IPSD: New Coverage Preserving and Connectivity Maintenance Scheme for Improving Lifetime of Wireless Sensor Networks

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Abstract:- In many applications it is necessary to have some guarantees on the coverage, connectivity and lifetime of the Wireless Sensor Networks(WSN). Coverage problem is regarding how to ensure that each of the points in the region to be monitored is covered by the sensors. In maximizing coverage, the sensors need to be placed not too close to each other so that the sensing capability of the network is fully utilized and at the same time they must not be located too far from each other to avoid the formation of coverage holes. On the other hand from connectivity point of view, the sensors need to be placed close enough so that they are within each other communication range thus connectivity is ensured. Once coverage and connectivity are ensured, the overall lifetime of the network gets increased thereby improving the quality of service (QoS) of the Wireless Sensor Network (WSN). The concept of Integer Programmed Sensor Deployment (IPSD) scheme is being proposed, with a set of relay nodes a triangular lattice is formed by the grid based approach thus providing maximum coverage and connectivity. Integer Linear Programming (ILP) is brought into existence for eliminating the unused relay nodes thereby enhancing the coverage and connectivity with minimum number of relay nodes. Simulation is performed using NS-2 and the results shows that the proposed scheme provides better results in large scale WSN with improved coverage and connectivity.

Key-Words:- WSN,ILP, relay node, coverage, connectivity.

1 Introduction

The structure of WSN is given in Fig 1.It consists of tiny sensing devices, deployed in region of interest. Each device has processing and wireless communication capabilities, enabling it to gather information about the environment, to generate and deliver report messages to remote base station [13].

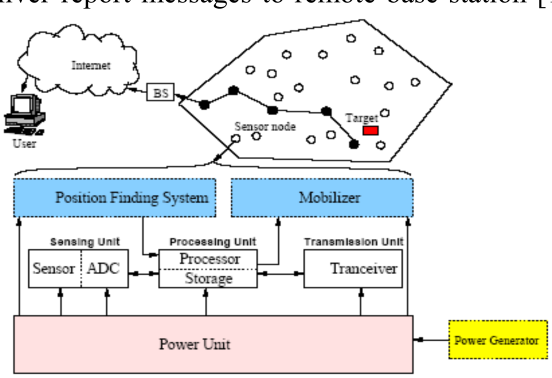

Fig 1: Structure of WSN

The base station decides event occurrences in the monitored area using the received reports. Wireless sensors have several constraints such as restricted sensing and communication range as well as limited battery capacity. These limitations bring issues such as deployment, coverage, connectivity, network lifetime, and scheduling and data aggregation. Sensor deployment is an important issue for wireless sensor networks since it will affect the cost and detection capability of a wireless sensor network. A good sensor deployment has to consider both coverage and connectivity [19]. Coverage is one of such issues since after deploying a sensor network; it would be likely to know how well the network can observe a given region of interest. In general, the goal of coverage is to make sure that each point, or each target of interest in a given physical space, should be within the sensing range of at least one sensor node[12]. The sensor nodes can be placed exactly in predefined locations in order to achieve the goal of coverage.

Coverage problem is caused by three reasons. They are not enough sensors to cover the whole ROI, limited sensing range and random deployment. Coverage can be improved by using sensors with larger sensing range but this is costly. Coverage can also be improved by carefully planning the positions of the sensors in the ROI to their deployment which can be done using predetermined plan.

There are many common strategies that are used to solve the problem of coverage in Wireless Sensor Networks (WSN). The strategies used here are categorized into three groups based on the approaches namely: force based, grid based (or) computational geometry based approach [21],[22],[27]. Force based methods use attraction and repulsion forces to determine the optimal position of the sensors while grid based methods use grid points for the same objective. As for the computational geometry approach, Voronai diagram and Delaunay triangulation are commonly used in WSN coverage optimization algorithm.

Besides coverage, connectivity is another fundamental issue in a WSN. The connectivity requirement ensures that any active sensor in the network is able to communicate to the monitoring station at all times using relay sensor nodes, if necessary.

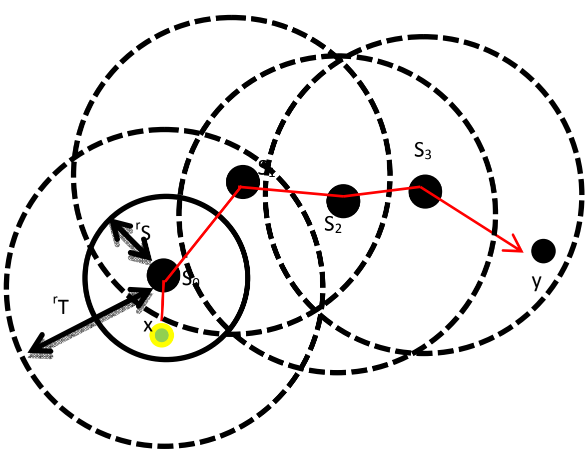

Fig 2: An example of sensor's coverage and connectivity

A suitable connectivity is highly required in order to achieve robust and smooth communication in a WSN.The communication range is twice of sensing range is the sufficient condition to ensure that complete coverage preservation implies connectivity among active nodes if the original network topology (consisting of all the deployed nodes) is considered [16],[6],[10]. For example in Fig 2, the node x is the source node, node y is the destination node, r_T is the transmission radius and r_S is the sensing radius of the source node. Nodes S_1, S2,S3 are the intermediate nodes. The source node transfers the packet to the destination node via intermediate nodes by sensing the transmission radius of each sensor nodes.

In hierarchical Wireless Sensor Networks (WSN) using relay nodes, sensor nodes are arranged in clusters. An Integer Linear Program (ILP) is used for determining the minimum number of relay nodes, along with their locations and a suitable communication strategy such that the network is able to meet specified performance guarantees with respect to coverage, connectivity and lifetime [1]. In a two-tiered sensor network, the individual sensor nodes, comprising the lower tier, are grouped into clusters, and transmit data to their respective cluster heads. The cluster heads form the upper tier of the network, and are responsible for collecting and forwarding data toward the base station. Each relay node collects data from the sensor nodes belonging to its own cluster and forwards the collected data to the base station (or sink). Data communication from relay nodes to the base station is generally multi-hop, where each relay node, in addition to the forwarding the data it receives from its own cluster, also forwards data it receives from other relay nodes, towards the base station, using multi-hop paths.

Relay nodes have been proposed for balanced data gathering, reduction of transmission range, connectivity and fault tolerance[2],[9]. The routing without flow-splitting concept maximizes the lifetime in two-tiered sensor networks[17,3].

The contribution of this paper is to first form a triangular lattice with a set of relay nodes by grid based deployment approach thus providing maximum coverage and connectivity.ILP is brought into existence for eliminating the unused relay nodes thereby enhancing coverage and connectivity with minimum number of relay nodes. Hence proposed IPSD scheme ensures lifetime of WSN.

The rest of the paper is organized as follows: Section 2 surveys the related work in literature. Section 3 describes the concept of DSR protocol. Deployment strategies are presented in Section 4.

Section 5 presents ILP formulation in detail. Section 6 deals with proposed IPSD scheme and its imolementation.Simulation results are presented in Section 7.Section 8 concludes this paper.

2 Related Works

In recent years, a numerous energy conservation techniques have been proposed based on deployment, coverage and connectivity of WSN. Following are the brief overview of some of these techniques and their limitations.

In [11],[23], [18] and [15], the placement of relay nodes are mainly considered in a sensor network architecture. In [8], maximizing the lifetime of a sensor network is considered, under the constraint that each point in the sensing region is covered by at least one sensor node, and proposed an algorithm for finding the location of nodes, along with their roles, to achieve the objective. In their model, any node can assume the role of a sensor node or the relay node.

In [26], an optimization problem was formulated which places relay nodes to ensure that the resulting network is connected. In [14], the relay node placement problem was considered, with the objective to maximize the lifetime of the network, as nonlinear program and proposed approximation algorithm. A New coverage maintenance scheme CASS (Coverage Aware Self-scheduling) probabilistically schedules a sensor's sensing activities according to the sensor's contribution to the sensing coverage. Sensors with high coverage contribution are more active. This reduces the number of sensors active for a coverage area. It deals only with coverage between the sensors. In order to provide connectivity, it should be combined with LEACH (Low Energy Adaptive Clustering Hierarchy) protocol. Simulation results show that CASS can considerably improve the energy efficiency of a sensor network with lower overheads[14].

In [5],[7] maintaining sensing coverage and connectivity is done by keeping a minimum number of sensor nodes in the active mode in WSN.The relationship between coverage and connectivity is investigated. Based on the optimality conditions, decentralized and localized density control algorithm OGDC (Optimal Geographical Density Control) was developed. Basic idea of OGDC is to minimize the number of working nodes, minimize the total amount of overlap and to maintain coverage and connectivity where only up to 50% improvement was obtained.

The Coverage Configuration Protocol (CCP) in [4],[8],[20],[25] can achieve different degrees of coverage requested by applications .Integrated CCP with a connectivity maintenance protocol (SPAN) provide both coverage and connectivity guarantees when sensing range is larger than half of the communication range. The network achieves longer life times when the number of nodes increases. Further extension must be provided to handle probabilistic sensing and communication models.

However, all of these approaches only consider coverage and connectivity, and do not take into account the energy dissipation of the relay nodes. Furthermore, they only determine the placement of the relay nodes and do not address the routing problem at all. The proposed scheme jointly optimizes energy-aware placement and routing of relay nodes in two-tiered sensor networks.

In the proposed scheme, a triangular lattice is being formed using the Grid based approach. Once the relay nodes are deployed, the unused relay nodes are found out and are eliminated by the concept of Integer Linear Program (ILP). By combining the above two approaches, a new concept of Integer Programmed Sensor Deployment (IPSD) scheme is being formulated. The data packets are made to move from one sensor node to other, from the sensor nodes to the relay node and from relay node to the base station with the help of DSR Routing Protocol, where coverage and connectivity are enhanced, with the minimized set of relay nodes.

The proposed scheme also provides different objectives like minimizing the number of sensor nodes to be deployed while maintaining the coverage and connectivity, minimizing the cost and the energy consumption, and maximizing the lifetime and the utilization of the resource in sensor networks.

3 DSR Routing Protocol

When a node decides to send a data packet and if it does not know the routing path to the destination, it initiates the route discovery procedure by broadcasting a control packet, called route request (RREQ). When an RREQ reaches the destination, it prepares another control packet, called route reply (RREP), and replies back to the source with the complete route information. Upon receiving an RREP, the source saves the route which is found by the routing protocol.

4 Deployment Scheme

Deployment refers to the placement of the sensor nodes in their appropriate place to ensure full coverage and connectivity between them[24]. Deployment also plays an important role in reducing the formation of coverage holes. Normally all the sensor nodes and their head relay nodes are placed in their Region Of Interest(ROI).The ROI reviews the strategies used in solving coverage problem in WSN which are done during deployment stage. The strategies are divided into three categories force based, grid based and computational geometry based. Grid based approach is used in this paper.

Grid points are used in two ways in WSN deployment; either to measure coverage or to determine sensors positions by using three common types of grids.

Types of Grids

Triangular lattice, in the Fig 3 below is the best among the three kinds of grids as it has the smallest overlapping area hence this grid requires the least number of sensors.The coverage redundancy is the least here when compared to the remaining two kinds of grids.

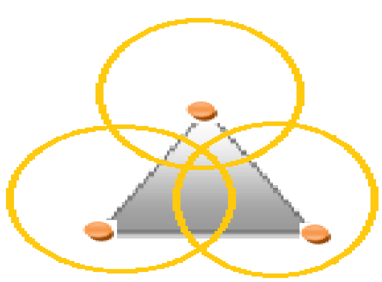

Fig 3: Triangular Lattice

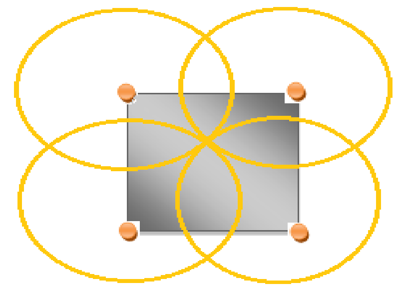

Fig 4: Square Grid

Square grid, in the Fig 4 has more overlapping area than a triangular lattice but less overlapping area than hexagonal grid.

Hexagonal grid, in the Fig 5 below is the worst among all the grids, since it has the biggest overlapping area.

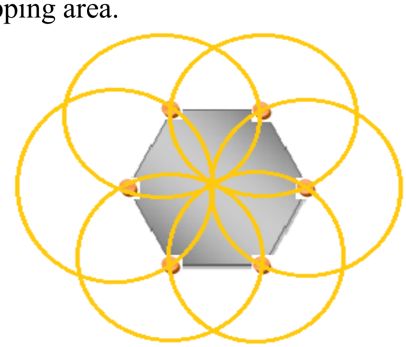

Fig 5: Hexagonal Grid

Therefore, the guaranteed coverage can be obtained by assuming grid based deployment and size of the grid. It mainly depends on how dense the WSN going to be.

5 Linear Programming

Linear programming (LP) is a method for determining a way to achieve the best outcome in a given model for some list of requirements represented as linear equations. In many applications it is necessary to have some guarantees on the coverage, connectivity and lifetime of the sensor network.

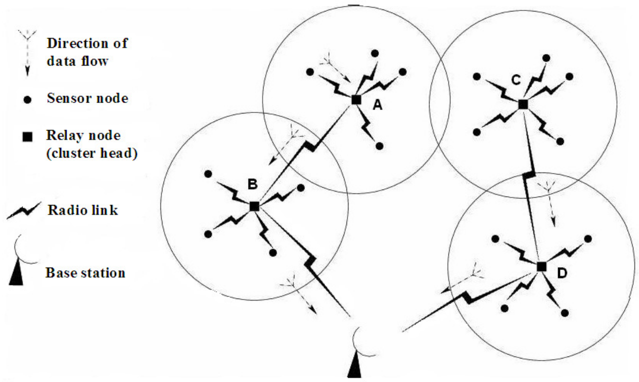

Fig 6: A hierarchical sensor network

The network should also be able to adapt to single and/or multiple node failures as well as disruptions due to the inherent limitations of the wireless communication medium. In hierarchical sensor networks using relay nodes, sensor nodes are arranged in clusters and higher-powered relay nodes can be used as cluster heads. An integer linear program (ILP) for determining the minimum number of relay nodes, along with their locations and a suitable communication strategy such that the network is able to meet specified performance guarantees with respect to coverage, connectivity and lifetime.

Single-hop communication, in Fig 6 above can be considered as a special case, where each relay node receives data only from its own cluster, and sends this data directly to the base station, provided that the base station lies within the transmission range of each relay node. Each relay node collects data from the sensor nodes belonging to its own cluster and forwards the collected data to the base station (or sink). Data communication from relay nodes to the base station is generally multi-hop, where each relay node, in addition to the forwarding the data it receives from its own cluster, also forwards data it receives from other relay nodes, towards the base station, using multi-hop paths.

6 IPSD formulation and its implementation.

Consider a two-tiered WSN, where the lower tier consists of n sensor nodes placed in the sensing area. The objective of this paper is to find the minimum number and position of relay nodes to form upper tier network. Also to find a best routing strategies to reduce the energy consumption of relay nodes.

The scheme that is proposed here is the Integer Programmed Sensor Deployment (IPSD) scheme for the Wireless Sensor Networks (WSN). In the Fig 7, deployment of sensor nodes is based on the concept of ROI. In ROI, a grid based approach is followed, where a hexagonal grid, a square grid and a triangular lattice is formed.

Once the set of locations of the relay nodes are given, Linear Programming can be used to form the upper-tier network, with minimum number of relay nodes which ensures desired coverage and connectivity. Let S be the set of all sensor nodes. Assign each node a unique label as follows:

1. for each sensor node, a label i, $1 \leq i \leq n$,

2. for each possible location of relay node, a label j; $n < j \leq n + m$ and

3. for the base station, a label $n + m + 1$.
   - In this model, at any given point of time, each sensor node communicates with only one relay node and in each cluster, one relay node acts as a cluster head.
   - Data are collected and forwarded to the base station periodically.

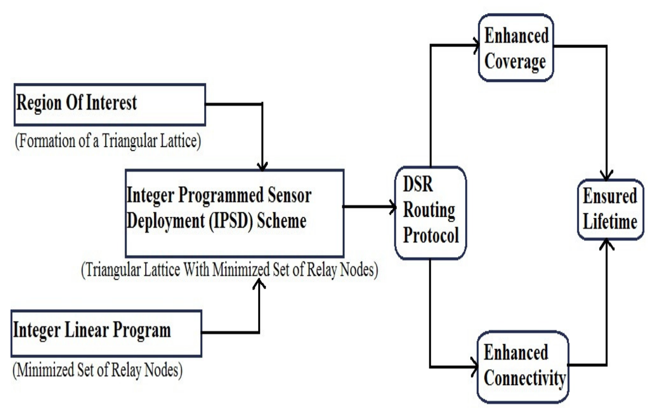

Fig 7: Integer Programmed Sensor Network.

Notations Used

In IPSD consider the following:

- n: The total number of sensor nodes, with each sensor node having a unique index between 1 and n.

- m: The total number of possible positions of relay nodes, with each position having a unique index between n + 1 and n + m.
- r_j : The relay node at location j; n + 1 ≤ j ≤ n + m.
- n + m + 1: The index of the base station.
- r_{max}: The transmission range of each sensor node.
- d_{max}: The transmission range of each relay node.
- $D_{i,j}$: The Euclidean distance from node i to node j.
- k_s: The number of relay nodes covering each sensor node.
- k_r: Desired connectivity of the relay node network.
- α1: Energy coefficient for transmission.
- α2: Energy coefficient for reception.
- β: Energy coefficient for amplifier.
- q: Path loss exponent.
- D: A large constant.
- b_i: Number of bits generated by sensor node i.
- e_{max}: Maximum allowable energy dissipation of a relay node.
- $X_{i,j}$: Binary variable defined as follows
- $X_{i,j} = \begin{cases} 1 & \text{if the sensor node i transmits to the relay node j.} \\ 0 & \text{Otherwise} \end{cases}$
- $P_{j,k}$: Binary variable defined as follows
- $P_{j,k} = \begin{cases} 1 & \text{if the relay node j transmits to the relay node k.} \\ 0 & \text{Otherwise} \end{cases}$
- Y_j : Binary variable defined as follows
- $Y_j = \begin{cases} 1 & \text{if the relay node at location j is included in the upper tier network} \\ 0 & \text{Otherwise} \end{cases}$
- C_j : Continuous variable indicating the number of other relay node(s) that may be used by relay node r_j to forward data towards the base station.
- T_j : Continuous variable indicating the number of bits transmitted by node j.
- G_j : Continuous variable indicating the amount of energy needed by the amplifier in relay node j to send its data to the next node in its path to the base station.
- R_j : Continuous variable indicating the number of bits received by node j from other relay nodes.
- E_j : Continuous variable indicating the total energy spent per round by the relay node j.
- w_j : Continuous variable indicating the total number of bits generated by the sensor nodes in cluster j.
- $f_{j,k}$: Continuous variable indicating the amount of flow from a relay node j to node k (may be another relay node or the BS).

The objective function is to minimize the number of relay nodes while maintaining a desired lifetime of the network. By setting the appropriate value for k_s and k_r, this formulation can ensure fault tolerance. Given the two tier network, the objective is to minimize the number of relay nodes, such that each sensor node can communicate with at least one relay node. The formulation is given below in (1).

$$\text{Minimize} \quad \sum_{j=n+1}^{n+m} Y_j \tag{1}$$

Subject to following constraints:

a) A sensor node i can transmit to a relay node j, only if the distance between i and j is less than the transmission range r_{max} of the sensor node i which is given in (2).

$$X_{i,j}.d_{i,j} \le r_{\max} \quad \begin{array}{l} \forall i, 1 \le i \le n, \\ \forall j, n+1 \le j \le n+m \end{array} \tag{2}$$

b) A relay node j can transmit to a relay node k, only if the distance between j and k is less than the transmission range d_{max} of the relay node j.

$$P_{j,k}.d_{j,k} \le d_{\max} \qquad \forall j,k : j \ne n+m+1 \tag{3}$$

c) The relay node at location j is included in the upper tier network, if it is selected as the cluster head by at least one sensor node i which is given in (4).

$$Y_j \ge X_{i,j} \quad \begin{array}{l} \forall i, 1 \le i \le n, \\ \forall j, n+1 \le j \le n+m \end{array} \tag{4}$$

d) A sensor node must be connected to at least k_s relay node which is given in (5).

$$\sum_{j=n+1}^{n+m} X_{i,j} \geq K_s \qquad \forall i, 1 \leq i \leq n \qquad (5)$$

e) Constraint that determines the number of the relay nodes that the relay node j can use to route data towards the base station.

$$C_j = \sum_{w:(d_{j,w} <= d_{max}) \text{ AND } (d_{w,n+m+1} < d_{j,n+m+1})} Y_w \qquad (6)$$

Constraint (6) has to be repeated for all j, n<j <=n+m. If the base station lies outside of the transmission range of relay node r_j, there must be k_r other relay nodes where r_j can forward its data using (7).

$$C_j \geq k_r . Y_j \qquad \forall j : d_{j,n+m+1} \geq d_{\max} \qquad (7)$$

f) Non flow-splitting constraint is given in (8).

$$\sum_k P_{j,k} = Y_j \qquad \forall j,k : j \neq n+m+1 \qquad (8)$$

g) Find the total number of bits generated in the cluster j by (9).

$$w_j = \sum_i b_i . X_{i,j} \qquad \begin{array}{l} \forall i, 1 \leq i \leq n, \\ \forall j, n+1 \leq j \leq n+m \end{array} \qquad (9)$$

h) Flow constraint is given in (10).

$$\sum_k f_{j,k} - \sum_k f_{k,j} = w_j \qquad (10)$$

i) Find the total number of bits transmitted by the relay node j by (11).

$$T_j = \sum_j f_{j,k} \qquad \forall j,k : j \neq n+m+1 \qquad (11)$$

j) Find the amplifier energy dissipated by relay node j to transmit to the next node by using (12).

$$G_j = \beta \sum_k f_{j,k} . d_{j,k}^q \qquad \forall j,k : j \neq n+m+1 \quad (12)$$

k) Find the number of bits received by relay node j from other relay node(s)by using(13).

$$R_j = \sum_k f_{k,j} \qquad \forall j, n < j \leq n+m+1 \qquad (13)$$

l) Base station does not transmit.

$$f_{j,k} \leq D.P_{j,k} \qquad \forall j,k : j \neq n+m+1 \qquad (14)$$

m) Only one outgoing link can have non-zero data flow.

$$f_{n+m+1} = 0 \qquad \forall k, 1 \leq k \leq n+m+1 \qquad (15)$$

n) Find the energy dissipated by relay node j.

$$\alpha_1 (R_j + w_j) + \alpha_2 T_j + G_j = E_j \quad \forall j : j \neq n+m+1 \qquad (16)$$

o) Constraint for maximum energy dissipation is given by (17)

$$E_j \leq e_{\max} \qquad \forall_j : j \neq n+m+1 \qquad (17)$$

Equation (1) is the objective function that minimizes the total number of relay nodes. The minimization of the number of relay is obtained after ensuring the required coverage and connectivity of all the individual sensor nodes and cluster head in the ROI as well as ensuring the desired lifetime of the relay nodes.

7 Performance Results

The performance of the proposed scheme is evaluated using the ns-2 network simulator [28],[29]. Here the DSR routing is integrated with the IPSD scheme and the simulation is done for 25 and 50 different number of nodes.

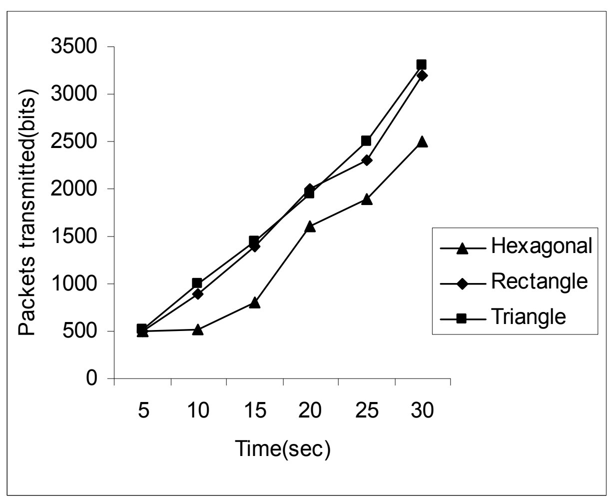

Fig 8: Comparison graph for 25 nodes

Performance analysis are done based on the total number of nodes that are deployed in the simulation region , amount of energy consumed by nodes during the transmission and reception, the lifetime achieved and packet loss in nodes.

The packet transmission for three different grids has been calculated and recorded to compare which grid works the best among the three. The recorded values for each of the grid lattice are taken for 25 nodes and compared with one another with the help of the graph shown in the Fig 8.

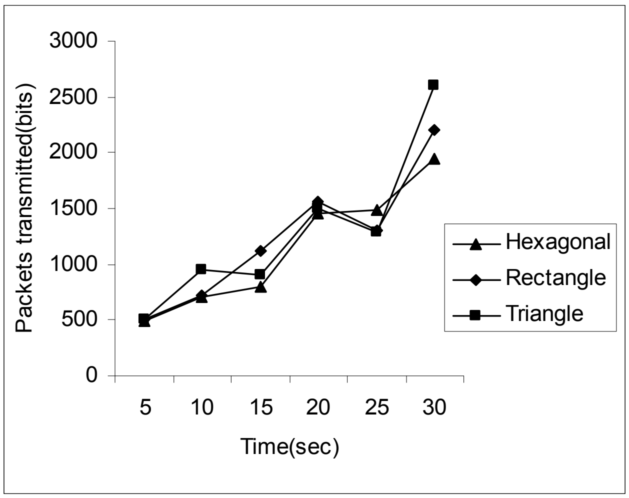

Fig 9: Comparison Graph for 50 nodes

Fig 9 compares the three grids for 50 numbers of nodes in which the triangular grid works the best. From the above analysis it can be inferred that triangular lattice works the best among the three for 25 and 50 numbers of nodes.

The Coverage percentage of the IPSD is calculated by the following results. Packets Sent, Packet received, Packet Drop.

The packet sent, dropped and received is calculated at different time period and plotted in a graph shown in the Fig 10

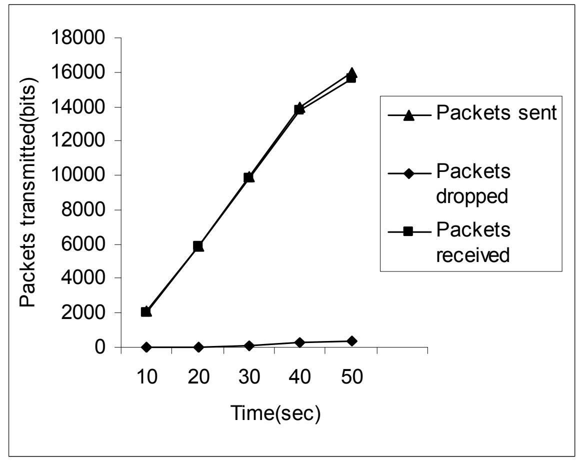

Fig 10: Calculation of Packet Transfer

The coverage percentage is found to be 99.5 which has attained its maximum.Fig 11 plots the coverage ratio for different time period.The coverage ratio is high because the IPSD scheme uses triangular lattice and minimizes the unused relay nodes for the packet transfer in which high coverage and connectivity can be obtained.

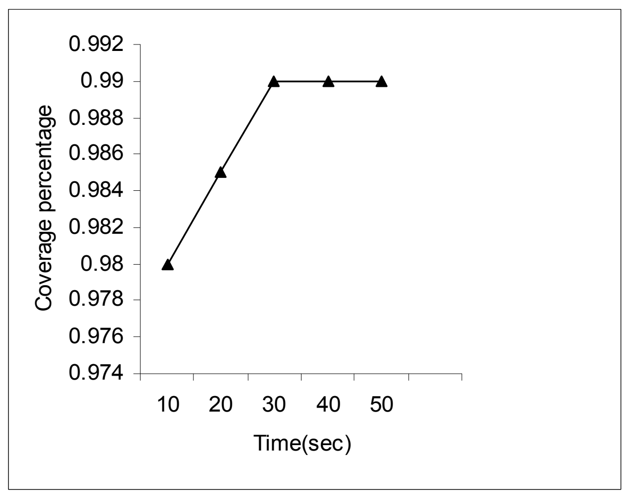

Fig 11: Coverage percentage

Fig 12 shows the impact of coverage ratio on packet delivery ratio. As shown in fig, IPSD is able to have PDR of more than 95% with varying coverage ratio.

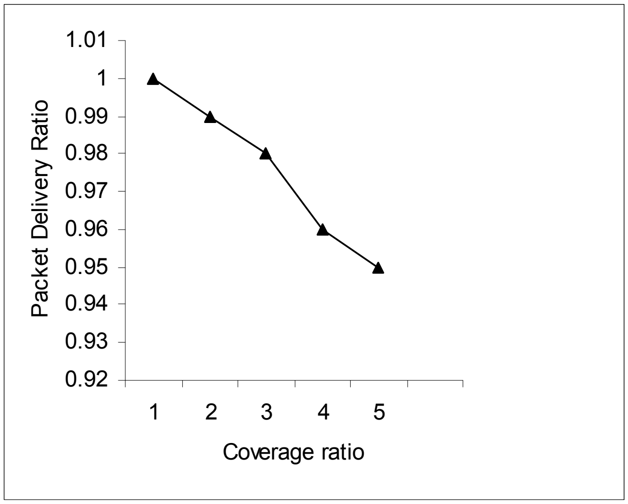

Fig 12: Packet Delivery Ratio

Fig 13 presents the energy consumption of the proposed scheme. The results demonstrate that IPSD consumes less energy.

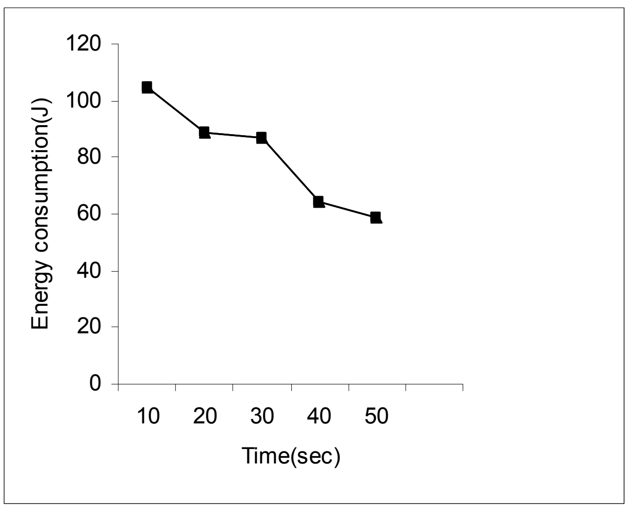

Fig 13: Energy Consumption

Fig 14 shows the network lifetime using IPSD on varying no of sensor nodes.

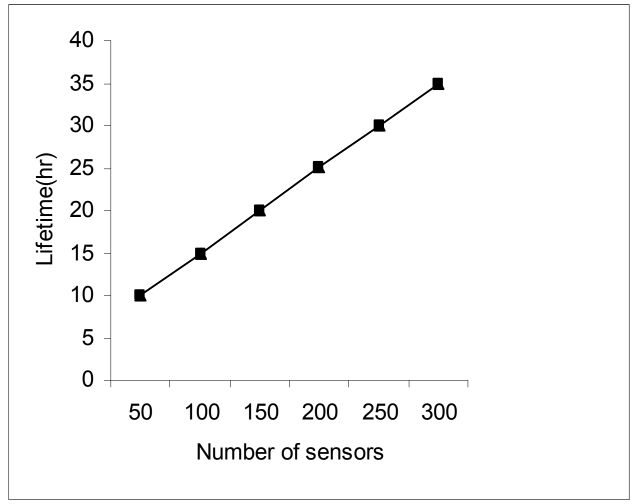

Fig 14:Network Lifetime

From the above analysis it is been found that coverage efficiency is significantly improved. IPSD is able to have PDR of more than 95%. Therefore IPSD provides better coverage and connectivity with minimized set of relay nodes.This better connectivity reduces the usage of many number of nodes for packet transmission and thus reduces energy consumption and provides significant improvement in lifetime of WSN.

8 Conclusion

Coverage and Connectivity are the two important aspects in Wireless Sensor Networks (WSN). Connectivity and coverage problems are caused by the limited communication and sensing range. Sensor deployment strategies play a very important role in providing better QOS, which relates to the issue of how well each point in the sensing field is covered. The IPSD scheme can offer an enhanced coverage and connectivity in a wireless sensor network, without the dependence on external infrastructure or complex hardware.

Results show that the coverage efficiency of this paper is increased with the minimized set of relay nodes. Even when the numbers of relay nodes are being decreased, packet transmission takes place without large number of packet drops. This shows that the concept of Integer Programmed Sensor Deployment (IPSD) scheme can be efficiently used in large scale Wireless Sensor Networks (WSN) for providing better coverage and with minimized set of relay nodes. Thus improves the lifetime of WSN.

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