Modified Energy and Link Failure Recovery Routing Algorithm for Wireless Sensor Network

M. Jayekumar, V. Nagarajan

***Abstract*—**Wireless sensor network finds role in environmental monitoring, industrial applications, surveillance applications, health monitoring and other supervisory applications. Sensing devices form the basic operational unit of the network that is self-battery powered with limited life time. Sensor node spends its limited energy for transmission, reception, routing and sensing information. Frequent energy utilization for the above mentioned process leads to network lifetime degradation. To enhance energy efficiency and network lifetime, we propose a modified energy optimization and node recovery post failure method, Energy-Link Failure Recovery Routing (E-LFRR) algorithm. In our E-LFRR algorithm, two phases namely, Monitored Transmission phase and Replaced Transmission phase are devised to combat worst case link failure conditions. In Monitored Transmission phase, the Actuator Node monitors and identifies suitable nodes for shortest path transmission. The Replaced Transmission phase dispatches the energy draining node at early stage from the active link and replaces it with the new node that has sufficient energy. Simulation results illustrate that this combined methodology reduces overhead, energy consumption, delay and maintains considerable amount of alive nodes thereby enhancing the network performance.

***Keywords*—**Actuator node, energy efficient routing, energy hole, link failure recovery, link utilization, wireless sensor network.

I. Introduction

WIRELESS Sensor Network (WSN) is prominent among researchers and users for its unique data gathering and remote monitoring processes in adverse on-demand environments. WSN consists of a large number of sensor nodes. Sensors are built using micro electro-mechanical systems which has led to develop limited resources nodes. Many types of sensors are available such as a) light sensors b) temperature sensors c) humidity sensors d) pressure sensors e) GPS modules f) seismic and h) rainfall sensors. Sensor node senses environmental conditions such as temperature, pressure and light and sends the sensed data to a base station (BS). The main resource of sensor node is energy, which is mostly utilized for sensing, data aggregating and forwarding. Frequent energy utilization leads to node drop-outs, dead node growth, link failures and network lifetime retarding. As the sensor nodes are powered by limited battery power and in order to prolong the life time of the network, low energy consumption is important for sensor nodes. Energy efficiency in WSN is attained through proper routing methods. Through optimal decision making process, energy constrained routing is considered to attain energy utilization of the devices. Factors like neighbor availability, link stability, route failures and reroute discovery directly influences energy efficiency and network lifetime.

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II. Related works

Many algorithms have been proposed to regularize energy utilization that ultimately aims at prolonging network lifetime. Advanced energy preserving techniques such as data aggregation and clustering increases the routing complexity and ceases the performance of the routing system, thereby affecting system convergence. In the following discussions, we coin on simple routing protocols that follow energy efficient neighbor selection without involving additional processes like data aggregation and cluster head selection. Some of the relevant and precise literatures are as follows.

Alemdar and Ibnkahla [1] studied various applications of WSN and discussed about the research issues. The WSN have vast applications such as military applications, environmental monitoring, industrial applications, habitat monitoring etc. Due to changes in micro electro mechanical systems, sensors have gained much attention towards deploying it in all possible applications. But there are challenges which have to be taken care of before organizing sensors in applications. The challenges include: a) Energy b) Integrated circuits c) Routing d) Distributed signal processing and e) Security. We consider energy, routing and security for our work from the above mentioned research issues.

Qaisar et al. [2] surveyed various communication and networking challenges and provides the most suitable next generation communication technology for WSN. For next generation wireless technologies, cyber physical systems (CPS) and cloud computing concept have been recommended and the integration of these technologies with WSN applications are gradually meeting the growth.

To identify the energy efficient route, Chakraborty et al. [3] proposed genetic algorithm inspired routing protocol (GROUP). Genetic approach is based on natural selection and evolution. During each generation, it yields new population which is known as chromosomes. Each chromosome is evaluated by fitness function which is known as the objective function. On this basis, next generation is populated by employing functions such as selection, crossover and mutations.

A population based approach namely A-Star and Fuzzy integrated Protocol (AF Protocol) is proposed in [4] to identify shortest energy conservation path. A* algorithm functions in three phases namely initialization, exploration and termination to optimize energy consumption of the network. The simulation results of this approach illustrates that there is significant improvement in optimal path selection compared with its existing approaches.

Ghaffari [5] proposed an energy efficient routing protocol (EERP) using A star algorithm which is used to find the shortest path between the source and the BS. The sensor nodes during initialization send its parameters to the BS and if nodes have data to transmit then it attaches with the parameters. On receiving all the nodes parameters, the BS provides the routing schedule to each of its nodes in the network. The residual energy of the node is tracked and compared with the predefined threshold value and if residual energy is less than the threshold energy then the node fails to take place in the network. Depending on the threshold energy the load is adjusted which extends the network lifetime. Through A-star "best-first search" algorithm, the optimal shortest path between the source and the base station is identified.

Devi et al. [6] proposed an energy efficient selective opportunistic routing (EESOR) algorithm in which the source node finds its neighbors and checks for the distance between source and destination. If the distance is more than one hop it forwards its packets through neighbors and by using EESOR, the shortest path is identified between the source and the destination. Each node maintains a routing table and broadcasts its routing table as packets to all the nodes in the network. On receiving routing table, each node updates its position and the distance between source and sink. This process is repeated until the destination is reached. Depending on the whole process the forwarding list are sorted in descending order according to the distance.

Amiri et al. [7] proposed a routing protocol namely fuzzy ant colony optimization routing (FACOR). It uses ants, namely, forward ants and backward ants in order to find the routing between the source and the destination. The forward ants move from source to all the nodes and reach destination maintaining a routing table. On reaching the destination, the backward ant travels over the same path laid by the forward ant and updates the routing table as well. This improves route stability in the network. The ant progresses in the network based on AODV protocol and fuzzy logics.

Sarma et al. [8] proposed a hierarchical based clustering protocol called Energy Efficient Reliable Routing protocol. The protocol proposed in [8] prolongs network lifetime and provides reliability on link failures. To reduce transmission energy multi hop forwarding is designed and clusters are formed in the network. Each cluster has a cluster head and two deputy cluster heads; the BS maintains a list of nodes which have more chances of becoming a cluster head or deputy cluster head. In the absence of cluster head the deputy cluster head performs the functions of the cluster head. The BS keeps on tracking the volume of data and presumes a threshold value if the cluster head retrieves and forwards less than threshold value then BS advices the cluster head to check for its connection with members. The BS maintains the routing decision so that the life time of sensor nodes are prolonged.

Mishra and Kaur [9] have studied various energy efficient neighbor selection algorithms such as flat protocols are analyzed under flat grid technology. In flat network all nodes are provided with same privileges and are classified as data centric, location based and quality of service protocols. These flat protocols are energy aware protocols which tracks its neighbors for residual energy. In flat network, all nodes are provided with same privileges and are classified as a) data centric, b) location based and c) quality of service protocols. In data centric protocols, the sink node forwards queries and waits for the reply. In location based protocols, each sensor node must know its position and its distance. Based on this, the transmission towards the target region is carried out. In quality of service protocols, the path selection takes place based on previous knowledge such as resource availability and tolerable delay.

Raj and Sumathi [10] proposed an algorithm namely enhanced energy efficient multipath routing based on cuckoo search (EEEMRP). It is an extension of AOMDV which is based on cuckoo search. AOMDV is a hop by hop routing approach which uses route discovery process by flooding route request packets to identify multipath between source and destination. The entry of a node will be removed from the routing table, if the source fails to receive route-reply packets. The best path is identified with the maximum amount of energy based on selfish cuckoo search.

Least disruptive topology repair (LeDiR) algorithm was discussed by Abbasi et al. [11]. LeDiR algorithm is a localized and distributed algorithm which detects failure through actor nodes. The algorithm periodically transmits messages to its one hop neighbors and if the messages are lost, the actor nodes are considered as dead nodes. To sustain the network lifetime, the next one hop neighbor is identified and replaced instead of the faulty node.

The identification of faulty actor nodes is done through depth first search algorithm. Likewise, in a group of nodes, the failed nodes are eliminated by finding its reachable neighbors i.e. the node in direct link between the failed node and the sink. The failed node will be an intersecting point of two reachable nodes. Through shortest routing algorithm, the reachable nodes are connected by eliminating the failed node. The failed node is replaced by its one hop neighbor who is considered to be gateway. The neighbors at one hop distance are considered to be parent nodes. Neighbors with two hops from the failed node are considered to be children and neighbors with three hops are considered to be the grandchildren.

Bakr and Lilien [12] proposed a clustering protocol based on Low-Energy Adaptive Clustering Hierarchy - *Spare Management (*LEACH-SM) protocol. The LEACH-SM protocol follows three phases in order to prolong the network lifetime. They are a) optimal spare selection, b) management of spare nodes, c) estimation of WSN lifetime. If more number of nodes is active in the network, the network lifetime will reduce. The LEACH-SM protocol wakes up the next node only when the primary node uses-up its energy. In this way, energy exhausted nodes are replaced by spare nodes to enhance the network lifetime.

Rao and Singh [13] proposed an algorithm, called, AODV routing with n^{th} backup route (AODV n^{th} BR) algorithm. With the application of AODV routing protocol, the nodes in the network maintains a routing table. The IP addresses of all the nodes in the network are mapped in the routing table. If the source fails to have the destination IP address, then it sends route-request packet and identifies the route. In AODV n^{th} BR algorithm, the distance between the nodes is computed by vector calculation. Depending on the distance calculated, the node ensures with the available energy. If the energy is more than the threshold value, transmission of packets over n^{th} backup route is initialized. If the node's energy in n^{th} backup route drains, then it checks for the next neighbor that has energy above the threshold value. The neighbor is also selected by analyzing vector based distance calculation; it is recursive and is repeated until the next node selects the nth backup route.

Naik and Reddy [14] proposed check point route recovery algorithm (CPRRA) with AODV routing protocol to overcome network link failure. CPRRA checks for the energy of the nodes by transmitting messages and the Actor node sends its own functionalities periodically as packets and if any mismatch or loss in periodic message then there exist some failure in the network. One hop neighbor of failed node would determine the serious situation of the node failure and connectivity to network. Based on the signal strength, the failed node is eliminated by CPRRA algorithm and the alternate shortest route is established through active node. The static node detects the node energy and if the node depletes its energy it intimates to the dynamic node and makes the failed node to be replaced. All these paths are maintained by network topology management.

Roy and Sarma [15] have studied energy efficient MAC protocols and tabulated their performances and their drawbacks. DCF, SMAC and TMAC are some of the protocols considered which are compared for energy efficient parameters such as throughput, delay and packet delivery ratio.

To improve the overall network performance and to overcome the trade-off issue in the existing techniques [4], [5]; E-LFRR algorithm is proposed. E-LFRR algorithm consists of Monitored Transmission phase and Replaced Transmission phase so as to combat worst case link failure conditions. The Monitored Transmission phase takes responsibility to monitor the energy level of node. Based on the monitored results, suitable nodes are selected.

On link failure condition, the proposed algorithm forecasts the alternate node information to carry out ongoing transmission. Replaced Transmission phase dispatches the energy draining node from the link and replaces it with the new node having sufficient energy. Hence, the energy drain nodes are identified at the early stage thereby reducing overhead and delay in network recovery.

The proposed E-LFRR algorithm is compared with existing AF Protocol [4] and EERP [5] model. These existing methods have not considered centralized energy monitoring and link utilization factors which greatly affect network stability. In addition, the existing methods [4] and [5] have not focused on post-link failure measures and routing-overhead consequences, leading to reduction in overall network lifetime. The E-LFRR algorithm jointly monitors energy level and link quality of each and every node in a centralized manner thereby addressing the post-link failure issue. The following section elaborates on network model, proposed algorithm with its phases.

III. Proposed Method

A. Network Model

We assume that a WSN is deployed with 'n' nodes in an X*Y region with multi-source multi-sink communication, where the communications between Source and Sink Node (SN) is multi hop based. Using broadcast, the sensor node initiates communication and establishes the path using control messages. To be continued in the active state for a longer time, each sensor node switches between active and sleep states. In general, the transmitting and the receiving nodes are said to be in Active State (AS), and the rest of the nodes are said to be in Sleep State (SS).

Few Actuator Nodes (ANs) are deployed in the network for monitoring and transmission purposes. AN does not require additional energy as in relay nodes. As well, AN does not transmit packets when all possible nodes remain above half drain state. The probability of AN to be available for its neighbor is 1: n_{tr}. AN is assumed to have lesser mobility. The source discards AN in its routing path until neighbors in range of AN are half drained or does not support multipath. Each node initiates data transfer (d_t) for N transmission cycles. The transmitting nodes are represented as t_n

B. E-LFRR Algorithm

The proposed routing method selects node based on optimal energy availability state; receiving update from the AN. E-LFRR Algorithm works in two transmission phases: Monitored Transmission (MT) phase and Replaced Transmission (RT) phase.

1. MT Phase

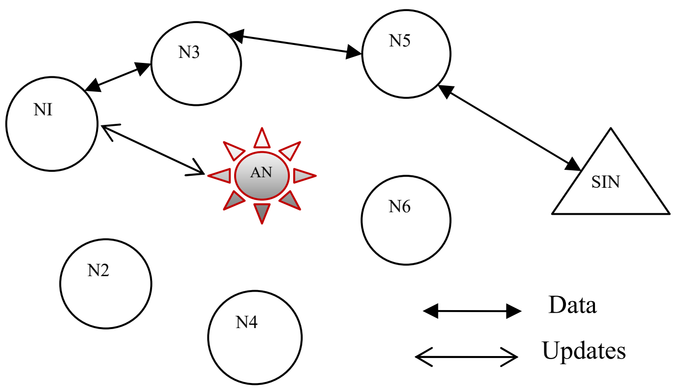

Fig. 1 MT phase

The MT phase takes responsibility of supervising the energy level of the nodes present over the active link. Fig. 1 illustrates the shortest path establishment from node N1 to sink. Initially, the source node (N1) monitors the available neighbors towards the SN.

One-hop neighbor to the source updates its energy level post transmission to the source node. Indirect neighbor energy levels are monitored and updated by the source node through ANs. Active neighbors and the nodes in the current transmission path are moved to transmission enabled state called AS. The rest-of-nodes are moved to idle state; the initial method to preserve unnecessary energy drain of unused nodes as per duty-cycle process [16], [17]. In a duty cycle process, an inactive node is moved to SS (s) to prevent energy drain. The nodes in AS (a) will be utilized for transmission. The frequent switch over between active and SS helps the node to remain active for longer period.

The Energy consumption (E) of a node [18]-[20] is given by (1):

$$E = E_{tx} + E_{rx} + E_s + E_l \tag{1}$$

where, E_{tx}, E_{rx}, E_s, E_l are the energy utilized for transmission, reception, SS and listen state respectively.

Energy utilized by a node for transmission and reception is given by (2) and (3):

$$E_{tx} = d_t \times E_{ut} \times t_t \tag{2}$$

$$E_{rx} = d_r \times E_{ur} \times r_t \tag{3}$$

where, d_t and d_r are the data transfer rate and received rate respectively, t_t and r_t are the transmission time and reception time; E_{ut} and E_{ur} are the energy used for transmission and reception respectively.

AN tracks the link utilization (LU) and Energy Level of the nodes in its range. A node on reaching its half drain energy level will be moved to SS because half drain nodes are no more capable of guaranteed transmission. The current SS in-range neighbor will be replaced in the path.

Half Energy (H_E) and Residual Energy (R_e) of a node are given by (4) and (5):

$$H_E = \frac{E_0}{2} \tag{4}$$

$$R_e = E_0 - E \tag{5}$$

where, E_0 is the initial energy of the node. A node, whose half drain is achieved, will be replaced with a current idle state node and the half drain node will be moved to SS.

2. RT Phase

AN prioritizes updates about half energy drain node to the source, recommending change in dead nodes. The AN forecasts the alternate active node information to the source and the source node re-routes further transmissions through next possible path. The nodes in the next path are moved to AS. When the nodes in the alternate path achieve their drain condition, sender initiates multipath concurrent transmissions. On initiating concurrent transmission, the AN monitors the LU of the multipath nodes. Link Utilization (L_U) of a current transmission node [21] is given by (6):

$$L_U = \frac{d_t}{l_r} \tag{6}$$

l_r is the link transmission rate which is given by (7):

$$l_r = \left(\frac{lr\max}{E_{tx}}\right) \tag{7}$$

where $lr\max$ is the maximum link acceptance rate. AN ensures link availability and forehand link failures for the node being replaced for a seamless transmission.

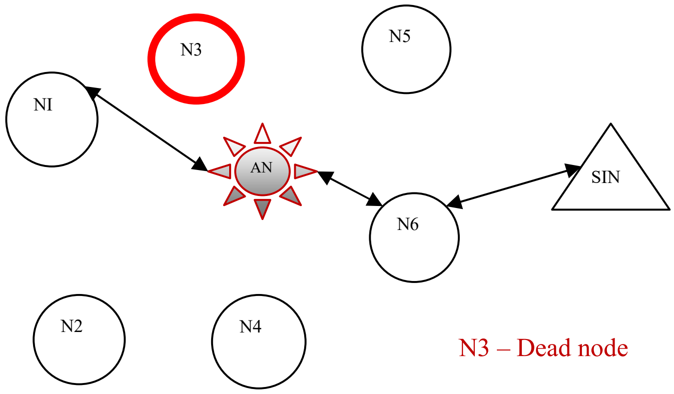

Fig. 2 RT phase

In replacement to the dead nodes, the AN appoints itself as relaying node (Fig. 2). This situation occurs when number of transmissions are still incomplete and the available neighbors in-range to the AN are not capable of transmitting data. Due to energy drain, the in-range dead nodes create an energy-hole problem where the entire transmission is blocked due to link failure. The integrated plane working of E-LFRR is described in Algorithm 1.

Energy efficient routing is employed through all transmission from source to SN. The proposed E-LFRR algorithm computes the transmission energy, reception energy and overall energy consumed by a transmitting node (step 6), the steps 7 and 8 indicate the nodes that are moved to active and SS. Steps 9 to 11 indicate the changeover of nodes as the energy is half drained and the replacement of nodes. Step 13 indicates the condition of multiple energy drain nodes analyzed, where a multipath is established (step 14). After multipath transmission, the AN computes and updates LU to the source node (step 15). If the LU is less than the data transfer rate (step 16), then AN is used as an intermediate (Step 17) from source to SN for further transmission.

Algorithm 1. E-LFRR Algorithm

1: For all ‘n’ $\in X * Y$
2: n $\in \{1,2,3,\ldots,\mathcal{N}\}$
3:{
4: Initiate data transmission (d_t)
5: For all transmission from S to SN do
6: Compute E_{tx} , E_{rx} and E of all t_n
7:$\{a_1, a_2, \ldots, a_i\}$: → Active State
8:Idle State ←:$\{s_1, s_2, \ldots, s_j\}$, $i \neq j$
9: If $E(a_i) = \frac{E_0}{2}$ then
10:$\{s_j\} \leftarrow a_i$
11: $a_i \leftarrow s_j$
12: end if

MT PHASE

13: If $E(a_i) = \frac{E_0}{2}$ && $E(s_j) = \frac{E_0}{2}$ then
14: S to SN ⟶Multipath
15: Compute and broadcast to L_U S
16: If $L_U < d_t$ then
17: S to SN :⟶ AN(i)
18: end if
19: end if
20: end for
21: }
22: end for

RT PHASE

Due to energy drain, the in-range nodes create an energy-hole problem, where the entire transmission is blocked due to link failure as shown in Fig. 3.

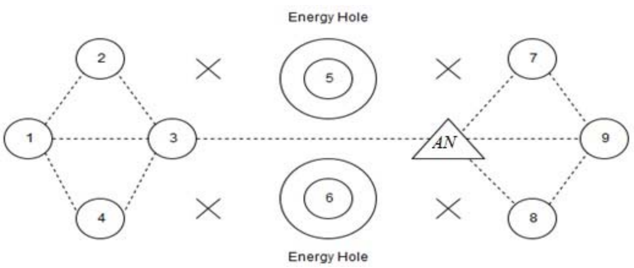

Fig. 3 Energy-Hole Problem

As observed in Fig. 3, nodes 5 and 6 are considered to lose all their energy and they can no more forward data to rest of the network. Thus, node 5 and 6 are energy-hole nodes that partition the network. Under such condition, AN will take responsibility in forwarding the data at lowest power thereby upholding the ongoing transmission. This will lead to prolonged network lifetime. The E-LFRR Algorithm establishes and monitors the link based on energy utilization and LU factors which still makes the WSN to be robust against network delay and routing overheads.

IV. Performance Evaluation

The performance of E-LFRR algorithm is analyzed using Network Simulator-2. A network with 1000x1000 region is used with random deployment of 100 mobile nodes. Limited number of ANs is deployed to monitor the network. Each node is assigned a transmission range of 250 m. Table I shows the simulation parameters used for evaluation.

TABLE I
Simulation Parameters

Parameter	Value
Network Area	1000x1000
Protocol	Dynamic Source Routing
No. of Sensor Nodes	100
Network Topology	Flat Grid
IEEE Standard	802.11
Broadcasting Range	250meters
Application Type	Constant Bit Rate
No. of Packets	1500
Initial Energy	10Joules

The performance analysis for the proposed E-LFRR algorithm is compared with AF Protocol [4] and traditional EERP [5]. Residual energy, count of alive nodes, delay and overhead are the network performance metrics considered for analysis.

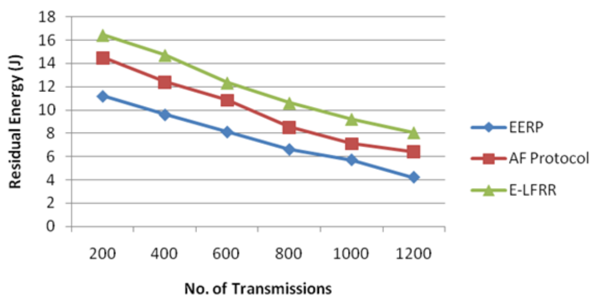

Fig. 4 No. of Transmission versus Residual Energy

Fig. 4 illustrates the performance analysis of E-LFRR, AF Protocol and EERP with respect to residual energy. As the number of transmission increases, energy utilization increases which eventually decreases the remaining/residual energy of the network. In an E-LFRR, a minimum count of nodes move to no-energy state as the nodes endures transition state switching. State Switching helps to prolong the node lifetime; finally a no energy node is replaced by an AN, conserving unwanted energy drain due to listening and broadcast. Therefore, the nodes retain an acceptable amount of energy which helps the network to preserve considerable residual energy. The proposed E-LFRR retains 47.83% and 20.5% of residual energy when compared to EERP and AF protocol respectively.

Fig. 5 shows the count of available nodes in E-LFRR, AF Protocol and EERP. In E-LFRR, the lifetime of a node is prolonged by monitoring energy levels by a dedicated AN. An early draining node is moved to SS that is replaced by a current SS node; preserving the node energy from reaching dead state. Due to dispersed ANs, certain lossy node links are replaced with that of the AN link, helping the network to increase the count of alive nodes after frequent transmissions. E-LFRR increases the alive node count in the network by 4.72% and 14.29% compared to AF protocol and EERP.

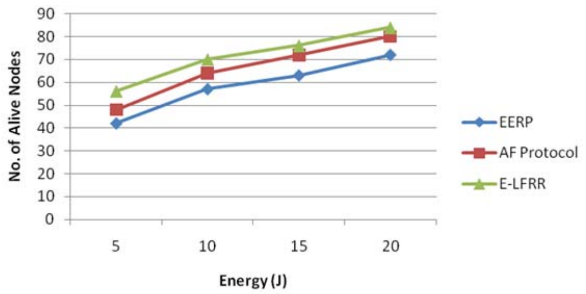

Fig. 5 Energy versus No. of Alive Nodes

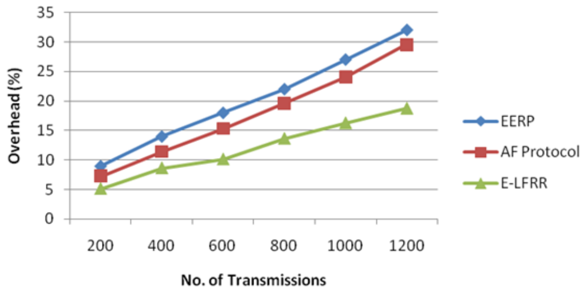

Fig. 6 No. of Transmission versus Overhead

Fig. 6 shows the overhead observed in the network based on EERP, AF Protocol and E-LFRR Algorithm. The number of frequent link discovery and path switching due to complete energy drain of a node is less in E-LFRR. In E-LFRR, the AN updates the link status and energy level of a node to the source as a fore hand information. Path changing decisions are fore hand, minimizing the alternate path selection frequency. Hence, the network overhead in the proposed E-LFRR algorithm is 36.79% and 41.53% less compared with AF protocol and EERP algorithm.

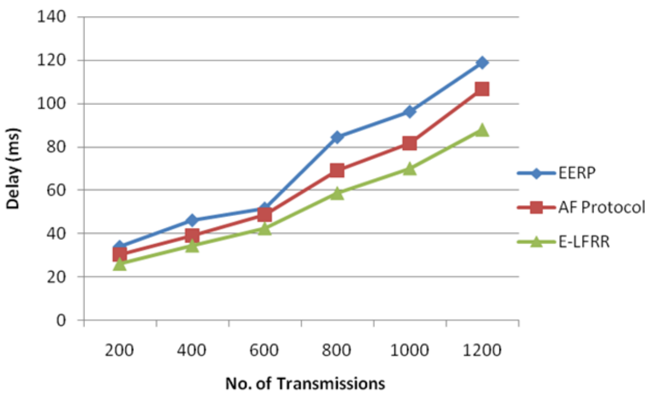

Fig. 7 No. of Transmission versus Delay

Fig. 7 illustrates delay observed using EERP, AF Protocol and E-LFRR algorithm. As the number of re-transmissions and frequency of neighbor selection is high in EERP and AF protocol, delay is high when compared to E-LFRR. E-LFRR uses multipath to retain throughput and concurrent transmissions to retain delay. When compared to AF protocol and EERP, E-LFRR minimizes delay by 17.42% and 25.78% respectively.

From the above analyses, it is explicit that the extra measure put-forth by the proposed E-LFRR algorithm leads to following advantages:

i. Proposed algorithm prolongs the network life. The residual energy retained in E-LFRR algorithm is 2 to 4 times more than existing algorithms.
ii. Average number of alive nodes in existing algorithms is 9% less (in average) compared with proposed algorithm.
iii. Reduction in control message transition impacts the overhead alleviation in proposed algorithm.
iv. In general, delay in decision making directly affects the network convergence. With the help of RT phase, the E-LFRR algorithm makes instantaneous decision on appropiate active node selection thereby helping in network convergence.

V. Conclusion

We propose an energy conservation and link recovery algorithm called E-LFRR Algorithm. The two independent processes, namely, MT phase and RT phase are integrated as one for the best neighbor selection process. The MT phase helps in identifying drain nodes at an early stage and the RT phase utilizes the long time idle AN as a replacement for lossy link. The neighbor is selected based on energy and LU factor of a node. The proposed algorithm works under adaptive states with different neighbors/AN. The proposed E-LFRR algorithm achieves maximum alive nodes in the network and minimizes network overhead and energy consumption. The proposed method outwits the traditional and trade-off based optimized techniques in terms of delay, overhead, alive node count and residual energy. The further process of E-LFRR Algorithm is the opportunistic neighbor selection process for energy efficient data gathering that probably optimizes energy and improves data transfer rate.

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