An Investigation of Energy Efficient Routing and Optimization Techniques in Wireless Sensor Networks

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***Abstract*— Energy efficiency is the most challenging topic in Wireless Sensor Networks (WSN). Because of the increasing demands of various applications, and the constraints of energy, memory and computational power of the WSN nodes, many studies have focused on these areas in recent years. The current challenge in wireless sensor networks is high data delivery ratio with low energy consumption. Since radio transmission and reception uses a lot of energy, energy saving is a major issue in wireless sensor networks. Ongoing researches include routing protocols design which need less energy and extending networks' lifetime as a result. For several applications, energy replacement is very costly. Energy consumption of wireless sensor networks allows using of nodes which are able to gather energy from the environment. We will propose a new routing algorithm to optimize the energy efficiency by reducing the number and total transmissions distance in order to save energy. We exclude the familiar optimization approaches and analyze distinct metric specific optimizations based on link failure, load balancing and distance. In medium and large scale, wireless sensor networks will have efficient energy.**

***Index Terms*— Energy Conservation, Energy Efficient, Link Failure, Link Recovery, Load balancing, Routing Protocols, Wireless Sensor Networks.**

I. INTRODUCTION

A wireless sensor network (WSN) is composed of different types of sensors which are used to send and receive data through the wireless network. Since sensors may be deployed randomly, WSNs are also different from traditional wired data communication networks because the sensors are densely deployed, and nodes may be easily damaged in some hazardous environments. The sensor topology may change from time to time, nodes may fail or be moved, and thus the links between nodes are subject to change. Therefore, maintaining a stable wireless sensor networks is a challenging task and it requires a mature monitoring and control strategy. Wireless sensor network applications are very board ranging from smart grid, military, health care, tracking, civil, industrial sectors, environmental monitoring and control. In most applications, a wireless sensor network may consist of hundreds or even thousands of sensor nodes [1].

Sensors are built using micro electro mechanical systems which has led to develop limited resources nodes. WSN finds its application in varied fields like surveillance, habitat and industrial monitoring, health sciences, etc. Sensing devices form the basic operational unit of the network that is self-battery powered with limited life time. Sensor devices utilize energy for transmission, reception, routing and sensing information that is shared with neighbors or a common base station. Frequent energy utilization leads to network communication degradation due to drop outs, dead nodes or link failures and limited energy efficient routes and network lifetime retarding [1, 2]. The fundamental approach is carried out using effective routing methods that relies on energy constraint of the devices. Energy constrained routing is

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considered to handle energy utilization of the devices through optimal decision making process [3]. Many algorithms have been proposed to regularize energy utilization that ultimately aims at prolonging network lifetime.

A general classification of energy consumption model in WSNs with node concentrated energy conservation techniques have been proposed earlier. Besides, energy optimization in WSN is a diverse approach depending upon the floor plan implemented and the purpose of the technique.

Existing major routing protocols for wireless sensor networks include LEACH [1], Directed Diffusion [2], Energy Aware Routing [3], Rumor [4], Braided [5], and MESH etc. Among the above-mentioned multi-hop protocols, only MESH is explicitly claimed as multi-path routing. Energy aware routing and Rumor routing are single-path ones. Generally, single path routing is simple and consumes less energy than multi-path routing. However, a single path failure will cause a break of transmission and hence completely destroy the delivery [2].

Consequently, more and more researchers are resorting to multi-path routing for delivery success. For instance, sending the same data packet along two fully node-disjointed paths (if they exist) almost doubles the delivery ratio. Using n-fully node-disjointed paths (n>2) can further increase the delivery ratio in approximate proportion to n. Moreover, if we relax the requirement for disjointed-ness, partial or interwoven multi-path routing schemes have shown higher resilience to single path failure theoretically and experimentally [6]. However, determining the width of multi-path routing (for instance, the value of n in n-fully node-disjointed paths) before transmission is not so easy, because sensor network topologies often change unpredictably due to sudden node malfunction, environmental physical damage and impulsive strong external interference. Large 'n' values can ensure success of deliveries, but may cause unnecessary energy waste. In contrast, a small 'n' value saves energy, but may not guarantee the highly demanded delivery ratio. Another disadvantage of a large 'n' value is that: the larger the 'n' value is, the more traffic is generated for one data packet delivery, which may cause network congestion. Given that the simplest CSMA scheme is used at the MAC layer, more traffic means a longer back off delay waiting for transmission and more collisions induced in the wireless channel. Unless the source nodes are notified of path quality in a certain way, it is impossible to adjust the optimal k value dynamically to adapt to unpredictable network topology changes.

The rest of this paper is organized as follows: in Section II, current work in the area of energy efficient multipath routing protocol with guaranteed data delivery for WSN is reviewed. In Section III, the energy optimization techniques which in this paper we survey three major energy optimization techniques viz, Link Failure and Recovery techniques, Load Balancing with energy constraint and Distance based energy optimization. Section IV provides a comparative analysis of our approaches with respect to the network performance metrics. Finally, Section V concludes the whole work. And Section VI gives the references.

II. Proposed Model

Certain assumptions are made to design the proposed protocol.

1) All the nodes need not know topology of the network and, synchronization amongst all nodes is not required.

2) Each node is given a node ID and only has the addresses of the nodes that come under its range.

3) WSN consists of several sensor nodes deployed randomly in a region with a single sink.

4) Source node use multipath routing schemes to distribute the traffic.

This chapter explains the concept of proposed Energy Efficient Routing protocol with a Guaranteed Delivery with an example.

A. Network Environment

A Wireless Sensor Network consisting of N nodes is generated by random placement of the nodes within the given area. Each of these nodes has the fixed communication range and has fixed buffer and energy availability. All the nodes are static. Fixed sink is placed at one of the corners of the network. All the sensor nodes are aware of the sink position and the distance between itself and the sink. Multi-hop routing is considered.

B. Energy Efficient Routing with Guaranteed Delivery Protocol

In this proposed Model, buffer is considered to be one of the important parameter for media access. Buffer is used for storing the data that has been sensed. Sensor nodes will have to act as routers, and will have to receive packets from its neighbors to forward to the sink due to multi-hop nature of sensor networks. This traffic will increase the delay variation that packets incur while traveling on different routes and even on the same route. Hence, the mechanism employed for energy efficient routing with guaranteed data delivery in proposed protocol is mainly based on the energy level and amount of buffer occupied at each sensor nodes.

Whenever a node has collected important data to be transmitted, it broadcast the buffer size, i.e., amount of occupied buffer along with its node id, which is considered as beacon bit. Similarly all other nodes which have detected the event transmit a beacon. These nodes have now entered the competition. The nodes under competition will compare the buffer sizes and its energy level to the threshold energy level. If their buffer size is less than others, they come out of competition, i.e., the node with higher data to be sent, will have access to the channel. This is denoted as active node.

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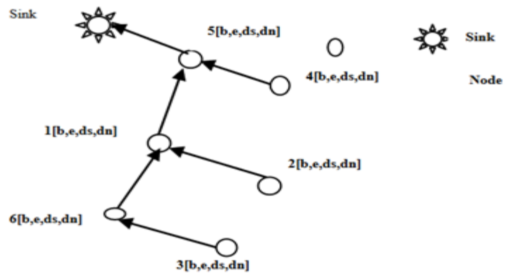

Fig. 1. Media access.

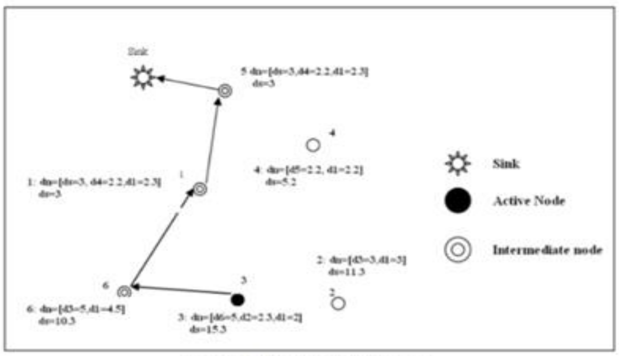

Fig. 2. Routing from node 3.

Fig. 1 shows three active nodes: 1, 3, and 5 with their respective occupied buffers and energy level. Neighboring nodes for 1 are 3, 4, 5, and 6. Neighboring nodes for 3 are 1, 2, and 6. Neighboring nodes for 5 are 1, 5, and sink. These nodes send beacon to their neighboring nodes as shown in the figure. In the above example, the nodes which are not active remain quite. Amongst these three nodes, node 3 has highest buffer and hence it is given chance to access the media. For the purpose of routing, intermediate nodes are selected by comparing their energy level with threshold energy, if the node has maximum energy it is selected for routing. For routing, each node will have the addresses and distances of the sink and their neighboring nodes. Packets are marked by their originators with their destination's locations. As a result, a forwarding node can make a locally optimal, greedy choice in choosing a packet's next hop. Specifically, if a node knows its radio neighbor's positions, the locally optimal choice of next hop is the neighbor geographically closest to the packet's destination. Forwarding in this regime follows successively closer geographic hops, until the destination is reached. Thus form the path list of the nodes to be followed.

Fig. 2 shows the routing from node 3. For node 3, the intermediate node is 6, as it is having maximum energy and it is in range to 3 and it is nearest to sink and farthest from itself. Following the same method, node 6 finds node 1 as its next node, and node 1 finds node 5 as its next node, and node 5 is having sink in its range, and finally the sink is reached by following the path as [3 to 6 to 1 to 5 to sink]. This is the setup of path list to be followed by the active node. This proposed work supports participation of multiple numbers of nodes for data transmission at a time if they are far away, or non-interfering with each. Suppose there are 'n' nodes in a given part 'Y1' of the whole area 'Y' and 'x' out of 'n' are interested in transmitting after event detection. Applying the above theory of media access, out of 'x' a single node will be selected as active node. In this way at a different corner part 'Y2' of the given area one more active node will be selected. And applying the same, multiple active nodes can be generated and all these active nodes will participate in transmission. All these active nodes will find their path list. The nodes in the path list are intermediate nodes. Initially these will be in sleep mode. Once they get into the path list, the active nodes will send a flag bit to wake (switch ON) them up. Technique which uses multiple radios, a low-power radio that is used exclusively to wake up the high power radio can also be used to wake these nodes. Buffer in these nodes may be used for self and are used for routing also.

III. Energy Optimization techniques

A. *Optimization Techniques based on Link Recovery*

A routing scheme based on genetic algorithm (GROUP) was proposed by Chakraborty *et al.* [3]. The basic genetic algorithmic operations like crossover and mutation are implied in selecting energy efficient node for relaying among the available population.

Chen *et al.* [4] proposed a genetic algorithm that selects effective paths with minimum energy consumption. Selective nodes are preferred from the population of that is obtained as a result of free search model.

An Energy Efficient Routing Protocol (EERP) is proposed by Ghaffari [5] that routes to the sink node considering distance metric. The authors employed A-Star algorithm to select shortest path through which the base station announces the schedule for each node communication. The schedule is to distribute load throughout the network depending upon the residual threshold of each node.

An Opportunistic routing protocol called EESOR is proposed by Devi *et al.*, [6] in which the nodes select forwarders based on periodic routing table update. Nodes update the position and distance of their neighbors through the periodic information and sort their forwarders in descending order for relaying.

Sarma *et al.*, [7] proposed a hierarchical cluster based Energy Efficient Reliable Routing to prolong network lifetime with higher fault tolerance capacity. Multihop energy dissipation is minimized using synchronized cluster head communications. The routing decisions are carried out using the base station so as to minimize overloading of the nodes.

A cuckoo search based multipath routing is proposed by the authors in [8] to relay packets to the destination. This approach minimizes the impact of route failures and aids neighbor selection based on higher energy of the nodes.

LeDiR proposed by Abbasi [9] is designed to detect route

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failures through a subordinate node called actor. Actors identify faulty links using depth first search. The relaying neighbors checks for failure prone nodes using periodically transmitted beacons.

Rao and Singh [10] designed a variant of AODV (AODV nthBR) that supports backup path routing at the time of link failure. The neighbor is selected based on distance and energy. The process is repeated till the destination node is reached. The new neighbor path serves as the backup route for transmission.

A Check Point Route Recovery Algorithm (CPRAA) is designed by the authors in [11] to prevent link failures. CPRRA employs actuator nodes to monitor the energy levels of the nodes. The actuator node recommends re-routing if a nodes' energy is below threshold.

B. *Energy Efficient Optimization with Load Balancing*

Jain *et al.*, [12] designed a conservative energy routing for the intermediate nodes between the source and sink. The nodes with higher energy consuming threshold are discarded from handling data to the sink. A node with minimum energy utilization is overloaded till it drops to the threshold. The process is carried out till a minimum count of neighbors is available to route to the destination.

Lee and Chang [13] proposed LEACH-ERE for optimal cluster head selection process for conserving energy. A node with threshold greater than the random threshold generated by the node is selected as a cluster head. This method improves network lifetime by tasking minimum nodes for selection and transmission process.

A hybrid compressive sensing based cluster approach is designed by the authors in [14] to minimize the number of transmissions at the time of cluster modification. More over the cluster approach is intended to prolong network lifetime by region dividing process that helps to conserve energy in an irregular network.

Particle Swarm optimization based clustering approach called PSO-ECHS is proposed by Rao *et al.*, [15]. This approach considers residual energy and distance at the time of selecting neighbors. The node with higher residual energy and appreciable shortest distance is preferred for transmission.

Adaptive Load Balancing Routing- Rainbow is a cross layer load optimization technique proposed by Petrioli *et al.* [16]. This optimization technique employs duty cycle for node life time prolonging and distributes load over selective relay nodes in the network. This method minimizes energy utilization and overhead.

Zhao *et al.*, [17] defined a triple layer framework for load balancing and energy optimization in WSN. The mobile collector agent in this approach works in a cooperative manner with Load Balancing Clustering Algorithm to prolong the network lifetime and to improve data collection rates. The combined approach minimized drops due to overloading.

Energy Balanced Routing Protocol (EBRP) is designed by the authors in [18] to improve energy balancing in networks with higher data concentration. The proposed routing protocol verifies a node on its distance level, density and remaining energy at the time of neighbor selection. EBRP improves network lifetime by preventing loops and preserving the available links to the sink node.

To minimize transmission delay post aggregation and thereby retaining network lifetime, the authors of [19] proposed an Energy Efficient Multilayered Architecture (EEMA) protocol. The protocol decides cluster head based on Euclidean distance and residual energy. The cluster head aggregates data depending upon the available energy at the time of data gathering.

C. *Distance based Energy Optimization Techniques*

Ant Colony Optimization based EEABR algorithm is proposed by Camilo *et al.* [20] to improve energy efficiency of the network. EEABR relies on ant updates for neighbor selection and packet transmission. The ants produce an optimal path for transmission with distance and energy awareness.

Energy Aware Routing Protocol (EAP) is designed by the authors in [21] for optimal cluster head selection. EAP selects header nodes with average remaining energy as constraint. This minimizes energy consumption in free space. The authors of [22] proposed an ant colony variant EAACA that considers shortest distance neighbor and energy consumption in a balanced manner. Nodes with average lesser energy consumption are selected for routing in the shortest path.

Young *et al.*, proposed a traffic and delay aware distance specific routing called A-ESR [23]. In order to balance network load, a node with lesser control discovery message is selected for transmission. The distance factor is estimated as min-max variance for the entire one-hop neighbor.

A distributed tree based technique called GSTEB [24] is proposed for conserving energy that estimates distance of each neighbor before selection. The base stations share information about the root nodes to the sensor nodes advising the sensor nodes to select shortest distance node to the sink.

Optimal Distance based Transmission Strategy (ODTS) is proposed by X.Liu [25] to prolong network lifetime. ODTS is an optimization technique based on ant colony that depends on balancing factors of energy and distance aware neighbor selection methods.

IV. Performance Analysis

Low Cost Path Selection comes into existence when a route error or link failure occurs at the time of transmission. In such cases, the neighbor transmits a Route Error message to the source and source initiates re-routing from the very first node. This increases the backtracking transmission retarding of the source node. To avoid this, DEA-OR seeks the aid of greedy routing. It initiates greedy routing in the node just backwards

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(predecessor node) to the error node.

Through greedy routing, the predecessor node selects all possible routes to the sink node. To minimize routing overhead, single path is selected based on low cost factor. Cost factor is estimated based on link availability and stability that a node possess over the transmission time. In the rerouting process, the source pursues the previous transmission path and the intermediate node initiates rerouting through a greedy low cost path. This process is called local route repairing process.

A. Simulation Parameters

The performance our proposed approaches, E-LFRR, ME2PLB and DEA-OR algorithm is evaluated using the network metrics: throughput, delay, overhead, energy utilization, network lifetime and alive nodes. The results are obtained by implementing the proposed algorithms using Network Simulator-2. Table I shows the simulation parameters and its values used.

TABLE I
SIMULATION PARAMETERS

Parameter	**Value**
Network Area	1000x1000
Protocol	Dynamic Source Routing
No. of Sensor Nodes	100
Network Topology	Flat Grid
IEEE Standard	IEEE 802.11
Broadcasting Range	250 meters
Application Type	Constant Bit Rate
No. of Packets	1500
Initial Energy	20 Joules

B. Results and Discussion

Table II shows the comparison of performance metric values obtained.

TABLE II
PERFORMANCE METRIC VALUES

	E-LFRR	ME2PLB	DEA-OR
Throughput (Kbps)	281.44	536.4	672.27
Delay (ms)	71.3	65.7	55.09
Overhead (%)	23.7	18.33	16.32
Energy Utilization (J)	9.1	7.7	5.862
Network Lifetime (s)	147	177	210
Alive Nodes	73	82	87

Fig 1 illustrates the throughput comparison of E LFRR, ME2PLB and DEA-OR.

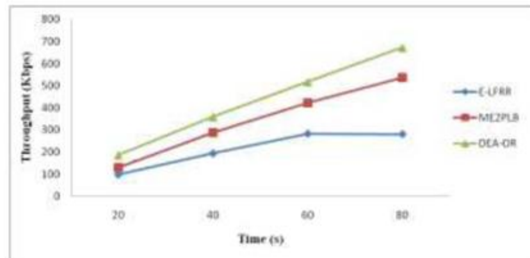

Fig 1. Throughput Graph.

The comparison of delay for DEA-OR with the E-LFRR and ME2PLB is portrayed in Fig 2.

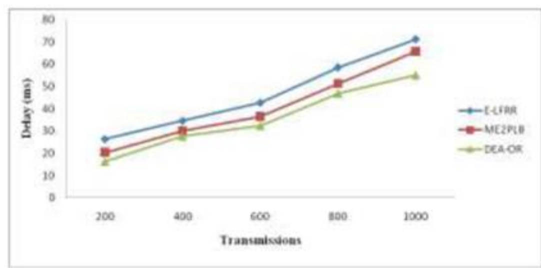

Fig 2. Delay Graph.

The percentage of overhead observed in local neighbor discovery is compared between E-LFRR, ME2PLB and DEAOR (Fig 3).

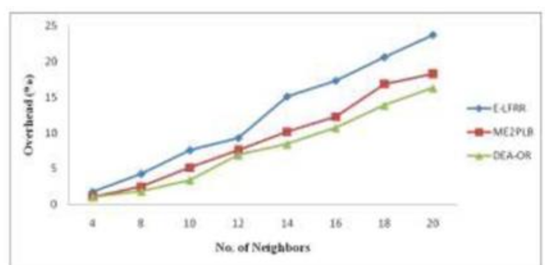

Fig 3. Overhead Graph.

Fig 4 illustrates comparison of energy utilization of different methods with respect to the distance from the optimal node to the sink.

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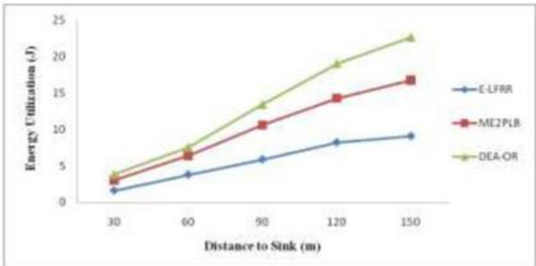

Fig 4. Energy Utilization Graph.

The comparison of network lifetime is illustrated in fig 5, compared between E-LFRR, ME2PLB and DEA-OR algorithm.

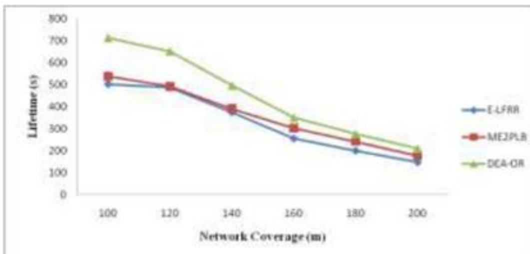

Fig 5. Network Lifetime Graph.

The comparison of alive node count is illustrated in fig 6, compared between E-LFRR, ME2PLB and DEA-OR algorithm.

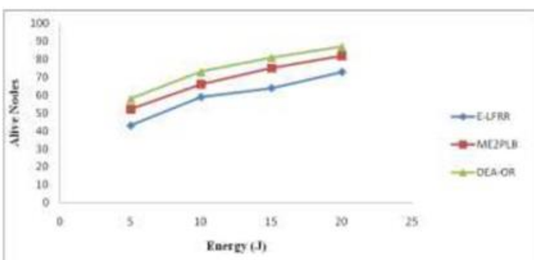

Fig 6. Network Lifetime Graph.

V. CONCLUSION

Designed protocols must exist with the purpose of maintaining sensors for a long time to meet the practical requirements and their scalability issues must be respected. This paper surveys different energy optimization techniques with different constraints in WSNs. We discussed the existing approaches on energy conservation and optimization with link failure recovery, load balancing and distance routing. Our proposed approaches intend to minimize the tradeoffs in optimization when considering multi objective metrics. The last approach of our proposal addresses premature convergence providing an optimal solution that result in performance improvement in WSN and we propose a path repairing approach, which can quickly find an alternate path against a broken link by doing a small survey around the break and only using already existing routing information. Special provisions in the protocol to handle a burst in the traffic is been done, by considering multiple-source to single sink. The protocol, as such, would survive although the performance could degrade to some extent, when all the nodes would detect and report at a time.

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