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Energy-Aware Duty Cycle Scheduling for Efficient Data Collection in Wireless Sensor Networks

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Abstract— **Wireless sensor networks include a large number of wireless Sensor nodes to gather the information from its environment. These sensor nodes for various applications are usually designed to work in conditions where it may not be possible to recharge or replace the batteries of the nodes. So the energy is a very precious resource for sensor nodes and communication overhead has to be minimized. All these constraints make the design of data communication protocols a challenging task. Recently, many routing protocols have been developed for Wireless Sensor Networks to improve its performance by overcoming constraints like Residual Energy, Communication Time, Communication Overhead and Energy Consumption. From the experimental studies it is revealed that our approach provides better energy efficient routing scheme when compared to L-PEDAP which outperforms the other recent protocols like PEDAP, PEDAP-PA and EESR in terms of Resource Utilization, Bandwidth and Communication Reliability. Our approach provides a duty cycle scheduling scheme so that the energy dissipation of the nodes could be minimized. The simulation results shows that this approach also provide a better Network Partition Time (NPT) and First Node Failure (FNF).**

Index Terms—— **Wireless sensor networks, link-cost, energy efficient routing.**

I. Introduction

A Wireless Sensor Networks (WSN's) is a wireless network that consists of distributed sensor nodes that monitor specific physical or environmental events or phenomena, such as temperature, vibration, sound, pressure, or motion, at different locations. The first development of WSN was first motivated by military purposes in order to do battlefield surveillance. The recent discoveries of alternatively less expensive sensor technologies, developments of energy efficient digital controllers and advancement in low-power radio frequency (RF) devices have given rise to the various applications of the Wireless Sensor Networks in environmental monitoring and control. With the help of these emerging technologies and advancement which has been the key factor towards the attraction of a great deal of research attention due to their high potential in wide range of applications.

Common scenario of sensor networks usually involves hundreds or thousands of low-cost, low-power sensor nodes deployed in a region from where information will be collected periodically. Wireless sensor nodes are called motes**.** The collected information can be further processed at the sink. So as to reduce the communication overhead and energy consumption of sensors while gathering, the data from same region can be combined to reduce message size. This is done by aggregating the data. Sensor nodes are inexpensive and equipped with limited battery power and it is constrained in energy. It is usually used for applications where it may not be possible to recharge or replace the batteries of the nodes. So maximizing network lifetime is one of the fundamental problems in wireless sensor networks. Some of the requirements for a routing scheme to be efficient includes that it should be distributed since a lot of energy is consumed while calculating optimum paths in a dynamic network and inform other nodes about the computed path in a centralized manner.

A study of earlier protocols showed that Power Efficient Data Gathering and Aggregation Protocol (PEDAP) [1] is a centralized routing protocol, when compared to LEACH and PEGASIS, PEDAP achieves improvement in network lifetime. The PEDAP is a minimum spanning tree (MST) based routing protocol where the node energy is directly related to its own degree and the distance to its parent. A new version of this protocol includes a power aware function called PEDAP-PA, where the author changed the cost of the link so that the remaining energy of the sender is also taken into consideration. As the link costs keeps on varying over time, the authors proposed re-computing the routing tree from time to time using a power-aware cost function, thus the load is balanced and lifetime is improved compared to the static version. Link cost is computed as the sum of transmission and receiving energy in PEDAP. In PEDAP-PA the cost is calculated by dividing the link cost of PADAP by the transmitter residual energy. The most important limitation of these two protocols is its centralized nature, thus it is not effective enough in load balancing. An extension of this work was done by Huseyin and Korpeoglu [2], they proposed localized power efficient data aggregation protocol (L-PEDAP). The main concern of this work was the lifetime of the network. In L-PEDAP the residual energy of both sending and receiving node is taken into consideration. The sparse topology is constructed based on local minimum spanning tree (LMST) and relative neighborhood graph (RNG) [3], [4]. Our work is divided into three phases: Topology and Route Computation, Duty Cycle Scheduling scheme and Route maintenance. An important problem is finding an energy efficient routing scheme for gathering all data periodically at the sink so that the network lifetime is prolonged as much as possible. The average energy, throughput, network lifetime, packet delivery ratio and drop comparison is made between PEDAP, L-PEDAP and our approach.

The remaining sections are organized as follows. Section II gives the survey of the related works for providing energy efficient scheme. Section III describes the problem statement and gives the system model. Section IV provides our approach for providing energy efficient routing for the wireless sensor network. The approach is divided into three phases first the topology construction and route computation, second phase includes providing the duty scheduling scheme and the final phase provides the route maintenance. Section V provides the performance analysis and simulation results of our work. Final conclusion of this paper is made in section VI.

II. Related Work

The data transmission in wireless sensor network is very expensive in terms of energy consumption, while compared with the energy consumption during data processing. The communication subsystem requires higher energy consumption than the computation subsystem [5]. The sensors have limited power and sensing ranges. Thus a routing protocol is required which effectively coordinates the activities of individual nodes in the network so as to achieve global goals. Hence network lifetime is totally dependent on the routing protocol. Several routing protocols have been developed for data gathering in which data aggregation is not involved here, shortest weighted path approach is adopted having metrics like reluctance, transmission power, hop count, and energy consumption metrics etc. There are also several protocols for data gathering which includes the concept of data aggregation. Most of these include a centralized approach which assumes that all the sensor nodes are in direct communication range of each other and the sink. A Low Energy Adaptive Clustering Hierarchy Protocol (LEACH) was proposed by Heinzelman, Chandrakasn, and Balakrishnan [6]. In LEACH sink is fixed and located far from the sensor nodes and the nodes are homogenous and energy constrained. In this one node is called as cluster-head which acts as a local sink. The high-energy cluster-head is rotated randomly so the activities are equally shared among the sensors and equally consumes the battery capacity. It also performs data fusion. The concept behind data fusion is compression of data when data is sent from the clusters to the sink. By this way it reduces the energy dissipation and increasing the system lifetime. Since the protocol relies on randomization, it is far from being optimal and also when the sink is far away from the Cluster head it requires high amount of energy for transmitting the data.

Lindsey and Raghavendra [7] proposed a chain-based power efficient protocol called PEGASIS (Power Efficient Gathering Sensor Information System). This protocol is based on LEACH, in this protocol all the nodes have the capability of transmitting data to the sink directly and each node has the information about all other nodes. Here we assume that all the sensor nodes have the same level of energy and they are dying at the same time. Chain creation is started at a node far from sink because all nodes are fixed and each node has a global knowledge of the network. Each node sends and receives data from the closest node of its neighbors. The nodes use the signal strength to measure the distance from the neighbor and adjust the signal strength to locate the closest node of its neighbor. To make a communication in both sides the node passes token through the chain to leader. While constructing the chain node fuses data with their own data. From the chain the node randomly choose the node to transmit the aggregated data to the sink. The path to the sink was constructed by chain which consists of those nodes that are closest to each other. The data which is in the aggregated form is send to the sink by the leader. By this way PEGASIS outperforms LEACH by eliminating the overhead introduced due to the dynamic cluster information, limits the number of transmission and minimizes the sum of distances. The drawbacks of these protocols are at any time each node requires the global knowledge about the network.

The PEDAP was proposed by Tan and Korpeoglu, which is also a centralized routing protocol like LEACH and PEGASIS. This approach achieves improvement in network lifetime compared to its alternatives. Here the packets are routed on the edges of an MST. In this protocol the link costs are calculated and the minimum energy cost tree is obtained using Prim's MST algorithm. The lifetime of the last node in PEDAP is increased by minimizing the total amount of data gathering in each round. Here, the link cost is computed as sum of transmission and receiving energy. The authors propose a new power-aware version of this protocol called PEDAP-PA. It balances the energy consumption at each node which is done by considering the cost by dividing PEDAP edge cost with transmitter residual energy. Hussain and Islam proposed a multipath routing protocol called EESR (Energy Efficient Spanning Tree Based) which is similar to PEDAP-PA, this protocol provides better lifetime using small number of routing trees when the network is dense.

A robust, localized and self-organizing protocol called L-PEDAP (Localized Power Efficient Data Aggregation Protocol) was proposed by Huseyin and Korpeoglu. L-PEDAP was developed based on LMST and RNG topologies which can approximate minimum spanning tree (MST) using only position or distance information of one hop neighbors. It tries to combine the feature of Minimum Spanning Tree (MST) and shortest weighted path gathering algorithm. This method computes the cost of a link using the remaining energy of both sending and receiving node based on its remaining energy rather than the prior method which includes the calculation of the cost based on the remaining energy of sending node alone is proposed. It saves a vital amount of energy compared to the other prior methods. Also, it provides an energy efficient routing scheme for gathering all data at the sink periodically so that the lifetime of the network is prolonged as much as possible.

III. Problem Statement And System Model

A. Problem Statement

Sensor networks usually for various applications involve deployment of hundreds or thousands of sensor nodes to a region from where information will be collected periodically. Thus the sensor networks will need to sense their nearby environment and send the information to a sink which is not energy limited. The information that is gathered at the sink can be further processed for end-user queries. For reducing the communication overhead and energy consumption of sensors while gathering the information, the received data can be combined to reduce message size. The best way for doing that is aggregating the data. Another way is data fusion which can be defined as producing a more accurate signal by combining several unreliable data measurements.

An important problem studied here is to find an energy efficient routing scheme for gathering all data at the sink periodically so that the lifetime of the network is prolonged as much as possible. The reachability of a sensor network can be shown using a visibility graph G = (V, E), here V represents the set of sensor nodes and the base station, and E represents the set of edges $e_{ij,}$ where the distance between the node I and j is smaller than the maximum transmission distance R. For the application of these networks we consider that for this network model, at each round of communication sensor nodes periodically sense the environment and generate data. For this scenario the routing plan should be able to make each sensor node receives the data from its children, which thereby aggregates them into one single packet, and then sends the packet to the next node on its way to the sink. Some common examples of such a scenario include event detection systems like fire, intrusion etc.

For the sensor networks the network lifetime can be defined in two different ways. One of the definitions can be stated as the time elapsed in terms of rounds until the first node depletes all of its energy. This definition is appropriate to measure the load balancing feature of a routing algorithm. Thus, if the energy is balanced well among the nodes, the time until when first node drains out its energy will be maximized. The other definition for the network lifetime can be stated as the time elapsed until the network is partitioned so that the sensor nodes that are alive cannot transmit their data to the base station. This definition is appropriate from which, one could measure how the bottleneck nodes are handled in the network. If the network gets partitioned quickly, that would mean that the energy expenditure of the bottleneck nodes is not managed well. Thus we need to consider both these definitions for designing the routing protocol and also the routing scheme should include a method for handling the node failures and the addition of new nodes.

B. System Model

Different models have been proposed for showing the energy consumption of a node. We use the first order Radio model proposed in [8]. The Energy Consumption Model is used to calculate the link cost and the energy consumed by each node and the Euclidean Distance formula is used to calculate the distance between the nodes. The energy consumed during the transmission and reception of packets is given by the below formula.

$$E_{tx} = ak + bkd^n \text{ , } E_{rx} = ck$$

Here, E_{tx} represents the energy consumed to transmit a k bit packet to a distance d. E_{rx} represents energy consumed to receive a k bit packet, "a" and "c" denotes the energy consumption constants of the transmit and receiver electronics, respectively, and "b" is the energy consumption constant for the transmit amplifier. Various studies have been made based on the literature for this model. Heinzelman et al. [8] which shows the use of this model, assuming that a = c = 50nJ/b, b = 0.1 pJ/b/m^2, and n = 2. On the other for energy constrained node, [9], (a + c) = 2 X 10^8, b = 1, and n = 4. The cost of transmission and reception of packets is given by the below formula. The total energy cost is represented as C_{ij} which can be given as follows:

$$C_{ij}(k) = ak + bkd^n_{ij} \text{ , if "j" is the sink,}$$

The above equation represents total energy cost of transmitting a "k" bit packet from a node "i" to a neighboring node "j". As there is no limitations of energy in the sink the expression can be written as follows:

$$C_{ij}(k) = (a + c)k + bkd^n_{ij}$$

We consider that for our network we are routing the data packets on a tree rooted at the sink. Thus, a sensor node will receive data from several child nodes and transmit it to a single parent after aggregation. Thus the total energy consumed at a node i for receiving a k bit packet from its children and for sending the packet to its parent is given as:

$$\omega_i (k) = \delta_i^+ ck + ak + bkd^n_{ij}$$

"δ_i^+" represents the in-degree of node "i" in the given routing tree. Thus the two factors that affect the energy consumption of a node are the in degree of a node and the nodes distance to its parent. The Lifetime of a node "i" (L_i) and the Lifetime of the network (L) can be given as $L_i = E_0 / \omega_i$ and L = min (L_i) respectively.

IV. Proposed Methodology

Our aim is to efficiently compute the routing path so as to obtain a superior network lifetime. The approach can be divided into three phases: Topology and Route Computation, Duty Cycle Scheduling scheme and Route maintenance.

A. Topology and Route Computation

Our aim is to efficiently compute the routing path so as to obtain a superior network lifetime. We combine the features of MST and the shortest weighted path method to develop the routing path. A sparse and efficient topology is created using the LMST and RNG topology. The relative neighborhood graph (RNG) is an undirected graph defined on a set of points in the Euclidian Plane by connecting two points *p* and *q* by an edge whenever there does not exist a third point *r* that is closer to both *p* and *q* than they are to each other. It contains (u, v) if and only if there isn't any node w within the intersections of two open disks centered at u and v with radius |uv|. Here node w within the intersections of two open disks centered at u and v with radius |uv|. Here the degree of a node is n-1. RNG is also direction based. Here also the node 'u' grows its transmission power until it finds a neighbor 'j' which is then added to its neighbor list. It is a distributed protocol which reserves connectivity and satisfactory performance in terms of network diameter. It has low fault tolerance and high communication overhead. In LMST every node collects information about one hop neighbor is then computed and forms a set. MST is then calculated using Kruskals algorithm or Prims algorithm. It uses a tree based approach. Degree of each node is 6. LMST-builds MST-like topology, where the traffic load and the transmission power distributions for each node is greatly unbalanced. Thus the energy consumption of node is badly unbalanced so that the network lifetime is limited. LMST delivered most amount of data .The main drawback is that it has low fault tolerance and high communication overheads. Even though the RNG and LMST structures are defined based on euclidean distances, they both can be used with other link cost functions as long as the functions are symmetric. The aim of this phase is determining the parent and the child nodes. The pseudo code for this is given below:

```
Algorithm 1
Send HELLO message
Collect HELLO messages for t_h
Reset Parent (π to null)
Compute neighbors on sparse topology
while ROUTE-DISCOVERY packet RD
received in t_discovery do
if update require for RD then
Update parent (π to source (RD))
Broadcast ROUTE-DISCOVERY
end if
end while
inform π to construct its child-list
```

Initially, the nodes and the sink are not aware about the environment in which they are deployed. In the setup phase, all nodes and the sink broadcast HELLO messages using their maximum allowed transmit Power, this message includes information of its location and remaining energy. The route computation is done via a broadcasting process which starts at the sink node where the sink initiates a ROUTE-DISCOVERY packet in order to find and set up the routes from all sensor nodes toward it. Sensor node receiving a ROUTE-DISCOVERY packet, broadcasts the packet to all its neighbors on the computed topology if it updates its routing table. In this way, the routing tree rooted at the sink is established over the sparse topology. Each ROUTE-DISCOVERY packet has three fields: a sequence ID, an optional distance field and an optional neighbor list field. Sequence ID is increased when a new discovery is initiated by the sink, distance field shows the cost of reaching the sink and neighbor list shows the list of neighbors of the sending node in the chosen topology.

The selection of the parent node is based on three methods: First Parent, Minimum Hop Method and Shortest Weighted Path Method. The algorithm used for our approach is shown below:

```
Algorithm 2
set Route-discovery packet RD
while(RD received)
if(seq-no==1)
set neighbor as parent
end if
end while
Minimum hop path method (MH)
set hop-count previous-req-hopcnt
set Route-discovery packet RD
while (RD broadcasting)
if(current-req-hopcnt<hop-count)
set neighbor as parent
end if
end while
Shortest weighted path method (SWP)
set cost previous-req-hopcnt
set Route-discovery packet RD
while(RD broadcasting)
if(neighbor-cost<previous cost)
set neighbor as parent
end if
end while
```

Link-Cost

Node	Neighbor	Distance	Link-Cost
1	2	159	0.00591054
1	3	104	0.00606168
2	1	159	0.00637843
2	3	161	0.00657237
3	1	104	0.00638788
3	2	161	0.00656327
3	4	178	0.00678094
4	3	178	0.00687263
4	5	98	0.00652555
4	6	135	0.00651805
4	7	239	0.00705306
4	8	204	0.00714112
5	0	201	0.00361633
5	4	98	0.00488486
5	6	103	0.00554556
5	7	207	0.00640949
5	8	206	0.00683646
5	28	238	0.00722562
5	29	168	0.00705532

Table I: Link-cost

The link-cost is computed as shown in Section III, the table above shows the link cost for the first 5 nodes. Here, we can observe that link cost increases after the first packet is send from node 1 to node 2, as some amount of energy is consumed for sending the packet at the first time. After computing link cost a set of path to reach destination node can be found out of which the best path can be selected based on the cost (C_{ij}).

B. *Duty Cycle Scheduling Scheme*

After the parent and child nodes are determined, we need to find the vertex nodes i.e. the key nodes from which the packets are forwarded to the sink. This can be done as follows: first the routing tree is formed to reach the base for all the nodes as shown below:

Source	Dest	Route
1	0	3 4 5
2	0	3 4 5
3	0	4 5
4	0	5
5	0	5
6	0	5
7	0	29
8	0	5
9	0	8 5
10	0	7 29
11	0	9 8 29
12	0	9 8 29
13	0	12
14	0	12
15	0	16 17
16	0	17
17	0	17

Table II: Route to Sink

From the above table we can observe that the node 5 act as the key node to forward the packet to the sink node from various nodes, we can keep a threshold value for selecting the vertex nodes based on the network density. After the vertex nodes are found, we can do a network partition based on the vertex node. Then a time slot assignment can be done as follows:

Algorithm 3

for
time slot for a node "t_n"
the number of child node "N"
(Depending on the partitioned network)
time slot for vertex node (V) t_v.
then $t_v = N * t_n$

The other usual schemes include a simple one variable linear table i.e. for a node having degree 6 can be assigned 6 as its time slot [10], [11]. Other schemes require the parent node to distribute time slots for all the child sensor nodes. This again increases the number of overheads thus draining off the energy. With our approach the parent node does not have to distribute its time slots to all the member sensor nodes. If the parent node does not contain any child node it just notify the sink and set its time slot as 1.

If the parent node has only one single child then set its time slot same as the child node and for a parent node which contains more than one child node then the time slot will be the sum of all its child nodes.

C. *Route Maintenance*

Thus after an effective routing path is formed we can go for the data gathering process can be carried out where

Each sensor nodes senses its nearby environment and generates the data to be sent to the sink. But before sending the data to the sink node the node waits for all the data from its child nodes and combines its data and then forwards it. Thus at each node the data gets aggregated to the way to the sink. Using this method the sensor only transmits its data once in a round saving the energy.

In this approach route maintenance is required because here we are using a dynamic link cost function, so the link cost has to be updated after a certain interval. Also in the network we can have node addition or node failure. Node Failure can be handled effectively due to energy depletion as the node can predict that it will die soon i.e. when its energy reduces below the preset threshold value then the node sends a broadcast BYE message using maximum allowed transmission power. The nodes which receive this broadcast message will immediately update their table. There can be a case where the nodes cannot reach the sink because of the energy depletion of their parent node. For this child nodes of the failed parent can enter the parent-discovery phase by broadcasting a special message PARENT-DISCOVERY to its neighbors on the tree. The receiver of that special message will resets its routing table and broadcasts the packet to its neighbors, if the sender is its own parent on the way to the sink. If a PARENT-DISCOVERY packet is received by a neighboring node of the sender which has a valid parent in the tree, then the receiver constructs a new ROUTE-DISCOVERY packet. For a newly deployed node, it first sends a Hello packet to its neighbor; the nodes that receive its message update their local structure and inform the newly deployed node about their existence and their location information by replying a Hello message. The nodes that update their local structure send back a ROUTE- DISCOVERY packet including their costs to the newly deployed node. The new node selects the node as its parent which provides an efficient route to the sink and then broadcast this information by a new ROUTE-DISCOVERY packet.

V. PERFORMANCE ANALYSIS AND SIMULATION RESULTS

For our scenario we consider that the sensor nodes are homogeneous and energy constrained. The sensor nodes and sink are stationary and are randomly deployed. Every node knows the geographic location of itself by means of a GPS device or some localization techniques [12], [13]. Each node senses its nearby environment periodically and sends it to the sink for each round. The simulation was done using the ns2 tool. The network model consists of 50 nodes, which are deployed randomly. The propagation model is taken as a Two Ray ground model, with the energy of a node as 5 Joules. The Fig 1, below shows the network model, here the sink node is represented as "0"and VN represents vertex node.

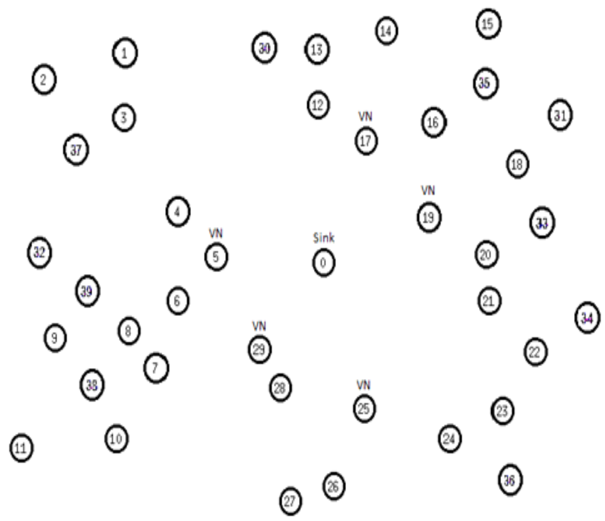

Fig 1: Network Model

Fig. 2 shows the graph for our proposed algorithm. The comparison of the average energy of proposed algorithm which is represented as "Energy Aware" in the graph shown in Fig. 3 with L-PEDAP and PEDAP is done. We can observe

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from the graph that as only the residual energy of the sending node only taken into consideration the energy gets depleted rapidly in PEDAP routing protocol, whereas for the L-PEDAP routing protocol which takes into consideration the residual energy of both the sending and receiving node the energy depletion is far more stable than the earlier approach. Our proposed scheme provides better result when compared with the L-PEDAP.

Fig. 4 shows the throughput comparison of the earlier schemes PEDAP and L-PEDAP with our scheme. The Throughput can be defined as the the average rate of successfully transmitted data packets over the communication channel. The throughput is measured in bits per second and in data packets per second. The system throughput is the sum of the data rates that are delivered to all stations in a network. We can observe that the PEDAP protocol takes less communication time to forward the data packets to the destination thereby having an early rise in throughput, but eventually fails to provide better results with time. From the graph we can observe that our scheme provides a better result when compared with the other two.

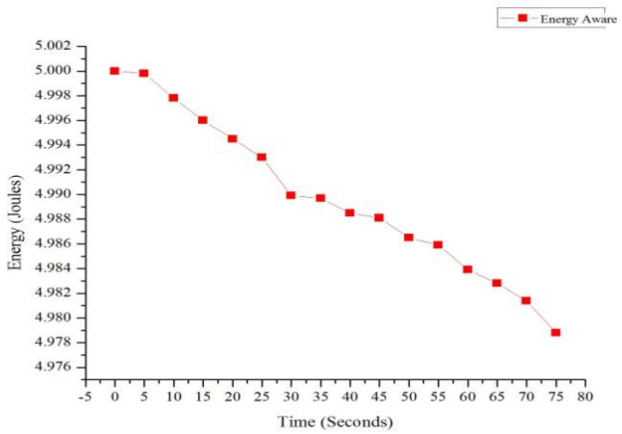

Fig. 2 Average Energy of our approach

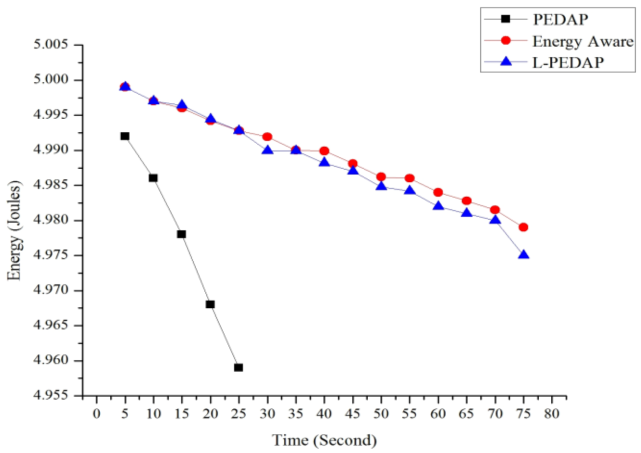

Fig. 3 Average Energy Comparison

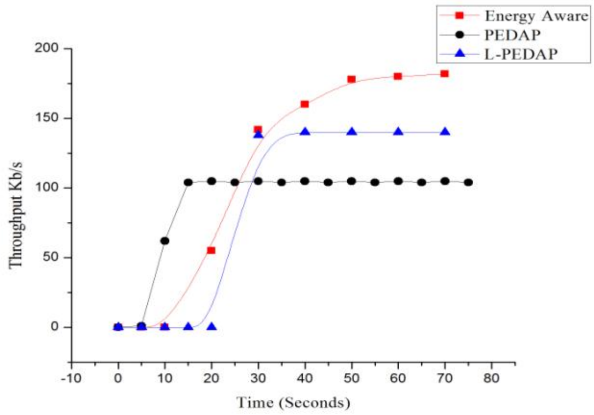

Fig. 4 Throughput Comparison

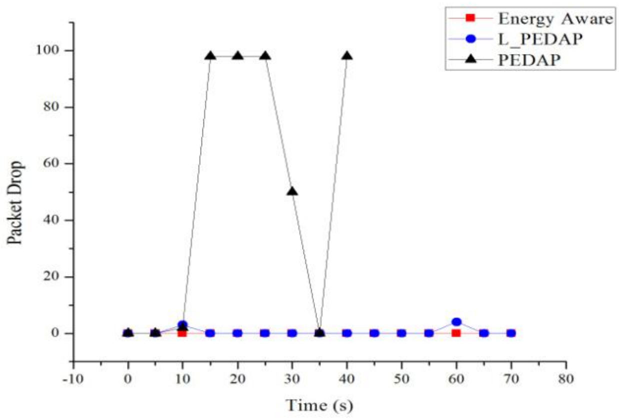

Fig. 5 Packet Drop Comparison

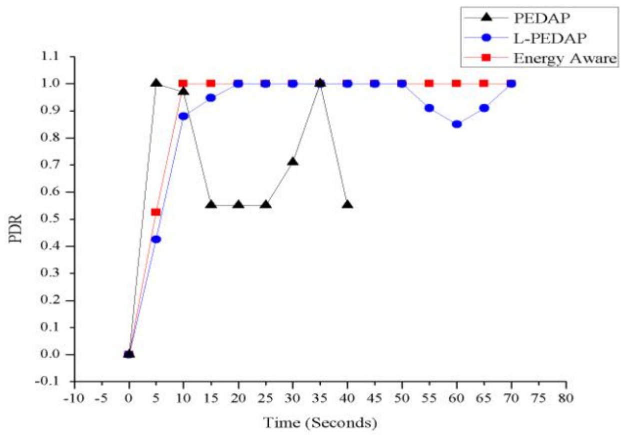

Fig. 6 Packet Delivery Ratio Comparison

The Fig. 5 shows the drop comparison between the three protocols. Fig. 6 shows the packet delivery ratio comparison which is defined as the ratio between the number of packets received by the destination and the number of packets generated by the application layer sources of the accepted calls. Packet delivery ratio was plotted based on the number of packets received at the base station. Here from the simulation result it is verified that L-PEDAP scheme provides a better packet delivery ratio compared with PEDAP-PA. Our scheme provides better stable result. Also as a dynamic method is used here it increases both FNF and NPT timing especially in higher densities.

Thus from the experimental results, it is revealed that our proposed algorithm provides better results compared to

L-PEDAP, PEDAP in terms of Resource Utilization, Bandwidth and Communication Reliability.

VI. CONCLUSION

The applications of Wireless sensor networks have a main constraint on its energy consumption. In this paper a new energy-efficient routing approach which combines the desired properties of minimum spanning tree and shortest path tree-based routing schemes is developed. The proposed scheme uses the advantages of the powerful localized structures such as RNG and LMST and provides simple solutions to the known problems in route setup and maintenance because of its distributed nature. This paper also compares our approach with the effective routing protocol like L-PEDAP and its ancestor PEDAP. The proposed algorithm is scalable, robust and self-organizing. This algorithm is appropriate for systems where all the nodes are not in direct communication range of each other.

Through simulations it can be observed that the proposed algorithm outperforms the shortest weighted path-based approaches, and can achieve 90 % of the upper bound on lifetime. The period of the re-computation is an important factor for achieving long lifetimes. This dynamic method tends to increase both FNF and NPT timings especially in reasonable densities for sensor networks. It is also observed from our results that the PEDAP protocol achieves less Communication Time to forward packets to destination. However, it fails to provide an energy efficient routing scheme and our approach provides improved results in terms of Resource Utilization, Bandwidth and reliability.

The concept can be extended by adding some security concepts which thereby increases the efficiency of the protocol. The problem of node failure can also be addressed in case of no alternative path find to send data to Base Station. In those cases the data collection can be done by a mobile node which will be in the surrounding region of base station. It will serve as a Best carrier from Base stations to child nodes of which the parent got failure.

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