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Adaptive Clustering in Energy Efficient Routing Protocol for Mobile Nodes in WSNs

Zawar Khan[1], Majid Ashraf[1]
[1]Electrical Engineering Department, University of Engineering and Technology, Peshawar.
* Correspondence: Zawar khan (zawar@uetpeshawar.edu.pk)

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Introduction: Wireless Sensor Networks (WSN) is a collection of large number of small sensor nodes which communicate sensed data over a radio channel covering wide geographical region.

Problem statement: A number of algorithms have been developed to enhance the network lifetime of WSN by efficiently utilizing the sources of energy. The most commonly used approach is clustering that is prone to uneven load balancing and instability issues. Furthermore, topological changes in WSN structure especially with mobile nodes significantly effect network lifetime.

Methodology: In this study, we have proposed an Adaptive-Cluster-based Energy Efficient Routing Protocol (A-EECBRP), which employs a novel geometrical Voronoi-based configuration to solve load balancing and mobility issues while maintaining network stability and coverage. Furthermore, energy cost function and Energy Harvesters (EH) devices were implemented to reduce energy consumption and increase network life. Moreover, the concept of handshaking and random waypoint model for nodes movement between cluster groups was examined to define mobile nodes.

Results: Simulation results obtained from network analysis performed on MATLAB® showed that A-EECBRP reduced energy consumption by almost 1500 rounds as compared to LEACH-M. This significantly improved the network lifetime of WSN as compared to the LEACH-M routing protocol. Therefore, our proposed scheme provides a huge potential for implementing energy-efficient routing protocols in mobile wireless sensor networks.

Keywords: Voronoi Diagram, Wireless Charging, Mobile Nodes, Routing Protocol, Clustering, Energy Harvesters.

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Author's Contribution.
All authors contributed significantly to the study.

Acronyms
(A-EECBRP) Adaptive- Cluster-based Energy Efficient Routing Protocol
(WSN) Wireless Sensor Networks
(VLSI) Very Large Scale Integration
(BS) Base Station
(IoT) Internet of Technology
(APTEEN) Adaptive Threshold TEEN
(BDI) Battery Discharge Index
EH Energy Harvesting

Project details. NiL **Conflict of interest:** The authors of this paper declare no conflict of interest.

Introduction

The vast development in Very Large Scale Integration (VLSI) technology has resulted in production of low-powered, and inexpensive miniature sensors, equipped with radio transceiver, which not only monitors chemical and physical changes in the environment but also communicate this information to other nearby devices. A large number of these devices, usually ranging from 500 to 1000s, are deployed in a space, where these form a wireless sensor network (WSN) with a sink node or base station (BS) to connect to the global internet for user interface. These sensor devices are called nodes when inside a network and perform functions such as processing the raw data, transmission of data over a network, and self-organization into a proper network. Figure 1 shows a cloud of nodes forming a wireless sensor network where the sink node behaves as an interface between global internet, and the cloud users can interact with WSN through a sink node [1].

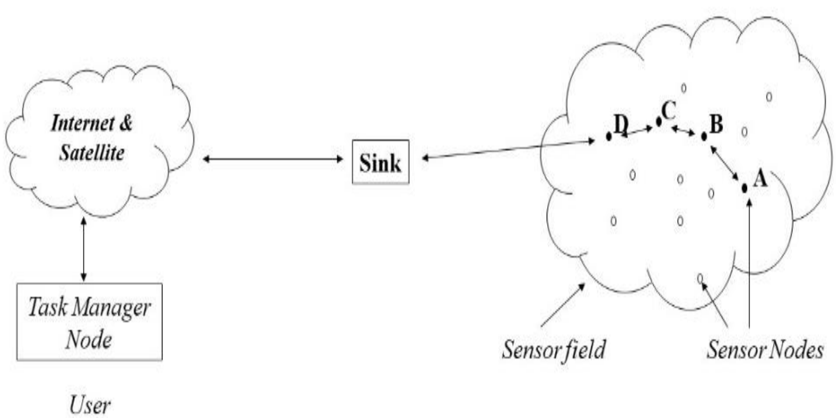


Figure 1: A typical WSN structure [1]

However, due to the small size of the nodes, there may have some limitations, such as low computational power, scarce amount of energy, and limited storage capacity [2]. Nowadays, WSN has many applications in internet of technology (IoT) where the most important challenge is energy efficiency [3]. ,To address these challenges, a number of routing protocols have been developed for WSNs, where majority of them have focused primarily towards achieving large number of nodes that are working together efficiently in utilizing the limited supply of energy for the extended period.However, there are other challenges associated with WSNs such as mobility of the nodes, induced stability effect on network due to topological changes in the structure of the network, security risk, congestion of the traffic, etc., which needs attention as well. In literature, most routing protocols include protocols developed only for static sensor nodes or WSNs. The most popular one is Low Energy Adaptive Clustering Hierarchy (LEACH) which uses cluster of nodes for a low energy consumption data transmission after each round of transmission. A probabilistic model determines the clusters to conserve energy and reduce load unbalancing [4]. However, LEACH is only applicable for static nodes since mobile networks are prone to sudden ,topology changes impacting network lifetime and the overall stability.

Furthermore, LEACH does not take into account mobility of the nodes. Another improvement in the routing protocol based on clustering and LEACH is energy efficient clustering algorithm which utilizes genetic algorithm concept for selecting CH, and all the computational tasks are assigned to BS. However, the evaluation parameters do not consider scalability or network size while compared to IEEE 802.15.4 protocol. An increase in node size may burden BS, and results in latency [5]. Recently, adaptive coded clustering, improves data reliability and energy consumption much more than LEACH[6].

Another very popular routing protocol is Threshold sensitive Energy Efficient sensor Network (TEEN) [7]. It's a reactive-based routing protocol that utilizes clustering model and soft and hard thresholds to greatly reduce redundant transmissions upon the assumption of no real time data transmission. Whereas Adaptive Threshold TEEN (APTEEN) is a modified version of TEEN protocol developed to resolve real-time data transmission problems faced in TEEN protocol through periodic data transmission from each node [8]. Another technique to efficiently utilize the energy resource is the computation of a level, also known as compound metric. A compound metric considers the data transmission load, and a variable battery discharge Index(BDI) which takes into account the battery status to assign a cluster head to a particular node thereby increasing network lifetime [9].

Energy aware routing protocols were first demonstrated by S. Natesan et al., [10], where energy is harvested from the sources surrounding the sensor node using energy harvesting devices to increase network lifetime and to reduce dependency on limited battery power supply. Investigation of the EH showed 29.7% improvement in the network lifetime[10]. ,The clustering technique has also been studied with EH to investigate its effects on network lifetime. The results showed improvement in network lifetime and reduction in congestion [11]. Similarly, a new approach to increase network lifetime is the use of mobile wireless charging, which has been studied in Energy Efficient Cluster-based Routing Protocol (EECRP) [12]. In this study, a wireless mobile charger continuously charges cluster heads placed at fixed location after a certain amount of time set initially. Although network lifetime was significantly increased, the protocol takes movement of node as static as its fundamental assumption. In addition, the sectoring method introduced in this study to resolve load balancing does not approximate to a real-life scenario where the large number of nodes are randomly and unevenly distributed.

Recently, the number of researches on the mobility of nodes in the wireless sensor networks have increased since the growing use of independent, mobile wireless sensor nodes in applications such as UAV, intelligent transport system, etc. Mobility impacts network lifetime in WSN greatly. Mobile nodes increase the number of disconnections, data loss, and energy dissipation [13]. LEACH-M or LEACH-mobile incorporated a cost function model so that it can include mobile nodes with varying speeds [14], [15]. But the overhead computational costs due to repeated calculation of cost function at each round of transmission reduces network lifetime, especially for a large number of mobile nodes. In [12] mobile sink equipped with EH has been used to recharge the nodes or CH, whereas path selection or path optimization is periodic with no algorithm defined for path strategy. Whereas for mobile sinks, path selection and path optimization techniques such as event-based routing technique, path-based routing technique, periodic routing technique, and random walk-based routing technique has certain drawbacks such as message overhead and sensor malfunction, etc.[16].

In this study, we aim to develop an adaptive energy efficient routing protocol which utilizes a novel geometrical localization technique together with an adaptive cost model algorithm and Energy Harvesters (EH) that will solve the issues of coverage holes, mobility, and computational cost. Our proposed approach will significantly improve the network lifetime as well. All simulations are done in MATLAB ® 2018.

The rest of the paper is organized as follows: next section is dedicated to methodology detailing the models and process of simulations, followed by a section on results where simulations done on MATLAB are presented, whereas the last section describes the is the discussion that correlates the results by various same researches for validations.

The objectives of this study will focus on investigating the movement of all nodes and their impact on the network lifetime and energy consumption in our proposed A-EECRBP routing protocol as compared to LEACH-M protocol. Furthermore, this study evaluates the performance parameters between static routing protocol (LEACH, TEEN), mobile routing protocol (LEACH-M), and our proposed A-EECBRP protocol.

Methodology

In the following section, models used in our proposed scheme have been discussed briefly before detailed description on adaptive energy efficient cluster-based routing protocol.

First order radio model

First order radio model is used as the energy model for our proposed scheme originally presented in [4]. This free space model for radio waves takes a propagation constant equivalent to 2 for most scenarios. Whereas the d_0 is the distance defined by the ratio given below in equation (1):

$$d_0 = \sqrt{\frac{E_{fs}}{E_{amp}}}$$

Energy dissipated during the transmission of k bits at a distance d< gives d_0 (2):

$$E_{send} = k \times E_{elec} + k \times \varepsilon_{amp} \times d^{\beta}$$

Similarly, the energy consumed while receiving k bits of data is given by:

$$E_{receive} = k \times E_{elec}$$

Whereas,

$E_{receive}$ = Reception of energy consumption by a node

E_{send} = Transmission of energy consumption by a node.

E_{elec} = Energy consumed by the transmitter circuit.

ε_{amp} = Amplifier amplification coefficient.

k = number of bits.

d = distance from transmitting node to receiving node.

E_{elec} is the cumulative sum of all energy factors such as filtering, digital coding, and modulation.

The values of above parameters are set according to the standard defined by [17].

Random way point model

To describe the mobility of nodes in WSN, an appropriate mobility model ,that can closely approximate real-life situation needs to be chosen. We chosed the random waypoint model for the definition and procedure of nodes mobility as per criteria defined in [18], [19]. Here, all the parameters such as direction, distance, and position are randomized, whereas speed was maintained constant throughout the scenario for the simplicity of our calculations. In this mobility model, a node n_i picks a random i_{th} direction from its initial position to final position covering a random distance d_i . Figure 2 shows the pictorial description of a random way point model.

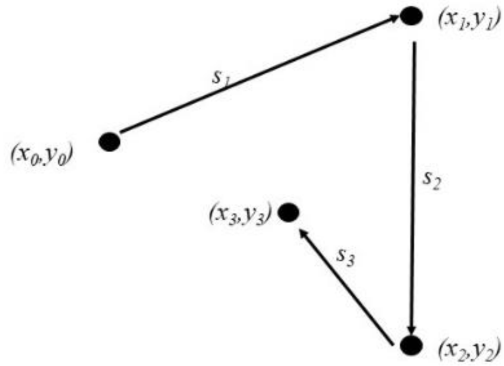


Figure 2: Random way point model

Localization technique based on Voronoi diagram

For the coverage of the network space, we have utilized Voronoi based region sectoring for maximum coverage and efficient load balancing. Voronoi based sectoring has been investigated in literature and is known to provide efficient coverage and load balancing [20], [21]. In our study, the regions are first divided into a fixed number of Voronoi regions with Voronoi centers. Later sensors are deployed randomly in Voronoi regions, and each node is allocated a region based on the closest Voronoi center criteria. After that, Voronoi centers with no or single sensors are disregard.

Adaptive energy efficient cluster-based routing protocol

For simplicity of model investigations and evaluation following assumptions were taken: -

1. At time $t = 0$ all n nodes are static.
2. All elected cluster heads are fixed for all rounds or transmission with $v = 0ms^{-1}$
3. All sensor nodes are homogeneous, ,with antenna gain, initial energy, etc.

A-EECBRP consists of three important phases,: setup, steady, and mobility. All of them are described in detail below:

Set up phase

The setup phase is initiated by the base station (BS), where BS calculates the optimal CH based on distance and cost function given by equations (1) and (4). Cluster heads are calculated from the set of nodes n, which are already deployed in $[(0,0),(x_m,y_m)]$ based on the localization technique described above. Here, Voronoi centers $(v_1,v_2,v_3.......v_i)$ where i<<n, are closest to cluster heads and serve the purpose of threshold value for CH. Furthermore, the information about elected cluster heads is broadcasted to all nodes by the BS before the next phase begins. Cost function and willingness function has been taken form [14],[15] with some modification shown in equation **(**4) and (5), respectively.

$$C_m^a = W_i^j \times d_{m,j}$$

Where

m= identity of current node.

j= identity of cluster head.

d= distance of node n_m to CH_j.

W_i^j= willingness of cluster head with id=j to accept node

a= the cost associated with cluster head a=1,2,3…j

The equation defines willingness of the node to join the cluster:

$$W_i^j = E_j / Nj$$

Here,

E_j = Remaining energy of the CH.

N_j = Total number of nodes grouped into a cluster.

Steady phase

Transmission of data from nodes to CH and CH to BS occurs in this phase. TDM scheme is adopted where each node transmits 4k bits of data to CH in its own allocated time, which is assumed to be very small than the pause time of the movement of the nodes that is $t_s \ll t_p$ .The amount of energy consumed during the data transmission is governed by first-order radio model and is calculated based on (2) and (3). Steady phase repeats in a loop until all nodes are dead.

Mobility phase

In this phase, all nodes move between the two consecutive round of transmission obeying the random way point model. Whereas CH remained fixed for all rounds to improve the network's total energy and computational cost. All child nodes follow the steps described below for movement:

1. A node n_i travels to the new position $(x_f, y_f)$with speed $v = 2\ ms^{-1}$, from its initial position (x_0, y_0)
2. Node initiates handshake if the threshold for its current Voronoi region is triggered or node moves out of its cluster region.
3. ,The routing table is updated between the two clusters exchanging the node, and the new cost function is calculated for each CH based on the new number of nodes.
4. The process is repeated for all alive nodes.

Handshake mechanism

Handshake event is triggered only when a threshold (defined as the maximum distance from Voronoi center to its edges) is reached by the node movement from one Voronoi region to the other. In our scheme threshold value is set to 12.5, or the cost for a node to reside in the current region is greater than a cost to stay in the adjacent region. This ensures balance of energy and load between the regions as well. Figure 3 shows the steps for the handshake procedure between the two cluster heads. The steps for the handshake process are summarized below:

1. A node sends a join request (Req1) to a new CH where the node has move.
2. After acknowledgment for new CH, node sends dis-join request (Req2) to old CH from where the node has to move.
3. Cluster heads update their routing tables and cost functions.

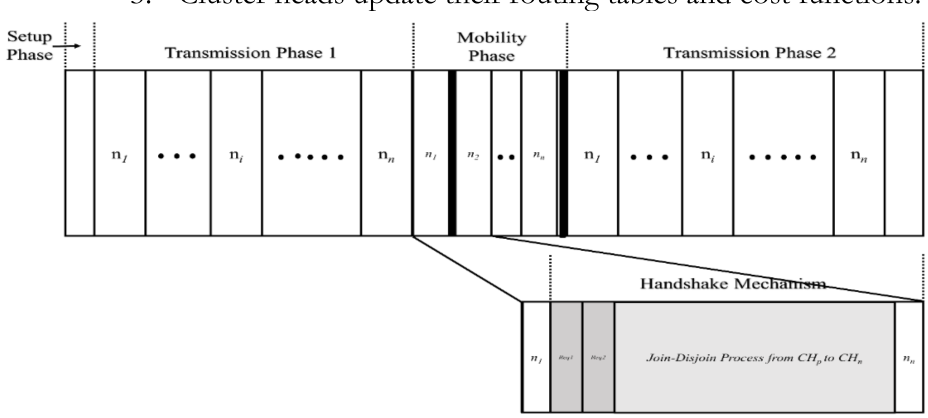


Figure 3: Handshake mechanism for node join-dis-join CH

Algorithm Design

Figure 4 shows the step-by-step flow diagram of the process involved in the methodology, and has been drawn in Overleaf Latex.

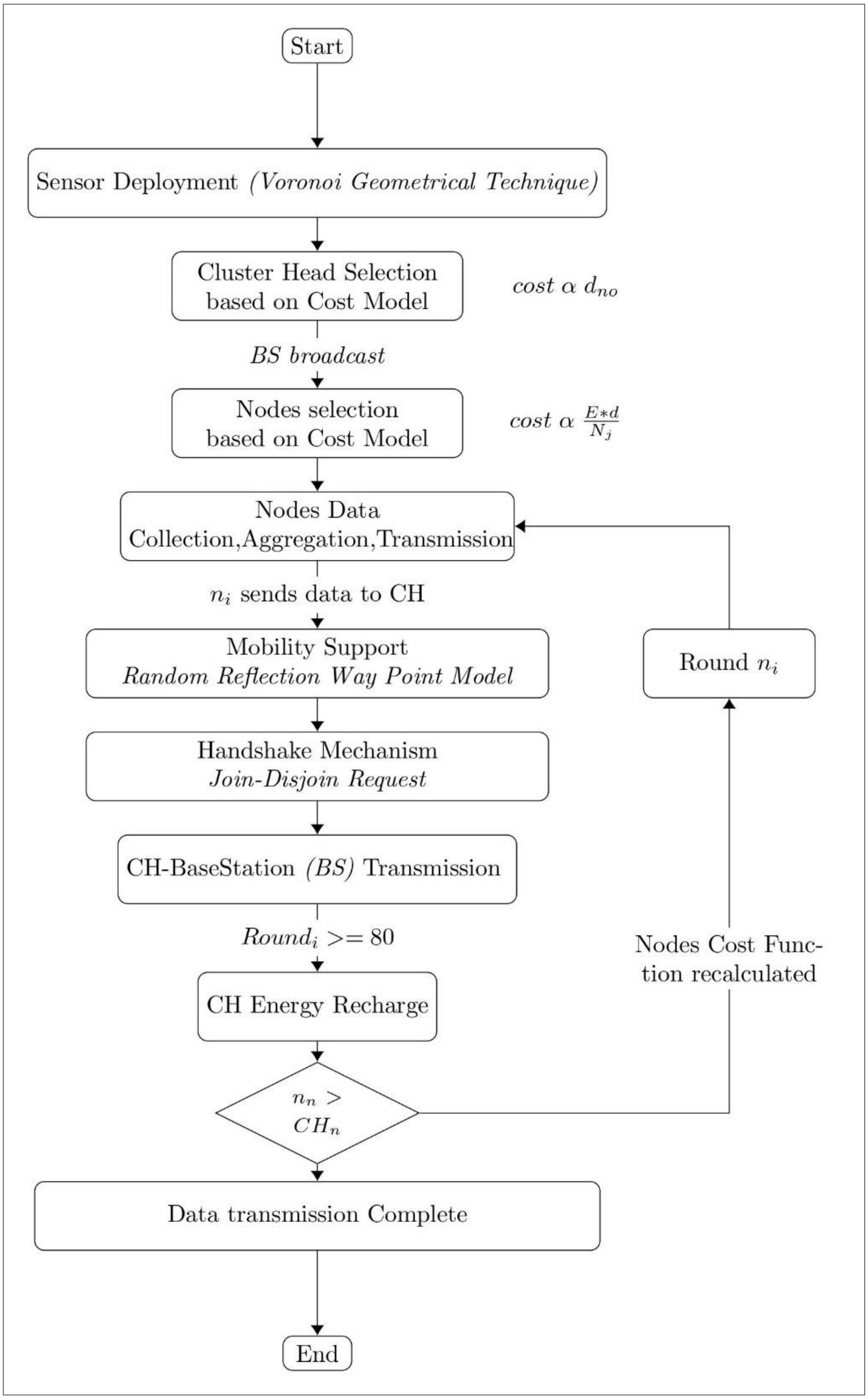


Figure 4: Step by Step flow chart for A-EECBRP

RESULTS

For performance evaluation of our routing protocol, simulations were made through **MATLAB® 2018a.** Whereas an average of 6 simulations were taken for the results and comparison. Network parameters for the simulation are given in Table 1. Performance results such as network lifetime and energy consumed during the life cycle of a network, of our routing protocol Adaptive energy efficient cluster-based routing protocol (A-EECBRP) is compared initially with the static routing protocols (LEACH, TEEN) and then mobile network routing protocol (LEACH-M) with velocity set to $2\ ms^{-1}$. LEACH source code was obtained from reference [22].

Table 1: Network Simulation parameters

Parameter	Values
Network size	100 *m* x 100 *m*
Number of nodes	10, 25, 50, 75, 100
E_{elec}	50 *nJ*
E_{amp}	100 *pJ*
E_0	1 *J*
E_{TX}	50 *nJ*
E_{RX}	50 *nJ*
Number of optimal regions	i^2 where *i*=2,3,4,5…..
Packet size	4000 bits

Random deployment of nodes in space

Figure 5 shows the initial position of sensor nodes (represented by black dots) at t=0 s in the network space and next position of the nodes (represented by blue dots) after the first round of transmission. The speed of the nodes is set to $v = 2\ ms^{-1}$. Here, the Voronoi regions are approximated as squares by maintaining a constant edge length; that can be changed accordingly.

Comparison with static routing protocols

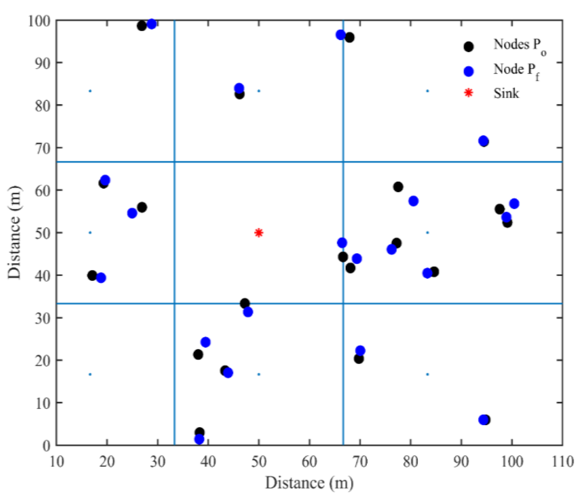
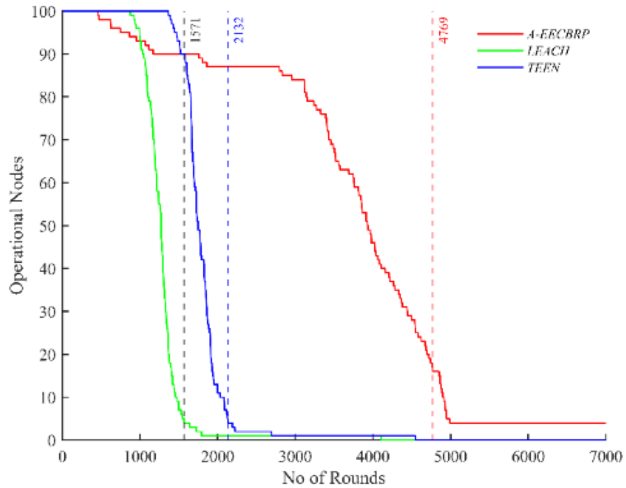
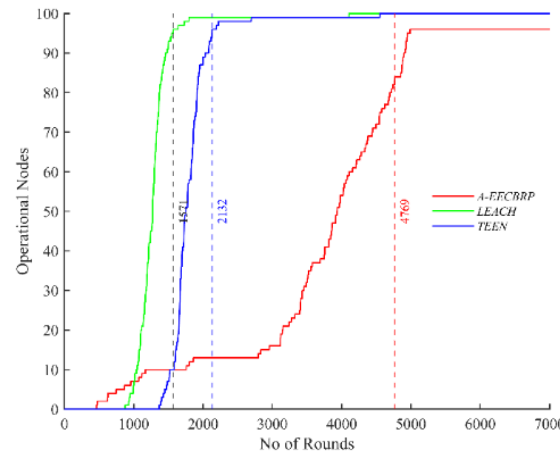


Figure 5: Nodes dispersion in space

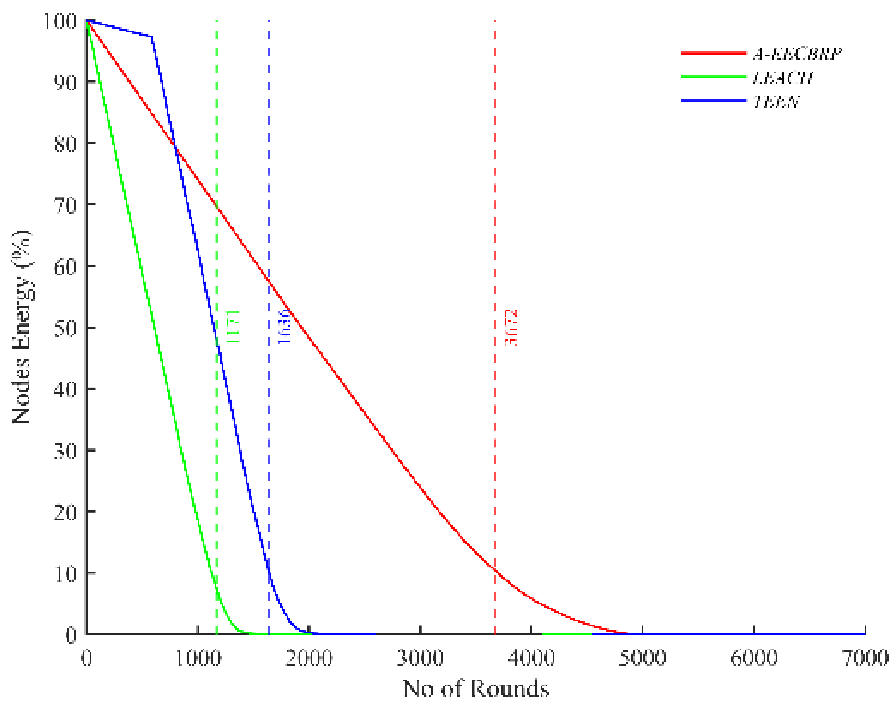
The network lifetime of static routing protocol LEACH, TEEN, and A-EECBRP is plotted in Figure 6. The speed of the nodes for A-EECBRP is set to $0\ ms^{-1}$ to compare it with the static nodes in LEACH and TEEN. A number of nodes alive or proportionally number of all dead nodes versus rounds is plotted in Figure 6a, and Figure 6b is approximately equal to 4700, 2100, and 1500 for A-EECBRP, LEACH, and TEEN, respectively. Figure 6c compares the total energy of all the nodes remaining after each round of transmission. Conventionally 10% times the network's initial energy is considered minimum energy where the system functions stable. About 10% times the ‚nodes' total initial energy is left in the network for LEACH, TEEN, and A-EECBRP at around approximately 1200, 1700 and 3700, respectively.



(a) Number of Alive nodes per each round



(b) Number of dead nodes per each round

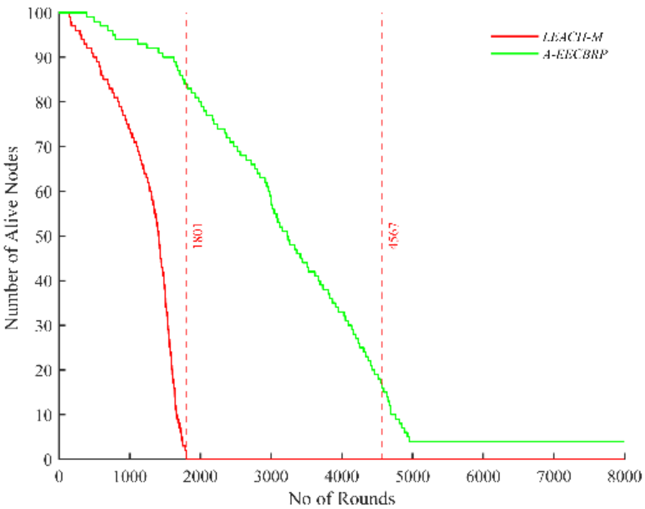


(c) Total energy of all nodes after each round

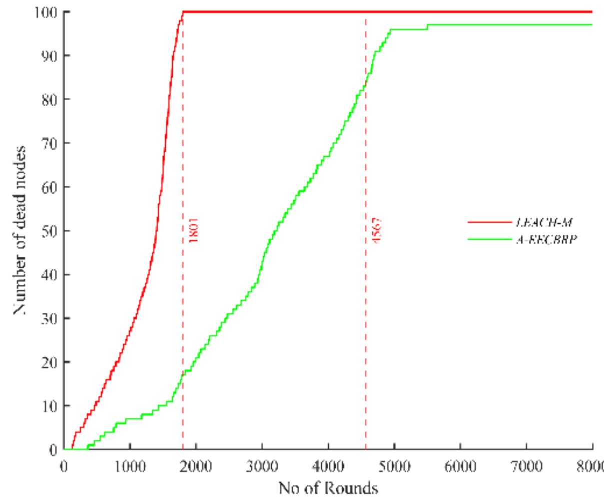
Figure 6: Comparison of static routing protocols LEACH, TEEN with A-EECBRP

Comparison with mobile routing protocols

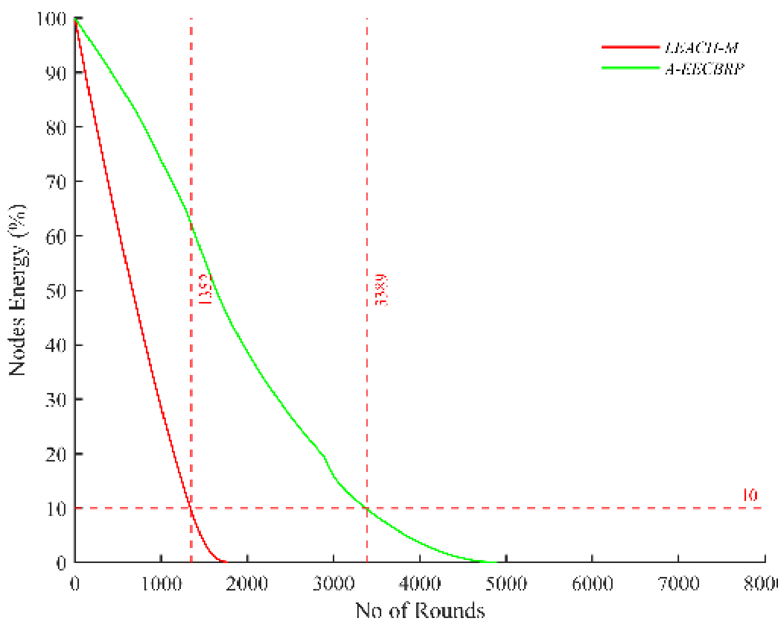
In Figure 7a, network lifetime based on alive nodes per each round between LEACH-M and A-EECBRP with velocity set to $2\ ms^{-1}$ is plotted. Similar results are obtained for number of dead nodes per each round of transmission between LEACH-M and A-EECBRP and are shown plotted in Figure 7b Figure 7c shows the network energy after each round of transmission between LEACH-M and A-EECBRP. Whereas 10% times the total initial energy of the nodes are left in network for LEACH, TEEN, and A-EECBRP at around approximately 1200, 1700, and 3700, respectively.



(a) Number of Alive nodes per each round



(b) Number of dead nodes per each round



(c)Total energy of all nodes after each round

Figure 7: Comparison of mobile routing protocols LEACH-M with A-EECBRP

Discussion

In this study, we proposed a scheme which performed significantly better in network lifetime and energy conservation as compared to static routing protocols (LEACH, TEEN) and mobile routing protocols (LEACHM). In the proposed routing algorithm, a novel geometrical technique known as Voronoi geometrical localization was used for sensors deployment and coverage and the augmentation of energy harvester modules to increase the in-dependency of nodes for energy significantly increased network stability and network lifetime[12], [23], [24]. Sensor nodes in each Voronoi cluster followed random waypoint model scheme for movement direction and speed. It can be seen in Figure 6 and Figure 7 that the inclusion of energy harvesters in cluster head achieves significantly improved performance in terms of alive nodes, dead nodes, and total energy of nodes per round. The benefits of the use of EH devices for sensor nodes or CH have already been demonstrated in [23]–[26].The network lifetime for A-EECBRP increased almost 1.5 times than the LEACH, TEEN, and LEACHM. In case of static nodes, the energy depletion of the nodes is also reduced due to Voronoi geometrical technique, which distributes the load among all Voronoi clusters based on size of the cluster determined by child nodes. Similarly, in case of mobile nodes where the nodes speed is set equal $2\ \mathrm{m}s^{-1}$ A-EECBRP performed significantly better than LEACH-M [10], as depicted in Figure 7, respectively. Voronoi localization technique is adaptive and robust to the changing environment energy needs and distribution of mobile nodes. It adjusts for load sharing and coverage based on the number of nodes in the Voronoi clusters. In addition, energy harvester augmentation to fixed cluster heads reduces the size and equipment costs associated when all nodes are equipped energy harvesters. Furthermore, computational costs are also lower than LEACH-M because in LEACH-M, repetitive calculation of cost function for each node increases computational costs and power as well add to the delay of message transmission. It was also demonstrated in energy graphs Figure 6c and Figure 7c that A-EECBRP has wider stability period than LEACH, TEEN, and LEACH-M [4],[7],[14],[15]. It must be noted that considering fixed CH equipped with EH while all other mobile child nodes moved freely in the network space approximates the real-world scenario where fixed roadside units (RSU) can be charged at ease [26].

Conclusion

In this study, an adaptive energy efficient routing protocol was proposed for WSN nodes that uses novel Voronoi geometrical-based localization and distribution of sensor nodes into clusters that are adaptive to size and number. The energy cost model was modified, and handshake mechanism was introduced for the mobility of nodes at different speed. The proposed routing protocol performs better than other routing protocols in terms of stability, network lifetime, and energy consumption. The adaptive nature also reduces the transmission of data on large sized clusters and is robust to topological variations due to nodes mobility and death of nodes. The energy cost model incorporated batteries' charge time using EH and discharge time to estimate the network lifetime.

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