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Improving the Stability Period Using Firefly Algorithm

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Abstract: *The research in the field of Wireless Sensor Networks (WSNs) is on the upsurge these days. These networks are application specific and can be used to gather information from the regions where our bodily presence is not viable. Routing protocols used to route information can be data centric, location based, hierarchical etc. The main objective is to efficiently put to use the limited energy available in a network. In this paper, we have implemented the Firefly optimization algorithm on hierarchical clustering based protocols LEACH and TEEN in both homogeneous and heterogeneous environments using first order radio model and compared the end results. Simulation results in MATLAB show that Firefly algorithm slightly improves the stability period in both LEACH and TEEN i.e. the First node dead (FND) time period increases.*
Keywords: *Wireless Sensor Networks, Cluster Head, Firefly Algorithm*

I. Introduction

With time technology has shifted from wired networks to wireless networks. Today Wireless Sensor Networks (WSNs) have invaded all domains of our daily life. Whether it is heath monitoring, area monitoring, habitat monitoring, weather monitoring, water level detection, forest fire detection and many more, WSNs have put a step forth in each of the above fields. WSN is used to enable interaction between the environment and the end user. Typically, a WSN comprises of hundreds or thousands of sensor nodes that are deployed randomly in a hostile environment. These sensor nodes have low cost, low power, small size and are multifunctional performing activities like sensing, computing and wireless communication. These nodes are usually battery powered and it is impractical to recharge or replace batteries in inaccessible terrains. So, improving the energy efficiency is the major area of research till date.

Wireless network nodes may be homogeneous or heterogeneous depending upon whether the nodes have same initial energy or different initial energy respectively.

Routing protocols are designed to reduce energy consumption. They may be proactive or reactive [1]. In a proactive routing protocol, data is always transmitted by a node but in reactive routing protocol data is transmitted only when its value exceeds a certain threshold. This reduces the number of transmissions thus saving energy. However, proactive routing protocols give a better view of the environment as inputs are always received but in case of reactive protocols data is received only when thresholds are met. Routing in WSNs may be carried out either in a single hop or a multi hop fashion. In single hop fashion, nodes transmit the sensed data to Cluster Head (CH) which further forwards it to Base Station (BS). The CH performs additional activity of data aggregation. In multi hop fashion, intermediate nodes forward the sensed data till it reaches the BS.

Also a network is static if the regions are predefined and node deployment is fixed whereas in case of dynamic networks each node associates to different CH in each simulation.

Hierarchical Clustering is an efficient method to arrange a wireless sensor network according to which, levels of hierarchy are formed to transmit data to BS. In this there are two types of communication that can take place i.e. intra cluster communication which is communication between the nodes within a cluster and inter cluster communication which is communication between the CHs. CH performs data aggregation as data within a cluster is highly correlated and data aggregation reduces the amount of data being sent which in turn saves energy.

Recently many optimization algorithms have been used to improve the stability period and network lifetime of Wireless Sensor Networks (WSNs). Firefly algorithm (FA) is one of these. Firefly algorithm was initially developed by Xin-She Yang [2] which was based on the flashing patterns and behavior of fireflies. The bioluminescence from the body of fireflies is due to a compound named 'luciferin'. Each firefly gets attracted to a brighter firefly which depends upon the distance between two fireflies as the amount of radiation received follows inverse square law. In this paper, we study the improvement in stability period using Firefly algorithm.

In this paper, section I was an Introduction to Wireless Sensor Networks (WSNs). Section II throws light on the work that has been done till date in the same field. Section III describes the basic first order radio model and the parameters have been listed, that are used for simulation. Section IV describes the basics of firefly algorithm. Section V describes the work done by us and hence explains the procedure carried out. Section VI lists the results that were experimentally found. Section VII presents our conclusion for the proposed work.

II. Related Work

Wendi Rabiner Heinzelman *et al.* in [3] proposed the basic clustering protocol named Low Energy Adaptive Clustering Hierarchy (LEACH). In this, all the nodes are assumed to be homogeneous i.e. having the same initial energy and based on some predefined probability 'p' some nodes are elected as Cluster Heads.

$$T(n) = \left\{\frac{p}{1-p*(rmod\ (1/p))}\right) if\ n€G \qquad (1)$$

Where 'G' is the set of nodes that have not been elected as cluster heads till now and 'r' is the current round number.

Nodes associate with these Cluster Heads based upon the minimum distance and transmission occurs, where Cluster Head nodes aggregate data from all the nodes falling within its cluster to eliminate redundant data. In order to prevent severe depletion of energy in case of Cluster Heads, there is randomized rotation of these Cluster Heads. However, being a proactive network data is always sent giving rise to unnecessary transmissions thus depleting energy.

Tran Cong Hung *et al.* in [4] proposed a modification to the conventional LEACH protocol in which the Cluster Heads are elected not only based upon probability but also on the residual energy of the node and its distance from the Base Station.

$$T(n) = \left\{\frac{p}{1-p*\left(rmod\left(\frac{1}{p}\right)\right)} * \frac{E(i)}{d(i)}\right) if\ n€G \qquad (2)$$

where E(i) is the residual energy of the node under consideration for being elected as Cluster Head and d(i) is its distance from the Base Station. This alteration improves the stability period and network lifetime of the network but still has the drawback of unnecessary transmissions.

Arati Manjeshwar *et al.* in [5] presented the reactive hierarchical routing protocol named Threshold sensitive Energy Efficient sensor Network Protocol (TEEN). Cluster Heads are selected in a way similar to LEACH protocol but it reduces the number of transmissions as data is forwarded only when the sensed value exceeds certain thresholds. These thresholds are named Hard Threshold (HT) and Soft Threshold (ST). However, the major drawback is that we may not receive any data from the network if thresholds are never met.

D. Baghyalakshmi *et al.* in [6] presented a survey of energy efficient clustering protocols. In this paper, modification to TEEN is studied referred to as Adaptive Periodic Threshold sensitive Energy Efficient sensor network protocol (APTEEN). APTEEN introduces an additional attribute i.e. Count Time (CT) in order to overcome the drawback of TEEN protocol. Count time is the maximum time period between two reports sent by a node even if the thresholds are not reached. So, APTEEN is a hybrid routing protocol that provides both periodic data and time critical data. However, addition of Count Time adds to the complexity of the network protocol.

Zibouda Aliouat *et al.* in [7] proposed Well Balanced TEEN (WB-TEEN) and Well Balanced TEEN with Multi-hop intra-cluster communication (WBM-TEEN). WB-TEEN deals with clusters being nodes balanced or slightly differing in sizes so that the amount of energy consumption can be minimized. WBM-TEEN involves multi-hop intra cluster communication instead of single hop communication directly to Cluster Head to save energy.

A.Kashaf *et al.* in [8] presented Threshold Sensitive Stable Election Protocol (TSEP). In this, there are three levels of heterogeneity consisting of normal nodes, intermediate nodes and advance nodes. Advance nodes are a fraction 'm' of total 'n' nodes and intermediate nodes are a fraction 'b' of total 'n' nodes. Energy of advance nodes is 'α' times the energy of normal nodes and energy of intermediate nodes is 'μ' times the energy of normal nodes where $\mu=\alpha/2$. Energy of normal nodes is Eo. The selection of CHs is based on probability. Transmissions occur only when sensed values exceed hard and soft threshold which can be changed as requisite.

N.Javaid *et al.* in [9] proposed Hybrid Energy Efficient Reactive Protocol (HEER) in which Cluster Head selection is based on the initial and residual energy of the node. Also, it a reactive protocol so transmissions occur only when thresholds are satisfied. HEER improves stability period and network lifetime.

Prabhleen Kaur *et al.* in [10] presented Threshold-sensitive Deterministic Energy Efficient Clustering (TDEC) reactive protocol. In this, for round 1 only, BS elects cluster heads randomly. After that elected CHs send advertisement messages to all non CHs. All non CH nodes reply with a join request message to the CH from which the received signal strength is maximum. This join request message consists of CH-ID, CM-ID (Cluster member ID) and RE (Residual Energy) of CM (Cluster Member). CH node receiving the join request message takes into account the node with maximum residual energy and elects it as CH for the next round. After that, data transmission occurs based on two thresholds hard and soft threshold. This setup improves the stability period.

E. Sandeep Kumar, S.M.Kusuma and B.P. Vijaya Kumar *et al.* in [11] applied firefly algorithm on basic LEACH protocol. Initially, the selection of cluster head procedure is similar to conventional LEACH protocol, and after that intensity values are calculated between each CH and normal node. The node attaches itself to CH with which its intensity is maximum i.e. distance is minimum. Simulation results show that this algorithm improves the node survival rate.

P.Leela and K.Yogitha in [12] proposed a hybrid approach for energy optimization. This approach combines Firefly optimization algorithm and Artificial Bee Colony optimization algorithm. Initially, cluster heads are selected similar to conventional LEACH protocol and after that energy based switching takes place in which each CH looks for a node having energy greater than its own (CH) energy within its cluster and shifts the role to it, if it exists. After that based on a fitness function best cluster heads are selected. Fitness function is defined as:

$$fit_{CH}(k) = \frac{E_{CH}(k)}{\sum_{i=1}^{n} {d_{ik}}^2 + d_{CH-BS}^2} \qquad (3)$$

After that ratio of the current energy of each cluster head and the energy required for transmitting or receiving is calculated, and if the value is greater than one it is eligible to become a cluster head. Otherwise, the process of random selection of CHs repeats and so on. Simulation results show that this adaptation improves network lifetime.

III. First Order Radio Model

We use the basic first order radio model for wireless communication. According to this, energy needed to transmit a k-bit message can be calculated as;

$$ETX(k) = \begin{cases} k * E_{elec} + k * \mathcal{E}_{fs} * d^2, d < do \\ k * E_{elec} + k * \mathcal{E}_{amp} * d^4, d \geq do \end{cases} \qquad (4)$$

Where $do = \sqrt{\frac{\mathcal{E}_{fs}}{\mathcal{E}_{mp}}}$

Table 1: Radio model parameters used

PARAMETER	VALUE
ETX (Transmitter Energy)	50nJ
ERX (Receiver Energy)	50nJ
E_{fs} (Free Space Loss Energy)	10pJ
E_{mp} (Multipath Loss Energy)	0.0013pJ
EDA (Data Aggregation Energy)	5nJ

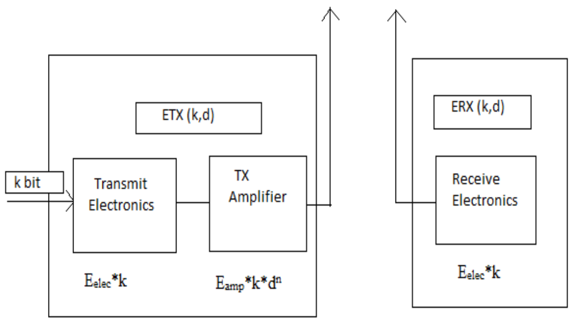

Fig 1: First Order Radio Model[10]

Also, energy required to receive a k-bit message is calculated as;

$$ERX(k) = k * E_{elec} \qquad (5)$$

IV. Firefly Algorithm

As aforementioned, Firefly Algorithm (FA) is based on the behavior of fireflies found in tropical and temperate regions. The flashing light produced by these fireflies is due to the process of bioluminescence. The light emitted by a firefly follows inverse square law according to which the amount of light visible decreases with the distance, which is due to absorption in the air. So, the amount of radiation reaching at a particular point will be different in all cases depending upon the distance from the respective firefly. There are three idealized rules on which Firefly Algorithm is based, these are:

1. All fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex.
2. Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases.

3. The brightness of a firefly is affected or determined by the landscape of the objective function [2].

Firefly Algorithm can be used as an optimization algorithm in order to improve the stability period.

V. Proposed Work

Initially in our work after the random deployment of nodes, Cluster Heads are selected randomly based on a predefined probability, similar to conventional LEACH and TEEN.

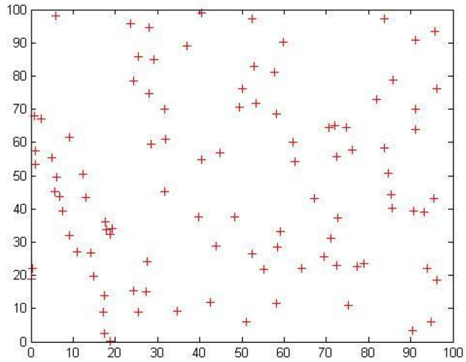

Fig 2: Random deployment of nodes in an area

Non cluster head nodes attach to the already selected Cluster Heads based upon the minimum distance. After this, each Cluster Head compares its energy with all the nodes falling within its cluster or we may say it's Cluster Members (CM). If the Cluster Head energy is maximum it holds on to its position as a Cluster Head but if there is a Cluster Member having energy greater than already elected Cluster Head, they switch positions and node with more energy becomes a Cluster Head. Re-clustering takes place based upon the minimum distance, after this energy based switching.

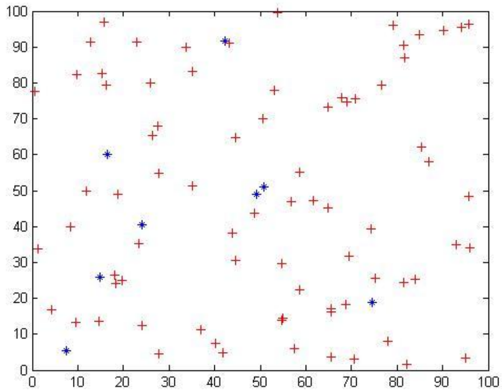

Fig 3: Normal nodes are shown in red and selected cluster heads in blue

Each Cluster Head calculates a Fitness Function (FF) and the 'k' Cluster Heads with the best Fitness Function are the finally elected Cluster Heads. The equation to calculate Fitness Function is (same as equation 3);

$$fit_{CH}(k) = \frac{E_{CH}(k)}{\sum_{i=1}^{n} {d_{ik}}^2 + d_{CH-BS}^2} \qquad (6)$$

Where,

E_{CH} is the residual energy of the Cluster Head whose fitness function is being calculated
d_{ik} is the distance of each node falling within the cluster to its Cluster Head and
d_{CH-BS} is the distance of Cluster Head to the Base Station or sink.

After the best Cluster Heads for the current round have been selected, data transmission occurs similar to those in conventional protocols. In case of LEACH protocol, data is always forwarded as it is a proactive network but in case of TEEN, being a reactive protocol that sends only time critical data, data is sent only when sensed values exceed threshold values.

VI. Simulations And Results

We have used MATLAB to experimentally verify our results. The parameters used during the entire course of simulation have been listed in Table 1 and Table 2. Also, we have evaluated LEACH v/s LEACH Firefly and TEEN v/s TEEN Firefly. Simulations have been performed 25 times, and the results have been averaged.

The following parameters have been taken into account during simulation.

Table 2: Parameters used while simulation

PARAMETERS	VALUES
Area of deployment	100*100
Position of Base Station	(50,175)
Number of nodes	100
Initial Energy, E_o	0.5J
CH percentage, p	0.05
Percentage of advanced nodes, m	0.5
Energy of advance nodes	$E_o(1+a)$ where a=1
Hard threshold (HT)	100
Soft threshold (ST)	2
Size of data packet	4000 bits
Size of control packet	50 bits

Stability period is the duration from the start of a network simulation till the time first node dies (FND).
Network lifetime is the time period from the start of the network till the time when last node is still alive.
As already discussed, TEEN protocol reduces the number of transmissions compared to LEACH protocol due to the presence of thresholds (HT and ST) that need to be met before any transmission takes place. The following graphs illustrate the improvement in stability period and network lifetime by TEEN over LEACH.

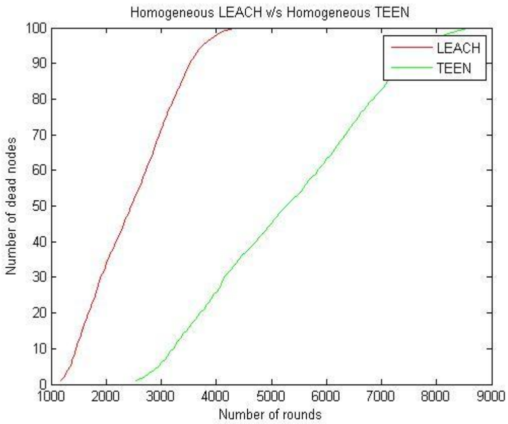

Fig 4: Dead nodes versus rounds

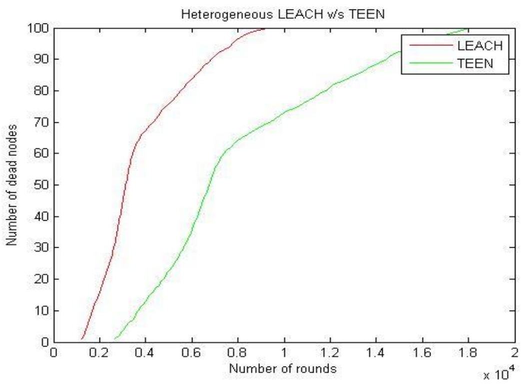

Fig 5: Number of dead nodes versus rounds

In case of homogeneous environment, all the nodes in the network have the same initial energy i.e. E_o which equals to 0.5J. During simulation of conventional LEACH in a homogeneous environment, first node dies (FND) in 1178th round whereas in case of LEACH Firefly same occurs in 1239th round improving stability period by 61 rounds.

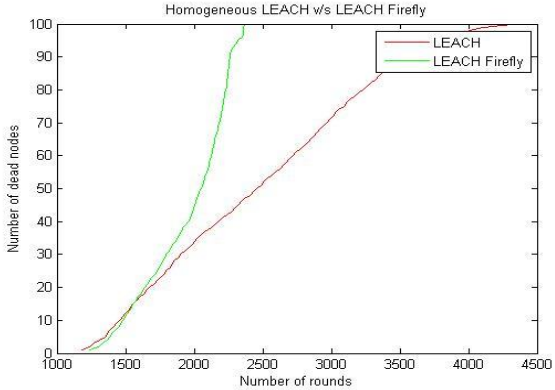

Fig 6: Number of dead nodes versus number of rounds

Similarly, in conventional TEEN first node death occurs in 2541^{th} round and in case of TEEN Firefly first node death occurs in 2691^{th} round improving the stability period by 150 rounds.

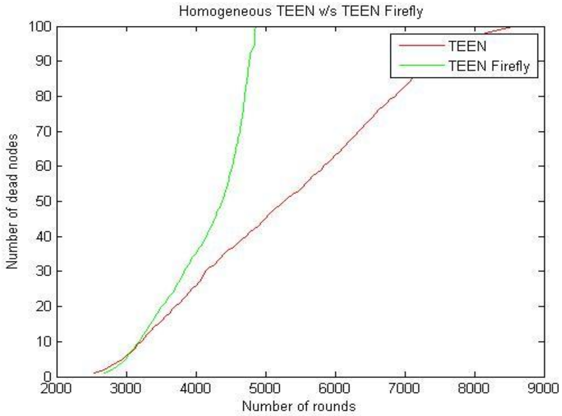

Fig 7: Dead nodes versus number of rounds

In case of heterogeneous environment, all the nodes deployed in the network have different initial energies which are distributed randomly to them. There are two types of nodes: normal nodes having energy equal to E_o i.e. 0.5J and advance nodes having energy equal to $E_o(1+a)$ where a=1 i.e. 1J. The improvement in stability period is more in case of heterogeneous environment. LEACH Firefly improves the first node death round number by 98 rounds and TEEN firefly improves the same by 196 rounds.

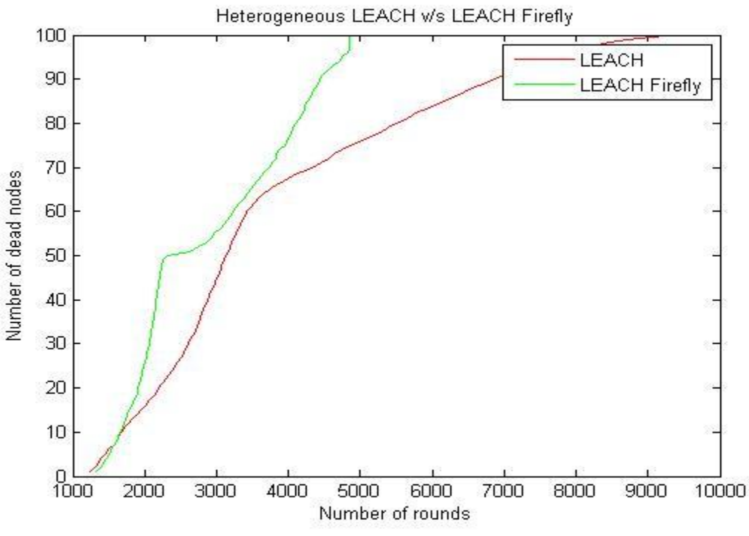

Fig 8: Dead nodes versus rounds

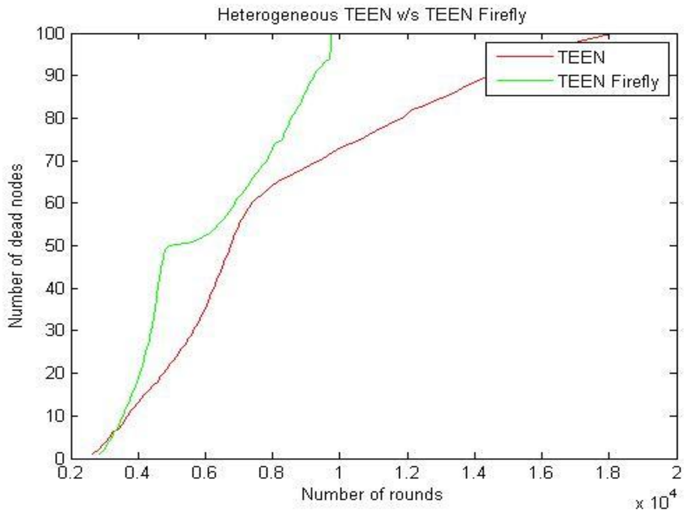

Fig 9: Dead nodes versus rounds

Further, comparison results show that TEEN firefly also offers an improvement over LEACH firefly in both homogeneous and heterogeneous environment by 1452 and 1527 rounds respectively.

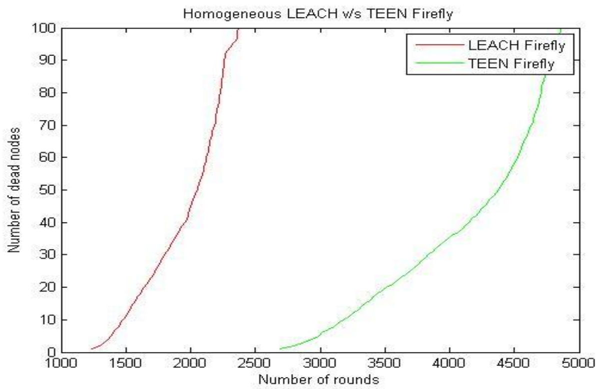

Fig 10: Number of dead nodes versus rounds

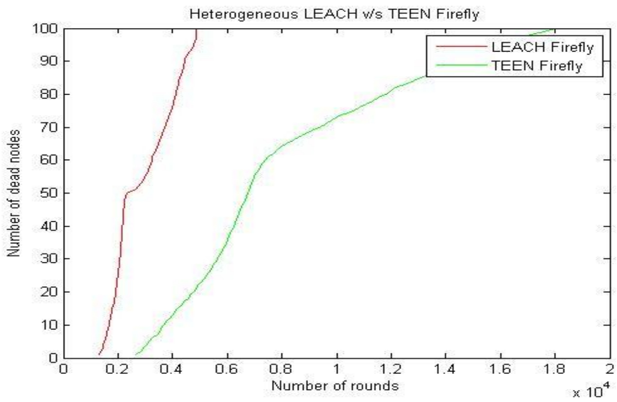

Fig 11: Dead nodes versus number of rounds

VII. Conclusion

As we have seen, the implementation of hierarchical routing protocols i.e. LEACH and TEEN using firefly algorithm improves the stability period or extends the first node death (FND) time period by few rounds. In future we would like to optimize the above routing protocols in such a way that it offers improvement in network lifetime too.

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