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EAGBRP: A Gateway Based Routing Protocol for Heterogeneous Wireless Sensor Networks

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Abstract

In most of the cluster-based routing protocols for wireless sensor networks (WSNs), cluster heads (CHs) are selected from the normal sensors which may expire rapidly due to fast energy diminution for such an additional workload. As a consequence, the network lifetime of such cluster-based routing protocol reduces drastically. To resolve these constraints, in this study, we proposed a gateway-based routing protocol-namely Energy-Aware Gateway Based Routing Protocol (EAGBRP) for WSNs. In our proposed protocol, the deployed sensor nodes of a WSN were divided into five logical regions based on their location in the sensing field. The base station (BS) was installed out of the sensing area, and two gateway nodes were inaugurated at two predefined regions of the sensing area. The CH in each region is independent of the other regions and selected based on a weighted election probability. We implemented our proposed routing protocol through simulations. To evaluate the performance of our EAGBRP, we simulated SEP, M-GEAR, and MGBEHA (4GW) protocols. The network lifetime, throughput, and residual energy parameters are utilized for performance analysis. It is revealed from the performance analysis results that WSNs with EAGBRP achieve maximum network lifetime and throughput over other considered protocols with minimum energy consumption.

Keywords: Wireless sensor network; Gateway; Network lifetime; Throughput; Routing protocol.

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1. Introduction

WSNs consist of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion, or pollutants [1,2]. The motivation behind the development of WSNs was military applications for instance battlefield surveillance. Nowadays, they are used in many

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civilian and industrial application areas, to name a few industrial processes monitoring and control, machine, health monitoring, environment, and habitat monitoring, healthcare applications, home automation, and traffic control [3]. Generally, they are networks of tiny and cheap application-centric electronic devices called sensor nodes with onboard sensing, processing, and communicating capabilities connected to other nodes via radio transceiver or other wireless communications devices such as infrared and optical media, a small microcontroller, and an energy source, usually a battery [4]. The size of a node may vary from a shoebox down to the size of a grain of dust. Similarly, the cost of a sensor node also varies, ranging from hundreds of dollars to a few pennies, depending on the size of the sensor network and the complexity required of individual sensor nodes.

Nowadays, the advancements in VLSI and Micro-Electro-Mechanical System (MEMS) technology are escalating, which made it is possible to set up thousands or millions of sensor nodes within a small area. The sensor nodes usually sense the environment and collect information of certain phenomena, subsequently, they process, aggregate and compress data to be transmitted to the BS [5]. Information carrying data can be sent to the BS in single-hop or multi-hop approach [6]. In single-hop approach, a sensor node communicates directly with the BS to send data. In this approach, more energy consumption occurred due to long range communication since the energy consumption in sensor nodes' communication dominated over other task. Therefore, the network lifetime of such network is low. On the other hand, in multi-hop approach, packet routing strategy is utilized. The sensor nodes send data packets to the nearest hop and process continues till it reaches the BS. Thus, in this approach, short range communication is used. It is noted that, the network protocol with multi-hop approach has larger overhead than single-hop approach. Since last decades, clustering protocols for WSNs are emerged as strategies to tackle the routing issues in WSN as they offer low energy consumption and prolong the network lifetime [7]. The formation of clusters in the network in rounds is the basic idea behind the clustering approach. Typically, a cluster consists of CH and member sensor nodes. Member nodes within a particular cluster collect measurement data of the environment and then send them to their CH. Then, CHs aggregate, and send the aggregated data to the BS. New clusters are formed with new CHs during the next round. In this way, the limitations of single-hop protocols are eliminated. Low-energy adaptive clustering hierarchy (LEACH) [8] is a widely accepted cluster-based routing protocol.

Cluster based routing protocols for WSNs can be categorized into homogeneous and heterogeneous networks. The sensor nodes in homogeneous networks are identical in terms of their initial energy storage, structure, design, etc., whereas, in the heterogeneous networks, sensor nodes are different in energy load, structure, hardware, etc. However, heterogeneous WSN are more realistic than homogeneous WSN especially in energy storage, as some nodes may have active sensing areas than others which is then reflected in the heterogeneity in energy storage [5]. A typical example of classical heterogeneous WSN includes stable election protocol (SEP) [9], weighted election protocols (WEP) [10].

In homogeneous settings, CHs are selected from the normal sensors which may expire rapidly due to fast energy discharge for such an additional workload thereby reduce the overall network lifetime. On the other hand, in the heterogeneous settings, CHs are selected from the advanced nodes which are usually equipped with additional energy. These settings may moderately prolong the network life time which is often not efficient in some applications. To prolong the network lifetime of a cluster based WSNs significantly, nowadays, researchers often use some extraordinary nodes of which are equipped with excessive energy and has wider communication coverage area than the traditional sensor nodes. Gateway Based Multi-Hop Distributed Energy Efficient Clustering Protocol (G-DEEC) [11], gateway-based energy-aware multi-hop routing protocol (M-GEAR) [12], Multi-Gateway-Based Energy Holes Avoidance Routing Protocol [13] are examples of such cluster and gateway-based routing protocols for WSNs.

The contribution of this paper is to propose a gateway-based energy efficient routing protocol for WSNs, namely, EAGBRP. Under our proposed EAGBRP, the sensor nodes are distributed into five logical regions in the sensing field. Two gateway nodes are placed at two predefined regions of the sensing field, whereas, the BS are installed at a predefined place which is out of the sensing field. The CH in each region which are independent of the other region. These CHs are selected based on a weighted election probability. We have implemented our EAGBRP and the results are compared using simulation.

The paper is organized as follows: Section 2 surveys number of researches in this field. Section 3 states the network model and methodology of our EAGBRP. Simulation settings, results of performance analysis are introduced in Section 4. Section 5 concludes the paper, and provides some ideas for future works

2. Related Works

Energy conservation in WSN is important for prolonging the network lifetime of resource-constrained nodes in the network [5]. The network lifetime can be defined as the time instant at which any sensor nodes fully consumed its energy [14], or the time beyond which a certain fraction of alive nodes remains in the network [15], or the time at which all nodes in the network die [16]. Designing energy-efficient cluster-based routing algorithms seem to be the most efficient method for prolonging the network lifetime of a typical WSNs [17].

The process of partitioning the network into groups is known as clustering, and it has been proven to prolong the longevity of the network and provide the required scalability [8,18]. LEACH [8], SEP [9], Hybrid Energy-Efficient Distributed (HEED) [19] are a few popular clustering-based routing protocols which got a great acceptance in many applications. Nadeem *et al*. proposed Quadrature-LEACH (Q-LEACH) for homogenous networks [20]. This scheme maximizes the throughput, lifetime of the network significantly. Later, Yadav *et al*. proposed a fuzzy logic-based improved clustering algorithm [21], which maximized the life-cycle of the network. This algorithm separated the network into clusters based on energy level, distant from CH, and crowdedness. If the scale of the cluster was greater than the threshold value, the cluster was divided into sub-clusters. Then the CH was selected based on the fuzzy logic method. Karim *et al.* raised a Location-aware and Fault-Tolerant Clustering Protocol [22] for Mobile WSN (LFCP-MWSN) to optimize energy consumption and reduce the end-to-end transmission delay. A Fault-tolerant mechanism was combined with the routing protocols to identify failures of data links and sensor nodes.

In the clustering techniques, clustering protocols allow prolonging network lifetime by evenly and repeatedly distribute energy consumption among CHs and within clusters by performing data aggregation and fusion. But normal nodes are often selected as CHs which may expire rapidly due to fast energy dissipations to aggregate data from member sensor nodes within cluster, and send the aggregated data to the BS.

To overcome this key limitation of clustering approaches where CHs are selected from the normal sensor nodes, the use of some extraordinary nodes called gateways or relay nodes were introduced in [4,12,13], which are equipped with superfluous energy and larger communication range than the normal sensor nodes. Nadeem *et al*. presented such a gateway-based multi-hop energy-aware routing protocol (M-GEAR) [12] to optimize energy consumption and network lifetime. The sensor nodes in M-GEAR were divided into four logical areas according to their location. The BS was installed out of the sensing area, while a gateway node was installed in the sensing area center. Finally, the node communication mode was selected based on whether two equal regions were beyond the threshold distance. It was a multi-hop routing protocol which improve network lifetime, residual energy, and throughput. Sheenam *et al*. proposed another gateway-based protocol called G-DEEC [4] in a heterogeneous sensor network. In G-DEEC, rechargeable and stationary gateway nodes were used, which are placed at the center, corners, and the middle of the sensor field. Although the number and position of gateway nodes facilitate the communication between each cluster head and the gateway nodes, the process of selection of the gateway nodes is not specified in the algorithm. Under this algorithm, a CH can transmit data to any gateway node. Rohini Sharma et al. proposed the Multi-Gateway-Based Energy Holes Avoidance Routing Protocol (MGBEHA) [13], which is a noble technique for the avoidance of energy hole near the sink region. This protocol has the provision of saving the energy of the nodes by decreasing the distance of transmission between the transmitter and the receiver. The BS here occupies the centermost position. The gateway nodes surround the BS. There are three main regions in this protocol. The first region called the BS region has the nodes which are closer to the BS; hence these nodes transmit directly to the BS. The second region called the gateway region has nodes in the vicinity of the gateway, hence these nodes also communicate directly with the gateway. The third region is called the cluster region, where the nodes are far away from both the BS and gateway forms cluster. The CH of each cluster is responsible for collecting the data from its sensors, aggregating and forwarding to the nearest gateway. The gateway node will then aggregate the data received from all its neighboring CH and its area sensors and forward it to the sink. Again, Qureshi *et al.* [23] proposed another gateway-based routing protocol called Gateway Clustering Energy-Efficient Centroid (GCEEC) for agriculture precision where CH is selected from the centroid position and gateway nodes are selected from each cluster. Gateway node reduces the data load from CHs and forwards the data towards the BS.

Thus, from the above discussion, it can be realized that gateway-based clustered routing protocols for WSN have a longer lifetime in general because of inclusion of superfluous energy equipped gateway nodes. Nevertheless, we believe that it is possible to improve some of these gateways based WSNs protocols in some specific sectors. For instance, it is observed that M-GEAR protocol has a lower network lifetime, throughput, and residual energy in particular network settings. At this situation, in this study, we attempt to resolve these issues of M-GEAR by introducing a new gateway-based WSNs protocol, namely Energy-Aware Gateway Based Routing Protocol (EAGBRP) of which is presented in details in the following sections.

3. Energy-Aware Gateway-Based Routing Protocol (EAGBRP)

Energy-aware gateway-based routing protocol (EAGBRP) is a geographical location based clustered heterogeneous routing protocol for WSNs. EAGBRP is an extension of M-GEAR. In M-GEAR, the sensor nodes are divided into four logical regions based on their location in the sensing field. The BS in M-GEAR is installed out of the sensing area and a gateway node is installed at the center of the sensing area. If the distance of a sensor node from BS or gateway is less than a predefined distance threshold, the node uses direct communication. The rest of the nodes were divided into two equal regions whose distance is beyond the threshold distance. These two regions use the clustering technique. The CHs are selected in each region are independent of the other region. EAGBRP is designed to improve the network lifetime and throughput of M-GEAR with minimum energy consumption, based on proper sectoring of sensor field, increment the number of gateway node, and the clustering hierarchy process using the characteristic parameters of heterogeneity, namely the fraction of advanced nodes (e) and the additional energy factor between advanced and normal nodes (α) as used in SEP. The network model and design methodology are described in the following subsections.

3.1. *Network model*

We assume that S sensors are randomly installed in an environmental monitoring field. Where the i-th sensor is represented with Si and the resulting $S = s_1, s_2, .., s_n$ sensor. We assume the network model is shown in Fig. 1, which has the following key features:

- The surveillance field is an area of two dimensions.
- Upon deployment, the sensors and BS are stationary.
- Two gateway nodes are deployed in the same network field at two predefined points.
- Gateway nodes are stationary after deployment and rechargeable.
- Heterogeneous sensor nodes with two levels of heterogeneity are used.
- Each sensor node is assigned with a distinctive identifier (ID).

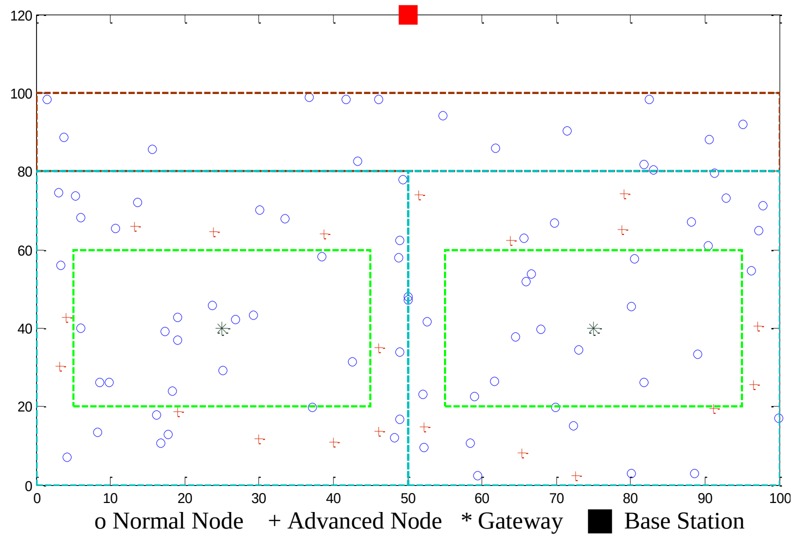


Fig. 1. Network model of EAGBRP.

The first order radio model [8,24] has been used while designing our EAGBRP. The dissipation of the energy of the sensor nodes for the transmission, reception, and collection of data reflects this pattern. The transmitter discharges more energy than the receiver, as the transmitter electronics and the amplifier take more energy. On the contrary, the only energy dissipation in the receiver is the electronic circuit, as shown in Fig. 2, where the energy required to transmit a *k*-bit data packet to distance *d* and receive a *k*-bit data packet is given as:

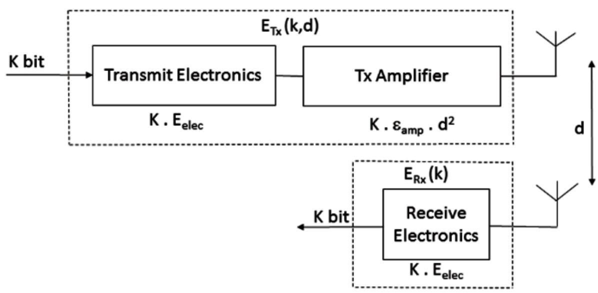


Fig. 2. First order radio model [20].

$$E_{Tx}(\mathrm{k,d}) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$

$$E_{Tx}(\mathrm{k,d}) = E_{elec} \times \mathrm{k} + E_{amp} \times \mathrm{k} \times d^2 \qquad (1)$$

$$E_{Rx}(\mathrm{k}) = E_{Tx-elec}(k) E_{Rx}(k) = E_{elec} \times \mathrm{k}$$

$$E_{Rx}(\mathrm{k}) = E_{elec} \times \mathrm{k} \qquad (2)$$

3.2. *Methodology*

The operation of EAGBRP is broken up into rounds, where each round begins with an initial phase followed by a setup phase, CH selection phase, scheduling, and steady-state phase. The initial phase, scheduling, and the steady-state phase of EAGBRP are the same as the M-GEAR. Detail discussion about those phases of M-GEAR can be found elsewhere [12].

3.2.1. *Setup phase*

In this subsection, the network field is divided into logical regions based on the location of the node in the network. BS divides the nodes into five different logical regions as shown in Fig. 3.

- Nodes in regions one, two and three use direct communication while region-1 transmits its data directly to BS as the distance of these nodes from BS is very short. Similarly, region-2 and region-3 transmit their data to their associated gateway nodes which aggregate data and forward to BS. These three regions are referred to as non-clustered regions.
- All the nodes away from the gateway node and BS are divided into two equal half regions, they are called clustered regions. In each clustered region sensor nodes organize themselves into small groups known as clusters.

3.2.2. *CH selection phase*

Our protocol provides an extra energy supply for a percentage of the population of sensor nodes, which is a source of heterogeneity. The nodes are deployed randomly across the sensing field. In the beginning, the BS split the network into regions. CHs are chosen separately in each region. The advanced nodes are more likely than the normal nodes to become CH. The weighted probabilities of initial energy p_{opt} are used to elect CH in the CH-region as like SEP protocol. This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. Let us define as p_{nrm} , the weighted election probability for normal nodes, and p_{adv} , the weighted election probability for the advanced nodes, where

$$p_{nrm} = p_{opt}/(1 + \alpha . e) \quad (3)$$

and, $p_{adv} = \frac{p_{opt}}{1+\alpha . e} \times (1 + \alpha)$ (4)

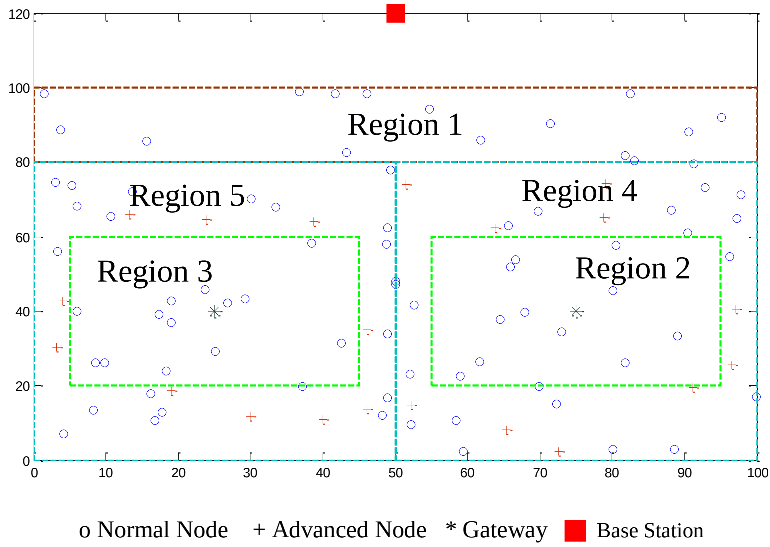


Fig. 3. Setup phase of EAGBRP.

For normal and advanced nodes, there are various threshold values. We define as $T(p_{nrm})$ the threshold for normal nodes, and $T(p_{adv})$ the threshold for advanced nodes. Thus, for normal nodes, we have:

$$T(S_{nrm}) = \begin{cases} \frac{P_{nrm}}{1-P_{nrm}\times\left(r\times mod\left(\frac{1}{P_{nrm}}\right)\right)}, & if\ S_{nrm} \in G' \\ 0, & otherwise \end{cases} \quad (5)$$

where r is the current round, G' is the set of normal nodes that have not become CHs within the last $1/p_{nrm}$ rounds of the epochs, and $T(p_{nrm})$ is the threshold for normal nodes in CH regions. Similarly, for advanced nodes, we have:

$$T(S_{adv}) = \begin{cases} \frac{P_{adv}}{1-P_{adv}\times\left(r\times mod\left(\frac{1}{P_{adv}}\right)\right)}, & if\ S_{adv} \in G'' \\ 0, & otherwise \end{cases} \quad (6)$$

where G'' is the set of advanced nodes that have not become CHs within the last$1/p_{adv}$ rounds of the epoch, and $T(p_{adv})$ is the threshold for advanced nodes in CH regions. CHs remind of their position to neighboring nodes after elected CHs in each region. Using a CSMA MAC protocol, CHs transmitted the control packet. When a control packet from CH has been received, the acknowledgement packet is transmitted from each node. The node who that find nearest CH becomes a member of that CH.

4. Performance Analysis of EAGBRP

Firstly, we implemented our proposed routing protocol-EAGBRP through simulation using MATLAB software [25]. In order to evaluate the performance of our proposed approach, secondly, we simulated SEP, M-GEAR, and MGBEHA (4GW) routing protocols using same software. We varied the heterogeneous parameter (α), and investigated the improvement of the of network lifetime, and throughput with each of the variations. Furthermore, we analyze the total energy utilization of the network. A brief overview about the stated performance parameters and the simulated network parameters are given in Section 4.1.

4.1. *Simulation metrics and settings*

In this subsection, we briefly introduce the following performance metrics by which we evaluate the performance of our proposed routing protocol for WSNs:

- *Network lifetime:* It is important to know when the first sensor node will die which indicates the stability period of typical WSNs. We denote it as one of the network lifetime metrics as *First node dies* (FND). Furthermore, sensors can be deployed in close proximity to each other. Thus, adjacent sensors are therefore able to record similar or identical information. Hence, the loss of a single or multiple node does not automatically diminish the quality of service of the network [10]. Based on the definition of network lifetime found in [15, 16], we also evaluated the network lifetime with the following metrics: *Half of the nodes dies (HND)*- indicates an estimated value for the half-life period of a micro-sensor network; *Last node dies* (LND)-provides the overall lifetime of the WSNs. In this study, additionally, we considered the following two more metrics with FND, HND, and LND for better illustration of the network lifetime of our proposed protocol: *10 % ND*-number of rounds until the death of 10 % of the total sensor nodes, and *90 % ND*-number of rounds until the death of 90 % of the total nodes.
- *Throughput:* The number of packets received by BS is compared to the number of packets sent through the nodes in each round to determine the performance of throughput.
- *Residual Energy:* In order to evaluate the energy consumption of nodes at each round, the residual battery energy of the network is considered. Residual energy ensures the graceful degradation of network life. Table 1 shows the parameter settings used in the simulation.

Table 1. Network parameters used in the simulation.

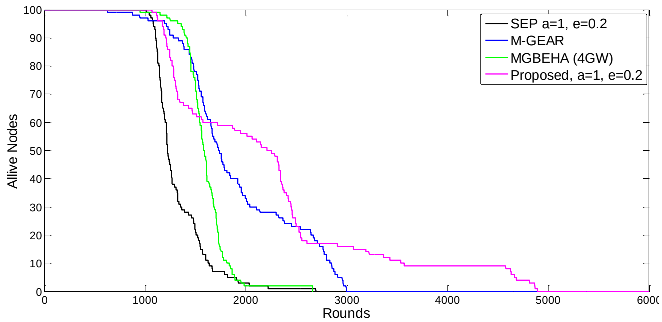
Parameters	Value
The network size	100×100 meter
Location of the BS (SEP, EAGBRP)	(x=50, y=120)
Location of the gateway pairs	(x=25, y=40), (x=75, y=40)
Number of nodes	100
The initial energy of normal nodes (SEP, EAGBRP)	0.5 joule
The initial energy of nodes (M-GEAR, MGBEHA)	0.6 joule
Data packet length	4000 bits
Transmitter/Receiver Electronics (E_{elec})	50 nj/bit
Aggregation energy, E_{DA}	5 nj/bit
Transmit amplifier, ϵ_{fs}, if $d_{toBS} \leq d_0$	10pj/bit/m^2
Transmit amplifier, ϵ_{mp}, if $d_{toBS} \geq d_0$	0.0013 pj/bit/m^2

4.2. *Simulation results*

Three different simulation results are shown in these subsections under two heterogeneity settings: e=0.2 and α=1, and e=0.2 and α=2.

4.2.1. *Network lifetime*

Fig. 4 shows the simulation result of the network lifetime analysis of a typical WSN for the case of e=0.2 and α=1. Although, it can be seen from Fig. 4 (above) that the network lifetime of our proposed approach in terms of FND is moderately improved with respect to other protocols (5.23 % from SEP, 41.58 % from M-GEAR, and 11.4 % from MGBEHA 4GW) but the network lifetime of our EAGBRP in terms of HND, 90 %ND, and LND has significantly increased (see Fig. 4 (below)). For example, the improvement of the networks lifetime of our proposed approach (EAGBRP) in terms of 90%ND is 54.11 % from SEP, 20.12 % from M-GEAR, and 48.9 % from MGBEHA (4GW). The reason can be explaining as the weighted probability of electing CHs is proportion to initial energy of the nodes and the inclusion of extraordinary nodes called gateways or relay nodes, which are equipped with superfluous energy and larger communication range than the normal nodes.



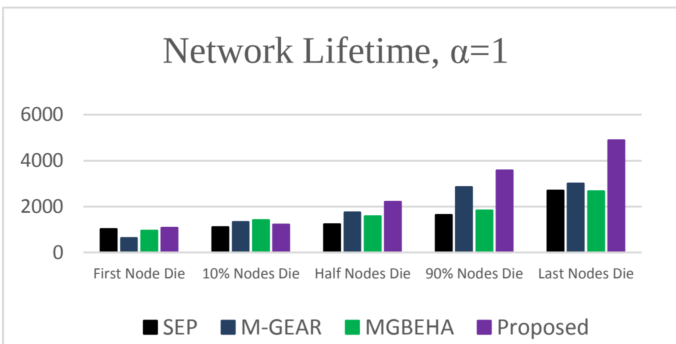
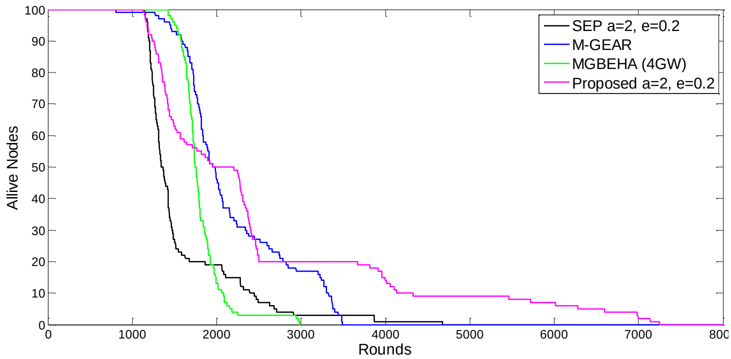


Fig. 4. Network lifetime comparison among SEP, M-GEAR, MGBEHA, and EAGBRP (proposed) for α=1 and e=0.2.

From Fig. 5, it is also observed the network lifetime with higher energy settings (e=0.2 & α=2). Although MGBEHA (4GW) and SEP achieved a better life time in terms of FND over our proposed approach, but the network lifetime in terms of HND, 90 % ND, LND are remarkably increased. For example, the networks lifetime of our proposed approach (EAGBRP) is increased in terms of LND by 35.45 % from SEP, 51.7 % from M-GEAR, and 58.72 % from MGBEHA (4GW) (see Fig. 5 (below)).



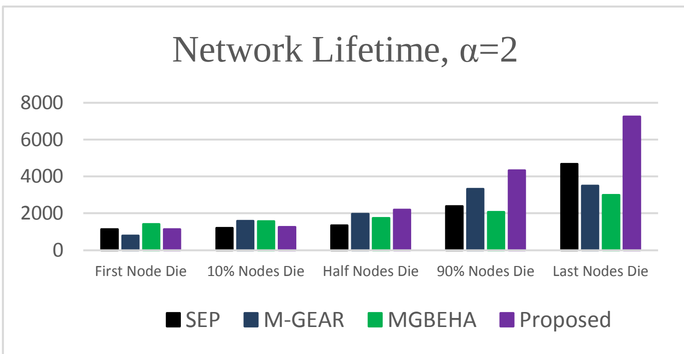
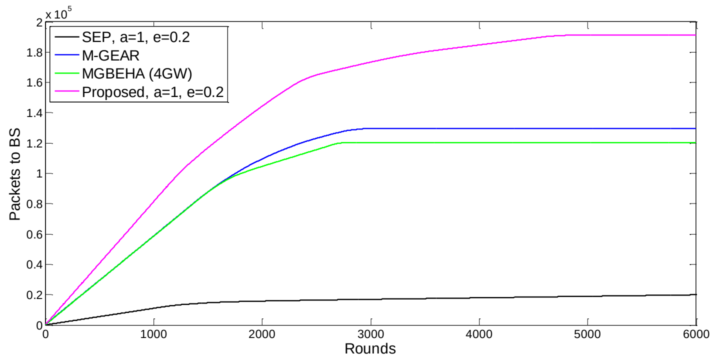


Fig. 5. Network lifetime comparison among SEP, M-GEAR, MGBEHA (4GW), and EAGBRP (proposed) for α=2 and e=0.2.

Since the nodes have limited energy and it is used during the course of network operation. Certain energy is reduced whenever a node transmits or receives data and whenever it performs data fusion. Once a node runs out of its energy, it is considered to be dead and it can no longer transmit or receive any data. The simulation ends when all the nodes in the network run out of their energy. High energy efficiency means low energy consumption and long stability period of the micro-sensor network. From the above Figs. we can found that the lifetime (in round) increases in EAGBRP. It is because of energy consumption is well distributed among nodes. Furthermore, the network is divided into logical regions and two of them are further subdivided into clusters. Sensor nodes near gateway nodes send their data directly to the gateway nodes, similarly, nodes near BS transmit data directly to BS. Sensor nodes in both regions consume less transmission energy therefore, nodes stay alive for a longer period. Besides, the presence of advanced node and weighted election probability for CHs also ensure the increment of a network lifetime.

4.3. *Throughput*

Average packets sent to BS are assessed through extensive simulations. Simulation results of the EAGBRP protocol illustrate increased throughput. Interval plots of EAGBRP, SEP, M-GEAR and MGBEHA (4GW) protocols in Fig. 6 clearly depict the performance of these protocols in terms of throughput. To calculate throughput, we assume that CHs can communicate freely with the gateway nodes. Simulation results show an increased throughput than the other protocols presented at this research.



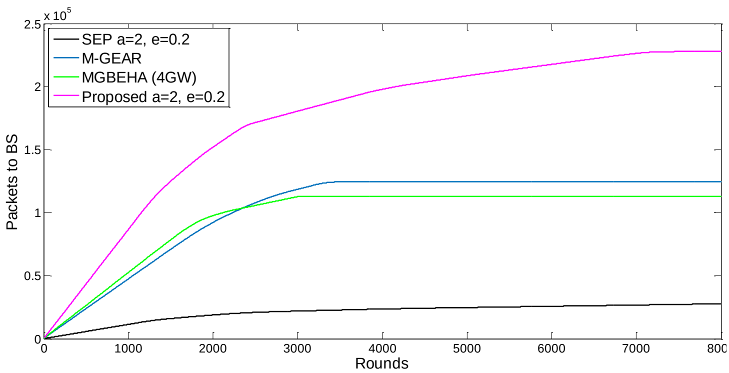


Fig. 6. Throughput comparison among SEP, M-GEAR, MGBEHA (4GW), and EAGBRP (proposed) (above) for α=1 and e=0.2, (below) for α =2 and e=0.2.

Specifically, it is seen from the Fig. 6 (above) where α=1 & e=0.2, our proposed protocol sends a much larger number of packets to BS, that is 88.2 %, 31.58 %, and 36.84 % more packet than SEP, M-GEAR, and MGBEHA (4GW) protocols, respectively. Similarly, Fig. 6 (below), where α=2 & e=0.2 shows that our proposed protocol also performs well with a higher power, provides 89.15 %, 42.22 %, and 49.9 % more throughput than SEP, M-GEAR, and MGBEHA (4GW) protocol, respectively. As a consequence, our proposed protocol produces a higher throughput.

4.4. ***Residual energy***

Fig. 7 shows the average residual energy of the network per round. We assume that a normal node has 0.5 joule energy whereas an advanced node has α times more energy. when α=1 and e=0.2, the total energy of the 100-node network is 60 joules for EAGBRP and SEP protocol since both of them are used heterogeneous nodes. Whereas, each sensor node of M-GEAR, and MGBEHA (4GW) protocols has 0.6 joule energy, hence a total of 60 joules for 100 nodes. In case of α=2 & e=0.2, the network of 100-node SEP, M-GEAR, MGBEHA (4GW), and EAGBRP protocols equipped with 70 joules. In both cases, EAGBRP yields minimum energy consumption over SEP, M-GEAR, and MGBEHA protocols which are depicted in Fig. 7. It was possible due to use of gateways, which are equipped with superfluous energy and larger communication range than the normal nodes. Deployment of such gateway nodes were at the appropriate positions, the presence of advanced node, and weighted election probability for CHs selection ensure the minimum energy consumption in our proposed routing protocols of WSNs.

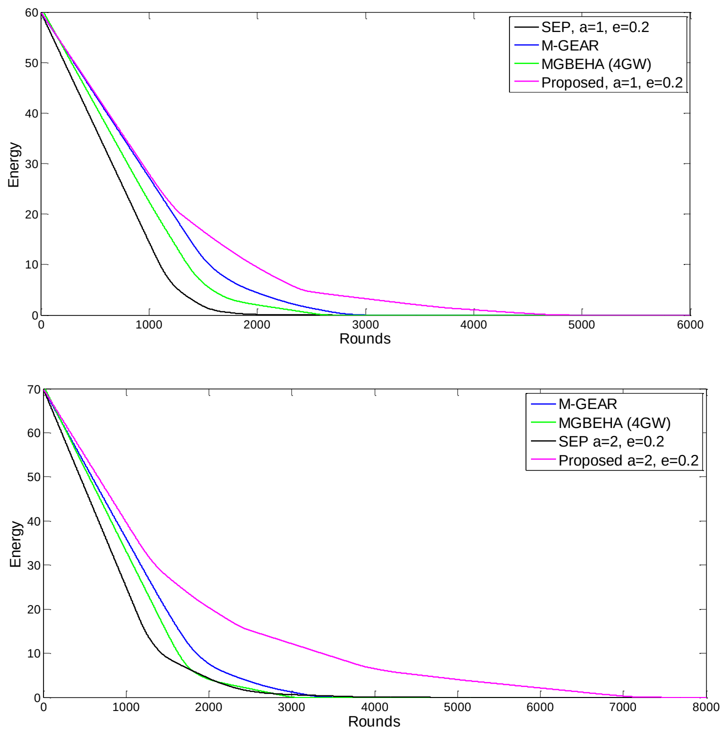


Fig. 7. Residual energy comparison among SEP, M-GEAR, MGBEHA (4GW), and EAGBRP (proposed) (above) for α=1 and *e*=0.2 (below) for α=2 and *e*=0.2.

2. Conclusion

In this paper, an energy efficient gateway-based clustered routing protocol, called-EAGBRP is proposed and compared its performance with M-GEAR, MGBEHA (4GW), and SEP protocols. In this study, the parameters considered to evaluate the performance of our EAGBRP are network lifetime, throughput, and energy consumption. It is seen from the performance analysis result that our proposed approach gently improves the network lifetime and throughput from other considered protocols with minimum energy consumption under some unique network settings which is crucial for some specific applications. Therefore, it can be concluded that our proposed protocol provides energy efficient routing that ensures longer lifetime of WSNs.

This paper reveals many aspects and challenges for future works. First, in this study uniform distribution of sensor nodes are considered. However, other sensor node distributions such as normal and exponential distributions can be utilized. Second, multiple BS usually can be used to prolong the WSN lifetime. Moreover, the impact of the locations of these BS are important to investigate whether they are inside, outside or a mixed configuration in the network. We leave this for our future research.

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