A Survey of Energy Efficient Routing and Optimization Techniques in Wireless Sensor Networks

Jayekumar Manikannu and Nagarajan V

***Abstract*—Wireless Sensor Network applications supporting diverse fields have gained a vital focus and interest from the researchers these days. WSN applications are designed to support scalable real time environment monitoring that depends on region of implication. The major challenges in WSN include energy optimization, routing, obstacle identification, security, etc. These constraints need prioritized optimization in fulfilling the requirements of the deployed environment. Many research approaches provide solutions for each of the influencing factors in WSN. We intend to survey the energy optimization techniques in WSN with distinct considerations. This paper focuses in surveying preceding optimization techniques under multi-objective perspective that results in tradeoffs. We exclude the familiar optimization approaches and analyze distinct metric specific optimizations based on link failure, load balancing and distance.**

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

I. Introduction

Wireless Sensors Networks (WSNs) is a assortment of miniature sensing devices, distributed over a large area for observing changes in the environment. The devices communicate with each other in an on demand through protocols that are specifically designed for autonomous communication. 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 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 an diverse approach depending upon the floor plan implemented and the purpose of the technique.

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 III discusses our proposed approaches for all the fore said optimization techniques. Section IV provides a comparative analysis of our approaches with respect to the network performance metrics. The future research course is given in Section V.

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II. 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 an hierarchical cluster based Energy Efficient Reliable Routing to prolong network lifetime

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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 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 n^{th}BR) 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 an 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 a 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) si 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.

III. Analysis of the Proposed Approaches

In this section we discuss our approaches towards energy optimization with respect to link failure recovery, load balancing and distance based routing. In all the three process, we intend to achieve energy efficiency with a minimum tradeoff co-joined with the other network metrics.

A. Energy-Link Failure Recovery Routing (E-LFRR) Algorithm

E-LFRR is a two level energy concentrated routing algorithm that minimizes delay and overhead in transmission and neighbor selection post link failures. E-LFRR works in two modes: Monitored Transmission and Replaced Transmission modes.

In the monitored transmission mode, the direct neighbor to the source node broadcasts the energy level information to the source node after each data transmission sequence. E-LFRR employs Actuator Nodes in the network to monitor the multi hop node energy levels. The actuator nodes broadcast the energy level of each of the active relaying node to the source node. The nodes that do not get chance for transmission are moved to sleep state in order to preserve their energy.

Actuator nodes monitor single level of node energy i.e. it observes the ceasing left back energy of a node after each transmission. If the nodes' energy reaches half of its initial energy state, the actuator node recommends the source to change the intermediate.

In replaced transmission mode, the current relaying nodes are moved to sleep state and the nodes in sleep state are called for pursuing transmission process. This prevents unnecessary broadcast that is initiated after link failures. E-LFRR minimizes the number of control messages involved in neighbor discovery by holding a predefined set of nodes that are replaced at the time of link failures. Besides, the route is changed with a fore hand actuator information that minimizes retransmissions and delay in the network. E-LFRR minimizes overhead, delay and improves the count of alive nodes in the network and retains appreciable amount of residual energy.

B. Monitored Energy Efficient Proactive Load balancing (ME2PLB) Algorithm

Load balancing in WSNs require a compromised improvement of energy or alive nodes in the network. To minimize the tradeoff between load balancing and energy optimization, the process of optimization is extended to work in a three-tier routing process integrated with load handling and energy optimization techniques. ME2PLB distributes the process of energy optimization, data gathering and load balancing in three levels of routing. It includes Energy Efficient Transmission, Switch over Transmission and Balanced Data Dissemination process. ME2PLB seeks the help of primary and secondary aggregator nodes and Monitoring Nodes (MN).

In Energy Efficient Transmission method, the Primary Aggregator initiates data gathering from all the active nodes. Primary Aggregator recommends the idle nodes to move to sleep state to prevent all time awake state. Monitoring nodes observe the energy of the primary aggregator and broadcast the same to the secondary aggregators that are present within the transmission range of MNs. MN holds a list of node information that are to be replaced due to lesser energy at the time of energy drain. MN recommends change of aggregator and nodes based on their energy levels and estimated Time-to-Live. When a node is replaced by its neighbor or other transmission node, the last transmission sequence is saved by the MN. It broadcasts the sequence information to the active source nodes. This minimizes duplication and retransmission of same data to the aggregator node. In the switched mode transmission, MN updates the new set of neighbors and aggregator information to the active transmitting nodes in the network.

In Balanced Data Dissemination mode, MN monitors the buffer level of the aggregator node. As the secondary aggregator may not be able to handle the same amount of data as the primary aggregator, MN takes the responsibility of arranging routing and data through the aggregator without loss. When the buffer constraints are not satisfied, MN recommends multi path data transmission. In multipath data transmission, the primary and secondary aggregators perform the process of data gathering. But the amount of data shared with the primary aggregator in the second chance is less than that of the data shared in the first chance.

ME2PLB ensures appreciable data transfer rates and count ability of active nodes in the network, with lesser delay and energy consumption.

C. Distance and Energy Aware Optimized Routing (DEA-OR)

Distance and energy optimization have always been a tradeoff approach that results in earlier or partial solution that is unable to persist for a long time. To lessen the bridging gap between distance based energy conservation, DEA-OR is proposed. DEA-OR operates in two phases viz., Energy and Distance Effective Path Selection and Greedy based low cost path selection.

In Distance based energy effective path selection, the source selects neighbor with two faces. Initially, source considers distance factor for neighbor selection and transmission. Source initiates a new neighbor discovery when the energy of the current path node drops down to threshold level. In the second neighbor discovery process, source considers energy along with the distance metric for neighbor selection. In this case, the source computes the weight of each node wherein the weight is computed as a joint metric of distance and energy. If both the factors are considered for neighbor selection, it results in unbalanced solution. The weight of each node is known to its direct neighbor from whom the neighbor can select its next hop neighbor. A node with higher weight factor is preferred for transmission.

Greedy Low Cos 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 (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.

Table I illustrates the network support factors of our proposed approaches

TABLE I
NETWORK SUPPORT FACTORS

	E-LFRR	ME2PLB	DEA-OR
Energy Conservation	Yes	Yes	Yes
Load Balancing	No	Yes	No
Avoids Premature Convergence	No	No	Yes
Initial Distance Metric	Yes	Yes	Yes
Final Distance Metric	No	No	Yes
Greedy Routing	No	No	Yes
Buffer Concentration	No	Yes	No
Link Recovery	Yes	No	Yes

IV. Performance Analysis

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 II shows the simulation parameters and its values used.

TABLE II
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 III shows the comparison of performance metric values obtained.

TABLE III
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.

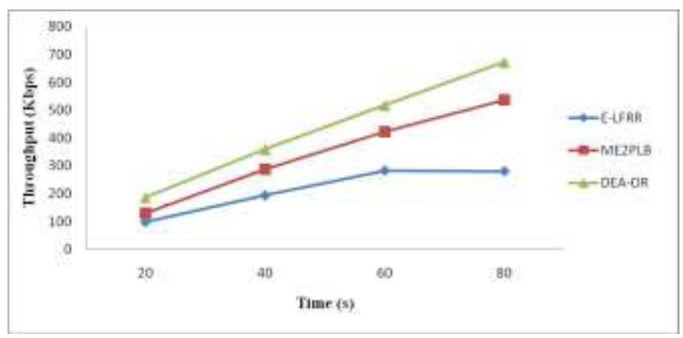

Fig 1. Throughput Graph.

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

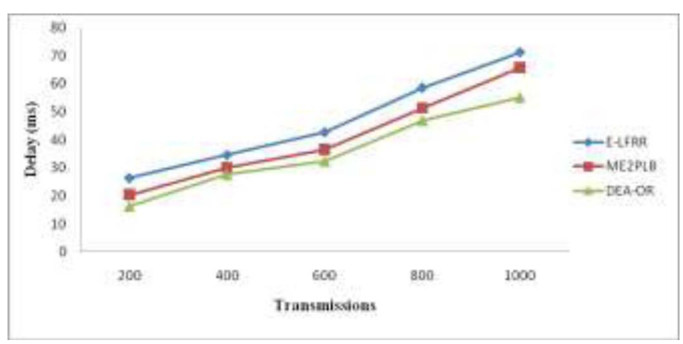

Fig 2. Delay Graph.

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

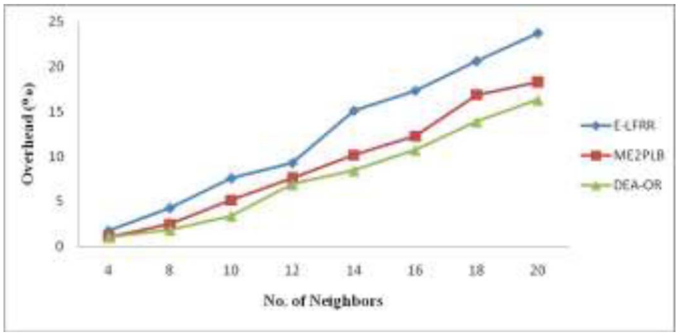

Fig 3. Overhead Graph.

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

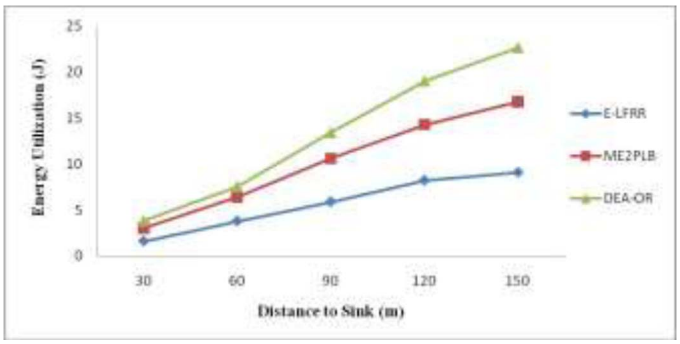

Fig 4. Energy Utilization Graph.

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

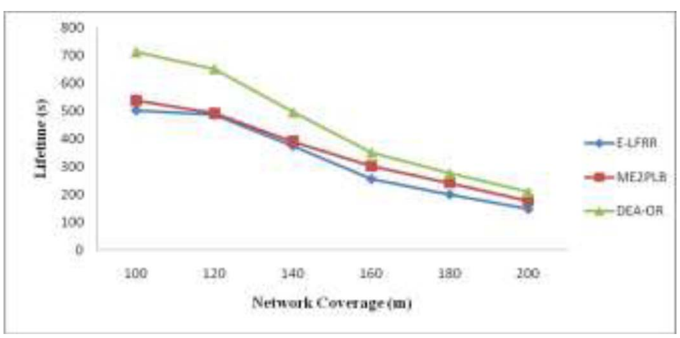

Fig 5. Network Lifetime Graph.

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

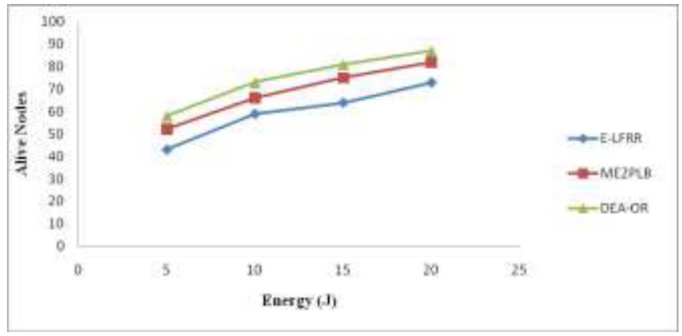

Fig 6. Network Lifetime Graph.

V. CONCLUSION

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.

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