Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2017) 25: 1448 – 1459

doi:10.3906/elk-1506-137

Threshold distance-based cluster routing protocols for static and mobile wireless sensor networks

Padmavati KHANDNOR*, **Trilok ASERI**
PEC University of Technology, Chandigarh, India

Received: 15.06.2015 • **Accepted/Published Online:** 17.05.2016 • **Final Version:** 10.04.2017

Abstract: In cluster-based wireless sensor network routing protocols, when the cluster head transfers data based on single hop transmission to the sink node, then the cluster heads that are farther away deplete more energy as compared to nearby cluster heads. This condenses load balancing in the network. If the cluster heads collaborate with each other and transfer data based on multihop transmission, then the cluster heads nearer to the sink node are burdened with significant relay traffic and deplete energy much faster, which causes a network coverage problem also known as a hot spot problem. To avoid both of the above problems, this paper proposes two protocols: LEACHDistance and LEACHDistance-M. LEACHDistance is proposed for static wireless sensor networks where cluster heads are chosen based on the upper threshold distance, lower threshold distance, and remaining energy. LEACHDistance-M is proposed for mobile wireless sensor networks where the selection of cluster heads is based on the upper threshold distance, lower threshold distance, remaining energy, and least mobility. The simulation results show that the proposed protocols increase network lifetime, increase the number of packets received by the base station, are more energy efficient, and are also more scalable when evaluated with other existing routing protocols.

Key words: Mobile WSN, base station, sensor node, cluster head, wireless sensor networks

1. Introduction

Many sensor nodes (SNs) are deployed in wireless sensor networks (WSNs). WSNs support a wide range of applications such as environmental monitoring, military applications, security, battlefield surveillance, and home intelligence [1]. In order to serve this assortment of applications, different WSN SNs are used to sense or monitor physical parameters and/or other conditions such as light, sound, vibration, pressure, temperature, soil composition, and air or water quality [2]. The main aim of routing protocols in WSNs is to propagate sensed data from the SNs to the base station (BS) (or sink node). Data dissemination and routing in WSNs is broadly classified into several groups; they are namely location-aided, layered, data-centric, multipath, mobility, quality of service (QoS), and heterogeneity-based protocols [3]. Due to the property of clustering, cluster-based routing protocols presented in the literature are more scalable and also energy-efficient and thus increase the network lifetime [4,5].

Mobility in WSNs is broadly classified as mobility in SNs, or sink nodes, or in relay nodes as shown in Figure 1 [6]. In some routing protocols, the sink is mobile throughout the network lifetime. With sink mobility, we can achieve load balancing and longer network lifetimes. The mobile WSN is considered as the one of the

*Correspondence: padmavati@pec.ac.in

main issues in routing protocols [7]. Mobility can be classified according to movement as random mobility, predictable mobility, and controlled mobility [8].

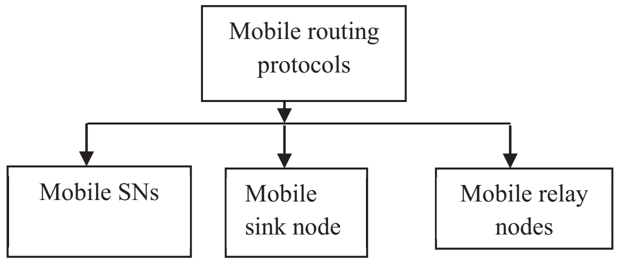

Figure 1. Classification of mobile routing protocols in WSN.

An outline of this research paper is as follows. Section 2 gives a brief review of related work. Section 3 describes proposed the protocols LEACHDistance and LEACHDistance-M. Section 4 presents simulation and results. Section 5 gives conclusion and future work.

2. Related work

The low energy adaptive clustering hierarchy (LEACH) routing protocol splits the network into many clusters, each cluster consisting of a few cluster members (CMs) and one cluster head (CH), which act as an intermediary between CMs and the BS [9]. This protocol consists of a number of rounds where every round consists of two phases. In the first phase, clusters are formed and CHs are elected. In this phase, each SN generates a random number between 0 and 1 and compares the generated random number with threshold $T(n)$, where n is the SN number. Threshold $T(n)$ is calculated using Eq. (1).

$$T\left(n\right)=\left\{\begin{array}{ll}\frac{p}{\left(1-p\times\left(r\,mod\,\frac{1}{p}\right)\right)} & \forall n\in G\\ 0 & \text{otherwise}\end{array}\right\} \tag{1}$$

Here, G is the set of SNs that have not been selected to become CHs in the last $\frac{1}{p}$ rounds, r is the existing round number, and p is the probability value of becoming the CH.

If the generated random number is less than the threshold value then the SN becomes the CH. After the selection of the CH, each CH advertises its selection to SNs using the CSMA MAC protocol. Based on the received signal strength of the CH announcement, every SN sends a request message to the appropriate CH to join its cluster using the CSMA MAC protocol to become a CM forming the cluster. Each CH creates a time division multiple access (TDMA) schedule and broadcasts it to its CM. In the steady-state phase, each CM (SN) then sends data to the CH during its allocated time slot. Each CH then aggregates the received data from its CMs and further broadcasts to the sink node.

The LEACH-Mobile (LEACH-M) protocol supports mobility in SNs [10]. In this protocol mobility in SNs is introduced in LEACH. The LEACH-M protocol achieves definite improvement in data transfer success rate as mobile nodes increase as compared to the nonmobility-centric LEACH protocol.

In the low energy dynamic cluster selection (LEDCS) protocol, data are gathered from mobile nodes efficiently [11]. The CH is selected based on its current velocity. When a SN has data to transmit to the sink node then it will be able to join the nearest CH and send the data. The simulation results show that with the increase in the velocity of mobile SNs, the total data rate received by the sink node in LEDCS is higher than in other protocols. An energy residue aware (ERA) protocol was proposed in [12]. In this protocol, CHs are elected based on probability as in LEACH but it is different in the cluster association method between CHs and their non-CHs. It also works in rounds. The first phase is the setup phase, followed by a steady-state phase. In the first phase, the first CH is elected based on probability and non-CHs associated with the CH based on maximum energy residue. Non-CH nodes compute the sum of residual energy of the CH and the node's residual energy and select a SN as CH that has the maximum sum of residual energy as in Eq. (2).

$$\max\left\{(E_{CH-res)i}+(E_{nonCH-res)j}\,|\,\forall\, i\in S_C\right\},\ j\in S_N \tag{2}$$

Here $(E_{CH-res)i}$ is the residue energy of the ith CH node, $(E_{nonCH-res)j}$ is the residue energy of the non-CH node, S_C is the set of CHs, and S_N is the set of non-CH nodes.

In the second phase (steady-state phase), the non-CH node sends data to its CH. Each CH then aggregates received data and forwards them to the sink node. Simulation results show that ERA performs much better than the LEACH protocol in terms of network lifetime and energy efficiency.

A protocol in which energy and distance are considered while electing the CH was presented in [13]. In this protocol, CH selection is based on Eq. (3).

$$\text{Random}\,(n) < T\,(n)\ \text{and}\ d_{dist} > D_d \tag{3}$$

Here Random(n) is a random number generated by node n, T(n) is the threshold value, d_{dist} is the distance between the node and current CH, and D_d is the distance threshold, which is calculated by Eq. (4).

$$D_d=\frac{\sqrt{S}}{\sqrt{N*p}} \tag{4}$$

Here S is the area of a limited region, N is the number of network nodes, and p is the percentage of CH nodes. The distance factor in the election method of CH will distribute CHs uniformly in an actual limited region. Simulation results show that the proposed protocol is better than LEACH in terms of network lifetime.

The LEACH-mobile enhanced protocol (LEACH-ME) is based on a mobility factor [14]. Thus, the CH is elected based on the mobility factor. The simulation results show that the proposed protocol works better than LEACH-M and LEACH protocols in terms of network lifetime and energy consumption.

The authors of [15] proposed a new routing protocol for mobile wireless sensor networks.

In [16] surveys of routing techniques were discussed. The performance issues, advantages, and disadvantages of each routing technique were also discussed [16].

To improve the efficiency of energy utilization in WSNs, an energy-balanced clustering routing protocol was proposed [17]. In this protocol, the SN selects CHs based on signal intensity and higher remaining energy. The simulation results show that the proposed protocol performs better as compared with the LEACH protocol in terms of the number of data packets sent and network lifetime.

In LEACH-selective cluster (LEACH-SC), the CH is chosen by the SN where it chooses a CH that is the closest to the center point between the BS and itself [18]. The LEACH-SC protocol greatly balances the energy consumption among the sensors and thus extends the network lifetime as compared to LEACH protocol.

A cluster-based routing protocol (CBR-mobile) in WSNs was proposed [19]. It is a cross-layer design protocol between MAC and network layers for free mobility of SNs in WSNs. This protocol improves the packet delivery ratio, energy consumption, delay, and fairness in mobility environments compared to the LEACH-M protocol.

A new protocol, location-aware fault-tolerant clustering protocol for mobile WSNs (LFCP), was proposed [20]. The CH is elected based on the least mobility factor. Simulation results show that the LFCP protocol is significantly efficient in terms of energy consumption and data transmission delay compared to LEACH-M and LEACH-ME protocols.

3. Proposed protocols

In this section, we present the proposed protocols, the LEACHDistance and LEACHDistance-M protocols.

3.1. Assumptions

The following assumptions are made for the proposed protocols.

1. SNs deployed in a network are homogeneous. Each SN is initialized with the same amount of energy and they are also assumed to have the same transmission range.
2. The BS is static and is located at the center of the network area.
3. Each SN knows its position.
4. In the LEACHDistance protocol, all SNs remain static after the deployment.
5. In the LEACHDistance-M protocol, SNs are mobile.

3.2. Protocol descriptions

3.3. Setup phase

Step 1: Sensor network initialization

Many SNs are randomly deployed in the network area as a square field (100 × 100 m). The BS is deployed at the center of the network area (50, 50). For example, Figure 2 shows that four SNs, a, b, c, and d, are deployed in the network with coordinate points (x, y) as (2, 2), (7, 7), (25, 25), and (40, 40), respectively.

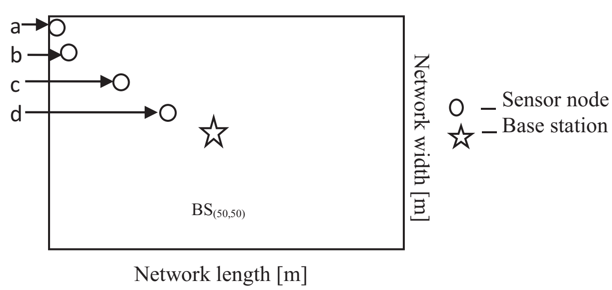

Figure 2. Sensor network initialization.

Step 2: Selection of eligible SNs for CH election process

Initially the BS selects a subset of SNs (G) whose distance is greater than the lower threshold distance, TD_L, and less than the upper threshold distance, TD_U, as shown in Eq. (5).

$$S_i \in G \text{ if } TD_L < \text{Distance } (S_i) < TD_U \tag{5}$$

Here TD_L = 20 m, TD_U = 60.8 m, and Distance(S_i) is the distance between SN, S_i(x1,y1), and BS(x2,y2) based on Euclidean distance as shown in Eq. (6).

$$\text{Distance}\,(S_i) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{6}$$

If the CHs elected are far away from the BS then the CHs will deplete their energy quickly if CHs use a single hop to transmit aggregated data to the BS. However, if CHs send the aggregated data to the BS using multihop transmission, the CH near the BS will deplete energy fast, thus introducing an energy hole in the network [21]. If the CHs elected are too near to the BS, then sensor nodes will deplete their energy fast in order to send data to their CH.

In order to overcome the above problems these regions are selected, i.e. the values of TD_L = 20 m, TD_U = 60.8 m are considered. Let a, b, c, and d be the four SNs deployed in the network with points (2, 2), (7, 7), (25, 25), and (40, 40), respectively. The Euclidean distance is computed between each SN and BS. The Euclidean distance between SN 'a' and the BS is 67.8 m, 'b' and BS is 60.8 m, 'c' and BS is 25.4 m, and 'd' and BS is 14.14 m. Based on Eq. (5), the 'b' and 'c' SNs are eligible for the CH election process as shown in Figure 3. Hence, $G = \{\text{b,c}\}$.

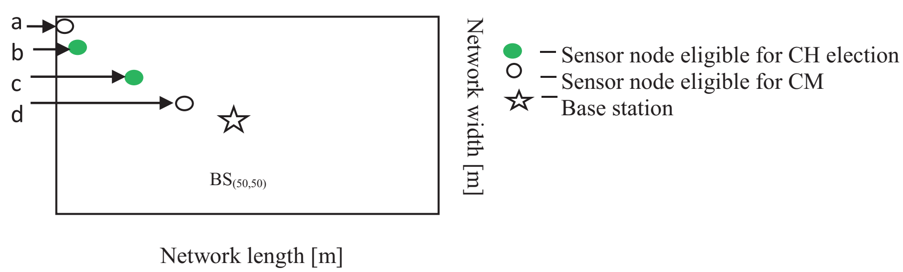

Figure 3. Selection of eligible SNs for CH election.

Step 3: The BS deselects SNs with greater velocity (applicable to LEACHDistance-M)

At the end of each round, all CHs provide a list of mobile SNs with their velocities to the BS. The BS now selects a subset of SNs, where greater velocity SNs will be removed from G in order to obtain G'.

Step 4: The BS now selects a SN as CH among the subset of SNs (G') based on remaining energy; that is:

$$T(n) = \begin{cases} \frac{P}{1 - P \times (r \bmod \frac{1}{P})} \times \frac{E_{n\_current}}{E_{n\_initial}} & \text{if } n \in G' \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Here P is the percentage of CHs, r is the number of rounds, G' is the set of nodes that have not been CHs in the last 1/P rounds, $E_{n\_current}$ is the current energy of the node, and $E_{n\_initial}$ is the initial energy of the node.

Step 5: After the CH is elected, it initially broadcasts a message to the SNs within its range using the CSMA/CA MAC protocol.

Step 6: A SN, upon receiving the messages from CHs, decides which cluster to join based on signal strength of the received messages.

3.3.1. Steady-state phase

Step 7: Each CH creates a separate TDMA schedule and broadcasts it to its CM. In the steady-state phase, each CM (SN) then sends sensed data to its CH during its allocated time slot.

Step 8: Each CH aggregates the received data from its CM and further broadcasts to the BS.

4. Simulation analysis

In this section the LEACH, LEACH-M, ERA, and proposed routing protocols (LEACHDistance and LEACHDistance-M) are simulated and their performances are analyzed and compared. Each of these protocols is simulated five times so a total of 25 random topologies is created.

4.1. Simulation parameters

LEACH, the LEACH-M protocol, ERA, and the LEACHDistance and LEACHDistance-M protocols are implemented in NS2. In our simulation, we have used a random waypoint model and the first-order radio model parameters, which are given in Table 1 [9]. In a random waypoint model, the SNs move randomly to reach the destination position with random direction and random speed from [0, Vmax], where Vmax is the maximum allowable velocity with which the SN may move. In the first-order radio model, the energy required to communicate between two SNs is symmetric. Based on the distance between transmitter and receiver, each SN consumes E_{TX} amount of energy to transmit a l-bit packet over distance d and E_{RX} amount of energy for receiving a l-bit packet, as shown in Eq. (8) and Eq. (9), respectively [22].

Table 1. Simulation parameters.

Parameter	Value
Network size	100 × 100 m
Number of SNs (N)	10–100
Percentage of cluster head	10%
EDA	5 nJ/bit/message
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_0	0.5 J
Percentage of mobile SNs	30
Velocity of SNs	0.5 m/s^2

$$E_{Tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, & \text{if } d < d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4, & \text{if } d \geq d_0 \end{cases} \quad (8)$$

$$E_{Rx}(l,d) = lE_{elec} \quad (9)$$

Here E_{elec} is the energy dissipated in the circuit, and ε_{fs} and ε_{mp} are free space (d^2 power loss) and multipath fading (d^4 power loss) channel parameters.

4.2. Simulation results and discussion

The protocols LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M are simulated and compared based on network lifetime, correlation coefficient, scalability, number of data packets received by the BS, and energy efficiency.

4.2.1. Network lifetime

The network lifetime is defined by using any of the following metrics. The time (or round) at which the first node depletes its energy (first node dies, FND), the time at which 50% of nodes deplete their energy (middle node dies, MND), or the time at which the last node depletes its energy (last node dies, LND) [23]. The network lifetime of the LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols when the number of SNs deployed is 100 and each SN is initialized with 0.5 J amount of energy is presented in Figure 4. In this experiment, it shows that the last node death (LND) occurs at round 106, 180, 224, 637, and 736 using the LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols respectively in the first trial. Thus, it is illustrated that the performance of the LEACHDistance protocol in terms of network lifetime is increased by 83.35%, 71.74%, and 64.8% as compared to LEACH, LEACH-M, and ERA protocols respectively and the performance of the LEACHDistance-M protocol in terms of network lifetime is increased by 85.59%, 75.54%, 69.56%, and 13.45% as compared to the LEACH, LEACH-M, ERA, and LEACHDistance protocols, respectively. Figure 5 presents the network lifetime of each of the routing protocols of the first trial in terms of MND. It illustrates that the MND of the proposed protocols is better than that of other protocols. The performance improvement occurs because in LEACHDistance-M and LEACHDistance, the selection of the CH is based on the upper and lower threshold distance and residual energy of the network as compared with the random selection of the CH in LEACH and LEACH-M and based only on energy in ERA. Furthermore, the LEACHDistance-M performs better than LEACHDistance as in LEACHDistance all SNs are static so the SNs that become CHs between TD_L and TD_U are now static and those SNs become CHs repeatedly and may consume energy faster. In LEACHDistance-M, if one SN is moving out of the threshold range, then there exists an equal probability that the other SNs may also enter into the threshold range. Hence, the newly entered SN's chance of becoming the CH increases. Thus, the chance of getting the same SN selected repeatedly as the CH is reduced in LEACHDistance-M as compared to LEACHDistance. Thus, LEACHDistance-M balances the network lifetime. Figure 6 provides error bars of the LND of each protocol for a repeated number of trials.

4.2.2. Correlation coefficient

To determine the correlation coefficient between energy and network lifetime, initially 100 SNs are deployed in the sensor network and each SN is initialized with energy 0.1 J and the network lifetime, i.e. the last node death, occurred at round 194. In the next experiments, the energy of SNs is initialized with 0.2 J, 0.3 J, 0.4 J, and 0.5 J and network lifetime is recorded as presented in Table 2. The correlation coefficient is computed using Eq. (10). The correlation coefficient ranges from –1 to +1 [24].

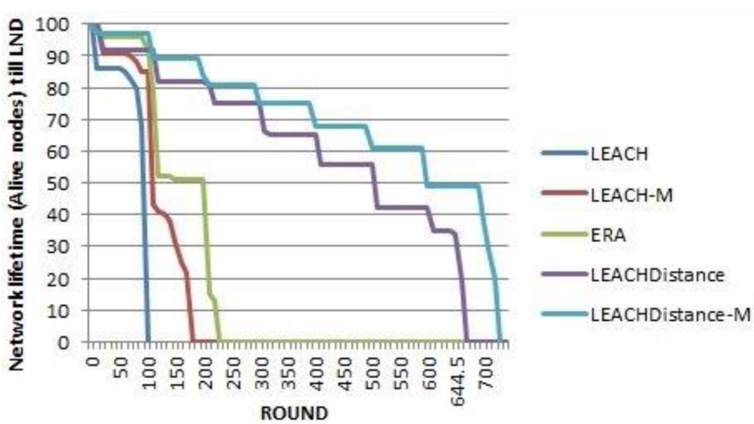

Figure 4. Network lifetime of LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols.

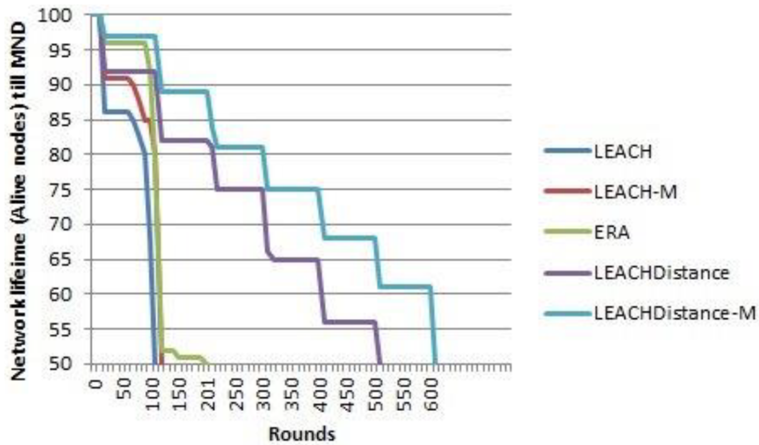

Figure 5. Network lifetime of each protocol illustrating MND.

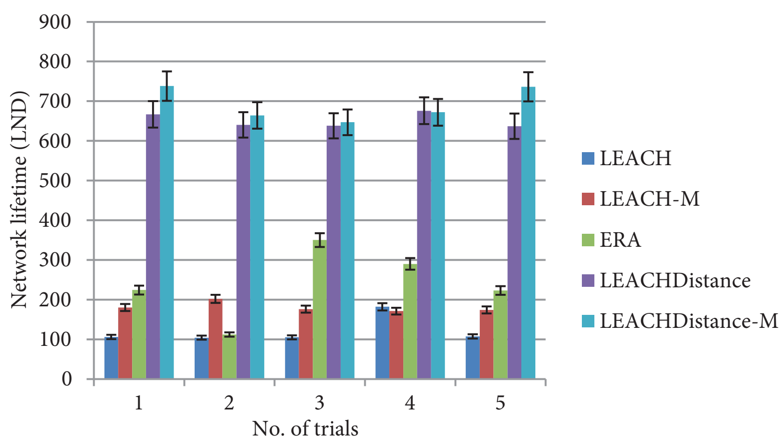

Figure 6. Network lifetime of LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols for repeated trials with error bars.

$$Correl\,(X,Y) = \frac{\sum(x-\overline{x})(y-\overline{y})}{\sqrt{\sum(x-\overline{x})^2(y-\overline{y})^2}} \tag{10}$$

The computed correlation coefficient is 0.981062. The value is close to +1, so there is a positive correlation between energy and network lifetime. This means that if we increase the energy of the SNs the network lifetime will increase.

Table 2. Network lifetime of LEACHDistance-M protocol with increased energy.

Experiment no.	Energy E_0	Network lifetime of LEACHDistance-M
1	0.1	194
2	0.2	348
3	0.3	445
4	0.4	510
5	0.5	736

4.2.3. Scalability

A scalable protocol should perform well as the network grows larger. To illustrate that our proposed protocols are more scalable as compared to existing protocols, experiments were carried out while varying the number of nodes from 10 to 100 and for all experiments the energy of each SN was initialized to 0.5 J. Initially 10 SNs were deployed in the network and for each of the protocols the round at which the last node depleted its energy was recorded. From Table 3, it can be observed that the proposed protocols LEACHDistance and LEACHDistance-M outperformed the LEACH, LEACH-M, and ERA protocols in terms of network lifetime. Thus, the proposed protocols are scalable as the size of the network grows larger.

Table 3. Scalability: network lifetime of LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols as the number of SNs is increased.

Experiment no.	Number of SNs	LEACH	LEACH-M	ERA	LEACH-Distance	LEACHDistance-M
1	10	99	116	120	117	109
2	20	136	178	199	203	199
3	30	230	270	286	270	284
4	40	156	110	323	345	339
5	50	205	262	372	409	442
6	60	189	227	435	437	502
7	70	226	201	435	523	526
8	80	108	205	518	534	622
9	90	240	205	603	626	798
10	100	106	180	223	637	736

4.2.4. Data packets received by BS

In Figure 7, we see the number of data packets received from the cluster head at the BS during the network lifetime when the network is initialized with 100 SNs, and each SN is initialized with 0.5 J energy. Figure 7 indicates that the number of data packets received by the LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols until the occurrence of LND is 6828, 7077, 7410, 8658, and 9500, respectively. Figure 8 presents the number of data packets received by the BS for each of the protocols until MND occurs. The number of data packets received at the BS (until MND occurs) is greater as compared to the other protocols. Thus, the proposed protocols LEACHDistance and LEACHDistance-M are more efficient than the LEACH, LEACH-M, and ERA protocols in terms of data packets received by the BS. This increased performance is due to the fact that the selection of the CH is based on a threshold range and the remaining energy in LEACHDistance and LEACHDistance-M is also based on the least mobility factor. The CHs are distributed over the entire threshold range and thus are able to connect with more SNs and thus gather more data packets as compared with other protocols. Figure 9 presents error bars of the number of data packets received by each protocol for repeated trials.

4.2.5. Energy efficiency

In this experiment, 100 SNs are deployed randomly and the initial energy of SNs is initialized with 0.5 J and energy efficiency is measured for each of the protocols. Figure 10 shows that 100 SNs have depleted their energy at round 106, 180, 223, 637, and 736 using LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M respectively in the first trial. Thus, the proposed protocols LEACHDistance and LEACHDistance-M are more energy-efficient as compared to the LEACH, LEACH-M, and ERA protocols.

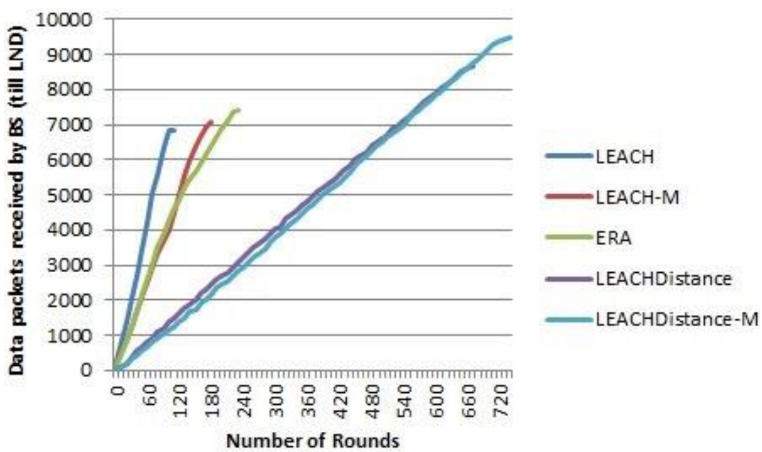

Figure 7. Number of data packets received by BS using LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols.

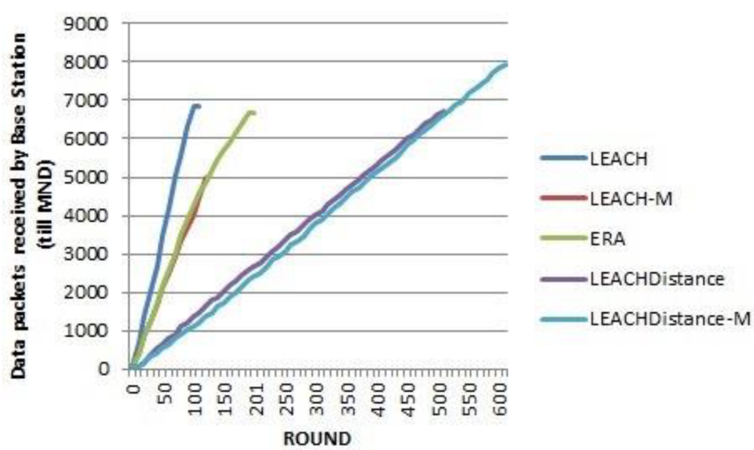

Figure 8. Data packets received by BS by each of the protocols until the occurrence of MND.

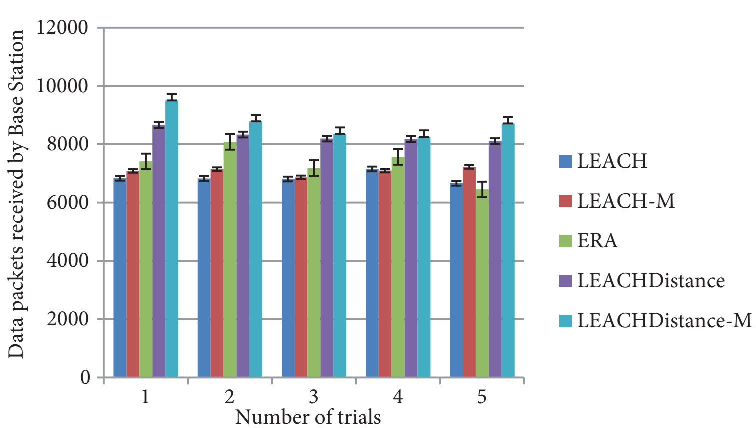

Figure 9. Number of data packets received by BS using LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols for repeated trials with error bars.

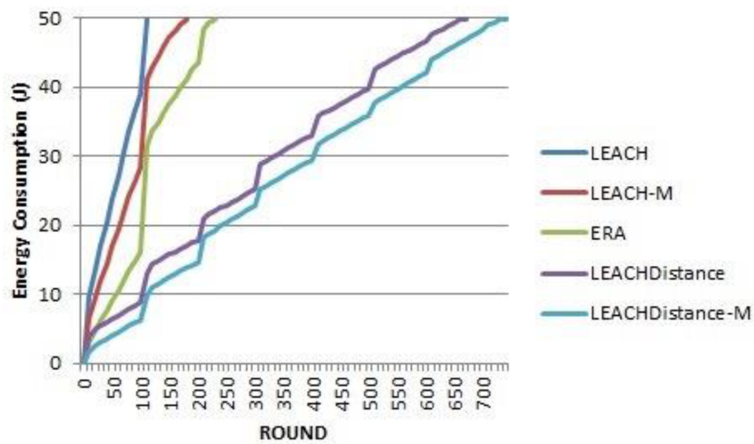

Figure 10. Energy efficiency of LEACH, LEACH-M, ERA, LEACHDistance, and LEACHDistance-M protocols.

5. Conclusion and future work

In this research paper, two protocols, LEACHDistance and LEACHDistance-M, have been proposed and simulated and their performance was compared with that of the LEACH, LEACH-M, and ERA protocols. If the selected cluster head (CH) is too far away from the sink node (BS) then the CH depletes high energy to forward the aggregated data; hence, it dies quickly. If the selected CH is too close to the sink node but far away from the SNs, the SNs deplete energy quickly and die fast in order to send the sensed data. Hence, in the LEACHDistance and LEACHDistance-M routing protocols, the CH is selected if its distance lies between the lower threshold (TD_L) and upper threshold (TD_U) distances and also based on remaining energy. The proposed protocols, LEACHDistance and LEACHDistance-M, work for static and mobile WSNs respectively and simulation results show that they perform better than the LEACH, LEACH-M, and ERA protocols in terms of network lifetime, scalability, number of data packets received by the BS, and energy efficiency. Simulation results also emphasize that the energy and network lifetime are correlated with each other.

In the LEACHDistance-M protocol, 30% of the SNs were mobile with velocity of 0.5 m/s. Furthermore, the work can be extended to analyze the network lifetime of this protocol with the increase in mobile SNs while varying their velocities and by computing the optimal number of mobile SNs. Heterogeneity in SNs may be provided in order to further increase network lifetime of the proposed protocol.

References

[1] Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. Wireless sensor networks: a survey. J Comput Netw 2002; 38: 393-422.

[2] Akyildiz I F, Stuntebeck E. Wireless underground sensor networks: research challenges. J Ad Hoc Netw 2006; 4: 669-686.

[3] Zheng J, Jamalipour A. Wireless Sensor Networks: A Networking Perspective. Hoboken, NJ, USA: John Wiley and Sons, 2009.

[4] Al-Karaki J, Kamal A. Routing techniques in wireless sensor networks: a survey. J IEEE Wirel Commun 2004; 11: 6-28.

[5] Abbasi A, Younis M. A survey on clustering algorithms for wireless sensor network. J Comput Commun 2007; 30: 2826-2841.

[6] Yang Y, Fonoage MI, Cardei M. Improving network lifetime with mobile wireless sensor networks. J Comput Commun 2010; 33: 409-419.

[7] Akkaya K, Younis M. A survey on routing protocols for wireless sensor networks. J Ad Hoc Netw 2005; 3: 325-349.

[8] Kansal A, Somasundara A, Jea D, Srivastava MB, Estrin D. Intelligent fluid infrastructure for embedded networks. In: 2nd International Conference on Mobile Systems, Applications, and Services; 6–9 June 2004; New York, NY, USA. New York, NY, USA: ACM. pp. 111-124.

[9] Heinzelman W, Chandrakasan A, Balakrishnan. Energy-efficient communication protocol for wireless microsensor networks. In: IEEE System Sciences 33rd Hawaii International Conference; 4–7 January 2000; Maui, HI, USA. New York, NY, USA: IEEE. pp. 1-10.

[10] Kim DS, Chung YJ. Self-organization routing protocol supporting mobile nodes for wireless sensor network. In: IEEE 2006 1st International Multi-Symposiums on Computer and Computational Sciences; 20–24 June 2006; Hanzhou, China. New York, NY, USA: IEEE. pp. 622-626.

[11] Zhang X, Wang H, Khokhar A. An energy-efficient data collection protocol for mobile sensor networks. In: Vehicular Technology Conference; 25–28 September 2006; Montreal, Canada. New York, NY, USA: IEEE. pp. 1-5.

[12] Chen H, Wu CS, Chu YS, Cheng CC, Tsai LK. Energy residue aware (ERA) clustering algorithm for leach-based wireless sensor networks. In: IEEE 2007 Systems and Networks Communications Second International Conference; 25–31 August 2007; Cap Esterel, France. New York, NY, USA: IEEE. pp. 1-6.

[13] Hou R, Ren W, Zhang Y. A wireless sensor network clustering algorithm based on energy and distance. In: IEEE 2009 Computer Science and Engineering Second International Workshop; 28–30 October 2009; Qingdao, China. New York, NY, USA: IEEE. pp. 439-442.

[14] Kumar GS, Paul V, Jacob KP. Mobility metric based leach-mobile protocol. In: IEEE Advanced Computing and Communications 16th International Conference; 14–17 December 2008; Chennai, India. New York, NY, USA: IEEE. pp. 248-253.

[15] Nguyen LT, Defago X, Beuran R, Shinoda Y. An energy efficient routing scheme for mobile wireless sensor networks. In: IEEE 2008 Wireless Communication Systems International Symposium; 21–24 October 2008; Reykjavik, Iceland. New York, NY, USA: IEEE. pp. 568-572.

[16] Lambrou TP, Panayiotou CG. A survey on routing techniques supporting mobility in sensor networks. In: Mobile Ad-Hoc and Sensor Networks 5th International Conference; 14–16 December 2009; Fujian, China. New York, NY, USA: IEEE. pp. 78-85.

[17] Lan Y, Fuxiang G, Peng L. An energy-balanced clustering routing protocol in wireless sensor networks. In: Power Electronics and Intelligent Transportation System 2nd International Conference; 19–20 December 2009; Shenzhen, China. New York, NY, USA: IEEE. pp. 283-286.

[18] Jun W, Xin Z, Junyuan X, Zhengkun M. A distance-based clustering routing protocol in wireless sensor networks. In: Communication Technology 12th IEEE International Conference; 11–14 November 2010; Nanjing, China. New York, NY, USA: IEEE. pp. 648-651.

[19] Awwad SA, Ng CK, Noordin NK, Rasid MFA. Cluster based routing protocol for mobile nodes in wireless sensor network. J Wireless Pers Commun 2011; 61: 251-281.

[20] Karim L, Nasser N. Reliable location-aware routing protocol for mobile wireless sensor network. J IET Commun 2012; 6: 2149-2158.

[21] Chen G, Li C, Ye M, Wu J. An unequal cluster-based routing protocol in wireless sensor networks. Wirel Netw 2009; 15: 193-207.

[22] Heinzelman WB, Chandrakasan AP, Balakrishnan H. An application-specific protocol architecture for wireless microsensor networks. IEEE T Wirel Commun 2002; 1: 660-670.

[23] Yu J, Qi Y, Wang G, Gu X. A cluster-based routing protocol for wireless sensor networks with nonuniform node distribution. AEU-Int J Electron C 2012; 66: 54-61.

[24] Walpole RE, Myers RH, Myers SL, Ye K. Probability and Statistics for Engineers and Scientists. 8th ed. New York, NY, USA: Macmillan, 1993.