i.e. *HE-SD, SD-DP, HE-DP, HE-EC, EC-DP, EC-SD, HE-SD-DP, HE-SD-EC, SD- DP-EC, HE-DP-EC, and HE-SD-DP-EC*), the most effective decision for selecting the next appropriate forwarder node to transfer the data-packet toward its desired destination is taken. When *HE* is calculated, a couple of contact opportunities of nodes takes place. More accurately:

$$HE = \frac{h_{p,q}}{\sum_{z=1}^{n} h_{p,q}} \tag{1}$$

where, $h_{p,q}$ is the value of encounter for a node p with respect to the desired (location) destination q and $\sum_{z=1}^{n} h_{p,q}$ is the sum of all hop (node) encounter values in the network. Identically, the Euclidean distance in the network is measured dynamically as:

$$SD = \frac{s_{p,q}}{\sum_{z=1}^{n} s_{p,q}} \tag{2}$$

where, $s_{p,q}$ is the distance between a node p and destined node q and $\sum_{z=1}^{n} s_{p,q}$ is the sum of all hops distances to the final node. The probability of delivering data of a hop within the network is formulated as:

$$DP = \frac{r_{p,q}}{\sum_{z=1}^{n} r_{p,q}} \quad (3)$$

where, $r_{p,q}$ is the probability of delivery of node *p* with respect to the destined node *q* acquired from equations (1), (2), (3), and $\sum_{i=1}^{n} r_{p,q}$ is the sum of all hop's probability distribution within the network. The energy consumption of a node within the network is formulated as:

$$EC = \frac{(k_c)_{p,q}}{\sum_{z=1}^{n}(k_c)_{p,q}} \quad (4)$$

where, $(k_c)_{p,q}$ is the energy consumed by a node *p* and $\sum_{z=1}^{n}(k_c)_{p,q}$ is the total energy of all the nodes within the network.

$$g_1 = g(HE) \propto 1/HE \quad (5)$$

$$g_2 = g(SD) \propto 1/SD \quad (6)$$

$$g_3 = g(DP) \propto DP \quad (7)$$

$$g_4 = g(EC) \propto 1/EC \quad (8)$$

In the proposed routing scheme, the decision on selecting the forwarding hops to route the information packets towards the destination node is constructed on the suggested multi-constraint function g, which involves the parameters *HE, SD, DP, EC* and their respective weights M_1, M_2, M_3, M_4 with a condition that the M_4 weight can never be equal to zero because the proposed scheme is energy efficient. More precisely:

$$g(HE, SD, DP, EC) = \sum_{i=1}^{4} M_i * g_i$$

$$M_1 + M_2 + M_3 + M_4 = 1 \quad (10)$$

Suppose *y* is the *n* decision variables vector, y_i^l and y_i^u are the upper and lower limit of the deciding variable, *v* and *w* are the objectives of equality, and there will be *M* objective (constraints) functions, *M* $\geqslant$ 1. Here, $f_v(y)$ and $h_w(y)$ are termed as the function parameters. Then, our multi-objective optimization problem can be formulated as: and Problem (P):

$$g_u(y), \quad where \quad u = 1.....M \quad (11)$$

Subject to

$$f_v(y) \geqslant 0, \quad where \quad v = 1....k \quad (12)$$

$$h_w(y) = 0, \quad where \quad w = 1....k \quad (13)$$

$$y_i^l \leqslant y_i \leqslant y_i^u \quad where \quad i = 1....n \quad (14)$$

Algorithm 1 is the procedure for E^2MOOR routing using different combination objectives and the different number of objectives.

Algorithm 1: E^2MOOR

```
Input L, O, M_1, M_2, M_3, M_4 ;
Number of Objective = O ;
Begin
Energy_{node_si} = getCurrentEnergy(node_si)
Energy_{node_n} = getCurrentEnergy(node_n)
if Energy_{node_n} ⩾ Energy_{node_si} then
    node is loaded into energy_sufficient_list
    if O = 2 then
        if M_1 = 0 then
            if M_2 = 0 then
                call g(DP,EC), which returns the set list
            end
            if M_3 = 0 then
                call g(SD,EC), which returns the set list
            end
        end
        if M_2 = 0 then
            if M_3 = 0 then
                call g(HE,EC), which returns the set list
            end
        end
    end
    if O = 3 then
        if M_1 = 0 then
            call g(SD,DP,EC), which returns the set list
        end
        if M_2 = 0 then
            call g(DP,HE,EC), which will return the set
              list
        end
        if M_3 = 0 then
            call g(HE,SD,EC), which returns the set list
        end
    end
    if O = 4 then
        call g(HE, SD, DP, EC), which returns the set
          list
    end
end
Transferring the information from the source/intermediate
  nodes to all the nodes in selected_list;
```

As reported in [6] an optimization algorithm that has multi-objective functions can be utilized to obtain the non-dominating set of solutions from the entire set of solutions. Applying this principle, a solution y_j to Problem (9)-(14) is non-dominating over the solution y_i, if the listed conditions exist, i.e.

1) y_i is better than y_j for $g_u(x_i) \geqslant g_u(y_j) \quad \forall \quad u = 1....M$.
2) y_i is always better than y_j for at least one objective $g_{\bar{u}}(y_i) \geqslant g_{\bar{u}}(y_j)$; and at least for one u $\in$ 1, 2, 3 ..... M.

A decision vector variable $y \in p \subset R^n$ is non-dominated with respect to *p*, if there is no $y \in p$ such as $g(y') \geqslant g(y)$. It is proposed as a solution set containing the vectors according to $y \in g \subset R^n$ and the non-dominating set with respect to *g*. There are many algorithms that can utilized to find out the non-dominating solution set in the entire set of solutions, for instance: The Kung Algorithm, the Naive and Slow Algorithm, to name a few.

We have used the Naive and Slow Algorithm because it has a high convergence compared to other algorithms. The parameters *HE, SD, DP and EC*, whose starting value can be measured using Equations (6), (7), (8), and (9) respectively, considered as parameters to identify the succeeding forwarding hop. The problem for optimization is as follows: maximize *HE*, minimize *SD*, maximize *DP*, and minimize *EC*; subject to the energy of all available neighbouring nodes of the sender, which is calculated by *getCurrentEnergy(node)* function. Thereafter, the variables $Energy_{node_{si}}$ and $Energy_{node_n}$ are calculated by using Equations (15) and (16). Here, Equation (15) gives residual energy of the sender/intermediate node ($node_{si}$) and Equation (16) gives the remaining energy of the neighboring nodes ($node_n$).

$$Energy_{node_{si}} = getCurrentEnergy(node_{si}) \quad (15)$$

$$Energy_{node_n} = getCurrentEnergy(node_n) \quad (16)$$

For all neighboring nodes, if ($Energy_{node_n}$ $\geqslant$Energy$_{node_{si}}$) then, the node is put into $energy\_sufficient\_list$. It is worth mentioning that the double objective function and the combination of objectives HE-SD, SD-DP, HE-DP, are inherited from [2]. In this work, the *EC* objective has been incorporated. According to these values, *g(HE, EC)*, *g(DP, EC)*, *g(SD,EC)* are calculated by taking under consideration the multi-objectives function *g(HE, SD, DP, EC)* along with the respective weights. Afterwards, the proposed scheme selects the nodes in the topology which has *g(HE, SD, DP, EC)* values higher than or equal to the thresholds S_{HE-EC}, S_{DP-EC} and S_{SD-EC} respectively entered; then it supplies this set of solutions in a *list*. Following this, the Naive and Slow algorithm is applied to derive the non-dominated solution set. Similar to the double objective funtion, for the triple objective function, *g(HE,SD,EC)*, *g(DP,HE,EC)* and *g(HE,SD,EC)* are calculated by taking consideration of *g(HE, SD, DP, EC)*. Next, the same process that was followed in the case of the double objective function to compare the respective threshold values, is performed, leading to the transfer of the message from the source/intermediate nodes to all the nodes in $selected\_list$.

In the case of quadruple objective function, when the source node generates a message, which is to be transferred or routed towards the desired destination node, it enquires the value of the weights M_1, M_2, M_3, and M_4. At the beginning of this proposed Algorithm 2, it measures the values of *HE*, *SD*, *DP*, and *EC* using the Equations (1) to (4) respectively. According to these values, the objective function *g(HE, SD, DP, EC)* is calculated by taking under consideration the multi-objectives functions. After this, the proposed scheme selects the nodes in the topology which has *g(HE, SD, DP, EC)* values higher than or equal to the respective threshold $S_{HE-SD-DP-EC}$ entered; then it supplies this set of solutions in a $list$. Following this, the Naive and Slow Algorithm is applied to conclude non-dominated solution set and transferred the information from the source/intermediate nodes to all the nodes in $selected\_list$.

Algorithm 2: g(HE, SD, DP, EC)

```
Input M_1, M_2, M_3, M_4 ;
Begin
Energy_{node_si} = getCurrentEnergy(node_si)
Energy_{node_n} = getCurrentEnergy(node_n)
if Energy_{node_n} ⩾ Energy_{node_si} then
    node is loaded into energy_sufficient_list
    for each data do
        for each node Z in the
          energy_sufficient_list do
            g_1 = g(HE) = h_{p,q} / Σ_{i=1}^{n} h_{p,q}
            g_2 = g(SD) = s_{p,q} / Σ_{i=1}^{n} s_{p,q}
            g_3 = g(DP) = d_{p,q} / Σ_{i=1}^{n} d_{p,q}
            g_4 = g(EC) = (e_c)_{p,q} / Σ_{i=1}^{n} (e_c)_{p,q}
            g(HE, SD, DP, EC) = Σ_{i=1}^{4} M_i * g_i
            if g(HE, SD, DP, EC) ⩾
              S_{HE-SD-DP-EC} then
                Node inserted in the solution set list
            end
        end
    end
end
Naive and Slow Algorithm is applied to conclude the
  non-dominated solution set selected_list.
```

IV. Simulation Results

In this section, the evaluation of the proposed E^2MOOR scheme is conducted using the java-based, opportunistic network environment (ONE) simulator [14]. This environment has the capability of using different movement models to generate the node movement. It also has the capability of analyzing real-time mobility and data passing using its graphical user interface. For simulation setup, we have used the haggle-one-infocom 2006 real mobility data trace [13]. The number of nodes were 98 and the simulation time was 337418 seconds. The transmission range was 10 meters.

A. Simulation Results using the double, triple, and quadruple objective functions

Initially, the proposed scheme, E^2MOOR is evaluated considering the objective which is *DP*, *HE*, *EC*, and *DP* using any of the double, triple, or quadruple objective functions, when the predefined threshold values are varied. As we know that the TTL of each message increases, when we maximize the TTL, we observe that the probability of delivery decreases considering all the objective functions. Due to this fact, a greater number of messages get stored in the node buffer, which leads to minimizing the delivery probability of messages. It is observed that the quadruple objective function (*HE-SD-DP-EC*) has the maximum probability of delivery in comparison with the other combination of objectives. In Figure 1, the delivery probability of *HE-SD-DP-EC* objective is way better than

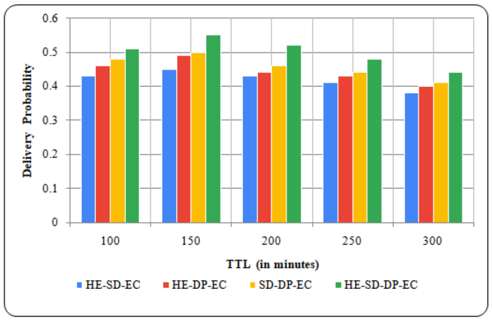

Fig. 1. Delivery Probability vs. TTL

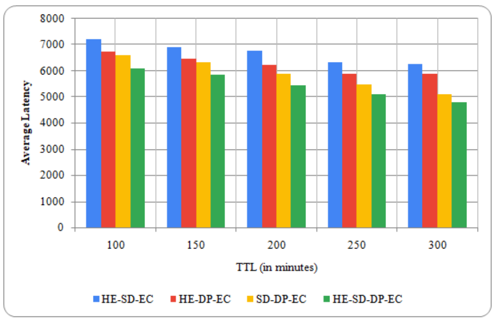

Fig. 2. Average Latency vs TTL

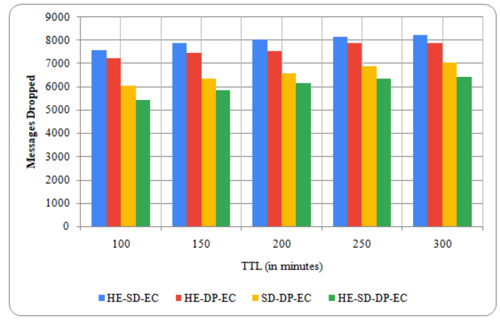

Fig. 3. Messages Dropped vs TTL

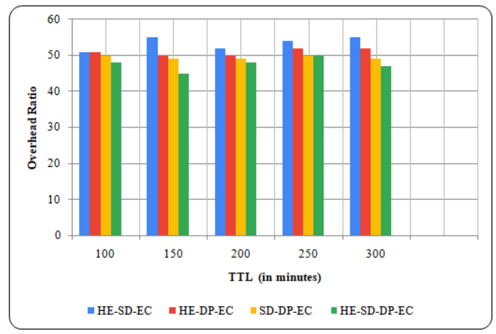

Fig. 4. Overhead Ratio vs TTL

that of the *HE-SD-EC* objective by 21%, the *HE-DP-EC* objective by 28% and the *SD-DP-EC* objective by 32% with varying TTL. This could be attributed to the fact that the forwarder node must be unable to predict the direction of the next forwarder short-listing process.

Further, the delay vs TTL was evaluated through Figure 2. We conclude that the delay of *HE-SD-EC*, *HE-DP-EC*, *SD-DP-EC*, *HE-SD-DP-EC* is maximized with maximizing TTL. This is because large values of TTL maximize the lifetime of the messages which is to be stored in the node's buffer space. The *HE-SD-DP-EC* objective function has the lowest delay in messages compared to the delays obtained for the other objective functions. This is due to the fact that the hop drifting apart from the destination has a high probability to be short-listed as the next message forwarder, leading to maximizing time for delivering the messages to the destination. In terms of delay, the quadruple objective function *HE-SD-DP-EC* is better than the *HE-DP-EC* objective by 22% and the *SD-DP-EC* objective by 22% and the *SD-DP-EC* objective by 26% respectively.

The number of messages dropped as compared to the increase in TTL is evaluated through Figure 3. It can be concluded that the *HE-SD-DP-EC* objective creates the lowest number of dropped messages with increased TTL. In terms of dropped messages, the quadruple objective (*HE-SD-SP-EC*) function is better than the *HE-SD-EC* objective by 14%, the *HE-DP-EC* objective by 19% and the *SD-DP-EC* objective by 24% respectively with varying TTL.

Figure 4 shows the maximization of the overhead ratio of the objective functions (*HE-SD-EC, SD-DP-EC, HE-DP-EC, HE-SD-DP-EC*) with the increase in TTL values. This has happened because through the increase in the value of TTL, there is an increase in the message lifetime in the network. When considering the overhead ratio, the *SD-DP* objectives has the lowest value compared to every other objectives. This relates to the fact that the parametric generation of messages and their delivery under the *SD-DP* objectives is minimum in comparison to the generation when all other combinations of the objective were considered. Specifically, the quadruple objective (*HE-SD-SP-EC*) function is better than the *HE-SD-EC* objective by 8%, the *HE-DP-EC* objective by 12% and the *SD-DP-EC* objective by 18% respectively with varying TTL.

B. Real Trace Simulation Results Using Existing Benchmark Protocols

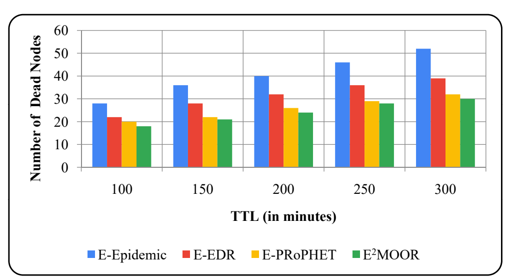

Fig. 5. Dead Nodes vs TTL

The proposed E^2MOOR protocol is simulated using the ONE simulator version 1.6.0 and its performance is

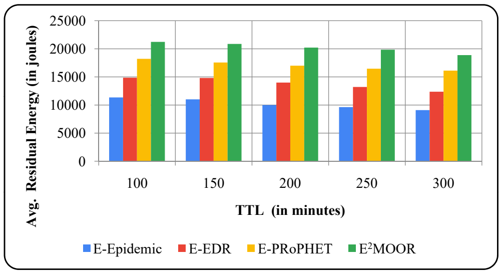

Fig. 6. Average Residual Energy vs TTL

compared against that of three benchmark routing protocols for OppNets, namely, the energy versions of Epidemic, EDR, and PRoPHET. In Figure 5 to Figure 8, the implementation of the presented scheme E^2MOOR is investigated. This experimental evaluation showed the supremacy of E^2MOOR protocols E-Epidemic, E-Prophet, and E-EDR in terms of aforementioned parameters.

Figure 5 and Figure 6, infer that, when the message life time value is raised, E^2MOOR outperforms the benchmark schemes. These figures infer that when the generation interval of messages is raised, the performance of E^2MOOR is 22.18% better than that of E-PRoPHET, 39.70% better than that of E-EDR, and 52.24% better than that of E-Epidemic, when the message interval value (generation time) is changed. Figure 7 and Figure 8 infer that when this time interval is varied, E^2MOOR outperforms the benchmark schemes.

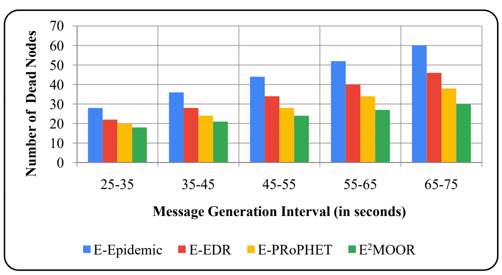

Fig. 7. Dead Nodes vs Message Generation Interval

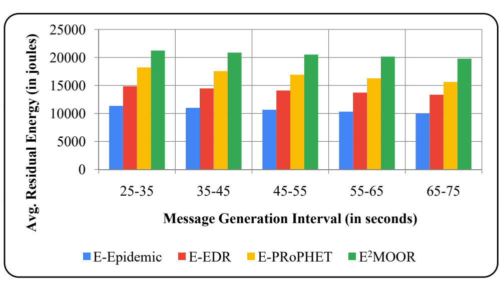

Fig. 8. Average Residual Energy vs Message Generation Interval

V. Conclusion and Future Work

This paper has proposed an energy-efficient multi-objectives optimized routing in opportunistic networks (called as E^2MOOR), which takes under consideration the context data of node: *HE*, *SD*, *DP* and *EC*. They act as decision-making patterns for routing, to select the best information forwarder from the source to the destination based on various combinations of objectives which are: maximizing *HE*, minimizing *SD*, maximizing *DP* and minimizing *EC*. Simulations results show that the proposed E^2MOOR scheme outperforms the E-Epidemic, E-PRoPHET, and E-EDR routing protocols, chosen as benchmarks. As future work, a security-aware version of the proposed E^2MOOR scheme to protect against few network attacks can be envisaged.

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