ORB ACADEMIC PUBLISHER

Int. J. Comput. Sci. Theor. App., 2014, vol. 1, no. 1., p. 12-17.
Available online at www.orb-academic.org

International Journal of
Computer Science:
Theory and Application
ISSN: 2336-0984

Fire-LEACH: A Novel Clustering Protocol for Wireless Sensor Networks based on Firefly Algorithm

E. Sandeep Kumar[1], S.M. Kusuma[1], B.P. Vijaya Kumar[2]

[1] *Department of Telecommunication Engg, M.S. Ramaiah Institute of Technology, Bangalore, Karnataka, India.*
[2] *Department of Information Science & Engg, M.S. Ramaiah Institute of Technology, Bangalore, Karnataka, India.*
Email: sandeepe31@gmail.com

ABSTRACT
Clustering protocols have proven to increase the network throughput, reduce delay in packet transfer and save energy. Hence, in this work, we propose a novel clustering protocol that uses firefly algorithm inspired approach towards improving the existing basic LEACH protocol for reduction in steady-state energy consumption, aiming to enhance the network lifetime. The simulated results prove that implanting these kinds of computational intelligence into the pre-existing protocols considerably improves its performance.

KEYWORDS
Clustering Protocol — Firefly Algorithm — LEACH Protocol — Computational Intelligence — Network Lifetime — Energy Saving.

1. Introduction

Wireless sensor networks are distributed systems with sensors used to monitor the environment in which it is being deployed. The application of sensor networks are vast and to mention few of them, military monitoring, healthcare monitoring, disaster and natural calamities monitoring, waste water monitoring, etc. These sensor nodes are resource constrained and always there is a necessity to construct novel algorithms and protocols that are energy aware in their operation. Researchers have proposed many protocols in this direction, and use of computational intelligence is also one of the wide spread approach. There are many heuristic and meta heuristic algorithms used for designing the protocol. To name few of them 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, so on. The usage of these computational algorithms has lead to effective algorithm design in tackling various issues in wireless sensor networks like routing, security etc. The usage of firefly algorithms is the recent trend started from 2008 in wireless sensor networks and few related works are afore mentioned. Ming Xu et al. [1] proposed a work of using firefly algorithm for finding optimal route in underwater sensor networks by considering data correlation and their sampling rate in sensor nodes. Geoffrey Werner-Allen et al. [2] proposed a work of using Reachback Firefly Algorithm (RFA) for timing synchronization and delay compensation in Tiny-OS based motes. Song Cao et al. [3] proposed a method of using fire fly algorithm in finding optimal location for sensor nodes. Our recent work [4] proposes a bio-inpired clustering protocol based on Rhesus Macaque animal's social behavior. Bharathi et al. [5] propose a data aggregation scheme using elephants swarm intelligence. Bio-inspired computing is slowly gaining its momentum in the present WSN research.

In this work, we present a methodology of using an algorithm inspired by the fireflies behavior for energy efficient clustering in wireless sensor networks, which serves to be a betterment on the basic LEACH protocol. The algorithm was simulated in MATLAB and results were compared with the LEACH, with respect to energy saving in the steady phase energy.

The rest of the paper is organised as follows: section 2 deals with the basic LEACH protocol, section 3 discusses the fireflies behavior and algorithm, section 4 highlights the radio model considered for the calculation of energy consumption, section 5 describes the proposed methodology, section 6 depicts the results and discussions associated with the protocol, finally the paper ends with the concluding remarks and the references.

2. LEACH Protocol

This section briefs out the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol which was proposed by W.R. Heinzelman et al. [6]. The protocol has two phases: set-up phase and steady-state phase. The protocol executes in rounds. Each round in LEACH has predetermined duration, through synchronized clocks, nodes know when each round starts. The setup consists of three steps. In Step 1 (advertisement step), nodes decide probabilistically whether or not to become a Cluster Head (CH) for the current round (based on its remaining energy and a globally known desired percentage of CHs). Nodes that decide to do so broadcast a message (*adv*) advertising this fact, at a level that can be heard by everyone in the network. To avoid collision, a carrier sense multiple access scheme is used. In step 2 (cluster joining step), the remaining nodes pick a cluster to join based on the largest received signal strength of an adv message, and communicate their intention to join by sending a *join_req* (join request) message. Once the CHs receive all the join requests, step 3 (confirmation step) starts with the CHs broadcasting a confirmation message that includes a time slot schedule to be used by their cluster members for communication during the steady-state phase. Given that all transmitters and receivers are calibrated, balanced and geographically distributed clusters should result. Once the the clusters are formed, the network moves on to the steady-state phase, where actual communication between sensor nodes and the Base Station (BS) takes place. Each node knows when is its turn to transmit (step 4), according to the time slot schedule. The CHs collect messages from all their respective cluster members, aggregate data, and send the result to the BS(step 5). The steady-state phase consists of multiple reporting cycles, and lasts much longer compared to the setup phase.

3. Firefly algorithm

The section highlights the behavioral aspects of fireflies and the firefly algorithm.

3.1 Behavior of Fireflies

There are around two thousand firefly species and most fireflies produce short and rhythmic flashes of light. The pattern of flashes is often unique for a particular species. The fundamental functions of such flashes are to attract mating partners and preys. Females respond to male's unique pattern of flashing within the same species. The light emitting from their body strictly obeys the inverse square law i.e. as the distance between two flies increases, the intensity of light decreases. The air absorbs light, which becomes weaker and weaker as the distance increases. The bioluminescence from the body of the fireflies is due to 'luciferin', which is a heterocyclic compound.

Figure 1. *Firefly (**Scientific name**: Photuris lucicrescens, courtesy: Wikipedia.org).*

These behaviors of fireflies have lead to implementation of Firefly Algorithm (FA) that serves to be a metaheuristic algorithm under computational intelligence.

3.2 Firefly Algorithm

This section highlights the implementation of the fireflies' behavior as described by Xin-She Yang [7]. The algorithm was formulated by assuming (i) All fireflies are unisexual, so that one firefly will be attracted to all other fireflies. (ii) Attractiveness is proportional to their brightness, and for any two fireflies, the less bright one will be attracted by (and thus move to) the brighter one; however, the brightness can decreases as the distance between them increases. (iii) If there are no fireflies brighter than a given firefly, it will move randomly. The brightness is associated with the objective function and the associated constraints along with the local activities carried out by the fireflies is represented by the following algorithm.

Firefly Algorithm: Pseudo code
Nomenclature

- u_i= i^{th} firefly, $i \in [1,n]$;
- n= number of fireflies;
- $max\_generation$= count of the generations of fireflies (indicates iteration limit);
- I_i= Light Intensity magnitude of i^{th} firefly depending on the objective function $f(x)$;
- γ = absorption co-efficient;
- r_{ij}= distance between i^{th} and j^{th} fireflies.
- $f(x_i)$ = objective function of i^{th} firefly, which is dependent on its location x_i that is of d-dimension

begin
Generate initial population of fireflies u_i with location x_i , $i = 1,2,3...n$;
Define objective function $f(x)$, where $x = (x_1, x_2, ...x_d)^T$;
Generate initial population of fireflies x_i , $i = 1,2,3...n$;
Light intensity I_i of a firefly u_i at location x_i is determined by $f(x_i)$;
Define light absorption coefficient γ;
while *($t < max\_generation$)* **do**
  /*for all n- fireflies*/
  for *i=1:n* **do**
    /*for all n- fireflies*/
    for *j=1:i* **do**
      if *($I_j > I_i$)* **then**
        move firefly i towards j in d-dimension
      else
      end
    end
    Attractiveness varies with the distance r via $exp[-\gamma r]$;
    Evaluate new solutions and update light intensity;
  end
end
Rank the fireflies and find the current best;
end

Algorithm 1: Firefly Algorithm: Pseudo code.

where d is the dimension of x in space that is also dependent on the context of the firefly, t is iteration variable. Intensity or the brightness I is proportional to some objective function $f(x)$ and the location update equation is given by (1).

$$x_i = x_i + \beta exp[-\gamma r_{ij}^2](x_j - x_i) + \alpha\varepsilon \quad (1)$$

where α is the step controlling parameter, ε is the variable that brings about randomness, γ is the attraction coefficient, β is the step size towards the better solution and x_i is the location information of the observing entity.

4. Radio Model

The proposed methodology uses a classical radio model [6] and the sensor node is a transceiver. Hence, this radio model gives the energy consumed for the transmission and reception. The block diagram representation is shown in fig. 2. The radio model consists of transmitter and receiver equivalent of the nodes separated by the distance 'd' where E_{tx} and E_{rx} are the energy consumed in the transmitter and the receiver electronics. E_{amp} 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 E_{fs} for free space propagation and E_{amp} 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 E_{agg} per bit if the node is a cluster head.

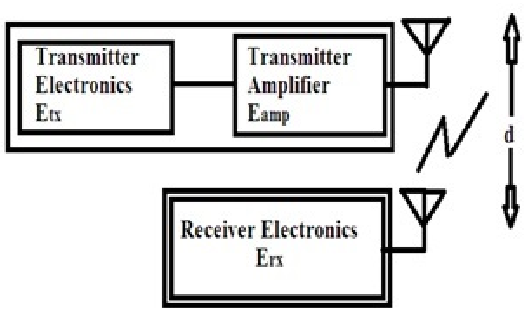

Figure 2. *Radio Model.*

4.1 Energy Consumption

This section describes the energy consumed for communication.

Packet transmission

$$E_t = (L_P * E_{tx}) + (L_P * E_{amp} * d^n) \quad (2)$$

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

Suppose a node transmits a packet. Each bit in a packet consumes E_{tx} amount of transmitter electronics energy, E_{amp} amount of amplifier energy. A packet of length L_P consumes an overall energy of E_t.

Packet reception

$$E_r = (L_P * E_{rx}) \quad (3)$$

where L_P is the packet length in bits.

Suppose a node receives a packet. Each bit in a packet consumes E_{rx} amount of receiver electronics energy. A packet of length L_p, consumes an overall energy of E_t.

5. Proposed Methodology

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

5.1 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 from CH to BS.
3. All the nodes are static, where the algorithm run at a particular time instant and update for next round, and all the nodes are location aware. They update their location information to the BS before entering into the set-up phase.
4. 2-D space is considered for sensor node deployment.

5.2 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 the formula (4).

$$T(n) = \begin{cases} P/(1 - P(rmod(\frac{1}{p}))), & n \in G \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

   If the random number is less than $T(n)$ the node declares itself as the CH. G is the number of ordinary nodes eligible for becoming a CH in a particular round.

3. First, the declared CHs start broadcasting the packet of interest. All the CHs learn about the ordinary nodes and other CHs in the plot. Then they broadcast the packet of interest by introducing the intensity value that it has calculated using (5), which serves to be an objective function for all sensor nodes (fireflies in the proposed work).

$$I(x) = I_0/(1 + \gamma x_i^2) \quad (5)$$

   The minimum the value calculated by (5), large is the distance between the CH and ordinary node. I_0 is the initial intensity value of all the nodes. Hence all the CHs store the maximum of the intensity values calculated with all the other ordinary nodes in the network belonging to a particular round. The value of x_i is calculated by using (6) as per the firefly algorithm [7].

$$x_i = x_i + \beta exp[-\gamma r_{ij}^2](x_j - x_i) + \alpha(rand - 0.5) \quad (6)$$

where x_i is the location of the CH and x_j is the location of the ordinary node and only the x co-ordinate is considered for the intensity calculation as a reference. r_{ij} is the distance between the CH and an ordinary node, calculated using Euclidean distance equation and ε is $(rand - 0.5)$. β, γ and α are the parameters that are adjustable and *rand* provides the randomness in the equation (6).

4. The ordinary nodes on receiving the packets from CHs calculate their intensity values using equations (5), (6) and (7), and store the maximum value of all the intensity values calculated with respect to all the CHs in the network. The ordinary nodes now compare their intensity values with all the other CHs intensity values and attach to a CH that is having more intensity value than their values, by sending a join request packet. This process leads to a cluster formation.

5. After the formation of the clusters, the network enters to the steady state phase, where 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.

6. 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.

6. Results and Discussions

Table 1. *Radio characteristics and other parameters chosen for simulation.*

Parameter	Value
Number of nodes	100
Transmitter electronics, E_{tx}	50 nJ/bit
Receiver electronics, E_{rx}	50 nJ/bit
E_{amp}	0.0013 pJ/bit
E_{fs}	10 pJ/bit
E_{agg}	5 nJ/bit
Length of plot	100m
Width of plot	100m
L_p(packet transmitted from CH to BS)	6400bits
L_{ctr}(packet transmitted from ordinary node to CH)	200bits
Initial energy of the node	0.5J

This section deals with the simulation results obtained for the proposed method. The simulations were carried out in PC with Intel I5 processor, and windows operating system. MATLAB 2009 is used as the simulating platform.

Uniform distribution was used to randomly distribute the nodes in $100m$ x $100m$ plot. The BS was located at $(50, 175)$ position. The deployment of sensor nodes is shown in the fig. 3. Table 1 shows various parameters set for the protocol. The

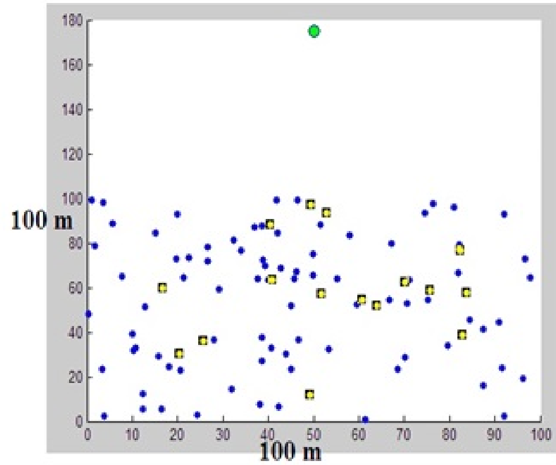

Figure 3. *Network deployment.*

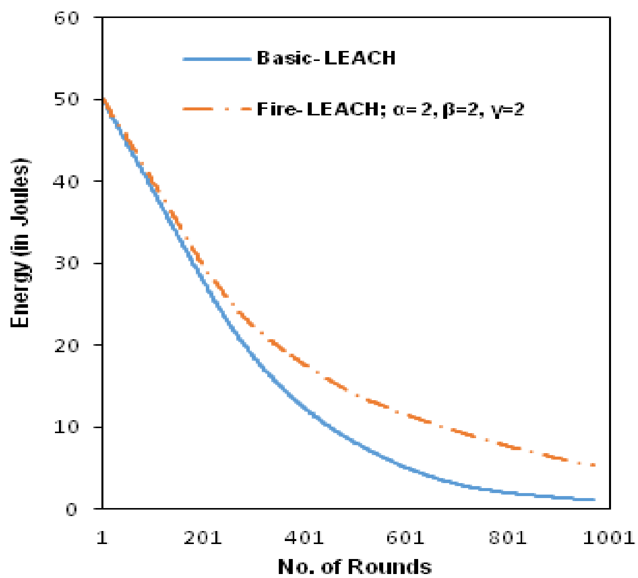

Figure 4. *Residual energy in the network for 1000 rounds.*

percentage of CHs requirement from the BS was set to 10% for all the rounds. The protocol was executed for one cycle of steady-state phase in each round, with the assumption of all the nodes having some data to transmit.

The parameters of the firefly algorithm were adjusted as follow: $\alpha = 2$, $\beta = 2$, $\gamma = 2$, $I_0 = 5$ and *rand* used was *rand*() function of MATLAB which offers an uniform distribution.

The simulation results are shown in fig.4 and fig.5. Graph in fig.4 shows that, as the simulations reaches approximately 1000^{th} round, the energy consumed by Basic-LEACH was observed to be more than the novel Fire-LEACH.

Fig.5 shows that as the simulations reaches approximately 1000^{th} round, the number of dead nodes in the network increases in the Basic-LEACH compared to the Fire-LEACH.

It was observed from graphs of fig.6, fig.7 and fig.8 that variation in the constants γ, α and β, there were shifts in the

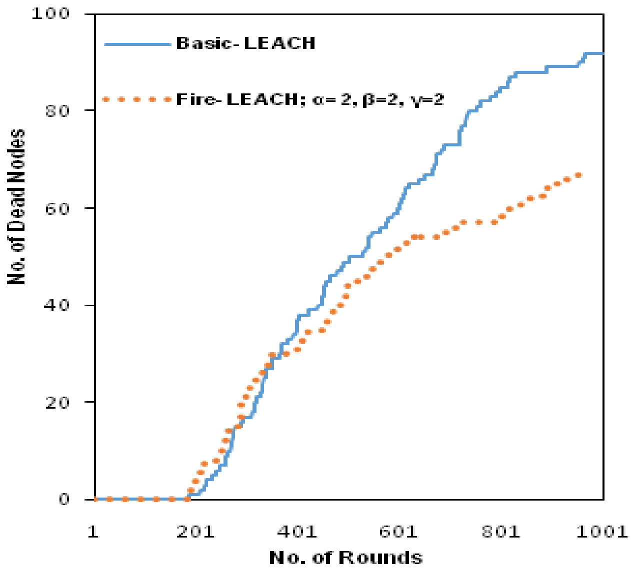

Figure 5. . *Number of dead Nodes in the Network for 1000 rounds.*

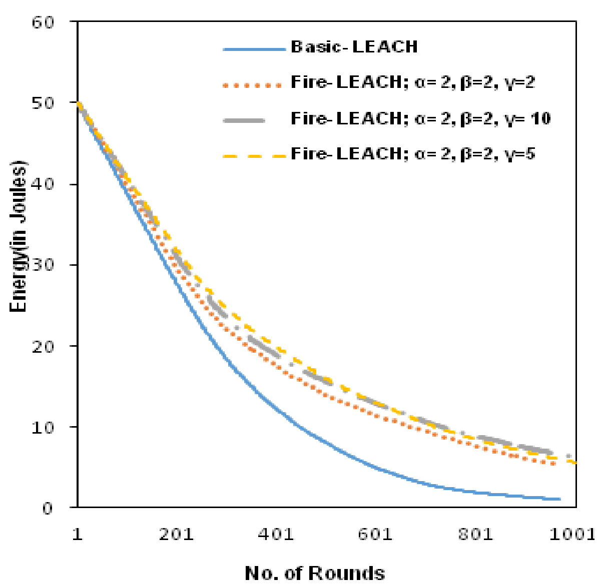

Figure 6. *Variations in the network residual energy for different values of attraction factor* γ *(1000 rounds).*

energy curves. Hence by prior adjustments of optimal values for these constants results in better reduction in the overall network energy consumption. A similar reason can be given for even the node survival rate graphs shown in fig.9, fig.10 and fig.11.

For the simulations only the steady phase energy was considered neglecting the set-up phase energy. It has to be noted that in all the clustering protocols, there is considerable amount of energy consumption in the set-up phase.

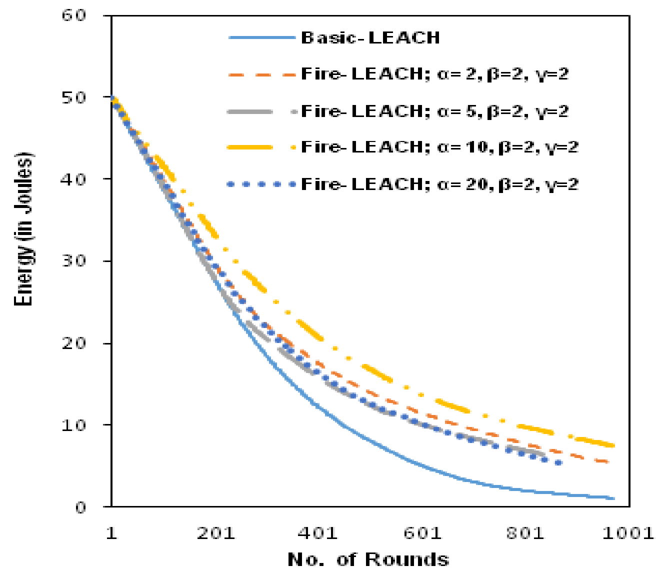

Figure 7. *Variations in the network residual energy for different values of* α *(1000 rounds).*

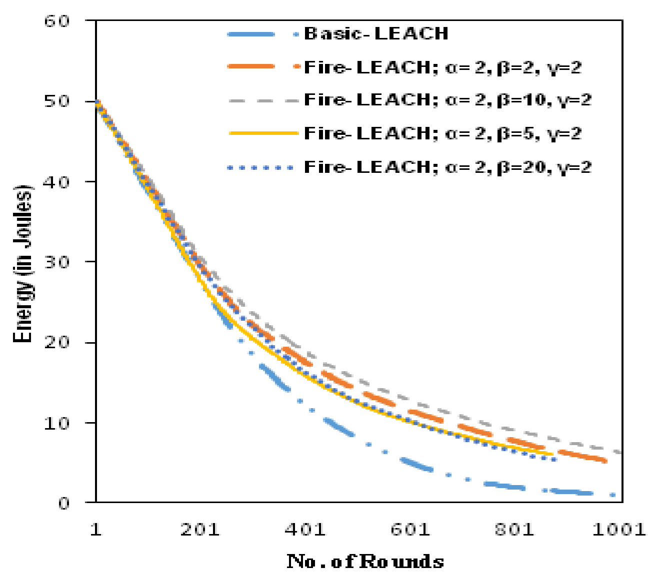

Figure 8. *Variations in the network residual energy for different values of* β *(1000 rounds).*

7. Conclusions

The work proposed in this paper demonstrates the use of computational intelligence in improving network performance by reducing the overall network energy consumption and increasing the node survival rate. The proposed methodology was applied to the basic LEACH protocol and simulation results prove that the algorithm enhances the energy efficiency thereby increasing the node survival rate and provides a proof that the method can be implemented in the future networks with ease.

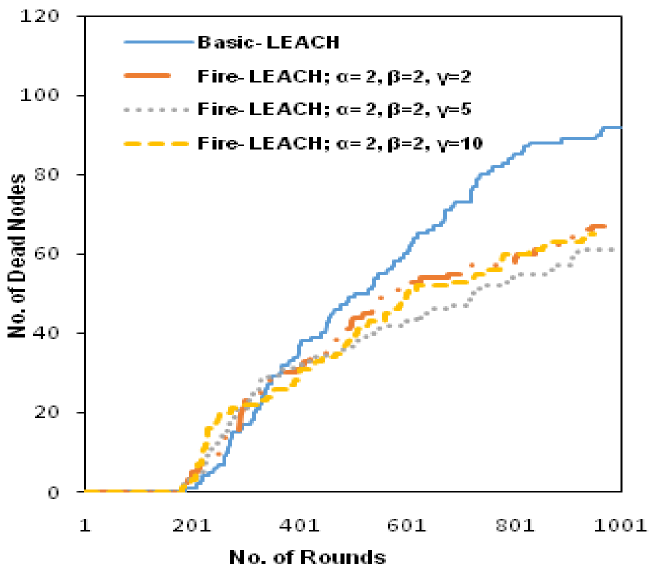

Figure 9. *Variations in the number of dead nodes for different values of γ (1000 rounds).*

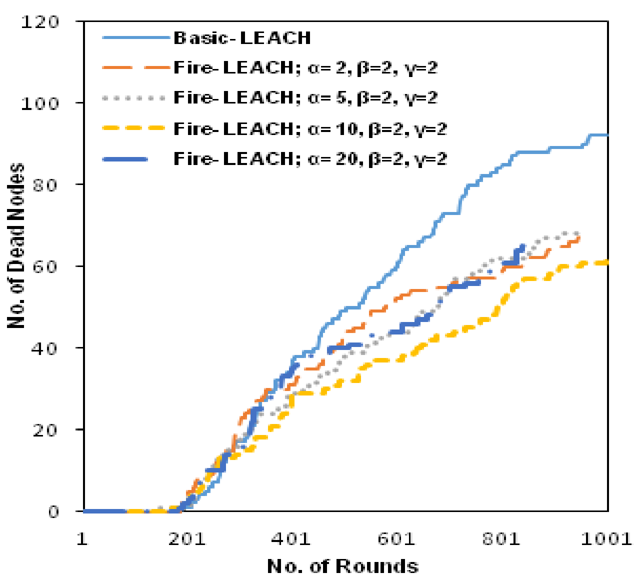

Figure 10. *Variations in the number of dead nodes for different values of α (1000 rounds).*

Acknowledgements

Authors like to thank Dept. of Information Science & Engg., M.S Ramaiah Institute of Technology for providing lab facilities for conducting the research work. Authors also like to thank Management and Dr. S.Y. Kulkarni, Principal of M.S Ramaiah Institute of Technology, for their constant support to carry the prospective research work.

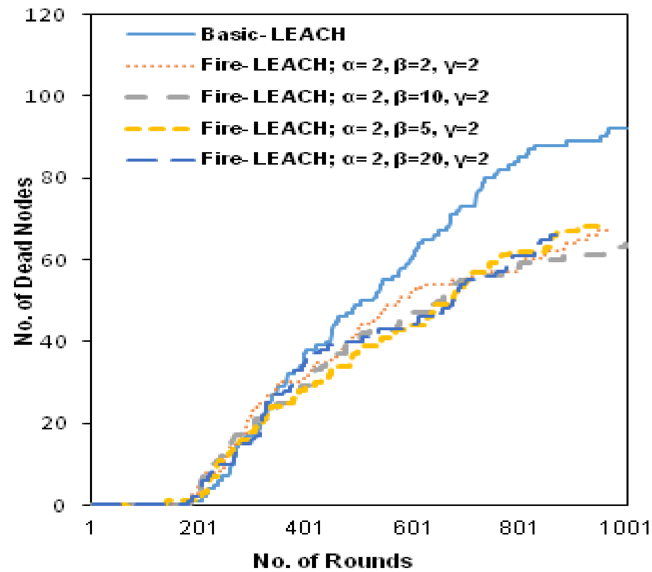

Figure 11. *Variations in the number of dead nodes for different values of β (1000 rounds).*

References

[1] LIU, Guangzhong. A multipopulation firefly algorithm for correlated data routing in underwater wireless sensor networks. *International Journal of Distributed Sensor Networks*, 2013, vol. 2013.

[2] WERNER-ALLEN, Geoffrey, TEWARI, Geetika, PATEL, Ankit, et al. Firefly-inspired sensor network synchronicity with realistic radio effects. In : *Proceedings of the 3rd international conference on Embedded networked sensor systems*. ACM, 2005. p. 142-153.

[3] CAO, Song, WANG, Jianhua, et GU, Xingsheng. A Wireless Sensor Network Location Algorithm Based on Firefly Algorithm. In : *AsiaSim 2012*. Springer Berlin Heidelberg, 2012. p. 18-26.

[4] KUMAR, Sandeep et KUSUMA, S. M. Clustering Protocol for Wireless Sensor Networks based on Rhesus Macaque (Macaca mulatta) Animal's Social Behavior. *International Journal of Computer Applications*, 2014, vol. 87, no 8, p. 20-27.

[5] BHARATHI, M. A., VIJAYAKUMAR, B. P., et MANJAIAH, D. H. Cluster Based Data Aggregation in WSN Using Swarm Optimization Technique. *system*, 2013, vol. 2, no 12.

[6] HEINZELMAN, Wendi Rabiner, CHANDRAKASAN, Anantha, et BALAKRISHNAN, Hari. Energy-efficient communication protocol for wireless microsensor networks. In : System Sciences, 2000. *Proceedings of the 33rd Annual Hawaii International Conference on.* IEEE, 2000. p. 10 pp. vol. 2.

[7] YANG, Xin-She. *Nature-inspired metaheuristic algorithms. Luniver press*, 2010.