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Traffic and Distance dependent Energy Efficient Algorithm for Wireless Sensor Networks

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Abstract- Wireless Sensor Networks, also abbreviated as WSN, are the new fast evolving technology that consist of a large number of micro chips that have limited energy resources and can gather data in different kinds of environment. In this paper, a Traffic and Distance dependent Energy Efficient Algorithm has been proposed which is motivated from the LEACH. The algorithm design concentrates on improvement of the network lifetime and the number of packets that are transmitted by all the CHs to the BS over the rounds. The simulations have been carried out in Matlab and the results show significant improvements in the network lifetime. The network lifetime improves by as much as 14.6% over Optimal Energy Adaptive Algorithm.

Keywords- **Wireless Sensor Network, energy efficiency, traffic, distance, LEACH, hierarchical.**

I. INTRODUCTION

Advances in wireless communication made it possible to develop Wireless Sensor Networks. Wireless Sensor Networks, also abbreviated as WSN, are the new fast evolving technology that have been successfully utilized to perform the function of monitoring of the socio-economic areas, environmental conditions, in military applications, home applications and many more commercial applications. They consist of spatially distributed sensors which supervise physical or environmental conditions, such as temperature, sound, pressure, etc. The information collected by these sensors is then passed to the main location through their whole network by using the interaction amongst themselves. (Fig. 1).

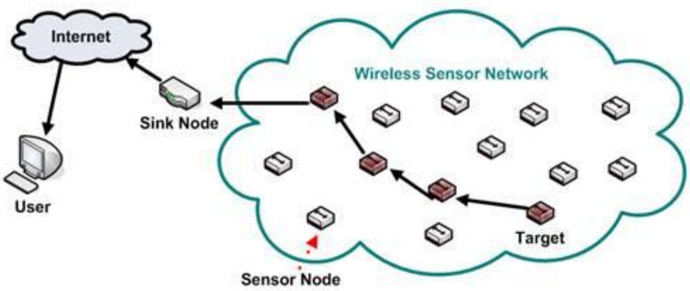

Fig. 1 Wireless Sensor Network [1]

These small sensing devices named sensors are also called nodes and consist of a sensing unit (for sensing the data and converting it into digital form), processing unit (for data processing and data storage), power unit (for energy) and transceiver unit (for receiving and sending signals or data from one node to another) (Fig. 2). There are also other subunits, which are application dependent. Most of the sensor network routing techniques and sensing tasks require a location finding system to have the knowledge of location with high accuracy. A mobilize may sometimes be needed to move sensor nodes when it is required to carry out the assigned tasks [2]. These nodes must [3]

• consume extremely low power,
• operate in high volumetric densities,
• have low production cost and be dispensable,
• be autonomous and operate unattended,
• be adaptive to the environment.

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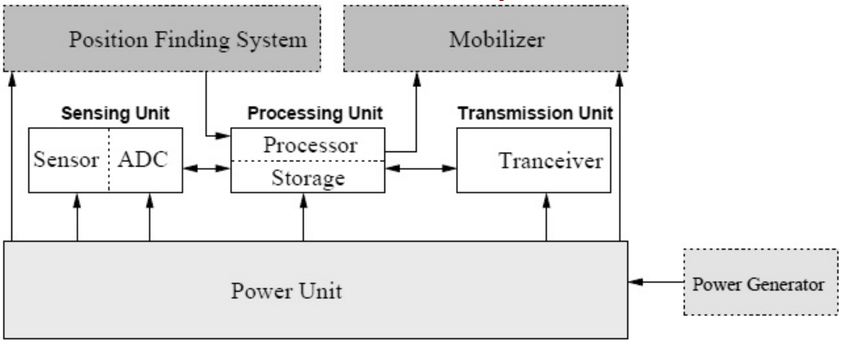

Fig. 2 The components of a sensor node [4]

Today, wireless sensor networks are widely used in the commercial and industrial areas. The employment of wireless sensor networks is increasing day by day but even after all the advancements it faces the problem of limited battery lifetime. And since each node depends on energy for its activities as it alone defines that for how long that node can play an active part in that network, it has become a major subject to deal with in wireless sensor networks. The energy is consumed by the sensing nodes either during the processing of the sensed data or during the communication amongst themselves or during idle-listening by the nodes. Now the energy consumed during the processing of data or during idle-listening cannot be reduced but the energy consumed during the communication in wireless sensor networks can be scaled down. The different ways which can be followed for the same are as follows [5]

- To schedule the states of the nodes (i.e. transmitting, receiving, idle or sleep).
- Changing the transmission range between the sensing nodes.
- Using efficient routing and data collecting methods.
- Avoiding the handling of unwanted data as in the case of overhearing.

Therefore, many researchers are trying to find the power-aware protocols and are also trying to implement the above stated ways in these protocols for the wireless sensor networks in order to overcome energy efficiency issues.

Despite the multitudinous applications of WSNs, these networks have several limitations, e.g., limited energy supply, and limited bandwidth available to each sensing node for communication etc. To overcome these factors, several routing protocols have been designed to obtain efficient Wireless Sensor Networks. The routing protocol basically specifies how routers in a network share information with each other and reports changes based on which routing in WSNs can be divided into three categories Flat-based Routing, Hierarchical-based Routing, Location-based Routing. One of the most popular routing protocol is LEACH which addresses cluster head election mechanism by means of probability. LEACH provides each node equal chance to become a cluster head for every round. However, becoming a cluster head drains out a higher amount of energy as it performs the function of receiving, aggregating and transmitting the data.

With the advancement in technology, various efforts have been put to evolve better results from LEACH protocol. In improved-LEACH (I-LEACH) [6], both the residual energy of the node and its distance from the base station (also called sink) are used as the parameters for the cluster head selection. The residual energy is calculated using the formula $E(current)/E(initial)$. For the same, the procedure is carried out by dividing the network equally into four quadrants. If the node lies in the same quadrant as that of the base station, then residual energy is given more weightage than the distance. If the node lies in the quadrant diagonally opposite to the quadrant of base station, then distance is given more weightage. But if the node lies in the other left two quadrants, then both are given equal weightage and the resulting selection is done on the basis of the threshold value chosen. I-LEACH outperforms LEACH in terms of network lifetime, amount of data transferred to base station and the energy consumed.

Energy efficient optimized LEACH-C [7], provides an improved energy consumption model. LEACH-C (LEACH Centralized) is a kind of improved LEACH in which before the set-up phase starts, the local

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information and the residual energy value of all the nodes of the network are sent to the base station. In this paper, authors have based the threshold value on the estimated largest energy consumption value for a single cluster head. Optimized LEACH-C involves selecting a group of cluster heads using LEACH-C following which a model of cluster head energy consumption is created by considering the retransmission and acknowledgment.

In LEACH-R [8], a relay node is used to diminish the gain in energy and thereby prolonging the network lifetime. The relay node selection is based on both the residual energy and the distance to base station, as using these two parameters, the relaying node is chosen from the list of decided cluster heads which relays all the data from the other cluster heads to the base station. LEACH-R on simulation proves that it is more energy efficient as compared to the LEACH protocol.

In the optimal energy adaptive algorithm [9], the LEACH's random cluster head election protocol is modified to ensure balanced energy dissipation over the entire network. The proposed algorithm involves modified duty cycle for the sensor nodes and to ensure the same, TDMA approach is optimized through sleep wake-up based decentralized MAC protocol. Battery health condition of the nodes has been taken up as a parameter in the cluster head selection, hence increasing the network lifetime. Results show that the proposed algorithm outperforms LEACH by around 30%.

In the proposed Algorithm, a modified technique has been introduced to select the most energy efficient nodes as cluster heads in every round. So, the nodes die rate will decrease which will automatically increase the network lifetime. Now, sometimes in event-driven networks, there is a possibility that the sensor nodes at a larger distance from the cluster head may hold more amount of data which is to be sent to their respective cluster heads. But due to the less number of slots allotted to those nodes, this setup may lead to the delay of data. So, LEACH has been optimized by depending the TDMA slot assignment on the distance and the traffic demand of the nodes within the cluster.

The remaining part of the paper has been organised as follows: In Section II, Network and Radio Models have been discussed. Section III discusses the proposed protocol in detail. In Section IV, simulation has been done using Matlab and performance comparisons have been made with Optimal Energy Adaptive Algorithm [9]. Finally, conclusions are drawn in Section V.

II. NETWORK AND RADIO MODELS

A WSN usually consists of tens to thousands of such nodes that communicate through wireless channels for information sharing and cooperative processing**.** The size of the network varies with the monitored environment. A WSN typically has little or no infrastructure. To ensure scalability and to increase the efficiency of the network operation, sensor nodes are often grouped into clusters [10] [11]. LEACH is basically the most popular cluster-based routing protocol and has been established as a promising protocol in wireless sensor networks domain. But still there are areas where this protocol can be made more efficient. So, in this paper, a modification has been done in the cluster head selection algorithm and also in the TDMA slot assignment algorithm. The system model used for the proposed protocol has following features:

A. The Network Model and the Architecture

This work assumes that 100 sensor nodes are randomly scattered in a two-dimensional square field of dimensions 100 × 100 square meters, and the network has the following properties:

- There exists only one BS at the centre of the square field.
- After deployment, the BS and all the sensor nodes are stationary.
- The energy of sensor nodes cannot be recharged.
- The WSN consist of sensors that are homogeneous in terms of their energies and hence are provided same initial energy.
- The BS is not energy limited in comparison with the energy of other nodes.
- The nodes are eligible enough to determine their current energy level.
- All the sensor nodes are immobile but they do not have the location information.

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B. The Radio Model

Currently, there is a great deal of research in the area of low-energy radios. Different assumptions about the radio characteristics, including energy dissipation in transmit and receive modes, will change the advantages of different protocols. For the radio hardware, transmitter dissipates energy to run the transmitter radio electronics and power amplifier, and the receiver dissipates energy to run the receive radio electronics.
In the model assumed for the work, the radio dissipates E_{elec} = 50 nJ/bit to run the transmitter or receiver circuitry and E_{amp} = 100 pJ/bit/m^2 for the transmit amplifier to achieve an acceptable E_b. Also in this thesis, both the free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models are used depending upon the distance between the transmitter and receiver.

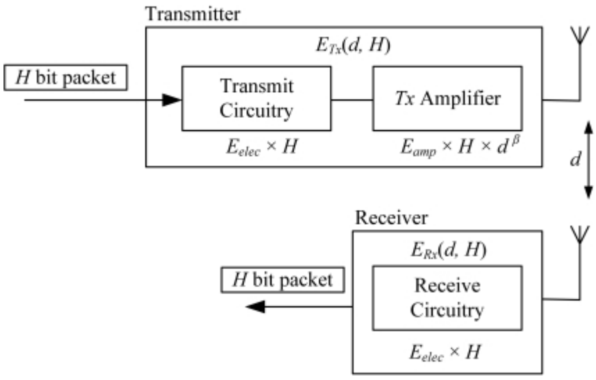

Fig 3. Radio Model [12]

In the radio model of the transmitter amplifier, β=2 for free space and β=4 for multipath model. Thus if a node transmits H number of bits over a distance d using the radio model, the radio expends:

$$E_{TX}(H, d) = E_{elec}(H) + E_{amp}(H, d)$$

$$E_{TX}(H, d) = \begin{cases} H.E_{elec} + H.\epsilon_{fs}.d^2 & if \ \ d < d_o \\ H.E_{elec} + H.\epsilon_{mp}.d^4 & if \ \ d \geq d_o \end{cases}$$

Threshold d_o is

$$d_o = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}$$

And to receive these H message bits, the radio expends:

$$E_{RX}(H) = E_{elec}(H)$$

Table 1 Radio Model Parameters

Description	Symbol	Value
Energy consumed by the amplifier to transmit at a shorter distance	ϵ_{fs}	10 pJ/bit/m^2
Energy consumed by the amplifier to transmit at a longer distance	ϵ_{mp}	0.0013 pJ/bit/m^4
Energy consumed in electronic circuit to transmit or receive the signal	E_{elec}	50 nJ/bit
Data Aggregation Energy	E_{DA}	5 nJ/bit

The radio channel is assumed to be symmetric so the energy dissipation between any two sensor nodes is same in both the directions [13].

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III. PROPOSED PROTOCOL DESCRIPTION

In this section, we present a modification over an already proposed algorithm, Optical Energy Adaptive Algorithm, in wireless sensor network domain. The whole algorithm was a modification on the already established well known clustering protocol, LEACH presented by Heilzmen et al [13]. LEACH basically allows to create clusters in each round in which few sensor nodes are assigned the job of cluster heads (CHs) where this selection is based on the received signal strength and rotates this role to evenly distribute the energy load among the other sensors in the network. The optimal number of cluster heads in a network in one round is estimated to be around 5% of the total number of nodes. The sink calculates a threshold value using the following equation:

$$T(n) = \frac{p}{1-p(r \bmod (1/p))} \quad \text{if } n \in G$$

Where p is the desired percentage of cluster heads
r is the current round
G is the set of nodes that have not been cluster heads in the last 1/p rounds

Now the sensor nodes with a value greater than this threshold value are chosen as the cluster heads while the rest become the sensor nodes in the cluster. The operation of LEACH is separated into two phases setup and steady phase. The setup phase is completed after each CH transmits the TDMA schedule for its cluster members. The steady phase allows the sensor nodes to send the sensed data to their respective CHs. This approach may avoid the packet collision but is energy inefficient when the member nodes far away from their CH have to dissipate more energy as compared to those near the CH. Also, the TDMA slot assignment allows every member node to use the allocated slot irrespective of the traffic demand which causes the inefficient use of slots and hence may lead to delay. In event-based networks, these issues may lead to the failure of the network. Therefore, an energy efficient modification has been proposed over the conventional LEACH by depending the CH selection on the distance of the nodes from the Base Station (BS) and also the TDMA slot assignment on the availability of the data in the node. The working of the proposed algorithm can be divided into the following three phases:

A. Cluster Setup Phase

In the proposed protocol, the cluster formation is done in the same manner as it is done in LEACH but cluster head election process includes two new parameters, node's energy level and the varying probability that varies with the distance of the node from the BS, since cluster heads had the maximum energy dissipation while transmitting the aggregated data to the sink (BS). The additional parameters that were required to define the threshold value for becoming a cluster head were: the ratio between the current energy level and the initial energy level of the node & the varying probability value with sensor nodes far away from the BS being less probable as compared to those near the BS. The main idea is to prefer those nodes as CHs which have more residual energy and are at a smaller distance from the BS. In every round, every node calculates its threshold value using the following equation:

$$T(n) = \left(\frac{p}{1-p\left(r \bmod \left(1/p\right)\right)}\right) \times \left(\frac{E_{n,r}}{E_o}\right) \quad \text{if } n \in G$$

Where p is the desired percentage of cluster heads (This value is different for those near the BS and for those which are far from the BS)
r is the current round
G is the set of nodes that have not been cluster heads in the last 1/p rounds
$E_{n,r}$ is the current energy of the node n in the r^{th} round
E_o is the initial energy of the sensor node

Now the sensor nodes with a value greater than this threshold value are chosen as the cluster heads while the rest become the sensor nodes in the cluster. The sensor nodes near to the BS are the most probable while those away from the BS are the least probable.

Now each node elected as a CH broadcasts an advertisement (ADV) signal to all the sensor nodes within the range using flooding mechanism. The non-cluster head sensor nodes are free to choose their cluster heads to which it will belong to the current round. This decision is based on the signal strength of the received advertisement signal. The non-cluster head nodes select the source of the largest signal strength as its cluster head and in turn transmits an acknowledgment (ACK) signal to its chosen cluster head. All the communications

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between the cluster head and the cluster members during the cluster formation phase is done through CSMA MAC protocol to avoid collisions.

B. TDMA Slot Assignment Phase

Based on the number of the ACK signals and their signal strength, the CH forms a modified TDMA schedule. The main idea behind this modification over the traditional TDMA schedule is that if the node is having weaker signal strength, then that means that it is located far from the CH compared to the other cluster members and hence it will dissipate much more energy to transmit the information as compared to the other member nodes. This shows that the traditional TDMA slot assignment may lead to irregular and inefficient slot distribution over the whole network. So, the modified TDMA schedule allows the distribution of the variable packet size slot to the sensor nodes depending upon their distance from their respective CH which means that the nodes with their distance from their CH being more than the threshold distance will be given a smaller packet size slot and the nodes with distance less than the threshold distance will be given a larger packet size slot. The objective is to assign smaller packet size slot to the node with low signal strength. This approach will lead to even distribution of loads over the network. No node will die too early and hence it prolongs network lifetime.

C. Slot Renting and Data Transmission Phase

Once, the clusters are formed, the modified TDMA schedules are sent to the cluster members. Each node can send its sensed data to the CH only when it has the sending slot. Now since every node can send data only during its assigned slot, it follows a modified duty cycle which includes periodical sleep and listen mode. The modified schedule allows the node to on and off their radio at listen and sleep period respectively during the intra cycle communication period, hence saving the energy used during the idle listening. When the node gets its time slot, it checks for the sensed data availability. If it has data to transmit, it transmits the data to its CH in its sending slot. If it does not have data to transmit, it donates its slot to the next node on the TDMA schedule and enters into the sleep mode. If that node doesn't have data either, it donates both the slots to the next node on the schedule and this process continues until the TDMA frame is completed. The same scenario is followed in all the rounds.

IV. PERFORMANCE SIMULATIONS

A. Simulation Description

1) ***Simulation Environment:*** In order to analyse the performance of the proposed algorithm, Matlab has been used to implement the simulation. The parameters used for the simulation purpose are listen in Table 2.

2) ***Simulation Metrics:*** To compare the performance of the proposed algorithm with the Optimal Energy Adaptive Algorithm, the following metrics are being measured.

- Network Lifetime: The time up to when the first node of the network dies.

Stability Period: The period from the start of the network operation till the first node dies.

Table 2. Network Parameters

Parameters	Value
Network Size (square meters)	100×100
Location of BS (meters)	(50,50)
Number of nodes	100
Threshold Distance	87.7
Initial Energy of all sensor nodes (Joules)	1

B. Results and Analysis

This section presents the results of the experiments comparing Optimal Energy Adaptive Algorithm and the proposed algorithm TDEEA. The deployment of the homogeneous sensor nodes in the WSN is shown in Fig 4., where a sensor node is denoted by a 'o'. The BS is at the centre of the field, depicted by '+'.

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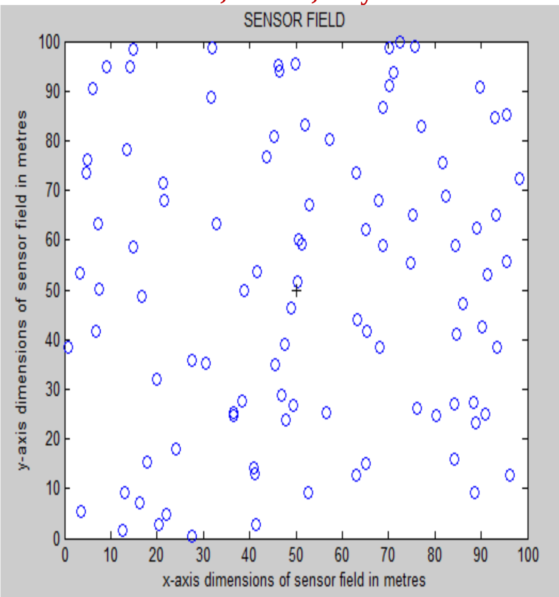

Fig 4. Deployment of the sensor network

After some rounds of network operation, some of the sensor nodes start to die. These dead nodes are denoted by a red coloured '.', as shown in Fig 5.

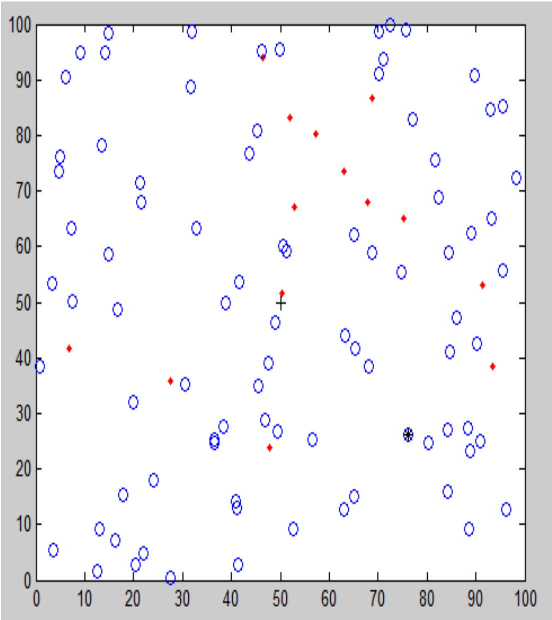

Fig 5. Depiction of dead nodes in the Network

Fig 6 shows the graph comparing the proposed algorithm TDEEA with Optimal Energy Adaptive Algorithm in terms of the network lifetime. The graph depicts the number of the dead nodes with respect to the number of rounds of network operation. The first node death in case of Optimal Energy Adaptive Algorithm occurs at round 1619 whereas the first node death occurs at round 2784 in case of the proposed algorithm TDEEA. Clearly, the stability period, or the period from the start of the network to the time the first node dies, is improved. Also, the last node in case of Optimal Energy Adaptive Algorithm dies at round 3270, whereas in case of the proposed algorithm TDEEA the last node dies at round 3749. The percentage improvement of the network lifetime is 14.6%. The sensor nodes that start to die out follow a random pattern rather than the nodes near or far away from the BS dying early as shown in Fig 7 and Fig 8.

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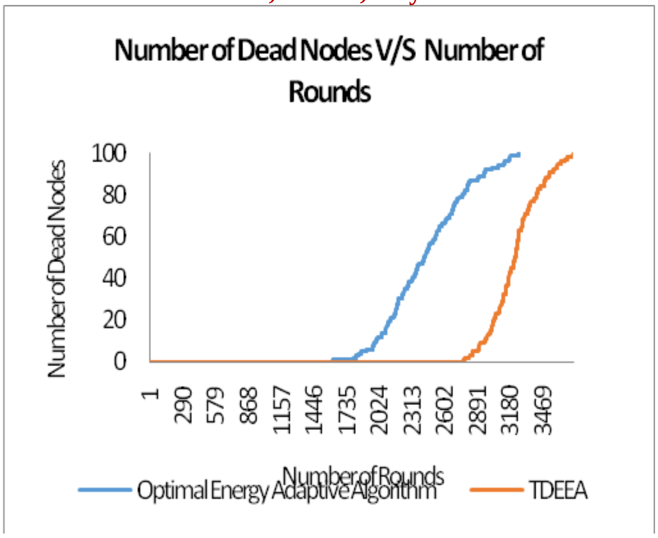

Fig 6. Network Lifetime of the WSN

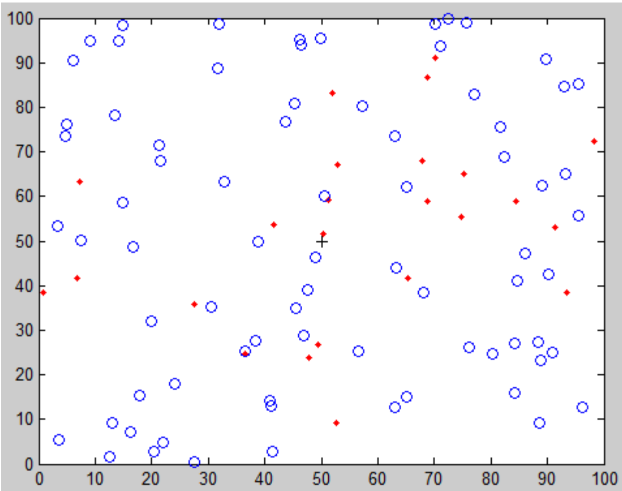

Fig 7. Sensor Nodes die in a random pattern

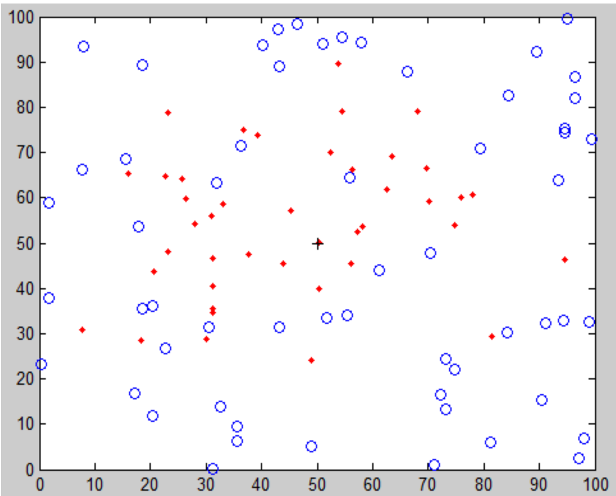

Fig 8. Nodes near the BS die early

V. CONCLUSION

This work modified the Optimal Energy Adaptive Algorithm, with an aim to increase the network lifetime. The probabilities of becoming a CH were made different for near and far nodes in order to make the far nodes less probable for being selected as a CH, since it would result in more energy wastage. Also, the data packet length is increased so as to allow more amount of data to be sent in case any event occurs which is quite helpful in event based situations. The simulation results show that the proposed algorithm TDEEA performs better as compared to the Optimal Energy Adaptive Algorithm for WSNs. The network lifetime improved by 14.6% over the existing algorithm. This clearly shows that the proposed algorithm TDEEA outperforms the Optimal Energy Adaptive Algorithm. However, the heterogeneity property, multi-hopping within the cluster, the mobility of the sensor nodes may improve the potentiality of the routing protocol in the wireless sensor network domain, although these are beyond the scope of this paper and can be considered as topics of future work.

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