Optimal Multipath Routing using BFS for Wireless Sensor Networks

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Abstract: One of the primary challenges in Wireless Sensor Networks (WSN) is to maximize the lifetime of sensor nodes. In WSN a battery-powered sensor nodes periodically sense the environment and transmits the collected data to a sink. A grid based dynamic clustering scheme is proposed for WSNs in this paper which attains data aggregation and less energy consumption without compromising the quality. Solution for routing and data gathering with-in the network aggregation is presented. The focus is on finding an optimal multipath using breadth first search algorithm such that the network lifetime is enhanced by exploiting data aggregation and routing techniques. The clusters are dynamically formed and operated using heuristic approaches having fewer number of aggregation points during forwarding sensed data to base station. When com-pared with other schemes, the results show that this proposed scheme improves network lifetime with reliability in data aggregation by reducing data redundancy.

Index Terms – Wireless sensor networks, Clustering, Data aggregation, Energy efficiency, Breadth first search, Network lifetime

1. INTRODUCTION

In WSNs, sensor nodes collect data collect from physical environment, process and forward it to a base station. An important challenge is node's energy and its limited resources for computing in WSNs, which is the major constraint on the network lifetime [1]. Hence new techniques are required to make the sensor nodes to work under the limited resources and enhance the node's lifetime and thus to increase the network lifetime. Applications of WSNs include medical applications, security, environmental monitoring etc. Energy consumption and data traffic can be controlled by the way the data is routed. Network lifetime can be prolonged by clustering [2]. The cluster heads (CHs) gather data from their cluster members, aggregate it and later forwards it to BS. Sensor nodes use routing algorithm to forward their sensed data and forward data received by neighboring nodes efficiently to BS.

Some of the routing protocols appeared in the literature minimizes the energy consumption of the sensor nodes so that the network stability and lifetime may be improved. Network lifetime indicates the time slice between the beginning of network and continues till expiry of last node, and stability period is the time slice between the beginning of network till expiry of first node. Clustering may be either static or dynamic.

Low-energy adaptive clustering hierarchy (LEACH) [2] adapted dynamic clustering technique which chooses CHs on heuristics basis because of which area of clusters and count of CHs may vary in every round. In addition, the number of packets sent to the BS also varies. Data aggregation and optimal multipath routing scheme called as grid-based dynamic clustering and data aggregator selection is presented in this paper. The approach is heuristics in nature and is used to identify less number of aggregation points and thus forward data to BS. It looks into the issue of selecting data aggregation points, best routing path to forward data from sensors to aggregation points and thereafter to BS. We adopt a hierarchical structure where cluster heads are elected by different group of sensors which are responsible for (i) gathering data from sensors, (ii) first level of data aggregation, and (iii) forward the aggregated data to BS.

The rest of the paper is organized as follows: Section II describes the related works. Section III describes Hierarchical clustering algorithm. Section IV contains proposed system. Section V describes multipath model. Section VI describes simulation and performance evaluation and finally Section VII concludes the paper.

2. RELATED WORK

There are many works carried on clustering techniques. Clustering provides various advantages like scalability, coverage, robustness, simplicity, load balancing and extended network lifetime. GRID-PEGASIS [3]–[5] establishes a new chain reducing the distance between the nodes, which prolongs the network life and reduces energy consumption. While establishing the chain, sensing environment is divided into multiple smaller grids. In chain area, a chain head is selected which is responsible for gathering data of its region and forward it to BS. Each node in the chain transmits data through the chain method only. Upon creating the chain, if node distance is more in chain, then energy consumed will be more, but measuring of equilibrium energy consumption of each and every node is practically not possible.

To minimize the energy consumed by nodes, energy efficient grid-chain based data gathering (EEGDG) [6] is proposed. Grid area is divided to minimize larger hops generated by greedy algorithm and control the transmission activity of nodes in each area. Every node is aware of its area and a grid node (GN) is chosen randomly among the nodes within the grid on turn basis, which makes the energy consumption of nodes more even. Rest of the nodes will transmit data to specified GN within grid area which will be in short distance. Choosing of GN randomly will make some nodes not to get a chance for becoming GN. A node would die before it is chosen as a GN. A distributed and energy efficient tree generation protocol in WSNs is proposed in [7] which is used to construct Breadth First Search (BFS) and Shortest Path Trees (SPTs). BFS and SPTs are taken into account as they reduce the distance of path in the tree from any node to root node (sink). Minimized path length reduces the amount of energy spent on transmitting data; and thus protocol becomes energy efficient. Further, routing along the root of the tree helps to aggregate data from different nodes which help in reducing the redundant data which in turn minimizes the number of transmission and saves considerable amount of energy. But the extra time consuming work is the construction of SPTs along with BFS.

Clustering-tree topology control algorithm based on the energy forecast (CTEF) [8] saves energy and ensures network load balancing by considering the link quality, packet loss rate, etc. CHs are chose by considering the parameters like residual energy of node, quality of link with the nodes, data loss rate and also their distance with other cluster members. Non-cluster members later decide to get added to cluster considering their distance and quality of the link with other CHs. The remaining cluster members under each cluster will play the role of relay node for forwarding data through multi-hop communication to reduce CHs load and enhance network lifespan. Cluster head usually deplete their energy quickly than non-cluster head nodes and making one of the non-cluster head nodes as a relay node would also lead to decrease the life of that node in a cluster. This leads to quick depletion of energy of both cluster head as well as a non-cluster head node.

The performance of Grid based dynamic clustering and aggregator selection scheme for WSNs has improved when compared with the results of EAMMH [9] and Stable Election Protocol (SEP) [10]. Energy consumption is measured in every round during the network lifetime, number of dead nodes is also reduced in each round and the number of cluster heads selected is comparatively more through dynamic clustering. The chance for each node in a cluster to become a cluster-head is more and energy of each node in a cluster is almost equally spent. Hence grid based dynamic clustering and aggregator selection scheme performs well and have enhanced life-time.

3. The Basic and Modified LEACH

Clustering has turned out to be a powerful approach for formulating the network into a linked hierarchy. The aim of clustering algorithms is to aggregate data in an way such that energy consumption is minimized and network lifetime is enhanced. Clustering algorithms adopt data fusion scheme and achieve extended network lifetime, fault tolerance, improve connectivity, load balancing reduced latency etc. LEACH is the oldest clustering algorithm for WSNs to enhance the life of network. It organises itself and nodes form clusters and a node from every cluster having more residual energy is chosen as a CH. Every node in the cluster is given a chance to act the role of CH on the rotation basis and thus avoids the draining of battery of a single node completely. Data fusion is performed to reduce the amount of data that is being forwarded from every CH to BS, which also reduces energy dissipation and enhances network life. A typical example of the WSN clustering is depicted in Fig. 1.

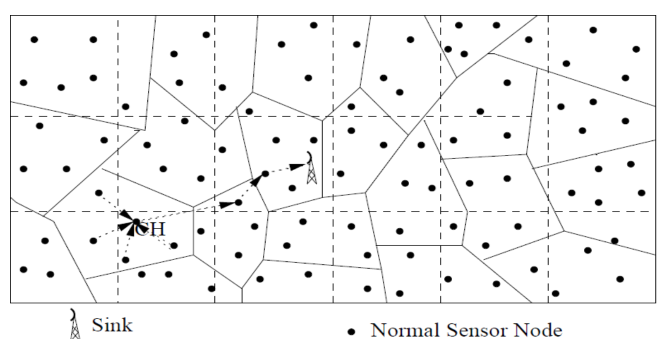

Fig. 1. Dynamic clustering

3.2. Modified LEACH (mLEACH) operation:

Here we propose a modified version of LEACH protocol in which more number of cluster heads are formed and multiple paths are established from the cluster head to sink. mLEACH operates in rounds and each round has two phases, first one is set-up phase and second is steady-state phase. Clusters are formed and organized in set-up phase and data transfer is performed to BS in steady-state phase. Steady-state phase stays for longer duration than set-up phase. The receivers of the CH are kept on to receive the requests from the nodes when nodes decide to join a particular cluster and become a member of that cluster. Upon receiving requests from nodes which likes to add to that cluster, TDMA schedule is created by CH [11] based on the number of requesting nodes and informs them when data is to be transmitted. The cluster members forward data to their CH within the allocated TDMA slot. After the expiry of TDMA slot, a node is pushed into sleep mode to save the battery of that node. CH compresses the received data from all cluster members into single signal and finally forwards it to BS.

4. Proposed System Model

In this section, the proposed system model is presented.

4.1. Level Assignment:

Let m*n be the area of sensor network divided into concentric circles described as levels. Depending upon the strength of the signal from BS, every node is assigned a level in the network. Parameters like node density or number of nodes and location of BS decide the number of levels in the sensor network.

4.2. Route Discovery Phase:

This phase works upon the creation of clusters in the sensor network. Clusters are created among the sensor nodes and a CH for each cluster is selected. Sensor nodes are supposed to forward data to its CH using multihop model. A sensor node requires a path to forward data to CH. BFS algorithm generates the disjoint path from source sensor to CH. Each sensor stores the path-table to reach CH.

4.3. Breadth First Search:

In BFS tree, we start from vertex v and mark it as visited. At this stage, the vertex v is marked unexplored. A vertex v is marked as explored when the algorithm has completed visiting all vertices from it. Remaining unvisited vertices adjacent from v will be visited next.

These unvisited vertices will be unexplored vertices. Vertex v has now been explored. The newly visited vertices which are not yet explored and are put onto the end of a list of unexplored vertices. The first vertex is the next to be explored on this list. The process of exploration is continued until all unexplored vertex are visited. The vertices which are still unexplored will operate in a queue which is represented using the standard queue representation. The nodes which are stored in a queue will then be processed one after the other and their corresponding neighboring nodes will get visited. Empty queue reaches the terminating condition. The states are characterized depending on the current state of the node: namely Ready State, Waiting State and Processed State. Node status will keep track of node's state. Ready State defines the nodes which are not yet visited and are waiting to get processed. At the beginning all nodes will be in Ready State. Once nodes get added into the queue, nodes will be in Waiting State. The node which is processed (whose neighbors have been added into the queue) will have Processed Status. Processed nodes will not be considered once again and it is monitored by visit field. Initially visit field is filled with value 0 for all nodes and once the node is visited, value gets updated to 1. The algorithm for BFS is given in Algorithm 1.

Algorithm 1: Breadth-First Search

Step 1: Each node is initialized to Ready-State, (status = 1)
//Let n be the number of nodes
for i = 0 to i ≤ n do
visit[i] ← 0
end for
Step 2: Enter first node in queue and update its state as Waiting-State (status = 2)
// Initialize first node v and update visit[v] = 1.
Add to queue[v], assign the pointers to keep track the rear and front queue elements
Front ← 0
Rear ← 0
Front ← front + 1
Rear ← rear + 1
queue[rear] = v
Step 3: Repeat the step number 4 and step number 5 until queue becomes empty
while front ≤ rear do
Step 4: Delete front node n from queue. Then process and update the status of n to the
Processed-State (status = 3)
v = queue[front]
front ← front + 1
Step 5: Add all the neighbours of n to rear of the queue which will in Ready-State (status = 1), then update their status to Waiting State (status = 2)
end while
for i = 0 to i ≤ n do
if Adj[v][i] == 1 and visited[i] == 0 then
rear ← rear + 1

Queue[Rear] = i
end if
end for
Step 6: Exit

4.4. Multipath Model:

Sensors in the sensor field senses the surrounding environment, collect and forwards the data to their respective cluster heads using the available path through their neighbor sensor nodes. Because of this, the nodes in between the path may die sooner and there would be disconnection in the path and also there will be congestion in the path. When the disconnection occurs in a path, the forwarding nodes have to search for an alternate path and perform the route discovery phase afresh. Hence, there is a need for finding multiple paths from source to the cluster and distribute the traffic load on available multiple paths. This will minimize end-to-end delay and thus improves network lifetime. Traffic load distribution among the sensor nodes is associated with the average energy consumption of the nodes to process the traffic within the path. Residual energy, number of packets in the nodes buffer and the distance from a node to its cluster head are considered to estimate the traffic load of a node. Fig. 2 shows the simple network with 6 nodes with source A with immediate neighbor B, C, D and F as CH and Fig. 3 shows the disjoint paths obtained through BFS algorithm.

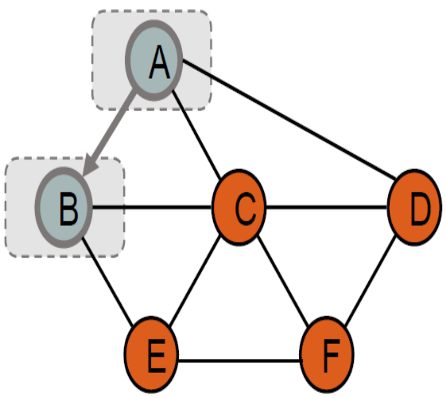

Fig. 2. Graph

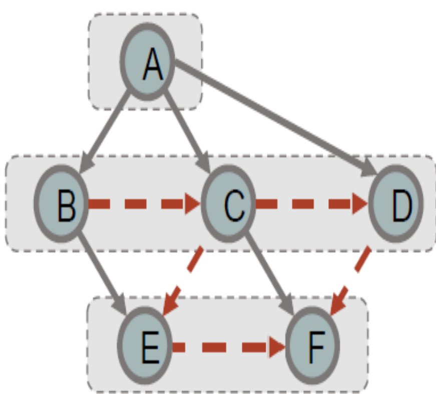

Fig. 3. BFS Tree

BFS algorithm yields disjoint paths and are shown in solid lines in Fig. 3. The availability of multiple paths are shown in the dashed lines called cross edges and are stored in pathlist table. For each source node s and the destination cluster head d, there exists a disjoint path P to forward the sensed data from s to d. The available path is chosen to forward data from source to destination. Monitoring on the condition of the available disjoint path, source node decides to chose alternate multiple paths to forward data to destination along with the primary path. A transmits data to F through C. C also transmits its own data to F. This leads to extra traffic on path A → C → F. When the traffic load on the path A → C → F reaches the threshold value, which includes the buffer capacity of each node in the path, the residual energy of each in the path and delay of the path, node A searches for the alternate path to forward its data. It searches in the path-table for the alternate path and the cross edges gives the alternate paths to A to transmit its data to F. Now multiple paths available from A to F include: A → B → E → F and A → D → F. A continues to use these available paths to transmit its data to F until it completes its transmission. The sample path-table for source A is given in Table 1.

TABLE 1

PATHLIST TABLE

Source Node	Destination Node	Disjoint Path	Multipath (Crossedge)
A	F	A → C → F	A → B → E → F A → D → F

Algorithm to chose multiple paths is given in Algorithm 2.

Algorithm 2: Algorithm to chose multiple paths

Step 1: path pathlist
// pathlist stores the disjoint paths to reach cluster head from various source nodes.
pathlist(bfs-paths(graph,source,destination))
bfs-paths (graph, source,destination)
queue = (source,[start])
while(queue)
for next in graph[vertex]-set(path)
if next == destination
yield path = [next]
else
queue.append(next, path + [next]) endif
endwhile
Step 2: if traffic > threshold-traffic-value then
Path ← select cross edges from pathlist
endif
Step 3: split the traffic among the available paths

5. Analytical Models

5.1. Modeling the problem into LPP:

The aim of this problem is to find optimal path for data transmission with a given total number of nodes in a particular area assuming homogeneous initial energy. The problem is extended to provide traffic over single and multiple routes.

Lifetime of sensor network: To position the sensor nodes to enhance the lifespan of node in the sensor network having *n* sensor nodes with same initial energy deployed in a particular area where node *i* should not directly forward data to *i + 1* as communication over long distance links is not desirable. The problem is formulated as LPP as follows:

$$\text{Minimize } E_i = T_{(i,i+1)} \sum_{k=1}^{t} e_k \quad (1)$$

and the distance constraint is given by:

$$\sum_{i=1}^{n} d_{(i,i+1)} = L$$

where $0 \leq d_{(i,i+1)} \leq R$.

Eq. (1) states the energy consumption of a node, where E_i depicts energy consumption of node i to forward sensed data, $T_{(i,i+1)}$ is the traffic load from node i to $i+1$, e_k is the energy consumed per unit time during the k^{th} discrete time interval, $d_{(i,i+1))}$ is the distance between nodes i and $i+1$, L is the network diameter and R is the sensing range of nodes. The nodes placed near the vicinity of sink will always carry heavy traffic than the nodes which are away from the sink node.

5.2. Traffic Engineering

A single path p has series of links in WSN. A multiple path set P have parallel system paths, splits the traffic generated by a source node and carry information along with it concurrently to destination node which attains load balancing along with faster data delivery. Single path and multiple path sets have performance parameters like energy consumption, delay that define quality of service (QoS) and reliability.

1) Single Path Delay, Energy and Reliability:

a) *Single Path Delay*: It is the delay between the nodes x_1 and x_n given by adding delay of all links in a path:

$$\mathrm{D}(p) = \sum_{i=1}^{n-1} D(x_i, x_{i+1}) \quad (2)$$

Where $D(x_{i,}x_{i+1})$ is the data delay over the link $(x_{i,}x_{i+1})$.

b) *Single path Energy:* Energy depletion between nodes x_1 and x_n in a path is defined as:

$$\mathrm{E}(p) = \sum_{i=1}^{n-1} E(x_i, x_{i+1}) \quad (3)$$

Where $E\left(x_{i,}x_{i+1}\right)$ is the needed energy for transmitting and receiving data between the node x_i and x_{i+1}, denoted as:

$$E(x_i, x_{i+1}) = f_{x_i} \rightarrow {}_{x_{i+1}} \cdot E(x_i, x_{i+1}) \quad (4)$$

Where $f_{x_i} \rightarrow {}_{x_{i+1}}$ represents rate of data over the link(x_i, x_{i+1}) and $E(x_i, x_{i+1})$ is the required energy by a node x_i to receive a bit and later to transmit the same to node x_{i+1}.

c) *Single Path Reliability:* Assuming that links of a path are independent, the path reliability $R(p)$ is given as:

$$R(p) = \prod_{i=1}^{n-1} R_{(x_i x_{i+1})} \quad (5)$$

Where $R_{(x_i x_{i+1})}$ is the reliability of the link(x_i, x_{i+1}). Assume that the lifetime of the i^{th} node is exponentially distributed with a parameter λ_i. Then the node reliability is given by:

$$R(p) = \prod_{i=1}^{n-1} R_{(x_i x_{i+1})} = \prod_{i=1}^{n-1} e^{-\lambda_i} = \exp[-(\textstyle\sum_{i=1}^{n-1} \lambda_i)p] \quad (6)$$

Node's lifetime is also exponentially distributed with a parameter $\lambda = \sum_{i=1}^{n-1} \lambda_i$. If X_i denotes the lifetime of node *i*, and *X* denotes the single path lifetime, then we can show that

$$0 \leq E[X] \leq \min\{E[X_i]\} \quad (7)$$

which gives common remark that a path is weaker than its weakest link. To prove the above, the single path lifetime

$$R_X(p) = \prod_{i=1}^{n-1} R_{X_i}(p) \leq \min\{R_{X_i}(p)\} \quad (8)$$

$$\text{Since} \quad 0 \leq R_{X_i}(p) \leq 1 \quad (9)$$

Then the expected life of the path:

$$E[X] = \int_0^{\infty} R_X(p)dt \leq \min\{R_{X_i}(p)dt\} \quad (10)$$
$$= \{E[X_i]\} \quad (11)$$

2) Multipath set Delay, Energy and Reliability:

a) Multipath set Delay: It is the delay faced by a data source which forwards data along the path set $\mathrm{P} = \{\mathrm{p1}, \ldots, \mathrm{p_N}\}$ is defined as:

$$D(P) = \max\{D(p) : p \epsilon P\} \quad (12)$$

b) *Multipath set Energy:* It is the energy spent by a data source which forwards data along the path set $P = \{p1, \ldots, p_N\}$ is defined as:

$$E(P) = \sum_{p \epsilon P} E(p) \quad (13)$$

Where $E(p)$ is expressed by eqn. (3).

c) *Multipath set Reliability:* It is the reliability of the data source which forwards data along the path set P is defined as:

$$R(P) = 1 - \prod_{p \epsilon P} (1 - R(p)), \quad (14)$$

Where $R(p)$ is the path reliability by eqn. (8).

Consider multiple path of n independent node with X_i denoting the lifetime of node i and X denoting the lifetime of the path. Then $X = \max\{X1, X2, .., X_n\}$

$$R_X(P) = 1 - \prod_{i=1}^{n-1} 1 - R_{X_i}(p) \geq 1 - [1 - R_{X_i}(p)] \quad (15)$$

for all i, which implies that the reliability of multipath is larger than that of any of its nodes. Therefore, the expected life of the path is

$$E[X] = \int_0^\infty R_X(P)dt \geq \max\{\int_0^\infty R_{X_i}(p)dt\} \quad (16)$$

$$= \max\{E[X_i]\} \quad (17)$$

is true with respect to the multi path routing in WSNs.

6. Simulation and Performance Evaluation

Simulation of dynamic clustering and optimal routing using BFS has been done on MATLAB [12] considering a random network of 100 nodes. We first introduce a performance bound for the optimization problem. The sensing area is divided into blocks of clusters, i.e. total number of clusters is obtained by dividing the total length of network by sensing range of nodes. The minimum energy required for transmitting data from each cluster to sink is calculated. Single BS is used in the network area for information gathering from different data sources. Location of the BS can be chosen arbitrarily in the network. Sensor nodes are randomly placed in a 100m x 100m square field ensuring that nodes results in connected graph. Assuming that the sensing range and transmission range are same, the default value of 10m is set as transmission range. The sensor field is divided into 30 zones (clusters). Four different scenarios are considered corresponding to the distribution of sensors in the sensing field, which result in z nonempty zones. In every zone, 10 nodes on an average are monitoring that zone. Data packets of different sizes are assumed to be generated and we fix the size of the packet for different settings for comparison purpose with different schemes. We illustrate the numerical results and compare the performance of the proposed idea, limits, and the uniform placement scheme in terms of network lifetime and overall energy dissipation with the same number of nodes. Below are the results of the proposed system.

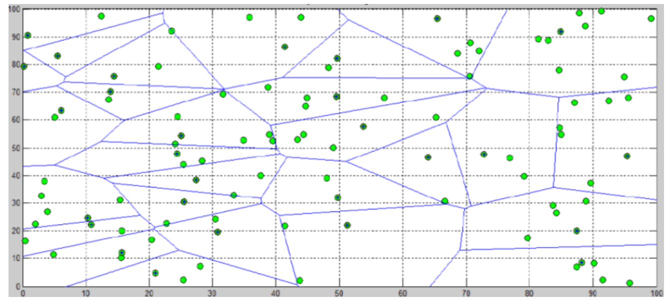

Fig. 4. Dynamic clustering

Fig. 4 shows clustering formation in a sensor field where clusters changes dynamically based on the traffic generated and nodes are placed in the form of levels and optimal path for routing is obtained using BFS algorithm.

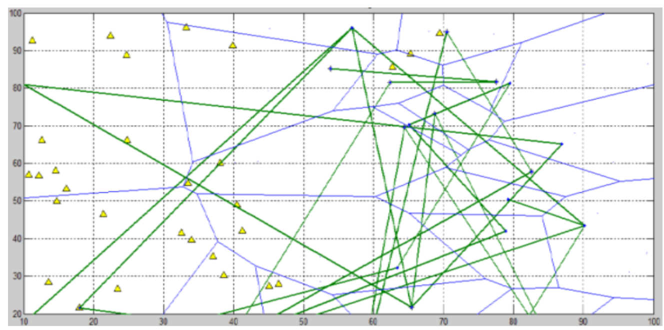

Fig. 5. Multipath Routing

Fig. 5 shows how multipath routing is accomplished in sensor field. In a cluster only one node can become cluster head and the selected cluster head can transfer traffic through multiple routes to BS. Fig. 6 shows the graphical result of the average energy consumption of nodes in each round. x-axis gives the number of rounds and y-axis gives the average energy of each node in the network. As the number of rounds increases, the energy of each node keeps decreasing.

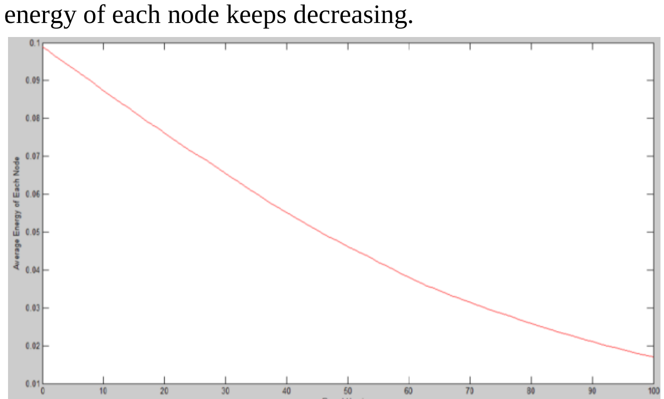

Fig. 6. Average Energy Consumption of nodes

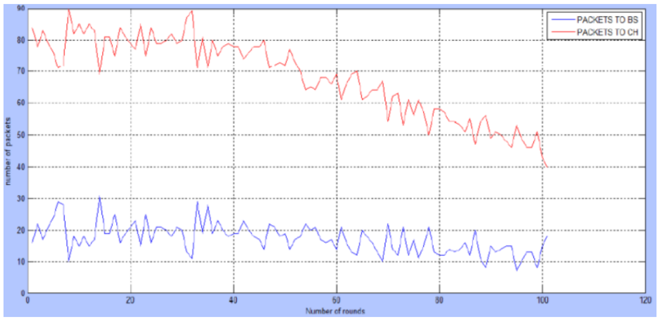

Fig. 7. Data aggregation over CH v/s BS

Fig. 7 figure shows the data aggregation performed over cluster head and base station. x-axis gives the number of rounds and y-axis gives the number of packets collected by CH and BS. As CH collects redundant data it aggregates the data and then is forwarded to BS. The number of packets received by BS is minimized when compared to the number of packets received by CH. Below are comparison results of proposed system with other routing and clustering protocols.

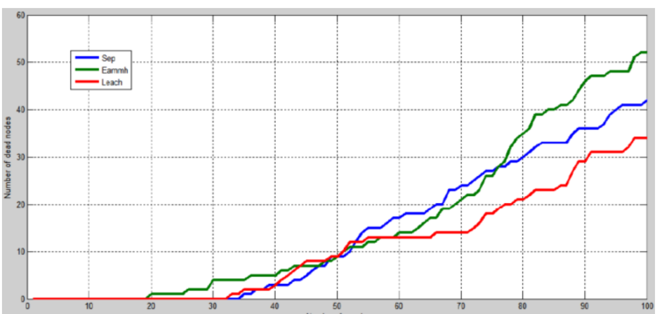

Fig. 8. Dead nodes in each round

Fig. 8 shows the comparison of dead nodes over each round in mLEACH, SEP [10] and EAAMH [9]. x-axis gives the number of rounds and y-axis gives the count of dead nodes in sensor network, where nodes in mLEACH relatively lasts long when compared to SEP and EAMMH.

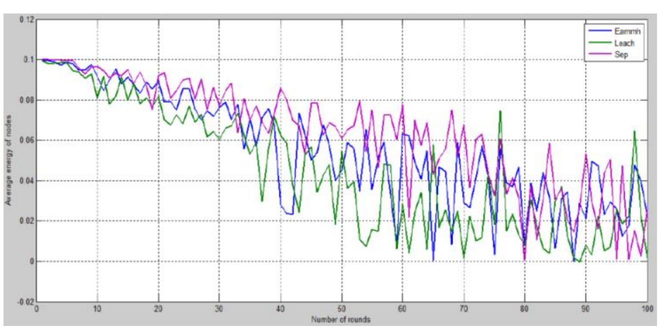

Fig. 9. Energy consumption of nodes

Fig. 9 shows the energy consumption of nodes in mLEACH, SEP and EAMMH. x-axis gives the number of rounds and y-axis gives the average energy consump-tion of mLEACH, SEP AND EAMMH, where nodes in mLEACH consume relatively less power compared to other protocols.

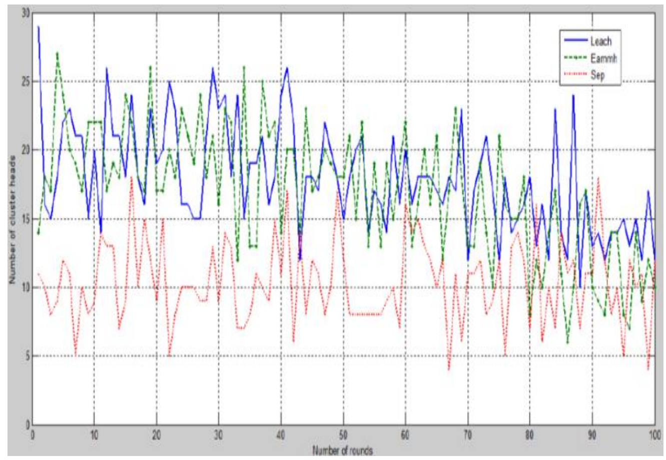

Fig. 10. Number of cluster heads

Fig. 10 shows number of cluster heads generated per round in mLEACH, SEP and EAMMH. x-axis gives the number of rounds and y-axis gives the number of cluster heads elected per round is more in LEACH and is through dynamic clustering.

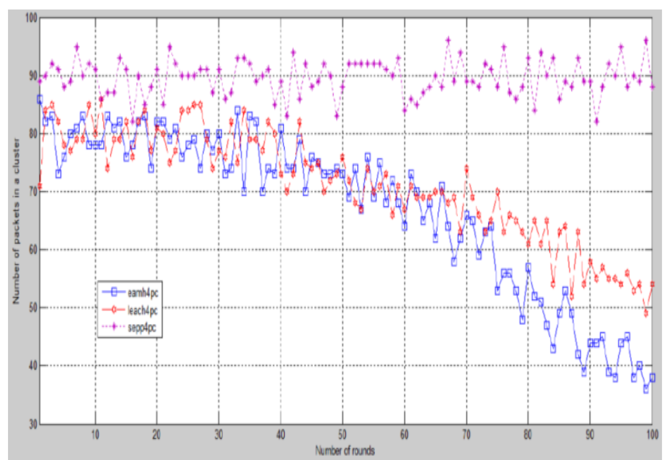

Fig. 11. Number of packets to CH

Fig. 11 shows the comparison of number of packets transferred by nodes to their cluster head. x-axis gives the number of rounds and y-axis gives the number of packets received by CH, where number packets received by cluster heads in mLEACH is in between packets received in SEP and EAMMH

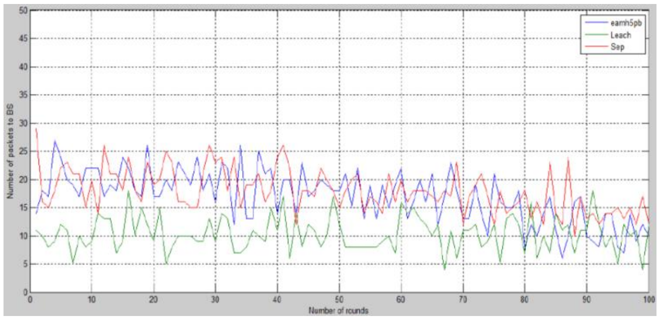

Fig. 12. Number of packets to BS

Fig. 12 shows that the comparison of number of packets transferred by cluster head to the base station. x-axis gives the number of rounds and y-axis gives the number of packets received by CH, where number of packets received by base station in mLEACH is relatively less than SEP and EAMMH because all the redundant data have been deleted and only required data is forwarded to base station.

7. Conclusion and Future Work

In this work, grid based dynamic clustering and data aggregation scheme for WSNs which attains low energy consumption is proposed. An optimal multipath routing obtained using BFS algorithm that enhances network life by exploiting data aggregation technique. The clusters are dynamically formed and operated using heuristic approaches that fit lesser number of aggregation points during forwarding data to BS. Analytical model is developed for single and multipath delay, energy and reliability. The obtained results depict the improvement in lifetime of sensor network when compared with the other various schemes. In future work, exploration can be done on ant-colony optimization and particle swarm optimization to enhance life of network.

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