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A Novel Energy-Efficient Multihop Communication Protocol (EEMCP) for Clustered Heterogeneous Wireless Sensor Networks

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Abstract: Recent research on heterogeneous Wireless Sensor Networks (WSNs) has been studied and employed in many new applications viz., medical monitoring, automotive safety, agriculture precision and many more. In this paper, a novel energy efficient multihop communication protocol (EEMCP) for clustered heterogeneous WSNs has proposed to analyze the network lifetime and stability. EEMCP consider heterogeneous nodes with different initial energy levels and adopt multihop communication approach for data communication from cluster heads to the base station. Simulation results show that EEMCP extends the network lifetime and stability by balancing energy consumption of the network.

Keywords: clustering, heterogeneous, lifetime, multihop, wireless sensor network

INTRODUCTION

Effective energy management in heterogeneous Wireless Sensor Networks (WSNs) is amore challenging issue compared to homogeneous WSNs. Many researchers have studied that existing energy preservation protocols for homogeneous WSNs do not perform efficiently when applied to heterogeneous WSNs.

We make the distinction between homogeneous and heterogeneous WSNs. A homogeneous WSN is composed of tiny, resource-constrained devices, using the same platform and having the same hardware capabilities. The functionality of a homogeneous WSN serves mainly the purpose of gathering the sensed data and sending it to a central location. The typical research questions focus on prolonging the lifetime of the network, by designing energy-efficient protocols which distribute the communication overhead evenly among the sensor nodes. A heterogeneous WSN employs a range of different devices, which are able to cooperate in order to achieve a global goal by combining the individual capabilities of the nodes. Small and cheap sensor nodes are deployed with high density and easily attached to people or objects moving in the environment, while the more powerful nodes are able to provide persistent data storage, intensive processing and actuation. In such a network, the objective is to distribute the workload depending on the capabilities of the nodes.

In [1], the authors compare homogeneous and heterogeneous sensor networks for single-hop clusters. In [2], the author presents a modified protocol, but it is still faulty and the performance metrics are complex. Multihop protocol is studied in paper [3], but it is quite complex.

In general, most research works [4-8] that consider a heterogeneous network model assume two different types of nodes are deployed with the more powerful node having more energy as compared to a normal node; nodes will be grouped into clusters and powerful sensor nodes will always be the Cluster Heads (CHs) for the clusters.

In this paper, we have analyzed the lifetime of the network with three types of nodes, normal, advanced and super, with super and advanced nodes having more battery energy than the normal node. The routing protocol proposed is based on dynamic clustering and a multihop approach is assumed to analyze the performance of the network. The proposed protocol is especially granting a large lifetime for the wireless sensor network with limiting energy.

The remaining of this paper is organized as follows. Section II includes a detailed survey of the related research. Section III exhibits the details of the proposed protocol. Simulation results and its discussion is given in Section IV. Finally, Section V concludes the paper.

RELATED WORK

Routing in WSNs is a challenging task firstly because of the absence of global addressing schemes; secondly data source from multiple paths to single source, thirdly because of data redundancy and also because of energy and computation constraints of the network [9, 10]. The conventional routing algorithms are not efficient when applied to WSNs. The performance of the existing routing algorithms for WSNs varies from application to application because of diverse demands of different applications. There is a strong need for development of routing techniques which work considerably across wide range of applications.

Low-Energy Adaptive Clustering Hierarchy (LEACH) [11] is one of the most popular distributed cluster-based routing protocols in wireless sensor networks. LEACH randomly selects a few nodes as cluster heads and rotates this role to balance the energy dissipation of the sensor nodes in the networks. The cluster head nodes fuse and aggregate data arriving from member nodes of the respective cluster. Then the Cluster Heads (CHs) send an aggregated data to the Base Station (BS), in order to reduce the amount of data and transmission of the duplicated data. Data collection is centralized to BS and performed periodically. The operation of LEACH is generally separated into two phases, the set-up phase and the steady-state phase. In the set-up phase, cluster heads are selected and clusters are organized. In the steady-state phase, the actual data transmissions to the BS take place. After the steady-state phase, the next round begins.

During the setup phase, when clusters are being created, each node decides whether or not to become a CH for the current round. This decision is based on a predetermined fraction of nodes and the threshold *T(s)*, which is given by (1):

$$T(s) = \begin{cases} \dfrac{p_{opt}}{1 - p_{opt}.(r \bmod \frac{1}{p_{opt}})} & if \quad s \in G \\ 0 & otherwise \end{cases} \qquad (1)$$

where p_{opt} is the predetermined percentage of cluster heads, r is the count of current round. The G is the set of sensor nodes that have not been cluster heads in the last $1/p_{opt}$ rounds. Using this threshold, each node will be a cluster head at some round within $1/p_{opt}$ rounds. After $1/p_{opt}$ rounds, all nodes are once again eligible to become cluster heads. In this way the energy concentration on CHs is distributed. LEACH does not consider the residual energy of each node so the nodes that have relatively small energy remained can be the CHs. This makes the network lifetime shortened.

Many research works have been proposed to deal with nodes' limitation problems; they are related to routing within the sensor networks. In [12, 13], we have presented a single hop energy-efficient heterogeneous clustered scheme for wireless sensor networks. The proposed protocol increased the network lifetime ten times than LEACH.

In [14], the authors have investigated the existing clustering algorithms. It is essential to improve energy efficiency for wireless sensor networks as the energy supply for sensor nodes is usually extremely limited. Clustering is the most energy efficient organization for wide application in the past few years and numerous clustering algorithms have been proposed for energy saving [15-17]. In clustered WSNs, two typical methods to aggregate data after it has collected from all member nodes before the inter-cluster communication occurs [18], another is to aggregate data over each passing hop [19]. In [20], the authors presented the multi hop routing algorithm for inter cluster communication.

EEMCP: THE PROPOSED PROTOCOL

In this section, we describe a radio energy dissipation model that is used in the analysis of EEMCP protocol. The energy consumption, the optimum number of clusters and multihop approach are used to evaluate the proposed protocol. We also define the performance measures that we have considered in this paper to evaluate the performance of protocols are as follows.

Network lifetime: This is the time interval from the start of operation (of the sensor network) until the death of the first alive node.

Number of cluster heads per round: This instantaneous measure reflects the number of nodes which would send directly to the sink information aggregated from their cluster members.

Number of alive nodes per round: This instantaneous measure reflects the total number of nodes and that of each type that has not yet expended all of their energy.

Throughput: We measure the total rate of data packets sent over the network, the rate of data sent from cluster heads to the sink as well as the rate of data sent from the nodes to their cluster heads.

Stability Period: This is the time interval from the start of network operation until the death of the first sensor node.

Radio Energy Dissipation Model

In this paper, we have use the simplified first order radio model presented in [11] for the radio hardware energy dissipation. In the specified model, the radio dissipates Q to run the transmitter or receiver circuitry. The τ and μ is the amount of energy per bit dissipated in the transmitter or receiver amplifier. Using the given radio model, the energy consumed (E_{TL}) to transmit a L-bit message for a longer distance, $d>d_0$, is given by (2) and the energy consumed (E_{TS}) for a shorter distance, $d \leq d_0$, is given by (3):

$$E_{TL} = L.(Q + \mu.d^4) \quad (2)$$

$$E_{TS} = L.(Q + \tau.d^2) \quad (3)$$

Moreover, the energy consumed (E_{RX}) to receive the L-bit message is given by (4):

$$E_{RX} = L.Q + E_{DA} \quad (4)$$

Additionally, data aggregation is adopted to save energy. It is assumed that the sensed information is highly correlated, thus the CH can always aggregate the data of its member nodes into a single packet. And this operation also consumes energy E_{DA}.

Energy Consumption during Election Phase

For a sensor network of N nodes, the optimal number of clusters is given as q. All nodes are assumed to be at the same energy level at the beginning. The amount of consumed energy is same for all the clusters. At the start of the election phase, the base station randomly selects a given number of cluster heads. First, the cluster heads broadcast messages to all the sensors in their neighborhood. Second, the sensors receive messages from one or more cluster heads and choose their cluster head using the received signal strength. Third, the sensors transmit their decision to their corresponding cluster heads. Fourth, the cluster heads receive messages from their sensor nodes and remember their corresponding nodes. For uniformly distributed clusters, each cluster contains N/q nodes. Using (3) and (4), the energy consumed by a cluster head (E_{CH}) is estimated as given by (5):

$$E_{CH} = L.Q.\frac{N}{q} + L.E_{DA}.(\frac{N}{q} - 1) + L.\tau.d^2 \quad (5)$$

The first part of (5) represents the energy consumed to transmit the advertisement message; this energy consumption is based on a shorter distance energy dissipation model. The second part of (5) represents the energy consumed to receive $(N/q-1)$ messages from the sensor nodes of the same cluster. Using Equation (3) and (4), the energy consumed by non-cluster head (E_{NCH}) sensor nodes is estimated by (6):

$$E_{NCH} = \{(q+1).L.Q + q.L.E_{DA} + L.\tau.d^2)\} \quad (6)$$

The first part of (6) shows the energy consumed to receive messages from q cluster heads; it is assumed that a sensor node receives messages from all the cluster heads. The second part of (6) shows the energy consumed to transmit the decision to the corresponding cluster head.

Optimum Number of Clusters

The optimal probability of a node being elected as a cluster head is a function of spatial density when nodes are uniformly distributed over the sensor field. This clustering is optimal in the sense that energy consumption is well distributed over all sensors and the total energy consumption is minimum. Such optimal clustering highly depends on the energy model we use. For the purpose of this study we use similar energy model and analysis as proposed in [11, 12].

The optimal probability of a node to become a cluster head, p_{opt}, can be computed as given by [13] and is given in (7):

$$p_{opt} = \frac{q_{opt}}{N} \quad (7)$$

where q_{opt} is the optimal number of cluster heads per round. The optimal probability for a node to become a cluster head is very important. In [10], the authors showed that if the clusters are not constructed in an optimal way, the total consumed energy of the sensor network per round is increased exponentially either when the number of clusters that are created is greater or especially when the number of the constructed clusters is less than the optimal number of clusters.

Our approach is to assign a weight to the optimal probability p_{opt}. This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. Let us define P_1, P_2 and P_3 are the weighted election probabilities for the normal advanced and super nodes. The weighted probabilities of average number of cluster heads for normal, advanced and super nodes are given by (8), (9) and (10) respectively:

$$P_1 = \frac{p_{opt}}{1 + m.Q} \quad (8)$$

$$P_2 = \frac{p_{opt}}{1 + m.Q}.(1 + \alpha) \quad (9)$$

$$P_3 = \frac{p_{opt}}{1 + m.Q}.(1 + \beta) \quad (10)$$

where $Q = \alpha - p.(\alpha - \beta)$

In this paper, we have expanded the work proposed in [12] and [13]. In this section, we have described an operation of the proposed protocol. During the setup phase, CHs are elected as in [13] and then clusters are formed, and then establish shortest-path-cost-based multihop routing among the cluster heads and BS. During the steady state phase, the sensor nodes sense the data from the environment and then transmit the sensed data to the BS according to shortest-path energy cost link. Finally, the path with the lowest cost link is the shortest-path to the sink or BS that saves the energy of the network.

Setup Phase

In [12], each CH directly communicates with sink no matter the distance between cluster head and sink is far or near. It will consume lot of battery energy if the distance of cluster head is far from the BS. In this phase, the proposed protocol performed the following steps: 1) cluster head election, 2) cluster formation and 3) shortest-path cost based multihop routing. The process of the setup phase is shown in Fig. 1(a).

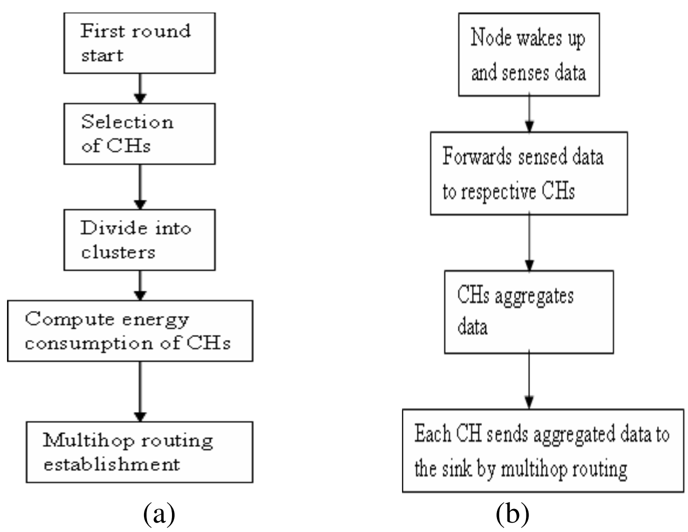


Figure 1: (a) Setup phase (b) Steady-state phase.

Multihop Routing

At present, there are two types of inter-transmission mode, single hop and multihop. In this paper, we have adopted the multihop mode to achieve the inter-cluster transmission. It means that the cluster heads transmitted their aggregated data to the sink node by passing several other cluster heads. When the furthest cluster heads want to transmit their own aggregated data to the BS, they have to calculate the shortest cost path to the BS node.

After the clusters are formed and cluster heads are selected, then each cluster head calculates the optimal path among cluster heads to the sink. We have implemented a shortest-path energy cost-based approach for multihop routing. In this approach we make use of comparative energy costs of different alternative routes to the sink as a basis to form a chain(s) of cluster heads. The main idea of the proposed algorithm is to build a shortest path among cluster heads and sink. First, all possible shortest-paths link costs are calculated from each CH node to the sink. Then, according to the optimal path, each CH transmits data to the corresponding CHs which is nearest to the BS. Finally, the path with the lowest cost link is considered as the shortest-path to the BS that saves the energy of the network.

Algorithm for Proposed Protocol

The proposed algorithm follows these steps:

Step1: There exists a graph of the cluster head network from which the CH and sink node are identified.

Step2: The Path matrix with their route energy cost, called the "adjacency matrix" represented in the form of array matrix in code implementation.

Step3: The graph builds a status record set for every cluster head in the network. The record contains three fields:

- Predecessor field - The first field shows the previous node.
- Length field - The second field shows the sum of the weights from the source to that node.
- Label field - The last field shows the status of CH node. Each CH node can have one status mode: "permanent" or “tentative”.

Step4: The graph initializes the parameters of the status record set (for all CH nodes) and sets their length to "infinity" and their label to “tentative”.

Step5: The graph sets a T-node.

Step6: The graph updates the status record set for all tentative nodes that are directly linked to the CH T-node.

Step7: The router looks at all of the tentative nodes and chooses the one whose weight to CH is lowest. That node is then the destination T-node.

Step8: If this node is not Sink (the intended destination cluster head), the graph goes back to step 5.

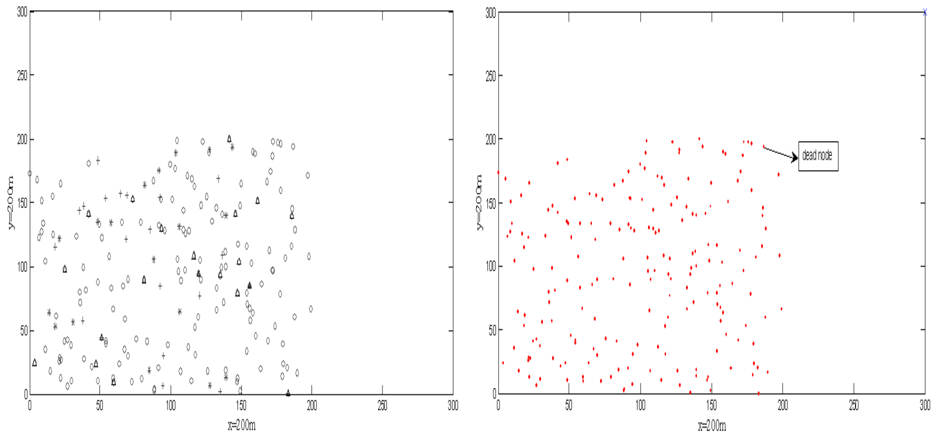
Step9: If this node is BS, the graph extracts its previous cluster heads (node) from the status record set and does this until it arrives at source CH node. Thus shows the best route from CH (source cluster head) to sink (destination).

Steady-State Phase

In the steady state phase, the cluster heads turn their receiver unit on for receiving messages from their members while non cluster head nodes are always placed into sleep mode in order to save their battery energy. In each cluster, the cluster head receives the messages then aggregates the received messages with its own message. The aggregated message is then forwarded to next hop receiver (sink or CH) on the routing information calculated by the optimal path approach. The flow chart of multihop between cluster heads and BS is shown in Fig. 1(b).

SIMULATION RESULTS AND DISCUSSION

In this section, we have introduced EEMCP whose goal is to increase the lifetime, load balancing and stability of the network in the presence of heterogeneous nodes. Let us assume the case where a percentage of the population of sensor nodes is equipped with more energy resources than the normal sensor nodes in the network. Let $m=2$ be the fraction of the total number of nodes N, and $m_o=0.5$ is the percentage of the total number of nodes m which is equipped with β=1 times more energy than the normal nodes, we call these nodes as super nodes. The rest $n.m.(1-m_o)$ nodes are equipped with α=2 times more energy than the normal nodes; we refer to these nodes as advanced nodes and remaining $n.(1-m)$ as normal nodes. We assume that all nodes are distributed uniformly over the sensor field. Note that new heterogeneous setting has no affect on the spatial density of the network so the setting of p_{opt} does not change. On the other hand, the total energy of the network changes. Suppose E_0 is the initial energy of each normal node. The energy of each super node is then $E_0.(1+\beta)$ and of each advanced node is then $E_0.(1+\alpha)$. The deployment of the network is as shown in Fig. 2(a), we denote with ‘o’ a normal node, with ‘+’ an advanced node, with ‘*’ a super node, and with ‘x’ the sink or base station (BS). Fig. 3 shows the general operation of the proposed protocol algorithm by implementing multihop routing approach, where the elected CHs transmit their aggregated data to the BS by passing through several other CHs using shortest path link. As shown in Fig. 2(b), a few nodes die after some rounds which are denoted with ‘**.**’.



(a) (b)

Figure 2: (a) Random Deployment of the network in an area of 200 by 200 m^2 (b) Dead nodes distribution in MEEHC

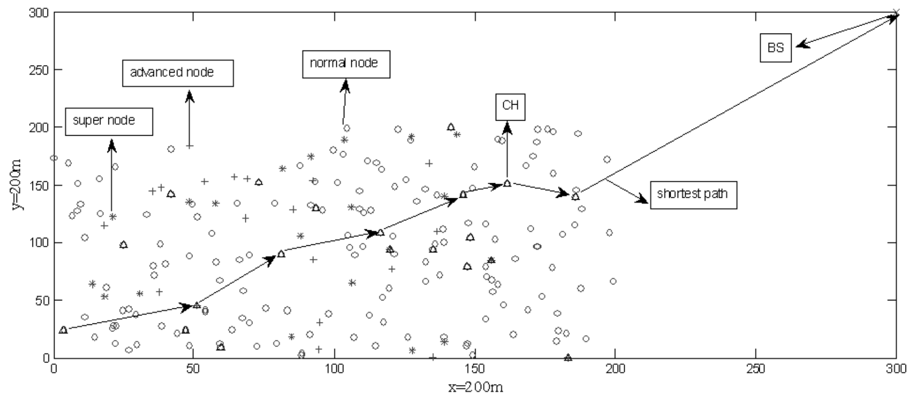


Figure 3: General operation of the algorithm with the BS at (300,300)

To validate the performance of our protocol, we have simulated the MEEHC, EEHC and the LEACH techniques. We have used a network with *N*=200 nodes randomly deployed between (x=0, y=0) and (x=200, y=200), and the sink or base station at (300,300), the distance is given in meter. Each data message is 4000 bits long in every round.

The initial power of normal nodes is considered to be 0.5J. To determine the number of cluster for our network, we have used the expression given in [12]. We take the communication energy parameters as: $Q=50nJ/bit$, $\tau=10pJ/bit/m^2$, $\mu=0.0013pJ/bit/m^4$ and the energy for data aggregation is set as $E_{DA}=5nJ/bit/signal$.

We have carried out a comparison among EEMCP, EEHC and LEACH protocols through simulations. Fig. 4 shows the performance of network lifetime in terms of alive nodes over number of rounds in the network. There are more alive nodes per round in EEMCP because more energy is required to transmit the data from CHs to BS in a single hop communication rather than multihop. It also indicates the first node die earlier in LEACH and EEHC protocol as compared to EEMCP. The nodes death rate is substantial in LEACH, EEHC as compared to EEMCP. So, EEMCP survives longer than LEACH protocol and EEHC protocol. Fig. 5 shows the energy cost calculated for shortest-path of each CH over number of rounds to transmit the data messages to BS. Each CH has different path link or energy cost to transmit the data to the BS, because the position of some CHs are near to the BS whereas some are far away.

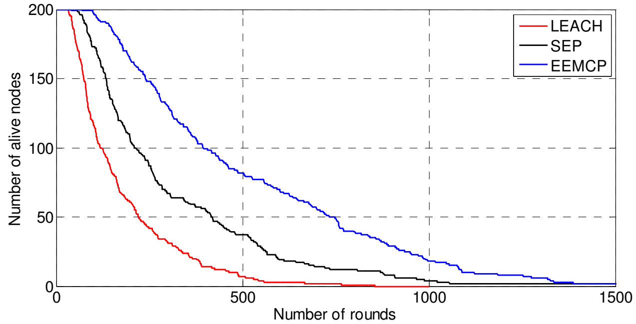
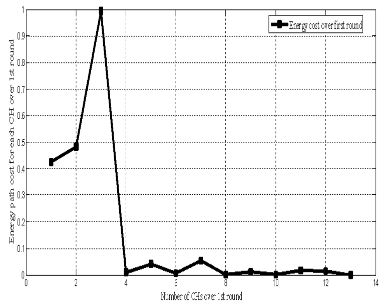
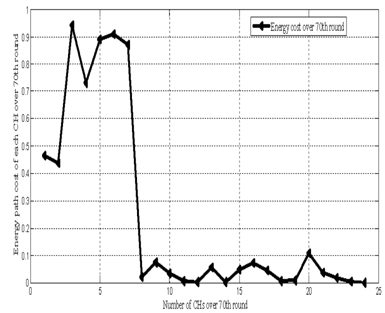


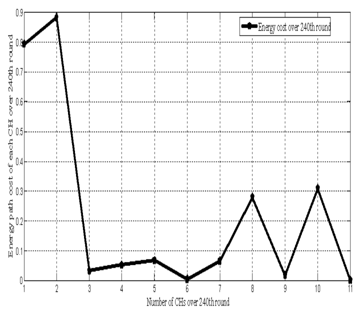
Figure 4: Number of alive nodes over number of rounds.



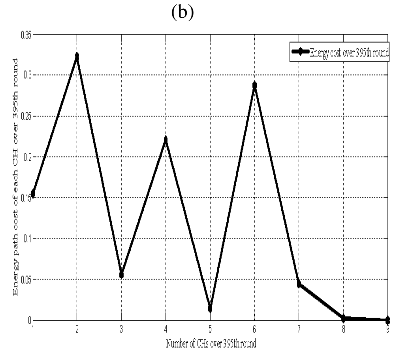
(a)



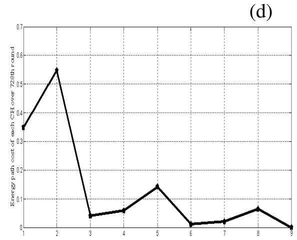
(b)



(c)



(d)



(e)

Figure 5: Shortest-path energy cost of each CH over: (a) 1^{st} round, (b) 70^{th} round, (c) 240^{th} round, (d) 395^{th} round and (e) 728^{th} round

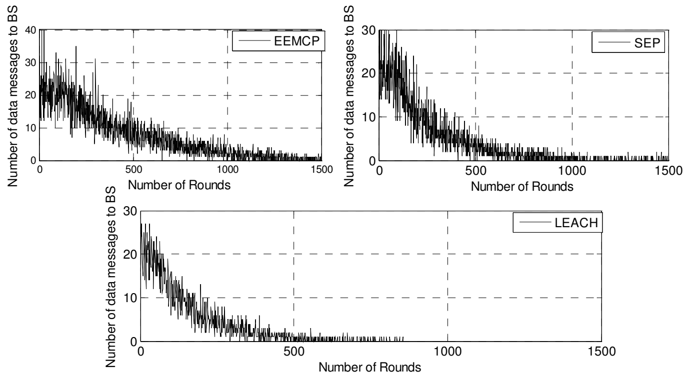


Figure 6: The number of data messages received at the base station over rounds

Fig. 6 represents the throughput in terms of the number of data packets received at the BS from CHs in LEACH, EEHC and EEMCP in the stable region and for most of the unstable region. This means that EEMCP guarantees more CHs in more rounds.

The extension of the network service duration is made by the reduction of the number of the messages transmitted intra-cluster due to avoiding the transmission of redundant information. Consequent to this reduction, the transmissions and reception nodes energy is economized, and, therefore, the network lifetime is extended. So, EEMCP survives longer than LEACH and EEHC protocols. All the simulation results show that the EEMCP grant a maximal network lifetime and throughput as compared to LEACH and EEHC protocol.

In EEMCP every sensor node in a heterogeneous wireless sensor network independently elects itself as a cluster head based on its initial energy relative to that of other nodes. We do not require any global knowledge of energy at every election round. The simulation results show that the EEMCP provides best characteristics compared to the LEACH and EEHC in terms of lifetime, throughput and energy. It allows a good energy balancing over the network's nodes. The first dead node appears later, and the death rate of node is lower, that permits surveying the environment fairly. Also, the number of messages transmitted to the base station is more as compared to LEACH and EEHC.

CONCLUSION

In this paper, we have studied heterogeneous wireless sensor networks with multihop approach. EEMCP adopts multihop communication between cluster heads and sink. Simulation results show that EEMCP offers better performance than LEACH and EEHC in terms of network lifetime, throughput and energy consumption across the network. We can note that, in our solution, the lifetime of network is greatly increased i.e., by a factor of 40%. For future work, EEMCP can be extended to deal with an energy efficient dissipation algorithm through data gathering in a mobile sensor network.

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