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A MODIFIED ZONAL STABLE ELECTION PROTOCOL FOR ENERGY EFFICIENCY IN HETEROGENEOUS WIRELESS SENSOR NETWORKS

Yakubu Abdul-Wahab Nawusu [1,*], Alhassan Abdul-Barik[2], Diyawu Mumin[1], Abukari Abdul Aziz Danaa[1]

[1] *Department of Computer Science, Tamale Technical University, Tamale, Ghana,*
[2] *Department of Computer Science, University for Development Studies, Tamale, Ghana.*

ABSTRACT

A wireless sensor network (WSN) comprises a large collection of spatially distributed and self-regulating tiny sensors that provide monitoring and reporting services in many commercials and home applications. A bane to the continuous function of this system is primarily due to its reliance on short-lived battery-powered sensor nodes. To minimize the energy dissipation of sensors, many routing protocols have appeared. The Zonal Stable Election Protocol (Z-SEP) is one of the popular protocols designed to improve the energy efficiency of heterogeneous wireless sensor networks. However, the protocol has a poor stability period and low throughput resulting in fewer packets delivered to the base station. This paper proposes a modification to the Z-SEP protocol, by further dividing the sensing region into four parts and allowing cluster heads to be selected from amongst the normal nodes to transmit data to the base station unlike in Z-SEP in which normal nodes send packets directly to the base station. The cluster head election criterion has been modified also to include both residual energy and node density. Based on simulation results from MATLAB, the performance of the proposed protocol is better than LEACH, SEP, and Z-SEP in stability, throughput, and network lifetime.

KEYWORDS: Stability, Network Lifetime, Throughput, SEP, Z-SEP

1. INTRODUCTION

Computing technologies and micro sensing has come a long way propelled largely by the urge of human beings to deal with the various computational and technological challenges (Bagula et al., 2016; Ismail, Bagula, et al., 2018; Ismail, Tuyishimire, et al., 2018; Tuyishimire et al., 2016). Many domestic and industrial applications are pervaded with smart agents that communicate wirelessly to achieve various goals for users. The complexities of such communication models, therefore, become even more real necessitating the need for research on better performance.

Wireless sensor network (WSN) research has come alive in the fields of computer science, mathematics, and technology in response. A WSN comprises a system of large numbers of spatially distributed, self-regulating, and cheap battery-powered tiny sensors. It has been used in many environments to provide critical services and outcomes. WSNs from inception have been helpful in monitoring and reporting on physical and environmental conditions such as traffic control, plant growth, water level and quality, animal tracking, the strength of buildings, target tracing in warfare matters, and recognizance efforts in healthcare provision centres. Recently drones and robots are embedded with microsensors to perform various tasks (Las Fargeas et al., 2015; Tuyishimire et al., 2016).

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[*] *Corresponding Author, Email: nabdul-wahab @tatu.edu.gh*

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The mechanical parts of a sensor node are sensors for sensing required environmental attributes; a processor for minimal data computation and storage; a radiofrequency transceiver for data reception and transmission to a human source; and a battery unit to provide energy to run the sensor (Nawusu et al., 2020). Mobility and energy-harvesting devices have been attached to sensors recently to boost the energy reserve of sensor nodes (Adu-Manu et al., 2018; Nawusu et al., 2022). Typically, sensors are deployed into a target environment manually or with the aid of a propelling mechanism either in a planned or random manner (Yuvaraj & Manimozhi, 2017). Sensors monitor, sense, and transmit data to a target base station (BS) autonomously after placement. Transmission could take place directly from individual nodes or through intermediary nodes. Some protocols will first construct clusters and then select a cluster head from among the cluster members to receive, aggregate, and send the unified data to the base station in a single hop or multiple hops via other cluster heads (Cengiz & Dag, 2017).

The overarching bottleneck of WSN stems from its low power source. Sensors, as of now, are mainly powered by batteries, which offer limited energy. Many times, because these sensors are not rechargeable or difficult to replace when deployed in hazardous terrains, the battery resources run out quickly as it performs tasks such as sensing, data processing, and communication to a safer destination for further analysis (Nawusu et al., 2022). John et al. (2016) have observed that sensor nodes consume the highest energy when it is communicating. Energy conservation approaches such as forming clusters, fusing data, better deployment strategies, and hierarchical cluster-based protocols have come up in literature to reduce the energy consumption of sensor nodes and extend the lifespan of WSNs (Jibreel et al., 2022).

In homogenous cluster-based routing protocols, the Low Energy Adaptive Clustering Hierarchy (LEACH) is the benchmark and was developed to achieve efficient energy use among sensor nodes. However, LEACH cluster head selection is random and does not ensure optimal selection of cluster heads. Again, LEACH performs poorly in a heterogeneous sensing environment. To achieve a prolonged sensing life of WSN, the Stable Election Protocol (SEP) is proposed by Smaragdakis et al. (2004) with two levels of heterogeneity and with an optimal cluster head election. An extension of SEP appears in Zonal-Stable Election Protocol (Z-SEP) proposed by Faisal et al., (2013). ZSEP uses the direct communication model among normal nodes, which expends more energy for nodes placed far away. Clustering which is a technique to minimize energy consumption arising from long-distance communication is applied only on advanced nodes deployed at the lower and upper ends of the sensing field. Consequently, in both the SEP and Z-SEP, the network's stability is poor and makes the WSN unstable and unreliable after the first node dies.

In this paper, a modified version of the heterogeneous Z-SEP protocol is proposed, in which the sensing region is further divided into four parts to minimize the chance of uneven deployment of nodes within the central part of the sensing field. We also leverage the energy preservation benefit of clustering to form clusters amongst normal nodes and assign selected cluster heads to receive, aggregate, and transmit data to the base rather than by individual nodes, as is the case in Z-SEP. The proposed MZ-SEP protocol uses the residual energy and node density, which has not happened in Faisal et al. (2013), of both normal and advanced nodes as criteria to choose cluster heads in the four regions. The protocol, therefore, favours nodes with more remaining energy and high node density to become cluster heads. Multi-hop communication is carried out amongst normal nodes to reduce the energy loss due to long-distance communication of data to the base station. A simulation analysis of the performance of the MZ-SEP protocols shows it is better than similar protocols in terms of network lifetime, network stability, and the number of packet transmissions.

The remainder of the paper is as follows: Section 2 provides an overview of several relevant wireless sensor network techniques. Section 3 provides the suggested enhanced Z-SEP protocols in detail. Section 4 describes the simulation analysis and the outcomes of the new protocol utilizing important performance measures. Section 5 concludes the paper.

2. RELATED LITERATURE

This review of the literature will focus on easily accessible cluster-based routing methods for energy efficiency in wireless sensor networks.

WSN communication has traditionally been done directly, with sensor nodes transmitting data directly to the base station. This strategy is extremely energy inefficient since distant nodes must waste more energy to broadcast to the base station, which may be in a faraway location. Researchers recognized the importance of using intermediary nodes with the shortest route to the base station to transmit data. This configuration employs the idea of minimum transmission energy (MTE), which picks nodes that require the least amount of energy to transfer data to the base station (Shepard, 1996). However, random deployment of nodes may place many nodes closer to the base station causing them to invariably act as relay nodes for all transmission towards the base station. Such relay nodes will drain their energy the quickest. Also, because data aggregation is absent, similar data sensed by neighbouring nodes may be transmitted. At worst, sections of the sensing field may become unmonitored and cause a wrong interpretation to be made about the data coming from the environment. To deal with these issues present in both Direct Transmission (DT) and MTE, hierarchical routing techniques have gained prominence as the better schemes to offer energy efficiency in wireless sensor networks (Sabri & Al-Shqeerat, 2014).

In a hierarchical design, nodes are organized into cluster communities, with each cluster electing a cluster head. A cluster head's functions typically include receiving sensed data from its members, aggregating it, and forwarding it to the base station directly or via many stops in the case of distant cluster heads. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol proposed by Heinzelman et al. (2000) is the first of such hierarchical routing methods. LEACH prides itself on prudently utilizing the energy of a homogeneous WSN. It implements randomized and dynamic formulae to elect cluster heads, thus giving each sensor node equal chance to attain cluster headship role. Despite the LEACH protocols setting the pace for cluster-based routing protocols in WSN, its major limitation is that it is not suited for heterogeneous environments (Faisal et al., 2013).

Manjeshwar and Agrawal (2001) explained the homogenous protocol, called Threshold Sensitive Energy Efficient Sensor Network (TEEN), specifically for use in applications where time is a critical essence. TEEN inherits the same mechanisms used in LEACH to select cluster heads. However, TEEN introduces the so-called hard and soft threshold to reduce the rate of transmissions thereby causing some energy to be saved. The stability and network lifetime increase with the TEEN protocol.

The LEACH, though homogeneous in form, was set up and analysed in a heterogeneous manner by Sharma & Verma (2013). The resulting comparison revealed a starkly significant reduction in energy consumption and longer network life when LEACH is deployed heterogeneously. For both systems of LEACH, the residual energy of sensor nodes is not considered in choosing the cluster heads (CHs) hence the lifetime of the network is affected.

The LEACH protocol is modified by Mahboub et al. (2016) using a triangular zoning technique. The zoning technique partitions the sensing region in such a manner as to allow nodes closer to the base station to be chosen as cluster heads. The approach used by Mahboub et al. (2016) is executed on sensor nodes with the same energy levels at the start of the deployment – for homogenous nodes.

Another modified form of LEACH called Modified LEACH (MODLEACH) has appeared in the work conducted by Mahmood et al. (2013) and has subsequently been extended by Jibreel et al. (2020b) with heterogeneous characteristics in the Servant-LEACH (S-LEACH) protocol. The authors used three types of nodes – normal nodes, advanced nodes, and servant nodes. The normal and advanced nodes perform the same tasks as in MODLEACH. The third-level nodes, servant nodes, are solely assigned the task of data aggregation. Throughput is higher and network lifetime is longer in S-LEACH. The energy gap issue, however, remains unaddressed in S-LEACH, despite that it employs a multi-hop communication technique to limit the energy consumption of distant nodes. Qing et al. (2006) described the Distributed Energy Efficient Clustering (DEEC) algorithm. DEEC combines various levels of heterogeneity, with high-energy nodes being more likely than low-energy nodes to become cluster heads. In DEEC, cluster headship is determined by node residual energy as well as the average remaining energy of all alive nodes in the network during each round.

Smaragdakis et al. (2004) offer the stable election protocol (SEP) with two levels of heterogeneity for heterogeneous WSN. In addition to normal nodes, there is a percentage of nodes with added energy levels called advanced nodes. These two types of nodes in SEP are given weighted probabilities to ascend to cluster headship, but advanced nodes have an increased chance to become cluster heads than normal nodes. The stable region in SEP is poor especially when the base station is placed outside of the sensing field, and thus, does not promise efficient deployment of nodes.

Aderohunmu and Deng (2009) proposed a three-level heterogeneous WSN protocol. In addition to normal and advanced nodes, E-SEP introduces an intermediary node with energy capacity lying in between those of normal nodes and advanced nodes. Cluster heads are elected on basis of energy levels only. As such, E-SEP suffers the same drawback as the original SEP.

Faisal et al. (2013) attempted to deal with the challenges in the SEP protocol without using such costly gateway nodes in their Zonal Stable Election Protocol (Z-SEP). The sensing field in Z-SEP is partitioned into three sensing zones. Advanced nodes are deployed in zone 1 and zone 2 whereas, normal nodes are installed in zone 0 which lies in between zone 1 and zone 2. Data transmission is done directly from zone 0 to the base station while cluster heads selected from the advance nodes in zone 1 and zone 2 transmit data to the base station using an intermediary node closer to the base station. Approximately 80% of the nodes in Z-SEP are normal nodes with relatively minimal energy support. It is also these nodes that are designed to transmit to the base station directly. Distant normal nodes will likely die early due to the need to use more energy to convey packets to the BS. A large part of the central portion of the sensing field may be left unmonitored when most of the normal nodes die. A biased report may be delivered to the base station and consequently, a wrong conclusion may be drawn from the analysis of such data.

A new energy-aware hierarchical routing protocol modifying the Z-SEP protocol appears in the work conducted by Durgam & Sadiwala (2021) that prides itself on an efficient technique for key management to ensure its safe use in Internet of Things environments. The key management technique uses cryptosystems to speed up communication and provide security benefits as well. Communication is by direct mode for normal nodes and via cluster heads for advanced nodes. The threshold formula for selecting cluster heads incorporates only the residual energy of advanced nodes competing for cluster headship. The baseline protocol used to measure the strength of the protocol in the work of Durgam and Sadiwala (2021) is the Stable Election Protocol proposed by Smaragdakis et al. (2004).

Jibreel (2019) proposed an extended threshold stable election protocol named, eTSEP. The new formulation assigns weights to election probabilities of each level of nodes taking into consideration distance and residual energy which is not so in TSEP. This makes nodes closer to the base station and with more residual energy to be elected as cluster heads. According to Jibreel (2019), eTSEP is better than TSEP when the throughput, residual energy, and network lifetime parameter are analysed. Cluster heads in eTSEP transmit packets to the base station in a single hop. The depletion of distant nodes is therefore high. An observable limitation of the setup of SEP and many of its variants is that it becomes too unstable when the base station is placed outside of the sensing region.

In another approach to deal with the challenge of placing the base station placed far away from the sensing field, authors (Jibreel et al., 2020a) suggested the Gateway Stable Election Protocol (G-SEP). In G-SEP, a gateway node is centrally placed in a sensing region allowing the base station to be placed outside of the region. While modifying the SEP, the election probabilities for selecting cluster heads are based on the distance of a node to the gateway, residual energy, and the average distance of all nodes. G-SEP has better coverage, stability, and network lifespan than SEP. The use of gateway nodes increases the deployment cost of WSN and may not be economically justified.

Nurlan et al. (2021) extended the Z-SEP in two ways. First, a new mechanism for electing cluster heads using the remaining energy value of sensor nodes is introduced. Clustering is applied only on advanced nodes and the highest revised energy of advanced nodes is used each round as the eligibility criteria to choose which advanced node becomes cluster head. Secondly, the strength of their scheme is tested on different measurement standards such as different base station locations in the sensing field, for variation in the depth of the sensing field as well as by altering the energy levels of the sensor nodes. Such enhancement favors the reduction in the energy consumption of advanced nodes and in turn keeps the network working for a longer time. Clustering is a notable energy preservation technique (Jibreel et al., 2022), but not utilized amongst the normal nodes in the setup by Nurlan et al. (2021).

Benelhouri et al. (2021), proposed a three-level routing algorithm consisting of normal nodes, super nodes, and advanced nodes. The authors execute a planned 5-zone deployment for these nodes depending on their level. Normal nodes are stationed close to the BS and communicate data directly to the BS. On the left and right sides of the normal nodes deployment region are advanced nodes, which communicate via selected CH. Super nodes are placed in the upper and lower zones of the sensing area and they transmit data to the BS through group heads. The selection of cluster heads for both advanced and super nodes is based on the energy remains of these nodes each round. The deployment strategy in the work of Benelhouri et al. (2021) will be impractical for hard-to-reach environments, which require random distribution of nodes.

An enhanced routing protocol that, introduces heterogeneity in the Gateway-based Energy-Aware Multi-hop Routing protocol (MGEAR) is proposed by Jibreel et al. (2022). The base station is placed outside the sensing region while a gateway node is placed at the center of it. Normal nodes in the uppermost region communicate directly to the base station whiles nodes in region 2 directly communicate to the base station instead. The heterogeneous nodes in regions 3 and 4 communicate via elected heterogeneous cluster heads to the gateway node, which in turn forwards the condensed data to the base station. Heterogeneous cluster head selection is based on residual energy. To eliminate energy holes that arise when nodes die, a mechanism, is devised and implemented to allow nodes to communicate data only if their energy level is below a pre-defined threshold level.

In a recent work by Alom et al. (2022), an improved Zonal-Stable Election Protocol (IZ-SEP) is proposed in which the sensing region is divided into two regions and nodes are set up to send data to the base station through a hybrid approach. Nodes in zone 1 are relatively closer to the base station than nodes in zone 2. The proposed MZ-SEP keeps the original zoning in Z-SEP but further divides the central zone 0 into two lower and upper zones. In IZ-SEP, the authors set out to allow normal nodes to send data to the base station directly whereas advanced nodes send data to the base station via a cluster head. The arrangement of the proposed MZ-SEP in this paper allows only cluster heads, selected from both normal and advanced nodes, to send data to the base station.

In this paper, a modified energy-efficient routing protocol has been proposed for wireless sensor networks. The technique uses residual energy and node density to advance the utility of the Z-SEP protocol used in Faisal et al. (2013). Further, rather than the single hop used in the Z-SEP, the proposed scheme employs clustering and multi-hop communication amongst normal nodes in region 0 of the sensing area. The suggested new protocol is to help minimize the energy waste of normal nodes, increase packet delivery, and increase the lifetime of the network.

3. THE PROPOSED MODIFIED Z-SEP PROTOCOL (MZ-SEP)

The proposed heterogeneous protocol is given and described in this section. The protocol is based on the work of Faisal et al. (2013). The protocol divides the central region of the Z-SEP sensing area further to produce four regions of fixed sizes. Two sets of nodes are deployed. Normal nodes are equally distributed into the two central regions while the advanced nodes are placed in the upper and lower regions of the sensing area, as is the case with the Z-SEP. The base station is placed in the middle of the network in such a way as to equally divide the two central regions and shorten the communication distance to the base station. Clusters formation takes place across all regions, with cluster heads transmitting data to the base station. All cluster heads use a multi-hop transmission technique to send data to the base station. Node density and residual energy will be considered to elect cluster heads.

3.1 Proposed network architecture

The technique used is designed to save energy and extend the life of the wireless sensor network. Fig. 1 depicts the network configuration of nodes for the new protocol that enhances the Z-SEP.

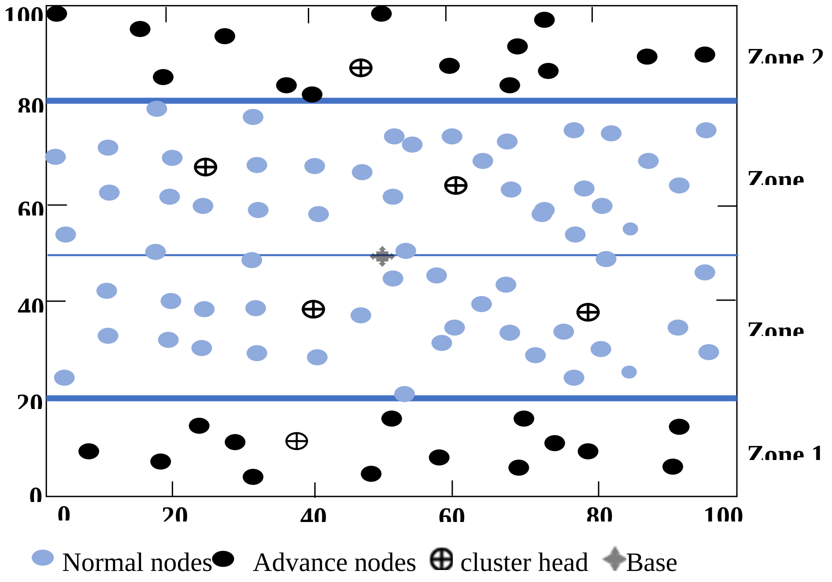

Fig. 1. Proposed MZ-SEP network architecture

The architecture in Fig. 1 is different from the one in Z-SEP mainly because it is set out to allow clustering amongst the normal nodes in Zones 00 and 01 which is not the case in Z-SEP. This is to reduce the likely chance of unfair distribution of normal nodes in the central part of the sensing area.

The following proprieties are applied on the network in Fig. 1:

i. The sensing zone 0 is further divided into two regions, zone 00 and zone 01 to reduce the chances of unfair distribution of normal nodes in the region.
ii. A fraction, $m = 0.2$, of the 100 deployed nodes are advanced nodes. The remaining are normal nodes.
iii. Advance nodes are deployed in zones 1 and 2. While normal nodes are evenly deployed in zones 00 and 01.
iv. Clustering is applied to nodes in zone 00 and zone 01 unlike in Z-SEP. Cluster heads are elected each round from the two zones as well.
v. Data transmission in zone 00 and 01 is done in multi-hops unlike in Z-SEP which uses direct transmission. Cluster heads, in this case, undertake packet transmission to the base station.
vi. As in Z-SEP, nodes in zones 1 and 2 transmit data using multi-hop communication.
vii. A further modification to the Z-SEP protocol is that residual energy and node density is used to determine which nodes become cluster heads.

3.2 Technique used for routing

Routing in the proposed technique is done in two phases (Faisal et al., 2013):

1. The cluster formation phase involves cluster formation and the election of cluster heads. This is also called the setup phase.
2. The steady phase starts with data sensing and progresses to data transmission to cluster heads, data aggregation by cluster heads, and finally data transfer from cluster heads to the base station.

3.2.1 The setup phase

This paper uses a setup phase like the one suggested by Faisal et al. (2013). However, in the proposed MZ-SEP, the election probabilities for nodes to become cluster heads are modified to include residual energy and node density. In this way, nodes with high residual energy and many connected neighbors will have a higher chance to become cluster heads. So, for each sensor node i in the network, the residual energy weight is computed as in Eq. (1).

$$R_w = \frac{E(i) - E_{min}}{E_0 - E_{min}} \tag{1}$$

where $E(i)$ is the value of the remaining energy for each alive node and E_{min} and E_{max} reference the min and max residual energy of nodes alive in the network at any given round.

The node density weight is computed as in Eq. (2):

$$D_w = \frac{N_{nb}(i)}{N_{alive}} \tag{2}$$

where $N_{nb}(i)$ is the number of neighbors node i has and N_{alive} is the number of alive nodes during each round.

Therefore, the probability formula used to determine which normal nodes become cluster heads in the network zones 00 and 01 is modified and presented in Eq. (3).

$$p_{NN} = \frac{p\,(1+\alpha)}{1+\alpha \times m} \times (R_w + D_w) \tag{3}$$

Similarly, the probability formula used to determine which normal nodes become cluster heads in network zones 1 and 2 is presented in Eq. (4).

$$p_{AN} = \frac{p\,(1+\alpha)}{1+\alpha \times m} \times (R_w + D_w) \tag{4}$$

m is the proportion of advanced nodes in the network. These nodes are α times more energy powered. p is the probability of each node becoming a cluster head per round.

Eq. (5) and (6) present the threshold formula for electing cluster heads for two categories of nodes.

$$\mathrm{T}(NN) = \begin{cases} \dfrac{p_{NN}}{(1-p_{NN}) \times \left(r \bmod \left(\frac{1}{p_{NN}}\right)\right)} & n \in G_{NN} \\ 0 & Otherwise \end{cases} \tag{5}$$

where $\mathrm{T}(NN)$ is the threshold defined for the normal nodes; r denotes the active round, G_{NN} is the group of normal nodes in zones 00 and 1 which did not become cluster heads in the previous $1/p_{NN}$ rounds.

$$\mathrm{T}(AN) = \begin{cases} \dfrac{p_{AN}}{(1-p_{AN}) \times \left(r \bmod \left(\frac{1}{p_{AN}}\right)\right)} & n \in G_{AN} \\ 0 & Otherwise \end{cases} \tag{6}$$

where $\mathrm{T}(AN)$ is the threshold defined for the normal nodes; r denotes the active round, G_{AN} is the group of advanced nodes in zones 1 and 2 which were not made cluster head in the previous round $1/p_{AN}$.

3.2.2 The steady-state phase

Nodes receive and transmit data in time slots to the base station for further processing during the steady phase. Each iteration of the process consumes energy. This section will examine the energy required to receive and transmit data, as well as the overall energy consumption of the network. Heinzelman et al. (2000) energy dissipation model will be used for the analysis. The model is depicted in Fig. 2.

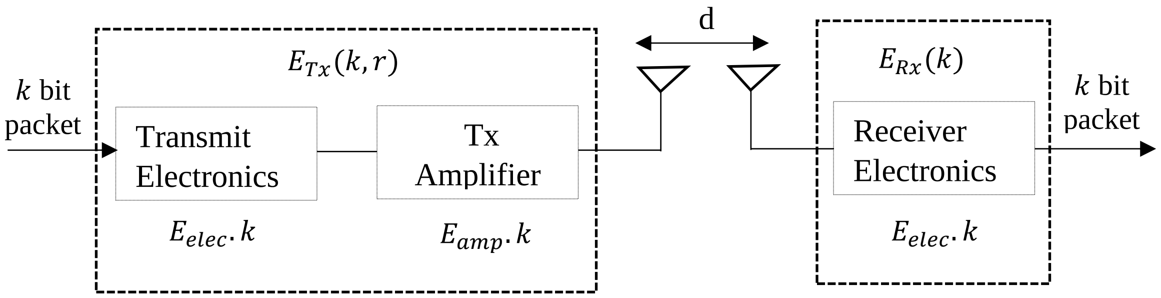

Fig. 2. Energy model for WSN

The energy model comprises transmission and receiving circuitries. Data transmission takes place in the transmitter electronics and so it expends energy to run the transmit and amplifier modules. Data is received by the receiver electronics and so it expends energy only to operate the radio circuitry. For a sensor to transmit a k-bit message over a distance d (in meters) the amount of energy dissipated is given in Eq. (7):

$$E_{Tx}(k,d) = k.E_{elect} + k.E_{amp} \tag{7}$$

Eq. (8) is used to compute the energy needed to receive a k-bit of data.

$$E_{Rx}(k) = k.E_{elect} \tag{8}$$

Where E_{Tx} is the combined energy used up per each bit of data transmitted by a sensor node and E_{Rx} is the energy expended to receive k-sized data.
Notice that additional energy is needed during data transmission to boost the signal strength. This is represented as E_{amp} in Eq. (7) and its value is proportional to the communication distance between transmitting nodes. For the free space model, E_{amp} is denoted as $\varepsilon_{fs} \,.\, d^2$. Multi-path models specify E_{amp} as $\varepsilon_{mp} \,.\, d^4$. Therefore, Eq. (7) can be restated as:

$$E_{Tx}(k,d) = \begin{cases} k.E_{elect} + k.\varepsilon_{fs} \,.\, d^2, & if\ d \le d_o \\ k.E_{elect} + k.\varepsilon_{mp} \,.\, d^4, & if\ d > d_o \end{cases} \tag{9}$$

where d_o is the threshold distance given as follows:

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{10}$$

The energy expended by each normal node in Zone 00 to transmit to a cluster head is given by Eq. (11)

$$E_{non_{CHoo}} = E_{Tx}(k, d_{toCH}) \tag{11}$$

d_{toCH} is the distance from a normal node in Zone 00 to a cluster head in the zone.

The energy required for cluster heads in Zone 00 to receive packets and transmit them to the base station is given by Eq. (12).

$$E_{CH_{00}} = k \times E_{elect} \times \left(\frac{n_{00}}{c_{00}} - 1\right) + k \times E_{DA} + E_{Tx}(k, d_{toBS}) \tag{12}$$

where n_{00} is the number of nodes deployed in zone 00 and c_{00} is the number of cluster heads in zone 00.

Eq. (13) computes the total energy used by nodes in zone 00 given by

$$E_{TOTAL_{00}} = c_{00} \times E_{CH_{00}} \tag{13}$$

The same energy consumption analysis is applied for normal nodes in zone 01.

The energy expended by each normal node in Zone 01 to transmit to a cluster head is given by Eq. (14)

$$E_{non_{CHo1}} = E_{Tx}\left(k, d_{toCH_{01}}\right) \tag{14}$$

$d_{toCH_{01}}$ is the distance from a normal node in Zone 01 to a cluster head in the zone.

The energy required for cluster heads in Zone 00 to receive packets and transmit them to the base station is given by Eq. (15).

$$E_{CH_{01}} = k \times E_{elect} \times \left(\frac{n_{01}}{c_{01}} - 1\right) + k \times E_{DA} + E_{Tx}(k, d_{toBS}) \tag{15}$$

where n_{01} is the number of nodes in zone 01 and c_{00} is the number of cluster heads in zone 01.

Eq. (16) computes the total energy used by nodes in zone 01 and it is given as follows:

$$E_{TOTAL_{01}} = c_{01} \times E_{CH_{01}} \tag{16}$$

Therefore, the total energy consumed by the normal nodes in zone 00 and zone 01 is given by Eq. (17).

$$E_{TOTAL_{NN}} = c_{00} \times E_{CH_{00}} + c_{01} \times E_{CH_{01}} \tag{17}$$

The energy consumption values for advance nodes in zone 1 and zone 2 are similar to the work of Faisal et al. (2013). Fig. 3 visualizes the flowchart for the proposed MZ-SEP approach.

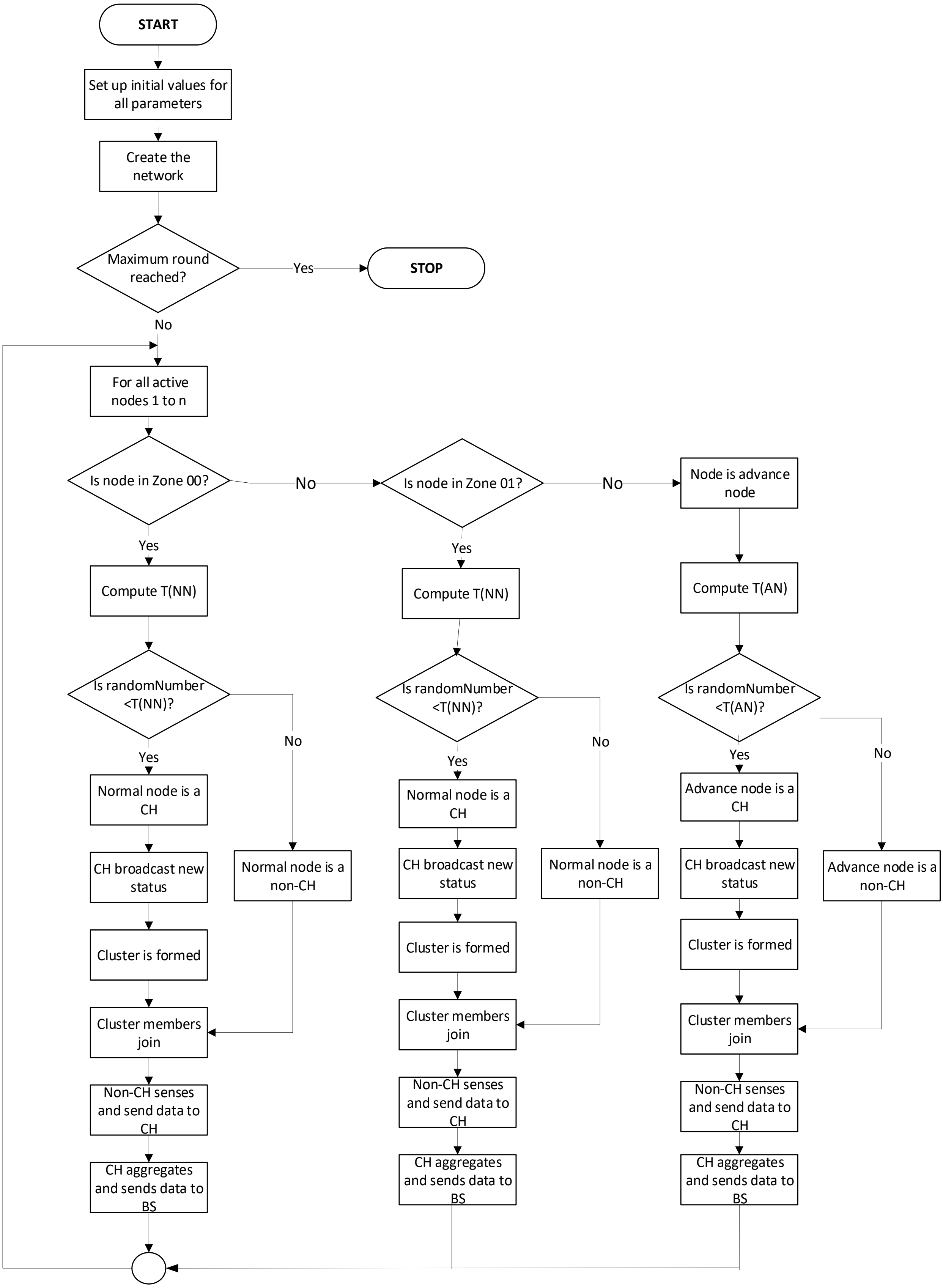

Fig. 3. Flowchart for the proposed MZ-SEP

4. DISCUSSION

A simulation of the proposed modified protocols was performed, and comparisons were made with the heterogeneous form of LEACH, SEP, and Z-SEP. The simulation was performed on MATLAB 7.5.0 (R2007b) using randomly discharged 100 stationary sensor nodes on a 100m-by-100m sensing region. The sink node is placed at the centre of the sensing network. Twenty percent ($m = 0.2$) of the deployed nodes are advanced nodes with higher energy ($\alpha = 1$) than normal nodes. The research adopts the data aggregation technique used by Heinzelman et al. (2000) which allows cluster heads to receive and then aggregate data from neighbouring nodes before transmission to the base station. Table 1 presents the simulation parameters and data adopted from Faisal et al. (2013), used for the simulation to analyse the performance of MZ-SEP. Each parameter value is measured for each round.

Table 1. Parameter used for simulations

Parameters	**Values**
Diameter of sending region	100m by 100m
Nodes (n)	100
The energy value for normal nodes (E_o)	0.5*Joules*
Message size	4000 *bits*
E_{elec}	50 *nj/bit*
E_{fs}	10 $nj/bit/m^2$
E_{mp}	0.0013 $Pj/bit/m^4$
p_{opt}	0.1

To evaluate the performance of the proposed routing protocol, the following commonly used performance metrics were considered.

i. Stability period: the period defines the time lapse before the death of the first node.

ii. Network lifespan: This signifies the longevity of the WSN and measures the number of nodes that are alive for every round and at the end of the final round. Generally, efficient energy use will keep more sensor nodes alive during the rounds of sensing and transmission.

iii. Throughput: It gives a measure of the number of packets delivered by active nodes to the base station during each round. This metric indicates the efficiency of energy use in the network.

iv. The number of dead nodes: This is the number of nodes that are dead due to the non-availability of energy during each round. The slower the death rate of a protocol the more energy efficient it is.

The result is presented by setting m=0.2 and α=1, which is adapted from Faisal et al. (2013) to allow two levels of heterogeneity in the deployed nodes. That means 20% of the total deployed nodes are advanced nodes, having α more energy, while the remaining 80% are normal nodes. Accordingly, 10 advance nodes are randomly placed in zones 1 and 2 each, while 40 normal nodes will be randomly deployed in zones 00 and 01.

4.1 Analysis of network stability

In Fig. 4, we present the stable period analyses in the proposed new scheme. The analysis compares the stable region in the LEACH, SEP, Z-SEP, and the proposed MZ-SEP protocols. It is observed that in the MZ-SEP, the network is more stable than LEACH, SEP, and Z-SEP. No death is encountered up until about 1600 rounds. The reliability of the network in MZ-SEP is therefore comparatively better. The stable region in MZ-SEP becomes relatively steady between rounds 2100 and 4400. The quicker nodes die, the more likely the sensing field will become sparse and cause the sensing process to be biased. Consequently, the feedback and the election of cluster heads will remain unreliable for extended periods. The new protocol keeps the death rate of particularly the normal nodes low for each round than the other protocols. This ensures there is and better distribution of alive nodes in the central sensing region consisting of normal nodes. With this, there is guaranteed delivery of data from the sensing environment. Therefore, for environments in which reliable data delivery is of importance, the MZ-SEP is preferred as evident in Fig. 4.

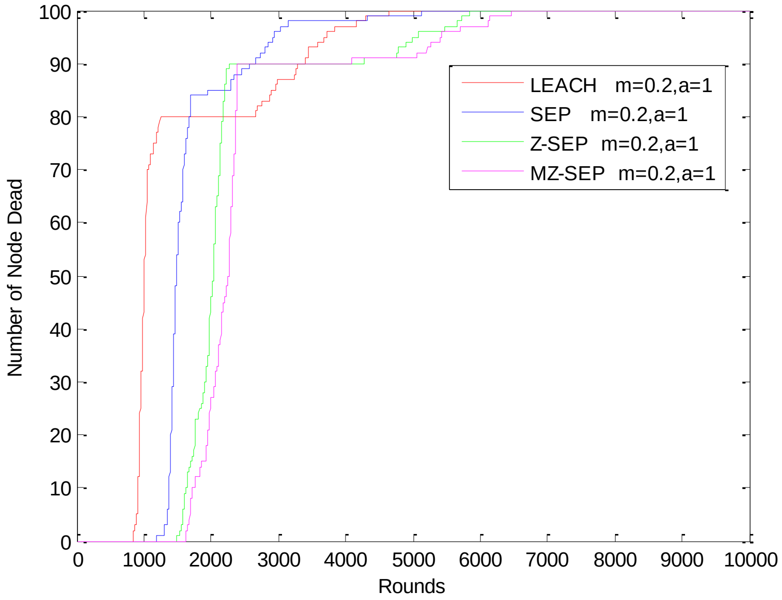

Fig. 4. Dead nodes analysis per round

The clustering applied in the normal node's regions helped conserve energy since transmission over a longer distance is curtailed. The overall network energy is judiciously utilized.

4.2 Analysis of network lifetime

The network lifespan metric is analysed in Fig. 5. The analysis is also done in rounds and compares the number of dead nodes for the LEACH, SEP, Z-SEP, and the proposed MZ-SEP protocol. It is observed that in the MZ-SEP, all the deployed sensor nodes were alive longer than in LEACH, SEP, and Z-SEP. The lifespan period in MZ-SEP is therefore comparatively better. The last node in MZ-SEP dies after about 6500 rounds and 10% of the nodes are still active after about round 4200. The longer sensor nodes are alive, the longer the sensor network is active to perform the defined sensing function on the target environment. The proposed method can maintain more alive nodes amongst the normal nodes because the long-distance communication, which consumes much energy, is taken away. Cluster heads communicate to the base station utilizing routes that generate the least energy. Therefore, the average total energy conserved in each round is more when the new routing protocol is implemented. To achieve a longer sensing period in a heterogeneous network, the MZ-SEP is preferred over SEP and Z-SEP due to its longer network lifetime as evident in Fig. 5.

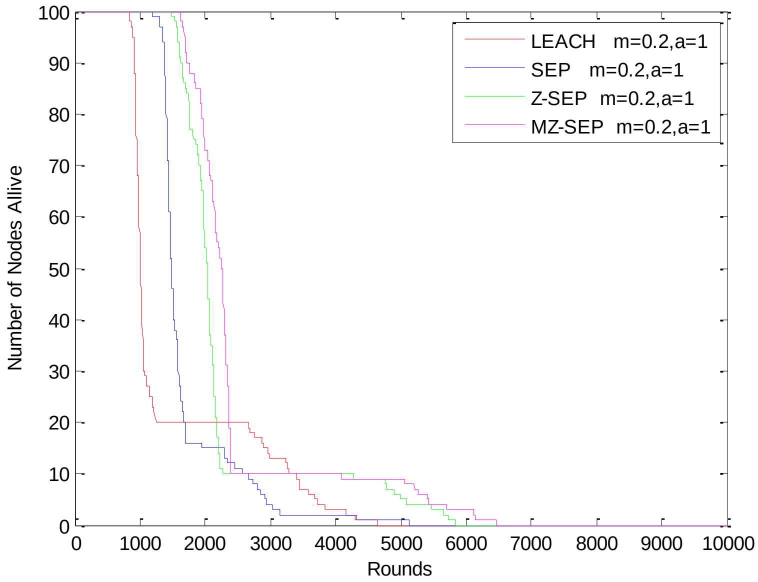

Fig. 5. Network lifetime analysis per round

Similarly, as is shown in Fig. 4 because the direct transmission amongst the normal nodes was eliminated, energy was conserved. Likewise, because data aggregation was done by selected cluster head nodes, a further portion of the sensor node energy was retained. Both benefits help maintain a low death rate and prolong the sensing time of WSNs.

4.3 Network throughput analysis

In Fig. 6, the network throughput is analysed from the simulation results. The number of packets transmitted to the base station is what is considered. After round 1000, it is seen that the proposed extended Z-SEP communicated more data to the base station compared with all the other schemes under consideration. The multi-hop transmission model adopted for the normal nodes' region meant communication was done over shorter distances, which requires lesser energy. The more residual energy a sensor node has, the longer it stays to capture more data and transmit the same to the base station. Therefore, the overall output of packets from the network to the base station will increase.

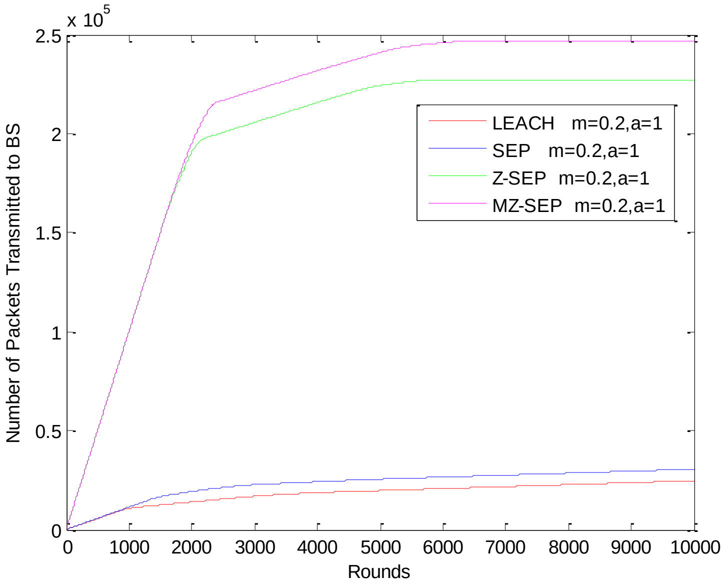

Fig. 6. Throughput analysis per round.

Table 2 provides a numerical illustration of the new protocol performance in this paper compared with other protocols.

Table 2. Performance comparison of protocols for $m = 0.2$ and $\alpha = 1$

Protocol	Performance measure		
	Stability (rounds)	**Network lifetime (rounds)**	**Throughput (Packets)**
LEACH	833	4652	2.4760e+004
SEP	1178	5136	3.0556e+004
Z-SEP	1487	5834	2.2703e+005
MZ-SEP	1630	6468	2.4665e+005

Based on Table 2, MZ-SEP has better performance in comparison with the other protocols in stability, network lifetime, and throughput metrics. MZ-SEP increased the stability period by about 9.62%. In the case of network lifetime, MZ-SEP is better than the rest, it extends the Z-SEP by almost 10.87%. More packets are delivered to the base station in the new MZ-SEP protocol by 8.64%. The simulation results for the four protocols remained the same when the value of m and α were varied to 0.1 and 2 respectively.

5. CONCLUSION

In this paper, a modified routing protocol for heterogeneous wireless sensor networks has been proposed. The new protocol is an extension of the heterogeneous Z-SEP, which modifies the node deployment strategy in Z-SEP and utilizes minimum-cost routes to transmit data to the base station. The election criterion in Z-SEP is based on only the residual energy of advanced nodes, which is modified in this paper to combine residual energy and node density. This ensures that high-energy nodes with more data reception and aggregation duties are favourites to act as heads of clusters each round. These modifications have substantially cut down the rate at which nodes die. In addition, the number of packets delivered to the base station has increased due to an extension in the active life of the network keeping it functioning for a prolonged period. Generally, results from simulation conducted in MATLAB show that the proposed protocol performs significantly better than existing schemes such as LEACH, SEP, and Z-SEP by decreasing power consumption, reducing the number of dead nodes per round, increasing the number of packet delivery, and extending the network lifetime. The proposed protocol is functional when the base station is placed at the center of the sensing field. The performance of the protocols is not guaranteed with the base station placed outside of the sensing field. A future extension of this work will seek to optimize the placement of the base station in our routing protocol.

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