An Optimal Solution to Minimize the Energy Consumption in Wireless Sensor Networks

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Abstract:-Wireless Sensor Network has been widely used in all the fields for the past few years. In many recent wireless sensor network applications such as environmental monitoring, medical applications and surveillance, there is a need for providing the uninterrupted coverage of a sensing field with long instant, this is one of the obvious problem attracted many researchers as well as general users. In any aspects, the sensor nodes are energized by low powered devices; it is one of the critical aspects to reduce the energy consumption to improve the lifetime to some extent. In this research, initially we concentrated on the energy consumption for the typical sensor node component by assuming the grid network with shortest path technique. Secondly, the direction is made to conserve energy in wireless sensor networks. Special focus is given over the areas which have not yet get more attention in the literature such as data aggregation along with load balancing techniques. Extensive simulations are conducted in Network Simulator-2 to test the effectiveness of the proposed load balancing scheme. The results proved that the proposed scheme achieves over 8% energy-saving per node and the throughput improves to 18.2% with data collection through multi-hop relay. The simulation results show that, our algorithm can balance the network traffic in real-time.

Keywords—WSN,Load balancing, Lifetime , Energy, Optimum Solution

1 Introduction

A wireless sensor network consists of sensor nodes deployed over a geographical area for monitoring physical phenomena. This network has various applications such as animal monitoring, environmental monitoring, medical applications, military surveillance and infrastructure maintenance. This kind of network is mainly intended for outdoor operation during long periods of time. There are many design challenges are incorporated with Wireless sensor networks (WSN). Among them, one of the important constraints in wireless sensor networks is to improve the life time of the wireless sensor network, since each sensor is provided with limited battery capacity. With this limited power, the sensor has to sense, transmit, receive and process. Each phase consumes certain amount of power, which leads to depletion of capacity of battery. Based on the states of sensors such as active, sleep and idle state energy capacity of battery can be optimized. Due to this limited source capacity, efficient management of source power is necessary to improve the life time of the network. The lifetime of the wireless sensor network is determined by which the time taken by the first node to die. Therefore, the usage of resource must be optimized to increase the lifetime of the network. The Lifetime of a sensor network can be extended by applying different techniques such as, using energy efficient protocols are aimed at minimizing the energy consumption during network activities. The node components like CPU, Radio, etc consumes large amount of energy even if they are idle. Thus, the power management schemes are used for switching off the node components whenever, they are not needed.

A wireless sensor network (WSN) consists of very tiny sensor nodes which are usually spread out in a particular geographical area for monitoring or surveillance applications. Each sensor node in the wireless sensor network collects the necessary information from its surrounding environment and forwards it to one or several sink nodes which is far away from the networked area in a single or multi hop way. These sensor nodes are energized by a tiny battery. Since, this WSN is usually utilized in hazardous or out of reach environments, replacing node batteries would not be easily possible. Hence, the main problem in these networks is that sensor nodes can operate for a long duration of time with this limited battery capacity. Figure1 illustrates the general Wireless Sensor Network model.

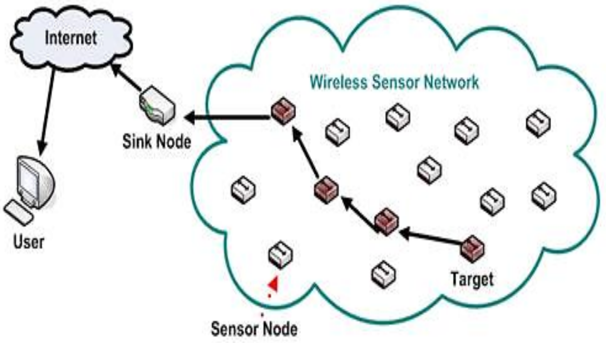

Figure 1: Wireless Sensor Architecture

The architecture of Wireless Sensor Node is shown in the figure 2. Each node consists of the basic components such as, a sensing device with one or more sensors, a processing device with ADC, a transceiver and a power supply unit. However, additional components like location finder and mobilizer can be included depend upon the application requirement. The primary function of the network is that, the data sensed by each node is delivered to the sink node or base station. There are many definitions available regarding lifetime the network.

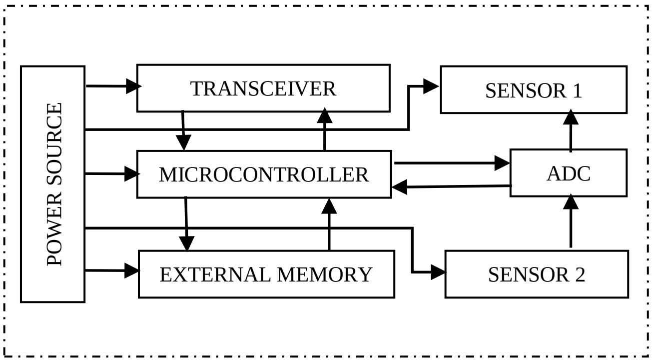

Figure 2: Architecture of Wireless Sensor Node

A sensor node is said to be dead, if the node is no longer able to sense and forward a data to the base station. However the definition is the period between the deployment and the instant when the node is non-functional. If one node dies, then the particular region is exempted from the coverage area. There is loss of coverage occurs. In a wireless sensor networks there are several activities which consume energy; hence it is important to find best tradeoff between energy consuming activities. From the literature, it is recognized that radio communication is the major part of energy consuming activity.

The rest of the paper is organized as follows, Section 2 discusses the literature survey to finding the methods and its limitations and it also presented the objective of this research. Section 3 deals with problem statement. Section 4 deals with research methodology with shortest path routing and the proposed method. Section 5 analyzed the performance with its results. Finally, the summary is made in section 6.

2 Objective and Literature Survey

The major objective of this work is to minimize energy consumption in multi hop battery powered wireless sensor networks. This issue is one of the important factors in wireless sensor networks, which is in most of the cases the data must be transmitted to the sink node or base station.

Kacimi et al (2013) [1] proposed a load-balancing heuristic technique based on transmission power control. They have been studied the impact of transmission power on the network topology and Link Quality (LQI) between each nodes. In next case they presented an optimal case to balance the energy consumption and improve the overall network lifetime in the combination of critical nodes in a 2-D grid topology connecting the base station at corner. They made this process with the help of each node from the base station by making it as proportional to the transmission power of each node.

Yuvaraja and Sabrigiriraj (2015) [2] made a solution about network lifetime with the combination of Fuzzy logic and Search Based Gravitational Routing Protocol (FSBGRP) and estimated the node cost by using fuzzy logic. Apart from lifetime the link quality, residual energy and system load are analyzed. To verify the FSBGRP they made energy and delay comparison with the A- star Algorithm which is made by AlShawi et al (2012) [3].

The concept of improving the lifetime is noticed in many ways, Likewise, Kalaiselvi and Priya (2015) [4] implemented the hybrid efficient Medium Access Control (MAC) protocol with load balancing algorithm. It combines the strength of both Time division multiple access (TDMA) and Frequency division multiple access (FDMA) schemes. They tested and simulated all these processes with the help of network simulator to verify the performance of the algorithm with unbalanced algorithm, these evaluations are made with energy, packet delivery ratio and delay.

The Load Balanced Clustering is employed in mobile data gathering which is proposed by Zhao and Yang (2013) [5]. They have been made a three-layer framework called as sensor layer, cluster head layer and mobile collector (SenCar) for mobile data collection. They combined the framework as distributed Load Balanced Clustering and Dual Data Uploading (LBC-DDU). They reviewed some traditional methods and framed a balancing network to generate and manage the multiple clusters heads in each cluster. They also utilized the Multi-User Multiple-Input And Multiple-Output (MU-MIMO) technique for uploading the data at collector layer. Finally, they coined out the suggestions to develop and partition the continuous space to locate the optimal polling point for each cluster.

Akyildiz et al., (2002) [6] made a detailed survey about the complex issues in sensor networks. Vast research studies have been conducted to improve energy and lifetime by proposing protocols, algorithms and solutions. Anastasi et al. (2009) [7] presented a survey in order to improve energy and lifetime of the sensor networks. They concentrated on two major techniques such as introduction of sleep/active modes of sensors and the usage of energy efficient routing. Their extensive research work has been carried out on energy efficient data gathering and data dissemination in the sensor networks.

Heinzelmanet al (2000) [8] presented a well–known energy efficient protocol such as Low-Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a clustering protocol which organizes sensor nodes in to clusters where it fuses the data sensed and transmitted to the base station. Lindsey et al.,(2002) [9] proposed a Power-Efficient Gathering in Sensor Information Systems(PEGASIS) to rectify the drawback incurred with LEACH by considering energy consumption and data gathering.

Chang and Tassiulas (2004) [10] made some routing schemes for wireless sensor networks to extend the network life time. They formulated the routing problem as a linear programming problem and they assumed the constant rates and an arbitrary process to enhance the features. Finally they compared the shortest path routing With Minimum Total Energy (MTE), Minimum Hop (MH) Routing and Max-Min Residual Energy (MMRE) routing. The summary made by them is the Minimum Total Energy (MTE) routing is not suitable for network-wise implementation.

Carle and Simplot (2004) [11] indicated the best method for energy conservation is to switch off most of the sensors as possible while functioning. Similarly, Pantazis et al., (2013) [12] proposed a Query-based protocol to avoid the problem occurred in shortest path routing. Milenkovic and Amft (2013) [13] made a real time sensing approach to save energy in office buildings. Recently, few researchers analyze the upper bound of the network.

Deng and Hu (2010) [14] made a load balanced group clustering in order to balance the entire battery power by implementing the dynamic route calculation according to the condition of energy distribution in the network. The major findings are to make use of heterogeneous energy to realize load balance. Zhang et al., (2011) [15] considered the load equalization for creating balanced cluster. They used comprehensive weight value and also use optimization threshold value to avoid load imbalance.

Ye et al (2013) [16] identified the problem in Heterogeneous Cellular Networks; it is stated as while optimizing a function of long-term rate for each user, it results in a massive utility maximization problem. To avoid this issue they made a low-complexity distributed algorithm with an improved throughput. Kim (2015) [17] proposed a dynamic load balancing scheme by analytical models.

Kumar, D. (2014) [18] made a performance analysis on two networks such as Single-Hop Energy-Efficient Clustering Protocol (S-EECP) and Multi-Hop Energy-Efficient Clustering Protocol (M-EECP). They detected the issue in cluster selection, in single hop the Cluster Heads (CHs) are elected based on the weighted probability; it is based on the ratio between residual energy of each node and average energy of the network. The nodes with high initial energy and residual energy will have more chances to be elected as CHs than nodes with low energy whereas in M-EECP, the elected CHs communicate the data packets to the base station via multi-hop communication approach.

From the literature analysis, several nodes are limited to one dimensional chain of N nodes. The authors calculated the mathematical expression for the sender to receiver distance and they gave numerical results of estimated lifetime. Several different techniques are discussed with its merits and demerits. However, in random routing protocol, the sensor nodes should be in ‘Mostly – On’ mode and the nodes are subjected to overhearing also.

The main contribution of this research work is to propose a solution based on application, topology and the network traffic which is shared with minimum signaling in order to optimize the network lifetime. Then it is necessary to analyze the energy balancing strategies in a grid topology with uniformly deployed stationary sensor nodes. Further, the comparison is made between shortest path algorithm and proposed energy driven load balancing technique to derive the optimal solution for energy consumption and maximize the network lifetime.

3. Problem Definition

As we deal with multi-hop networks, the stations that are in reach of each other helps in obtaining and maintaining the connectivity. At the same time the selection of path is critical in case of grid topology. Hence, in multi hop network this is one of the major constraints. It is important to forward the sensed data to the base station or to the sink even if it is in non-uniform manner on the sensor nodes which is closer to the base station. Hence, in this research the sensor nodes are deployed in different topologies to know the impact of network performance based on transmission power and Link Quality Index (LQI) between sensor nodes. We observe that all the sensor nodes try to connect with the closest nodes to the base station. Apparently, the burden on the nodes in the bottle neck zone is higher than the nodes far away from the base station. The nodes in the bottle neck zone die quickly consequently either the performance of the network is poor or makes the network useless. Hence, there is a need to discuss different network strategies to ensure maximization of network life time by balancing the load equally as possible.

4 Research Methodology

Normally, in multi-hop wireless networks the packets are transferred through routes that could be composed of multiple relay nodes between sources and destinations. Most of the cases the shortest path routing is used because of its simplicity and scalability. Thus, in this paper, we will focus on both shortest path and energy efficient routing for delivering packets from sources to destinations.

A. Shortest path routing

Shortest path routing simply refers to the process of finding paths along a network that has a minimum distance or any other cost metric. One of the examples of this type is routing of data packets over an Internet is an example of involving millions of routers in a multilevel network. The optimum routing on the Internet has a major impact on performance and cost. Sharing the load between the shortest paths is a common method to prevent neighbors from consuming energy. There are several shortest paths from each node and it is necessary to identify a path which involved lowest cost of energy consumption.

B. Problem Formulation

The solution given to the above problem is given by assuming a network model, we assume that the network as grid network which is represented in figure 3 and sensors to sink traffic pattern is considered.

i. All the sensor nodes are uniformly distributed in a grid network with size of N=M x M, Grid topology network is taken, since, it is widely studied in Wireless Sensor Networks and the reason also that it is used in many applications such as agriculture, ware house monitoring, urban networks, etc.
ii. Every node generates constant bit rate(CBR) data and sends to the base station by multi hop routing.
iii. Between all the nodes multi hop routing and load sharing is done and the energy level is calculated in the base station.
iv. The network pattern preferred is "off" than "on" pattern. In "on" network pattern the transmission power due to overhearing has a major impact. Sleep/Wakeup scheduling is done without collision and retransmission.

C. *Assumption of network model*

Each node consists of two Transmission Power Level (TPL), the range is d and √2d which is based on free space equation. According to the well-known formula,

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

Where, P_t – Transmitted power, P_r– Received power, G_t, G_r - transmit and Receive antenna gains of dimensionless quantities, λ – Wavelength, d – Distance between transmitter and receiver. T1 is the transmission power level for the range d meters and T2 is the transmission power level for the range $\sqrt{2}$d meters. We assume that $E(T_2) \approx 2 \times E(T_1)$.

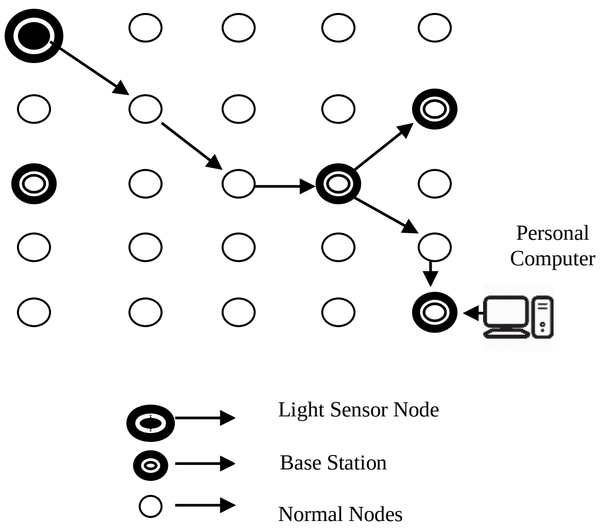

Figure 3: Sensor Network Test bed

D. *Assumption of network model*

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E. *Network Lifetime*

The lifetime of network is defined as the operational time of the network during which is capable of performing the committed task(s). Meghanathan and Mumford (2014) [19] defined it as the number of rounds of network disconnection due to the failure of one or more sensor nodes. If the first node in the network dies or a percentage of nodes die, then the network partitions or loss of area coverage occurs is specified by the Kacimi et al., (2013) [20]. Due to this node failure, a part of area is not covered. In this network model we assume that there is a regular packet delivery which requires load balancing. Based on this model, we consider the critical nodes nearer to the sink, through which all the data are relayed to the base station. Hence, the lifetime of the network is depending on these critical nodes.

In this region the death of one node will lead to death of other nodes due to over load.

$L_{Network} = \min_{i \in \omega} T_i$, Where T_i is the lifetime of node i.

Furthur, maximizing network lifetime is done by balancing the load among the sensor nodes around the sink. For this, it is necessary to determine the maximum lifetime of first node, and thus minimizing the maximum energy E consumed by other sensor nodes in the network. The network is considered as a grid network topology. The sensor nodes in the bottle neck zone deplete their energy quickly.

Step 1: The output traffic rates of all the nodes are given by $\Lambda = (\Lambda^{(1)}, \Lambda^{(2)} \ldots\ldots \Lambda^{(n)})$.

Step 2: $\lambda_g^{(i)}$ is the traffic proportions generated by the node i.

Step 3: E(i) is the energy consumed by the node i.
$\Lambda(i)$ is the traffic load sent by node i.
λ_r^i is the traffic load received by the node i.

Step 4: q_{ij} is the transmission power, when the node i communicates with node j.

Step 5: The energy consumption of one receiving packet is normalized to 1 unit.

The above solution can be applied only for grid network. Let the network topology contains N=MXM sensor nodes, and $\Lambda = (\Lambda^{(1)}, \Lambda^{(2)} \ldots\ldots \Lambda^{(n)})$ is the output traffic rates of all the nodes. Let $\Lambda^{(i)}$ of i^th nodes can be written as $\Lambda^{(i)} = \lambda_g^{(i)} + \sum_j \Lambda^{(j)} p_{ji}$, where $\lambda_g^{(i)}$ is the traffic proportion generated by node i to j, if $p_{ji} = 0$ means i is not connected with j. Thus the equation becomes,

$\Lambda = \lambda_g 1 + \Lambda P$, where, 1 is the identity vector, P is the stochastic matrix.

$$P = \begin{matrix} p_{11} & p_{12} \cdots & p_{1N} \\ p_{21} & p_{22} \cdots & p_{2N} \\ p_{N1} & p_{N2} \cdots & p_{NN} \end{matrix} \text{ and } Q = q_{11} \quad q_{12} \cdots \quad q_{1N}.$$

for $\sum_{j=1}^{N} p_{ij} = 1, \forall i, j \epsilon \{1,2,\ldots\ldots N\}^2$

q_{ij} is the transmission power used by node i to j. In order to maximize the network lifetime we must minimize the energy consumption of nodes in the bottle neck zone.

$$E^{(i)}(P) = \lambda_r^i + \sum_j \Lambda^{(i)} p_{ij} q_{ij}$$

Then $E = \min_P \|E(P)\|_\infty$

The problem associated with the network model is a nonlinear with linear constraints. Since, the network is a grid network, q_{ij} is equal to 2. The optimal solution is demonstrated with three nodes and the sink node in the corner.

The maximum energy consumed by the node is M, therefore, $\frac{E_{(1,2)}}{\lambda_g} = \frac{5+3\emptyset_s}{4} = \frac{3M^2-7}{4}$ ›M, if M>2.

The energy consumed by the nodes in the diagonals 1 to M is expressed in the table 1 with the main diagonal.

TABLE 1
REPRESENTATION OF DIAGONAL FROM 1 TO M

Diagonal	Number of Nodes	Total Receiving	Received per node (x)	Transmitted per node (y)	Energy(x+y)
1	1	0	0	1	1
K	K	$\frac{k(k-1)}{2}$	$\frac{k-1}{2}$	$\frac{k-1}{2}+1$	k
M	M	$\frac{M(M-1)}{2}$	$\frac{M-1}{2}$	$\frac{M-1}{2}+1$	M

The energy consumed by the nodes in the diagonals 4 to M-1 above the main diagonal is given by,

TABLE 2
REPRESENTATION OF DIAGONAL FROM 4 TO M-1

Diagonal	Number of Nodes	Total Receiving	Received per node (x)	Transmitted per node (y)	Energy(x+y)

M-1	M-1	M^2-$\frac{M(M-1)}{2}$	$\frac{M^2}{M-1}-\frac{M}{2}$	$\frac{M^2}{M-1+1}-\frac{M}{2}$	$\frac{2M^2}{M-1}-(M-1)$
K	k	M^2-$\frac{k(k+1)}{2}$	$\frac{M^2}{k}-\frac{k+1}{2}$	$\frac{M^2}{k+1}-\frac{k+1}{2}$	$\frac{2M^2}{k}-k$
4	4	M^2-10	$\frac{M^2}{4}-\frac{5}{2}$	$\frac{M^2}{4}-\frac{5}{2}+1$	$\frac{2M^2}{4}-4$

By applying calculation rules proposed in the two tables, we obtain the routing proportions. At the same time the matrix P for which E(P)=η and $E = \lambda_g\,(\frac{3N-7}{4})$

Based on the deployment considerations of the optimal solutions, all the calculations can be carried out by the base station that transmits routing decisions to the various nodes like Flooding.

The proposed methodology follows the energy efficient path for load balancing and to find the optimal solution for grid topology. So we propose a heuristic which can be used in more general contexts. This heuristic distributes the contributions of each node beginning from the base station by considering them as proportional to the transmission power of each node. We consider only the nodes within the same range. A neighbor node is said downstream (resp. upstream) from another node if it is closest to (resp. farthest from) the base station. The heuristic illustrated by Fig. 4.

```
Initialize: G(N,A), V ={vi}
Ensure: Proportion(i, j)
      Contributions calculation
      For all i,jє Ω do
         if j  є V(i)et d(i,SB)< d(j,SB) then
      Contribution (j,i)←Sum Contributions(i) *W(j,i)
      Sum Contributions (j) ←
      Sum Contributions (j)+ Contribution(j, i)
         end if
     end for
     Proportions calculation
For all j 2 X do
     Proportion (i, j) ←Contribution(i, j)/
     Sum Contributions (i)
end for
Return Proportion (i, j)
```

Figure 4 Load balancing Pseudo code

In case of grid topology, the nodes always directed towards the border line leading to the base station, while other shortest paths takes its way along the diagonal link. It is concluded that most of grid lines are close to the base station are on the main diagonal.

- Nodes on both sides always send their data packet in the border direction through the border nodes.
- All the other nodes send their data through the main diagonal towards the base station.
- It is important to calculate the possible shortest paths for each node in order to balance the traffic load.

5. Performance Evaluation

The performance of the shortest path algorithm and the proposed energy efficient load balancing algorithm were compared with the parametric average energy consumption, Packet delivery ratio and throughput. Based on the results the performance of optimal load balancing technique is better for our grid network model. The implementation of these methods made in network simulator-2 with 250 nodes to find the optimal solution. The simulation setup is represented in the table 3.

TABLE 3
ENVIRONMENTAL SETUP

Channel type	Wireless Channel
Antenna type	Omni Antenna
Number of nodes	50
Initial energy	100 J
Band width	2e6
Frequency	914+e6
Data rate	2e6

We start the calculation from initial traffic proportions λ_g for each node to the base station. The traffic should according to the traffic proportions in descending order form diagonal to diagonal. Figure 5 represents the energy consumption of shortest path (Ex_Energy.xg) and the proposed energy efficient load balancing (Energy.xg) techniques. The shortest path method the network has 80% of energy , but the proposed load balancing method has 88% of remaining energy

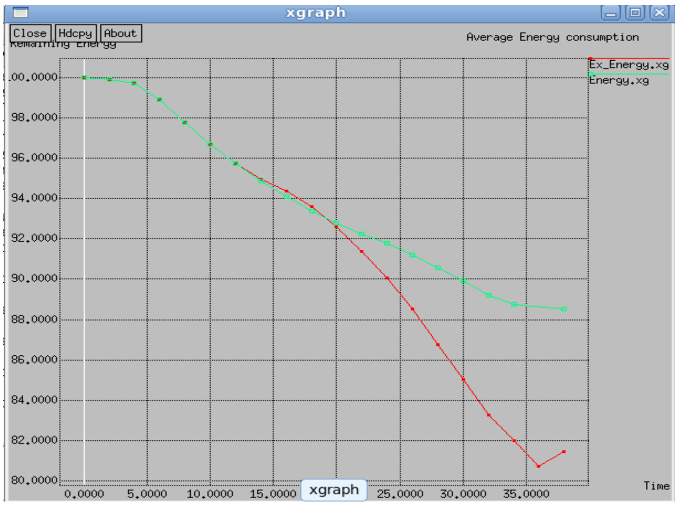

Figure5: Average energy consumption

Packet Delivery Ratio (PDR) is defined as the ratio of actual packet delivered to total packets sent. Here, the PDR for conventional and proposed is more or less similar because of its uniqueness in transmission. As shown in the figure 6, the result shows the similarity between shortest path (Ex_Energy.xg) and the proposed energy efficient load balancing (Energy.xg) techniques. Mathematically, it can be defined as: $PDR = S1/\,S2$ Where, S1 is the sum of data packets received by the each destination and S2 is the sum of data packets generated by the each source. There is much variation in packet delivery ratio.

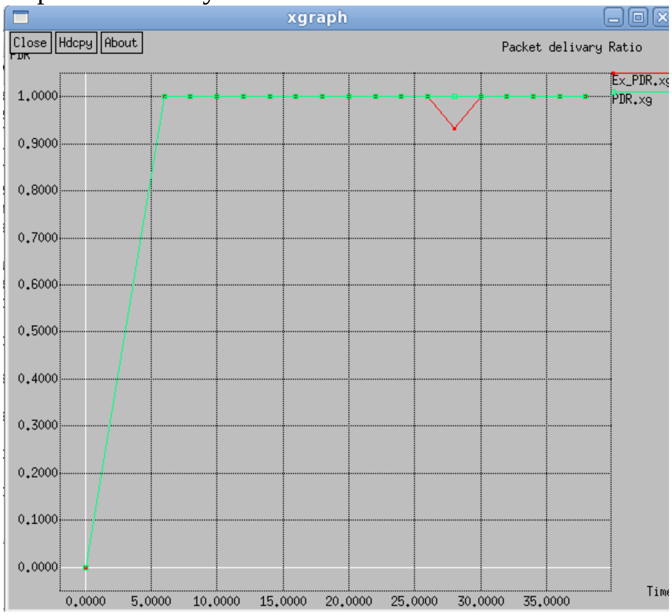

Figure 6: Packet Delivery ratio

Throughput is defined as the ratio of the total packet or a data reaches a receiver from the sender. Throughput is expressed as bytes or bits per sec (byte/sec or bit/sec). A high throughput is absolute choice in every network. Throughput can be represented mathematically in the following equation,

$$Throughput = \frac{numberofdeliveredpacket * PacketSize}{totaldurationofsimulation}$$

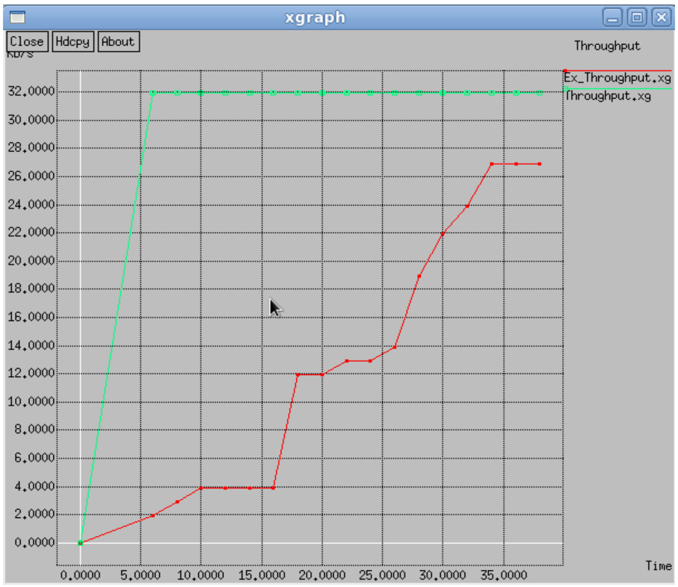

Figure 7: Throughput analysis

As shown in the figure 7, the shortest path (Ex_Energy.xg) and the proposed energy efficient load balancing (Energy.xg) techniques are compared with its throughput values. In proposed energy efficient load balancing scheme the maximum throughput 32.1kb/s is achieved for the entire instant. Since, the shortest path routing represents the maximum throughput as 26.73kb/s.

6 Conclusion

Minimizing energy consumption using load balancing is the main objective of this research, it is successfully achieved by comparing the shortest path balancing algorithm with the proposed energy efficient load balancing algorithm on the basis of various performance metrics and we have reached to a conclusion that the lifetime of the multi grid topology is improved because of the diagonal representation of each node. The throughput of the proposed method improved to 18.256%. The issues that occur due to the network performance and problems regarding energy efficient data transmission can be solved effectively by using energy efficient path balancing technique. In order to make some improvement in accuracy and efficiency for this proposed model, there is a need to extend this research with testing platform and benchmarks. Another suggestion is to make an improvement in Quality of Service Aware Clustered architecture.

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