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EECDC: Energy Efficient Coverage Aware Data Collection in Wireless Sensor Networks

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Abstract

Energy efficient head node selection is the major issue in wireless sensor networks. Due to irregular node distribution energy consumption is not a balanced one in cluster-based wireless sensor networks. The proposed system provides techniques to rectify this problem through: (i) Forming Maximal Independent Set (MIS) (ii) Effective Set Head selection (iii) Multi-hop communication. Non adjacency of nodes has been leveraged for creating MIS. Intra-set energy consumption has been reduced by selecting a node as Set Head (SH), which is geographically nearer to all other nodes. Inter Set efficient energy consumption is achieved by using multi-hop communication between SH to BS. The proposed system EECDC forms more efficient and stable sets, which increases the lifetime of sensor networks i.e., Number of data collection rounds.

Keywords: Energy Efficient, Maximum Independent Set (MIS), Coverage, Wireless Sensor Networks.

1. Introduction

Wireless Sensor networking is a challenging technology used for atmospheric monitoring, personal health monitoring systems, robotic exploration, etc... Each sensor node has more than one sensor, a processor and low power radio. As sensor nodes have some degree of non-rechargeable battery power, energy should be managed cautiously to increase life time of the sensor network.

Sensor nodes are rigorously controlled according to its available battery power. Since wireless communications requires considerable amounts of battery power, sensor network must be designed to use less energy for receiving and transmitting data. Sensor node's life should be maximized by communication protocol and reduce the bandwidth consumption by using local cooperation among the nodes.

Coverage exhibits how much a sensor area is monitored. Coverage is one of the most important performance factors to assess sensor networks.

Coverage becomes serious problem when large numbers of nodes are deployed randomly. Sensor coverage model reflects the characteristics of sensors such as shift function, sensibility, active range and correctness etc. These measurements used to measure sensing ability and value of a sensor. Collected quality of services in various locations used to measure sensing coverage of the wireless network.

Wireless Sensor Networks have specific constraints and rigorous requirements. From these specific requirements, increasing the lifetime of sensor is the major issue. Therefore, the primary constraint on WSN to making batteries runs longer. In recent years, researchers have involved to prove that clustering is a qualified method for improving

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the lifetime of WSN. Clustering has two forms of nodes; first one of the form is Cluster Head (CH) and second is several Cluster Members (CMs). CM collects data from the surroundings location regularly and transmits the data to CH. CH combines the data from their CM and sends the aggregate data to the BS.

Maximal Independent Set (MIS) is an self-governing set which is having at least one endpoint and not a subset of any other self-governing set. Weili Wu, et al., [15] explains maximum independent set is related with minimum connected dominating set by comparison of these sets. This will show how many vertices are required to connect a maximal independent set. In this paper, we step forward a Set-based routing protocol for WSN whose core is based on Maximal Independent Set (MIS). It has the following advantages over clustering as:

i. MIS avoids overlapping
ii. Maximum area coverage
iii. Network life time is prolonged by set based routing

Set creation contains two kinds of nodes, one as Set Head (SH) and specific number of set Members (SMs). This paper MIS forms the sets based on non-adjacent nodes. To equalize the energy conservation amongst set members, SH activity is assigned to next higher residual SM node. The rest of the paper is structured as follows: Section 2 deals the related works. Section 3 gives the details of System model. Section 4 exhibits proposed work in detail. Section 5 describes performance analysis obtained in detail. Finally, Section 6 gives the conclusion of this paper.

2. Related Work

LEACH [12] is a cluster- based protocol that forms the clusters by using Received Signal Strength Indication power from neighbour nodes, which works in decentralized manner. LEACH-C [6] elects Cluster Head nodes in a centralized fashion. PEGASIS [10] is optimal chain-based protocol that communicates only with close neighbour nodes for transmitting the data to BS which reduces the energy spent per round.

S-MAC [14] auto-synchronize on sleep schedules for their neighbouring nodes. ETSP [5] identifies the condition to toggle between receiver-receiver as RBS and sender-receiver TPSN based on the threshold value.

GESC [8] selects the CH based on the residual energy and forward through multi-hop paths to sink. OWFA [11], evaluate optimal wake up frequency by totalling the operating cost values and data broadcast energy values of all child nodes. This frequency assigns by the root node such as head node to all child node. ML-MAC [7] reduces the wake up time of each sensor node by listening the periods of nodes in various layers.

R-MAC [13] allots time slot to every node that will be traced up by nearby sender node to transmit its message to the receiver node using time stealing mechanism. TDMA [9] maintains path wake-up aggregation techniques for low end-to-end delay from the sensors to the gateway.

EADC, [4] directly sends the data from one CH node to the sink, if its distance is less than the Threshold level, otherwise it will send its data to next CH node which is having higher residual energy, to reach the sink node. The above algorithms like LEACH explain layered based CH selection as single-level clustering as well as multi-level clustering strategy. EADEEG [6] elects the cluster head based on the proportion among the middling residual energy of neighbour nodes and the residual energy of the node itself. EADEEG achieves a prolong network life time by good cluster head distribution.

EEGTP [1] avoids direct transmission from CH to BS which uses multi-hop data communication. ECCA [3] minimizes the energy conservation by reducing the activated nodes using sleep/wake up schedules. The less number of sensor nodes selected in closely atmosphere while keeping complete coverage. PEAS [2] maintain coverage by adjusting the probing range of nodes and energy gets reduced by activate only those set of nodes to cover the intended region.

3. System Model

Sensor nodes are scattered in non uniform manner over the field. The Set Head nodes get elected based on the link connectivity and its remaining energy levels of specific rounds. The Set Members nodes have to send its data to the SH which aggregate it into a single data packet.

The following assumptions have been made,

1. All the nodes in the network know its position by using GPS receivers.
2. After the deployment of the nodes, it becomes stationary nodes,
3. All the nodes are Homogenous, having equal sensing range, battery power and uses same type of sensor.
4. Nodes can communicate with each other and with the Base Station
5. All the nodes exhibit the same Deterministic coverage model.

4. Proposed Work

EECDC, Energy efficient Coverage aware Data Collection protocol works based on energy efficient Maximum Independent Set (MIS) concept. This protocol elects the SH based on two parameters: i) link connectivity ii) residual energy. In terms of link connectivity, SH selects based on the node degree which have higher numbers of neighbor nodes.

The proposed EECDC protocol has three phases as follows,

1. Maximal Independent Set Formation phase
2. Set Head election phase
3. Communication phase

4.1 MIS Formation Phase

The nodes participating in the network knows its own location and other nodes location with the help of GPS receivers or by some other cost effective techniques. The distance between one node to all other nodes are calculated using Euclidean distance [3] formula,

$$\text{Distance d} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{1}$$

The distance 'X' is computed such that the nodes which are 'X' distance far away from each other is eligible to form a set.

$$\text{D} = \sum_{i=1}^{100} d_{n,i} / 100 \tag{2}$$

where 'n' can be any random node from the network and $d_{n,i}$ denotes the distance between the node '*n*' to '*i*'.

$$\text{X} = \text{D} + \delta \tag{3}$$

where δ is negligible when compared with D.

MIS formation phase has been worked with the following control messages: i) Idt_msg, ii) Set_msg.

i. **Idt_msg:** All the nodes will send their location details to the BS.
ii. **Set_msg:** The BS will form the MIS with 'X' as the minimum distance between the set members. It sends the Set_msg to all the nodes indicating its membership to particular set.

4.2 Set Head Election Phase

After the MIS sets have been formed, the distance between each node to all other nodes in each set is calculated as 'Y',

$$\text{Y} = \sum_{n=1}^{10} \sum_{i=1}^{10} d_{n,i} \tag{4}$$

The proper eligible SH is chosen in such a way that SH=min(Y)

Set Head Election phase has the following control messages as i) Head_msg, ii) Slot_msg.

i. **Head_msg:** Within each set, BS identifies a node which is easily reachable by all other set member & it is elected as Set Head. BS sends Head_msg to all the newly elected Set Head nodes.
ii. **Slot_msg:** After receiving the Head_msg, each Set Head in turn will generate a separate data collection time slot for each member nodes and sent it to the set members.

4.3 Communication Phase

The data generated by sensor nodes by sensing the field will be communicated to the base station at equal interval of time. It has been divided into two sub-phases as intra-cluster communication and inter-cluster communication phases.

4.3.1 Intra Set Phase

The Set Member nodes send its data to the Set Head nodes in its allotted time slots regularly. After collecting all the data from its set members SH node will aggregate the data.

4.3.2 Inter Set Phase

Each SH node has to calculate its distance with the Base station. If the distance is less than the threshold level 'T', then it directly transmits its packet to the BS, otherwise it forwards its aggregated data packet to the next nearest neighbour SH node and it reaches the BS.

When the above formed Set is working for long time, the Set Head nodes will loses its energy fastly and may not be in a position to survive in the network. In order to avoid this, EECDC reorganises the existing Set for every 'r' data collection rounds and elects new Set Heads to balance energy consumption among nodes. The new Set Heads elected after 'r' rounds are based on link connectivity and residual energy.

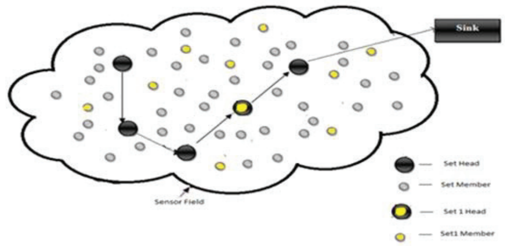

Figure 1. MIS based System Architecture.

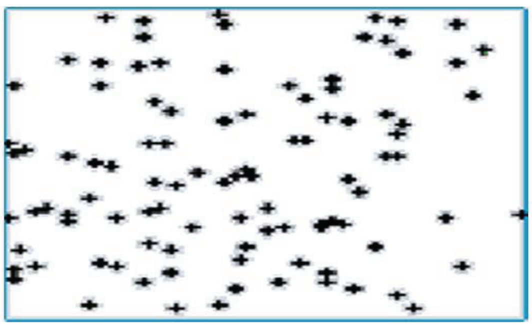

Figure 2. Sensor node deployment in the field region.

5. Performance Analysis

5.1 Experimental Set Up

The sensor node is scattered in the target region as given below in Figure 2. For our experimental set up we have taken the field area 100×100 m.

As given above all the nodes transmits its location details to the Sink node located far away from the field region. Then the Sets have been formed and its heads are elected at the subsequent steps. Each Set Member (SM) will send its data to its Set Head (SH) nodes at its allotted time slots. The energy consumed in this transmission is calculated by,

$$E_T = n^*E_{elec} + n^*\varepsilon_{fs}d^2 \quad (5)$$

Each Set Head node receives the data sent by its SM nodes by spending the energy given below,

$$E_R = n^*E_{elec} \quad (6)$$

where, number of bits n = 4000, Electronics energy E_{elec} = 50nJ per bit, power loss in free space ε_{fs}=10pJ per bit. Each node is initialized with 1joule energy. Apart from this the aggregation cost for Set Head node is E_A= 5nJ per bit.

5.2 Performance Evaluation

When EECDC is evaluated, its performance is compared with a clustering protocol LEACH-C. EECDC set is being compared with the clusters in the LEACH-C. Figure 3 depicts the number of overlap between cluster members in LEACH-C and Set Members in EECDC.

By reducing the overlap between the sensor nodes, unnecessary energy wastage will be reduced in the overall network.

The energy spent over single data collection round is an important parameter to determine the lifetime of the network. In Figure 4, the comparison has been shown for EECDC with LEACH-C in terms of average energy spent during a data collection round in the above given network setup. EECDC shows the tremendous improvement in average energy spent for a single data collection round than LEACH-C.

Figure 5 shows the coverage area by LEACH-C and EECDC. LEACH-C senses the entire coverage region continuously which is unnecessary in many real time applications. EECDC covers a part of its field at a particular instance of time through activating Set members, whereas the other uncovered region will be covered when other Set members have been activated. In overall LEACH-C senses its environment continuously and EECDC senses its environment at discrete time intervals.

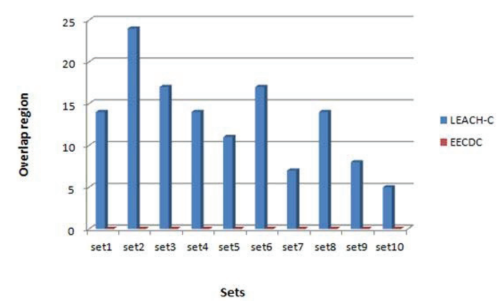

Figure 3. Number of overlap in LEACH-C and EECDC.

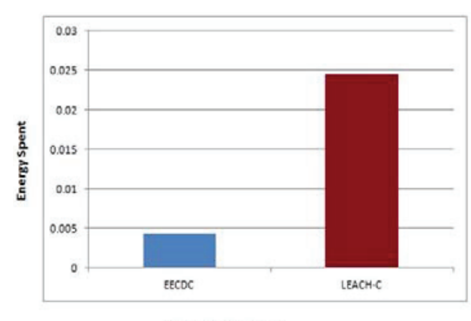

Figure 4. Average Energy spent for a Data Collection Round.

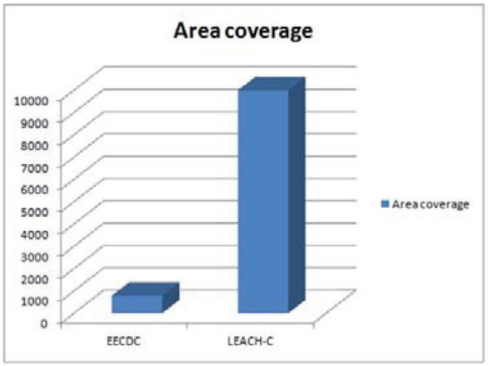

Figure 5. Area coverage in EECDC and LEACH-C.

6. Conclusion

EECDC works by exploring the features of Maximal Independent Set concept. Instead of activating every node in the network, it divides this into equal numbered sets. Each set is activated in sequence in such a way that when one set is activated all other set nodes will be sleeping state. Since the node which is having minimum distance with all other nodes in the network is elected as Set Head, Intra Set Communication cost is reduced. Also Inter Set communication cost is reduced by using multi-hop communication between Set Head to BS node if necessary. But EECDC does not monitor the surrounding environment all the time. When a particular Set is activated it covers certain area in the target region and through activating the Set sequentially the uncovered area will be monitored by other Sets at different timing interval. In total EECDC achieves 10 fold times better energy efficient coverage of the region when compared with other existing protocols.

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