Energy Balanced and Expected Transmission Count Routing in IoT

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***Abstract*—With the advent of 5G technology Internet of Things (IoT) and its routing protocols are receiving anew attention. As most cIoT (consumer IoT) devices operate at low energy levels and have limited energy an energy conserving routing protocol is a must. IoT devices often form cooperative networks to conserve energy. The routing strategy in a multipath IoT network requires further exploration. In this paper we propose an energy balanced and expected transmission count based routing decision strategy ($EBETX$) for cIoT networks. $EBETX$ makes use of two physical parameters, one of them is received signal strength indicator (RSSI) and the other one, battery voltage, to obtain the best decision by our proposed decision strategy. In order to predict the future packet reception rate (PRR), the RSSI is used and for estimating the residual energy of network nodes, battery voltage is used to balance their load. To evaluate the performance of our routing algorithm, we use NS-2.35. We also compared its performance with state of the art algorithm, E^3TX. Our simulation results show that our proposed $EBETX$ performs better than E^3TX, in terms of reliable data transmission, end-to-end delay, network lifetime, network utilization and operational overhead.**

***Index Terms*—IoT, transmission, protocol, load factor, lifetime, operational overhead.**

I. Introduction

IoT devices have been around us since 1999 [1]. However they have emerged as one of the most influential technology only after the commercial deployment of 4G or 4G LTE in 2010 [2]. Now the 21st century contemporary world in every leading field such as, agriculture, healthcare, structural health monitoring, building and home automation, automotive, smart manufacturing etc have been taken over by IoT. Major usage of IoT infrastructure can be seen in two primarily fields e.g. consumers IoT (cIoT) [3], [4] and industrial IoT(iIoT) [3], [4]. cIoT is concerned with making our day to day life convenient, easier and safe. Therefore, the most important feature of cIoT would be low energy consumption [5] so that the users could enjoy the services of applications e.g. smart watch without having to worry about charging them at little intervals. Then again the battery technology is also advancing at a rapid pace [6]. As the size of the batteries need to be smaller therefore store only a small amount of energy [7]. Whereas iIoT networks have been widely used in various industries for automation and high risk tasks. Most iIoT applications require data transmission reliability and lower latency [8, 9, 10, 11], such as industrial measurement and control among others [12].

Next generation of wireless communication (5G) would not only concentrate on mobile broadband communication but also take on the next billion connections [13]. Which is IoT. With 5G wireless technology knocking at our doors promising several improvements e.g. enhanced speed, converged networks with new radio core, zero latency, cost reduction, true ubiquity [14] research community is faced with new challenges. One of the crucial challenges would be energy efficient routing. Even with very dense deployment and every device having its own connection with the base station cooperative routing will remain economical in terms of energy consumption as there will never be as many base stations as devices. Therefore in this paper we design an energy balanced routing algorithm in order to prolong the lifetime of the IoT network consequently enhanced service time from every application involved. We can leverage the segregation of radio core from control plane and user plane [15] to deploy such an algorithm.

Most of the IoT communication standards e.g. Thread, LoRaWAN, Sigfox were developed for specific use cases. Some of them are good for covering a large area while others excel in reliability. And they all have certain shortcomings, such as co-channel interference e.g. IoT using Wi-Fi [16], multipath fading e.g. networks deployed in urban jungles [16], asymmetric links e.g. we assume we will always have more download need than upload which is rarely true for IoT [17], and limited lifetime [18]. 5G technology enables us to deal with these problems while the underlying infrastructure is oblivious of the optimization. In this paper we design a routing algorithm for the IoT devices which could be taken advantage of by both cIoT and iIoT. Our algorithm balances the total traffic load among the available and participating devices even if they are not part of the same IoT network. In this article we design an energy balanced and efficient routing decision strategy for routing information from IoT devices to the base station such that we can ensure maximum lifetime for at risk devices, proper bandwidth utilization.

To the best of our knowledge, there is no such protocol for enhancing the lifetime of IoT devices which considers lifetime of the at risk devices through load balancing. There are extensive [19] studies based on single devices residual energy to choose the best path for sending data. However, such networks often results in disproportionate utilizatio‘n of available paths. The main contribution of this paper comprises the following aspects:

- First ever IoT routing algorithm to prolong the lifetime of at risk devices.
- Leveraging the features of emerging 5G technology as well as traditional cooperative routing with intelligence embedded to favour the weaklings.
- A multiple-factor routing decision strategy to overcome the drawbacks of E^3TX.
- Performance evaluation using NS-2.35 to validate the strategy and compare with state-of-the-art routing decision strategy E^3TX.

The remainder of this article is organized as follows. We present an overview of related work in Section II. We present an overview of the network model in Section III. In Section IV, we provided our proposed model, energy balanced and expected transmission count routing in IoT. Section V describes the numerical analysis. Section VI the performance evaluation and analysis based on NS-2.35. Finally, the paper is concluded in Section VII.

II. Related Work

The literature for routing protocols in Internet of Things (IoT) is quite rich. Some of them tends to re-use the techniques that were built for the internet. Others are specific to IoT. There exists an almost perplexing choice of routing protocols in the Internet of Things (IoT), such as Thread, LoRaWAN, Sigfox etc. In these routing protocols, the routing metrics are the network variables used to decide which path is selected to deliver information to the destination. These metrics can be static or dynamic. Most common metrics are hop count, delay, reliability, bandwidth, cost, traffic or workload and energy [27]. As most of the IoT devices are small and often wireless energy considerations during route selection is of utmost importance [28], [29]. Next we discuss several state-of-the-art IoT routing protocols and their power saving mechanism, if any.

One of the most common routing protocols in todays IoT networks is Thread [30]. It is a IPv6-based mesh networking protocol aimed at devices in and around the home. Thread is based on IEEE802.15.4, 6LoWPAN and designed in order to set up an easy, secure connections between hundreds of devices (up to 250 devices). The connections could be either to other IoT devices in the vicinity or directly to the cloud. Thread wireless connectivity ensures security, simplicity and reliability. A self-healing mesh networking solution is provided by Thread. It supports sleepy nodes, allowing long term operations from a single AA battery [33]. Thread's robustness comes into action when considering mobility. Continuously updating the path is a must if the IoT devices are moving in and around locally in an IoT network. Thread can handle device mobility gracefully. Most interesting characteristic of Thread is the devices can connect to the cloud the directly. However, this is also the most devastating aspect of Thread [36]. As this is rarely the requirement for IoT networks. Additional circuits and complexities are need to deploy this capability, which is often a burden for these small IoT devices. Thread is also not suitable for large scale development.

Another widely used routing strategy is Sigfox [32]. It is an ultra narrow band technology. Sigfox is the very first LPWAN (Low-Power Wide-Area Network) technology proposed for IoT and it was founded in 2009. In Sigfox, gateway can handle up to a million connected IoT devices, covering 30 to 50 km in rural and 3 to 10 km in urban areas. Sigfox listens to billions of IoT devices without establishing or maintaining network connections. The network that Sigfox provides has no signaling overhead and IoT devices are not attached to the network. In Sigfox, the Cloud manages all the computing complexity and also the network, rather than the device. For these reasons, costs of connected devices and energy consumption are reduced drastically. Sigfox gives good results in fixed position network. However, in the mobility environments, interference and frequency inaccuracies are the major issues. It is not used for high data rate applications because of low data rate support. One way communication is supported by Sigfox. But it is supported without the acknowledgement. When server does not receive data, multiple transmissions are needed. Power consumption will increase drastically due to the number of re-transmission.

LoRaWAN [31] is a MAC protocol for WAN. It is designed to communicate over long range wireless connections for low-powered IoT devices. It supports low-cost, mobile, and secure bi-directional communication. The mobility and ease of use of Internet of Things and end-to-end security are ensured by LoRaWAN. However LoRaWAN cannot handle real time data [35]. It can send small packets every couple of minutes, which is the major drawback of LoRaWAN. We cannot use this protocol in some types of IoT applications such as Smart Health, Smart Security System.

Among other routing decision strategy that emerged from the existing routing protocols developed for the internet or large scale wireless sensor networks is ETX [22]. It is a link quality based routing decision strategy. On multi-hop wireless networks. ETX finds the high-throughput paths. ETX routing metric scheme that estimates the expected transmission count using probe packets. ETX is regulated by Equation (1).

$$ETX = \frac{1}{d_f \times d_r} \tag{1}$$

Here forward packet delivery rate is denoted by d_f. This indicates the packet reception rate from the source IoT device to the destination IoT device and the backward packet delivery rate is denoted by d_r. This indicates the ACK(acknowledgement) reception rate from the destination node to the source node. In order to successfully deliver a packet to the destination, ETX lessens the expected total number of packet transmissions which also includes retransmission. However, in the event of an asymmetric link, ETX may not be able to get the optimal result. While developing ETX De Couto *et al* did not factor in energy efficiency, end-to-end transmission delay, how long the network will survive and more importantly energy balancing.

Authors of [23], developed a modified version of ETX called mETX (modified ETX). They have also considered ENT (Effective Number of Transmission) metric for optimizing the aggregated throughput. ENT value is the result of the variability of the error probability and mETX value is the average of the error probability. Combining these two gives a better result than ETX. However, network lifetime and energy of nodes were not considered in this article.

In [24], the authors presented a novel source-based routing (SBR) metric method. They considered packet loss, load at gateways, interflow, intraflow interference to select the best path to reach the selected gateways. SBR outperforms the existing routing decision strategy and also improves the network performance. However, the authors did not consider energy expenditure and load balancing. These two metrics dominate IoT networks and their usability.

Finally, in [25], the authors primary motivation was energy conservation. Their proposed strategy promised improvement over ETX's energy consumption. The optimal distance from source to destination and energy balance are taken into account. The lifetime of the network is improved using clustering protocol which in turns increases the end-to-end data delay. However if the nodes are randomly distributed or uniformly distributed, then the proposed method does not give desired results.

Another noteworthy contribution was proposed by Run Ye *et al*. [19], the authors have developed the following Equation (2) to solve the asymmetric link problem of ETX.

$$ETX_i = \frac{1}{d_f^i \times d_r^i} = \frac{1}{d_f^i} \tag{2}$$

The authors of E^3TX set the data packet reception rate to 1. They only worked with the data packet forward rate. They presented an energy-efficient expected transmission count routing decision strategy titled E^3TX. They stated that a path will be selected based on a single intermediate nodes residual energy that is the node with least amount of residual energy in a path. As the node with the least residual energy decides the path using which the device will send data, this may not give the best result in many cases. Specially when the other IoT devices in the path have very high residual energy. It might also force the data packets of the device to take longer paths which will invariably increase latency. Moreover, load balancing is not ensured by E^3TX. That is when a device is detected to have lowest energy among all the forwarders it is exempt from being a relay until some other devices energy level stoops even lower. This will keep a large portion of the network inactive. Often device around destination devices drain out faster than others. Therefore, choosing a different route just because one of the relay's have lower energy level than others is not a good strategy for the longevity of the entire network. To eradicate the drawbacks of the existing protocols we are proposing a noble routing protocol which is an improved and balanced version of E^3TX.

III. Network Model

We assume there is a $X \times Y\ m^2$ vicinity and there are N IoT devices in the vicinity. All the IoT devices might not be aiding the same application and are heterogeneous in nature. The IoT devices are stationary and all of them communicate their produced data to a base station B directly or otherwise. The base station need not be same for all devices. All the devices have direct communication links with their respective base stations. We also assume the location and the energy levels of the devices are known to all other devices. How the devices discover each other is out of the scope of this paper. To attain the residual energy of each node we use flooding at regular intervals. Statistical estimation of residual energy for other devices is left as a future work.

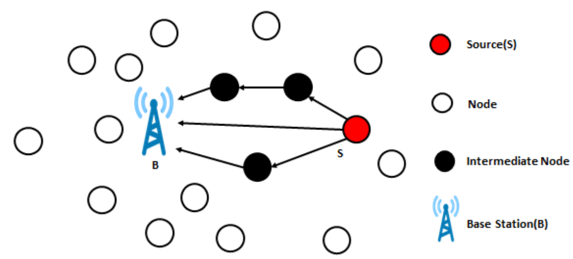

Fig. 1. Network model

Though the devices can reach the base station directly, it is very expensive to say the least in terms of energy consumption. IoT devices are usually very densely deployed and are expected to grow by a multitude in the future. Number of connected IoT devices from 2018 to 2025 will increase from 23.14 to 75.44 billions [20]. Market value of IoT devices in 2018 and 2019 will be 1391 and 1710.4 billion US dollars [21]. Therefore it safe to say that they will have other IoT devices nearby which can perform the role of a forwarder with far less energy expenditure. In Fig. 1 we can see such a scenario where there is one source device, s (red) and one base station B. The device could choose to send its data direct with high energy cost or it could choose a nearby device to forward its data to the base station.

As we have said several times over that, nowadays the IoT devices are densely deployed therefore a device might need to choose a forwarder from an array of candidates. Moreover, there might be more than one viable path the data packet could take. Needless to say, some nearby devices might not be suitable to perform the role of forwarder as it might not have a path to the corresponding base station for the source device. In summary we are faced with numerous devices many of which could be a forwarder with a route to the base station therefore we have multiple routes to the base station.

All the IoT devices can act as a source device and as a forwarder. And there will always be data available to transmit.

In this context we would like to define network lifetime. In our proposed network model a source can send data to the destination directly or using any of multiple routes available. There will be multiple sources and destinations in our proposed network. We assume that every source communicates with the other sources using flooding at regular intervals. When a source will not receive any probe packets from the other sources and also cannot send data to it's destination then the source will declare that the network is dead.

In this context, we would like to define energy model for our proposed decision strategy. Smart Home, Smart Health, Smart Wearables are some popular cIoT applications. Most of them are battery powered. Fig. 2 shows a simple energy profile of an IoT device. As the energy of cIoT devices are very low, it is very much important to focus on energy consumption of cIoT devices. In our energy model, we assume that 70% IoT devices are at risk devices and others have initial energy (1028 J). A device loses energy when it sends data to another devices and also loses energy when it receives data packet from another devices. Every device also loses some energy for sensing, sending prob packets, configuring and also for being idle [39]. As a result its very much important to focus on energy consumption of IoT devices.

IV. Proposed Model

In this section, we discuss the proposed energy balanced routing decision strategy for IoT networks. This algorithm will extend the lifetime of the overall network with proper utilization of the entire network.

Routing techniques in IoT networks has been studied since the inception of IoT devices in 1999. And with the emergence of new wireless networking technologies this field has been investigated over and over again. However, most of them lack in one particular criteria. That is if the network is using cooperative routing through nearby devices then the device with lowest energy level will suffer severely. Our proposed algorithm diminishes this problem.

In order to achieve the above, we investigate a subset of all the viable paths. We consider residual energy of all the intermediate nodes of a path from source to destination. The reason behind this strategy is, to maximize network lifetime and ensure proper utilization of the network. Therefore, our routing algorithm is called Energy Balanced and Expected Transmission count ($EBETX$) routing protocol. This algorithm comprises of four phases. Details of these phases are discussed as follows.

A. Determination of Multiple Candidate Paths

In this phase we calculate all possible paths from source (s) to destination (B) using a popular multipath routing algorithm, Adhoc On-Demand Multipath Distance Vector [34]. After determining all possible paths m, we select a subset of viable paths p, where $p \subset m$. In order to select p viable paths we determine the cost of each path. The cost is calculated using a function $f(|A - S|)$. Here,

$$f(|A - S|) = 697.78 \times e^{-1.984 \times |A-S|} \tag{3}$$

In the above Equation (3) A is the average of the residual energies of all the intermediate devices on a path. And A is calculated as follows:

$$A = \frac{1}{n} \times \sum_{i=1}^{n} (E_i \times \lambda_i) \tag{4}$$

The other parameter S is used to calculate $f(|A - S|)$, is the standard deviation of the residual energies of all the intermediate devices on a particular path. This is derived as:

$$S = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} ((E_i \times \lambda_i) - A)^2} \tag{5}$$

In Equation (4) and (5) λ_i is a load factor of i_{th} device (load factor is discussed later in this section) and n is the total number of intermediate devices on this particular path. After calculating the the cost function for all possible paths, we choose p paths with lowest $f(|A - S|)$ values. Because when the value of $f(|A - S|)$ is low the overall energy cost of the path is low as well.

In Fig. 3 source $S1$ wants to send data to base station B1 and there are two paths from S1 to B1, $Path_{S1-A-B1}$, $Path_{S1-C-G-B1}$. S1 can use any one of them based on overall condition of the paths. In the meantime, source S2 also wants to send data to another based station B2 and there are three paths from S2 to B2, $Path_{S2-C-B2}$, $Path_{S2-D-B2}$ and $Path_{S2-F-E-B2}$. Here intermediate node C is the common node of $Path_{S1-C-G-B1}$ and $Path_{S1-C-B2}$. As a result the value of load factor of node C will be 0.5 where other intermediate nodes have 1. So S2 should find another suitable path to send the data to B2. Load factor (λ) decreases network delay and congestion.

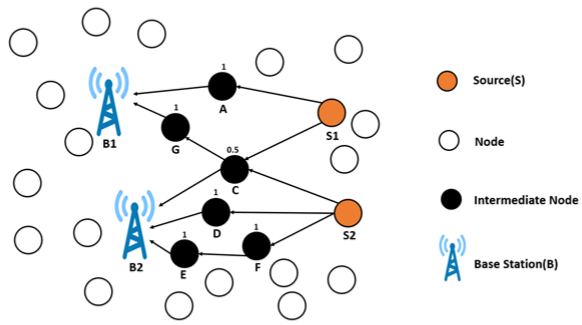

Fig. 2. Load factor

Notation for the equations

Symbol	Description
d_r	Backward packet reception rate
d_f	Forward packet reception rate
A	Average of residual energy of intermediate devices
S	Standard deviation of residual energy of intermediate devices
E_i	Residual battery energy of "i-th" device
λ_i	Load factor of "i-th" device
n	Total number of intermediate devices

In this work we choose $p = 3$. Therefore we will have 3 candidate paths from source to destination. We assume we can always find more than 3 paths from source to destination. Determination of optimal number of candidate paths is left as a future work. After selecting p candidate paths, we calculate the link qualities of each path. Link quality measurement is discussed next.

B. Determination of Link Quality

Our ultimate function $EBETX$ is a function of energy cost and link quality of a path. In order to calculate link quality we use ETX or Expected Transmission count of the path. ETX is the expected number of times a packet needs to be re-transmitted to reach the destination. This value varies from 1(the original packet reaches the destination in the first try) to infinity (the packet cannot reach the destination). Therefore a value (not necessary an integer) between 1 and infinity represents more than one try. Equation (6) is used to measure path quality [22].

$$\beta = \sum_{i=1}^{n} ETX_i \tag{6}$$

Where the expected transmission count is denoted as β.

C. Determination of $EBETX$ Path

Using equation (3) and (6), we propose our noble path selection strategy $EBETX$. Equation (7) represents a weighted value of energy cost and link quality. This weight is controled by α. Here α is a tunable parameter ranging from $0<\alpha<1$.

$$\begin{aligned} EBETX &= (1-\alpha) \times \sum_{i=1}^{n} ETX_i + \alpha \times f(|A - S|) \\ &= (1-\alpha) \times \beta + \alpha \times f(|A - S|) \end{aligned} \tag{7}$$

Using the above equation we obtain the value of $EBETX$ for the candidate paths. We will choose the path with the lowest value of $EBETX$ to send data. A lower value of $EBETX$ indicates that, the overall residual energy of the intermediate IoT devices are better than the others. Lower value of ETX ensures good path quality and higher value of ETX means poor path quality.

D. On-Demand Calculation of $EBETX$

As we implement $EBETX$ over the routing algorithm $AOMDV$, we calculate $EBETX$ whenever, $AOMDV$ is triggered. Therefore, the residual energy computation is up-to-date and the value of $EBETX$ reflects current network scenario.

In the next section we demonstrate the numerical results obtained by ETX, E^3TX and $EBETX$.

V. Numerical Results

We present a simple network with 9 IoT devices. The data above the line comprises the packet reception rate (PRR), and the residual battery energy is given above IoT devices. In this article, we use battery voltage to represent the residual battery energy. In Fig. 3, we take $Path_{S-A-B-C-D}$, $Path_{S-E-D}$ and $Path_{S-F-G-H-D}$ as an example.

There are 4 hops from S to D along $Path_{S-A-B-C-D}$. If we use the ETX to calculate, we get the following Equation (8).

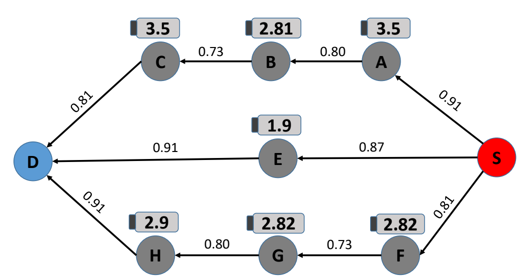

Fig. 3. A network of IoT devices

$$ETX = \frac{1}{0.91} + \frac{1}{0.80} + \frac{1}{0.73} + \frac{1}{0.81} = 4.95 \tag{8}$$

If we calculate the cost value using E^3TX, we can obtain the following result which is shown in Equation (9).

$$\begin{aligned} E^3TX &= (1-\alpha)\times\sum_{i=1}^{4} ETX_i + \alpha\times \max_{i\in S_n}(f(E_i)) \\ &= 0.7\times(\frac{1}{0.91}+\frac{1}{0.80}+\frac{1}{0.73}+\frac{1}{0.81}) \\ &+ 0.3\times f(2.81) \\ &= 4.26 \end{aligned} \quad (9)$$

However if we calculate cost value using our proposed method we can obtain a different result which is shown in Equation (10).

$$\begin{aligned} EBETX &= (1-\alpha)\times\sum_{i=1}^{4} ETX_i + \alpha\times f(|A-S|) \\ &= 0.7\times(\frac{1}{0.91}+\frac{1}{0.80}+\frac{1}{0.73}+\frac{1}{0.81}) \\ &+ 0.3\times f(|3.27-0.32|) \\ &= 4.07 \end{aligned} \quad (10)$$

Considering path $Path_{S-E-D}$ there are 2 hops from S to D along $Path_{S-E-D}$. If we use the ETX to calculate, we can get the following Eq (11).

$$ETX = \frac{1}{0.91}+\frac{1}{0.87} = 2.25 \quad (11)$$

If we calculate the cost value using E^3TX, we can obtain the following result which is shown in Eq (12).

$$\begin{aligned} E^3TX &= (1-\alpha)\times\sum_{i=1}^{2} ETX_i + \alpha\times \max_{i\in S_n}(f(E_i)) \\ &= 0.7\times(\frac{1}{0.91}+\frac{1}{0.87}) \\ &+ 0.3\times f(1.9) \\ &= 6.40 \end{aligned} \quad (12)$$

However if we calculate cost value using our proposed method we can obtain a different result which is shown in Eq (13).

$$\begin{aligned} EBETX &= (1-\alpha)\times\sum_{i=1}^{2} ETX_i + \alpha\times f(|A-S|) \\ &= 0.7\times(\frac{1}{0.91}+\frac{1}{0.87}) \\ &+ 0.3\times f(|1.9-0|) \\ &= 6.40 \end{aligned} \quad (13)$$

Considering path $Path_{S-F-G-H-D}$ there are 4 hops from S to D along $Path_{S-F-G-H-D}$. If we use the ETX to calculate, we can get the following Eq (14).

$$ETX = \frac{1}{0.81}+\frac{1}{0.73}+\frac{1}{0.80}+\frac{1}{0.91} = 4.95 \quad (14)$$

Path	Result			
	Hop Count	**ETX**	E^3TX	$EBETX$
$Path_{S-A-B-C-D}$	4	4.95	4.26	4.07
$Path_{S-E-D}$	2	2.25	6.40	6.40
$Path_{S-F-G-H-D}$	4	4.95	4.24	4.26

If we calculate the cost value using E^3TX, we can obtain the following result which is shown in Eq (15).

$$\begin{aligned} E^3TX &= (1-\alpha)\times\sum_{i=1}^{4} ETX_i + \alpha\times \max_{i\in S_n}(f(E_i)) \\ &= 0.7\times(\frac{1}{0.81}+\frac{1}{0.73}+\frac{1}{0.80}+\frac{1}{0.91}) \\ &+ 0.3\times f(2.82) \\ &= 4.24 \end{aligned} \quad (15)$$

However if we calculate cost value using our proposed method we can obtain a different result which is shown in Eq (16).

$$\begin{aligned} EBETX &= (1-\alpha)\times\sum_{i=1}^{4} ETX_i + \alpha\times f(|A-S|) \\ &= 0.7\times(\frac{1}{0.81}+\frac{1}{0.73}+\frac{1}{0.80}+\frac{1}{0.91}) \\ &+ 0.3\times f(|2.85-0.04|) \\ &= 4.26 \end{aligned} \quad (16)$$

In the above section we have calculated Hop Count, ETX, E^3TX, $EBETX$ on the paths shown in Fig. [3]. After calculation different results are obtained. There is a significant difference between the E^3TX and $EBETX$ value.

Comparative results between Hop Count, ETX, E^3TX, $EBETX$ are given in a tabular form. According to the table above, $Path_{S-E-D}$ is selected by Hop Count and ETX. $Path_{S-F-G-H-D}$ is selected by E^3TX but our proposed method $EBETX$ selects $Path_{S-A-B-C-D}$ because the overall residual energy of intermediate IoT devices are better than others.

VI. Performance Evaluation

In this section, we evaluate the network lifetime and operational overhead of our proposed method $EBETX$ and compare it with state of the art E^3TX. We have used NS-2.35 and Java for evaluation.

A. Simulation Environment

Initially all IoT devices are equipped with 3.5V (1000 mAh) batteries. We can calculate the energy in Joules using the following equation [17].

$$J_{ev} = u\times i\times t \quad (17)$$

Where J_{ev} is the energy of the battery in Joules. Battery voltage and battery capacity is denoted by u and $i\times t$

respectively [19]. As a result, the initial energy an IoT device is $1000 \times 3600/1000 \times 3.5 = 1028(J)$.

The parameters of the simulation are shown in table 5.

Parameter	Value
Network area $(m \times m)$	200×200
Initial energy (J)	1028
Transmission range of each device (m)	50
Number of simulation in each case	10
Number of IoT devices	110
Initial value of load factor	1

In our simulation, we assume that 70% IoT devices are at risk devices. We consider the transmission energy as 90 mj/pkt, reception energy as 45 mj/pkt , transmission range of each IoT devices is 50m and packet size is 1024 bytes [37], [38].

B. *Performance Metrices*

We analyze the performance of our proposed decision strategy on the following metrics.

- Network Lifetime.
- Operational Overhead

C. *Control Parameters*

We analyze the performance of our proposed path selection strategy on the following parameters.

Number of IoT Devices: We increase the number of IoT devices and evaluate the performance of the network.

Network Size: We increase the size of the network and evaluate the performance of the network.

D. *Simulation Results*

In this section we discuss the impacts of the number of IoT devices and network size.

1) *Network Lifetime:*

- **Impact of Increasing Number of IoT Devices:** Incrimination of the number of IoT devices increase network lifetime in both algorithms because sources get more IoT devices as a forwarder. In our method, source gets intermediate IoT devices with higher energy as a forwarder compared with E^3TX which ensures less device processing delay and achieve more network lifetime.
  In Fig. 4 we evaluate the impact of increasing number of IoT devices on network lifetime. We have increased the number of IoT devices and compared the network lifetime with our proposed method $EBETX$ and E^3TX. Fig. 4 depicts that our proposed method $EBETX$ achieves better lifetime.
- **Impact of Increasing Network Size:**
  In Fig. 5 depicts the effects of increasing network size on network lifetime. While increasing network size we maintain the node density in the network for fair comparison. Fig. 5 depicts that our proposed method $EBETX$ achieves better lifetime. Increasing the network size decreases network lifetime in both methods because sources get less number of intermediate IoT devices as forwarders.

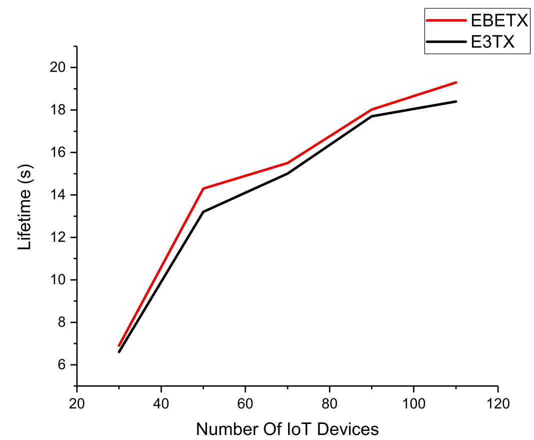

Fig. 4. Lifetime comparison of different number of IoT devices

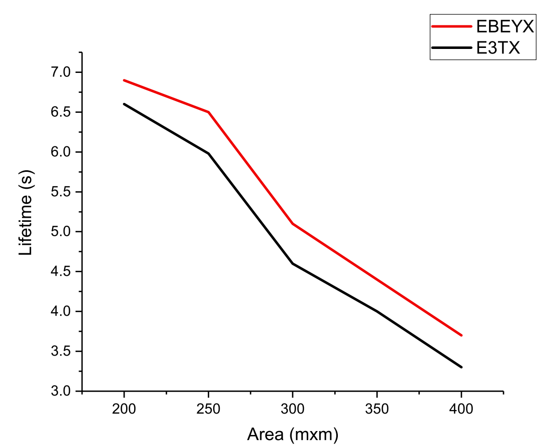

Fig. 5. Lifetime comparison of different area

2) *Operational Overhead:*

- **Impact of Increasing Number of IoT Devices:**
  In Fig. 6 shows the effects of increasing number of IoT devices on operational overhead. Incrimination of the number of IoT devices increase operational overhead in both methods. Fig. 6 shows that $EBETX$ has more operational overhead compared with E^3TX because we need to carry all intermediate IoT devicess residual energy in RREP (Route Reply) to calculate the decision value and in order to communicate with other sources, we send some extra probe packets to them for detecting whether the network is dead or alive whereas E^3TX needs to carry only the minimum residual energy of intermediate IoT devices.
- **Impact of Increasing Network Size:**

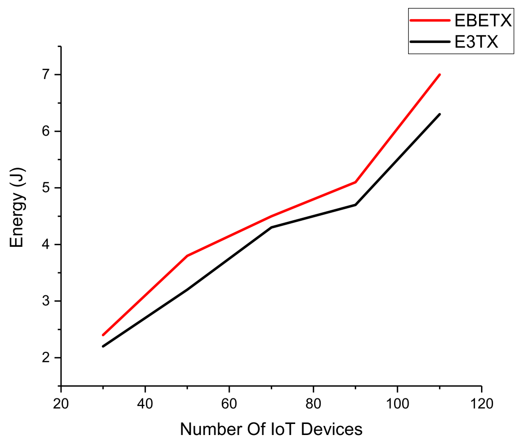

Fig. 6. Operational overhead comparison of different number of IoT devices

In Fig. 7 shows the effects of increasing network area on operational overhead. We maintain the node density for fair comparison. Incrimination of network area increases operational overhead in both methods. Our proposed method $EBETX$ has more operational overhead compared with E^3TX.

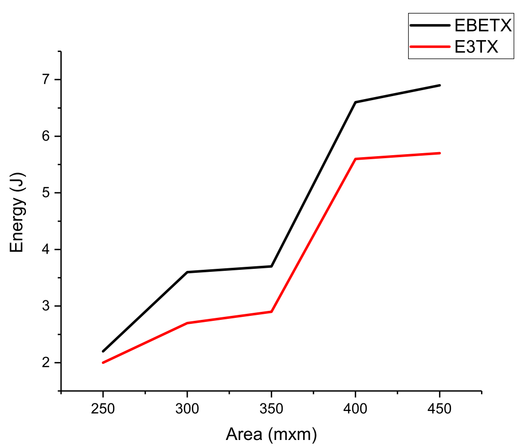

Fig. 7. Operational overhead comparison of different area

According to above mentioned methods and simulation results, $EBETX$ performs better than E^3TX in terms of network lifetime. However E^3TX performs better than $EBETX$ in terms of operational overhead and it will be our future work to reduce the operational overhead of our proposed path selection method $EBETX$. $EBETX$ performs better than E^3TX in terms of average residual energy of intermediate IoT devices. Fig. 8 clearly depicts that our proposed method chooses the path with higher average residual energy compared with E^3TX because we have considered all the residual energy of intermediate IoT devices whereas E^3TX has only considered the maximum residual energy of the intermediate IoT devices for path selection.

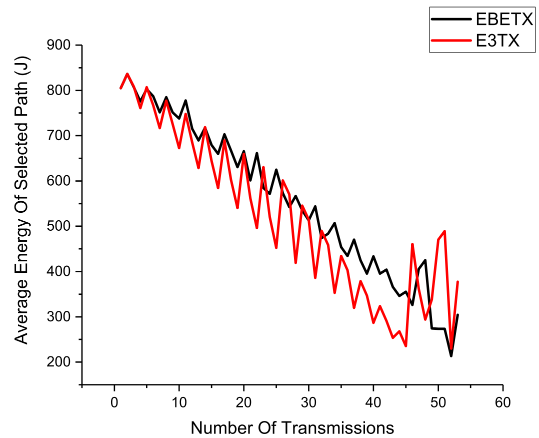

Fig. 8. Selected path's energy comparison between E^3TX and $EBETX$

VII. Conclusion

We have proposed a novel path selection method considering both energy requirements and expected transmission count for multipath routing in IoT network. Our routing strategy solved few drawbacks of an existing mechanism E^3TX. We have generated uniform random typologies using NS-2. Moreover, we have used multipath AODV and implemented our $EBETX$ in Java. Our simulation result shows that $EBETX$ improves network lifetime and network utilization.

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