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B-LEACH: A Clustering Protocol for Wireless Sensor Networks based on Bacterial Foraging Algorithm

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Abstract - Wireless sensor networks [WSN] are popular as they are potentially low cost solution to various real world challenges. Environment is monitored by the autonomous nodes of the WSNs. Recent research in WSN has led to various new routing protocols. Routing protocols have proven to increase the network throughput, reduced delay in packet transfer and save energy. Hence in this work we propose a novel clustering protocol that uses bacterial foraging algorithm [BFOA] inspired approach towards improving the existing basic LEACH protocol for reduction in energy consumption with respect to communication, aiming to enhance the network lifetime. Simulated results prove that implementing this kind of computational intelligence in the pre-existing protocol considerably improves its performance.

Keywords - Clustering *Protocol, Bacterial Foraging Algorithm, LEACH Protocol, Computational Intelligence.*

1. Introduction

The need of monitoring and measuring various physical phenomena like temperature, humidity, vibration etc is common to many areas including agriculture, forestry, healthcare, logistics, transportation and military applications. Even though wired sensor networks have long been used to support such environments, the low cost involved in installing, terminating, testing, maintaining, trouble shooting of wireless sensor networks make them potentially attractive. The sensors that, when distributed in the environment comprise WSNs include cameras as vision sensors, microphones as audio sensors, and those capable of sensing ultrasound, infra-red, temperature, humidity, noise, pressure and vibration. Although the individual sensor's sensing range is limited, WSNs can cover a large space by integrating data from many sensors. Diverse and precise information on the environment may thus be obtained[1].

Plethora of applications of WSN, these networks have several restrictions like limited energy supply, limited computing power. Many routing protocols are proposed by researchers to improve lifetime of network and to prevent connectivity degradation by employing aggressive energy management techniques. Use of computational intelligence is also one of the wide spread approach in this direction. There are many algorithms like swarm intelligence including Ant Colony Optimization, Bee Colony Optimization, Particle Swarm Optimization, genetic algorithms, Intelligent water drops, glow worm optimization, fire fly optimization, Artificial Immune Systems, Evolutionary Algorithms, neural networks etc whose usage of has lead to effective algorithm design in tackling various issues in Wireless Sensor Networks like routing, security etc.

Bacterial foraging optimization algorithm (BFOA) being one of them has been widely accepted as a global optimization algorithm of for distributed optimization and control. BFOA is inspired by the social foraging behavior of *Escherichia coli*. Bacteria Foraging Optimization Algorithm (BFOA) was proposed by Passino [2]. Application of group foraging strategy of a swarm of *E.coli* bacteria in multi-optimal function optimization is the key idea of this new algorithm. Bhakwad K.M. et al. (2011) [3] proposed a new approach to enhance PSNR of highly corrupted image affected by impulse noise using BFOA. In [4], a new protocol called BIHP (BIO INSPIRED HYBRID ROUTING

PROTOCOL) Bacteria foraging optimization technique is used for the selection of cluster head and Hybrid protocol for the improvement of the short coming of LEACH & PEGASIS routing protocol. In [5] a new clustering protocol called LEICP (low energy intelligent clustering protocol), an improvement of the LEACH protocol is proposed. At each round the node called auxiliary cluster-head calculates the position of the cluster head using Bacterial Foraging Optimization Algorithm. After aggregating the data received, the cluster-head node decides whether to choose another cluster-head as the next hop for delivering the messages or to send the data to the base station directly using Dijkstra algorithm to compute an optimal path.

In this work, we present a proposal of using the bacterial foraging algorithm. Cluster heads are initially chosen by LEACH. Later each node finds its optimal cluster head by calculating fitness function using BFOA. It was found that new algorithm serves to be as betterment on the basic LEACH protocol. The algorithm was tested and executed in MATLAB 2009. The rest of the paper is organized as follows: section 2 deals with the basic LEACH protocol, section 2.1 deals with the bacteria behavior and algorithm. Section 3 highlights the proposed methodology. Section 4 deals with the results and discussions associated with the protocol, section 5 with the concluding remarks and finally the references.

2. LEACH (Low Energy Adaptive Clustering Hierarchy) Protocol

This section briefs out the LEACH protocol which was proposed by W.R.Heinzelman [6]. LEACH (Low Energy Adaptive Clustering Hierarchy) is a self-organizing, adaptive clustering-based protocol that uses randomized rotation of cluster-heads to evenly distribute the energy load among the sensor nodes in the network. LEACH based on two basic assumptions:

(a) base station is fixed and located far away from the sensors, and
(b) all nodes in the network are homogeneous and energy constrained.

The idea behind LEACH is to form clusters of the sensor nodes depending on the received signal strength and use local cluster heads as routers to route data to the base station. The key features of LEACH are:

(a) Localized coordination and control for cluster set-up and operation.
(b) Randomized rotation of the cluster ”base stations” or ”cluster-heads” and the corresponding clusters.
(c) Local compression to reduce global communication.

In LEACH, the operation is separated into fixed-length rounds, where each round starts with a setup phase followed by a steady-state phase. The duration of a round is determined priori. LEACH algorithm works as follows:

1. Advertisement phase: in this phase, nodes elect themselves to be a cluster-heads for the current round (r) through a cluster-head advertisement message. For this cluster-head advertisement, the cluster heads use CSMA MAC protocol. After the completion of this phase, and depending on the received advertisement signal strength; the non cluster-head nodes (their receivers must be kept on during this phase to hear the advertisements of all cluster-heads) determine the cluster to which they will belong to for this current round(r). At each round, a node n selects a random number k that is between 0 and 1. If k is less than a threshold T(n),then the node becomes a cluster-head for the current round(r).

$$T(n) = \frac{P}{1 - P\left(rmode\left(\frac{1}{p}\right)\right)}, if\ n \in G$$
$$T(n) = 0\ otherwise \qquad (1)$$

Where *P* is the desired percentage of cluster-heads, *r* is the current round, and *G* is the set of nodes that have not been cluster heads in the last 1/*P* rounds. Since *k* is randomly selected, then the number of cluster heads may not be fixed.

2. Cluster set-up phase: after each non-cluster-head node will has decided to which cluster it belongs, it informs the cluster-head node that it will be a member of the cluster. So, each node transmits this information back to the cluster head using CSMA MAC protocol.

3. Schedule Creation phase: The cluster-head node receives all the messages for nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster.

4. Data Transmission phase: after the creation of both the clusters and the TDMA schedule (TDMA is fixed), nodes in the cluster start transmitting the data they already have during their allocated transmission time to the cluster-

head(Cluster-head node keeps its receiver on all the time to receive the sent data). Once all the data (sent by nodes in the cluster) have been received by the cluster-head node, it will perform signal processing function to compress the data into a single signal (the steady-state operation of LEACH networks)Although, LEACH has shown good features to sensor networks, such as clustering architecture, localized coordination and control, randomized rotation of cluster head, and local compression to reduce global communications (energy consumption minimization), it suffers from the following drawbacks.

(a) It cannot be applied to time-constrained application as it results in a long latency.
(b) The nodes on the route a hot spot to the sink could drain their power fast. This problem known is as "hot spot" problem.
(c) The number of clusters may not be fixed every round due to the selection of k .
(d) It cannot be applied to large sensor networks.[7]

2.1 BFOA Algorithm

The section highlights the behavioral aspects of E-coli bacteria and the bacterial foraging algorithm with its modification to the proposed work.

2.1.1 Behavior of Bacteria

Escherichia coli (commonly abbreviated E.coli) is a Gram-negative, facultative, bacterium of the genus Escherichia that is commonly found in the lower intestine of warm blooded organisms. BFOA is inspired by the group foraging behavior of the E.coli bacteria.[8]

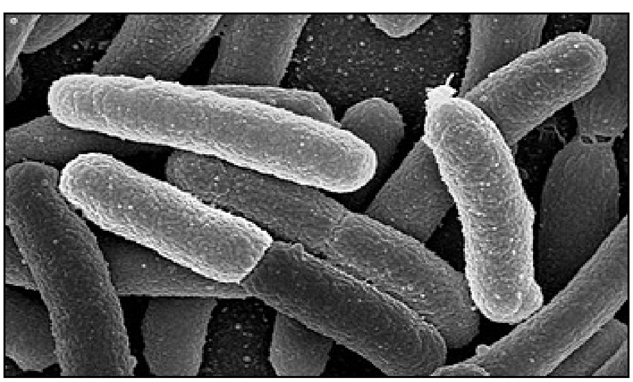

Fig.1.E.coli(Scientificname:*Escherichia coli,*courtesy:www.bnl.gov)

E.coli will perceive chemical gradients in the environment (such as nutrients) and move toward or away from specific signals. Similarly, they secrete attracting and repelling chemicals into the environment and can perceive each other in a similar way. Using locomotion mechanisms (such as flagella) bacteria can move around in their environment, sometimes moving chaotically (tumbling and spinning), and other times moving in a directed manner that may be referred to as swimming. Bacterial cells are treated like agents in an environment, using their perception of food and other cells as motivation to move, and stochastic tumbling and swimming like movement to re-locate. Depending on the cell-cell interactions, cells may swarm a food source, and/or may aggressively repel or ignore each other.

2.1.2. The Bacteria Foraging Optimization Algorithm

During foraging of the real bacteria, locomotion is achieved by a set of tensile flagella. Flagella help an E.coli bacterium to tumble or swim, which are two basic operations performed by a bacterium at the time of foraging. When they rotate the flagella in the clockwise direction, each flagellum pulls on the cell. That results in the moving of flagella independently and finally the bacterium tumbles with lesser number of tumbling whereas in a harmful place it tumbles frequently to find a nutrient gradient. Moving the flagella in the counterclockwise direction helps the bacterium to swim at a very fast rate.

In the above-mentioned algorithm the bacteria undergoes chemotaxis, where they like to move towards a nutrient gradient and avoid noxious environment. Generally the bacteria move for a longer distance in a friendly environment. Swim and tumble of a bacterium: When they get food in sufficient, they are increased in length and in presence of suitable temperature they break in the middle to from an exact replica of itself. This phenomenon inspired Passino to introduce an event of reproduction in BFOA. Due to the occurrence of sudden environmental changes or attack, the chemotactic progress may be destroyed and a group of bacteria may move to some other places or some other may be introduced in the swarm of concern. This constitutes the event of elimination-dispersal in the real bacterial population, where all the bacteria in a region are killed or a group is dispersed into a new part of the environment.

Now suppose that we want to find the minimum of $J(\theta)$ where $\theta \in \Re^P$ (i.e. θ is a p-dimensional vector of real numbers), and we do not have measurements or an analytical description of the gradient $\nabla J(\theta)$. BFOA mimics the four principal mechanisms observed in a real bacterial system: chemotaxis, swarming, reproduction, and elimination-dispersal to solve this non-gradient optimization problem. A virtual bacterium is actually one trial solution (may be called a search-agent) that moves on the functional surface.

Let a chemotactic step to be a tumble followed by a tumble or a tumble followed by a run. Let j be the index for the chemotactic step. Let k be the index for the reproduction step. Let l be the index of the elimination-dispersal event. Also let

p: Dimension of the search space,

S: Total number of bacteria in the population,

N_c : The number of chemotactic steps,

N_s: The swimming length.

N_{re} : The number of reproduction steps.

N_{ed} : The number of elimination-dispersal events.

P_{ed} : Elimination-dispersal probability,

C (i): The size of the step taken in the random direction specified by the tumble.

Let P(j,,k,l)= { (j, k,l l) i 2,1 ,..., S} represent the position of each member in the population of the S bacteria at the j-th chemotactic step, k-th reproduction step, and l-th elimination-dispersal event. Here, let J (i, j, k,l) denote the cost at the location of the i-th bacterium θ^i (j, k,l) $\in\Re$.

The four prime steps in BFOA are described below.

i) Chemotaxis: This process simulates the movement of an E.coli cell through swimming and tumbling via flagella. Biologically an E.coli bacterium can move in two different ways. It can swim for a period of time in the same direction or it may tumble, and alternate between these two modes of operation for the entire lifetime. Suppose $\theta^i(j,k,l)$ represents i-th bacterium at jth chemotactic, k-th reproductive and l-th elimination-dispersal step. C(i) is the size of the step taken in the random direction specified by the tumble (run length unit). Then in computational chemotaxis the movement of the bacterium may be represented by

$$\theta^i(j+1,k,l)=\theta^i(j,k,l)+(C(i)(\Delta(i)/\mathrm{sqrt}(\Delta^T(i)\Delta(i)))) \quad (2)$$

where Δ indicates a vector in the random direction whose elements lie in [-1, 1].

ii) Swarming: A group of E.coli cells arrange themselves in a traveling ring by moving up the nutrient gradient when placed amidst a semisolid matrix with a single nutrient chemo-effecter. The cells when stimulated by a high level of succinate, release an attractant aspirate, which helps them to aggregate into groups and thus move as concentric patterns of swarms with high bacterial density. The cell-to-cell signaling in E. coli swarm may be represented by the following function.

$$J_{CC}(\theta,P(j,k,l))= \sum_{i=1}^{S} J_{CC}(\theta,\theta^i(j,k,l)) \quad (3)$$

$$= \sum_{i=1}^{S}[-d_{attractant}\exp(-w_{attractant} \sum_{m=1}^{p}(\theta_m-\theta_m^i)^2)] + \sum_{i=1}^{S}[h_{repellant}\exp(-w_{repellant} \sum_{m=1}^{p}(\theta_m-\theta_m^i)^2)] \quad (4)$$

where J_{CC} (θ,P(j,k,l)) is the objective function value to be added to the actual objective function (to be minimized) to present a time varying objective function, S is the total number of bacteria, p is the number of variables to be optimized, which are present in each bacterium and $\theta = [\theta_1, \theta_2 ... \theta_p]^T$ is a point in the p-dimensional search domain. $d_{attractant}$,$w_{attractant}$, $h_{repllant}$, $w_{repellant}$ are different coefficients that should be chosen properly.

iii) Reproduction: The least healthy bacteria eventually die while each of the healthier bacteria (those yielding lower value of the objective function) asexually split into two bacteria, which are then placed in the same location. This keeps the swarm size constant.

iv) Elimination and Dispersal: Gradual or sudden changes in the local environment where a bacterium population lives may occur due to various reasons e.g. a significant local rise of temperature may kill a group of bacteria that are currently in a region with a high concentration of nutrient gradients. Events can take place in such a fashion that all the bacteria in a region are killed or a group is dispersed into a new location. To simulate this phenomenon in BFOA some bacteria are liquidated at random with a very small probability while the new replacements are randomly initialized over the search space.[9]

The flowchart of the algorithm is as shown in figure 2.

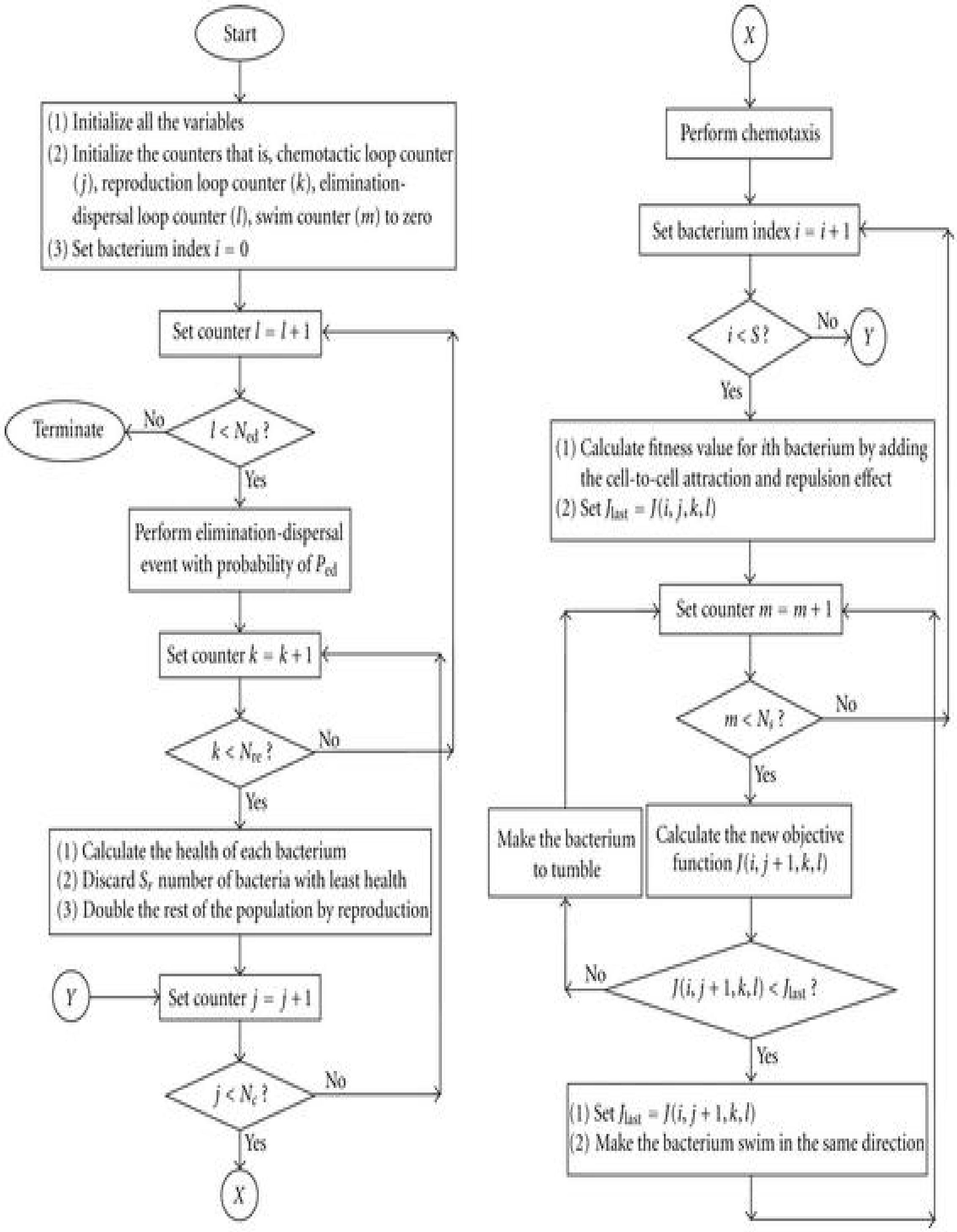

Fig.2 Flow Chart of BFOA[9]

3. Radio Model

The proposed methodology uses a classical radio model. The sensor node is a transceiver. Hence this radio model gives the energy consumed for the transmission and reception. The transmitter and block diagram representation is shown in Fig.3. The radio model consists of transmitter and receiver equivalent of the nodes separated by the distance'd'. Where Etx, Erx are the energy consumed in the transmitter and receiver electronics.

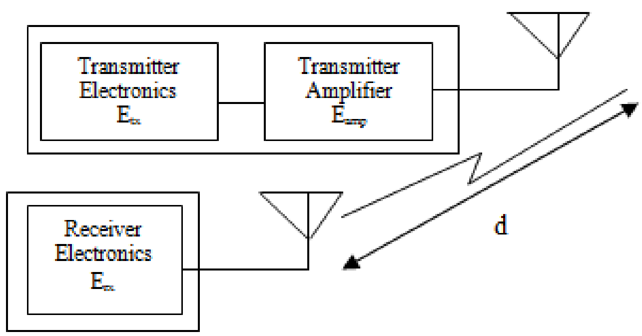

Fig.3 Radio Model

Eamp is the energy consumed in the transmitter amplifier in general, and it depends on the type of propagation model chosen either free space or multipath with the acceptable bit error rate. We consider Efs for free space propagation and Emp for multipath propagation as the energy consumed in the amplifier circuitry. The transmitter and the receiver electronics depends on digital coding, modulation, filtering and spreading of data. Additional to this there is an aggregation energy consumption of Eagg per bit if the node is cluster head.

A. Energy Consumption

This section describes the energy consumed for communication.

Packet transmission

$$E=(LP*Etx)+(LP*Eamp*d^n) \tag{5}$$

Where, L_p is the packet length in bits ,n is the path loss component which is 2 for free space and 4 for multipath propagation.

Packet reception

$$E=(L_p*Erx) \tag{6}$$

Where, L_p is the packet length in bits.

3.1 Proposed Methodology

This section deals with the modified BFOA with the assumptions made for building this novel protocol.

A. Assumptions

1. All the nodes can communicate with each other and with the BS directly.
2. There is a single hop from ordinary node to CH and multi hop from CH to BS.
3. All the nodes are static and all the nodes are location aware. They update their location information to the BS before entering into the set-up phase

B. Description of protocol

1. The BS broadcasts the percentage of CHs requirements for the entire network. Let this be P. Also it broadcasts the location information of all the nodes to the entire network.

2. After receiving this information, all the nodes will calculate a random number and compare with T(n) given by equation (1).If the random number is less than T (n) the node declares itself as the CH.

3. If the calculated random number is more than T(n) the nodes behave as ordinary nodes(0_n).

4. Each ordinary node calculates a fitness value using the fitness function given below with respect to all CHs.

$$f(0_n)=(P_1+P_2+P_3)/3 \tag{7}$$

where,

$$P_1=(\gamma*E_{CH})/E_{max} \tag{8}$$

$$P_2=D_{CH\text{-}O}/\text{sqrt}(d_1^2+d_2^2) \tag{9}$$

$$P_3=D_{CH\text{-}BS}/\text{sqrt}(d_x^2+d_y^2) \tag{10}$$

P_1: normalized energy of the cluster head.

E_{CH}: energy of cluster head

E_{max}: initial energy

γ: environmental degradation factor ($0.1< \gamma <=0.2$)

P_2: normalized distance between CH and ordinary node

$D_{CH\text{-}O}$: distance between CH and ordinary node

d_1: length of the plot

d_2: width of the plot

P_3: normalized distance between the CH and base station

$D_{CH\text{-}BS}$: distance between the CH and base station

d_x:x co-ordinate of the base station location

d_y:y co-ordinate of the base station location

5. Each ordinary node attaches to that CH which is having least fitness value, by sending a join request packet. This process leads to a cluster formation.

6. After the formation of the clusters, the network enters to the steady state phase. Here the nodes actually start transmitting their sensed values to the based station. This happens in rounds and usually a steady phase is accompanied by multiple rounds.

7. After finishing the steady phase, the network enters into the set-up again and the process repeats. It is to be noticed that the intra cluster communication is accompanied by TDMA and CH- BS communication is accompanied by CDMA.

4. Results and Discussions

This section deals with the simulation results obtained for the proposed method. The simulations were carried out in PC with Intel I7 processor, and windows operating system. MATLAB 2009 was used as the simulating platform. Uniform distribution was used to randomly distribute the nodes in 100 yards X 100 yards plot. The BS was located at (50,175) position. The deployment of sensor nodes is shown in the Fig. 4. Table 1 shows various parameters set for the protocol. The percentage of CHs requirement from the BS was set to 10%. The protocol was executed for one round of steady-state phase with the assumption of all the nodes having some data to transmit.

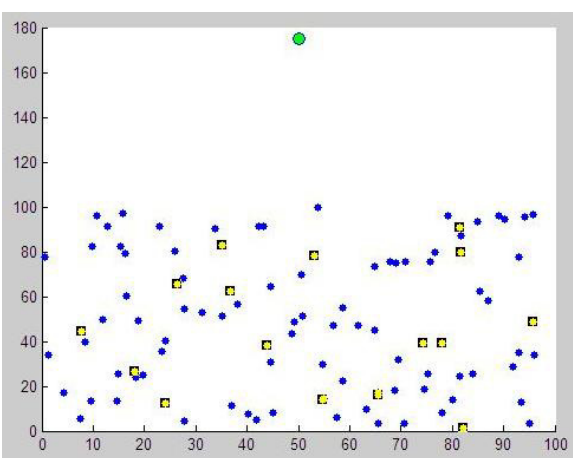

Fig.4 Network deployment

The parameter of the BFO algorithm was adjusted as follows: γ = 0.15 rand used was rand() function of MATLAB which offers an uniform distribution.

Table 1. Radio characteristics and other parameters chosen for simulation

Parameters	***Value***
Number of nodes	100
Transmitter electronics, Etx	50nJ/bit
Receiver electronics, Erx	50nJ/bit
Emp	0.0013pJ/bit
Efs	10pJ/bit
Eagg	5nj/bit
Length of plot	100 yards
Width of plot	100 yards
L_p(packet transmitted from CH to BS)	6400bits
Initial energy of the node	0.5J
Lctr (Packet transmitted from) ordinary node to CH	200bits

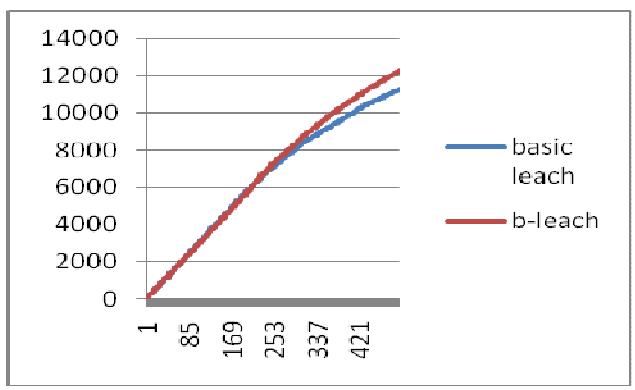

Fig.5. Packet sent to base station v/s number of rounds (X-axis: No. of rounds, y-axis: packet sent to B.S)

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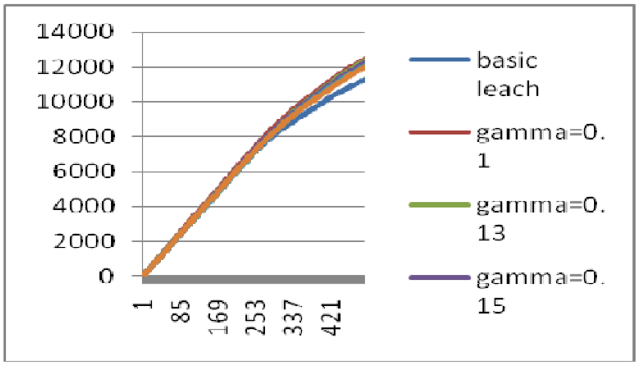

Fig.6. Variations in the energy packets sent to base station for different values of gamma (X-axis: No. of rounds ,y-axis: packet sent to BS)

Graph in Fig.5, shows that, as the simulations reaches approximately 500th round, the packet of energy sent to B.S by Basic-LEACH was observed to be less than the novel B-LEACH. Graph in Fig.6, shows the variations in packets sent to base station for different values of gamma for around 500 rounds.

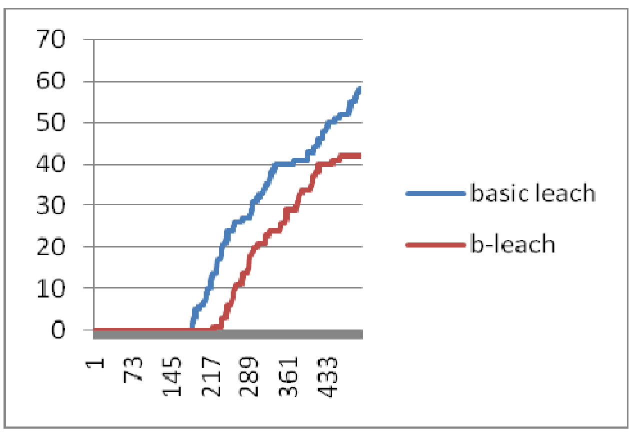

Fig.7. number of dead nodes v/s number of rounds
(x-axis: No. of rounds, y-axis no. of dead nodes)

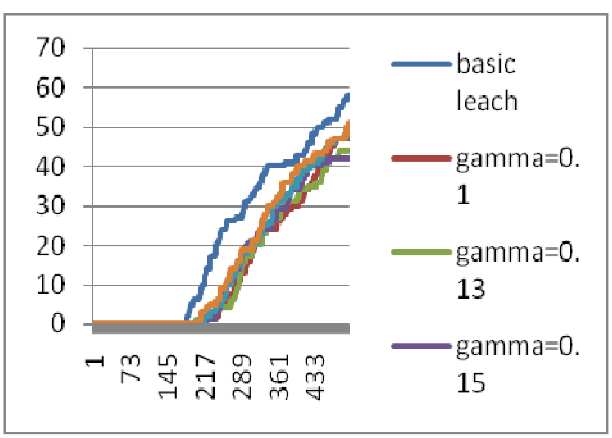

Fig.8. Variations in the Nodes survival curve for different values of gamma
(X-axis: No. of rounds, y-axis no. of dead nodes)

Fig.7 shows that as the simulations reaches approximately500th round, the number of dead nodes in the network increases in the Basic-LEACH compared to the B-LEACH. Fig .8 shows the same for different values of gamma.

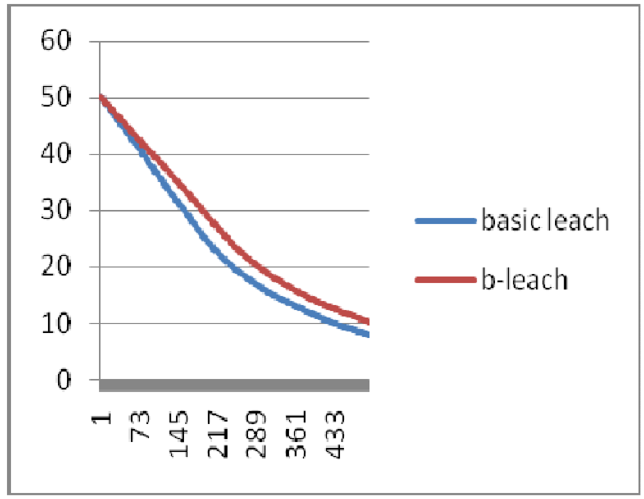

Fig.9. energy v/s number of rounds
(X-axis: No. of rounds, y-axis energy in Js)

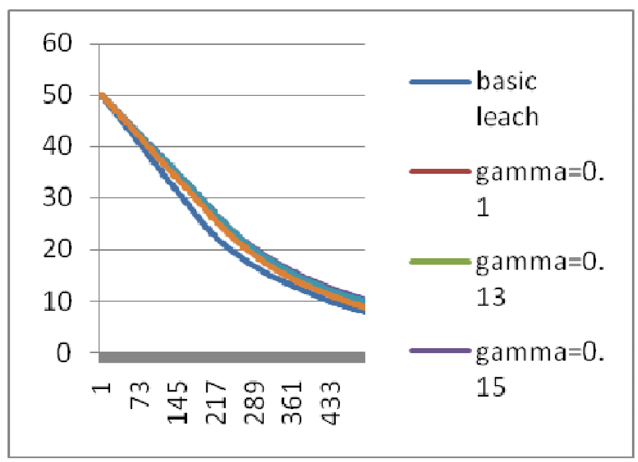

Fig.10. Variations in the network energy consumption for different values of gamma factor (X-axis:No. of rounds, y-axis energy in Js)

Graph in Fig.9 shows that, as the simulations reaches approximately 500th round, the energy consumed by Basic-LEACH was observed to be more than the novel B-LEACH.Fig.10 shows the same for different values of gamma. It is observed from graph Fig.6 that variation in the constant γ leads to shifts in the packet sent to base station curve. Hence by prior adjustments of optimal value of this constant results in better reduction in the overall network energy consumption. A similar reason can be given for even the node survival rate graph and energy graph shown in Fig.8,and Fig.10.

5. Conclusions

The novel idea proposed in this paper reflects on the computational intelligence in improving network performance by reducing overall network energy consumption and increase in node survival rate. The proposed methodology is an improved version of basic LEACH protocol. To validate this algorithm simulations had been performed using MATLAB. The simulation results proved the higher performance of B-LEACH as compared to basic LEACH, in terms of performance metrics like number of alive nodes ,data transmission rate and energy dissipation within the network and hence provides a proof that the method can be implemented in future network with ease..

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