Energy Efficient Routing and Coverage Using Modified Fire-Fly Algorithm in Wireless Sensor Networks

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Abstract

In this paper, one of the fundamental problems of coverage in Wireless Sensor Networks (WSNs) is addressed. Coverage, answers the questions about quality of service that can be provided by a particular Sensor Network. The ultimate goal is to have at least one sensor in a network able to cover the area of interest. In the research work presented here, energy efficient routing and coverage using Modified Fire-Fly algorithm is obtained. The objective function of conventional Fire-Fly algorithm is modified by introducing a new parameter called convergence parameter used for premature converging of the Fire-Fly algorithm. The algorithm presented here emphasizes on network lifetime of the sensor network, because of the energy constraints of the nodes. After the nodes are deployed, the lifetime of wireless sensor network must be increased as much as possible. In addition to this we also make sure that WSN is fault tolerant as after the deployment of wireless sensor nodes the information must not be lost. The focus is on to ensure maximum coverage while maximizing the data delivery to the sink node. The simulations done in NS2 platform show that the Modified Fire-Fly is better than Greedy algorithm and Conventional Fire-Fly algorithm in terms of covering whole of the network while ensuring the data delivery.

Keywords

Modified Fire-Fly Algorithm, Fire-Fly Algorithm, Greedy Algorithm, Energy Efficiency of Wireless Sensor Network, Network Lifetime of Wireless Sensor Network, Residual Energy of Wireless Sensor Network, Convergence Parameter, Fault Tolerance.

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Introduction

From past few decades WSN has been a rich field in terms of research because of its potentially wide range applications including surveillance, tracking, detection of intruders, traffic control, disaster prevention etc.[12–14]. WSN consists of wireless sensor nodes and one or more base stations. The nodes are used to monitor the area of interest or region of interest and detect parameters like distance, temperature etc.

These nodes are very small in size in order to have less consumption of power. These nodes communicate with each other through RF signal with the help of in–built antennae. Sensor nodes operate in four modes. In active mode, sensor monitors the environment and communicates with other sensors in the network. In sleep mode, a sensor neither monitors nor communicates with other nodes. Sleep mode of sensor is employed because of several constraints of sensor nodes like battery power, communication and computation capabilities. When a node awakes from sleep mode it enters the listen mode, where it listens to the environment to receive the signal otherwise it will enter the wait mode, till the signal comes. Wireless Sensor Networks have emerged as an acceptable methodology for sensing events and acquire data generally spread over various locations in a geographic area[12].

One of the most critical parameter for successful implementation of a WSN is the Coverage provided by the deployed sensors over the geographical area which is being monitored. Coverage is defined as the area of interest that the sensor can monitor efficiently without missing out on the events that may occur within any part of the geographical area[15]. Coverage can be categorized as one of the parameters towards the measure of quality of service (QoS) rendered by the deployed WSN[16]. The goal of coverage is to cover whole of the region of interest or area of interest by at least one sensor node. There is lot of work contributed to towards coverage related problems in wireless sensor networks (WSN) for many years[15,16]. The work includes covering each point in the region of interest (RoI), surveillance and coverage versus connectivity issues when wireless sensor network (WSN) is deployed[16]. The issue of energy efficiency tends to be the over-riding criteria for establishing the effectiveness of a network and there generally is a trade-off between coverage and energy efficiency.

Depending upon the deployment of the actual Wireless sensor nodes in a sensor network, the deployment is generally classified as dense deployment or sparse deployment[15]. Dense deployment is the case when the sensor nodes deployed in a sensor network are relatively large in number and there is significant overlap between the coverage areas of the deployed sensors whilst ensuring that no part of the area is left uncovered by the nodes. Sparse deployment is the case where the number of sensor deployed in a sensor network are few and there is no significant overlap between the coverage areas of the deployed sensors. Dense deployment will be the preferred mode of deployment in a case where detection of every minute event over the complete area is a requirement. On the other hand, sparse deployment is preferred when there are constraints like cost, number of sensors etc. The critical problem in sparse deployment is to achieve maximum coverage using minimum number of sensors[17].

Another mechanism of distinction is depending upon the deployment mechanism utilized which may result in deterministic or random placement depending on the alignment/placement/location of the wireless sensor nodes. In deterministic deployment the position of each node and topology of the network is pre-determined. In this type of deployment the nodes can be added or deleted as per need of the network to adjust the density of nodes in a sensor network or to obtain the better coverage efficiency. In case of random deployment, the node density could vary significantly over the deployed area and is not predeterministic.

Post-deployment, an algorithm is chosen that is run through the network constituting the nodes in order to check the efficient coverage exists in the area. The algorithms are classified into centralized and distributed algorithms. On one or more nodes centralized algorithm is run in a centralized location fashion often near the data sink in the area whereas distributed algorithm operates on many nodes throughout the wireless sensor network. A distributed algorithm involves working together of multiple nodes to solve a computing problem. Distributed algorithm have special case which is called localized algorithm, localized algorithm also made to run in many nodes but localized algorithm implies that many or all of the nodes run the algorithm separately on the information each node has gathered. Both distributed and localized mechanisms spreads the workload evenly as compared to centralized algorithm. Distributed algorithms and localized algorithms are more complex than centralized algorithms because they are run on more than one node.

Energy is one of the most crucial and most discussed issue in modern world applications. Energy efficiency is a motive by which amount of energy that devices require to run and provide services are reduced. Energy efficiency improvements are required and generally achieved by adopting a good better efficient technology or process production or to introduce a method or application by which energy losses will be minimized. Various motivations are available to improve energy efficiency. Less power consumption has proved to be a cost effective strategy.

Since sensor nodes once deployed may not be accessible, as a result changing the battery of these nodes may not be feasible. Also sensor nodes are deployed in remote sensing environment and the size of sensor nodes is very small and has limited battery.

Network lifetime depends upon the lifetime of majority of nodes in a network. Hence it is the time during which a Wireless Sensor Network (WSN) would be fully operative. Simply one can define network lifetime as the time taken by the all network node to run out of energy for sending a packet, which is crucial for the network as to lose a node could result in losing some functionalities. The energy may be the battery power in many cases which may die out, whenever other WSN nodes are using desired information or forwarding the information to their destination. Thus for efficient use of energy sources which are limited, the WSN should be organized into clusters, when the sensor nodes are deployed. However, there is a problem of unbalanced energy consumption in the network which is tightly bound to the location as well as role of a particular node. It is important to balance the energy dissipation of cluster heads in a network, in which the cluster heads nodes which control the processes, are designated by few more powerful ones, by sequencing them into heterogeneous clusters. Clustering in a network can be done in two ways equal clustering & unequal clustering.

Related Work

The aim of current research is to identify the various strategies by which the various issues like energy efficiency, power consumption, routing, number of active nodes, coverage area density, algorithm used, residual energy, fault tolerance related with coverage of wireless sensor networks are tackled. As coverage is a typical issue in sensor networks to fulfil condition of sensing in particular area, therefore sensing coverage area is the actual region that represents an area which is monitored by sensors to best possible. The efficiency of a wireless sensor network can be judged by the levels of coverage, power consumption and connectivity provided by them. The coverage problem in wireless sensor networks has been studied extensively in[1–9], but the current studies suggest the coverage efficiency in terms of network lifetime and fault tolerance needs to be improved. Most of work is done on coverage density especially when combined with energy efficiency and connectivity[2,10,11]. Constructing a fully covered, fault tolerant and energy efficient sensor network is more valuable for real world applications due to the limited resources like cost, size, and energy.

The authors in[1] used sophisticated deterministic deployment of sensors method and arranged all the sensors in diamond pattern which would correspond with a Voronoi polygon. This pattern addresses four ways connectivity from each of the nodes with full coverage when the communication region is divided by the sensing range is greater than the square root of two. The authors have proven validity of the pattern mathematically as well. In deterministic deployment we assume the sensing range is perfect circle and sensors have exact location. Random deployments of sensor nodes are usually dense in which sensor nodes are distributed within the field stochastically and independently. The authors in[2] have developed centralized and distributed algorithms for k-coverage network. From the results they conclude centralized and distributed algorithms always return to near optimal solution. Authors in[4] also run centralized and distributed version of their algorithms also consumes less energy than comparable algorithms.

From the above, it can be concluded that with reference to network coverage problem, following issues need to be taken care of:

1. To provide a new parameter for judging the quality of service of the algorithm as well as it will prevent the large scale computations by premature convergence.
2. Reasonable lifetime of the network to be achieved.
3. Energy efficient Network to be maintained
4. Fault Tolerant Network

Problem Statement

Based on the literature survey, there are various issues in the coverage that needs to be addressed as after the wireless sensor node are deployed, user is detained to have an access to the sensor nodes. Because of the energy constraint we cannot change the battery after the battery gets dead.

So in order to have efficient coverage we need to decrease power consumption as much as possible. Also because of the energy efficient coverage the network lifetime will be increased that is the main issue as far as modern sensor networks is concerned. Another issue that need to be addressed is fault tolerance, may be because of some circumstance or machinery failure sensor node stops sensing after deployment.

The area covered by that node will remain vacant and uncovered, thus making the network less efficient. We must also take care of the number of sensor node, keeping the factors like cost, labor, compactness etc. in mind the number of wireless sensor nodes must be less. Routing of data also is important while considering the Point of Interests (POI) in the particular area and needs to take care off.

Proposed Solution

The first step toward the solution is to deploy the nodes in a selected grid, taking care of the power management. The steps followed in the solution part are shown by a flow chart in Fig.1.

As we see algorithm implemented is modified firefly algorithm. Firefly algorithm is a meta-heuristic algorithm which takes into flash of fireflies as the signal. When the algorithm is implemented various parameters like network lifetime, residual energy possessed by a node, length of a sensor set and probability of covering a Point Of Interest (POI) are obtained. NS2 is utilized as the network simulator.

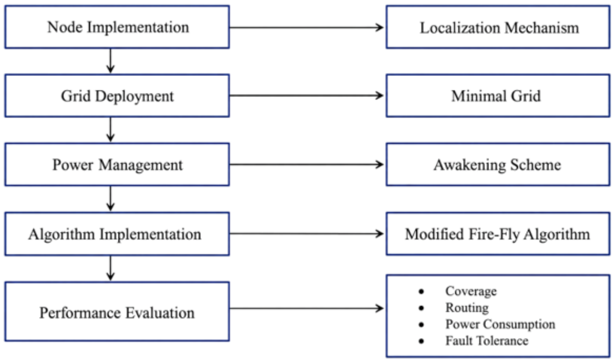

Figure 1. Proposed Solution

In the solution we have implemented the Modified Firefly Algorithm and compared it with existing Firefly algorithm and Greedy algorithm in terms of performance.

Firefly Algorithm

Fire-Fly algorithm is a meta-heuristic algorithm that came into existence because of the flashing behavior of the Fire-Flies. The flash of the Fire-Flies act as a signal to attract other Fire-Flies with the aim of finding the location of the particle that results in the best evaluation of the given fitness function. This algorithm works on three main rules as given below:

1. Fire–Flies will be attracted towards each other regardless of their sex i.e. all Fire-Flies are unisex.
2. The attractiveness of a Fire-Fly is directly proportional to the brightness i.e. on increase of the brightness of Fire-Fly attractive between the Fire-Flies increases and inversely proportional to the distance i.e. on increase of distance the attractiveness decreases.
3. Objective function determines the brightness of a fire fly.

The objective function of the Fire-Fly algorithm is given below

$$I = I_o e^{[-\gamma r^2]} \tag{1}$$

Where I_o is the original fluorescence intensity at the location of $r = 0$, and γ is the fluorescence absorption coefficient. This equation gives the Florescence Intensity of the Fire-Flies.

The attractiveness of a Fire-Fly is defined as below

$$\beta = \beta_0 e^{[-\gamma r^2]} \tag{2}$$

Where β_0 is their attractiveness at $r = 0$ that is the two Fire-Flies are located at same point, γ is the fluorescence absorption coefficient and r is the distance between two Fire-Flies.

The displacement of Fire-Fly i on getting attracted to another more attractive firefly j is determined by

$$\Delta x_i = \beta e^{[-\gamma r^2]}(x_j - x_i) + \sigma \varepsilon_i \tag{3}$$

Where $r = [(x_j - x_i)]$ is the Cartesian distance between two fireflies at x_i and x_j locations, α is the step size controlling parameter and while ε_i is a vector drawn from a Gaussian or other distribution.

Fire-Fly Algorithm Pseudo Code

The existing Fire-fly algorithm is represented by pseudo code as below:

1. Objective Function ; f(x)
2. Generate initial population of Fireflies (i = 1,2,3,4,. . . . . . ,N)
3. Intensity of Florescence I of a firefly Ui at location Xi is determined by $I = I_o e^{[-\gamma r^2]}$
4. Define Light absorption Coefficient γ
5. while t > Max Generation
6. for i = 1 : n (all n fireflies)
7. for j = 1 : n (all n fireflies)
8. if (Ij > Ii)
9. Move Fire-Fly i towards Fire-Fly j;
10. end if
11. Vary attractiveness with distance r via $\beta = \beta_0 e^{[-\gamma r^2]}$;
12. Evaluate new solutions and update light intensity;
13. end for j
14. end for i
15. Rank fireflies and find the current best;
16. end while
17. Post-Processing the results and visualizations;
18. End

Greedy Algorithm

In Greedy algorithm at each stage the set of optimal solution are created for problem solving heuristics with the hope of attaining global optimum. Greedy algorithm may not follow the same procedure to solve all the problems that create a set of optimal solution to find the global solution but nonetheless greedy heuristic may yield the optimal solutions locally which resemble the global solution in reasonable time. For example, if we study the greedy strategy of Travels Salesman Problem having complexity in computations.

This problem follows the heuristics: "At each stage visit an unvisited city nearest to the current city". This heuristic do not find the best solution directly but end with large number of optimal solutions requiring many steps from which he chooses the best solution. Greedy algorithms produce best solutions on some mathematical problems but not on all of them.

Greedy Algorithm pseudo code

1. The existing Greedy Algorithm is represented by pseudo code as below:
2. Objective function $f(x), x = (x_1, x_2, \ldots\ldots, x_d)$

3. Find sets S_i of sensor nodes for every Point of Interest(POI) i
4. Choose random sensor nodes from S_1,and append it to F
5. for i=2:N (total no of POI)
6. for j=1:lenght(F)
7. if(F_j in S_i)
8. save energy and probability parameter
9. break;
10. else
11. ind←generate random index between 1:length(S_i)
12. F←append(S_{ind})
13. save energy and probability parameter
14. end if
15. end for j
16. end for i
17. end

Modified Firefly Algorithm

The proposed algorithm is a modification of is actually the modified version of Fire-Fly algorithm to provide much better solution to the routing and coverage in sensor networks. The Fire-Fly algorithm is based on the flash of the Fire-Flies. The flash of the Fire-Flies act as a signal to attract other Fire-Flies with the aim of finding the location of the particle that results in the best evaluation of the given fitness function. In Modified Fire-Fly algorithm we have also taken these parameters luminous intensity and attractiveness as the basic parameters comparing them with residual energy of the node and distance between the nodes.

The objective function of the Fire-Fly algorithm is given flow chart given in fig.2.

$$I = I_o e^{[-\gamma r^2]} + \xi \tag{4}$$

Here ξ is convergence parameter. This equation gives the Florescence Intensity of the Fire-Flies. The attractiveness of a Fire-Fly is same as in (2).

The displacement of Fire-Fly i on getting attracted to another more attractive firefly j is determined by:

$$\Delta x_i = \beta e^{[-\gamma r^2]}(x_j - x_i) + \xi + \sigma \varepsilon_i \tag{5}$$

The nodes having maximum luminous intensity will be preferred first followed by decreasing luminous intensity. In addition to these parameters we have added a new parameter to the fitness function called a convergence parameter (ξ).

Because all the evolutionary algorithms try to converge prematurely in order to attain global solution from the local computations. The reason behind this is these algorithms make large number of computations resulting in large set of local solutions. This parameter is expected to make algorithm converge prematurely if there is no significant change in this convergence parameter or if the best solution can be chosen from the computation so far generated. This will result in minimum complexity and less simulation time is required for the algorithm to give global results. Also energy consumed by the computation generation will be preserved which in turn increases the network lifetime.

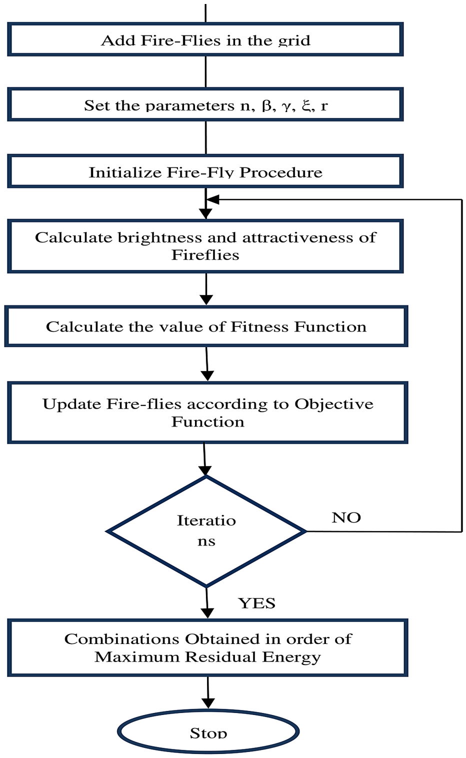

Figure 2. Flowchart of Modified Firefly Algorithm

Operation of Modified Fire–Fly algorithm Consider a grid consisting of 3 Point of Interests (POI) and 15 sensor nodes were deployed in Department lab computer. The grid in order to cover the set of Point Of Interests (POI's) as shown Figure 3.

When the nodes are deployed these nodes will remain in sleep state until a request is sent or a node senses that the point needs to be covered. At that time sensor node will enter to the Beacon state and when it starts sensing the particular Point of Interest (POI) the node remains active. Now the POI's which fall in the sensing range the sensor nodes will sense them. Each POI can be sensed by more than one node as shown below. Each node will try to sense and start sending and receiving data from the sensor nodes. The Fire-Fly algorithm will make set of nodes at a time one node covering that POI. The set of nodes from the computation obtained having maximum residual energy will be preferred to cover the POI and then followed by decreasing residual energy set.

When the residual energy of the first one decrease after sensing the POI's, the second set automatically will start sensing the set of POI's as a result we will get efficient and fault tolerant coverage. Because

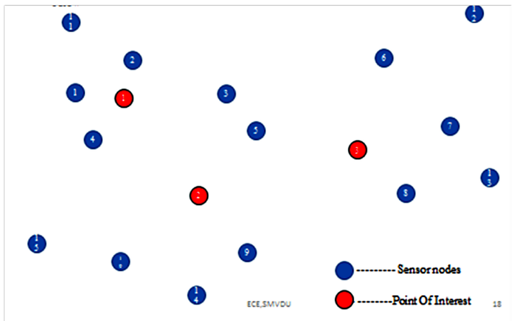

Figure 3. Random Deployment with 3 POI and 15 Sensor Nodes

when sensors are deployed we do not have an access to amend it if because of some circumstances the node stops working normally. We will not lose any data as the next set automatically will start sensing the POI. This provides the fault tolerance mechanism to the network.

As can be seen in Fig.4, a combination set of sensor nodes covering the point of interests are formed as per the maximum residual energy possessed by set of nodes as shown below:

1,5,8
2,9,7
1,10,6
3,8
4,5,13
2,5,6
4,8,13
4,5

From the combination set the first set will start sensing the Point of Interests (POI's) when the residual energy.

With the passage of time the energy gets decreased, when the residual energy of first set becomes less than that of second set, second set automatically starts sensing the Point Of Interests (POI's). The process continues till the residual energy of all the combinational sets expires and all nodes stop working at a same time.

Results

The simulation results are provided in Fig 5- Fig. 8 which compare the Average residual energy, coverage probability, number of sensor nodes used to obtain full coverage and fitness function value using all the three algorithms viz. conventional greedy algorithm, conventional firefly algorithm and modified firefly algorithm and compare the values of all the algorithm with each other varying number of nodes (NN) and number of Point Of Interests (NP). All the three algorithms conventional greedy algorithm, conventional

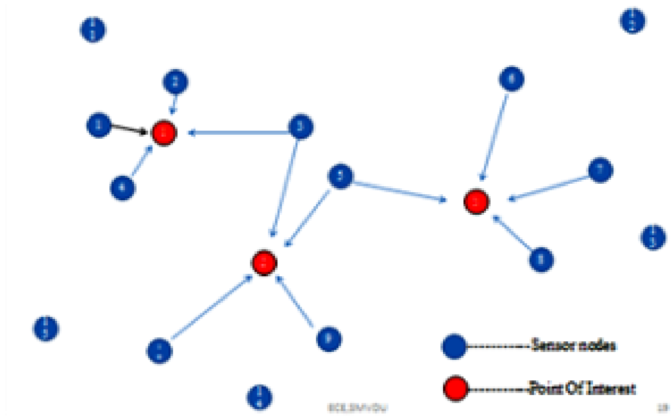

Figure 4. Network Coverage with Proposed Algorithm

firefly algorithm and modified firefly algorithm are compared with each other. The number of nodes (NN) = 50 and number of POI's = 10.

From the first graph in Fig. 5, it is clear that the average residual energy of a sensor node is significantly more in new modified meta-heuristic algorithm as compared to conventional ones. In fact a careful observation reveals that because of the addition of the new convergence parameter (ξ), the modified algorithm provided better sensor utilization than the conventional one.

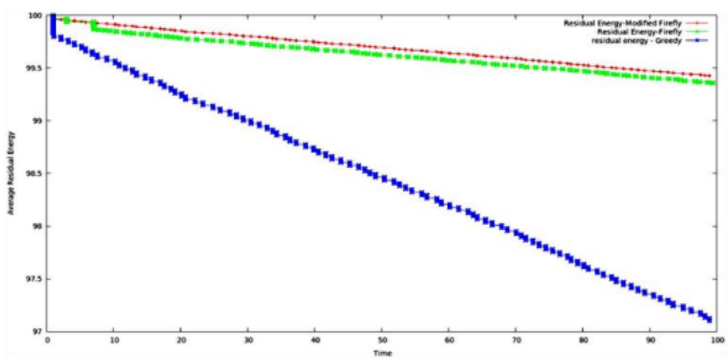

Figure 5. Average Residual Energy vs. Simulation Time in Seconds.

The results depicted in Fig. 6 indicate that the coverage probability is also greater when using modified firefly algorithm viz a viz the original fire fly algorithm with the same number of sensor nodes.

The third graph in Fig. 7, determines the length of set, which is the number of sensor required to cover all the POI's in the area given. From the graph it is clear that in case of modified Fire fly algorithm

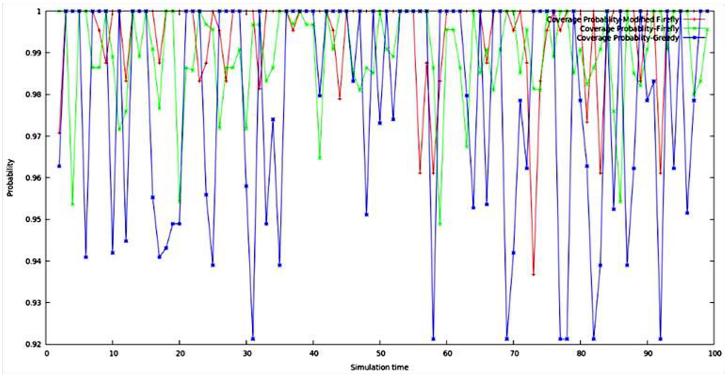

Figure 6. Coverage Probability of Proposed Algorithm in comparison to Firefly and Greedy Algorithm vs. Simulation Time

the number of sensors required is less than that of conventional algorithm. This is an important results as this indicates a more optimized coverage with lesser number of nodes which has a direct bearing on the energy efficiency figure as well as the cost of implementation of a network. This also indicates that the probability of maintaining coverage despite failure of nodes is higher in case of modified fire fly algorithm. This indicates that the sensor network has a higher degree of fault tolerance.

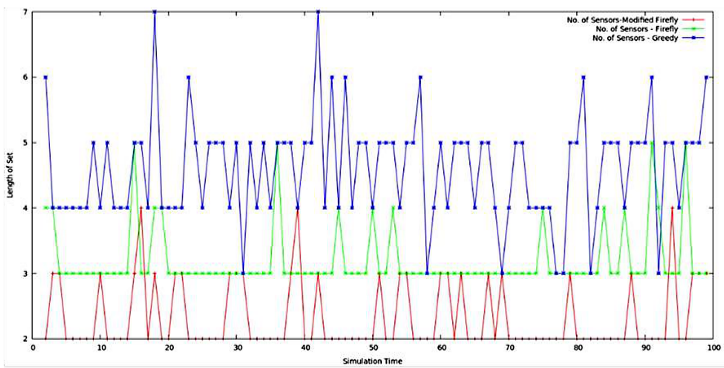

Figure 7. No of Sensors Required for full coverage vs. Simulation Time

The fourth graph in Fig. 8, shows fitness function value of all the algorithms under observation. Because of the convergence parameter, the fitness function value is far better than the conventional fire fly algorithm.

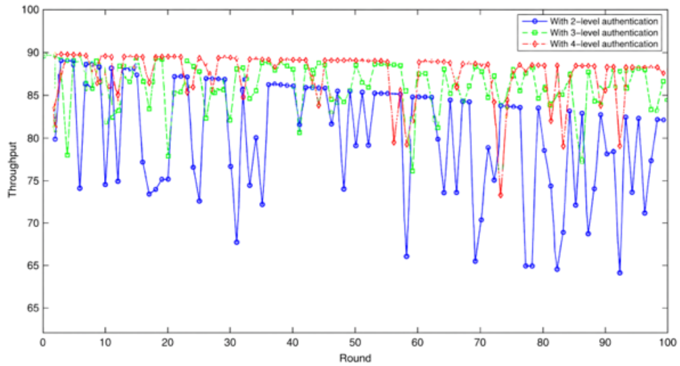

Figure 8. fitness Function value vs. Simulation Time

Conclusion

The current research work has achieved all the objectives of the network coverage problem in which network Life time is increased, network has become fault tolerant and energy efficiency is increased. Also the new parameter introduced in the fitness function used for comparison of Quality of Service (QOS) for various possible algorithms proved fruitful and has given better results than conventional and existing algorithm in terms of premature convergence. The local computation so obtained is less in number resulting in dealing with smaller computational set. Also, since computation set is small energy consumed will be less resulting in increase in network lifetime. Also best solution among the computational set is retained. Besides all these results achieved above, the Modified Fire-Fly algorithm is compared with Greedy Algorithm. The simulation results proved the Modified Fire-Fly algorithm to be better than the former one. Also, The Modified Fire-Fly Algorithm is compared with Original Fire-Fly Algorithm. The simulation results proved Modified Fire-Fly Algorithm better than Original Fire-Fly Algorithm. Based on these observation and analysis idea for a new algorithm was developed. It is argued that the new algorithm is both computationally efficient and also outperforms the conventional and existing algorithm in maximizing the network lifetime.

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