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Deterministic Energy Efficient Clustering Protocol For Wireless Sensor Network Using Evolutionary Optimization Technique

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***Abstract* - Wireless sensor network (WSN) technologies have been employed in recent years for monitoring purposes in various areas from engineering industry to our home environment due to their ability to intelligently monitor remote locations. In this paper, we have studied a purely deterministic model that utilizes clustering to organize the WSN. We propose a deterministic energy-efficient clustering protocol using evolutionary optimization Technique that is dynamic, distributive, self-organizing and more energy efficient than the existing protocols. It utilizes a simplified approach which minimizes computational overhead-cost to self-organize the sensor network. Our simulation result shows a better performance with respect to energy consumption, which is reflected in the network lifetime in both homogeneous and heterogeneous settings when compared with the existing protocols.**

I. INTRODUCTION

With the advancement in micro-fabrication technology, Wireless Sensor Networks (WSNs) have started to play a vital role in our daily lives. Efficient design and implementation of wireless sensor networks have become a hot area of research in recent years, due to the immense capacity of sensor networks to enable applications connecting the physical world with the virtual world. It is possible to obtain data about physical or environmental phenomena by networking large number of tiny sensor nodes that was difficult or impossible to obtain in more conventional ways. WSN is a collection of wireless nodes with limited energy capabilities that may be mobile or stationary and are located randomly on a dynamically changing environment. The routing strategies selection is an important issue for the efficient delivery of the packets to their destination. Moreover, in such networks, the applied routing strategy should ensure the minimum of the energy consumption and hence maximization of the lifetime of the network. A lot of work on the WSNs field has been carried out resulting in the development of the WSNs on a wide variety of applications and systems with vastly varying requirements and characteristics. At the same time, various energy-efficient routing protocols have been designed and developed for WSNs in order to support efficient data delivery to their destination. Thus, each energy-efficient routing protocol may have specific characteristics depending on the application and network architecture. A routing protocol is required when a source node cannot send its packets directly to its destination node but has to rely on the assistance of intermediate nodes to forward these packets on its behalf. Routing in WSNs is very challenging due to several inherent characteristics that distinguish them from contemporary communication and wireless ad hoc networks. First, it is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Therefore, classical IP-based protocols cannot be applied to sensor networks. Second, in contrast to typical communication networks almost all applications of sensor networks within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization. Fourth, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage. Thus, they require careful resource management Due to such differences, many new algorithms have been proposed for the routing problem in WSNs.

II.DEC Protocol:

A deterministic energy-efficient clustering protocol that promises a better election of cluster-heads is proposed. This proposed protocol uses the sensor node's residual energy solely as the election criterion. Simulation results show that the proposed model is able to manage energy consumption better and achieves the desired result for wireless sensor networks

III. WIRELESS SENSOR NETWORK MODELS

Developing a protocol that can optimize the energy consumption has been the focus of several authors. One of the main attributes of these protocols such as LEACH is that they utilize clustering schemes to collaborate among the sensors in the network.

So far we have used a probabilistic-based model to manage energy consumption in WSNs. One of the goals of these protocols is to extend the WSN lifetime using the global information derived from the network without considering the local information i.e the residual energy of each node. The downside of such protocols is that there is no guarantee that the desired number of clusterheads (CHs) will be elected or the elected CH will have enough energy to perform its duty as a leader. Also, it was noted that a deterministic cluster head selection algorithm can outperform a probabilistic-based algorithm in terms of energy consumption. Though many other protocols have been an improvement over the original LEACH protocol with respect to network lifetime. However, the model used is still probabilistic-based with deterministic components introduced. Their model suffers from similar problem of unguaranteed cluster-head election per round as with the other probabilistic-based models. Although, LEACH proposed an optimal setting that can guarantee the best performance using their stochastic model, but most of the time the result could be sub-optimal due to the uncertainties in the cluster-head election process. A generic probabilistic model used by these protocols is given in Eq.(1).

$$T(n_x) = \begin{cases} \frac{P_x}{1-P_x[r \ mod(1/P_x)]} \times Q & \text{if } n_x \in G'; \\ 0 & Otherwise, \end{cases} \quad (1)$$

where x could be nrm, int or adv i.e normal, intermediate or advanced nodes respectively and Q is an additional quantity that can be defined as a function of the ratio of the residual energy of each node or just a constant value. For example Q is set to one in other models. However we use a deterministic quotient for the value of Q, which is computed in each round for all the nodes in order to improve on the LEACH protocol. According to the threshold indicator function in Eq.(1), every node decides to be cluster-head for each round r, the sensor node chooses a random number between 0 and 1. If this is lower than the threshold for node n, (n), the sensor node becomes a CH. Here G denotes a set of non-elected cluster members (CMs) and Px is the probability of being elected as CH. SEP, improved LEACH by considering a two-node heterogeneous setup. Likewise, SEP-E, improved both SEP and LEACH, by using a three-node heterogeneous setup. Both the SEP-E and SEP protocols adapted the indicator function in Eq.(1) to suit their model estimations by using intermediate and advanced nodes respectively. These studies also defined different probabilities Px for the different types of nodes use in the network to achieve their goals of improved lifetime. According to these protocols, the operation of the clustering process begins with a setup phase when all nodes use the indicator function for election as CHs. The elected CHs broadcast advertisement message (ADV) using the non-persistent carrier sense multiple access (CSMA MAC) protocol. This message contains the CH's ID and a header that indicates it as an announcement message. The non-elected nodes called clustermembers (CMs) determine their cluster by choosing the CH with the minimum communication cost based on the received signal strength of the advertisement message. The CMs send join-request to their chosen CH using CSMA MAC protocol. This message contains the CM-ID (cluster member-ID), CHID (cluster head-ID) and the header that indicates the message as a request. The CHs set up a TDMA for their intra cluster communication, which ends the setup phase. The steady-state phase begins when sensed data are sent from CMs to CHs and from CHs to BS. The inter-cluster communication is achieved using the direct sequencing spread spectrum (DSSS). Motivated by these studies, we propose a deterministic based model that can yield a better lifetime and ensures the node with the largest residual energy will get elected as the CH. This method provides a more ideal solution for energy consumption in WSNs. To the best of our knowledge we are the first to attempt a purely deterministic model that can guarantee a fixed number of cluster-heads election per round.

IV.DETERMINISTIC PROTOCOL

Deterministic Energy-efficient Clustering protocol (DEC) that determines CH election based on the residual

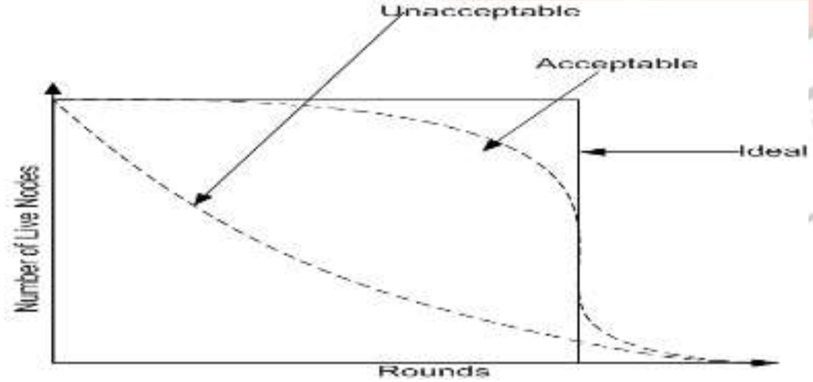

Fig. 1. Behavior of node energy consumption overtime

energy (RE) of each node. The threshold function in Eq.(1) is completely abandoned, firstly, due to the uncertainties in the CH's election process and secondly, due to the underutilization of the potential for lifetime maximization in clustered WSN. In simple term, the aim is to conform DEC algorithm to look similar to an ideal solution as shown in Fig. 2. The major advantage in DEC model is that the uncertainties in the cluster-head elections have been minimized.

A modified setup phase used in LEACH is used, but keep the steady-state phase as the same. Since node's energy can be determined a priori, the CH election process is reorganized to only use the residual energy (RE) of each node. In DEC, at round m, the BS elects $Nopt$ cluster-heads for the network. The BS can only take part in the election of CHs if and only if $m = 1$. The elected CHs advertise their role using CSMA MAC just as in LEACH. However, in DEC unlike in LEACH, the join-request message will contain CM-ID, CHID, CM-RE (cluster member-residual energy) and the header that indicates it as a request. This way the RE information of CMs is known by their respective CHs, thus localized and it can be utilized for CH rotation in the subsequent rounds. After the setup phase ends, the steady phase begins, but before the end of this phase, the current CHs checks the piggy-backed CM-RE's information received to decide whether they will remain as CHs or relinquish their roles by choosing any node in their clusters with the highest RE as the new CHs. After this decision is made for the new CHs and all the data from the current round is communicated to the BS, the current round ($r = m$) ends (a perfect synchronization is assumed, just as in

LEACH). The next round $r = m+1$ begins; but since the new CH's are already chosen in the previous round, they broadcast their role in the new round, CMs join their cluster as already explained above. The steady phase begins again. This process continues in each round until the last node dies.

V.RESEARCH METHODOLOGY

A modified setup phase used in LEACH is used, but keep the steady-state phase as the same. Since node's energy can be determined a priori, the CH election process is reorganized to only use the residual energy (RE) of each node. In DEC, at round m, the BS elects $Nopt$ cluster-heads for the network. The BS can only take part in the election of CHs if and only if $m = 1$. The elected CHs advertise their role using CSMA MAC just as in LEACH. However, in DEC unlike in LEACH, the join-request message will contain CM-ID, CHID, CM-RE (cluster member-residual energy) and the header that indicates it as a request. This way the RE information of CMs is known by their respective CHs, thus localized and it can be utilized for CH rotation in the subsequent rounds. After the setup phase ends, the steady phase begins, but before the end of this phase, the current CHs checks the piggy-backed CM-RE's information received to decide whether they will remain as CHs or relinquish their roles by choosing any node in their clusters with the highest RE as the new CHs. After this decision is made for the new CHs and all the data from the current round is communicated to the BS, the current round ($r = m$) ends (a perfect synchronization is assumed, just as in LEACH). The next round $r = m+1$ begins; but since the new CH's are already chosen in the previous round, they broadcast their role in the new round, CMs join their cluster as already explained above. The steady phase begins again. This process continues in each round until the last node dies.

With this method, the battery life of WSNs is significantly optimized. The flowchart for our DEC algorithm is presented in Fig. 3. Based on our simulation studies, the followings are observed, which makes the DEC protocol desirable:

- The CH election is locally decided based on each node's RE. And each round is independent of the subsequent round unlike in LEACH, SEP and SEP-E.
- DEC guarantees every node a chance of election as long as its RE is higher than its neighbors.
- DEC ensures a fixed $Nopt$ cluster-head is chosen.
- DEC significantly reduces the overhead cost of computation associated with CH search in the existing protocols, by refining this search to cluster Ni at round m.
- DEC guarantees that every CH has enough energy to take up its role, until at least the end of the network lifetime, unlike in LEACH.

The following flow chart explains the process of selection of the cluster head at the beginning of each round, whether or not a new CH is to be selected or the already selected cluster head will continue to act as the head based on the residual energy of the nodes.

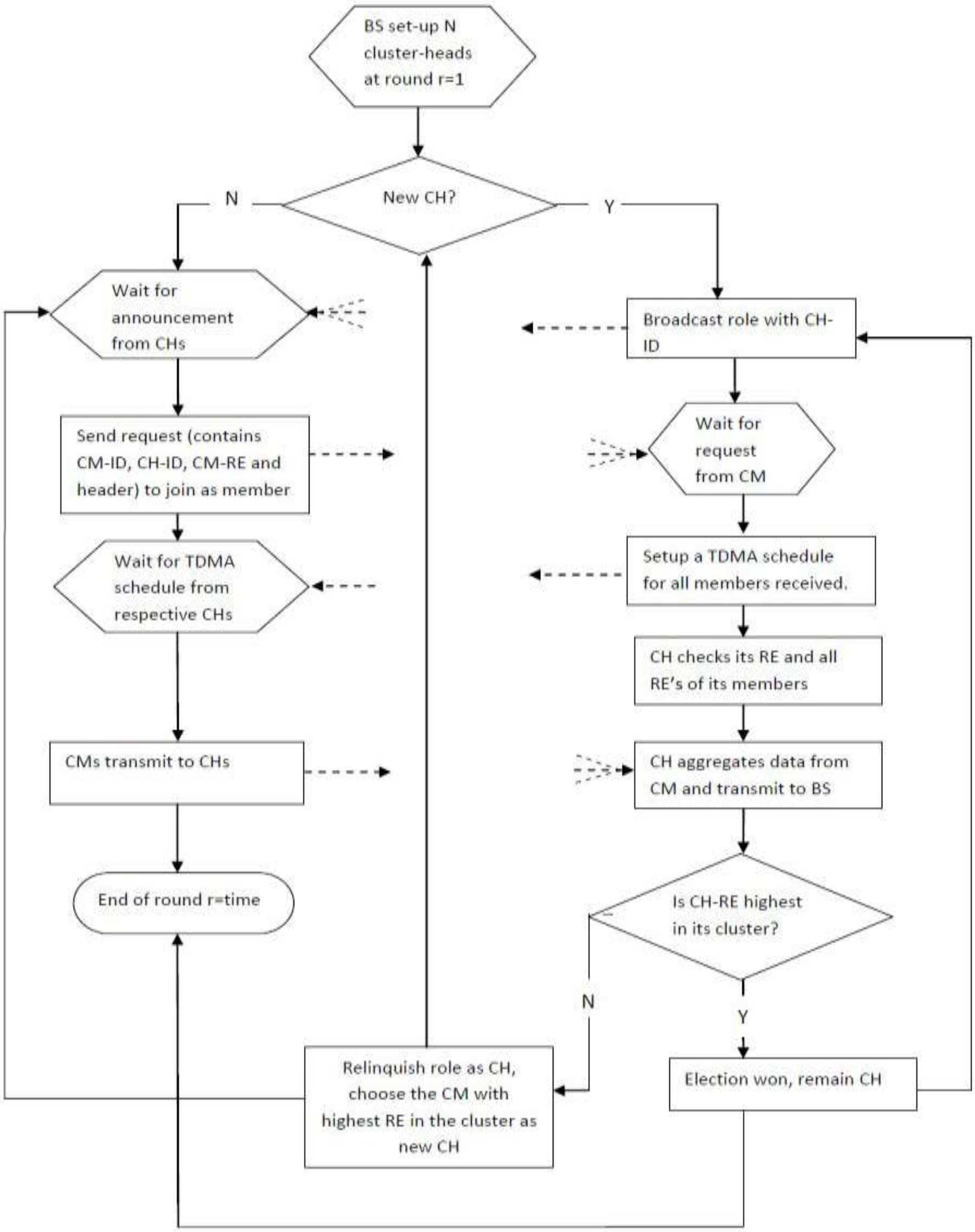

Fig. 2. Flowchart of DEC algorithm

VI.SIMULATION SETUP

DEC protocol is verified using simulations and its performance is compared with existing protocols i.e. LEACH, SEP and SEP-E. The performance metrics also are defined as FND (First Node Dies, also known as stability period), PNA (90, Percent Nodes Alive) and LND (Last Node Dies, also known as instability period). These protocols are compared both in homogeneous and heterogeneous setups. The LEACH protocol is used as representation of homogeneous scenario, because this is the purpose for which it was designed. Likewise, SEP, SEPE and LEACH are used as representation of heterogeneous setup, especially, since both SEP and SEP-E are designed by their authors to be robust to heterogeneity.

We test these protocols using two setups:

- Setup 1: A $100m \times 100m$ of randomly dispersed homogeneous nodes, each with 0.5J of energy and BS located at the center of the network system.
- 2) Setup 2: A $100m \times 100m$ of randomly dispersed heterogeneous nodes with energies varied between 0.5J to 2.25J and BS located at the center of the network system. For the sake of brevity and complete fairness, the total energy of the system for each protocol are ensured to be the same, we use a total energy of 102.5J. In LEACH, SEP-E and DEC, 20% of the nodes are equipped with 2J of energy, 30% with 1.25J of energy and 50% with 0.5J of energy. However, in SEP two types of nodes are assumed. In order to be fair, 30% of the nodes are equipped with 2.25J of energy and 70% with 0.5J of energy. The total energy of the system remains 102.5J. Also, the optimal parameters of these protocols are used in order to yield their respective highest performances.

VII. ANALYSIS OF OPTIMUM CLUSTER-HEADS:

In DEC, the clustering algorithm was created to guarantee that the expected number of cluster-heads per round is fixed as $Nopt$, which can be set a priori. In Fig. 4, we use a probabilistic-based model such as LEACH, to analyze the number of elected cluster heads per round. The solid curve, which represents LEACH protocol shows the inherent uncertainties in the model, the consequence is that the required fixed number of cluster heads election cannot be guaranteed per round. Due to this, in some rounds very few cluster-heads are elected, and the cluster-members will need to transmit at a much longer distances to reach their cluster-heads. Likewise, if the number of elected cluster-heads is higher, not much data aggregation will be done, since the cluster size is smaller. Thus, more energy will be used for transmitting. This is one of the major drawback of this model. Another disadvantage of this model is that, the energy consumption across nodes become increasingly uneven as the network progresses. This phenomenon is explained later in the following subsection.

Fig. 4 plots the number of elected CHs overtime as given by LEACH and DEC. The dotted line represent the DEC protocol which reveals that the uncertainties in the cluster-head election has been completely eliminated. This ensures that, for any network size, once the $Nopt$ is decided at the beginning of the network operation, our DEC protocol guarantees that the number of cluster-head election remain fixed at $Nopt$. The advantage of this behavior is that, the energy across node is balanced as the network evolves and for the majority of the time the cluster-members will have relatively shorter distances to transmit to their cluster-heads. Overall, the energy gain is reflected in the simulation results in favor of the DEC protocol. This makes DEC to be very close to an ideal clustering solution for WSN.

Furthermore, the optimal number of cluster-head $Nopt$ is empirically determined as shown in Fig. 5. The number of cluster-head is varied between 1 and 30, as the cluster-heads increases, the FND improves significantly till the cluster-head number reaches 10. The DEC's curve is flat between 10 and 20 cluster-heads with little spikes in-

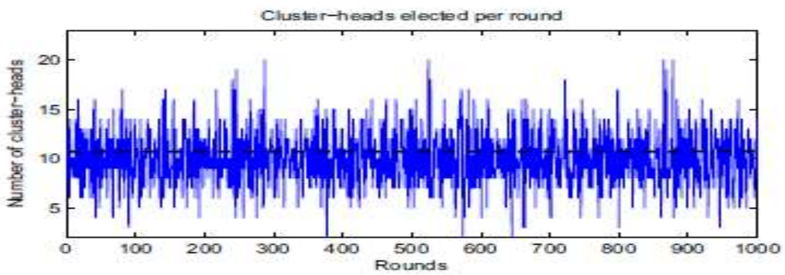

Fig. 4. Number of cluster-heads per round. The solid line represent a LEACH, which does not guarantee the election of a fixed number of cluster-heads per round. The dotted line represent the DEC protocol, which guarantees a fixed number of cluster-head election per round.

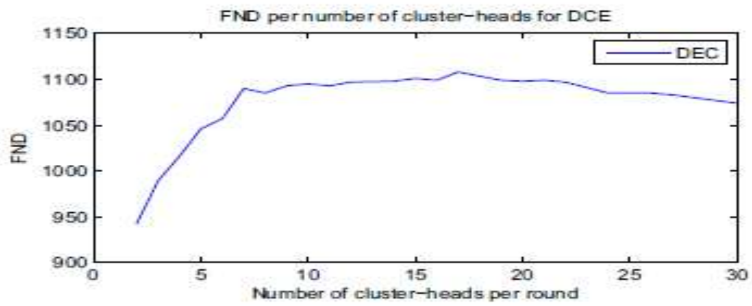

Fig. 5. FND in DEC as the number of cluster-head varies from 1 to 30. This graph shows that DEC is more efficient when cluster-heads are between 10 and 20 and the optimality lies around 16 clusters in homogeneous setup.

between. Beyond 20 clusterheads, the curve starts descending. The optimality of *Nopt* lies around 16 cluster-heads. As already explained above, when there are few cluster-heads, non-cluster head nodes will often transmit data very far to their cluster-heads, this drains their energy faster. When there are more cluster-heads (from 10 to 20), non-cluster head nodes can easily locate a nearby head. But when the number of CHs increases beyond 20, there is not much local data aggregation being performed, thus more energy will be consumed because the size of the cluster is reduced. DEC is stable when the number of cluster-head varies between 10 to 20, this shows the robustness of DEC to variable number of cluster-head election.

VIII. ENERGY CONSUMPTION ANALYSIS

We analyze the residual energy of each node during the network operation, by observing the variation of energy levels between the nodes at 100-round intervals from round 100 to 5000. We use the standard deviation to verify these differences among the nodes using Setup 1 and 2. Our objective is to verify the relative energy consumption pattern across the sensor nodes, as this can tell us whether the energy in the system is evenly consumed across the nodes. Using Setup 1, as shown in Fig. 6, DEC has a flat and much lower standard deviation over time compared with LEACH which increases consistently as the network progressed from 100 to 1000 rounds. This clearly showsthat energy is not evenly consumed among the nodes as the network evolves in LEACH. This is a result of the randomized cluster-head election process in LEACH, making the entire network operation to be very unstable. In Setup 2, we observe a similar phenomenon in DEC, SEP-E, SEP and LEACH. Again, we compute the standard deviations for the residual energy among the nodes of each protocol as shown in Fig. 7. The fast decrease in the DEC curve from 100 to 1000 rounds shows clearly that DEC balances the energy consumption in the network better than the other protocols, by adapting well to heterogeneity. As the network progresses from 100 to 1000, DEC reduces the energy gap (measured as standard deviation) within the network by ensuring that nodes with higher residual energy are elected often than nodes with lower residual energy, hence lower standard deviation at 1000 round than the other protocols. Although SEP-E and SEP adapt to the energy heterogeneity, they are much slower in coping with this phenomenon. It is obvious that LEACH protocol is indifferent to heterogeneity, as there is no response to the different energy levels in the network. Overall the performance of DEC compared with the other protocols is significant. The DEC protocol has achieved our goal of a well balanced energy

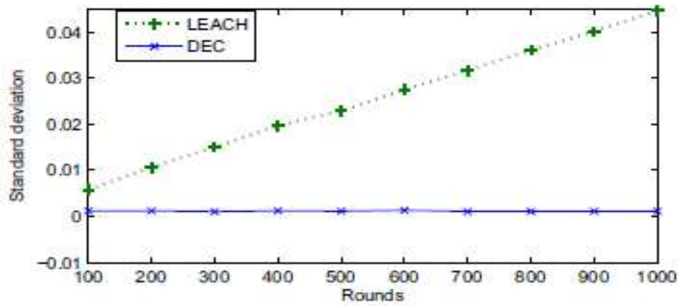

Fig. 6. The residual energy standard deviation across the sensor nodes at rounds 100, 200...1000, in Setup 1.

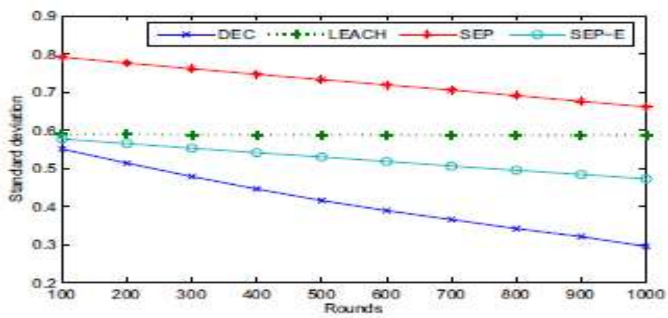

Fig. 7. The residual energy levels across the sensor nodes at rounds 100, 200...1000 in Setup 2.

consumption pattern across the nodes regardless of the energy hierarchies in the network system. This result supports our model of a fixed elected number *Nopt* of cluster-heads in each round as used by the DEC protocol to balance the energy consumption among the nodes.

We investigate the number of live nodes per round for both homogeneous and heterogeneous setups. The simulation results are discussed below.

- Setup 1: Fig. 8 shows the network lifetime of DEC and LEACH. DEC outperforms LEACH protocol by extending the lifetime in homogeneous setup. DEC mimics the ideal solution shown in Fig. 2 by extending the knee point as desired by our model estimation. Although, the performance of LEACH is also acceptable, however, for a critical application that requires about 90-100% monitoring requirement, DEC proves to be more suitable. But for less critical applications, with about 70% monitoring requirements, LEACH protocol could still be useful. However, the practical applicability for LEACH scenario is very limited as most often new nodes will be deployed to replace dead nodes.

- Setup 2: Network lifetime analysis is performed with the protocols considered using Setup 2. In general, DEC improves the WSN lifetime compared to LEACH, SEP and SEP-E up to a magnitude of 45%, 24% and 21% respectively. Fig. 9, shows the behavior of these protocols to energy heterogeneity. It is worthy of note that DEC curve is at right angle to the knee point, the gradual decent at the beginning is as a result of different energy levels of the nodes in the network. DEC proves to be superior up to when 60% of the nodes are alive. SEP-E, SEP and LEACH descends slowly until the end of the network, although both SEP-E and SEP outperformed the LEACH protocol. This is expected because LEACH was designed for homogeneous scenario. For applications that have minimal monitoring requirements LEACH, SEP and SEP-E could still be desirable. However, it is expected that most applications will introduce new nodes as the network evolves, which makes DEC a more ideal protocol for most WSN deployment scenario. It should however, be noted that the simulations do not account for the setup time or the energy consumed during the update processes; they do however give an approximation of the network lifetime that can be achieved using these protocols.

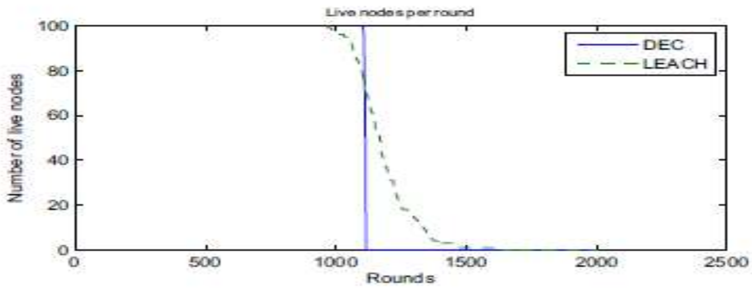

Fig. 8. Performance of the protocols using Setup 1.

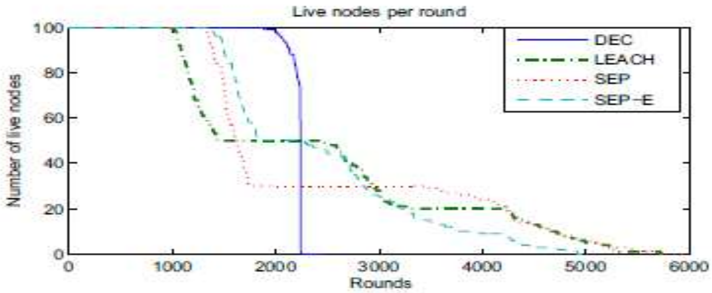

Fig. 9. Performance of the protocols using Setup 2, with the proposed optimal parameters. This is done in order to have complete fairness for all the protocols.

Our simulation has resulted in the following graphs and results:

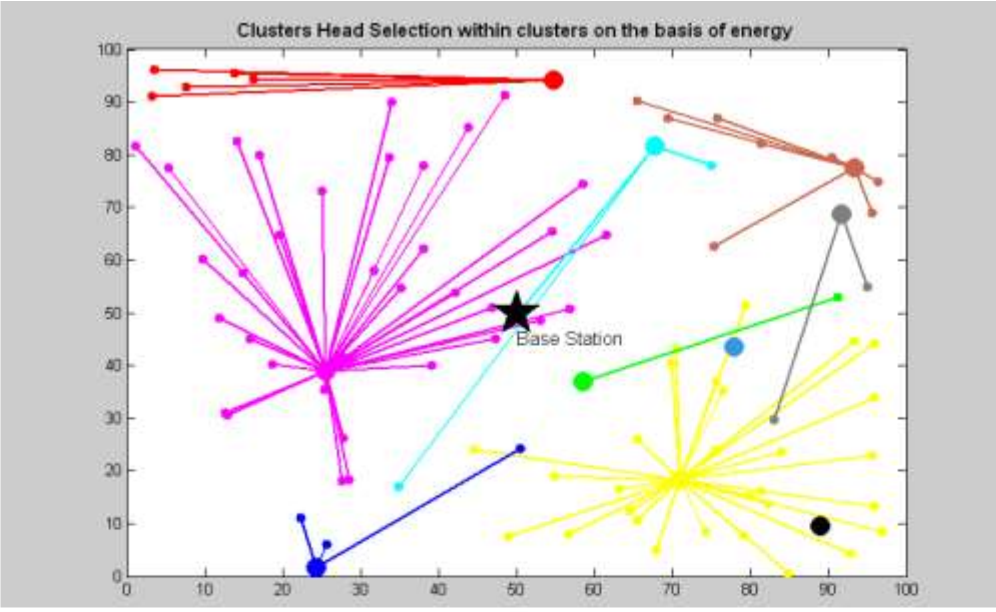

Fig.1.Different Cluster Heads getting selected based on energy level.

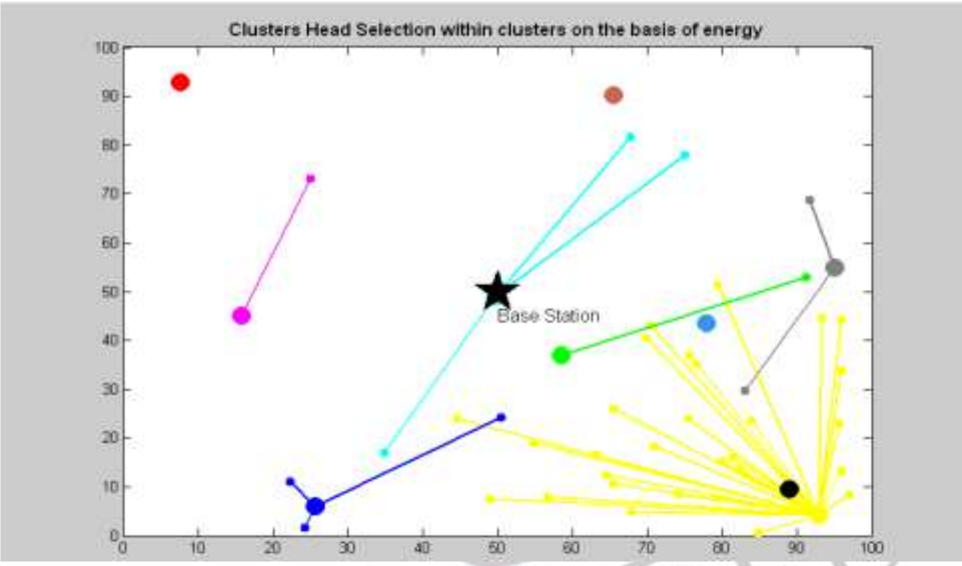

Fig.2. Clusters dying out after the exhaustion of energy from nodes.

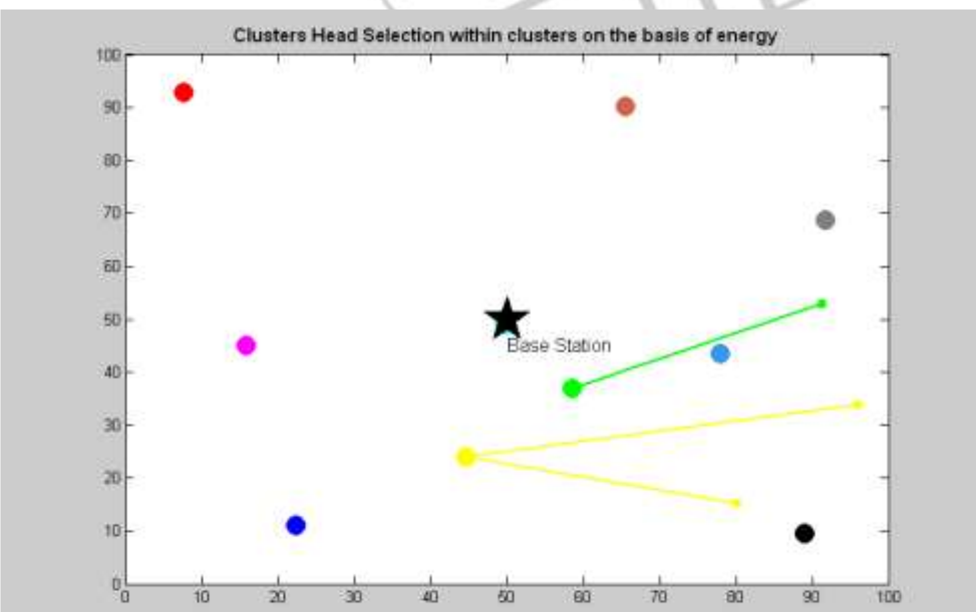

Fig.3. Small numbers of clusters remaining after the exhaustion of energy.

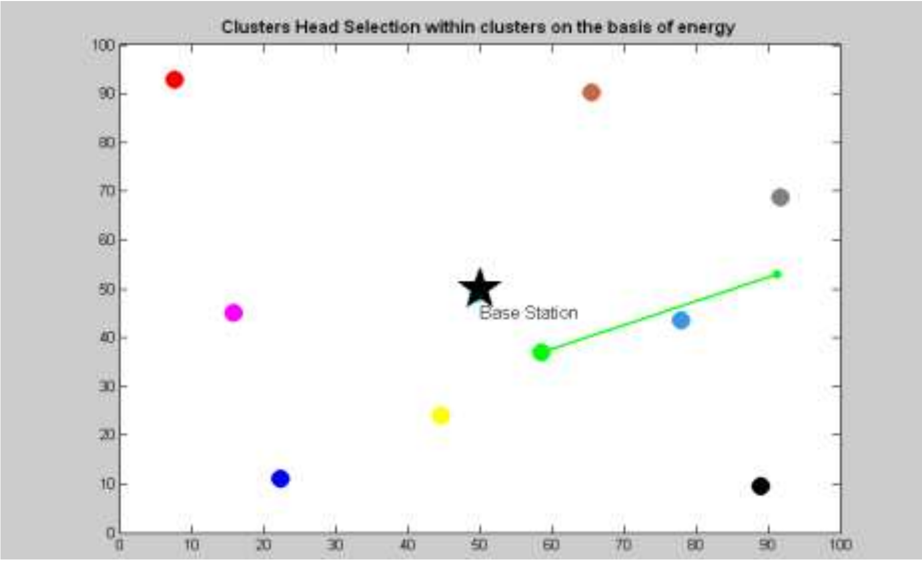

Fig.4.Final figure after exhaustion of energy from all nodes after proposed number of Iterations.

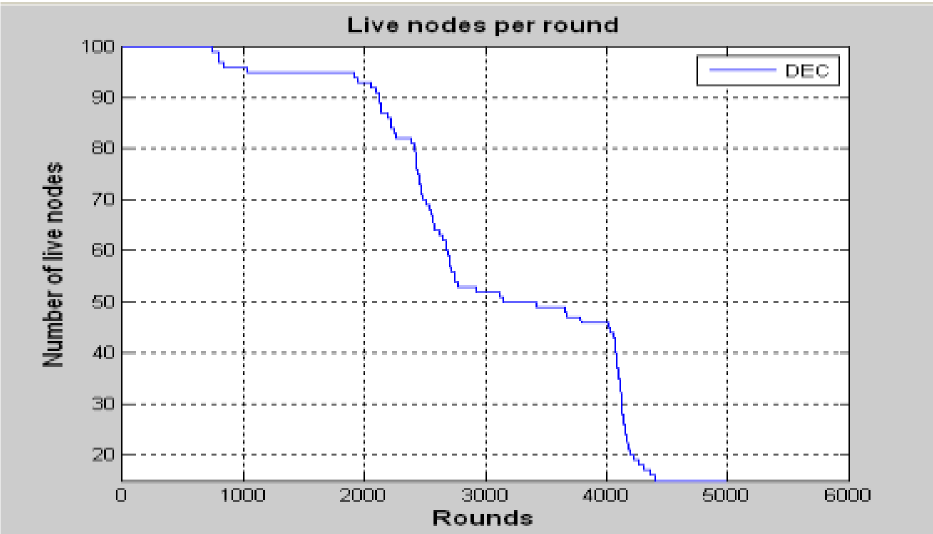

Fig.5 Nodes left after proposed number of iterations.

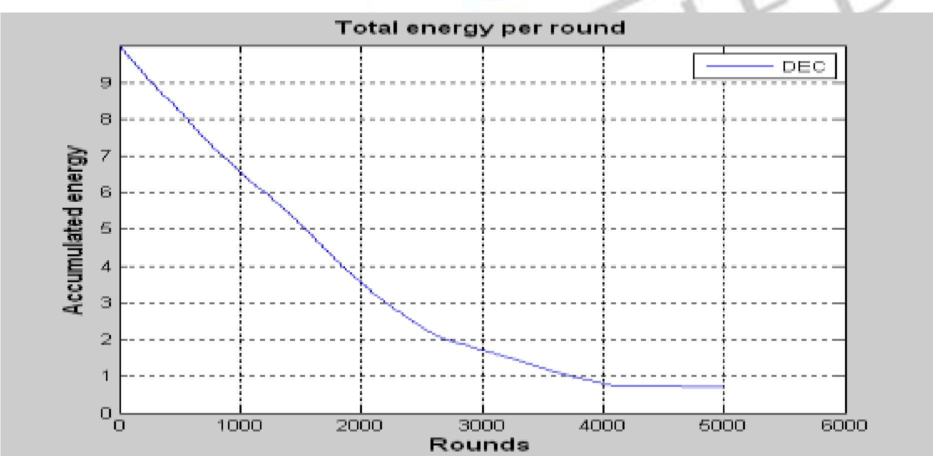

Fig.6 Total Energy decrement from round 0 to proposed iterations.

IX. RESULT AND DISCUSSION

A purely deterministic protocol DEC that better utilizes the most valuable network resource (energy) in WSN is introduced. DEC outperforms the probabilistic-based models we have considered, by guaranteeing that a fixed number of cluster-heads are elected per round. At different rounds cluster-heads are elected using the local information of their residual energies within each cluster to choose the appropriate cluster-heads.

X. CONCLUSION

DEC improves the lifetime of wireless sensor networks by an order of magnitude which is significant when compared with LEACH, SEP and SEP-E. DEC takes advantage of the local information i.e. the residual energy of each node to optimize the energy consumption in both homogeneous and heterogeneous scenarios we have considered, regardless of the level of energy hierarchies in the network. In our future work, we intend to adapt DEC protocol to a real world application setting such as in agricultural farmland for fertilizer spraying operations. It is our hope that this method can provide more insight into optimizing WSN energy consumption in real-world scenarios.

XI. ACKNOWLEDGMENT

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