Energy Efficient grid based routing algorithm using closeness centrality and BFO for WSN

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Abstract - *The principle objective of wireless sensor network is not only to perform the operation of data communication but also to increase the network lifetime by retaining the energy of nodes for the longer period . To achieve this objective, in this paper, grid clustering- which is the simplest, feasible and efficient way of clustering is utilized for clustering the entire sensor network, after that closeness centrality is utilized for cluster head selection, which is based on the distance criteria, as energy consumption is directly proportion to square of distance, hence this centrality approach will select the cluster head at optimal location to minimize the energy utilization. For routing, BFO which is nature inspired algorithm is utilized, by considering energy and distance in its fitness function. Among all the optimization techniques, BFO is preferred as it can provide optimal solution for any multi-objective function. Simulation is done in MATLAB and it is observed that proposed algorithm outperforms the existing one in terms of retaining number of alive nodes for more number of rounds and maintaining the stability in the network for longer time.*

Key Words: Wireless Sensor Network, Base station, Scalability, Energy Efficiency.

1. INTRODUCTION

Wireless sensor networks (WSNs) are highly distributed application specific organized sensor network that empowers applications for critical decision-making through collaborative computing, communications, and distributed sensing. Over the past decade Wireless Sensor Networks (WSNs) is rapidly growing area because of fast growth in Micro electro-mechanical system (MEMS) technology, low power digital and analog circuitry, RF design, and wireless communication and sensor technology.WSN is a self-configured and infrastructure less wireless network that is utilized for performing monitoring, tracking and detecting operations in real time environmental. This wireless sensor network can be utilized for continuous sensing, sensing the location and also for event detection [1]. It comprises of expansive number of densely deployed multifunctional autonomous devices or detection stations called sensor nodes or sensor hubs for sensing and monitoring physical or environmental conditions. These nodes are equipped with sensors, embedded microprocessors and microcontroller, radio transmitter and receivers and have not only sensing capability but also processing and communication capabilities. These sensor node cooperatively send their sensed data from the senor network to the main location called base station or gateway or sink node through radio waves. The principle outline objective of these sensor networks is to perform the operation of data communication while attempting to increase the network lifetime as well as forestall connectivity degradation by utilizing vigorous energy management techniques. WSNs are utilized in commercial and industrial applications. Monitoring, tracking, and controlling are the three main area of application of the wireless sensor network. Some of the specific applications from these three typical applications are monitoring of habitat, health care services, military application (enemy tracking, target detection, smart fencing, monitoring tracking surveillance of border etc.), nuclear reactor controlling, fire detection, volcanic earthquake, traffic monitoring, and weather forecasting and so forth [2]. These networks are basically utilized for low bandwidth, and delay tolerant application ranging from civil, military to environment and healthcare.

The main objective of WSN is to guarantee a certain network lifetime and to ensure that all the nodes in the network die at the same time, so that very little energy left behind in the network when the network expires. As nodes in the network are resource constraints because of limited battery, limited computation and communication capability because of small size processors, so to have longer lifetime there is a need of energy optimization of network resources which can be achieved by doing efficient routing. Routing protocol are responsible for discovering and maintaining energy efficient routes in order to make the communication reliable and efficient [3]. Clustering routing emphasis on keeping up the energy utilization of the sensor hubs by including them in multi-hop fashion for routing (which reduces the long distance communication) and perform data aggregation and fusion to reduce the number of messages delivered to sink hence reduces the number of transmissions[4]. Clustering offers the advantages of scalability, fault tolerance, data aggregation load balancing, stabilized network topology, maximal network lifetime reduced routing delay, energy saving, increases system capacity, make the network robust and guarantee of connectivity[5]. There are different approaches of making clusters that may be same or different sized, static or dynamic, layered, grid approach etc. Grid based clustering is most efficient way of clustering where every grid running in parallel and independently form a cluster making it suitable for large scale network. Grid technique having the advantages of simplicity, scalability, and uniform energy consumption [6]. Research is going on selecting the size of the grid, fair selection of cluster head and many more for making it suitable for various applications like for large scale wireless network, for solving hot spot problem , for load balancing, energy efficiency etc. Cluster head has the responsibility of transferring the data from the entire cluster head to the base station, hence due to extensive load cluster head consumes more energy and die soon. Efficient approach for the selection of cluster head and increases the network lifetime and reliability of the network. Cluster head is selected based on the various parameters like current energy of the network, distance from the base station and node degree, also rotation of the role of cluster head among the cluster members is preferred to distribute the load among the nodes [7].

In this paper, static grid approach for clustering and dynamic cluster head based on the closeness centrality is utilized to have energy efficiency in the network. Energy consumption is calculated by transmission distance hence it is important to choose the CHs at optimum location to minimize the energy consumption [8]. In graph theory the term node centrality is measure of importance of node in the graph. Among different types of centralities, closeness centrality measure how fast information can spread from node to any other node in the network (i.e. based on the distance) [9]. Different routing protocols have been designed to select a data transfer path upto the base station which is having minimum consumption of energy in order to prolong the network lifetime, reduce energy consumption and reducing the delay. Bio inspired or heuristic routing is gaining popularity as these algorithms offer an energy efficient network, by finding the optimal solution in terms of finding the best path between source to destination. Hence BFO (Bacterial Foraging Optimization) is utilized in this paper for routing purpose.

2. GRID CLUSTERING

In grid clustering, the entire area is divided in small grids, where each such grid is a cluster. Grid based approach is most popular for dynamic network configuration and selection of routing paths [10]. Moreover the existence of multiple paths between source and base station in grid topology minimize energy dissipation at node by splitting the traffic over multiple path [11].

Advantages of grid clustering:

a) It has fast processing time when it is compared with all other types of clustering algorithms. Because all clustering operations are performed in grid cells instead of data objects.

b) The decision of selecting cluster head per grid is usually done by nodes themselves which makes it suitable for large scale network. Grid based techniques are popular due to its simplicity, scalability, and uniformity in energy consumption across the network [12].

c) Simple and feasible [13]

d) Once grid structure is establish nodes can communicate locally with their grid head and read data processing centre or sink node through neighbor grids.

e) They can transmit data directly, no need of explicitly path creation [14].

f) Existence of multiple paths between source and base station in grid topology minimizes energy dissipation at the node by splitting the traffic over multiple paths.

3. NODE CENTRALITY

Node Centrality measures are tools to identify most central node in the network i.e. it defines the relative importance of node in the network. It defines how important a particular node is, that may be in terms of number of connections it has , how fast it convey the information in the network, and information flow control [15]. It is of four types:

a) Degree centrality: It measures the number of links or connections of a node with all another nodes in the network i.e. how many nodes are connected to a particular node. It simply counts the number of edges a particular node have. Node with the highest degree of node will be the important node in that network.

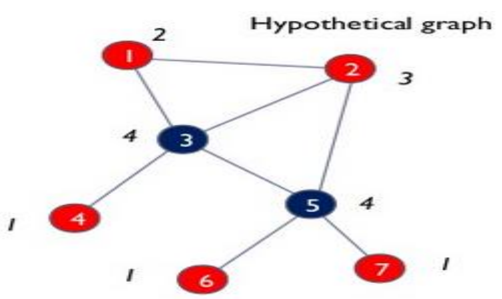


Fig.1 Degree of nodes in the network

b) Closeness centrality: It is a measure in terms of how quickly any information from a node reached at every another node in the network. It is stated as the inverse of the farness and this farness is summation of the shortest path that every pair of nodes in the network have. If C_c (i) defined the centrality for i^{th} node, d (i, j) is the shortest path from node i to node j then closeness centrality is given as:

$C_c(i)=(n-1)(\sum_{j=1}^{n} d(i,j))^{-1}$ (1)

Smaller is farness, higher is centrality.

c) Betweeness centrality: In this node importance is defined in terms of its frequency belonging to the shortest distance among other pairs of nodes. It defines the number of time a particular node act as a bridge in shortest distance among the pairs of nodes. If C_B (i) defines betweeness centrality, $g_{jk}(i)$ isnumber of shortest path connecting jkand passingvia node i and g_{jk} is total no. of shortest path then between centrality of node is given as:

$C_c(i)= \sum_{(j\neq k)}(g_{jk}(i))/g_{jk}$ (2)

d) Eigen vector centrality: It measure the influence of a particular node within the network. It defines which node in the network is connected to the most important or connected node in the network. Hence, Eigen vector centrality of a node also dependent on its neighbors but not in terms of number of neighbors as in degree centrality but in terms of connections that the neighbor nodes have[16 , 17].

3. BACTERIAL FORAGING OPTIMIZATION:

Optimization means to minimize cost function and/or maximize the performance. Hence, to optimize is to find the best solution for a particular problem. Over the past decades, nature inspired algorithms like PSO, ACO are gaining attention as they offer solution for complex problems like non linear, non differential, multifunction etc. BFO is an addition to these bio inspired algorithm. Prof. K.M. Passino proposed this swarm based algorithm in 2002, inspired by food searching behavior if the E. coli (Escheerichia coli) bacteria present in the human intestine. The key thought of this new algorithm is the utilization of group foraging technique of swarm of E coli bacterium to optimize the multi-objective function. This algorithm is drawing the attention of researchers because of its biological motivation and its efficiency to solve optimizing problem in the real world. BFO having the advantage of parallel searching, its ability to jump out of the local minima, less computation burden, less time required for computation and capable to optimize multi-objective function. Size and non linearity of problem have no concern with this algorithm. This algorithm mimics the food searching behavior of Ecoli bacteria. E coli bacteria search for the nutrients in order to maximize its energy intake (E) per unit time (T). Each bacterium also set up communication with other bacteria by sending signals. Then depending on these two factors foraging decisions are taken[18].

The basic procedure of BFO to solve optimization problem is initialization of parameter, evaluation of fitness function, optimization using group interaction. The foraging procedure of the bacteria is divided into four steps:

a. Chemotaxis: This is the behaviour of the bacteria to decide the direction of movement. The main aim is to move the bacteria to nutrient rich area and avoid noxious environment. During foraging process, motion is gained by set of tensile flagellum which make bacteria to tumble and swim. When the base of the flagella is rotated anticlockwise, then it will push the bacterium and bacteria will swim in same direction. And if flagella rotate clockwise, each flagellum will pull the cell, results in independent movement of each flagellum due to which bacterium tumbles. These bacteria can move in two ways biologically, either it may swim in the same direction for a particular period of time or it may tumble in the other direction and alternate between these two modes for its whole lifecycle. Let us suppose if $\Theta^i(j,k,l)$ is i^{th} bacteria at j^{th} chemotaxis step, k^{th} reproductive step and l^{th} elimination and dispersal step. C(i) is the step size in random direction during tumbling, then movement of bacteria is represented as

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

(3)

Here, Δ represent a vector in random direction whose elements lie in [-1, 1].

b. Swarming: When a group of Ecoli bacteria is placed in the centre of semisolid matrix with a single nutrient chemo effector, they arrange themselves in a travelling ring by promoting nutrient gradient achieved by consuming of nutrients by that group. Cell when fortified by a large amount of succinate, discharge a attractant aspirate, provide an attraction signal to each other which cause them to gather in a group and in this manner move as concentric circle of swarms with high bacterial density. The numerical representation of cell to cell signaling is given by

$$J_{cc}(\theta,P(j,k,l) = \sum_{i=1} J_{cc}(\theta,\theta^i(j,k,l))$$
$$= \sum_{i=1}^{s}\left[-d_{attrac\tan t}\exp(-w_{attrac\tan t}\sum_{m=1}^{p}(\theta_m-\theta_m^i)^2)\right]+$$
$$\sum_{i=1}^{s}\left[h_{repellant}\exp(-w_{repellant}\sum_{m=1}^{p}(\theta_m-\theta_m^i)^2)\right]$$

Where, $J_{cc}(\theta,P(j,k,l)$ =value of the objective function that has to add to original objective function which is to be minimized,

S = number of bacteria, p=variable number that has to be optimize and θ = (θ_1, $\theta_{2.......}$ θ_p)^T is any point in p dimensional search space. $d_{attrac\tan t}$, $w_{attrac\tan t}$ $h_{repellant}$ $w_{repellant}$ are different coefficients.

c. **Reproduction:** The most unhealthy bacteria get die whereas every healthy bacteria get divided in 2 bacteria asexually and placed in same location as parent bacteria to maintain same size swarm population.

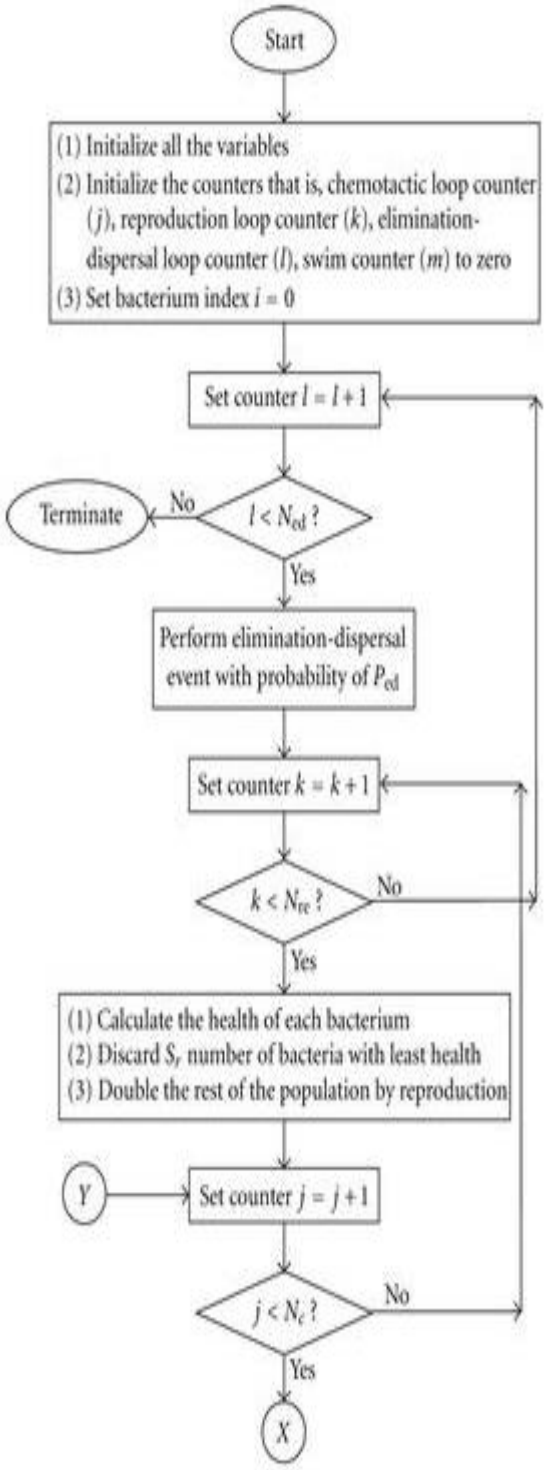
d. **Elimination and dispersal:** changes in the local environment like temperature change may occur either often or sudden which may result in either killing of group of bacteria in the region of nutrition rich area or dispersion of group in other ne location. To fortified this , sum of the bacteria get randomly liquidated with small probability whereas random initialization of new replacement is done over search space [19].

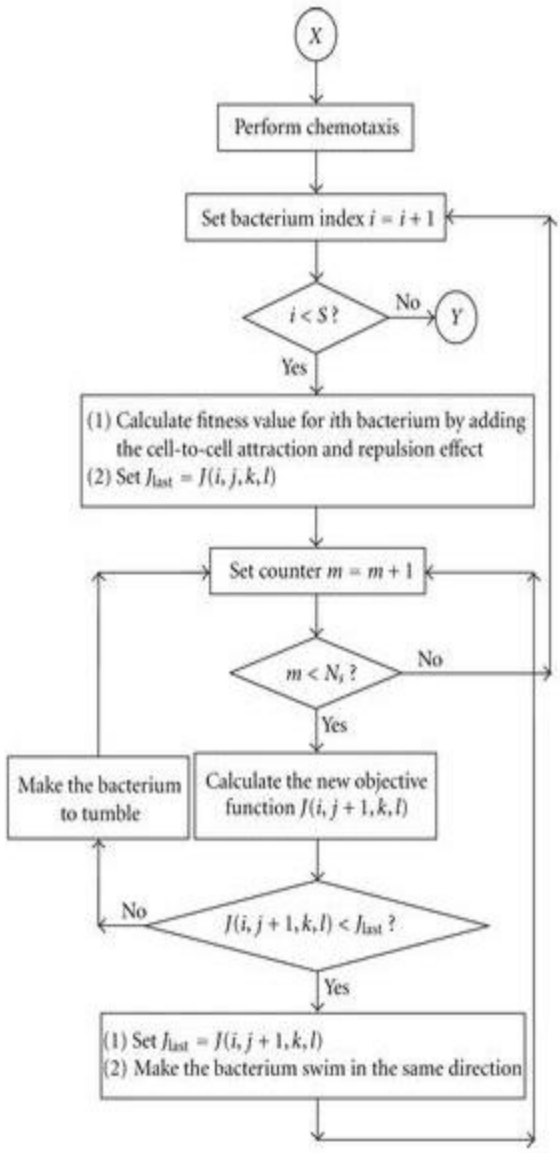
3.1. Psedocode for BFO

Assume following parameters:
i: particular bacteria
j: chemotactic step index
k: reproductive step
l: elimination and dispersal step
p: search space dimension
S: no. of bacteria
N_c : no. of chemotactic step
N_s: swarming length
N_{re}: no. of reproduction steps
N_{ed} : no. of elimination steps
P_{ed}: probability of elimination dispersal
C(i): Step size

Initialize Parameters $p, S, N_c, N_s, N_{re}, N_{ed}, P_{ed}, C(i) (i=1,2,3...S), \Theta^i$
for $l=0$ *to* N_{ed}
for $k=0$ *to* N_{re}
for $j=0$ *to* N_c
for each bacterium in population set Health=0
for $i=0$ *to* S
Calculate $J(i,j,k,l)=J(i,j,k,l)+J_{cc}(\Theta^i(j,k,l),P(j,k,l))$
$J_{last}=J(i,j,k,l)$
Generate a random tumble vector $\Delta(i) \in \Re^p$ *in* $[-1,1]$
Move $\Theta^i(j+1,k,l)=\Theta^i(j,k,l)+C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$
$J(i,j+1,k,l)=J(i,j,k,l)+J_{cc}(\Theta^i(j+1,k,l),P(j+1,k,l))$
Set Swim length counter $m=0$
while $m< N_s$
$m=m+1$
if $J(i,j+1,k,l)<J_{last}$
$J_{last}=J(i,j+1,k,l)$
Move $\Theta^i(j+1,k,l)=\Theta^i(j,k,l)+C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$
Calculate new $J(i,j+1,k,l)$ *using this* $\Theta^i(j+1,k,l)$
else $m=N_s$
end while
end for
end for
for each $i=1,2..,S$ *calculate* $J^i_{health}=\sum_{j=1}^{N_c+1}J(i,j,k,l)$
Sort Population in ascending order of J^i_{health}
Copy top half of onto bottom half of the population.
end for
for each $i=1,2,...,S$ *with probability* P_{ed}, *perform ele.disp.*
end for

3.2 FLOW CHART OF BFO:





4. PROPOSED WORK AND SIMULATION

In this paper, for the purpose of simulation, a square sized network area is taken with dimensions 100*100 meter^2.100 homogenous senor nodes in term of energy homogeneity, are randomly deployed in the entire area. These sensor nodes are static in nature i.e. they remain fixed throughout the network lifetime. Base station is considered to be present at the centre of the network area. Sensor nodes are represented by the small circles. This algorithm works in rounds. Each round has two phases: clustering and routing phase. Clustering phase is further divided in initialization phase for cluster formation and setup phase for cluster head selection. In initialization phase the entire cluster sensor network region is divided into same sized square shaped grid, such that each such square is a grid. This grid size depend upon the transmission range of the sensor node. Here clustering is static i.e. once the cluster are formed they will remain same for the entire lifetime of the network. In the setup phase, cluster head is selected from each such grid. Closeness centrality is calculated for each node in the cluster by using (1), then the node with the minimum value of this centrality in each cluster is chosen as a cluster head. In the routing phase BFO is utilize to select the optimal route from CH(cluster head) to BS(base station). in the fitness function of residual energy of next hop cluster head and Euclidean distance are considered as sub-objective function. Next hop cluster head is selected which has highest energy and at minimum distance from cluster head and base station. So, fitness function that has to be minimized is:

Fitness function= f_1+f_2

Where

$$f_1 = \sum_{i-1}^{m} \frac{1}{E_{CHi}}$$

$$f_2 = \sum_{i=1}^{m} dis(CHi, NH) + dis(NH, BS)$$

Where m= no. of cluster head

CHi= cluster head of ith cluster

NH= next hop cluster head

This proposed algorithm is simulated in MATLAB considering following parameters.

Table1: Parameters

PARAMETER	VALUE
Network area	100*100
Shape of the network	square
No. of nodes	100
Transmitter/receiver electronic circuit	E_{elc}= E_{tx}= E_{rx}= 50nJ/bit
Data aggregation energy	EDA=5nJ/bit/Signal
Transmit amplifier(if d to BS <d0)	Efs=10pJ/bit/m^2
Transmit amplifier(if d to BS >d0)	Emp=0.0013pJ/bit/m^4
Number of bacteria	15
Nc	20

Nre	20
Ned	20
Ns	10
C(i)	0.01
Ped	0.9

The simulation results are shown in Chart 1 and results are compared with the existing grid technique defined in[12]

Table2. No. of alive nodes at different rounds

No. of rounds	No. of alive nodes	
	Existing technique	Proposed technique
1850	100	100
1900	98	100
2045	68	95
2100	65	75
2300	33	40
2404	0	25
2523	0	0

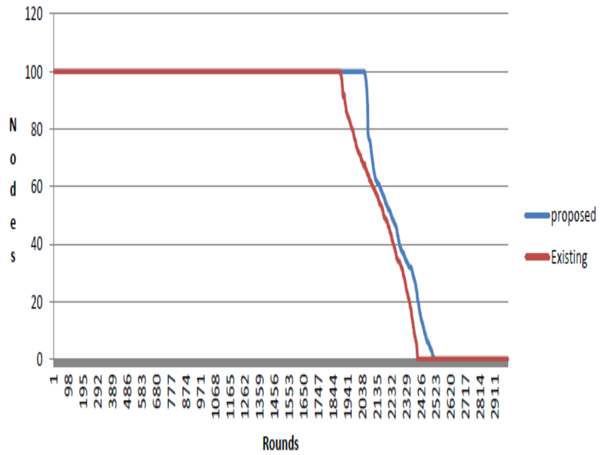


Chart 1. Comparison of no. of Rounds vs no. of Alive Nodes for proposed and existing grid technique

Table3: Percentage of lifetime improvement

Network Lifetime	Round at which node start dieing	Round at which entire network vanishes
Existing technique	1900	2404
Proposed	2045	2523
Percentage of improvement	7.6	5

From the chart 1, table 1 and table 2 it is clear that the alive nodes are retained upto 2523 rounds where as in the existing grid technique these nodes are alive only upto 2045 rounds. Hence the network lifetime is improved by using this centrality and BFO techniques.

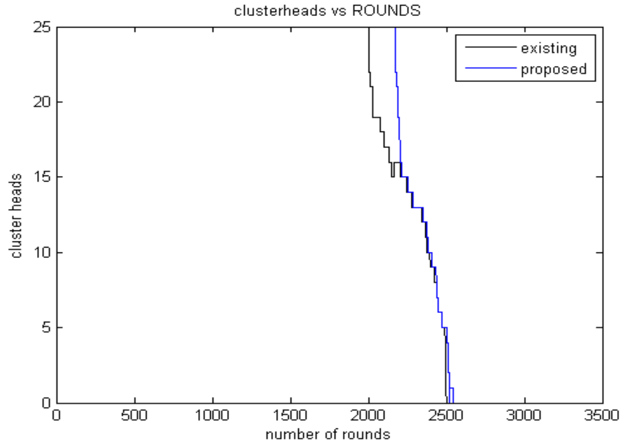


Chart 2. Cluster head vs number of rounds

From chart2 it is clear that initial number of cluster had i.e. 25 cluster heads are maintained stable upto 2000 rounds for existing grid technique, after which they start die. And for the proposed scheme 25 cluster heads are maintained for 2150 rounds. Hence this proposed scheme enhances the network stability up to 7%. Increase in network lifetime and stability makes the network more energy efficient.

5. CONCLUSIONS

In order to increase the lifetime of the network, an energy efficient grid based clustering algorithm is proposed for WSN, in which each grid is of same size square cluster, which provide the simplest way of clustering, with fast processing time and provide simplicity, and uniform energy consumption in the entire network. Energy consumption is each round is reduced by selecting cluster head based on the centrality. Optimal path is selected for routing which optimize the route from cluster head to the base station in terms of residual energy and distance, which improve the energy consumption of the network and hence improves system lifetime and stability.

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