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Energy Efficient Green Wireless Sensor Network using Tree-Based Distributed Clustering (GTBC) Routing Protocol

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Abstract

In the world of IT, current and updated information plays a vital role. This demand leads to the extensive use of wireless sensor network in many application domains. WSN constitutes of small sensing units which are responsible to sense the event, compute its sensed data and communicate it to the receiving base station for further processing and decision making. These sensors are battery operated and mostly deployed in unfavorable conditions, where human intervention is either difficult or not feasible, so if the battery support ends for any sensing device, it cannot be replaced. This situation brings our focus to energy conservation. Here, establishing an efficient route for data communication is one of the remedial solutions to manage on this critical energy source. Routing protocols which are based on network structure are said to consume less energy for transmitting the sensed data. Among which hierarchically structured homogeneous routing protocols are best-suited solution for reducing energy utilization, as it avoids unnecessary and repetitive data transmission.

In this paper, our aim is to develop a novel Green Tree-Based Distributed Clustering Routing Protocol (GTBC) for energy efficiency in WSN. The proposed method comprises of three steps, which are Constructing a Hop Tree structure, creating a Cluster and Selection of Cluster Head and finally establishing an efficient and reliable route. The simulation analysis is done using Network simulator, MatLab2019b. Secondly, the performance of GTBC is analyzed and an optimal ratio of number of nodes deployed in the network to the area of the network is identified and it also suggests the permissible levels in tree structure, so as to increase the energy efficiency in WSN. Lastly, the performance of GTBC is compared with the existing hierarchically structured routing protocols such as Leach, HEED, Pegasis and TBC. Results shows GTBC outperforms all the other protocols on the parameters of, Round

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at which the first node completely exhausts it energy, Average residual energy of the network, packet delivery ratio, packet loss rate and Throughput of the Network, increasing the lifespan of the network.

Keywords: *Green wireless sensor network, tree-based distributed clustering, routing protocols, energy efficiency, network lifespan.*

Introduction

In the past few years, rapid development in the world of Information Technology has increased the use of wireless sensor network to a large extent. WSN consists of small battery-operated devices, which are deployed in a fixed geographical area, where their aim is to sense the event around, process the sensed data and communicate this data to the adjoining sensor or to their reporting base station. In WSN, a Base Station (BS) is a transceiver that is connected to a number of other nodes or to a wider area [1,2,3].

A WSN may constitute of hundreds to thousands of sensor units. These sensors are used to monitor and analyze a wide variety of events ranging from environmental parameters such as temperature, humidity, seismic activities to healthcare, wildlife habitat and surveillance [4]. Sensors operate on a finite energy support and since they are established in unfavorable environmental conditions, therefore their battery cannot be changed after deployment [5,6]. Also, the major part of sensor's energy is used in communication, so if the node dies, the WSN has to be created again, which would turn into a costly affair [7].

Due to this reason, our main focus has inclined towards the aspect of energy conservation and exploring renewable sources of energy. This concept is termed as "Green IT", which primarily deals in 3R's – Reduce, Renew and Recycle.

Green Wireless Sensor Network aims to reduce this energy consumption factor of communication. Here, efficient routing of data is one of the suitable mechanisms to preserve the energy of these tiny devices and improve the life span of the network [8]. The characteristics of Green WSN are -Periodic data reporting, No Time Stamp synchronization and most important of them all is, that sensors can be customized as per the requirement of the site [9]. Routing protocols which are classified on the basis of the structure aspect of the network are further divided as Flat, Hierarchical and Location-oriented Protocols. Among which Hierarchically structured routing protocol with homogenous configuration of nodes is considered to be the best suited for creating Green Wireless Sensor Network (GWSN). Leach, Heed, Pegasis and TBC are some of the existing homogeneous hierarchical clustering methods that deals in energy efficiency. Here, Clustering gets a larger credit in delaying the time for first node dead in the network and aggregation process on the other hand, helps in delaying the last node dead [10,11,12].

In this paper, we have proposed a novel Tree-based Distributed Clustering Routing Protocol for Green Wireless Sensor Network (GTBC). In section 2, we have discussed the related work of existing routing protocols. In section 3, the proposed GTBC is designed and simulated. In Section 4, results and network simulation set up is discussed, in Section 5, a comparative analysis of GTBC with existing hierarchical routing protocol (Leach, Heed, Pegasis, TBC) is presented and finally, in Section 6, Conclusion and future work is discussed.

Related Work

In the last few years, many surveys and research have been conducted on conserving the energy aspect in communication by designing efficient routing protocols. In this section, we have given a brief information over the recent development in network structure based hierarchical routing protocols. As per the literature survey, Leach, Heed, Pegasis and TBC are some of the homogeneous hierarchical clustering methods that deals in energy efficiency.

Low Energy Adaptive Clustering Hierarchical routing (LEACH) is widely studied as an energy efficient protocol. It creates clusters with nodes who are in close vicinity and every cluster elects their Cluster Head (CH) through a random function, to whom each participating node send their sensed set of data. All the CH then communicate the data to the BS. In every round a new CH is elected. In LEACH although load balancing is achieved, minimum energy of the CH is maintained as well as collision in transmission is prevented, But Leach has few disadvantages also, like unsystematic selection of CH, asymmetric distribution of Clusters and one hop communication between CH and BS. Due to which its network lifetime is low [13,14].

Hybrid Energy Efficient Distributed routing (HEED) elects the cluster head who has the highest residual energy and requires the minimum distance for communication. Here, Intra cluster communication cost is calculated which is a function is cluster size and permissible levels of power in the cluster head. Evaluating this function value for every round lead to overload in CH selection because of which the network dies sooner [15].

Power Efficient Gathering in Sensor Information System (PEGASIS) is another homogeneous routing protocol which creates chain-based network structure. Here, Nodes will sense the data and transmit it to the closest neighboring node. The consecutive node takes up the data, aggregate with its own sensed data and forward it to the next closest node forming a chain structure. Finally, the last node in the chain transfers the set of sensed data to the BS. Although Pegasis very efficiently creates a balance of energy utilization, between CH election and sensed data transmission but since there is only one node acting as head, it may be led to network congestion and delay in data processing [16].

Tree Based Clustering routing protocol (TBC) is used to solve the energy utilization issue for the CH's which are situated at a larger distance from the BS. Through Tree based clustering (TBC) inter-cluster distance is calculated and a shortest path routing table is created among Cluster head as parent and child node, and Base Station as a root node, where their distance is calculated for every round and the table is updated [17,18]. Transmitting sensed data through multiple hops between CH to finally BS is an energy efficient method for establishing Green WSN. The CH instead of using direct communication method for data transmission to the BS, chooses to send the sensed set of data to the nearby CH. This scheme suffers from delay in data processing and overhead of maintaining the routing table after every round [19,20].

Furthermore, in recent times, tree-based and cluster-based routing protocols are gaining a lot of attention of researchers due to their efficient routing through different tree branches and clustering techniques. A Tree-Based Threshold-Sensitive Energy-Efficient Routing [21] aims to preserve energy on each sensor node of the network. This algorithm uses flower pollination method to selects the parent node based on residual energy and their distance to BS as well as it maintains three level hierarchical tree so as to reduce the load on the cluster head. But, the performance of this protocol falls if the residual energy of the parent node goes below the threshold value in any round, the tree has to be reconstructed.

Energy-Efficient Compressive Sensing-based clustering Routing (EECSR) periodically update the network topology and select the node with larger degree and high residual energy as the cluster head, who would be responsible for data aggregation and transmission. As the nodes selects and joins a CH who is in the optimal radius, the energy consumption is well distributed among the cluster members, hereby increasing the lifespan of the network. Although EECSR protocol fairly deals in energy management of the Cluster head but suffers from network congestion for large area network. [22].

A new clustering protocol based on Yellow Saddle Goatfish Algorithm proposed a routing protocol [23] which finds the total no of CH, selects the CH and finds the optimal distance of CH to the BS, thereby reducing the transmission distance and increasing the energy efficiency of the network. An energy overhead in identifying the total no. of cluster heads and optimal distance calculation is observed in this scheme.

Improved-Adaptive Ranking based Energy-efficient Opportunistic Routing protocol (I-AREOR) subdivides the focus of energy conservation to the round at which First node, half node and all nodes dies in the network. It considers regional density, relative distance, and remaining energy aspect, by maintain a dynamic threshold value for selecting cluster heads which increases the number of rounds before the first node completely exhausts its energy [24]. But maintaining a dynamic threshold causes an overhead on average residual energy for large area sensor networks.

A novel technique named Two-level distributed clustering routing algorithm for large scale networks is based on unequal clustering method [25]. This algorithm creates two cluster heads, primary and secondary cluster heads within the cluster. So as to reduce the transmission distance between CH and Other cluster members. It can handle load balancing to a good extend but selecting and maintaining two cluster heads in each round consumes considerable amount of energy.

An Efficient Distributed Clustering and Gradient based Routing Protocol for Wireless Sensor Networks [26] ensures the energy level to be maintained as per the set value. As the energy of any node goes below the threshold value, this algorithm enables a control mechanism to reduce the number of data packets. As well as a periodic data collection mechanism from all CH is been used by the Base Station to avoid congestion. Energy efficiency of the network is handled well in this routing scheme but Quality of service is neglected as it controls the number of packets to be transmitted, thereby unable to handle the sensed data from each and every node.

Motivation and Objective of Research

All the above-mentioned recent research work does not focus on the parameter of appropriate number of nodes to be selected and deployed in the region. And also, there is no consideration on the depth or the permissible level of tree structure to avoid latency, congestion and fault tolerance in communication. Our objective of this research is to design an efficient Green wireless Sensor Network using Tree-based distributed clustering (GTBC) routing protocol and to evaluate and analyze the performance of the proposed protocol based on network throughput, average residual energy and network lifetime parameters, packet Delivery ratio and packet loss rate, with the existing hierarchically structured routing protocols.

Proposed GTBC Routing Protocol

The proposed Green Tree-Based Distributed Clustering (GTBC) routing protocol is composed of three main steps:

Step 1: Hop Tree Building

Step 2: Cluster formation and Cluster Head Selection

Step 3: Establishing the Route.

Table I.

List of Notations

Notation	Definition
BS	Base Station
CC	Cluster Configuration message
CH	Cluster Head node
CM	Cluster Member node
dead	No. of Dead nodes
HC	Hop Configuration value
i	Iterative value
ID	Identification number of the node that generated the message.
LT	Link to the Tree
n	No. of nodes
NHop	Variable to hold the information to the next hop
PM	Message for Path building
R	No. of rounds
State	Variable used to store the state value with the ID of the node

Step: 1 Hop Tree Construction-Sensor nodes are randomly distributed in the field and this algorithm initiates whenever any node in the network sense a data.

Algorithm 1:

1. The BS transmits a Hop configuration message with link to the tree as a single hop (LT=1).
2. For all the nodes who receive this message and have the LT value > 1, becomes the child to their predecessor node else connects directly to the BS.
3. NHop(n)=ID (HC) // stores the next hop of the node.
4. LT(n)=LT(HC)

   ID(HC)=ID(n)

   LT(HC)=LT(n)+1

   State (HC)=state(n)
5. n transmits the HC message to its neighbors
6. Else if (LT(n)==LT (HC) & state (NHop(n)) <state (HC))
7. NHop(n)=ID(HC)

Step: 2 Creating a Cluster and Selecting CH-The main role of this step is to create a cluster and to elect an appropriate cluster head.

Algorithm 2:

1. For each node n that sense an event
2. R(n)=CH
3. n creates a Cluster configuration (CC) message and broadcasts it
4. For each node n that receives a cluster configuration message for this event.
5. If LT(CC)<LT(n)
6. R(n)=CM and n retransmit the CC

   Else if LT(CC)==LT(n) & state (CC)>state(n)
7. Role(n)=CM and n retransmit the CC message

Step: 3 Route Setup-In this phase a reliable and shortest route for data transmission has been established.

Algorithm 3:

1. If LT(x)==0 // then node x is the CH and no need to build the path.

   Else if the Energy (NHop(x)) < Threshold energy and node x can find a neighbor who satisfies that its residual energy is greater than the threshold value and with less hop to BS.
2. x broadcasts a message to the remaining nodes in the path for creating a route for the purpose of data transmission.

   Else x joins the path and transmits its status information (PM< ID, LT, state>) to the node in its next hop.
3. For each node n that receives the PM message, if LT(n)==0; then the route is successfully established

   Else it repeats step 2 to3.
4. The node with the smallest Hop value and at best state in the event field will be chosen as the new cluster head.
5. NHop(n)=x; n joins the path and send its PM message to its next hop node.
6. For each node y which receives this message, IF y==BS than route is created. Else it repeats step 6 to7.

Results and Network Simulation Setup for Proposed GTBC Protocol

Performance Evaluation

Performance of a network depends up on the subsequent factors:

- Network Throughput- It is the average data rate of all positively acknowledged set of data transmitted over the particular communication channel.
- Network lifetime- It is the time when the first node of the network gets completely exhausted and dies.
- Average Residual Energy of the Network -It is the optimal amount of energy of all alive nodes after completing all rounds [21,22].
- Packet Delivery Ratio-The ratio between the number of packets received successfully to the number of packets sent.
- Packet Loss Rate-It is the rate at which packets are dropped in the communication and does not reach to the receiver end.

Network Model and Radio communication Energy Model:

It is supported by the successive assumptions:

- Sensor nodes in a square area A (a∗a) are randomly distributed.
- At fixed location within this region (A), is a unique base station (BS).
- Nodes are stationary after deployment. All nodes have a same capability, equal standing and same amount of energy.
- Transmission power is manageable and controlled so that nodes can adjust with reference to the transmission distance.
- The energy model follows multipath fading model.

Radio Communication Energy Model

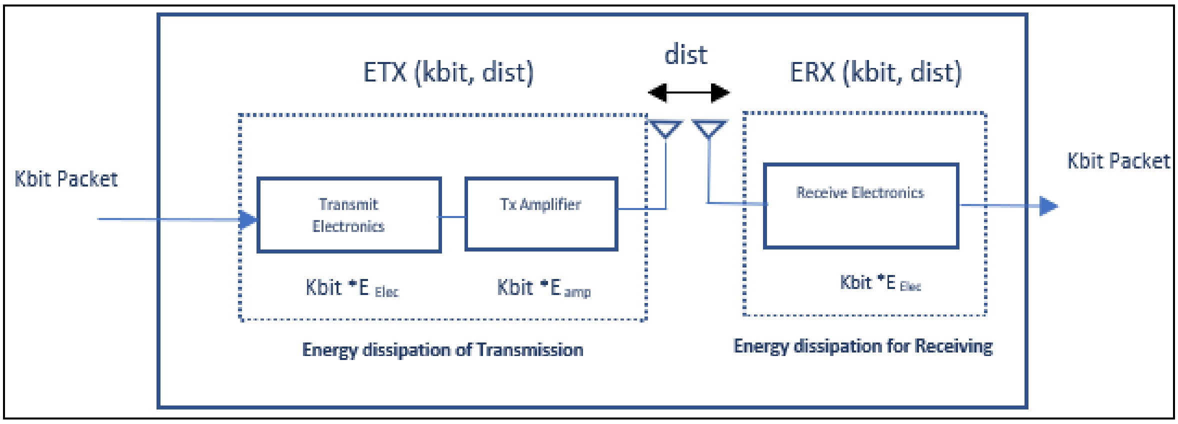

Fig. 1. Radio Energy Consumption Model For WSN

Total energy consumed can be calculated by the following formula:

Etotal=ETX+ERX

i.e., When sending k-bit of data to a dist-distance, the nodes will consume the energy as:

ETX (kbit, dist) = ETX-elect(kbit)+ETX-Eamp (kbit, dist)

ERX (kbit, dist) =ERX-elect(kbit)

Where, dist denote the distance between transmitter and receiver node, Eamp is energy consumed by the amplifier to transmit at dist-distance, Eelec represents the energy consumed per bit by the electronic circuit to transmit or receive the signal.

Network Simulation Tool-MATLAB 2019b

Table II.

Simulation Setup for GTBC Protocol

Type	Parameter	Value
Topology of Node	Size of Network	300m×300m
	Number of nodes	100
	Location of Base station	100,75
	Node distribution	Random
	Channel	Wireless
	Type of Network	Fixed
Setting of Node	Initial energy(E0)	0.5 J
	Sleep and idle energy	~0J (ignored)
Radio Model	ETX = ERX	50 nano Joules per bit
	Efs	10 Pico Joules per bit sq.mt.
	Emp	0.0013 Pico Joules/bit/m4
	EDA	5 nano Joules per bit
	Packet header size	25 bytes
	Size of Data packet	4000 bytes

Simulation of GTBC on MATLAB 2019b

GTBC routing protocol is been simulated in a virtual environment using Network simulator MatLab2091b with different sets of nodes 50, 100, 150, 200, 250, 300.

Table III.

Performance Analysis of GTBC Protocol

No. of Nodes	Lifetime of the network	Throughput of the network	Average Residual Energy of the Network (nJ)
50	153	12926	0.1879
100	250	17650	0.4284
150	276	19536	0.2739
200	306	21720	0.2776
250	325	26626	0.2576
300	348	31514	0.2028

[a] For 50 nodes

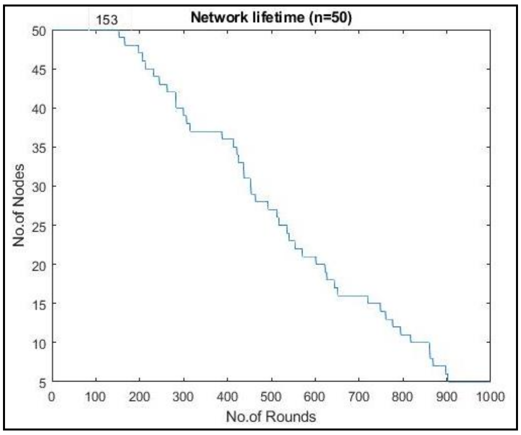

Fig. 2(a). Network Lifetime

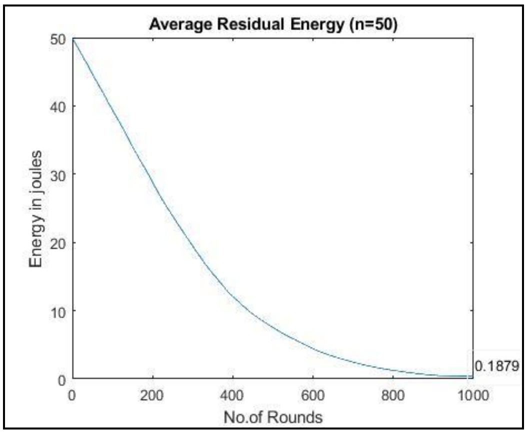

Fig. 2(b). Average Residual Energy

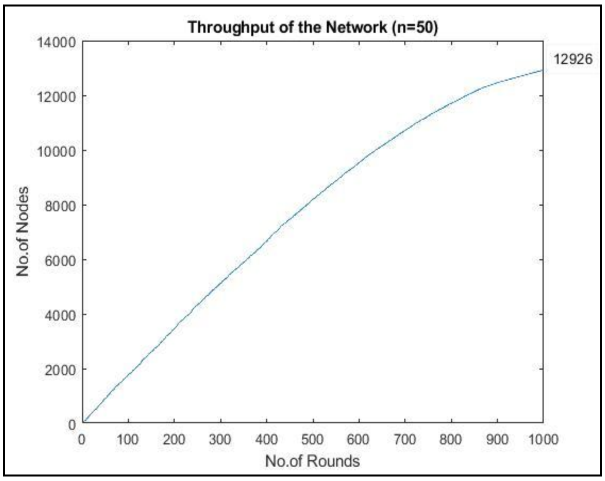

Fig. 2(c). Throughput of Network

[b] For 100 nodes

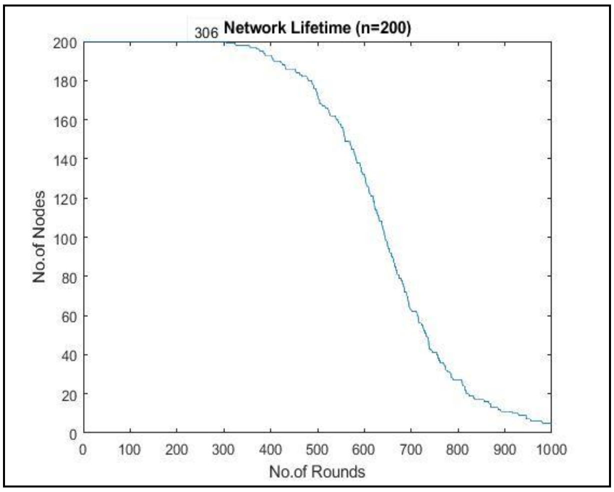

Fig. 3(a). Network Lifetime

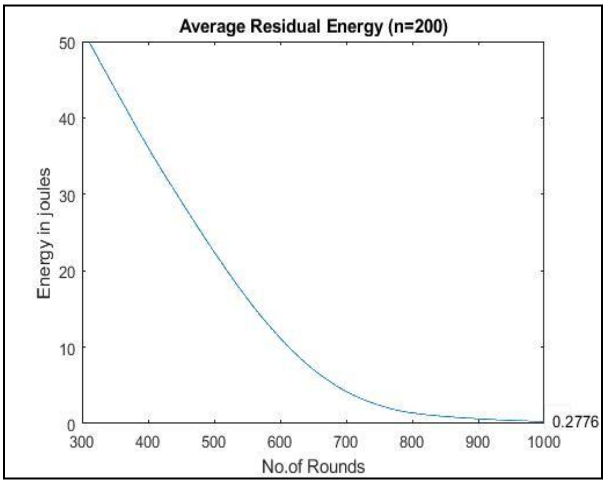

Fig. 3(b). Average Residual Energy

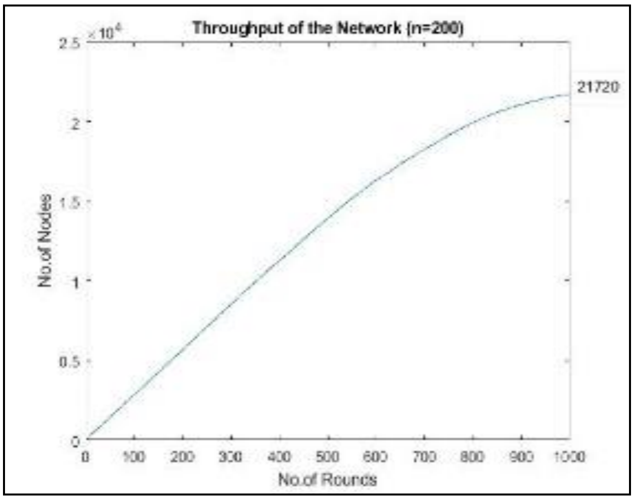

Fig. 3. (c). Throughput of Network

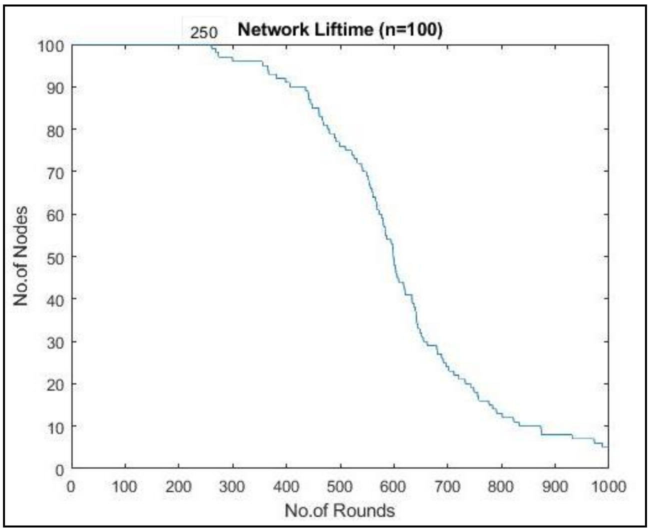

Fig. 4(a). Network Lifetime

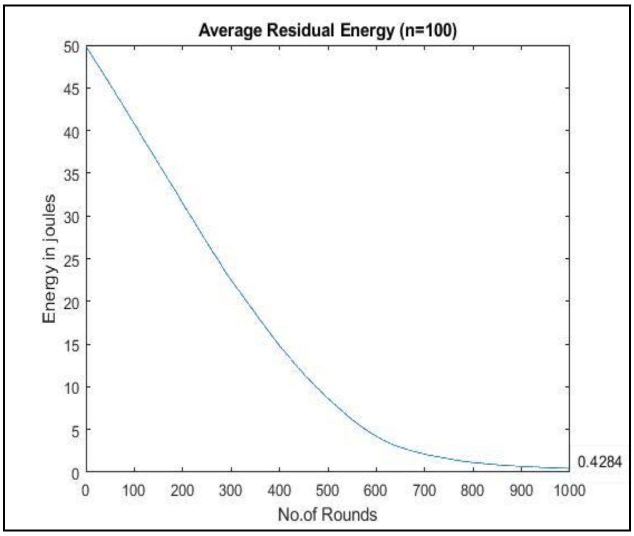

Fig. 4(b). Average Residual Energy

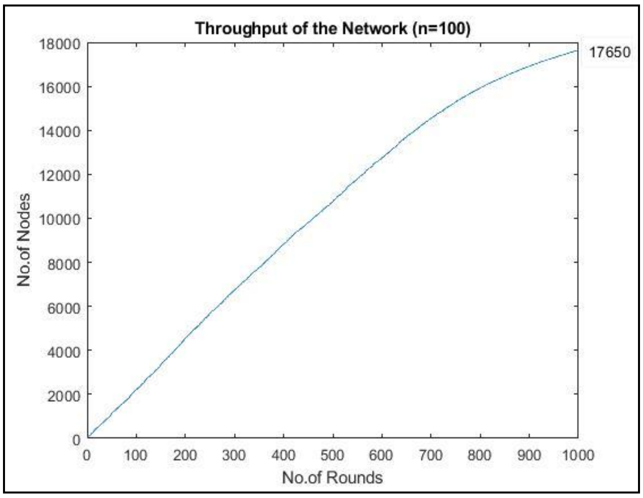

Fig. 4(c). Throughput of Network

Result

- As the number of nodes increase, the time at which the first nodes die also increase because alternate path exists for data transmission. Hereby increasing the Network lifetime.
- As we double the number of participating nodes, we find that Lifetime of the network, is low for scarcely distributed network and gradually increases for compact networks, because not all load is on a single node or cluster head.

Table IV.

Network Lifetime Analysis of GTBC

No. of Nodes	Percentage of First node dead for GTBC network (%)
50-100	61.20
100-200	81.69
200-300	87.93

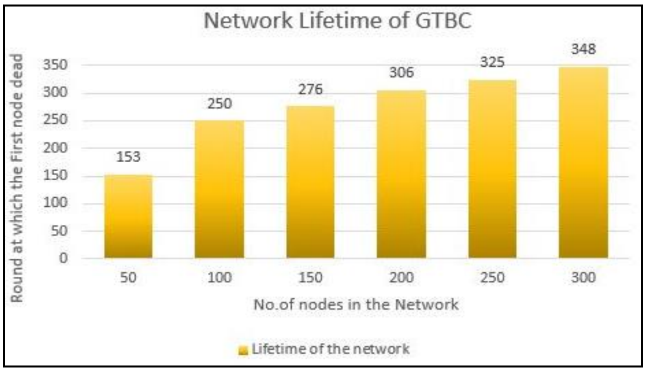

Fig. 5(a). Network Lifetime of GTBC

- Average Residual Energy is low when no. of node was 50 (scarcely distribution), after completion of all rounds. When the number of nodes increased to 100 nodes (optimal distribution) the average residual energy of the network increases. Furthermore, the increase in the no. of nodes (compact distribution) in the network leads to decrease in the average energy of the network.
- This Compact deployment of nodes will lead to increase in energy drainage, delay and also network congestion. Hence an optimal ratio of 1:3 for No. of nodes to the network area is suggested.

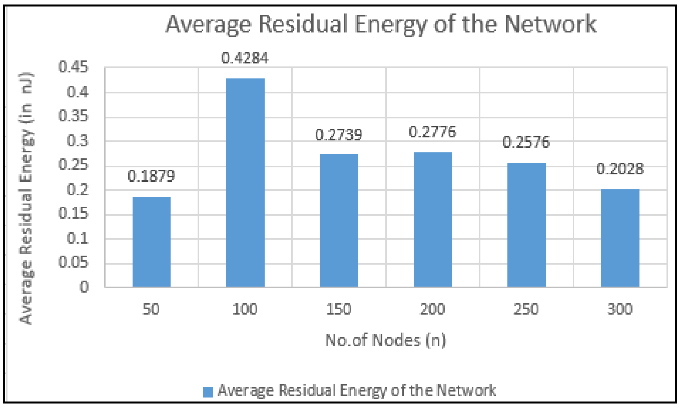

Fig. 5(b). Average Residual Energy of Network

Table V.

Throughput Analysis of the Network

No. of Nodes	Percentage of Throughput of the network (%)
50-100	73.24
100-150	90.35
150-200	89.94
200-250	81.57

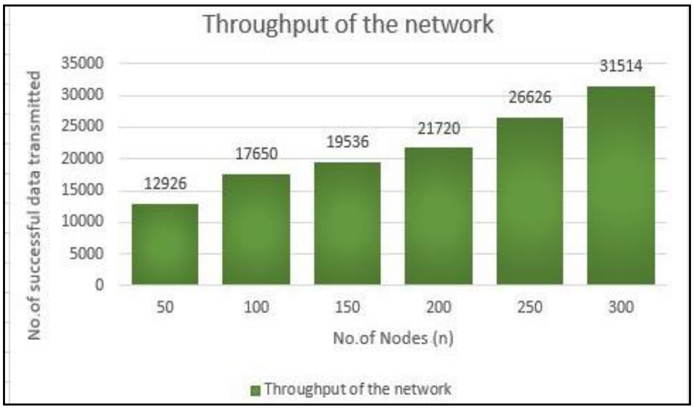

Fig. 5(c). Throughput of the Network

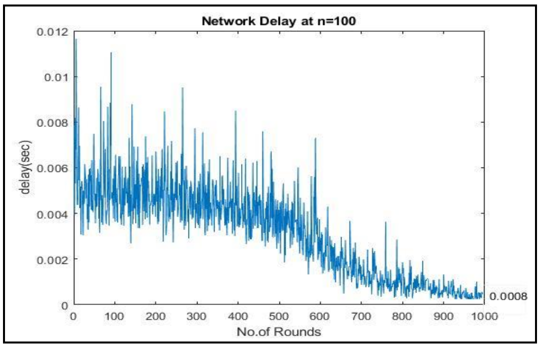

Fig. 5(d). Average Delay of the Network for GTBC Protocol

Comparison of GTBC Protocol with Existing Hierarchical Routing Protocols

The proposed Green Tree-Based distributed clustering routing protocol is compared with the existing Hierarchically structured routing protocols that are Leach, Heed, Pegasis and TBC to analyze the energy efficiency parameters, Network Lifetime, Network throughput and Average Residual Energy of the network, Packet Delivery Ratio and Packet loss rate respectively.

Tabke VI.

Comparison of Lifetime of the Network of GTBC with Leach, Heed, Pegasis & TBC

No. of Nodes (n)	**Lifetime of the Network**				
	Leach	**Heed**	**Pegasis**	**TBC**	**GTBC**
50	70	25	86	96	153
100	113	42	97	168	250
150	128	88	150	147	276
200	106	102	33	151	306
250	149	120	17	155	325
300	154	131	35	123	348

Table VII.

Comparison of Average Residual Energy of the Network of GTBC with Leach, Heed, Pegasis & TBC

No. of Nodes (n)	**Average Residual Energy of the Network (nJ)**				
	Leach	**Heed**	**Pegasis**	**TBC**	**GTBC**
50	0.2319	0.1850	0.0601	0.0018	0.1879
100	0.1589	0.0660	0.1280	0.0712	0.4284
150	0.1522	0.1245	0.1575	0.0069	0.2501
200	0.1893	0.1611	0.1656	0.0061	0.2776
250	0.2011	0.2284	0.1978	0.0312	0.2576
300	0.1854	0.1722	0.1689	0.0895	0.2028

Table VIII.

Comparison of Throughput of the Network of GTBC with Leach, Heed, Pegasis & TBC

No. of Nodes (n)	**Throughput of the Network**				
	Leach	**Heed**	**Pegasis**	**TBC**	**GTBC**
50	10131	9950	7753	4590	12926
100	16738	16054	6651	7585	17650
150	17096	15231	10817	11232	19536
200	21050	19241	5626	14747	21720
250	25074	22500	9021	18676	26626
300	26443	24680	14022	22149	31514

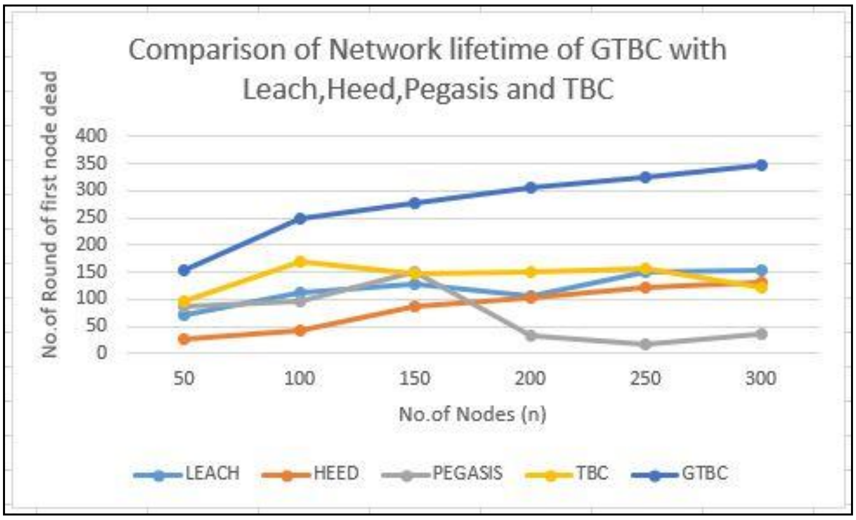

Fig. 6(a). Comparison of GTBC with Leach, Heed, Pegasis & TBC routing Protocol for Network Lifetime

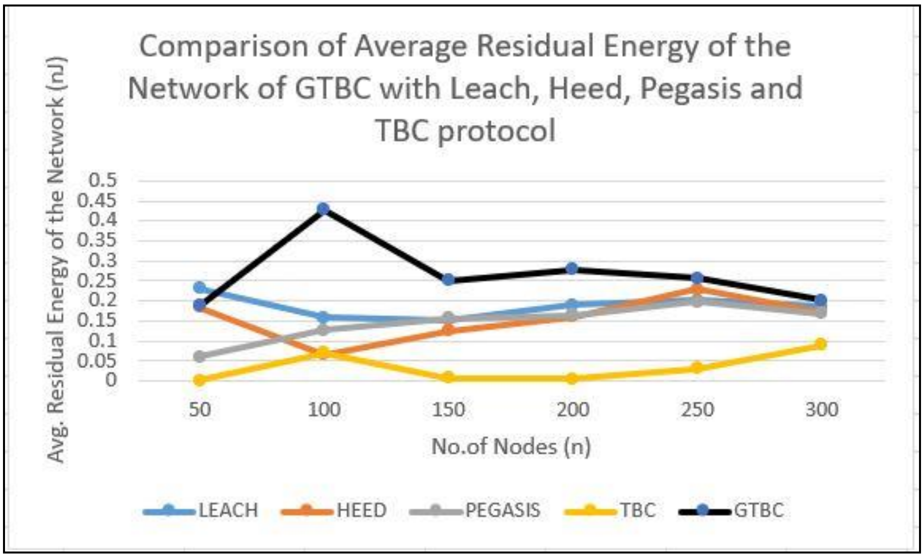

Fig. 6(b). Comparison of GTBC with Leach, Heed, Pegasis & TBC routing Protocol for Average Residual Energy of the Network

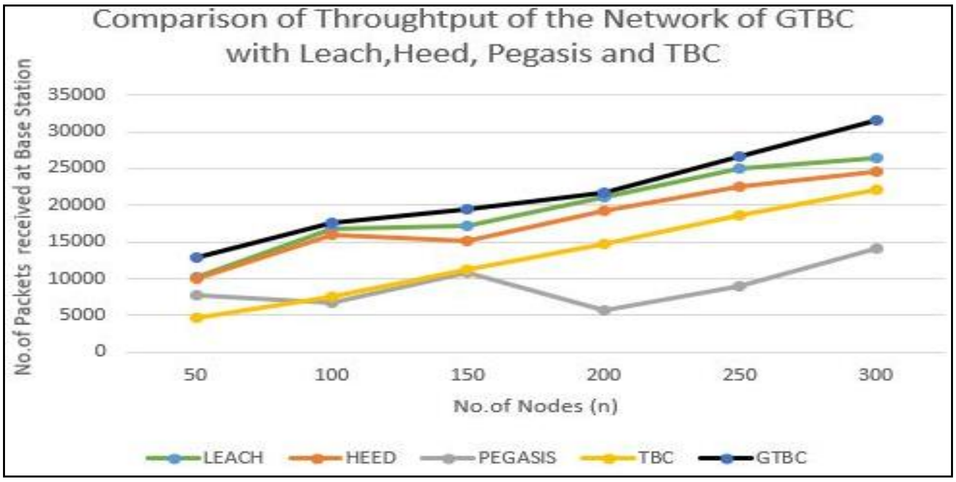

Fig. 6(c). Comparison of GTBC with Leach, Heed, Pegasis & TBC routing Protocol for Throughput of Network

Table IX.

Comparison of Packet Delivery Ratio & Packet Loss Rate of Network for Leach, Heed, Pegasis, TBC& GTBC

No. of Nodes (n=100)	Packet Delivery ratio (%)	Packet Loss Rate
Leach	92.98	0.070
Heed	89.18	0.108
Pegasis	66.51	0.335
TBC	63.20	0.360
GTBC	98.05	0.019

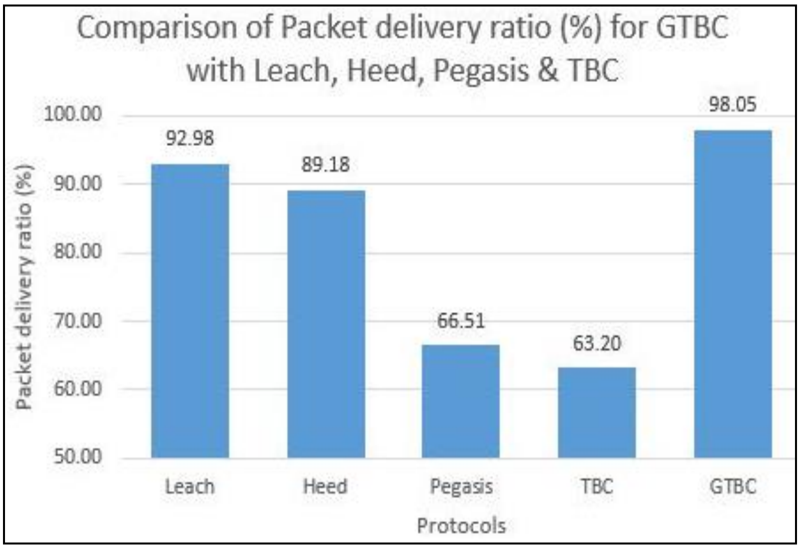

Fig. 6(e). Comparison of Packet Delivery Ratio for Leach, Heed, Pegasis, TBC, GTBC

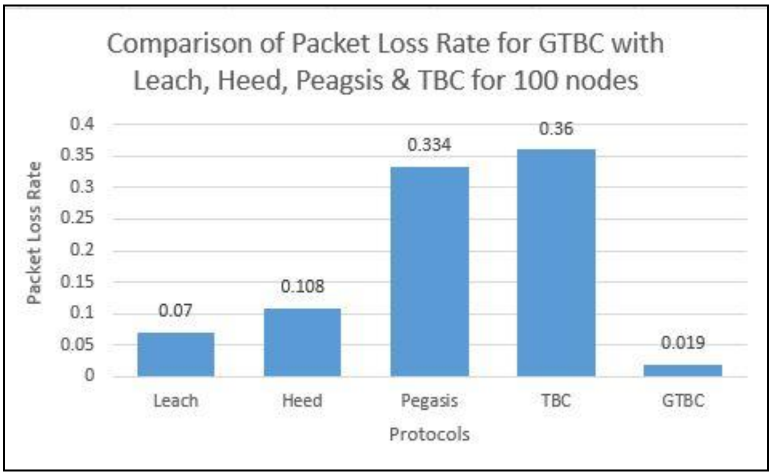

Fig. 6(f). Packet Loss Rate for Leach, Heed, Pegasis, TBC, GTBC

Conclusion and Future Work

Green Tree-Based Distributed Clustering Routing Protocol (GTBC) is an energy efficient routing protocol, where the average energy of the network is maintained well. As GTBC follows a hierarchical tree structure, load balancing issue is achieved successfully. GTBC can handle maximum level of 4 in the hierarchy for high throughput value for the network.

This paper highlights the important aspect of wsn, that is, an energy efficient routing protocol will perform best if it can manage the communication efficiently, and at the same time being fault tolerant, and can cater the messages from all the nodes in the network. Hence, GTBC protocol emphasizes on maintaining an optimal ratio of 1:3, for number of nodes to the network area, to establish a Green WSN. As per the analysis done in section 4 and 5, results show GTBC outperforms existing hierarchically structured routing protocols. With respect to the optimal ratio of 1:3 (number of Node deployed to the area of network), for a network of 100 nodes, Lifetime of the Network with 100 nodes for GTBC is 20%, 31%, 22%, 12% more than Leach, Heed, Pegasis and TBC routing protocols respectively. Average Residual Energy of the network is 21%, 42%, 35%, 42% more than Leach, Heed, Pegasis and TBC routing protocols respectively and similarly we found that the Throughput of the Network is 1%,2%,17%,15% more than Leach, Heed, Pegasis and TBC protocols respectively.

Furthermore, GTBC has the high ratio of packet delivery (98.05%) and Lowest packet loss rate (0.019) among the above stated protocols.

As Future perspective, the Green Tree Based Distributed Clustering Routing (GTBC) protocol can be further experimented for large scale wireless Sensor network with mobile sink and heterogeneous network configuration.

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