Optimization in Stable Region and Network Lifetime of Heterogeneous Wireless Sensor Networks using Multi-Sink based Routing and Threshold Aware Transmission

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Abstract: **In Wireless Sensor Networks, effective energy management is of great significance. This paper examines the impression of multi-sink based routing on stable region and network lifetime of heterogeneous WSNs. We mainly address 'WSN's stable region and lifetime optimization problem" which is to construct an energy effective routing algorithm such that energy depletion of sensors due to transmission is minimized which results in an improved stable region and elongated lifetime of WSNs. The idea of threshold aware transmission along with static clustering are also applied to accomplish these objectives. The outcomes of proposed technique are analyzed with the corresponding outcomes of two well known traditional clustering protocols namely SEP and LEACH using network lifetime, stable region, unstable region and throughput as evaluation metrics and proposed technique performs superior than other techniques under consideration.**

Keywords: **Heterogeneous WSNs, Threshold Aware Transmission, Multi-sink, Stable Region, Network Lifetime**

I. INTRODUCTION

A Wireless Sensor Network is characterized as one classification of wireless networks that is composed up of an extensive number of circulating, self-configured, small, low powered devices named as sensor nodes. Sometimes a single term motes is also used in place of sensor nodes [2]. These networks cover an immense number of spatially circulated, little, battery-operated, embedded devices that are arranged to gather, process, and transfer sensed data to the administrator. WSNs have attained extensive fame as a consequence of their adaptability in taking care of issues in variety of use zones and can possibly change lives of human beings from several aspects. Nowadays Sensor networks have been effectively utilized in various sorts of application domains such as military, health, transportation, agriculture etc.

Routing technique contributes a significant part in WSNs [7]. In most of the circumstances, various sources are required to transfer their acquired data to a specific sink. In such conditions, nodes located close to the sink deplete energy at faster rate and henceforth eventually die. This causes dividing of the system; thus network lifetime gets the chance to lessen. This issue can be fixed by using multiple sinks based routing protocol. It can slow down energy exhaustion of all nodes due to transmission and hence can elongate the network lifetime. Clustering is another important technique used in WSNs [8]. Partitioning of sensing units into distinct clusters is referred as Clustering. In every cluster, a sensor node is chosen to govern all other nodes of that cluster for a specific interval of time. This node is referred as cluster head (CH) and other nodes related to that cluster are named as cluster nodes for that interval of time. Sensed data from cluster nodes are received and accumulated by the CH. Finally accumulated data is transferred by CH to the sink for further processing. Thus overall energy exhaustion of the network along with number of messages conveyed to sink is minimized. On the premise of opening energy level of sensor nodes, clustered WSN can be characterized into two classes namely homogeneous and heterogeneous Sensor Networks [10]. In homogeneous sensor networks, all the sensing units are supplied with identical amount of battery energy along with similar hardware complexity while heterogeneous clustered networks consist of two or more distinct kinds of sensing units with unequal amount of battery energy and hardware complexity.

In this paper, a multi-sink based routing technique has been suggested for the optimization of stable region and network lifetime of heterogeneous sensor networks having three sorts of nodes namely normal nodes, Intermediate nodes and advanced nodes. In addition, threshold aware transmission is also utilized for this purpose.

Division of rest of the paper is as follows: second segment demonstrates related works. Third segment exhibits the motivation. In fourth segment, proposed protocol model is described. Fifth segment exhibits the experimental outcomes together with discussion. Last segment exhibits conclusion with future direction.

II. RELATED WORK

A substantial research work has been realized on clustering based energy saving protocol in recent years. Many distinct routing techniques and CH selection strategies have been produced in the area of WSNs. CH selection is a primary task of these protocols because it plays a significant part in the effective energy management of sensor networks. A CH might be either pre-allocated by the network architect or elected by associated nodes of the cluster. In addition, nodes may associate themselves to distinct clusters either statically or dynamically.

In this area, LEACH [8] is a most remarkable clustering protocol which had given birth of many further clustering protocols. The main characteristic of LEACH is its CHs election scheme to decrease energy cost of transmitting data by normal sensor nodes to a distant sink. LEACH utilizes dynamic clustering and CHs are chosen on probability basis. Due to these factors nodes die at faster rate. In addition, LEACH [6] is not good enough for larger network.

TEEN [9] is the fundamental reactive networks protocol in this area. TEEN is most applicable for time critical applications. It is very efficient in energy exhaustion and response time too. But it is not much suitable for the applications where user requires data regularly at short interval. SEP [11] was proposed for heterogeneous WSNs to eliminate the flaws of LEACH which also assures network's stability. SEP adopts heterogeneity parameters to enhance the stable region and consequently enhances the total lifetime of the WSN.

Ahmed *et al.*, [1] presented another routing strategy that is called Density controlled divide and rule (DDR) for WSNs. DR Technique depends on static clustering along with least distance based CH choice. Network region is intelligently separated into small clusters (groups). Both SEP and LEACH are outperformed by this approach in terms of energy dissipation, stable region and network lifetime. A multi-sink based routing technique EMCA [12] was introduced to overcome some problem associated with single sink based protocols. A major issue related with WSNs is energy-hole problem. EMCA attempts to solve this issue by utilizing the multi-sink based routing procedure. In EMCA, remaining energy of sensing units play a significant part in CHs selection. The major benefit of this approach is that it solves the energy-hole problem efficiently through multi sink deployment and efficient routing procedure.

Some other popular single sink based and multi-sink based routing approaches such as Z-SEP [3], REECH-ME [5] and KPS [4] were developed for effective energy utilization of WSNs.

III. MOTIVATION

In WSNs, sensing units are battery driven and in several applications these batteries cannot be restored in the middle of operation once sensing units are dispersed in the field being sensed. As energy sources are very scant and limited. Furthermore batteries are small and low-powered; energy efficient transmission is considered a major task in WSN applications.

In LEACH, clusters are composed dynamically and CHs are chosen on probability basis. These factors cause the formation of variable numbers of CHs which contributes in quick death of sensing units. After LEACH, some other approaches were established which use static clustering but they involve periodic transmission of data. It means sink receives the sensed data by nodes at a regular time interval. Because of this reason, sensor nodes die at faster rate thereby reduced stable region together with shorten network lifetime is obtained.

A major drawback associated with the single sink based WSN is that it consists of a single point of failure. Due to some reason if sink goes down then entire work of data gathering and transmission by the sensing units become useless. Another problem associated with a single sink based sensor network is energy hole problem that is nodes near to the sink deplete energy at much faster rate than other nodes. This problem can be resolved by the utilization of multiple sinks. In addition, load of sensing units are fairly distributed to multiple sinks that leads to an extended stable region of the network.

IV. PROPOSED PROTOCOL MODEL

In this segment, firstly we explain the energy dissipation model together with partition of the network field into small regions. After that cluster head selection strategy and routing procedure are presented. Finally we demonstrate the proposed protocol operation at the end of the segment.

4.1 Energy Dissipation model

A simple first order radio model is assumed in proposed approach to calculate the energy depletion of nodes due to data transmission or aggregation. It is additionally taken into consideration that d^2 energy is depleted every time because of channel transmission. Hence to send a message of length k-bit at a distance d by applying this radio model following mathematical expressions are used.

$$E_{Tx(k,d)} = E_{elec} \times k + \epsilon_{fs} \times k \times d^2, \text{ if } d < d_0 \quad (1)$$

$$E_{Tx(k,d)} = E_{elec} \times k + \epsilon_{mp} \times k \times d^4, \text{ if } d >= d_0 \quad (2)$$

Energy depleted in gathering data:

$$E_{Rx(k)} = E_{elec} \times k \quad (3)$$

Where, $$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \quad (4)$$

E_{elec}, denotes energy depleted per bit to run the transmitter or receiver circuit. Values of ϵ_{fs} and ϵ_{mp} depend upon the model of transmitter amplifier we use.

4.2 Network Model

An area of 100m× 100m is taken as network field for the deployment of sensor nodes. The coordinates of central point $C_p(x_1, y_1)$ of field is determined which also works as a reference point. A total of 100 nodes are uniformly dispersed in the field. As static clustering based approach is utilized in proposed technique so number of clusters and CHs remain constant throughout the network operation.

i) *Regions Formation:* In the initial step, we partition the entire network area into N equally distanced concentric squares. Here N=3 is taken for simplicity. It implies that total area of the network field is partitioned into three concentric squares which are denoted as Inner Square (I_s), Mid Square (M_s) and Outer square (O_s). Following equations are applied for partitioning of the network area into concentric squares.

Coordinates of top right corner of I_s denoted as T_r^{Is} and determined as

$$T_r^{Is}(x_2, y_2) = (x_1+\beta, y_1+\beta) \quad (5)$$

Coordinates of lower right corner of I_s, denoted as B_r^{Is} and determined as

$$B_r^{Is}(x_2, y_2) = (x_1+\beta, y_1-\beta) \quad (6)$$

Coordinates of top left corner of I_s denoted as T_l^{Is} and determined as

$$T_l^{Is}(x_2,y_2)=(x_1-\beta,y_1+\beta) \quad (7)$$

Coordinates of bottom left corner of I_s denoted as B_l^{Is} and determined as

$$B_l^{Is}(x_2,y_2)=(x_1-\beta,y_1-\beta) \quad (8)$$

Where, $\beta = x_1/N$ is distance factor from central reference point (C_p) to the border of inner square (I_s). T_r^{Is}, B_r^{Is}, T_l^{Is} and B_l^{Is} are the top right, bottom right, top left and bottom left corners respectively. Same equations can be applied to obtain the coordinates of Ms , Os and n^{th} square by taking β as a multiple 2 and 3 and n respectively.

In second step, four quadrilaterals of equal area are obtained by partitioning the gap between two concentric squares. Later we obtain two sorts of regions namely non corner regions (NCR) and corner regions (CR). The division of complete network area into small regions is exhibited in fig. 1. By adding distance β in the x coordinate of bottom right corner and y coordinate of top right corner of I_s i.e. $B_r^{Is}(x_2+\beta, y_2)$ and $T_r^{Is}(x_2, y_2+\beta)$, the coordinates of NCR2 is obtained. By subtracting factor β from x- coordinate of top left corner of Is i.e. $T_l^{Is}(x_2-\beta, y_2)$, region NCR3 is formed. After Subtracting factor β from y- coordinate of bottom left corner of Is i.e., $B_l^{Is}(x_2, y_2-\beta)$, NCR4 and NCR5 are formed. By applying the same procedure for the gap between M_s and O_s, other four quadrilaterals NCR6, NCR7, NCR8 and NCR9 are obtained.

In third step, every quadrilateral obtained between M_s and O_s is further segmented into three triangles. For this purpose, we determine the midpoint of every inner side of these quadrilaterals. Suppose these mid points that lie on one side of NCR2, NCR3, NCR4 and NCR5 are denoted by m_1, m_2, m_3 and m_4 respectively for each outer quadrilaterals. Now by joining m_1 to its two opposite corners of the corresponding outer quadrilateral, one non-corner region NCR6 and two corner regions CR1 and CR2 are obtained. By joining m_2 to its two opposite coordinates of respective outer quadrilateral, a non-corner region NCR7 and two corner regions in the form of CR3 and CR4 are created. Similarly the other mid-points m_3 and m_4 are joined to its two opposite coordinates of their respective outer quadrilaterals. Thus two other non-corner regions NCR8 and NCR9 and four other corner regions CR5, CR6, CR7 and CR8 are obtained. Hence entire network field is divided into 17 regions including 9 non-corner regions and 8 corner regions.

ii) *Heterogeneity factors and Node's Deployment:* Three sorts of sensor nodes are utilized in the suggested technique namely: normal nodes, intermediate nodes and advanced nodes. Heterogeneity factors are utilized to improve the stable region of the network. These factors are named as proportion of advanced nodes (m), proportion of intermediate nodes (b), extra energy factor (a) between advanced nodes normal nodes and extra energy factor (u) between intermediate nodes and normal nodes.

Now 20 normal nodes are dispersed in region NCR1 which denotes inner square as well. Every region between Inner Square (I_s) and Mid Square (M_s) is deployed with 8 intermediate nodes. Such regions are denoted by NCR2, NCR3, NCR4 and NCR5. Similarly every non-corner region between M_s and O_s are deployed with 8 advanced nodes. These regions are denoted by NCR6, NCR7, NCR8 and NCR9. Finally 2 advanced nodes are dispersed in every corner region between Ms and Os. Hence total of 100 nodes are dispersed uniformly over entire network area including 20 normal nodes, 32 intermediate nodes and 48 advanced nodes. Nodes distribution in every region is displayed in fig 1.

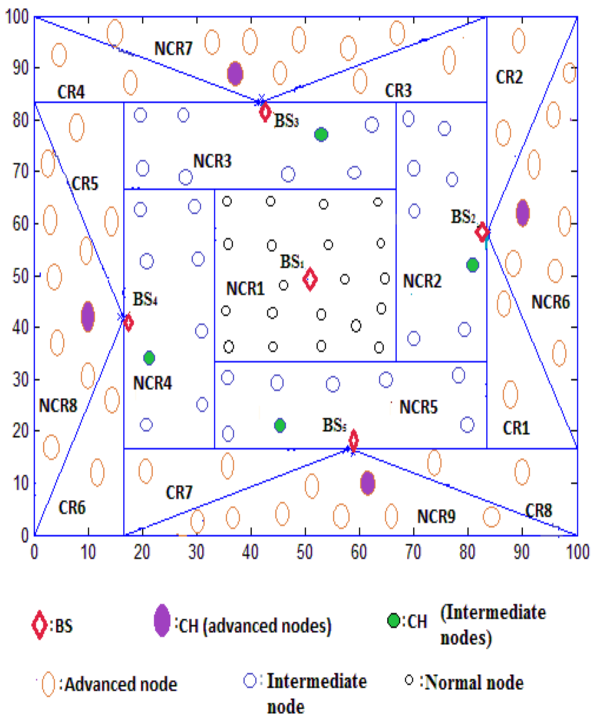

Fig. 1. Regions formation and nodes distribution in network area

iii) Optimum Placement of multiple sinks: There are k sink nodes placed at fix positions of the area. They are designated as $\{BS_1, BS_2, BS_3 \ldots BS_k\}$. The number of sink nodes (k) to be placed is decided upon number of concentric square (N) in which network is divided and total number of sensing units (n) in the field. Here for N=3 and n=100, the value k is taken as 5. It means five sink are placed in the network field at fix positions as exhibited in fig 1. It is tried to place the sinks at optimal position of the field so that distance of transmission between sensing unit and sink or between CH and sink can be minimized.

4.3 Cluster Head Election Scheme

In every round one CH is elected for every region except NCR1 and corner regions. For CH election, firstly we determine the Fermat point of every non-corner region. Fermat point is described as a point inside a polygon or triangle, such that the summation of distances of that point from all the corners of the polygon or triangle is least, when compared with the summation of whatever other point inside the limit of that triangle/polygon to all the vertices. After the determination of Fermat points, the distance of every node with its respective Fermat point is calculated. Now CHs are chosen according to ascending order of distances. In Opening round, node having smallest distance with the region's Fermat point becomes cluster head. In next round node with second smallest distance is chosen as CH and so on.

4.4 Routing Procedure

In this work, a single hop based routing procedure is adopted for making good utilization of multi-sink topology. The major benefit of single hop routing is that it consists of less transmission delay as compared to multi-hop routing. Every node of NCR1 or Inner Square transfers its sensed data straightly to the BS_1. Communication procedure for the regions between I_s and M_s is little bit different. Each non-CH node of these regions firstly determines its distances with related CH and BS. Both distances are compared with one another. If its distance with BS is found minimum when compared with CH then it transfers sensed data straightly to the BS otherwise sensed data is forwarded to the CH of that specific region. CH of that region accumulates data from remaining member nodes. CH now compares its distance with BS_1 and respective region's BS and forward its accumulated data to one of these sinks which is closer than other. For an instance, non-CH nodes of NCR2 region compare its distance with CH of that region and sink BS_2. If distances of some nodes with BS_2 are found minimum as compared to CH then those nodes transmit their data straightly to the BS_2 and remaining nodes transmit to the related CH. Then CH of NCR2 region compares its distance with BS_1 and BS_2 and transmits its accumulated data to the one that is closer as compared to other.

Routing procedure for regions lie between Ms and Os is approximately same to that of previous one. Every member node of a non-corner region and two neighboring corner regions first computes its distances with CH of that non-corner region and with the BS located at the obtuse angle vertex of the related non-corner region. Both distances are compared with each other. If for some nodes, distances with respective BS is found shorter when compared to distance with CH then these nodes forward straightly to the BS. Remaining nodes forward their data to the CH. CH accumulates the data and forward to respective base station. For instance CH of NCR6 aggregates its data from nearest nodes of its region and two neighboring corner regions CR1 and CR2 and transmits it to BS_2. Remaining nodes of those regions transmit straightly to BS_2.

4.5 Protocol Operation

Flowchart of protocol operation is exhibited in fig 2.

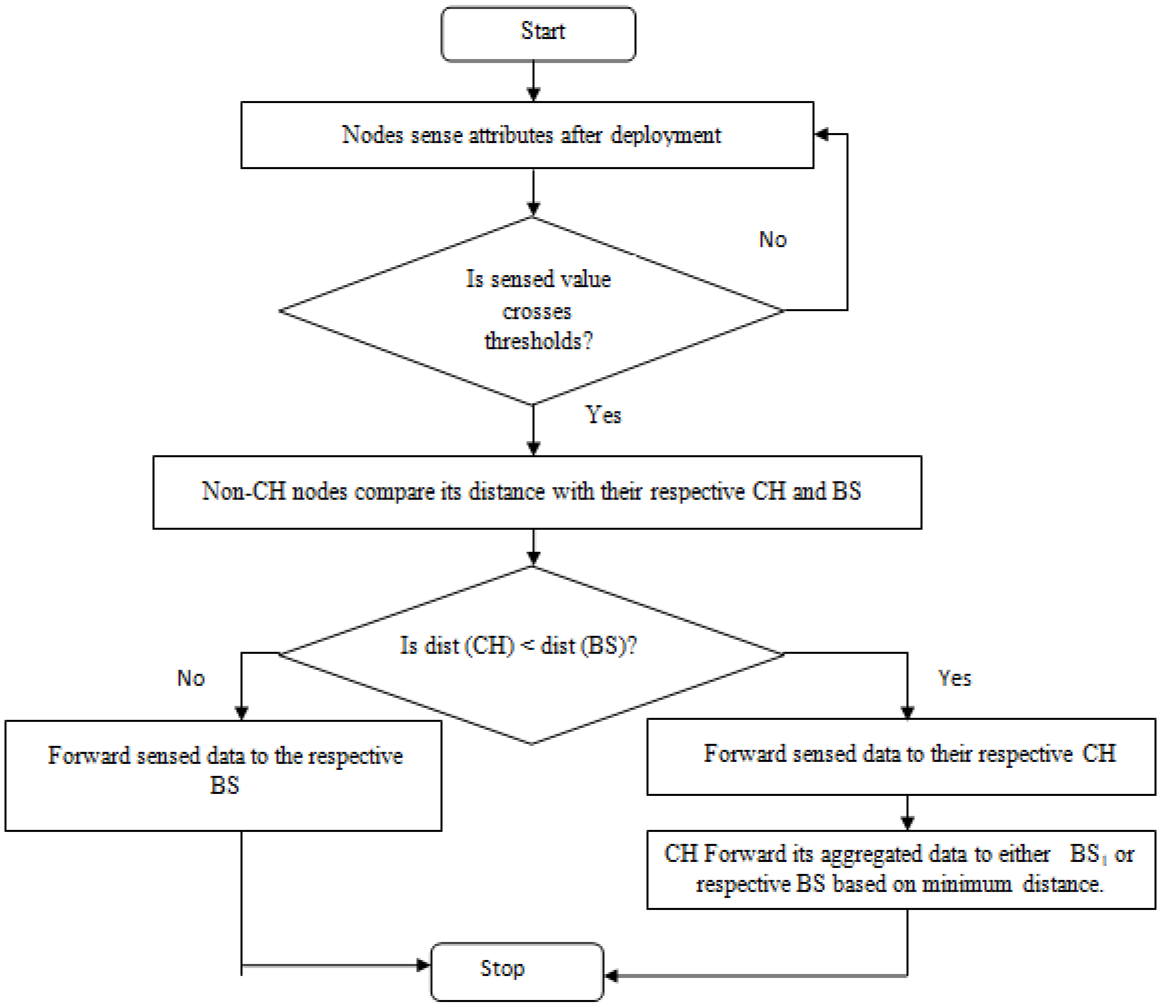

Fig. 2. Flow chart of Protocol Operation

A reactive WSN is materialized in this work. It means data is transmitted by any node to CH or BS only if its sensed attribute value goes across a pre-defined threshold and its transmitter is kept off otherwise. Sensing process is started by sensing unit once the network is deployed with nodes and initialized. Transmission by any sensing unit happens only when sensed attribute value go across the threshold value. Two levels of thresholds are applied which are described as follow:

i. Hard Threshold (HT): This is characterized as primary threshold value with which each normal, intermediate and advanced node compares its sensed attribute value. It is an absolute value of the attribute which is predefined initially before start of the operation. Whenever a node crosses this value, turns its transmitter on and reports to its CH.

ii. Soft Threshold (ST): The secondary threshold value with which a sensing unit compares its value is termed as soft threshold. A sensor node compares with this value only when its sensed value has crossed the primary hard threshold value. It is a little variation in the previously sensed value of the attribute which prompts the node to turn its transmitter on and report to its CH.

V. RESULTS AND DISCUSSION

This section focuses on the presentation and discussion of the simulation outcomes for the proposed protocol. MATLAB is used as a simulation tool. The outcomes are compared with two very well known conventional protocols namely SEP and LEACH by considering stability period, network lifetime, instability period and throughput as performance metrics.

5.1 Setting of Simulation Parameters

For simulation of the results, values of m and b are set on 0.48 and 0.32 respectively. It means 48% of nodes are advanced and 32% are intermediate nodes. Remaining 20% nodes are normal nodes. The values of heterogeneous parameters are taken as a=2 and u=1. It means advanced nodes contain two times additional energy than that of normal nodes whereas intermediate nodes contain one time more energy than that of normal nodes. Values of other simulation variables are listed in table 1.

Table 1: Simulation Parameters

Parameters	Value
Energy of normal nodes at beginning E_o	0.5 J
Energy of advanced nodes at beginning	$E_o(1+a)$
Energy of Intermediate nodes at begining	$E_o(1+u)$
Energy required for data aggregation E_{DA}	5 nJ/bit/signal
Energy exhausted in transmitting and receiving E_{elec}	5 nJ/bit
amplification energy needed for short distance ϵ_{fs}	10 pJ/bit/m^2
amplification energy needed for long distance ϵ_{mp}	0.013 pJ/bit/m^4
Number of sinks	5

5.2 Performance Evaluation and Discussion

Outcomes of the suggested protocol are compared with LEACH as well as SEP at the equal values of heterogeneity parameters. Proportions of advanced, intermediate and normal nodes are also set on same values in all three protocols. Average result is recorded after simulating the results 40 times. Comparison of results for every performance metric under consideration is discussed below:

i) Stable Region: Stable region is characterized as “the time interim when the network begins its operation to the demise of the first sensor node. This period is also named as “stability period”. It is decided by observing first node die time (FDT). Fig. 3 illustrates that first node die time (FDT) of proposed work is around 3500 rounds while it is around 1050 and 1500 rounds for LEACH and SEP respectively. So the stable region in proposed technique is around 2450 and 2000 rounds more than that of LEACH and SEP respectively. This period is prolonged in proposed technique because of the fact that communication distances between nodes and CHs and between CHs and BSs are reduced.

ii) Unstable Region: It is characterized as the time interim when first node demises until the demise of the last sensor node of the network. Value of this metric is obtained by subtracting first node die time from all nodes die time. For proposed approach, average value of this metric is around 3500 rounds whereas for LEACH and SEP it is around 4950 and 3700 rounds respectively. So the average value of this metric for proposed approach is smaller than that of LEACH and SEP which is good for the network operation.

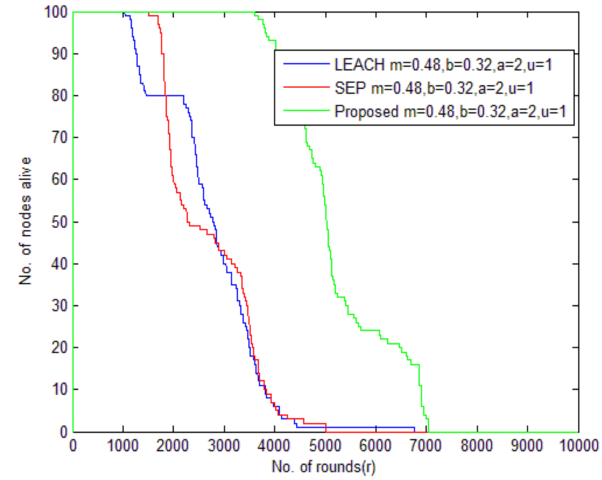

Fig. 3. Comparison of nodes alive

iii) Network Lifetime: It is the time interim when the network starts its operation until the death of the last sensor node. Network lifetime is decided upon all nodes die time (ADT).

Fig. 4 clarifies that average all node time of proposed technique is around 7000 rounds while it is 6000 and 52000 rounds for LEACH and SEP respectively. So the average network lifetime in proposed technique is 1800 rounds more than LEACH and 1000 rounds more than SEP. Balanced energy dissipation, uniform random deployments of nodes and efficient utilization of multi-sink scheme helps to increases the network lifetime.

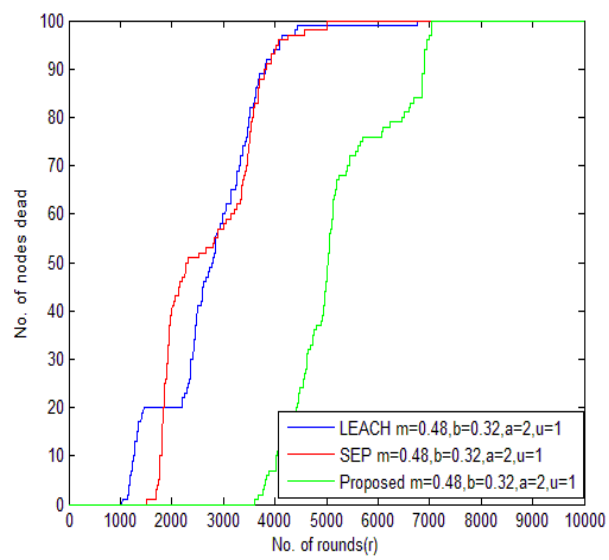

Fig. 4. Comparison of dead nodes

iv) Number of Dead Advanced, intermediate and Normal Nodes: Fig 5 illustrates the comparison of dead advanced nodes per round. First advanced node in proposed work dies after 3500 rounds whereas first advanced node of LEACH and

SEP die after 2400 and 2700 rounds respectively. All advanced nodes in proposed approach die after 7000 rounds whereas all advanced nodes of LEACH and SEP die after 6000 and 5000 rounds respectively.

Fig. 6 exhibits the stability and functional lifetime of intermediate nodes. First intermediate node in proposed technique dies after 3800 rounds whereas first intermediate node of LEACH and SEP die after 2200 and 1500 rounds respectively. All intermediate nodes of proposed protocol die after 5000 rounds whereas all intermediate nodes of LEACH and SEP die after 2200 and 1500 rounds respectively.

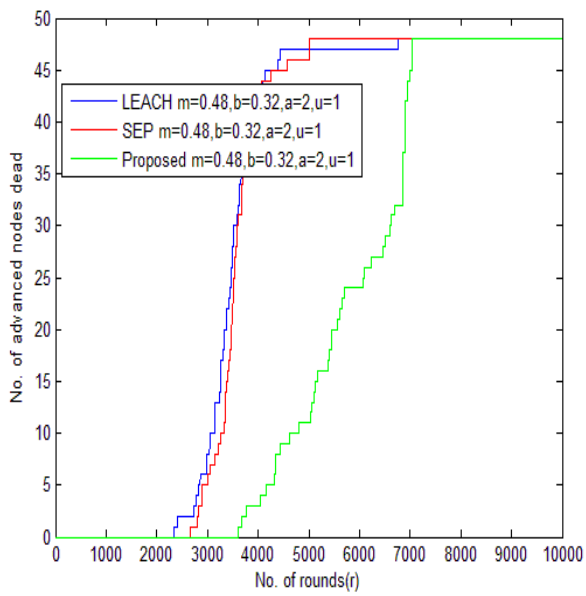

Fig 5. Comparison of Dead Advanced Nodes

Stability period and functional lifetime of normal nodes are compared in fig 7. First normal node in proposed approach dies after 4800 rounds whereas first such type of node in LEACH and SEP dies after 1000 and 1500 rounds respectively. All normal nodes of proposed approach die after 5200 rounds whereas all normal nodes of LEACH and SEP die after 1450 and 2000 rounds respectively. This later dying of advanced, intermediate and normal nodes in proposed technique is due to utilization of multiple sinks in effective way and its threshold sensitive nature.

v) Comparison of Throughput: In fig. 8, experimental outcomes for number of packets collected at sink nodes are demonstrated. Throughput is characterized as rate of packets received at BSs. After 10000 rounds, sum of packets received at BSs in the proposed technique is around 14×10^4 whereas in LEACH and SEP is that of 6.5×10^4 and 5×10^4 respectively. So the mean value of throughput in our technique is found 14.68 packets per/round which is considerably good as compared to LEACH (6.2) and SEP (5.1). Hence our techniques outperforms both SEP and LEACH with respect of throughput as well.

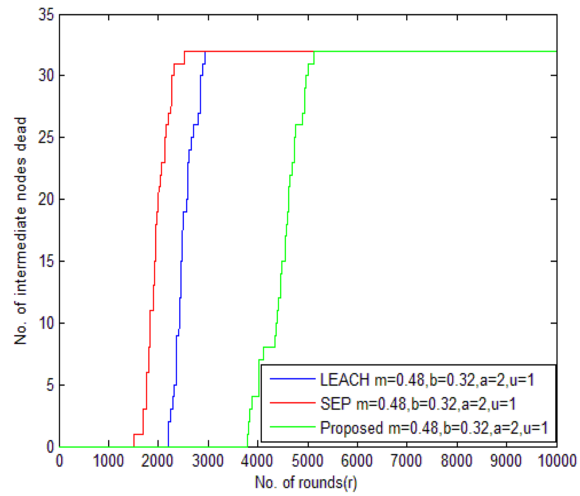

Fig. 6. Comparison of Dead Intermediate Nodes

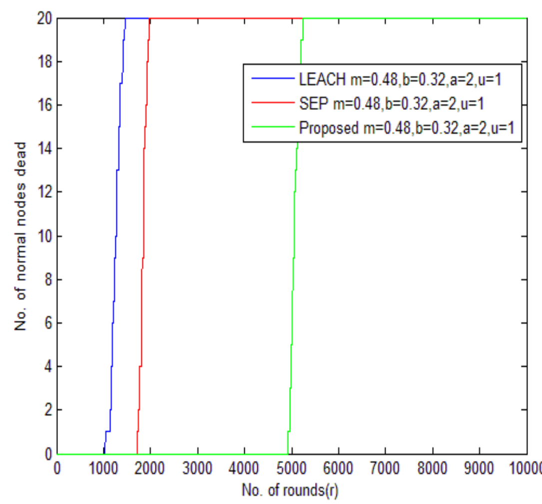

Fig. 7. Comparison of Dead Normal Nodes

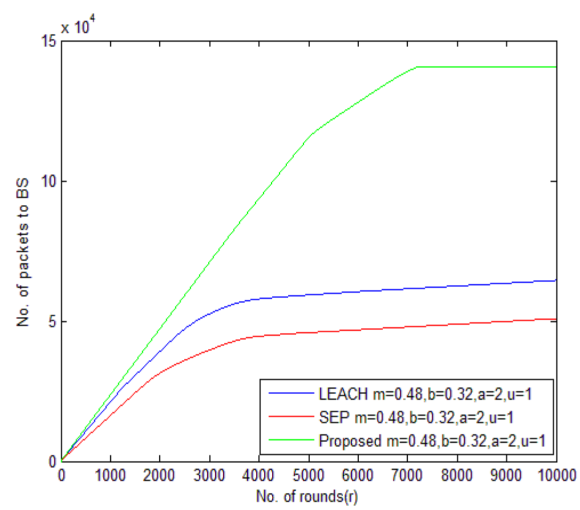

Fig. 8. Comparison of packets to base stations

VI. CONCLUSION AND FUTURE DIRECTION

In this study, a threshold sensitive multi-sink routing scheme has been introduced for the WSNs having three levels of heterogeneity. Static clustering based technique is adopted to design the network model. In addition, two levels of thresholds are utilized to lessen the number of communications. The results prove that proposed technique defeats the two popular effective energy management techniques with respect of stable region, network lifetime, throughput and unstable region. In this approach, position of sinks are made fixed, one can work by making sink nodes mobile with similar approach. In future, this approach can be extended for user defined number of sensing units and for large area as well.

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