Firefly Algorithm for Self Organization of Mobile Wireless Sensor Network

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Abstract—For a Wireless Sensor Network (WSN), designing low power scalable network remains a challenge for researchers. The sensor nodes find it difficult to gather and transfer data to sink node when they are deployed in hostile and unfavorable environment. Hence, establishing and maintaining connectivity among the mobile sensor nodes in decentralized network play an important role when the environment is unfavorable. Senor nodes self organize themselves in order to establish and maintain the connectivity. This paper proposes a nature based Swarm Intelligence (SI) technique, based on insect firefly to enhance connectivity among the sensor nodes for a decentralized mobile WSN in an energy efficient manner. The foraging feature of insect firefly is used in the proposed algorithm for which a multi-objective fitness function with parameter energy and distance has been designed. The proposed algorithm is theoretically analyzed and verified by simulation and the results show that the proposed algorithm leads energy consumption compared to existing firefly algorithm and prolongs the network lifetime significantly.

Index Term—Wireless Sensor Network (WSN), firefly algorithm, Swarm Intelligence (SI), connectivity, self organization.

I. Introduction

Recent trends of sensor technologies have provided promising Green Computing techniques for enhancing gathered information in an environment to base station. A typical WSN involves large number of sophisticated intelligent sensors with a limited transmission range and usually have unstructured infrastructure. Sensor nodes are composed of a sensing unit, a battery power, processor, radio transmitter and a storage device. With these resources sensor nodes have the ability of sensing, collecting the data, compute and establishes communication within the sensors networking field. These sensors nodes can be found in huge number of applications like physical system, biological system, information technology, military and other applications. Despite of its usefulness sensor nodes are usually prone to failures such as hardware degradation, node displacement, and environmental causes [1]. Studies also show that resource constraints such as limited battery power, computational capabilities and storage capacity remain as a challenge in synchronization of nodes with changing network topologies.

As an extension to WSNs capabilities, sensor node mobility and network dynamism provide a new chain of interesting way for Mobile Wireless Sensor Networks (MWSNs). Movement and self organization of sensor nodes characterize MWSNs from typical WSNs. MWSN are dynamic; the sensor nodes are deployed randomly and are able to change their position depending on the scenario. The advantage of MWSN over stationary WSN is when node failure occurs in stationary WSN, it may results in the partitioning of the network which affects the network topology. While in MWSN the mobile nodes have the property of self- organization to establish connectivity during the node failure without interrupting the network efficiency. Hence in MWSN the sensors arrange themselves to achieve coverage and establish optimized connectivity. The applications of the MWSNs can be widely divided into time-driven, event- driven, on-demand and tracking based applications. Sensor network topologies can be of type flat (decentralized), cluster based (centralized), tree and hybrid. Based on the network topology sensor nodes self organize to establish an optimized connectivity. Hence in MWSN the sensors arrange themselves to achieve coverage and establish optimized connectivity. Although fully static WSNs were not considered mobility of sensor nodes initially faced several challenges that needed to be overcome, including localization [2], sensor deployment [3], energy consumption [4] coverage and connectivity [5] among others. To overcome the limitations sensor nodes need to self organize to maintain the connectivity by effectively utilizing the power with low computational methodologies.

Self organization is an essential feature of MWSNs which has resulted in global level response. The network system interacts among its local level components i.e., sensor nodes without a central authority, nor through a dedicated path. Sensor network must be able to self organize as in sensor nodes can move to form multi-hop network connectivity dynamically and autonomously. Optimized connectivity is a basic problem in WSN as it reflects performance of sensor network. Self organization property aims to establish an optimized connectivity within the sensor network field [6]. Wireless sensor nodes can effectively establish communication in the monitoring region by adopting connectivity control strategies in order

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to keep up the network performance. This paper proposes optimized energy efficient connectivity among sensor nodes by self organizing of nodes with varying topology within a decentralized sensor field.

Many nature inspired SI [7] techniques are adopted to solve the connectivity and coverage issues in WSN. SI is concerned with study of combined behavior of individuals within the environment for coordinating among themselves to establish connectivity through decentralized controls and self organization techniques. These algorithms [8] are based on nature inspired intelligence and are highly robust, adaptive and scalable. As the SI techniques have the ability of self organization, this property is inherited and can be adopted for the self organization of MWSN [1]. There are many Swarm Intelligence (SI) techniques such as Ant Colony Optimization (ACO), Particle warm Optimization (PSO), bird flocking algorithm, honey bee optimization, firefly algorithm etc, which have been inspired many researchers to optimize self organization and connectivity issues.

Hence, in this paper a novel approach is proposed using one of SI technique, firefly algorithm, to achieve energy efficient connectivity optimization in MWSNs. The rest of the article is organized as follows. Section II gives the related work and section III gives the network model for our proposed algorithm. In section IV, the proposed fire fly algorithm has been discussed in detail and in section V the results and comparison has been given. Section VI gives the conclusion of the article.

II. Related Work

Many different approaches are considered in literature which includes self organization and connectivity with energy efficient methodologies and this section highlights the most important articles of those.

Comprehensive and meticulous study on reliability theory of MWSNs has been surveyed by Ying-Gao *et al* in [9]. With reference to recent year's development authors outlines the classification and features of MWSNs. The existing methods like Connectivity-Based Energy-Efficient Opportunistic Robust (CBEEOR) routing protocol for MWSNs [10], LEACH Distance-M routing protocol [11] and PHASeR (proactive highly ambulatory sensor routing) protocol [12] are systematically presented with their pros and cons. And finally authors have given the comparison of existing methods with respect to time delay, network size, energy efficiency, scalability, and reliability parameters.

Sheng. Z *et al.* [13] proposed a novel energy consumption minimization approach for processing an application in MWSNs. Authors specifically introduce the concept of cooperation among the sensor nodes with logics and propose Energy Optimization technique using energy as its parameter for the node selection so as to achieve cooperative computing in MWSNs. Performance analysis of the proposed methodology is simulated to show the significant saving of energy.

In [14] Jean-Matthieu Etancelin et.al have proposed a new approach for building a connected dominating set of decentralized mobile sensor nodes. In order to maintain the network connectivity authors have considered attractive and repulsive forces for the movement of sensor nodes. Proposed approach is implemented by considering hybrid decentralized algorithm: *Decentralized Algorithm under Connectivity constraint with mobility for Coverage and Lifetime Maximization (DACYCLEM)*. Algorithm is formulated to maximize the lifetime and coverage of the network by enhancing the local interaction among the sensor nodes. Authors also add that the sensor nodes self organize with the changing behavior of the network in order achieve an optimized connectivity. And furthermore simulation results of proposed DACYCLEM algorithm shows the efficiency in life time and coverage of the network.

In [15] Wang-Yan has presented formulation model for WSNs in his article. Author has analyzed the feasibility of applying self organization based on the characteristics of WSNs. And with this the author has proposed architecture for implementing self organization in management layer. As a result efficiency of the network will be optimized based on different application as self organization is introduced in management layer of network architecture.

Nuria Gomez Blas *et al*. in [16] have proposed a nature inspired Ant Colony Optimization(ACO) algorithm for self organization of sensor nodes in WSNs. Using the location information of sensor nodes authors have defined Position based Ant colony routing algorithm (POSANT) to find a optimum routes within a given network field. The simulation result of proposed algorithm shows that POSANT routing algorithm is efficient finding the optimal route selection in WSNs.

Random deployment of sensor nodes is a non-uniform arrangement, where mobile nodes relocate to accomplish optimized connectivity and extend the life time. Self organization mobile sensor networks are defined using different swarm intelligence techniques. One of the popular SI techniques ACO was proposed by Anudeep Reddy *et al* [17] where self organizing strategy was used for easy deployment and connectivity. The efficiency of proposed ACO technique is compared with Greedy Perimeter Stateless Routing (GPSR) method which is defined in [18] considering different metrics such as energy, time and delivery ratio. Simulation results show an improvement in energy and throughput of ACO by 3.74% and 4.45% with respect to GPSR method. Likewise Artificial Bee Colony algorithm [19] and Particle swarm optimization [20] methods aims to achieve performance and self organized connectivity utilizing MWSNs. Reflecting these related works an intricate network model involving its computational methodology for self organization of MWSNs is defined in section III. Studies also show that researches on SI based algorithms have the potential to achieve optimal solutions in real world applications.

III. Network Model

In this section network model of MWSNs is formulated. Dynamic connectivity and self organization solution of mobile sensor nodes is derived to establish an efficient communication. In this paper MWSN model is considered which are composed of randomly dispersed mobile sensors nodes in the network field and each of them having the same sensing range *r*. Quality of the coverage inside the circle with radius *r* is constant. Also, In order to simplify, following assumption are made:

- Sensor nodes are randomly deployed and the positions of sensor nodes are known.
- Sensor nodes are mobile, they move within the network field to establish connectivity among the nodes.

Area that needs to be connected, i.e. sensing field was recognized as $m* n$ grid where each grid has size 1m and N represents the number of the sensors. Each sensor node xi $(i=1,2,3,\ldots\ldots,N)$ has its own sensing radius r with in which sensor nodes try connecting with the other nodes to establish communication.

Sensor nodes after their initial random deployment arrange themselves as they have the moving property they change their location to establish connectivity. Sensors movement is defined according to the firefly algorithm in Algorithm(1).To establish an effective connectivity a fitness function is defined using the energy and distance parameters. Each sensor node undergoes fitness function to decide whether it is eligible for establishing a communication with other nodes. An eligible node based on the fitness value establishes connectivity with other nodes. In order to achieve this residual energy of each node and distance parameter between the two sensor nodes are given as an input to fitness function f(x) and is defined in equation(4). Equation for choosing an higher Residual Energy (RE) node within given area can be given in the following equation(1) .The input for this function is the nodes characteristics, including its *RE* and the number of neighbor sensor nodes($n(x_i)$), the output is a value expressing the energy level of each sensor node with respect to its neighbor nodes. Fitness function with respect to residual energy F_{ER} is maximized as

$$F_{RE}= p|N(x_i)| + p\sum_{i=1}^{N} x_{RE} \ , \quad N_{(xi)}<r \qquad (1)$$

where, p is random numbers in the range [0,1], $n(x_i)$ is the number of sensor neighbors for particular x_i and x_{RE} is the neighbor node's residual energy. The neighbor node with the highest $F(_{RE})$ is chosen meaning that the node with highest residual energy is considered for connectivity.

Euclidean distance given by equation(3) is considered to calculate the distance between the sensed nodes to the next-hop i.e. higher energy node. If the distance is minimum between two nodes then it will expense less amount of energy. Therefore, second objective is to minimize distance between node x_i and next hop x_{i+1}. Fitness function F_D with respect to distance is maximized as

$$F_D = \frac{1}{\sum_{i=1}^{n} d(x_i, x_{i+1})} \ , \text{where } d(x_i, x_{i+1}) < r \qquad (2)$$

where $d(x_i, x_{i+1})$ is Euclidean Distance according to[21] and can be given by considering two sensor nodes say node1 with (x_i, y_i) and node2 with (x_{i+1}, y_{i+1}).

$$d(x,y) = \sqrt{(x_{i+1}-x_i)^2 + (y_{i+1}-y_i)^2} \qquad (3)$$

The above mentioned residual energy and distance function are combined to define a overall fitness function *f(x)* and it is given by following equation:

$$f(x) = (F_{RE}) + (F_D) \qquad (4)$$

with its fitness function $f(x)$ the node establishes the connectivity by relocating sensor nodes to the nearest higher energy sensor node in the sensor network field. As nearest node is considered, minimum energy of sensor node is required to maintain the connectivity in the network and increase the lifetime of the network.

IV. Firefly Algorithm for Self Organization in MWSN

Firefly Algorithm (FA) is swarm intelligence technique that was introduced in 2010 by Yang [8]. FA are population based SI algorithms having multiple agents interacting in a non linear manner. It belongs to metaheuristic type of algorithms where their exits a randomness in the proposed algorithm. FA is nature inspired algorithm where behavior of fireflies is mimicked. Fireflies are unisexual they attract the other fireflies by flashing of light irrespective of their sex, the reason behind light emission is to attract the prey and some times to escape from the predator. Recent years, FA was successfully applied and adjusted for many different hard optimization problems. Firefly algorithm was adjusted for continuous connectivity optimization [22], coverage [23], mobile connectivity [24], self-organization [25], [26] etc. Firefly algorithm is based on fireflies light attraction behavior. The attractiveness is proportional to the brightness of the light emitted thus lesser bright fireflies get attracted towards more bright fireflies. In the proposed FA algorithm firefly's brightness depends on the fitness function. The goal of the proposed FA is to obtain an efficient self organized connectivity among sensor nodes. Fitness value decides the brightness of the sensor node hence the fireflies with lesser fitness value move towards greater fitness value. Sensor nodes are considered as randomly deployed fireflies and their movement and connectivity is given in the algorithm1. Brightness of the sensor is directly proportional to the fitness value of the sensor node. Here the brightness B of a firefly at the location x is defined by the following equation:

$$B(x) \propto f(x) \qquad (5)$$

where x is d-dimensional point in d-dimensional space and $f(x)$ is the fitness function. B(x) is the Brightness of the firefly which is directly proportional to the value of defined fitness function. In this paper two dimensional sensing field is considered, thus for N sensors, position of each firefly is point in $2N$-dimensional space. Fitness function is defined by Eq. 5.

Attractiveness β of a firefly depends on the distance between two fireflies and it is indirectly proportional to their brightness. As increase with the distance between the fireflies the attractiveness decreases. In [8] attractiveness was defined by the following equation:

$$\beta\,(x) = \beta o\; e^{-\gamma d^2}\;, \tag{6}$$

where $\beta 0$ is the attractiveness at d= 0 and γ is constant. The movement of a firefly i toward more attractive, i.e. brighter firefly j is determined by the following equation [8]:

$$x_i^{t+1}=x_i^t + \beta\; e^{-\gamma d_{ij}^2}\,(x_j^t - x_i^t) \tag{7}$$

where dij is the distance between fireflies i and j, t is the iteration number. Distances between fireflies were calculated as Euclidean distances formula as given in equation . Convergence speed depends on parameter γ. In [8] it was reported that the suitable value for γ varies between 0.01 and 1.

Basic steps of the firefly algorithm are presented in Algorithm 1.

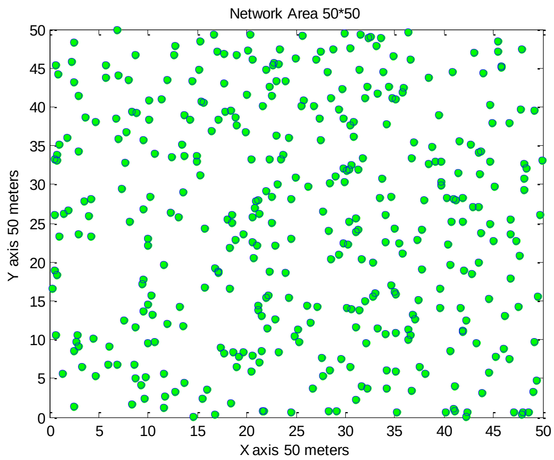
Algorithm 1 The proposed firefly algorithm

Firefly algorithm
fitness function $f(x)$ is defined by Eq. 5, x = (x1, ..., xN) where N is the number of the sensors;
Initialize population of n fireflies xi, (i=1,...n);
Brightness Bi at point xi is defined by $f(xi)$;
Define light absorption coefficient γ;
Define number of iterations *Iteration Number= Max Iterations*;

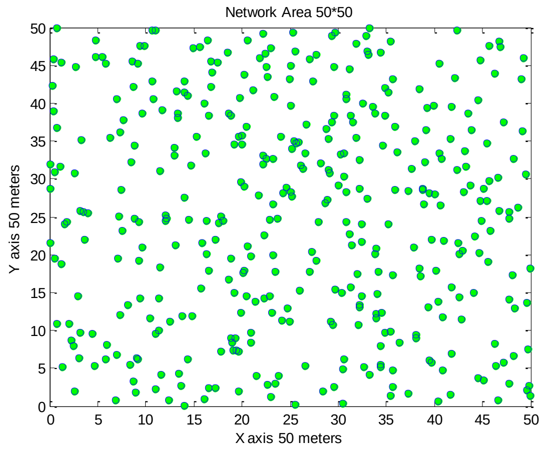
```
t=0;
while t!= Iteration Number do
  for i=1 to n do
    for j=1 to n do
      if Bi <Bj then
      Move firefly i towards firefly j in d-dimensional space;
      Vary attractiveness with distance d is give by e^-γr2 ;
       Evaluate new position and update light intensity;
      end if
    end for
  end for
end while
End
```

V. Simulation Results

Our proposed algorithm and existing algorithm are implemented using MATLAB R2016a. We simulate the number sensor nodes by deploying randomly within the sensor field. The distance of the proposed algorithm is compared with the [19] distance and energy parameter of existing FA. In [19] the optimized distance equation is defined to have the optimal placement of mobile nodes. Here the sensor node relocates using the energy and distance parameter to establish optimized connectivity and to enhance the network life time. The proposed method is tested for MWSNs where sensor self organize in given sensor field of area 50m * 50m.The method is tested for 400 and 500 sensors deployed randomly within the sensing field each having the sensing radius of r =5m. With the fitness function defined in equation(4) sensor nodes establishes self organized connectivity in network field. For the graph of the sensor set, among the randomly arranged sensors, those connected with the sensors within communication radius used and the energy value ranging from 0 to10 J. Here the parameters α which varies randomly with in [0-1], γ= 1 is a constant, β=1 is attractiveness with sensing radius.



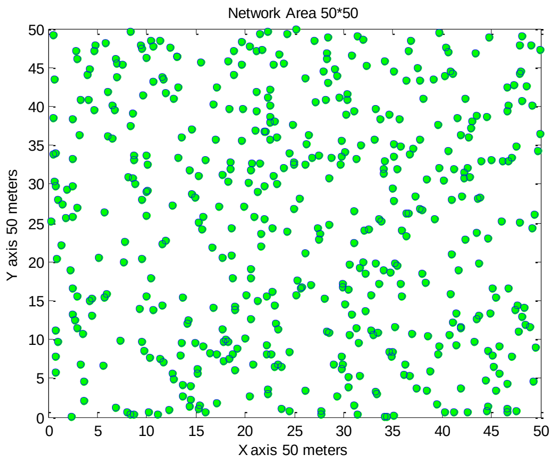
(a)



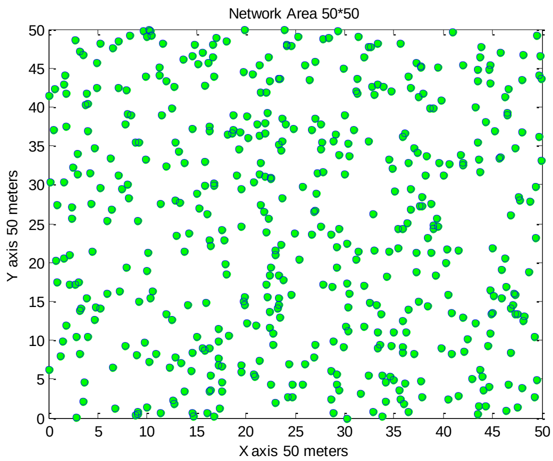
(b)

Fig. 1. (a) Initial deployment of 400 Sensor Nodes (b) Optimal Placement of 400 sensor nodes after proposed FA

Fig. 1 (a) shows the initial deployment of sensors in the network area for 400 mobile sensors nodes and Fig. 1 (b) gives the optimal placement of mobile sensor nodes according to the proposed algorithm. Fig. 2 (a) shows the initial deployment of sensors in the network area for 500 mobile sensors nodes and Fig. 2 (b) gives the optimal placement of mobile sensor nodes according to the proposed algorithm. The Sensor nodes are randomly deployed in the sensor area. Sensor nodes senses the environment to which it is intended for and try establishing the connectivity by self organization of sensor nodes using the proposed FA. Sensor node are mobile and move towards the higher energy node and movement path of the sensors deployed are shown Existing model in [21] is compared with proposed model with respect to energy efficiency. Fig.3 (a) and (b) gives the difference in their energy graph with respect to 100 iterations for 400 and 500 sensor nodes respectively. Proposed algorithm graph line shows that it consumes less energy than the existing algorithm graphline.

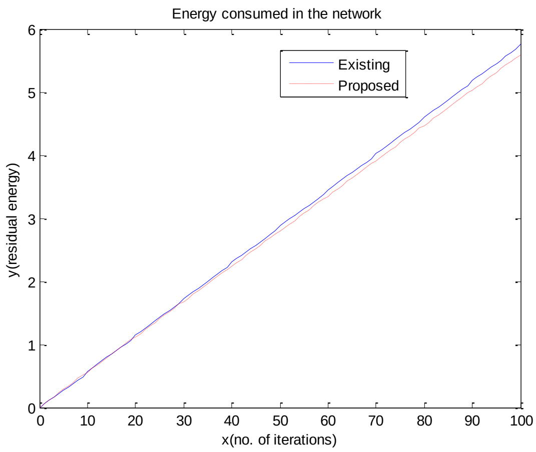


(a)

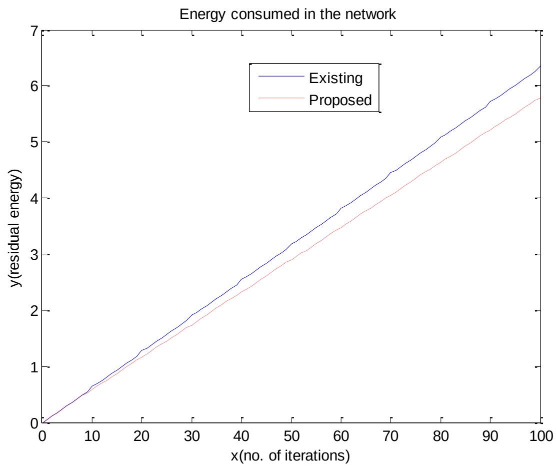


(b)

Fig. 2. (a) Initial deployment of 500 sensor nodes (b) Optimal placement of 500 sensor nodes after proposed FA



(a)



(b)

Fig. 3. (a)Energy comparison graph for 400 sensor nodes (b) Energy comparison graph for 500 Sensor nodes

VI. Conclusion

In, this paper, maximum self organization connectivity in WSN with minimal displacement and energy is considered. For solving this problem swarm intelligence algorithm, firefly algorithm was adjusted. A firefly based optimization is proposed by considering energy, distance parameter for its fitness function. The proposed method was theoretically analyzed and simulated for WSN with reference to other methodologies in the literature.

Conflict of Interest

Declaring that the submitted work was carried out without a conflict of interest.

Author Contribution

Both the authors Mamatha K M and Kiran M have contributed equally to this work in conduct of research, analysis of data, writing the paper. And both authors have approved final version.

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