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Zone Based Transmissions for Homogeneous Wireless Sensor Networks

Yamuna Devi C R[1], S H Manjula[1], K R Venugopal[1]
[1]Department of Computer Science and Engineering
University Visvesvaraya College of Engineering, Bangalore India

L M Patnaik[2]
[2]Honorary Professor, Indian Institute of Science
Bangalore, India

***Abstract*—Wireless Sensor Network is a set of sensors deployed in the area of interest, for the purpose of monitoring physical or environmental conditions. Due to limited battery capacity of sensors, Wireless Sensor Networks have limited lifetime. A large number of sensors deployed in a circular grid, sending the sensed data to base station located at the center are considered and the parameters of interest are monitored. This paper proposes three algorithms to enhance the lifetime, reliability and throughput of the Wireless Sensor Network. The first two algorithms Reliable Zone Based Transmission (RZBT) and Reliable Circular Transmission (RCT) reschedule the packet transmission time of the sensor nodes, to reduce the loss of packets and ensures reliability of network functioning. The third algorithm Energy Efficient Reliable Transmission (EERT) reduces the number of transmissions, without the loss of data, thus extending lifetime of the network. Simulation results prove that 1) RCT outperforms conventional DiReCt Transmission (DRCT) and RZBT with respect to throughput and 2) EERT reduces the packets transmitted in each round, thus improves the lifetime of the sensor node and the network.**

***Index Terms*— Energy Balancing, Packet Delivery Factor, Reliability, Throughput, Wireless Sensor Networks, Zone Division.**

I. INTRODUCTION

The function of sensors in a Wireless Sensor Network is to report the sensed data to the base station at regular interval of times. Major applications of Wireless Sensor Networks are environment monitoring, target tracking, intrusion detection, health monitoring and machine failure diagnosis. Sensor nodes have limited initial power storage, because of size and weight constraints. So, minimal energy consumption by a node for receiving, transmitting and for sensing activities, is the first challenge in Wireless Sensor Networks. The second challenge in a Wireless Sensor Network is the Packet Delivery Factor. Making sure that, most of the packets sent are received at the destination node, is a measure of performance of the network.

Wireless Sensor Networks find applications in many fields of real life. Initially, Wireless Sensor Networks were applied in the Military field, for intruder detection, enemy movement detection and battle field surveillance. Wireless Sensor Networks are used in emergency situations like fire detection, water detection and hazardous chemical level detection. Medical and health field finds abundance of applications of wireless sensors like monitoring of blood flow, respiratory rate, oxygen level measurement, electrocardiogram, patients location and health condition. In automotive field, wireless sensors are used for tire pressure monitoring, active mobility and coordinated vehicle tracking. For weather monitoring applications, the sensors are placed nearer to the base station, and are required to report the gathered data periodically. Many of the home appliances like refrigerators, washing machines, mixers, microwave ovens, used in the modern world use embedded wireless sensors.

In Wireless Sensor Networks, there are a number of sensor nodes uniformly deployed around one or more base station/s. All the sensors are required to sense a parameter in the environment, like temperature, humidity, light and transmit the sensed data to the base station periodically. When all the sensor nodes send the sensed data at the same time to the base station, many packets will be lost because of congestion in the network, or, the buffer size of the sensors. Another disadvantage of this system is redundancy in data transmission causing a lot of energy and time loss. The algorithms implemented in this paper, reduce the redundant data transmission and reduce the packet loss in the network.

Contribution: In this paper a technique is proposed for transmission of data from source to the base station zonewise. The sensor nodes are divided into different zones depending on their position in the network. Zonewise transmission reduces the loss of packets in the network improving the network throughput. The next technique proposed reduces the number of transmissions from the sensor nodes to the base station in each round, by performing a test at the sensors. The sensor nodes are made to send the data to the base station, only when the sensed data is out of an acceptable range. This reduces the energy consumption by a degree of 40 percent.

Organization: The rest of the paper is organized as follows. Section II includes the related work in the field of Wireless Sensor Networks. Background work required for problem formation is discussed in section III. Section IV contains a brief outline of the problem statement and assumptions in our approach. Section V includes the implementation details, with an example network. Section VI presents the performance analysis of the parameters of interest in the network. Finally, Section VII concludes the paper with possible future enhancements.

II. LITERATURE SURVEY

To optimize the the network parameters in Wireless Sensor Networks several Multiple Access Control protocols and routing protocols have been proposed in the literature.

Azad and Joarder [1] propose an energy-balanced transmission policy for multiple source and single destination Wireless Sensor Network. The source sensor nodes placed around the destination node are divided into concentric rings and nodes send packets in multi-hops to the destination node. The heuristics implemented do not consider the delay in packet transmission. Jenn-Yue Teo, Yajun Ha, and Chen-Khong Tham [2] focus on increasing the throughput in a high-rate streaming Wireless Sensor Network using multiple paths, congestion control and load balancing. The transmission between nodes randomly deployed are be affected by interference and this problem needs to be addressed in future work. Zhang and Shen [3] focus on balancing the energy consumed by the sensors in the network to enhance the network lifetime. A mix of single-hop and multi-hop transmissions is used to balance energy of nodes nearer to a centrally located base station. The protocol implemented gives better network lifetime compared to conventional transmission schemes and cluster based schemes. Shadi Saleh Basurra, Marina De Vos, Julian Padget, Tim Lewis, Simon Armour, [4] propose Zone based routing protocol with parallel Collision Guidance Broadcasting for MANET. This protocol minimizes redundant rebroadcasts and time latency by using the most reliable and capable nodes in the network called zone leaders. The protocol provides fast routing and reduction in control overheads compared to AODV protocol. But the disadvantage of this protocol is the security issues associated with zone leaders are not considered.

Yuki Sato, Akio Koyama, Leonard Barolli, [5] reduces the number of control packets transmitted periodically in a mobile ad hoc network and ensures minimal power consumption. This algorithm uses a fixed zone radius for the wireless sensor area for the evaluation of parameters. Wang and Olariu [6] propose a novel hybrid routing protocol that aims to decouple the protocols ability to adapt to traffic characteristics from its mobility. In this protocol every node maintains two zones: a Crisp Zone and a Fuzzy Zone. But these zones do not ensure symmetry in the route discovery and the protocol does not focus on large scale networks. Lin and Chen [7] formulate a model that divides the network into a number of optimal coronas that uses data fusion and slicing. Simulated results show that energy equilibrium is achieved and network lifetime is prolonged. Mario Joa-Ng, I-Tai Lu, [8] divide network into different zones and use node id and zone id for connecting source and destination. This protocol reduces traffic bottleneck and avoids single point failures that are caused by cluster head in a network. Arvind Giridhar and P.R. Kumar, [9] define the functional lifetime of a network with a new dimension as the number of times a certain data collection function or task can be carried out with all the nodes having sufficient balance energy. Two topologies- regular linear array and regular two dimensional networks are considered for derivation of optimal communication strategy to yield a nearly optimal lifetime. The protocols defined do not assure optimal network lifetime all the time and one of the important characteristics of Wireless Sensor Networks the network connectivity is not ensured.

Y. Thomas Hou, Yi Shi, Jianping Pan, and Scott F. Midkiff, [10] achieve optimal network lifetime with single session flow routing solutions for two-tier Wireless Sensor Networks. Hui Wang, Nazim Agoulmine, Maode Ma, and Yanliang Jin, [11] formulate network lifetime maximization as a mixed integer-convex optimization problem to achieve the upper bounds for small scale planar networks. The same is extended for large scale networks by an iterative algorithm to obtain sub-optimal approach to network lifetime in general planar networks. Aubin Jarry, Pierre Leone, Olivier Powell, Jose Rolim, [12] show that maximizing the lifespan, balancing the energy among individual sensors and maximizing the message flow in the network are same. The proposed algorithm is better than the best centralized multi-hop routing strategy. Lutful Karim, Nidal Nasser and Tarek El Salti, [13] deploy minimum number of sensors to monitor an agriculture area and prolong the network lifetime compared to LEACH and DSC protocols. Yun Zou, Huazhong Zhang, Xibei Jia, [14] divide the area with sensor nodes into several zones with unequal clustering to avoid hotspots problem. It is shown by simulation experiment that energy consumption is balanced, hotspot problem is solved and network lifetime is prolonged.

Kai Lin and Min Chen, [15] consider a circular multi-hop sensor network with uniform node distribution and constant data reporting model and show that maximum energy equilibrium is obtained only if the area increases in geometric progression from the outer corona to the inner corona except the outermost corona. Mhatre and Rosenberg [16] present a cost based analysis of single-hop and multi-hop communication between sensors and their cluster heads in a network. Hybrid communication mode that is a mix of the above two modes is proposed. The new mode is found to be more cost-effective than either of the two modes.
Schurgers and Shrivastava [17] focus on data aggregation and shaping the traffic flow for increasing the network lifetime. Advantage of aggregating the packet streams in a robust way is the energy reduction of a factor of 2 to 3. Jia Jia, Jian Chen, Xingwei Wang, and Linliang Zhao [18] investigate the network load and node density parameters systematically. Duplication of messages is reduced by using a new pixel-based transmission mechanism. Node energy is balanced by activating nodes on different energy layers with a non-uniform distribution. The protocol requires each node to be location aware for the route discovery in the network.

Though many of the works mentioned above focus on minimizing energy in a network and prolonging the network lifetime there are a very few papers that try to reduce the packet loss in the network. This paper focuses on reducing energy consumption, increasing network lifetime and on increasing the network throughput.

III. BACKGROUND

Routing is establishing the path between two nodes in a network wishing to communicate. Most of the Wireless Sensor Network applications require flow of sensed data from multiple sources to a particular base station. Position awareness of sensor nodes is important, because data collection is based on the location. Different data reporting models available in Wireless Sensor Network model are time driven, event driven and query driven. It can be flat based or hierarchical, or geographical.

A large number of static, homogeneous sensors, distributed uniformly in a circular monitoring area [3] are considered. All these sensors are sensing the parameter of interest and send the same to the base station located in the center of the circular area that results in DiReCt Transmission (DRCT). In each round, all the nodes sense the data and send it to the base station depending on the value of the sensed data.

The most common constraints on Wireless Sensor Networks are: power, transmission medium, scalability, Fault tolerance, cost, hardware limitations, changing topology, and hostile environment. A large number of static, homogeneous sensors, distributed uniformly in a circular monitoring area [3] are considered. All these sensors are sensing the parameter of interest and send the same to the base station located in the centre of the circular area that results in DiReCT Transmission (DRCT). In each round, all the nodes sense the data and send it to the base station depending on the value of the sensed data.

The sensor nodes in the network are assigned zone id, and corona id given by *(z, c)*. The nodes in the corona will send their data to the nodes in the corresponding corona nearer to the base station if they are not within the transmission range of the base station. The nodes deliver their data to the single base station in the centre of the network. This congestion results in packet loss and increased latency during packet transmission in the network.

IV. PROBLEM DEFINITION

In a real time application the sensors and the environment have different behaviour. But for the purpose of simulation, the following assumptions are considered for the evaluation of network parameters.

1) The sensor nodes deployed and the base station are static.
2) The node density in the network is uniform.
3) All the sensor nodes are deposited with same initial energy.
4) The nodes have same transmission range.
5) All the nodes are one hop distant from the base station.

The first four assumptions confirm that the network is homogeneous, and network coverage is ensured. The last assumption ensures the connectivity in the network and puts a constraint on the network size because the sensors have limited transmission range. By dividing the sensor nodes into different zones, and allowing the nodes in each zone to send the sensed data to the base station at a time, packet losses can be reduced, thus increasing the packet delivery factor. Fig. 1 shows the network nodes divided into four zones and nodes in one zone are transmitting their data to the base station. This reduces the packet loss due to congestion to a maximum extent.

The nodes sense the data once in a second and all the nodes transmit it to the base station instantly without any delay. Because of large number of sensors, it is possible that network becomes highly congested and possibility of loss of information is more. An algorithm that reduces the number of transmissions by putting a constraint on the number of data transmissions between the sensor node and the base station is introduced in this paper. All the nodes are sensing the data, but, a sensor node will transmit it to the base station, only if it more than an upper permissible value or less than a lower permissible value. The algorithm achieves energy saving by putting the sensor nodes into sleep state when they are not sensing or transmitting any data.

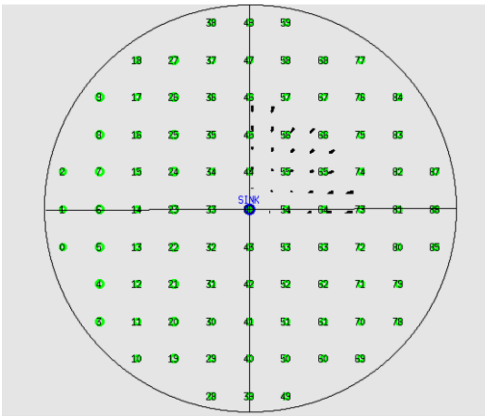

Fig. 1. Zone Based Transmission

The notations used in the network model and their descriptions are listed in Table I.

TABLE I

NETWORK PARAMETER NOTATIONS

Variable	Description
N	Number of nodes in the network
X,Y	Maximum value for node's position
Nr	Total number of rounds
t	Number of transmissions in each round
l	Number of live nodes in the network
EI	Initial energy of the node
Er	Remaining energy of the node
Z	Number of Zones
A	Number of nodes in each zone

For a network with *N* nodes and no condition for data transmission the packet delivery factor is represented by *P*. When the nodes transmit data conditionally the possibility of packet delivery factor is *P+p1*, where *p1* is the improvement. When the nodes transmit data zone-wise, the packet delivery ratio can be represented as *P+p1+p2*, where *p2* is the further improvement. The number of bits transmitted in each round *d* depends on the value of data sensed by the sensors in each round. Each node is loaded with initial energy EI and energy is consumed by the nodes for sensing, receiving and transmitting. Since all the nodes have same initial energy the energy needed for all the nodes for the sensing of data is balanced among all the nodes. The node has to decide whether transmission is needed in every round or not depending on the value sensed. This action requires some computation time and energy. But these are negligibly small compared to time and energy needed for data sensing and transmission and is not taken into account.

The network scenario can be represented by the optimization problem shown below.

$$\text{Maximize } Nr; \qquad (1)$$

subject to constraints

$$Tp = 0 \text{ or } 1 \qquad (2)$$

$$Er >= EI \text{ for all nodes}; \qquad (3)$$

$$0 < Nx <= X;\ 0 < Ny <= Y; \qquad (4)$$

Objective of the function in eq. 1 is to maximize the number of Rounds the sensors can function reliably. The constraints applied to the model are represented eq. 2, 3 and 4. The constraint 2 indicates whether transmission has to take place or not. A 0 indicates no transmission and a 1 indicates transmission. The constraint number 3 confirms the transmission by all the nodes having sufficient remaining energy. The last constraint ensures that the nodes are deployed within the boundary considered for the sensing operation to be performed.

V. IMPLEMENTATION

The sensor nodes in the network are divided into a number of equal sized zones. The zone id of anode is computed by its position with respect to the base station co-ordinates. Z represents the number of zones. Z = 1, represents the original network with a single zone. Increasing the number of zones, will decrease the packet losses and hence increasesthe packet delivery factor. As a small delay is introduced for nodes in each zone to transmit thesensed data to the base station, Z should be small enough for all the nodes to transmit their data to the base station in each round. In other words, the time gap between each round should be large enough for all the nodes to send their data to the base station. To balance between these two factors data is sensed and transmitted by the nodes once in every second. The number nodes in each zone A is almost a constant as uniform distribution of nodes in the network is maintained and the zones are of same size.

The number of nodes in each zone is a constant as uniform distribution of nodes in the network is maintained and the zones are of same size. The network is considered to be alive till at least 10% of nodes are functioning in the network. The number of rounds for sensors to send the sensed data to the base station Nr is increased by reducing the number of transmissions. The Packet Delivery Factor in a network is an important measure of the network performance.

In the Reliable Zone Based Transmission algorithm shown in Table II the deployed nodes in the network are divided into Z zones, each zone having approximately ρ nodes. All the sensor nodes are provided with an equal amount of initial energy EI. Next each node is assigned the zone number according to its position with respect to the base station. The nodes in each zone send the sensed data to the base station in turn. After each node sends a packet the energy required for transmission is deducted from its residual energy Er. This reduces the number of nodes transmitting simultaneously in each round. After each round of transmission is completed the Packet Delivery Factor is computed. As an effect of reduction in the number of simultaneous transmissions, the Wireless Sensor Network Packet Delivery Factor is increased making the network more reliable.

In Reliable Circular Transmission in Table III the sensor nodes in the corona transmit their packets in a circular order with a small delay. This method reduces the number of collisions in the network as compared to zone based transmission. The delay introduced in the transmission is very small as compared to the improvement in the throughput of the network.

The technique used in the algorithm Energy Efficient Reduced Transmission shown in Table IV uses congestion control scheme that is able to adjust the loading rate of the source nodes. If all the nodes in the network start transmitting their data to the base station the possibility of packet loss at the base station is very high. An acceptable range of values for the parameter measured is considered. The sensor nodes are provided with initial energy EI for their functioning. The sensed data will be sent to the base station if the data is greater than lower acceptable value of the parameter

Table II

Algorithm RZBT: RELIABLE ZONE BASED TRANSMISSION

Input: Set of sensors arranged as a circular grid represented by their x and y coordinates and base station in the centre.

Output: Maximum Packet Delivery Factor.

```
Nr = 1; l = N
for i = 1,2,...,N
  Assign initial energy
endfor
while ( l > N / 10)
  for i = 1,2,...,N
    assign zone-id for each node.
  endfor
  for j = 1,2,...,Z
    for i = 1,2,..., α
      sense the data
      Transmit to base station
      Deduct energy required for transmission
      Increment Nr
    endfor
    Compute Packet Delivery Factor
  endfor
endwhile
```

TABLE III

Algorithm RCT: RELIABLE CIRCULAR TRANSMISSION

Input: Set of sensors arranged as a circular grid represented by their x and y coordinates and base station in the center.

Output: Maximum Packet Delivery Factor.

```
Nr = 1; l = N
for i = 1,2,...,N
  Assign initial energy
while ( l > N / 10)
  for i = 1,2,...,A
    Sense the data,
    Transmit to base station
    Deduct energy required for transmission Delay()
    Increment Nr
  Compute Packet Delivery Factor.
```

measured or it is lesser than the higher acceptable value of the range considered. After each packet is transmitted to the base station the energy required for transmission is deducted from the residual energy Er of the node. The number of transmissions and the number of live nodes l in the network is computed after each round. This process is repeated till 1 % of the sensor nodes in the network are alive. Reduced number of transmissions by sensor nodes in the network reduces the energy spent in packet transmissions and the number of rounds the nodes can function is increased. As a result the Wireless Sensor Network lifetime is increased.

VI. PERFORMANCE ANALYSIS

In all simulations the sensor nodes are uniformly deployed in a circular area and the base station is in the centre of circular area. Initial energy of all the sensor nodes in the network is equal to 1

Joule. The radius of the circular area is varied from 100m to 1000m. The number of nodes transmitted data sensed to the base station is varied from 10 to 80.

Table IV
Algorithm EERT : ENERGY EFFICIENT REDUCED TRANSMISSION

Input: Set of sensors arranged as a circular grid represented by their x and y coordinates and base station in the centre.

Output: maximum number of rounds the nodes can function.

```
Nr = 1; l = N
for i = 1,2,...,N
  Assign initial energy
endfor
while ( l > N / 10)
   t = 0
   for i = 1,2,...,N
      Sense the data
         if ( data > minimum limit and data <
              maximum limit )
            Transmit to base station
            Deduct energy required for transmission
            Increment t
         endif
   endfor
   Increment Nr
Compute l
Endwhile
```

Fig. 1 shows an example of the network, where all the sensor nodes are transmitting the sensed data to the base station. When the nodes are divided into different zones, the throughput of the network increases, as the loss of packets is reduced. The same for four zones in the network is shown in Fig. 1 for DiReCt Transmission (DRCT), Reliable Zone Based Transmission (RZBT) and Reliable Circular Transmission (RCT).

The quality of Wireless Sensor Networks is evaluated based on the parameters of interest. The following metrics are considered in this paper.

A. Network Lifetime: Sensor node lifetime is considered as the time before which the node is left out with less than 10 % of its initial energy storage. The sensor node is considered to be dead, if it has less than 10 % of initial energy, otherwise it is said to alive or active. The time duration elapsing between the functioning the network and at least 1 % of the nodes are alive, is considered as the network lifetime.

B. Packet Delivery Factor: represents the ratio of number of packets sent from a source node to number of packets received at the destination node. Packet delivery factor can reach a maximum value of 1, when all the packets sent are received. But, normally because of congestion and presence of malicious nodes and other factors, it has a value lesser than 1. When it reaches 1, the network can be considered as an ideal network.

C. Throughput: is the number of Kilobits transmitted by the source nodes in a network per second. Higher is the value of throughput, better is the performance of the network.

Figure 2 plots the Packet Delivery Factor obtained by Direct Transmission (DRCT), Reliable Zone Based Transmission (RZBT), and Reliable Circular Transmission (RCT). When the number of nodes transmitting is only 10, the packet loss is either negligible or zero. As the number of nodes transmitting increases the Packet Delivery Factor for Direct Transmission decreases and less than 25% of packets reach the destination. Reliable Zone Based Transmission increases the Packet Delivery Factor to nearly 80% when all the nodes are transmitting, but the best Packet Delivery Factor of around 93% is obtained in Reliable Circular Transmission. The number of packets dropped versus number of nodes transmitting for the three transmission methods is depicted in Fig. 3.

The throughput of the network versus the number of nodes transmitting is shown in Fig. 4 in Kilobits per second. In the given network number of nodes transmitting data to the base station is varied from 10 to 80 in steps. In DiReCt Transmission the number of dropped packets is more because of congestion and throughput is less. Reliable Circular Transmission gives the best throughput as the congestion is reduced. It shows an improvement of 68% compared to DiReCt Transmission and 18% compared to Reliable Zone Based Transmission in the network. The throughput of Reliable Zone Based Transmission is in between that of DiReCt Transmission and Reliable Circular Transmission.

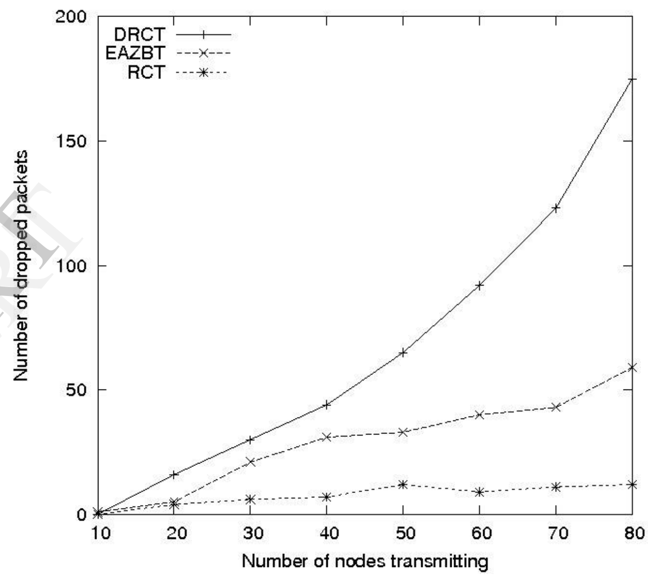

Fig. 2. Packet delivery Factor

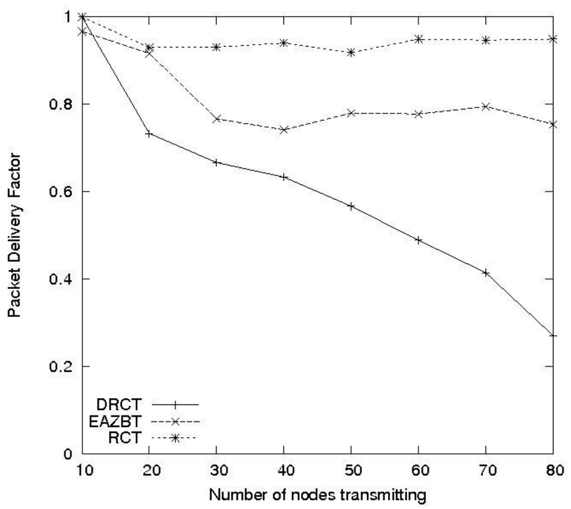

Fig. 3. Number of dropped packets

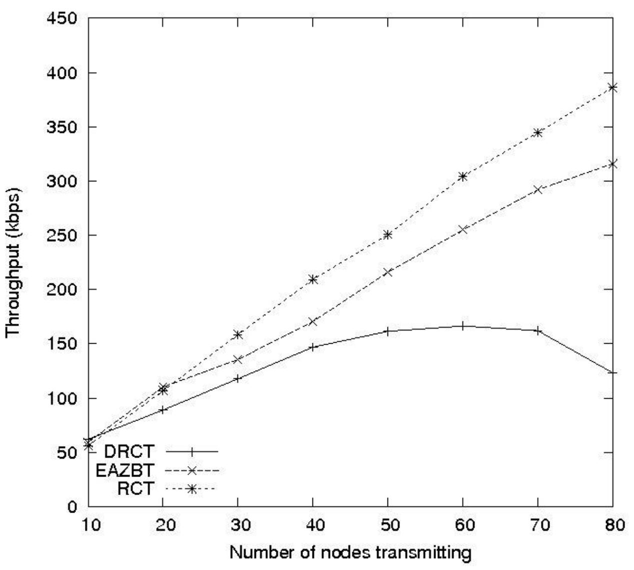

Fig. 4. Network Throughput

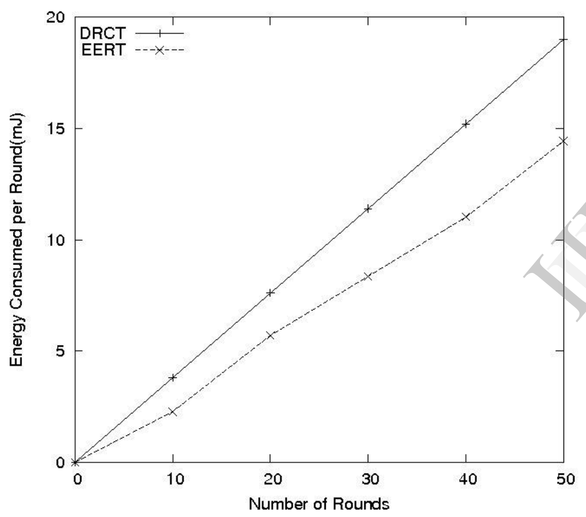

Fig. 5. Average Transmission Energy Consumed per Round

Figure 5 shows the average of transmission energy consumed by all the nodes versus number of rounds the simulation is run. The graph shows the transmission energy values up to 50 rounds. For Direct Transmission the energy consumed by the nodes increases constantly because all the nodes transmit at the same time to the base station. Energy Efficient Reduced Transmission reduces the number of transmissions to about 24 %. Since in each round different nodes transmit the data depending on the data sensed, energy is balanced among all the nodes in the network. This reduces the energy needed for transmission by the nodes in each round, enhancing the lifetime of the sensor node and the network.

Table V shows the total and the average transmission energy values of the nodes in the network for 25, 50 and 75 rounds. It can be seen from the Table that, as the number of rounds increases, the saving in average transmission energy of the nodes reduces. The reason for energy saving is load balancing among the nodes of the network as the number of rounds increases.

TABLE V

SUMMARY OF THE TRANSMISSION ENERGY VALUES FOR RZBT

Number of Rounds	Total Energy	Average Energy
25	18.62	0.21
50	15.19	0.17
75	14.82	0.16

VI. CONCLUSIONS

In this paper algorithms are proposed to increase the Network Reliability, Network Throughput and the Network Lifetime in a large Wireless Sensor Network. A single hop network is considered to save the overload of multi-hop routing and cluster based routing. The main idea is to balance the transmission load on all the sensor nodes in the network. The proposed and implemented algorithms RZBT, RCT and EERT reduce collision of packets, increases the Packet Delivery Factor and Network Lifetime of the Wireless Sensor Network. Better Network Reliability is achieved by reducing the loss of information from source to base station. A small overhead is introduced at the node level in deciding whether it should transmit or not in each round. There is a small delay in transmission starting time of the nodes with higher id number. But these are negligible compared to the benefit of the throughput obtained in the network. The directions for future work are combining the zone based transmission and conditional transmission by the nodes to the base station, considering residual energy of the node and using heterogeneous nodes in the network.

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