RESEARCH ARTICLE OPEN ACCESS

Energy Harvesting Clustering Methodology for Lifetime Enhancement of Wireless Sensor Networks

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Abstract:

In the modern era, wireless sensor network (WSN) has one of the new horizons among the research community. A WSN provides largest range of network in most of the application fields and it can be deployed anywhere. WSN has low cost, low power sensor nodes, can be deployed in large numbers and also used in hazardous environment. However, the sensor nodes in WSN do not have longer lifetime and always energy budget plays vital role in the context of wireless sensor network. Therefore, this paper focuses on the issues related to network stability and complexity of the network. Moreover, maintenance of fault tolerance ability and minimization of data losses through improved network stability are accomplished in this work. As a result, the field lifetime of sensor nodes should be enhanced to encounter the aforesaid challenges through sensor node. Therefore, the present study proposes the energy harvesting clustering model for increasing lifetime of the network node via application of energy towards the sensor node through energy harvesting concept and clustering technique. The proposed model is validated through MATLAB and a comparative assessment is performed with an existing model.

Keywords —**Clustering, Degradation, Energy harvesting, Field Lifetime, Wireless Sensor Network (WSN).**

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I. INTRODUCTION

Energy harvesting in wireless sensor networks (WSN) [1, 2] is one of the essential concerns to be considered, as energy in the sensor node (SN) decreases when it is utilized in wide spectrum applications. Indeed, wireless SN, is being frequently utilized for outdoor applications [3] in almost all fields, ranging from environment monitoring to battlefield scenario and in computing as well as communication platforms. Additionally, WSN sets a new level for monitoring environments and concerned to remote geographical area where human intervention is not possible [4]. Every sensor node in WSNs consists of four basic units namely sensor unit, transceiver unit, processor unit and power unit [5]. Fig.1 shows the different units of a typical sensor node, which is consisting of analog to digital converter (ADC), processor sensor, transceiver and power unit. However, the performance of the sensor unit is to sense the specific environmental conditions such as temperature, pressure level, humidity level and other useful information [6, 7]. This information is converted to digital signal for communication purpose through an ADC.

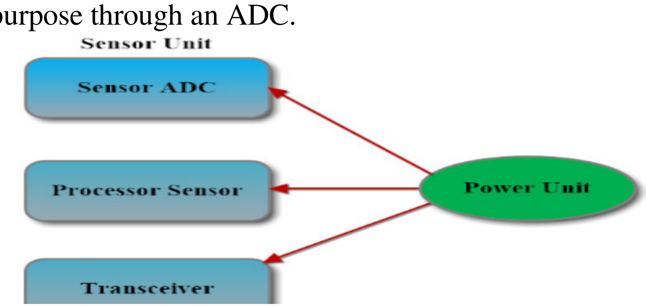

Fig. 1 Different units of a typical sensor node

Moreover, the processor unit includes a microcontroller and memory unit for saving the sensed data [8]. The transceiver unit comprises of wireless radio transmitters and receiver stations. Furthermore, the power unit consists of batteries that provide necessary power to other sensor units. Numerous protocols are proposed [9, 10] to reduce the energy consumption and increase the lifetime of the sensor network. Conversely, these protocols are categorized into three types. The first category focuses on controlling of transmission power at node level and at the same time maintains the connectivity of the network [11], thus the possible probability can increase the network capacity and compromise with the cost of the network. The next category is utilized for routing decisions based on power optimization goal technique. Moreover, the last category protocols are employed for formulating essential and valuable decisions about control topology. Subsequently, the sensor nodes which are involved in the network activity are entitled as active mode, or otherwise termed as sleep mode. However, based on the requirement, nodes are employing in the appropriate position in the network to acquire the maximum strength signal and permit the signal perfectly to other node [12].

Additionally, the routing algorithms [13] operate in WSN context for establishing the communication path among the sensor node. These communication paths are utilized in the network for efficient data transmission between the nodes and also they provide energy transmission among the sensor nodes from the power supply station for maximizing lifetime of sensor node. However, this process is not an accurate solution for maximizing lifetime of the sensor network [14]. Customarily, sensor nodes are powered through battery source [15]; hence design of optimal routing protocol plays a very crucial role in WSN. Subsequently, battery replacement is a crucial issue in most of the sensor nodes, when it is deployed in more numbers. Thus, the algorithm can arrange the routing path of the sensor network in such a way that the nodes get their energy automatically from the power source, when they are deployed in different places. Subsequently, energy harvesting can be possible through ambient power sources such as solar, thermal, mechanical and radio frequency etc.

Moreover, Fig.2 shows the energy utilization system of the WSN. The function of the energy-harvesting device is to harvest energy from different renewable sources and generate power for the sensor nodes in the network. The role of the energy-consuming device is to consume the harvested energy by delivering different workload activities such as sampling, communication and computation. The energy storage device performs the role of storing harvested energy and provides power to external sensor nodes. Thus, it performs a dual role, either as a producer or as a consumer of energy based upon present situation demands.

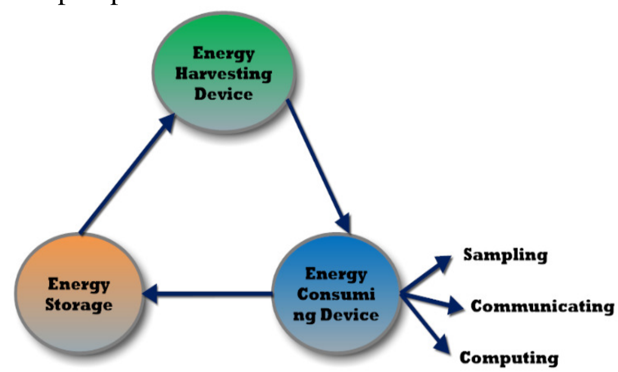

Fig.2 Energy utilization in WSN.

Subsequently, in most of the usages, clustering protocol has not been utilized for energy harvesting purpose, however, it is a favorable approach for WSN. Therefore, the energy harvesting clustering protocol is utilized in the network field for accumulation of energy and is applied upon the sensor nodes before the node completely dissipates the energy. Consequently, this energy is applied to locally available node by utilizing the routing algorithms, which can establish proper path for supplying the energy to a node that is functioning in the network [16, 17].The renewable energy concept (e.g., solar and wind) has been utilized in numerous literature [18-20] for energy harvesting in support of WSNs. Sensor nodes need to exploit the sporadic availability of energy to sense and transmit the data quickly.

This paper demonstrates the smart wireless sensing nodes which are capable of performing its operation in low power by utilizing the radio frequency clustering technique. Moreover, this paper considers a novel model for WSN system which is based upon energy harvesting clustering method for increasing lifetime of the network node. However, wireless sensor node can be considered either as server node (cluster head) or as sensor node with respect to various conditions. The cluster heads share its energy to the neighbor's sensor nodes based upon the energy required by the sensor node. However, the cluster node utilizes routing algorithms for sharing its energy for improving lifetime of the sensor node in the network. Therefore, the cluster head node attains the requisite energy from energy harvesting system and delivers to the expected sensor node based upon energy balancing system. The energy balancing system can be represented as follows.

Available Energy (E_{av}) $\geq$ Consumable Energy (E_{out}) (1)

II. PROPOSED CLUSTERING METHODSFOR SENSOR NETWORK

Assuming that n number of sensor nodes are distributed in a network or a geographical area with respect to the aforesaid assumption ($Eav \geq Eout$) of energy harvesting system. The aim of this paper is to identify a set of cluster heads, which cover the entire field of network. Each sensor node is considered as V(i), where $1 \leq i \leq n$ must be mapped to exactly one cluster C(j), where $1 \leq j \leq n(c)$ and n(c) is the number of clusters ($n(c) \leq n$). A sensor node is able to communicate directly with cluster head via a single hop. Cluster heads can use a routing protocol to compute inter cluster paths for multi hop communication with sensor node. For accomplishing aforesaid communication, the following necessities must be met.

1. Clustering is completely distributed. Each node independently makes its decision based upon obtainable local information.
2. Clustering terminates within a fixed number of iterations regardless of network diameter.
3. At the end of each transmission control protocol (TCP) phase, each node is acting either as a cluster head or as a sensor node based upon exactly one to one basis. Clustering head should be efficient in terms of processing complexity and message exchange.
4. Cluster heads are well distributed over the network and relatively have high average residual energy compared to sensor nodes.

A. Reduction in power budget

(i) Power reduction strategies for the wireless sensing nodes are summarized below:

- During the sampling period power mode is 'on' for sensor node.
- When any event is occurred, sensors are sampled and power mode is 'on' for signal conditioning at that instance.
- Sensor sampling rate is minimized as per application requirement.
- Sleep technique is used between samples and is utilized at lowest standby current.
- Bandwidth is maximized to reduce settling time.
- Fast ADC is used to reduce sensor 'on' time.
- In low data rate (5-10 Hz) applications, all the components consume very less power as compared to micro-power components.

(ii) Power reduction strategies for the RF transceiver are summarized below:

- Amount of wireless data transmissions should be reduced by data compression technique.
- Transceiver duty cycle and frequency of data transmissions should be minimized.
- Strict power management is implemented by using sleep modes.
- An event-driven data transmission strategy is implemented during sensor event.
- Packet reception ratio (PRR) is maximized and end-to-end packet delay is reduced.
- Energy efficiency as well as energy consumed per packet (ECPP) of the network are improved.

III. ALGORITHM FOR PROPOSED MODEL

The proposed model is based upon smart distribution of clustering node and energy harvesting technique. Consequently, routing technique is closely related to the network system architecture and the corresponding design of routing protocols in WSN system is influenced by many challenging factors such as the sensor nodes are either equipped with global positioning system (GPS) or the sink node is sensed to learn about their locations. Another challenge is the location management of the sensors. Subsequently, end-to-end delay is time occupied by the sensor node to send packet to a sink node or vice-versa. It can be either one way or round trip (packet sent from source node to sink node and from sink to source node). Sensor nodes are deployed with respect to usage and accordingly, it can affect the performance of routing protocol.

A. *Algorithm for Dynamic cluster head selection with general stable election protocol (G-SEP)*

Step-1: Distribute all the sensor nodes in the network and the corresponding energy level is sent to the base station. Then divide the network into four clusters.
Step-2: The Node which has highest average residual energy level is selected as a cluster head for the network.
Step-3: The communication cost is calculated for each node.
Step-4: The status of the cluster head is broadcasted and according to that number of cluster heads is found out.
Step-5: Received signal strength indication (RSSI) is checked.
Step-6: Joint request is sent by the sensor node to cluster head and the corresponding acknowledgement message is sent by the cluster head to sensor node for joining as the member of the cluster.
Step-7: The sensor node calculates the required amount of energy spent for choosing new cluster head.

B. *Algorithm for Dynamic cluster head selection with Multilevel SEP (M-SEP)*

Step-1: Distribute all the sensor nodes in the network, energy level of each node is sent to the base station and after that divide the network into four clusters.
Step-2: The Node which has highest average residual energy level is selected as cluster head for the network.
Step-3: If the node has second highest residual energy, then select as an assistant cluster head for the network.
Step-3: The communication cost for each node is calculated.
Step-4: Cluster head and Assistant cluster head status are broadcasted and the number of cluster heads as well as assistant cluster heads is found out.
Step-5: Received signal strength indication (RSSI) is checked.
Step-6: Joint request sent by the node to cluster head as well as assistant cluster head node and the corresponding acknowledgement message sent by the cluster head to sensor node are represented as the member of the cluster.
Step-7: The energy required for choosing new cluster head and Assistant cluster head is calculated.

C. *Algorithm for Energy Harvesting LEACH (EH-LEACH)*

Step-1: Distribute all the sensor nodes in the network and the corresponding energy level is sent to the base station.
Step-2: Node with highest residual energy level is selected as cluster head for the network and node with second highest residual energy level is selected as second cluster head for the particular cluster.
Step-3: The criterion for multi hops communication between cluster heads is enhanced by using the grid value method.
Step-4: Cluster head status is broadcasted and the number of cluster heads are found out.
Step-5: Received signal strength indication (RSSI) is checked
Step-6: Joint request sent from the node to both cluster heads and acknowledgement message sent by the cluster heads to sensor node are represented as the member of the cluster.
Step-7: RSSI value is calculated and checked. Before a sensor node becomes faulty or dead node, the node sends all the useful data to the second cluster head. Therefore, information loss is controlled to a large extent.

Step-8: The harvested energy for each node is calculated.
Step-9: The response time for energy harvesting is calculated by considering the distance of sensor node and harvesting system present in the network. The energy harvesting can be possible through energy storage system.
Step-10: The energy spent for choosing new cluster head is calculated.
Step-11: The communication cost is calculated for the network.

IV. PERFORMANCE EVALUATION

To evaluate the proposed protocol, simulation study via MATLAB tool is carried out. In this study, the proposed protocol (EH-LEACH) is assessed with G-SEP and M-SEP.

Additionally, Table 1 demonstrates the simulation parameters for general stable election protocol (G-SEP) and corresponding Fig.3 shows the implementation of G-SEP for 1200 rounds. It is illustrated from the graph that approximately 17-18 nodes are dead. Thus, G-SEP performs well for 1200 rounds. This paper considers the relation of number of rounds with lifetime of the network. If number of rounds is more, lifetime of the network is more. However, number of dead nodes are related to stability of the network. Therefore, G-SEP is stable for 1200 rounds. Conversely, when the number of simulation rounds is increased, this protocol does not hold the same stability.

Similarly, Fig.4 demonstrates the implementation of general stable election protocol (G-SEP) for 2000 rounds and consistently almost all nodes are dead. This figure clearly shows that the G-SEP stability factor drastically decreases for 2000 rounds. Therefore, some modifications are done over the protocol and named as multilevel Stable Election Protocol (M-SEP). Table 2 illustrates the simulation parameters for M-SEP and corresponding Fig.5 shows the implementation of M-SEP protocol for 2000 rounds. It is observed from the figure that very few number of dead nodes are present. In this paper multilevel refers to multiple cluster head selection per round. Consequently, one is cluster head and another isassistant cluster head. Sensor nodes in a cluster are reported to cluster head, if cluster head of a cluster becomes dead or fails due to any fault then assistant cluster head does the job of cluster head.

Table 1
Simulation Parameters for G-SEP

Simulation Parameters	Values
Network area	100m*100m
Number of nodes	100
Initial Energy for normal sensor nodes	0.5J
Initial Energy for Advanced sensor nodes	0.7J
Percentage of cluster head	0.5
Percentage of Advanced nodes	0.1
Base Station Position	50m*50m
Eelec	50nJ/bit
Etx=Erx	50nJ/bit
Eamp	10pJ/bit
Packet size	2000bit
Rounds	1200/2000

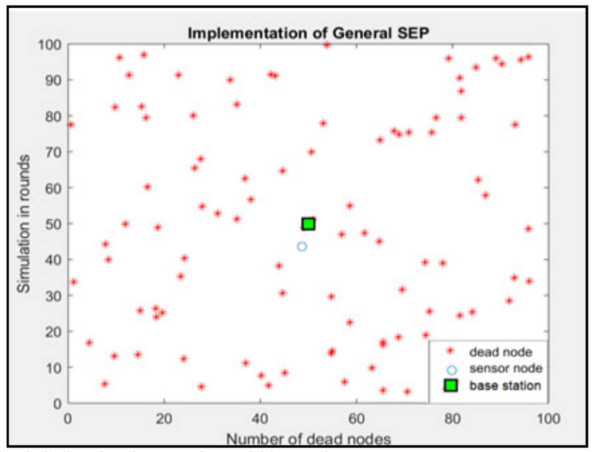

Fig. 3 G-SEP implementation (1200 rounds)

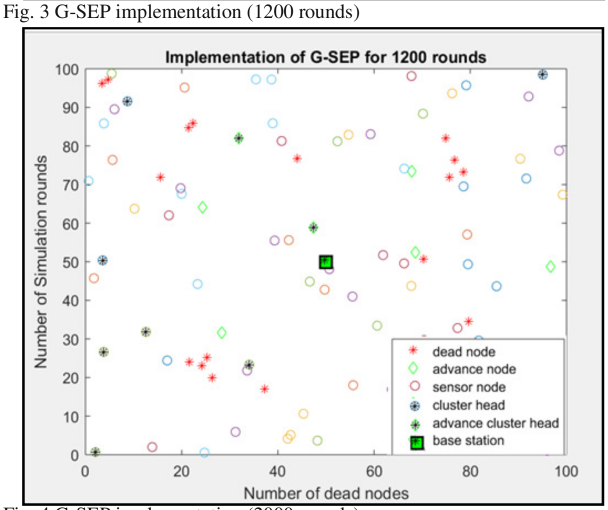

Fig. 4 G-SEP implementation (2000 rounds)

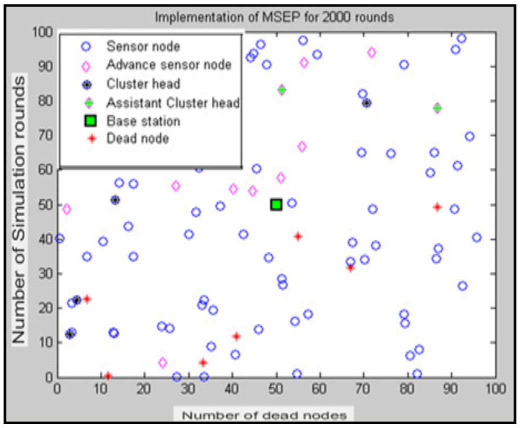

Fig. 5 M-SEP implementation (2000 rounds)

Table 2
Simulation Parameters for M-SEP

Simulation Parameters	Values
Network area	100m*100m
Number of nodes	100
Initial Energy for normal sensor nodes	0.5J
Initial Energy for Advance sensor nodes	0.7J
Percentage of cluster head	0.5
Percentage of Advance nodes	0.1
Percentage of Assistant cluster head	0.1
Base Station Position	50m*50m
Eelec	50nJ/bit
Etx=Erx	50nJ/bit
Eamp	10pJ/bit
Packet size	2000bit
Rounds	2000

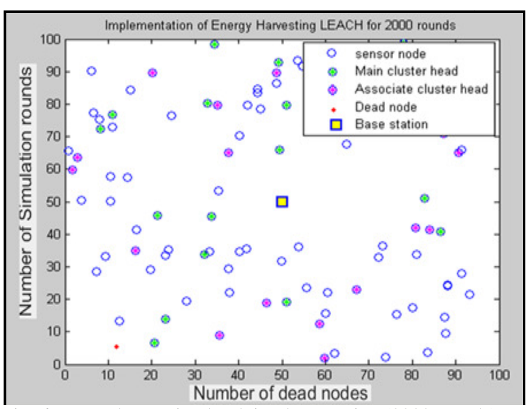

Fig. 6 Energy harvesting leach implementation (2000 rounds)

So data loss is minimized to a greater extent and consistently network stability improves a lot. Still some nodes are dead at 2000 rounds, therefore improvement is needed. Additionally, this paper considers the energy harvesting concept using leach protocol.

Table 3
Simulation Parameters for EH-Leach

Simulation Parameters	Values
Network area	100m*100m
Number of nodes	100
Initial energy	0.07J
Percentage of cluster head	0.1
Base Station Position	50m*50m
Efs	10nJ/bit
Etx=Erx	50nJ/bit
Eda	5.0nJ/bit
Packet size	2000bi
Rounds	2000
cm	32
dm	4000
grid value	10m
Harvesting energy	20nJ/node
Response time	0.1ms

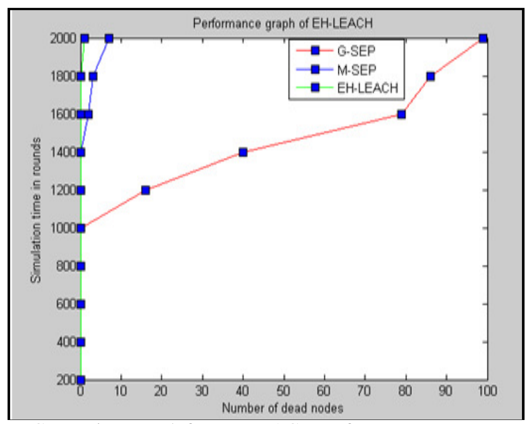

Fig. 7 Comparison graph for EH-LEACH performance

Leach is chosen for proposed model, because leach is the basic model and uses less energy compared with other clustering models.Table 3 demonstrates simulation parameters for Energy-harvesting Leach (EH-Leach) and the corresponding implementation of EH-Leach is shown in Fig. 6. It is observed from the figure that this model performs better than G-SEP and M-SEP. Subsequently, dead nodes are minimized up to a greater extent with only one sensor node as dead. Almost all nodes are active at 2000 rounds, which indicate network is more stable. Therefore, life time of the network is enhanced and network cost also minimized by low energy budget. Consequently, energy harvesting concept gives good result with Leach model.

Energy budget in wireless sensor network is an emerging issue. However, another issue associated with WSN is fault tolerance. If dead node is considered as faulty node, then proposed model can work smoothly. For better network stability and noble life time of nodes, this method ensures that the network has also fault tolerance capability. The proposed model also provides zero data loss due to network stability and fault tolerance capability. Fig.7 shows an evaluation between the aforesaid discussed model (G-SEP, M-SEP) and proposed model (EH-Leach). From the comparative assessment, it is perceived that the proposed model EH-Leach can perform better than the other two models. As the proposed model provides very less number of dead nodes, the network is significantly stable. Additionally, simulation time in rounds refers to the network lifetime. Less number of dead nodes present at maximum simulation rounds means more enhancement of network life time.

V. CONCLUSIONS

This paper proposes an energy harvesting clustering based on double cluster head selection and energy harvesting concept for effective utilization of energy and minimization of the data losses during communication. Moreover, the proposed EH-Leach improves the lifetime of the network largely. From the comparison result, it is observed that EH- Leach model provides better result as compared to G-SEP and M-SEP. As a consequence, the proposed model enhances the lifetime of the wireless sensor network to a great extent, which is the real motto in current WSN scenario. The model can be more optimized with other advanced clustering models like TEEN and HEED protocol. Further the security concept and machine learning concept can be added for providing more advancement in the WSN system.

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