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Bi-level Tree Sector Clustering for Energy Efficient Routing in Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks, which are composed of a collection of sensor nodes, have found enormous applications nowadays. These networks have the responsibility to sense, aggregate, fuse and transmit data to the Base Station (BS). In view of the fact that the existed limitations, such as tiny batteries in these sensor nodes, could critically affect their operation, having a low-power operation is one of the most obligated obligations. In order to decrease energy consumption and increase the network life time, we proposed a new hierarchical routing protocol, by dividing the network area to sectors and two levels and choosing Cluster Heads (CHs) from the lower level which is more near to the BS. In order to minimize the reverse flow of the data from BS, we use a tree structure in each sector. Also, the frontier between two levels can be moved during network life time and having dead nodes. The results of simulations show that our proposed TSBC protocol outperforms LEACH and many other conventional routing protocols in energy conservation and in network life time. One of the most important properties of our scheme that can distinguish it from any other scheme is reverse flow from BS cancellation or at least deduction. The special formula which is used in our protocol for CH selection, in order to prevent battery depletion in a special spot, can also be adapted to any other hierarchical clustering protocol to achieve higher energy-efficiency.**

Keywords_ Wireless Sensor Network; WSN;Hierarchical Routing; Cluster; head node; Sector; Minimum Spanning Tree; MST.

I. INTRODUCTION

Wireless Sensor Networks, which are consisted of several sensor nodes with sensing, computational and communicational capabilities, are actually a type of the wireless ad-hoc networks.[1][2] In spite of this kind of classification, some of fundamental features of wireless sensor networks such as having a tiny, restricted battery can prevent us from employing many current routing protocols.[2] Then as a result a low-power operation is an unavoidable solution that could be achieved through using a power efficient protocol.[3]

In defiance of this kind of limitation and other kinds such as memory, bandwidth and computational constraints, still WSNs provide numerous and unpredictable applications such as battle field surveillance, environment monitoring, health care and disaster prediction.[4]

Between many routing protocols which have been proposed in order to balance the energy load and prolong the network lifetime, hierarchical routing protocols have significant saving in total energy consumption.

In hierarchical routing protocols a cluster head would be assigned to each created cluster. This CHs would receive data, do some data processing (data aggregation, fusion, filtering and etc., which can effectively decrease the number of massage to be sent to the sink) and transmit the aggregated data to the BS.[3][5]

The transmission of data through clusters occurs, relatively over short distances. Proposed hierarchical clustering protocols such as Low Energy Adaptive Clustering Hierarchy (LEACH) [6] and its other extensions[7][8], Power Efficient Gathering in Sensor information System (PEGASIS)[9], Concentric Clustering Scheme (CCS)[10] and Track Sector Clustering (TSC)[5] have taken grand steps in conserving energy. However these conventional routing protocols still have to be modified in energy consumption aspect and have to be ameliorated in the aspect of reverse data flow from BS.

In this paper using Tree Sector Bi-level Clustering scheme (TSBC) to remove reverse data flow from BS using a tree structure and distribute the energy consumption in the network uniformly using a tree-sector structure is proposed. Also the nearest (first-leveled) nodes to BS have been used as CHs, in order to reduce the energy which is used for sending aggregated message to the BS.

The reminder of the paper is organized as follows:

Section II summarizes related works. In section III the radio model which is used in our proposed scheme will be discussed. Section IV describes the architectures and

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details of our TSBC. In section V our simulation results will be compared with those of well-known LEACH protocol. Finally, in section VI we will present our conclusion of all the discussed arguments.

II. RELATED WORKS

Various routing protocols have been proposed in order to decrease the energy dissipation and increase network life time. And still this fact is considerable that clustering routing protocols are the best-performing protocols in conserving the energy as compared to flat routing protocols.[11] In this part of the paper is tried to present some of hierarchical routing protocols in which the researchers try to achieve energy conservation goal.

Thanks to reduction of direct transmission to BS and balancing WSN load, LEACH achieves a factor of 8 times improvement compared with direct transmission. As a matter of fact LEACH causes a very high level of energy consumption in the head nodes and that is the reason to early death of head nodes.[6]

One extension which has been proposed to LEACH algorithm has been named TL-LEACH. It benefits two levels of cluster heads (CHs), primary CHs and secondary ones. In this algorithm, the primary cluster head in each cluster communicates with the secondary ones, and the corresponding secondary ones communicate with the nodes in their sub-clusters. Data fusion could be done just like what happened in LEACH. CHs will be selected based on a priori probability of becoming a primary CH less than secondary one. In addition, communication within a cluster is still scheduled using TDMA time-slots.[8]

In the other extension of LEACH named *LEACH-C*, the base station is used for the formation of clusters, while in LEACH protocol the nodes configure themselves into clusters [7]. After getting the information regarding level of energy and about the location of the nodes from different nodes in the network, BS uses this information to select the number of cluster heads and configures the network into clusters. Now the cluster grouping is to be done, so that when clusters send their information to the corresponding cluster heads, energy utilization should be minimum.[12]

S.Lindesey et al. proposed an algorithm named PEGASIS. In PEGASIS all the nodes in the network will form a chain and data will be aggregated continuously through the chain. In this near-optimal algorithm, in any given transmission time-frame, only one node will be transmitting to the BS. In round i, while the total number of node is N, the $(i \, mod \, N)$th node will become a leader and then will be the only node who has to transmit data to the BS during this round. Unfortunately, the reverse flow of data from BS in this approach is actually high.[9]

Another protocol named CCS has been proposed to improve the deficiencies of PEGASIS. In CCS the whole area of the network was divided into concentric tracks and then the whole number of nodes in each track will play the role of a cluster. This tracks will be leveled form level 1 which is the nearest to BS to level n which is the farthest one. In each cluster one node will be chosen as a cluster head using a special approach. Here also just like PEGASIS all the nodes will transmit their data to their nearest neighbor and the head node in each level transmits the data to the lower head node. Finally level 1 head node will complete this task by transmitting the final form of data to the BS. [10]

The other protocol which has been presented was TSC [5] which is basically a hierarchical clustering scheme in which the cluster is a curved strip form area which has been denoted by the intersection of circular tracks and triangular sectors. This kind of clustering could decrease the redundant data transmission in the network by breaking the long chain in the tracks into smaller chains, but still reducing the amount of this redundant data transmission or the reverse flow of data from BS is possible. So we decide to present our scheme of TSBC while trying to decrease the energy consumption and increase network life time, too.

III. FIRST ORDER RADIO MODEL

In this research a simple radio model is assumed [6] in which the radio dissipation to run the transmitter or receiver circuitry is equal to $E_{elec} = 50nJ/bit$ while the required energy for the transmit amplifier is equal to $E_{amp} = 100\, pJ/bit/m2$. The energy loss which can occur in a transmission channel through a distance of d for a k-bit message can be modeled as follows:

$$E_T(k,d) = E_{Telec}(k) + E_{Tamp}(k,d)$$
$$E_T(k,d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2 \qquad (1)$$

And for the reception process we have:

$$E_R(k) = E_{Relec}(k)$$
$$E_R(k) = E_{elec}(k) \qquad (2)$$

We made the assumption that the radio channel never will be saturated and is completely symmetric. As another assumption we assume that all the nodes have data to send to the BS during each round.

IV. PROPOSED PROTOCOL

The main aim of TSBC is to achieve a prolonged network life time using decreased energy dissipation specially by minimizing the reverse flow of data from BS. In each round both sectoring and levelling will be occurred dynamically based on number of alive nodes or even the amount of residual energy in the network. In each sector a tree structure will be constructed with a root which is a designated node from first level, the nearest

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level to the BS. Using MST (Minimum Spanning Tree) will guarantee that all of the nodes will send their data to their nearest neighbour, where this neighbour will fuse it with its own data and then will transmit it to its one-hop neighbour. Finally the cluster heads or, in this paper, the roots of each tree will transmit final form of data to the BS.

Now let us explain our term of "Bi-level Tree Sector Clustering" in more details. Generally it means that a cluster will be shaped by merging all of these elements, such as: trees, sectors and finally levelling them up to two levels.

Partitioning the area of the network to sectors, using a tree structure in each sector and levelling the whole area of the network to two levels absolutely will decrease redundant data transmission and still reduce the energy consumption caused by large distance between head nodes and the BS. The new proposed protocol consists of the following steps:

1. Imaginary circle

Drawing an imaginary circle with the radius of the distance of the farthest node to the BS, in that way all the nodes will be placed into our imaginary circle.

2. Level assignment

Assigning a level number to each node based on its distance from BS, in that way the nearest nodes to BS will become first-levelled nodes and the remaining ones will become second-levelled ones. This levelling radius or levelling constraints could be dynamically changed by having some dead nodes or by changing the position of mobile wireless nodes. After levelling, they are just first-levelled nodes who have the authority to become a cluster head after satisfying other conditions.

3. Sector assignment

In this step, dividing the whole area of the network to some sectors could be done, regardless of our recent bi-levelling partitioning. In most of the cases it's desirable to divide the imaginary circle to six sectors. The number of sectors could be determined based on the optimal number of clusters to have in the system. This will depend on several parameters, such as the network topology and the relative costs of computation versus communication. However sectoring phase could be done dynamically and even the number of sectors could be changed during the network life time.

4. Selecting CH

So till now we have sector-shaped clusters in which just the nodes which are located in the intersection of lower level and sectors are authorized to become cluster heads. Cluster heads will be chosen using the following formula:

$$A = E_{res} + \alpha * \left(\frac{1}{D^2}\right) - \beta * \left(\frac{1}{d^2}\right) \qquad (3)$$

In which E_{res} is residual energy of one of probable CHs (one of the new candidates); α and β are constant values which could be chosen based on the approximate number of first-levelled nodes in each sector , network dimensions, maximum and minimum distance of nodes to each other in each sector and still some other factors. Even α and βcould be varied during network life time by having dead nodes or the mobile nodes that have changed their positions.D is the distance between the new candidate and BS and d is the distance between the new candidate and the recent cluster head. In the case that changing CH is necessary and there are many candidate nodes, the node that can achieve the highest amount of A could become CH for the next round. Even we can change our criteria in such a way that the distance to the CHs of adjacent clusters be effective on our selection of CH, too. This formula helps us to avoid battery depletion in some spots by balancing energy load between the probable CHs. This will work in such a way by using distance between cluster heads themselves, as a factor to prevent battery depletion in some spots. It also appreciates the nodes with the shortest distance to the BS. Hence in each round that changing the CH is required one of the nearest first-levelled candidates will be chosen that has the farthest distance from the recent CHs and simultaneously has a relatively good residual energy. In the first round, one of the first-levelled nodes with the highest amount of energy and shortest distance to the BS will become CH. In the case that all the nodes start their work with the same amount of energy the nearest node to BS will be chosen as CH.

This level could be done using any other Cluster Head choosing algorithm.

5. Forming a Tree

In this step a tree structure will be formed in each sector. The roots are actually selected head nodes in the recent step. Using the tree structure will guarantee the lowest level of redundant data transmission specially when the root node or in the other word our cluster head is one of the nearest nodes to the BS. In our work we have used MST, and we use the square of the nodes' distance as the link cost. In that way if the distance between node A and node B was a, cost of the link between them would be a^2. So the used Minimum Spanning Tree algorithm will form a tree in which all the nodes have the capability to send their data to their nearest neighbour.

6. Data Transmission

When the configuration of clusters becomes clear, it is time to transmit data to the BS. Each node sends its data to its one hope precedent node in the tree structure. There,

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the mentioned precedent node fuses the received data with its own data and then transmits it to its own precedent node. This process will be repeated till the whole data of the sector arrives at CH; there the CH will merge its data with the aforementioned received data and finally send it to the BS, which is located in relatively nearest distance to the CH.
Figure1 can illustrate partly our aforementioned steps in our proposed algorithm.

V. SIMULATION AND RESULTS

A. Simulation

We used MATLAB R2013b for performance evaluation of our proposed TSBC scheme. For our simulation we used a network of 100 nodes deployed in a round area with a radius of 10 m and BS at the center of this area. We set the initial energy of each node to 0.5 J. Therefore the total initial energy of all nodes in the field is 50J. Since the BS was located in the center, we set the number of sectors to 6, so that each sector projected an angle of 60° at the BS. Each sector had variable number of nodes. Size of each data was set to 2000 bits. The energy consumption both to receive and transmit one bit is 50 nJ and the energy required for data aggregation was set to 5 nJ/bit. The energy dissipation to amplify one bit in free space propagation has been set to 10 pJ and in multipath case, this quantity was set to 0.0013 pJ.

Just for simplicity and considering the point that we have just a few numbers of probable CHs we didn't use our special formula to select the CH in each round. We just select our cluster heads in a way that profit the highest amount of residual energy and nearest distance to BS.

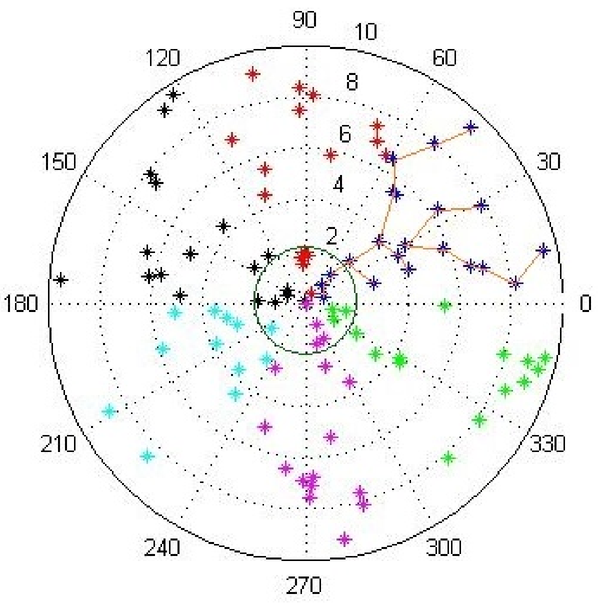

Figure 1. Overall steps which has been done in TSBC

TABLE 1.Variables Used for Numerical Analysis & Network Simulation

Type	Value
Number of Nodes	100
Number of Tracks	6
Initial Energy of Each node	0.5 J
Reception Energy	50 nJ/bit
Transmission Energy	50 nJ/bit
Data Aggregation	5 nJ/bit
Data Size	2000 bit
Free Space Amplification	10 pJ
Multipath amplification	0.0013 pJ

B. Results

We used two performance metrics for the performance evaluation of the proposed TSC scheme: Number of dead nodes per round and Network residual energy per round. The first metric, which is number of dead nodes per round give an idea of the time over which the network can send the data before all the nodes in the network die. The other metric which is Network residual Energy gives an idea of the rate of consumption of energy in the network. We compared our proposed TSBC with LEACH which is the most popular routing protocol. Simulation results showed that our proposed TSBC has alive nodes even more than 3000 rounds after the round in which the last alive node of LEACH has been dead. Figure 3 showed that our network residual energy has been remained at least 3500 rounds more than the LEACH's one. All of these good results will be fortified with the fact that our reverse flow of BS will be almost zero because of using a tree structure.

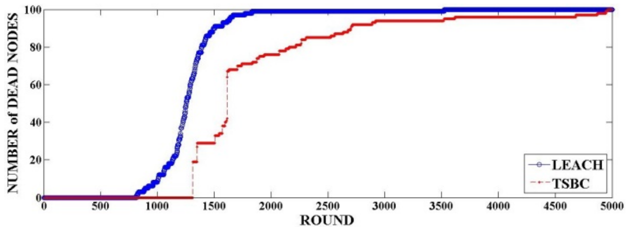

Figure 2. Number of dead nodes per round

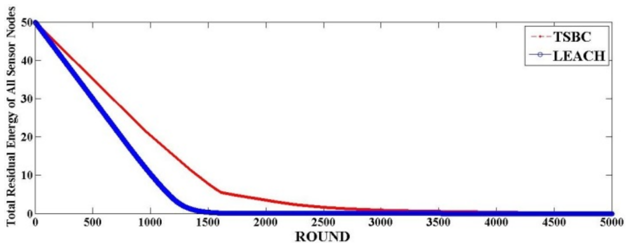

Figure 3. Total residual energy of all sensor nodes per round

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VI. CONCLUSION

In this paper the TSBC scheme has been proposed for energy efficient routing in WSN. In simulation results it is revealed that a good level of improvement in network lifetime and the rate in which the nodes die have been achieved, in comparison with conventional routing protocols. The proposed scheme cancels or decreases the amount of reverse flow from BS by using a Minimum Spanning Tree structure. Almost all the computations are done in the BS, so our protocol will not impose high computational tasks on low power, low memory and restricted wireless sensor nodes. Therefore, the proposed TSBC scheme is suitable for application in which energy conservation is a must. Unlike in many other conventional routing protocols, there is no or negligible redundant data transmission, because the reverse flow from the BS has been cancelled using the tree structure. So the proposed protocol will best suit the application in which redundant data transmission must be as less as possible.

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