JSR Publications

Available Online

J. Sci. Res. **14** (2), 419-433 (2022)

JOURNAL OF SCIENTIFIC RESEARCH

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Energy-Aware Threshold Sensitive Stable Election Protocol (EATSEP) for Wireless Sensor Networks

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Received 25 August 2021, accepted in final revised form 14 February 2022

Abstract

In most of the traditional cluster-based hierarchical routing protocols, the cluster head (CH) selection is made on a random basis. As a result, some unlucky sensor nodes (SNs) become dead quickly; thereby, network lifetime reduces drastically. To overcome this problem, in this paper, a new cluster-based routing protocol- Energy-Aware Threshold Sensitive Stable Election Protocol (EATSEP) is presented for wireless sensor networks (WSNs). In the EATSEP protocol, the CH selection is an optimum process where the initial and residual energy of each SNs are considered within a heterogeneous SNs energy environment. Additionally, our proposed EATSEP protocol has managed to reduce long-distance transmission by routing data among CHs to the base station. In our present study, we have simulated the EATSEP protocol through MATLAB to compare its performance with other popular protocols under some well-known performance metrics. The experimental results indicate that the network stability of the EATSEP protocol improves by 80.81, 66.41, and 27.06 %, respectively, compared to the low-energy adaptive clustering hierarchy (LEACH), Stable Election Protocol (SEP), and Threshold Sensitive SEP under a particular setting. In terms of energy consumption and network throughput, the EATSEP is also superior to other protocols.

Keywords: WSN; Network stability; Lifetime; Throughput; Heterogeneity; Hierarchical routing protocol.

doi: http://dx.doi.org/10.3329/jsr.v14i2.55330 J. Sci. Res. **14** (2), 419-433 (2022)

1. Introduction

Nowadays, the application of wireless sensor networks (WSNs) in telecommunications, environmental services, military services, surveillances, agriculture, etc., has increased tremendously [1]. Usually, WSNs are mainly composed of a base station (BS) and a finite set of randomly distributed sensor nodes (SNs) in a target environment [2]. The limited powered non-replaceable batteries are the main energy source of such networks when placed in a complex or harsh environment. For this reason, relevant researchers are actively engaged in designing and implementing energy-efficient routing protocols to lengthen the network lifetime of WSNs [3].

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In the early 20th century, a cluster-based hierarchical routing protocol is introduced to achieve energy efficiency in WSNs. The key idea behind the clustering protocols is to form clusters in the WSNs in the round. A typical cluster is composed of a single CH and associated member SNs. The sensed data by the SNs from the environment are usually sent to their associated CH. Thereafter, CHs aggregate and fuse the received data and send it to the BS. Usually, the CHs will forward data to the BS either by single-hope or multi-hop transmission modes, and the transmission mode is mainly realized by the distance from the CH to the BS [2]. Every upcoming round will begin by forming a new set of clusters with new CHs, and data will be forwarding the same fashion as described above. This procedure will continue till the end of the network lifetime.

The WSNs settings can be broadly categorized into homogeneous and heterogeneous settings [4]. Inhomogeneous settings, regarding the hardware and battery energy, all SNs are the same as the heterogeneous settings. Theoretically, the heterogeneous settings of WSNs are mainly reflected in computing, link, and energy [5]. In computational heterogeneity, the SNs have a more superior microprocessor and high capacity memory so that WSNs can offer intricate data processing and everlasting memory storage. In link heterogeneity, the heterogeneous SNs have a high-bandwidth and long-distance network transceiver to provide faithful data transmission. The SNs in WSNs have different levels of energy in energy heterogeneity. It is noted that the former two heterogeneities inherently depend on energy as these types of SNs consume more energy. Thus, the energy-based heterogeneity may be considered as the most dominating etrog. The cost incurred in increasing the energy of a sensor is much less than that of deploying additional sensors of the same amount of energy [6]. It has been reported that providing heterogeneity in SNs prolongs the network lifetime, improves throughput, and decreases the latency of data transportation. This aspect indicates the effect of energy heterogeneity.

The HWSNs routing protocols with the heterogeneity of SNs energy such as Stable Election Protocol (SEP) [7], and its different modifications such as Modified SEP (MSEP) [8], Threshold Sensitive SEP (TSEP) [9], Prolong-SEP (PSEP) [10], and many more routing protocols such as Distributed Energy-Efficient Clustering Algorithm (DEEC) [11], Weighted Election Protocols (WEP) [12], Traffic Energy-Aware Routing (TEAR) [13] have been proposed. However, how to more properly utilize the heterogeneity of nodes' energy to prolong the network lifetime and increase the network throughput is one of the crucial issues of the HWSNs routing protocol [14].

The key contribution of this paper is summarized as follows: we proposed a new routing protocol named Energy-Aware Threshold Sensitive Stable Election Protocol (EATSEP) for energy efficiency and load balancing in heterogeneous WSNs. The proposed protocol is different in the sense of election of CH from the SNs in an optimum process where the residual energy of each SNs and the initial energy of each SNs is considered in a heterogeneous SNs energy environment. EATSEP is a residual energy-aware heterogeneous aware routing protocol in the sense of electing CH. It considers the residual energy of each SNs in each round, the initial energy of each level of heterogeneous SNs, and the average residual energy of the network. To measure our proposed EATSEP's effectiveness, we first implemented it using MATLAB simulation tools and compared its performance with other prevailing techniques by considering some prominent performance metrics.

2. Literature Review

The cluster formation and various communication modes of transmitting data have been the most emphasized approaches [15]. In general, cluster-based routing protocols can efficiently use the SNs in the network compared with non-clustering protocols [16]. The authors of the paper [17] developed such a cluster-based routing protocol called Low Energy Adaptive Clustering Hierarchy (LEACH) which works for cluster formation and communication activities. The SNs arrange themselves into local groups or clusters in LEACH, with one node behaving as a CH in each group. It uses the randomization technique to distribute the energy load uniformly among sensors in the network by not selecting fixed CHs and opting for random ones in each iteration. Moreover, LEACH performs local data fusion at CHs to squeeze the amount of data captured from sensors and then send it to BS, reducing energy consumption and enhancing the life span of the network. There have been discussed different variants of LEACH such as LEACH-C [18], LEACH-M, LEACH-V [19]. The main goal of each cluster-based routing protocol is to prolong the network lifetime.

To further prolong the network's lifetime and make WSNs more suitable for various scenarios, some researchers proposed WSNs with heterogeneity [20]. A maiden heterogenous cluster-based routing protocol, SEP, was introduced by G. Smaragdakis et al. in [7], where two-level SNs' heterogeneities (advanced and normal) are considered. Extended versions of SEP protocol called PSEP [21], MSEP [8], WEP [12] are proposed thereafter. In all of these protocols, the advance SNs have more energy than normal SNs, and the CH selection probability of the advance SNs is more than normal SNs.

Later, Enhanced Stable Election Protocol (ESEP) [7], TSEP [9], P-SEP [10], NoHet [22] are presented where three-level SNs' heterogeneities are considered. These protocols have three SNs called normal nodes, intermediate nodes, and advance nodes. The cluster head selection probability of the advance SNs is the highest, then the intermediate SNs and least rm proposed heterogeneous routing protocols tried to satisfy the key properties of WSNs: balancing energy consumption, the coordination of communication, effectiveness for computation and storage [23]. In most of these protocols, the CHs selection probability depends on some random number generated by the SNs. But there is a possibility that an SN may be selected more frequently than some other nodes. As a result, there may be some SNs energy drain quickly. But if the CH selection probability can be done in a way where the residual energy will also be considered, then the energy dissipation will be more optimized. To this point, we have proposed a new routing protocol for WSNs called Energy Aware Threshold Sensitive Stable Election Protocol (EATSEP). The proposed protocol is a modified version of the TSEP protocol in which the CHs selection probability and threshold calculation of TSEP are significantly modified to improve network lifetime, energy consumption, and network throughput. Details of our proposed EATSEP are presented in the next section.

3. EATSEP: Proposed Approach

Energy-Aware Threshold Sensitive Stable Election Protocol (EATSEP) is a cluster-based heterogeneous hierarchical routing protocol. The protocol forms several clusters. Each cluster has a CH, and the other cluster nodes are the cluster's member nodes. The member nodes sense the environmental parameters and send this data to the CHs. The cluster head then sends the data to the BS. Details about the EATSEP are described in the following sections.

3.1. *Network architectures*

Our proposed EATSEP protocol has three types of SNs, which are deployed randomly in the sensor field. Three types SNs are Advance nodes, Intermediate nodes, and Normal nodes. The number of advances and intermediate SNs can be determined by the parameters m, and b, respectively. Both parameters reflect the value of fractions of all total SNs. The rest of the SNs of the network are considered normal nodes. The advance SNs are the nodes that have the most initial energy among the SNs, whereas the intermediate SNs have initial energy less than the advance SNs. The normal SNs have the least initial energy among all the SNs. We assume that the BS is located in the middle of the network. Fig. 1 shows a snapshot of our proposed EATSEP based sensor node deployment in the WSN network under simulation environment, where the BS, CH, normal nodes, intermediate nodes, advance nodes, and cluster regions are illustrated.

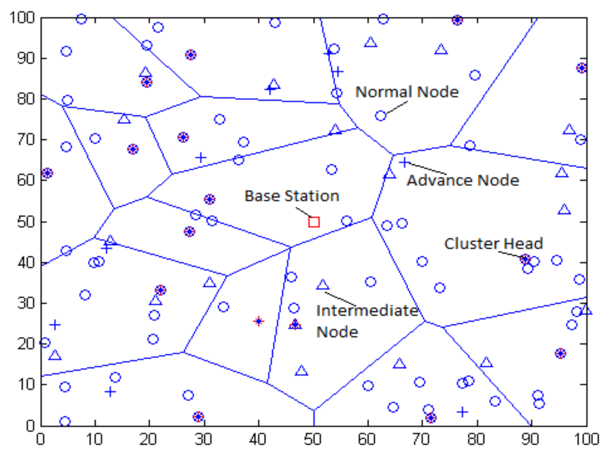

Fig. 1. A snapshot of the sensor node deployment under EATSEP protocol when all the nodes are alive.

3.2. *Energy consumption model*

The energy consumption model is used in our proposed EATSEP to exchange data, i.e., data transmission and reception. The model mainly has two portions: data sender-to send and receiver-to receive data. These portions of the energy consumption model are separated by a distance d [17]. The energy expended by the radio for the transmission and reception of l-bit message over a distance d is given by equations as:

$$E_{TX}(l,d) = \begin{cases} l.E_{elec} + l.\epsilon_{efs}.d^2 & if\ d \leq d_0 \\ l.E_{elec} + l.\epsilon_{amp}.d^4 & if\ d > d_0 \end{cases} \tag{1}$$

$$d_0 = \sqrt{\frac{\epsilon_{efs}}{\epsilon_{amp}}} \tag{2}$$

$$E_{Rx} = l.E_{elec} \tag{3}$$

Table 1 shows the used symbols in the energy consumption model of our EATSEP protocol, along with their meaning (see Fig. 2).

Table 1. Parameters of energy consumption model.

Symbol	Meaning
d	Distance between sender and receiver portion
l	The data bits
$E_{TX}(l,d)$	Required energy for transmitting l bits data over d distance
E_{Rx}	Required energy for receiving data
E_{elec}	Required energy by the transmitter/receiver to send/receive a data bit
ϵ_{efs}	Amplification coefficient
ϵ_{amp}	Energy for amplification

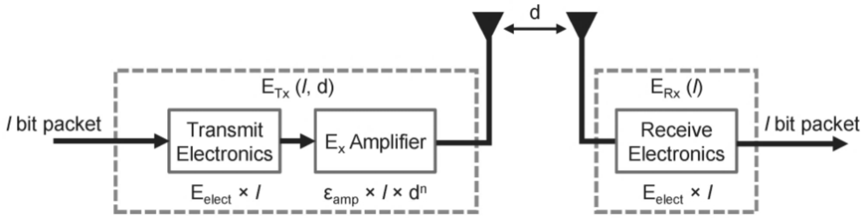

Fig. 2. Radio Energy Model used in our EATSEP [15].

3.3. *Energy distribution and CH election procedure*

During the initialization stage of network formation, the initial energy of each of the SNs is given as:

- Normal SNs, $E_{nrm} = E_0$
- Intermediate SNs, $E_{int} = E_0(1 + \mu)$
- Advance SNs, $E_{adv} = E_0(1 + \alpha)$

Where $\mu = \alpha/2$, α denotes each advance SNs have α times more initial energy than the normal SNs and μ denotes each intermediate SNs have μ times more energy than the normal SNs. If n is the total number of SNs, $m,$ and b are the portion of advance and intermediate SNs, respectively to the total number of SNs, then the total energy of normal, intermediate, and advance SNs will be $n * E_0 * (1 - mn - bn)$, $n * b * E_0(1 + \mu)$, and $n * m * E_0 * (1 + \alpha)$, respe i , the energy distribution in the considered WSNs is given as:

$$n * E_0(1 - mn - bn) + n * m * E_0 * (1 + \alpha) + n * b * E_0(1 + \mu) = n * E_0(1 + m\alpha + b\mu) \quad (4)$$

For electing the most efficient SN as CH, our proposed EATSEP uses distinct probability models for the normal, intermediate, and advanced SNs as follows:

$$\text{Normal SNs, } P_{nrm} = \frac{P_{opt}}{(1+m\alpha+b\mu)} + [E_0 \times RE_{nrm}] \quad (5)$$

$$\text{Intermediate SNs, } P_{int} = \frac{P_{opt}*(1+\mu)}{(1+m\alpha+b\mu)} + [E_0 \times (1+\mu) \times RE_{int}] \quad (6)$$

$$\text{Advance SNs, } P_{adv} = \frac{P_{opt}*(1+\alpha)}{(1+m\alpha+b\mu)} + [E_0 \times (1+\alpha) \times RE_{adv}] \quad (7)$$

where P_{opt} represents the probability of optimal CH selection from SNs in each round, and RE_{nrm}, RE_{int} , and RE_{adv} are residual energy of normal, intermediate, and advanced SNs, re ec of the key factors for the CH selection process of our proposed EATSEP. The formulation of the threshold function as all the SNs has to go through the threshold function for becoming CH. Our introduced protocol considers the initial and residual energy of each of the types SNs for designing the threshold function. To this point, each SNs randomly generates a binary number from 1 to 0. If the generated value is less than the threshold, these SNs become CH. For each SNs, we have different formulas for calculation of threshold depending on their probabilities, which are obtained from the general threshold formula for our proposed protocol is given as:

$$T(n) = \begin{cases} \frac{P_{opt}}{1-P_{opt}\left[r \bmod \left(\frac{1}{P_{opt}}\right)\right]} \times \left[\frac{E_{RE}}{E_0}\right] & if\ n_{opt} \in G \\ 0 & otherwise \end{cases} \quad (8)$$

where the optimal CH selection probability of SN is represented by P_{opt} in each round, r signifies a round number, and n symbolizes the number of SNs. E_0 and E_{RE} denoted the initial and residual energy of each of the SNs, respectively. G reflects the set of SNs.
Hence, the threshold function formula for the normal SNs will be

$$T(n_{nrm}) = \begin{cases} \frac{P_{nrm}}{1-P_{nrm}\left[r \bmod \left(\frac{1}{P_{nrm}}\right)\right]} \times \left[\frac{E_{RE-nrm}}{E_0}\right] & if\ n_{nrm} \in G' \\ 0 & otherwise \end{cases} \quad (9)$$

where E_0 signifies the normal sensor node's initial energy, E_{RE-nrm} denotes the normal node's residual energy, P_{nrm} represents the normal sensor node's CH selection probability. G' symbolizes the set of normal SNs.

The threshold function formula for the intermediate SNs will be

$$T(n_{int}) = \begin{cases} \frac{P_{int}}{1-P_{int}\left[r \bmod \left(\frac{1}{P_{int}}\right)\right]} \times \left[\frac{E_{RE-int}}{E_0*(1+\mu)}\right] & if\ n_{int} \in G'' \\ 0 & otherwise \end{cases} \tag{10}$$

where $E_0 * (1+\mu)$ symbolizes the intermediate sensor node's initial energy, E_{RE-int} denotes the intermediate node's residual energy, P_{int} represents the normal sensor node's CH selection probability. G" reflects the set of intermediate SNs.

$$T(n_{adv}) = \begin{cases} \frac{P_{adv}}{1-P_{adv}\left[r \bmod \left(\frac{1}{P_{adv}}\right)\right]} \times \left[\frac{E_{RE-adv}}{E_0*(1+\alpha)}\right] & if\ n_{adv} \in G''' \\ 0 & otherwise \end{cases} \tag{11}$$

where $E_0 * (1+\alpha)$ symbolizes the advanced sensor node's initial energy, E_{RE-adv} denotes the advance node's residual energy, P_{adv} represents the normal sensor node's CH selection probability. G'" reflects the set of advance SNs.

The main goal behind the design of EATSEP is to improve the network lifetime effectively by utilizing the residual energy of different types of SNs. The operation of our proposed EATSEP is stated in detail in Section 3.4.

3.4. *EATSEP protocol operation*

The operation of the EATSEP protocol is controlled through rounds where each round consists of two phases: the setup and the steady-state phase. During the setup-state phase, CHs are selected, clusters are formed, and the cluster communication schedule is determined, whereas, during the steady-state phase, data communication between the cluster members and the CH is performed. The duration of the steady-state phase is longer than the duration of the setup phase to minimize the overhead. So, the total operation is divided into four phases for description.

3.4.1. *CH selection phase*

The CH selection phase begins with the announcement, where the SNs broadcast a CH advertisement message. Here initially, an SN chooses a number between 0 and 1 randomly. If the randomly chosen number is less than $T(n)$, the SN becomes a CH. The threshold is calculated with the help of Equations 5, 6, 7, 9, 10, and 11. Here are the main improvements of the EATSEP protocol. The CHs are selected depending on their residual energy. The nodes having more residual energy have a higher probability of becoming CH. On the other hand, the nodes having less residual energy have less probability of becoming a cluster head.

3.4.2. *Cluster setup phase*

In this phase, the selected CHs then announce to their neighbors that they are the new CHs in the WSNs. For this operation, EATSEP relies on a CSMA-based random access scheme. To avoid announcement collisions from multiple CHs, our EATSEP faithfully relies on a CSMA-based random access technique. Once the SNs receive the announcement, they figure out the cluster they belong to. If an SN receives an announcement from a single CH, it automatically becomes a member of that cluster. But, if an SN receives an announcement from multiple CHs, the cluster selection is performed based on the strength of the announcement signal from CHs to the SNs. The CH with the highest signal strength will be selected among the announcement received from multiple CHs.

3.4.3. *Schedule creation phase*

The CHs assign the time according to the reactive routing protocol during which the nodes can send data to the CHs.

3.4.4. *Steady-State Phase*

In this phase, SNs begin sensing and transmitting data to their concerned CHs. The CHs also aggregate data from the within-cluster SNs before sending these data to the BS. The nodes keep sensing the environmental parameters but don't transmit the data to the cluster heads. Whenever a node sense-data beyond the hard threshold value, it transmits the data to the CH. The next sensed data will only be transmitted to the base CH if it exceeds the hard threshold value or the difference between the previous data and the present exceeds the short threshold value. Thus, it saves energy. Then the CHs aggregates the data and sends it to the BS. Here, if the distance between the BS and CH is less, free-space data transmission will occur. If the distance is large, then multipath data transmission will take place among the CHs. Thus, it reduces energy consumption by avoiding long-distance data transmission, which consumes more energy than short-distance transmission.

4. Simulation and Results

In this section, we demonstrated different parts concerning implementation through simulation and evaluated its effectiveness. In the beginning, EATSEP is implemented through simulation using the MATLAB simulation tool. To evaluate the performance of our proposed approach, LEACH, SEP, and TSEP routing protocols are additionally simulated using the same software. Some well-known, relevant performance metrics are considered to compare the effectiveness of our proposed EATSEP. A brief overview of the performance metrics and the network parameters are described in Section 4.1.

4.1. *Simulation setup and performance metrics*

In this research, we consider 100 m ×100 m WSNs, with a BS node deployment scenario at the center of the WSNs fields. The SNs deployment scenario is illustrated in Fig. 1. The parameters used for the simulation of our proposed protocol are summarized in Table 2.

Table 2. Network parameters used in the simulation.

Parameters	Value
The network size	100×100 $meter$
Location of the BS	$(x = 50, y = 50)$
Number of SNs, n	100
Data Packet Size	4000 $bits$
Initial Energy of Nodes, (E_0)	0.5 joule
Transmitter/Receiver Electronics, (E_{elec})	50 nj/bit
Data Aggregation Energy, (E_{DA})	5 nj/bit
Transmit Amplifier, $\in_{fs}$, if $d_{toBS} \leq d_0$	10 $pj/bit/m^2$
Transmit Amplifier, $\in_{mp}$, if $d_{toBS} > d_0$	0.0013 $pj/bit/m^4$

Three performance evaluation metrics are used; namely, network stability which indicates the lifetime of the network before the death of the first sensor node; network lifetime, which indicates the entire lifetime of the network till the death of the last sensor node; network remaining energy which indicates the network residual energy after each round of the clustering protocol; and cumulative network throughput which indicates the cumulative number of packets reached the BS.

4.2. ***Simulation results***

Three different simulation results are shown in these subsections under the following three heterogeneity settings:

- Setting-1: $m = 0.1, b = 0.2, \alpha = 1$
- Setting-2: $m = 0.1, b = 0.2, \alpha = 2$
- Setting-3: $m = 0.1, b = 0.2, \alpha = 3$

In every setting, 10%, 20%, and 70% of the total deployed SNs are advanced, intermediate, and normal SNs, respectively. The energy distribution on every SNs is initialized according to the assumption discussed in Section 3.2. Although the different level of heterogeneity is added to the protocols, the network's total energy is the same for all the protocols under any particular settings.

4.2.1. *Network stability and lifetime*

In Fig. 3, the survival of the nodes is shown in different rounds under et energy in the network is depleted in performing diverse network activities. The proposed approach utilizes the total residual energy in the network and CH probability in the clustering phases to help the network in sustaining for the higher rounds.

Fig. 3a illustrates the number of alive SNs in different rounds to showcase the network stability (FND) and network lifetime. It is revealed that the SNs can be deployed close to each other. Thus, adjacent SNs have the possibility to sense and record identical data. Hence, the death of a single or multiple SNs which are close to each other does not automatically diminish the QoS of the deployed network [12]. We evaluated the network lifetime with the following network lifetime metrics found in literature [24,25]: Half of the SNs dies (HND)- realize an estimated value for the half-life period of a WSNs; the Last node dies (LND)-indicates the overall lifetime of the WSNs. In this study, additionally, we considered the network lifetime metric, NND -number of rounds until the death of 90 % of the total SNs, for better illustration of the network lifetime of our proposed protocol.

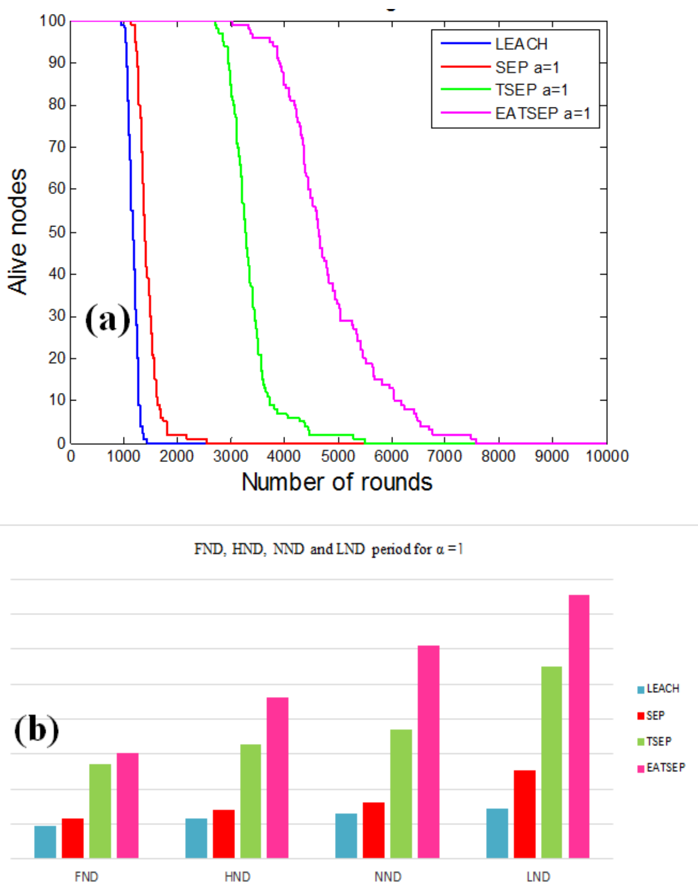

Fig. 3. Network lifetime.

Fig. 3b illustrates the network stability (FND) and network lifetime (HND, NND, LND) in detail. It is seen that the network stability is maintained for 950, 1148, 2708, and 3032 rounds in LEACH, SEP, TSEP, and EATSEP protocol, respectively. So, our proposed EATSEP protocol moderately improves the network stability concerning other protocols (68.67 % from LEACH, 62.14 % from SEP, and 10.69 % from TSEP). The results demonstrate the competence of the proposed protocol in making the network more stable and efficient. Thus, the energy dissipation is more optimized in the EATSEP protocol over other considered protocols.

It is also observed from Fig. 3b that the network lifetime of our EATSEP in terms of HND, NND, and LND has significantly increased. For example, the improvement of the network lifetime of our proposed approach (EATSEP) in terms of LND is 80.81 % from LEACH, 66.41 % from SEP, and 27.06 % from TSEP. Thus, we can say that under our proposed protocol, more SNs survive than the other considered protocols at the same time. Hence, the EATSEP protocol has prolonged the network stability and lifetime. Fig. 3 illustrates the performance analysis comparison in terms of FND, HND, NND, and LND of LEACH, SEP, TSEP, and EATSEP protocols for Setting-1, Setting-2, and Setting-3. It is seen from Table 3 that the higher the initial energy level in advance and intermediate sensor node, the higher the network lifetime.

Table 3. Network stability and lifetime analysis of LEACH, SEP, TSEP, EATSEP under different settings.

Protocols	$Setting-1$				$Setting-2$				$Setting-3$			
	FND	HND	NND	LND	FND	HND	NND	LND	FND	HND	NND	LND
LEACH	950	1163	1288	1451	1328	1505	1676	1862	1370	1626	1866	2063
SEP	1148	1399	1627	2540	1331	1578	1820	4299	1402	1760	2064	5288
TSEP	2708	3261	3713	5515	2921	3564	5175	9933	3055	3626	6529	10005
EATSEP	3032	4632	6092	7561	3080	4528	7571	11320	3574	4530	8737	13860

4.2.2. *Energy consumption analysis*

Energy is consumed in a wireless sensor network in a number of ways. Such as advertising the neighbor nodes, aggregating data, transmitting data. A routing protocol always tries to design a protocol in a manner that consumes as little energy as possible. In the proposed protocol, energy dissipation is optimized. Long-distance data transmission is excluded from the protocol as long-distance data transmission requires more energy than short-distance transmission. When the distance between the cluster head and the base station is short, free-space data transmission has taken place. If the distance is large, then multipath data transmission has taken place. Fig. 4 shows the energy consumption in terms of average residual energy of each sensor node for Setting-1, Setting-2, and Setting-3. From these Figs., it can be seen that the average residual energy of each sensor node under EATSEP is higher than other protocols under any considered settings. As the heterogeneous SNs' energy increases, the network survives a longer period, and energy is also dissipated in that manner. As the energy in the heterogeneous SNs still remains after the death of the normal SNs the network lifetime enlarges. So, the residual energy of the EATSEP based network under Setting-3 lasts a longer period than under Setting-1 and Setting-2.

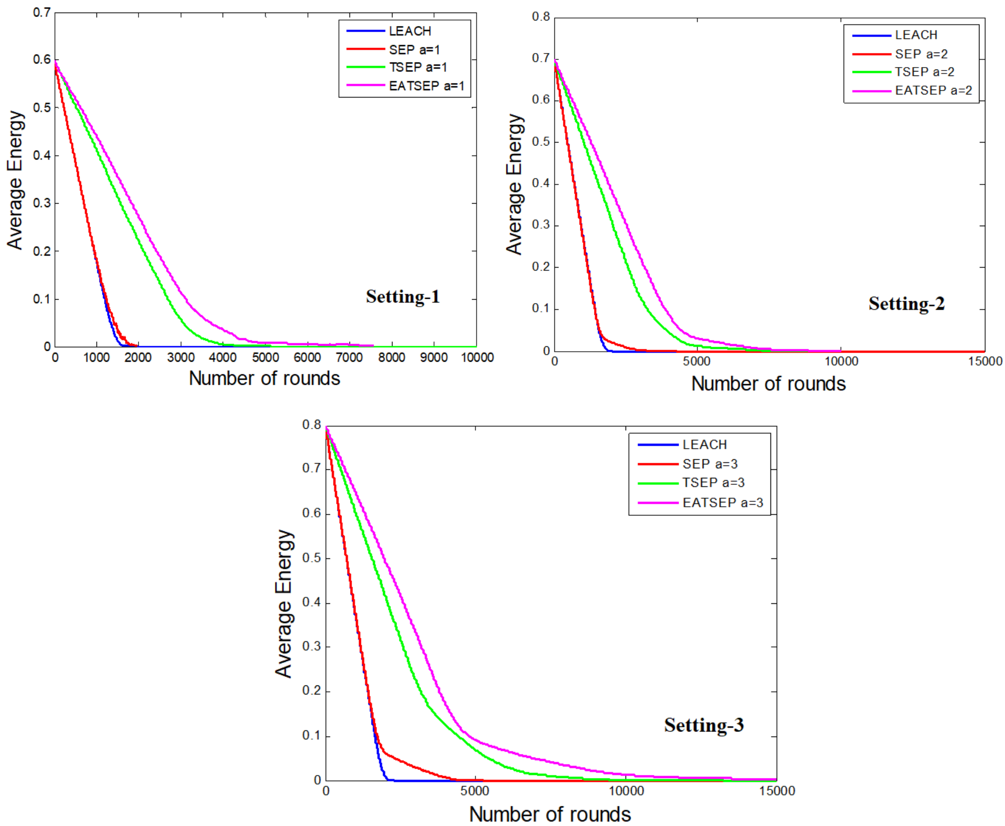

Fig. 4. Energy consumption analysis.

4.2.3. *Throughput analysis*

Fig. 5 shows the number of packets that reached the BS during the network lifetime under Setting-1. It can be easily noticed that the network with our proposed protocol has the largest throughput compared to the other routing protocols. Numerically we can say that the network throughput is 15010, 24740, 34820, and 63150 packets for LEACH, SEP, TSEP, and EATSEP, respectively. Statistically, it can be concluded that our proposed EATSEP protocol sends 76.23 %, 60.76 %, and 44.86 % more packets to BS than LEACH, SEP, and TSEP protocols, respectively.

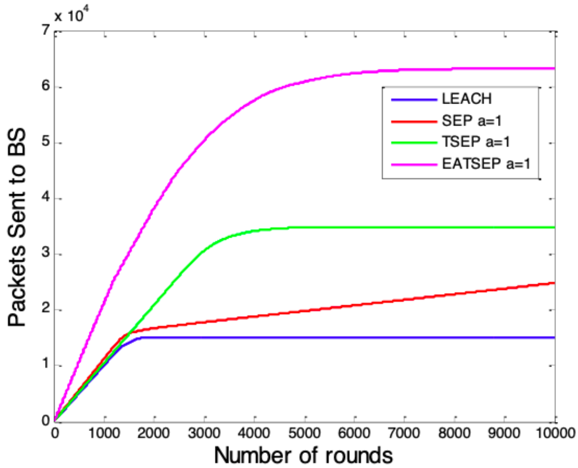

Fig. 5. Throughput.

Table 4 illustrated the performance analysis comparison of LEACH, SEP, TSEP, and EATSEP protocols in network throughput for Setting-1, Setting-2, and Setting-3. It can be concluded from Table 4 that the EATSEP protocol illustrates increased network throughput under every considered setting.

Table 4. Network Throughput Analysis of LEACH, SEP, TSEP, and EATSEP protocols under different settings.

Protocols	$Setting-1$	$Setting-2$	$Setting-3$
LEACH	1.501×10^4	1.751×10^4	1.951×10^4
SEP	2.478×10^4	3.331×10^4	3.922×10^4
TSEP	3.482×10^4	4.361×10^4	5.458×10^4
EATSEP	6.315×10^4	9.072×10^4	12.520×10^4

5. Conclusion

In this paper, a new routing protocol called EATSEP is proposed where SNs with three different levels of energies. For electing the most efficient sensor node as CHs, our proposed EATSEP uses the probability model, which utilizes the residual energy of the SNs. The threshold equation is also optimized depending on the residual energy of the SNs. The performance of the proposed EATSEP protocol is compared with the performance of the LEACH, SEP, and TSEP protocols. The results are compared in terms of network stability (FND), network lifetime (HND, NND, and LND), energy consumption, and network throughput. The simulation results show that the above performance metrics shown are better for the proposed protocol than the other considered protocols. So, it can be concluded that EATSEP is a more effective energy-efficient WSN routing protocol than the LEACH, SEP, and TSEP protocols under some network settings.

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