Optimal Relay Node Placement Algorithm for Coverage and Connectivity in Wireless Sensor Networks

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Abstract:

Background: Coverage is one of the main research interests in Wireless Sensor Networks (WSN) and it is used to determine the Quality of Service (QoS) of Networks. In this Wireless Sensor Networks, the Sensors are Energy constrained devices and hence Wireless Sensor Networks faces many numbers of challenges and design issues particularly Guaranteed Coverage and Maximize Network Lifetime.Objective: One approach to prolong the lifetime of a wireless sensor network (WSN) is to deploy a large number of relay nodes for routing data and to communicate with the sensor nodes. Unlike contemporary schemes for relay node placement, the proposed approach deduces a relay node density function based on balancing power consumption among all sensor nodes and relay nodes. The relay nodes are placed in the sensing field according to the relay node density function. Results: The simulation results show that our strategy cannot only achieve high energy utilization but also extend network lifetime, coverage and connectivity.

Keywords: Coverage, connectivity, Wireless sensor network, Relay node, Sensor node, Sink, Power consumption.

Introduction:

Sensor networks are tiny power constrained devices, which can be scattered over a region of interest, to enable monitoring of that region for an extended period of time. The nodes sense environmental changes and report them to other nodes sover flexible network architecture. Area monitoring is a common application of WSNs. For example, a large quantity of sensor nodes could be deployed over a battlefield to detect enemy intrusion instead of using landmines. When the sensors detect the event being monitored the event needs to be reported to one of the base stations, which can take appropriate action. Applications have been envisioned where sensor nodes are scattered from a helicopter over a region of interest, and the nodes self-organize themselves suitably. Once the network is established, the sensed data needs to be routed to a common base station, usually at the periphery of the network. A few potential applications are in order here. Military applications require sensors to be scattered in the enemy territory. The sensors sense the environment for acoustic signatures of vehicles (tanks, jeeps, etc.), and deliver the sensed data to the appropriate base stations (Akyildiz, I.F., W. Su, 2002). These and numerous other applications of sensor networks require that every point on the region of interest be sensed by at least one sensor.

1.1 Wireless Sensor Network Architecture:

A Wireless Sensor Network (WSN) generally consists of a base station that can communicate with a number of wireless sensors via a radio link. Data is collected at the wireless sensor node, compressed, and transmitted to the gateway directly or, if required uses other wireless sensor nodes to forward data to the gateway.

In WSNs, the architecture of the network depends on the purpose of the application (Lloyd, E.L., G. Xue, 2007). The sensor nodes are scattered in a sensor field. Each of these scattered sensor nodes has the capability to collect data and route data back to the sink node in a multi hop manner. For example, a large quantity of sensor nodes could be deployed over a battlefield to detect enemy intrusion instead of using landmines. The role of the sink node is to monitor the overall network and to communicate with the task manager, which was described in Fig. 1. The main constraint of sensor nodes is their very low battery energy, which limits the lifetime and the quality of the network. The role of the relay nodes is to forward data packets from the source nodes to the sink. Relay nodes are required when the source node is not within direct communication range of the sink.

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Wireless Sensor Network (WSN) technology has its own limitations such as relatively low amounts of battery power and low memory availability compared to many existing technologies. A typical sensor network consists of a larger set of miniaturized sensor nodes reporting their data to significantly fewer actor nodes.

1.2. Factors Influencing Sensor Network Design:

1.2.1. Reliability:
Reliability is one of the most important factors. A sensor node can fail due to several reasons such as environmental interference, physical damage, etc. The failure of a single node should not affect the overall network performance.

1.2.2. Energy Consumption:
A sensor node is equipped with a limited energy source and hence has a lifetime that is dependent on that source. In a WSN, each node can originate data and also has to route data. A sensor node’s task is to sense data, perform some processing and then transmit the data.

1.2.3. Fault Tolerance:
Node failure is a very common problem in WSN’s. The ability of a network to react to node failures is a design concern. A failure of a single node should not affect the functioning of the entire network. Fault tolerance in WSN’s is mainly handled by the MAC and routing layers.

II. Earlier works:

2.1 Placement of Relay Nodes based on Communication Range:
A relay node can be placed based on the communication range by assuming that the communication range of sensor nodes is \( r > 0 \) while the communication range of relay node is assumed to be \( R \geq r \). The connecting path should be established using sensor and/or relay nodes. In single-tiered relay node placement the path consists of relay and/or sensor nodes between every pair of sensor nodes (Lloyd, E.L., G. Xue, 2007). In two-tiered relay node placement the path consists solely of relay nodes. The problem considered is Steiner Tree problem and it get varies for single-tiered relay node placement and two-tiered relay node placement.

2.2 Constrained Versions of Relay Node Placement:
In this constrained version the relay nodes are placed at a set of candidate locations (Misra, S., S.D. Hong, 2010). The relay nodes are placed in such a way that there should be a bidirectional path between each sensor node and the base station. This is the case occur in connected relay node placement problem whereas in survivable relay node placement problem the relay nodes are placed in such a way that each sensor node is connected to one base station through two node-disjoint bidirectional paths. Linear programming schemes are used for computing lower bounds on the optimal solutions of the relay node placement problems. This technique meets both connectivity and survivability requirements in wireless sensor networks.

2.3 Fault Tolerant Relay Node Placement:
In this fault-tolerant relay node placement technique the main objective is to place a minimum number of relay nodes such that each sensor node should be able to communicate with minimum two relay nodes and the relay nodes network should be 2-connected that is at least two node-disjoint paths between every pair of relay nodes in the relay node network. By placing the relay node in the 2-connected relay node network, when one relay node fails then the other backup relay node can cover the sensor node so that the network will remain connected (Hao, B., J. Tang, 2004). In this work it is assumed that all sensor nodes have the same communication range \( r \). A sensor node can be covered by a relay node only if it is within a distance of \( r \), the communication range of the sensor nodes. The communication range of relay node is assumed to be \( R \), much bigger than \( r \).
2.4 Localized Approaches:

2.4.1 Distributed Actor Recovery Algorithm (DARA):
To restore the connectivity of an interactor network DARA, is used. DARA is a localized scheme that re-establishes communication links among impacted actors (Abbasi, A., M. Younis, 2005). The main idea of DARA is i) to replace the dead actor by a suitable neighbor and ii) identifies the nodes that are affected and relocate some of these nodes.

2.4.2 Distributed Partition Detection and Recovery Algorithm (PADRA):
Actors in WSANs are movable units which can process the sensed data perform appropriate actions and make decisions. To self-restore the connectivity a Distributed Partition Detection and Recovery Algorithm (PADRA) is used (Akkaya, K., F. Senel, 2010). PADRA assumes that only one node fails at a time and no other nodes fail until the connectivity is restored. Hence, concurrent failure of multiple nodes is still possible. PADRA cannot handle multiple simultaneous failures.

III. System design:
The relay node placement problem for wireless sensor networks is concerned with placing a minimum number of relay nodes into a wireless sensor network to meet certain connectivity or survivability requirements (Hou, Y.T., Y. Shi, 2005). The connectivity can be achieved by placing least number of relay nodes using the density based relay node placement approach.

3.1 Power Consumption Density:
The network lifetime gets maximized when the power consumption of each node is balanced. Mostly the power consumption of each sensor node is equal. But while considering the power consumption of each relay node it highly varies based on its location and the number of relay nodes around it.

The relaying power consumption density of a zone is defined by the total power consumption of relay nodes in the zone divided by the area of the zone. If a zone is with larger relaying power consumption density then more relay nodes should be placed in that zone so as to make the average power consumption of a relay node equal in different zone.

3.2 Relay Nodes:
Nodes in sensor networks are often prone to failure, particularly when deployed in hostile territories, where chances of damage/destruction are significantly higher. There is also the possibility for the loss of connectivity between nodes due to the inherent limitations of the wireless communication medium. Therefore, a sensor network should be designed in such a way that the network is able to continue to operate, even if some of the nodes/links in the network fail. The scalability and the lifetime of sensor networks are affected by the limited transmission range and the battery power of sensor nodes. Recently, relay nodes have been proposed for balanced data gathering, reduction of transmission range, connectivity and fault tolerance.

A Relay Node is assumed to have high computation capacity and ample power supply. They are used to coordinate the operation of SNs, relay the data from SNs to BS, and aggregate data received from different sources whenever possible. The RNs are assumed to have no power constraints and are similar in functionality and cost.

3.3 Steps Involved In This Approach:
The following are the steps involved in density based relay node placement approach:
• Layout creation consisting of sensor nodes
• Finding the number of zones needed
• Finding the zone area
• Relay nodes are deployed based on the density of the zone
• Finding the sink area
• Placement of sink nodes based on the density of the zone around sink
• Data communication between the sensor node and sink node through the relay nodes
• Performance Analysis is done based on the delivery rate of the data.

3.4 Overall Design of the Proposed System:
The proposed system provides an optimal solution for relay node placement. The objective is to deploy the fewest RNs such that every SN can reach at least one RN node and that the RNs form a connected network. Fig. 2 depicts the overall design of the proposed system.
Fig. 2: Overall System Design.

Relay nodes are then deployed along the zone between a source node and the sink node. The relay nodes that are in the path between the source node and the sink node will be in the communication range of each other, and the nodes thus become connected. Deploy additional relay nodes until all nodes are connected.

To do this density based relay node placement approach first need to identify the number of zones needed between the source node and the sink node, and then need to find an appropriate place in each zone for placing the relay node. This is done by finding the probability of each point in the zone. Relay nodes are placed in the location that has higher probability.

IV. Implementation Methods:

4.1 Finding Number of Zones needed:
The network lifetime depends closely on the geographical deployment of relay nodes in the wireless sensor network. Two main things have to be considered to maximize the lifetime the first thing is, to support the communication link between the sensor node and the sink node how many relay nodes are needed in the communication path (Lu, K., G. Liu, 2010). The second thing to be considered is where to place the relay nodes in the sensing field, so that only minimum numbers of relay nodes are deployed to establish communication between sensor nodes and sink node.

Initially a layout containing the area of interest (damaged area) is created and then the sensor nodes those are not in the communication range of sink node are taken into account. From each source node and sink node calculate how many zones are needed. This is calculated by considering the distance between the source node and the sink node and the communication range of each node.

4.2 Finding Probability of each Point in the Zone:
Pick a representative from each zone randomly. These representative nodes are all considered and among this the one have highest probability is taken. This probability is calculated by taking the communication range and transmission range of each point. Relay nodes are placed at the point that has higher probability so that the number of relay nodes to be placed in the network gets minimized.

Another important thing to be considered for maximizing the lifetime of the network is that the power consumption of each node in the network must be so balanced. All the nodes in the network should use up their own energy until the lifetime of the network. The power consumption of each zone is highly related to the location of the node in the network and how many nodes exist nearby.

The relaying power consumption density of a zone is defined by the total power consumption of relay nodes in the zone divided by the area of the zone. And the zone that was closer to the sink has more density compared to other zones because the relay node in the zone around the sink needs to relay more data. If a zone has more relaying power consumption density then more relay nodes have to be placed in that particular zone. This is to be done to make the average power consumption of a relay node in different zones equal.

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\text{Number of Zones} = \frac{\text{Dist}_{\text{sd}}}{\text{Sensing Rate}} \times \text{Dist}_{\text{sd}}
\]

where \( \text{Dist}_{\text{sd}} \) is the distance between Source to Destination.

4.3 Iterative Based Relay Node Placement Location Detection:
Relay nodes are deployed to boost the performance of WSNs in terms of several metrics other than connectivity. RNs are deployed to reduce the communication energy consumed by a gateway node in sending
the data to the base station. A relay is a more capable node with significantly more energy reserve and longer communication range than sensors. They can be equipped with sensor circuitry, relays mainly perform data aggregation and forwarding. Unlike sensors, a relay may be mobile and has some navigation capabilities.

Relays are favored in the recovery process, because it is easier to accurately place them relative to sensors, and their communication range is larger, which facilitates and expedites the connectivity restoration among the disjoint segments. Given a deployment of sensor nodes, the problem is to find the minimum number of RNs and where they can be placed to meet the constraints of network lifetime and sensor-RN connectivity.

Relay Nodes are placed in the intersections of the communication range of the largest number of sensors. RNs are placed in such a way that fewest RNs should be used and each SN should be able to reach at least one RN node and that the RNs form a connected network. Two partitions are usually linked through a single path of RNs. Careful placement of RNs has also been used to support connectivity and fault tolerance.

4.4 Finding Number of Zones needed around Sink:
In the sensing field the sink node is placed at the corner. In many scenarios the location of the sensors inside the sensing field are usually not accessible. Normally the around the sink the energy of the relay nodes becomes very fast. This happens because the relay nodes around the sink need to relay data that comes from all sources towards the sink. The sink node usually stays in a network to collect the sensed data from the network for a relatively long period of time. This approach focus solely on the minimization of the RN count, the formed network topologies often lack other important properties in the context of WSNs, e.g., robustness to failure and area coverage. One possible solution for the problem considered would be to try to improve the quality of the formed topology after restoring connectivity.

4.5 Placing Relay Nodes around Sink:
Ensuring full connectivity with robust topology features is crucial for application-level requirements. After deploying relay nodes on the path between the sensor node and the sink node see whether all the partitions are connected then place additional relay nodes around the sink node based on the power consumption density of the zones around the sink.

5. Performance Evaluation:
To evaluate the proposed relay node placement method, have conducted extensive simulations by the network simulator ns-2. For evaluating the performance the following metrics are considered:
• Number of Relay Nodes. This metric reports the total number of relay nodes needed to achieve connectivity. Thus this metric reflects the cost of repairing the network.
• Delivery Ratio. This metric reports the total amount for delivery rate obtained after placing relay nodes to restore the connectivity. This metric value should be maximum that maximum efficiency can be obtained.

5.1 Simulation Results:
Fig. 3 shows the simulation results obtained under varying the number of relay node counts [9]. After each time the relay nodes are deployed the connectivity status of the current and neighboring lines get updated.

The results shown in the Fig. 3 shows that the delivery ratio obtained after employing the density based relay node placement technique. The ratio is much better than the previously employed techniques.

6. Conclusion and future work:
The proposed method provides an optimal solution for the relay node placement in the wireless sensor network and by using this power density based relay node placement method the number of relay nodes needed for restoring the connectivity is also much less compared to the other approaches.

Density based relay node placement approach not only guarantees connectivity among a set of disjoint segments of a partitioned WSN but provides topologies with several desirable features as well, e.g., robustness, extended coverage, and balanced traffic load. By this approach multiple sources get connected with sink at once. The idea is to place the relay nodes in a correct location so that the connectivity is also obtained and the number of relay nodes used is also less.

The proposed density based approach is new and effective since it achieves both connectivity and coverage by placing the relay nodes in an efficient manner in the network. The proposed algorithm is very fast when compared to other algorithms previously used and the recovery time taken is also reduced. The experimental results confirm the better performance of the proposed system.

This project can be further enhanced for improving connectivity and minimizing the probability of failures by considering the case of mobile nodes. The source node should be able to reach sink even the sink node was in mobile. So that even if sink node takes some other position in the sensing field the source should be able to
transfer packets and the network will remain connected. The performance of the approach will also be improved further and the failure rate gets minimized to a greater extent.

![Graph of Relay Nodes vs. Delivery Ratio](image)

**Fig. 3**: Delivery Ratio Obtained.

**REFERENCES**


