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# A Robust Coverage based on Optimal Backoff Sleep Time in Wireless Sensor Networks

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*Abstract*— **There is a random deployment of nodes through aerial dispersion in some of the typical remote applications of wireless sensor networks like earthquake monitoring, seismic activity monitoring, disaster relief operations, and surveillance for military purposes and marine applications. Thus, node density varies throughout i.e. nodes will be scattered, more nodes in some part while very less in the other due to which some area of sensor field would be left uncovered. The ideal coverage means no part of sensor field should be left uncovered. Practically it is not possible to achieve it. Hence effective covering of the possible area with an energy efficient utilization of nodes becomes important. The paper proposes Optimal Backoff Sleep Time Protocol for improvement in network performance by increasing the coverage lifetime. An embedded hardware that resembles a mote has been developed for implementation of the protocol at the virtual level. The various parameters like the average life of node, the radio range of the protocol, the probing time, the probing frequency and the Coverage Lifetime (CL) were observed practically. The paper presents runtime evaluation results, their statistics and the future scope for development of the reported work.**

*Index Terms*— Optimal Backoff Sleep Time, coverage, network performance, Coverage Lifetime etc.

## I. INTRODUCTION

Wireless Sensor Networks (WSN) constitutes a large number of spatially dispersed sensors laid down over a huge area in the order of several acres functioning autonomously. The sensors are distributed to monitor various evironmental or physical conditions or naturally occurring phenomenon that mainly include temperature, sound, pressure, wind speed, direction, pollution level, humidity etc. The sensors are known as sensor nodes. The steps involved in the functioning of nodes are sensing the parameter, processing it and sending data or gathering data from all nodes and collectively transmitting it to base station or sink.WSN's bridge the gap between real and virtual worlds. The timeline of development in sensor networks [1] is as follows:

*1970's*: Wired sensors connected to central location
*1980's*: Distributed wired sensor networks
*1993*: LWIM project at UCLA
*1999-2003*: DARPA SensIT project: UC Berkeley, USC, Cornell etc.
*2001*: Intel Research Lab at Berkeley focused on WSN
*2002*: NSF Center for Embedded Networked Sensing
2001-2002*:* Emergence of sensor networks industry; startup companies including Sensoria, Crossbow, Ember Corp, SensiCast plus established ones: Intel, Bosch, Motorola, General Electric, Samsung.
*2003-2004*: IEEE 802.15.4 standard, Zigbee Alliance.

WSN's possess the ability to permit observation of previous unobservable over large spatiotemporal scales. The technology has a very wide scope for the development of all potential applications in the field of science, industry, civil infrastructure, transportation, and security. But there is a very less real development of WSN applications due to numerous reasons like cost of manufacturing a mote, their deployment in remote areas, maintenance and limited battery capacity.

The various challenges and considerations taken into account for the implementation of WSN [1] are listed below:

*i. Energy Efficiency:* The energy usage forms major constraints in the development of WSN.The energy consumption of sensor nodes is divided into following parts: the energy required by the transducer, energy for microprocessor computation and communication amongst deployed nodes. Each of the bit to be transmitted utilizes energy same as needed to execute 800-1000 instructions [2]. Thus, communication is much costlier than computation. The paper [3] gives a detailed literature survey of energy efficient performance in WSN in all the working aspects.

*ii.Scalability:* The ability of a network to expand in terms of the number of nodes attached resulting into an excessive overhead is termed as scalability [4]. As the size of the network grows, the number of packets will also grow, there are chances that the communication links established also break and very less bandwidth will be available for application data transmission.Hence, achieving scalabilty is a challenging task yet important.

*iii. Responsiveness:*

The term responsiveness refers to the ability of a network to any change in the topology. However, there are many downfalls in achievement of it. The latency incurred in the delivery of packets in the dynamic environment and scalability is reduced in a highly responsive network[4] which leads to a better performance.

*iv. Reliability and mobility:*

A network is said to be a reliable network if it ensures a reliable data transmission even when the network undergoes a continuous change of structure [4]. The term mobility refers to the ability of a network to handle mobile nodes and changeable data points [4]. These two characteristics play an important role in the design of a WSN.

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*v.Privacy and security:*

In some applications like human healthcare systems, the privacy and security of the information being transmitted and resistance to the cryptographic attacks play an important role. However, only if the information is sensitive, this factor needs to be given a considerable significance in the design.

## II. PROBLEM OVERVIEW

There are two types of node deployment methods i.e. structured deployment and randomized deployment [1]. The random graph theory is used for the analysis of random deployment. The most common random graph model is the function G (n, R): deploy n nodes randomly with a uniform distribution in a unit area, placing an edge between any two that are within Euclidean range R. In the second type of node deployment method, where aerial dispersion of nodes through air vehicle like helicopter takes place, the following problems are observed:

i. There is a scattering of nodes due to random falling. Hence, node density will vary throughout i.e. more nodes in some part while very fewer nodes in the other. Thus, some of the area being monitored will remain uncovered

ii. The clustering of nodes for power efficient data aggregation is also difficult as forming the clusters of varying size with a different number of nodes in each cluster will again lead to overlapping coverage of the adjacent clusters.

iii. Human intervention in the area of deployment is not possible. Thus replacement of the batteries of nodes, replacement or renewal of nodes by removing the already present ones is cannot be done.

Therefore, the possible effective coverage of the given area is important.

The aim of the work is to achieve energy efficient coverage by increasing the coverage lifetime of the network. This can be accomplished by keeping a minimum number of nodes active in sensor field and putting the rest of them into the sleep state.

## II. FLOW OF WORK FOR PROJECT COMPLETION

The flow for the successful completion of the work is given in Fig.1 and the steps outlined for it are highlighted.

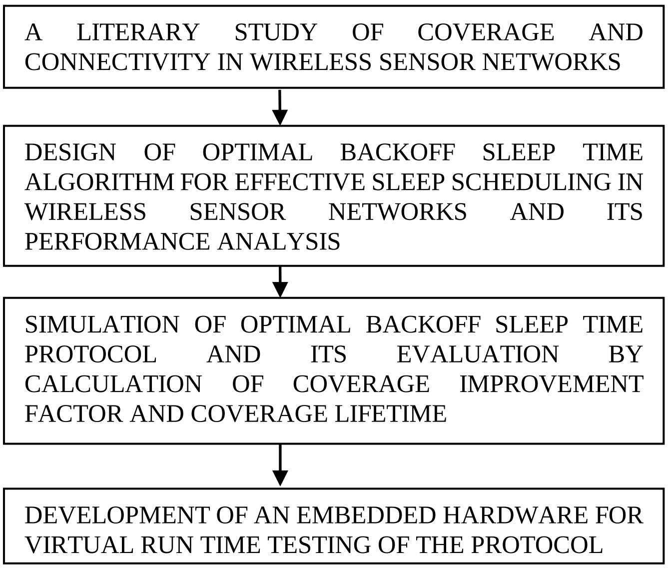

Fig.1. Flow of work for project completion

## IV. RELATED WORK

The paper [5] presents a complete literary study of coverage and connectivity in sensor networks for the optimal performance. The various research challenges in WSN coverage and the possible solutions to overcome them are highlighted. The study of existing WSN coverage protocols, the approach they follow, and their limitation is provided. The interdependence of coverage and connectivity is discussed. The paper gives a fair idea about the recent trends of research in this area. The paper [6] presents a comparative study of various energy efficiency schemes in sensor networks. The analysis has been done by simulation of LEACH, TEEN and SEP protocols. The average energy of node and number of dead nodes were found out after several rounds which shows SEP protocol outperforms the other two in the overall performance. The clustering of nodes has been used in WSN coverage improvement. In paper [7], LEACH protocol in addition with a new algorithm ECAE to maintain a coverage absence resulted from the random selection of non-uniform distribution of cluster heads. However, clustering of nodes is not an effective method to achieve power efficiency in the typical remote applications of WSN where nodes are randomly scattered in the sensor field. The PEAS protocol [8] is proposed to extend the network lifetime by maintaining a necessary set of working nodes and turning off redundant nodes. This protocol results into the extension of life of the network proportional to population of sensors. The limitation of it is frequently waking up nodes due to use of exponential distribution function. The PECAS protocol [9] has been developed on the similar lines but performs better than PEAS as it enables scheduling of an active node into sleep mode after a specified time which reduces the occurrence of coverage hole and able to maintain a sufficient number of live nodes to monitor the given area. The paper [10] proposes RBSP protocol in which the sleep time of a probing node is computed based on the residual energy level of active node with ten levels of binning. This protocol outperforms PEAS by maintaining adequate number of nodes for longer period approximately 12.5% longer. In the next paper [11] OBSP is proposed, this protocol aims to maximize the coverage lifetime by avoiding unnecessary and frequent wakeup of nodes at lower level of residual energy. The reduction in the energy consumption of nodes is output by it but the limitation of the work reported is that it doesn't take into account the likelihood of failure of an active node which may hamper the ultimate aim of obtaining energy efficient coverage. The purpose of sleep scheduling algorithm is to compute a right amount of duration for which the node should be in sleep state and wakeup immediately when required. In paper [12] Optimal Backoff Sleep Time algorithm for effective sleep scheduling of sensor nodes is provided. It calculate the sleep time for probing node depending on the percentage of the battery left with active node within its coverage with multiple levels of binning after which the next wakeup is expected. In addition, the maximum allowable latency in the inter-node communication is also incorporated which variant sleep profiles are obtained for different applications leading to a latency tuned network coverage. The paper [13] suggests blacklisting of failure prone nodes in the sensor field based on RSS and TTT. But practically experimenting this with a number of randomly scattered nodes and identifying the nodes likely to undergo failure or faulty nodes is certainly not possible. Even if done so, the exact probability or chances of node failure is not determined. Hence, the problem of active node failure affecting network coverage remains still unattended. In the work presented in the paper, the probing node will decide its sleep time considering the remaining life of all the active nodes within its coverage and their probability of failure. The probability of node failure of an active node is obtained by mapping or curve-fitting the practical average node life to bathtub curve. The next sections discuss the Optimal Backoff Sleep Time protocol, its implementation & results.

## V. OPTIMAL BACKOFF SLEEP TIME PROTOCOL

The flowchart of *Optimal Backoff Sleep Time Protocol* is as shown in Fig.2.

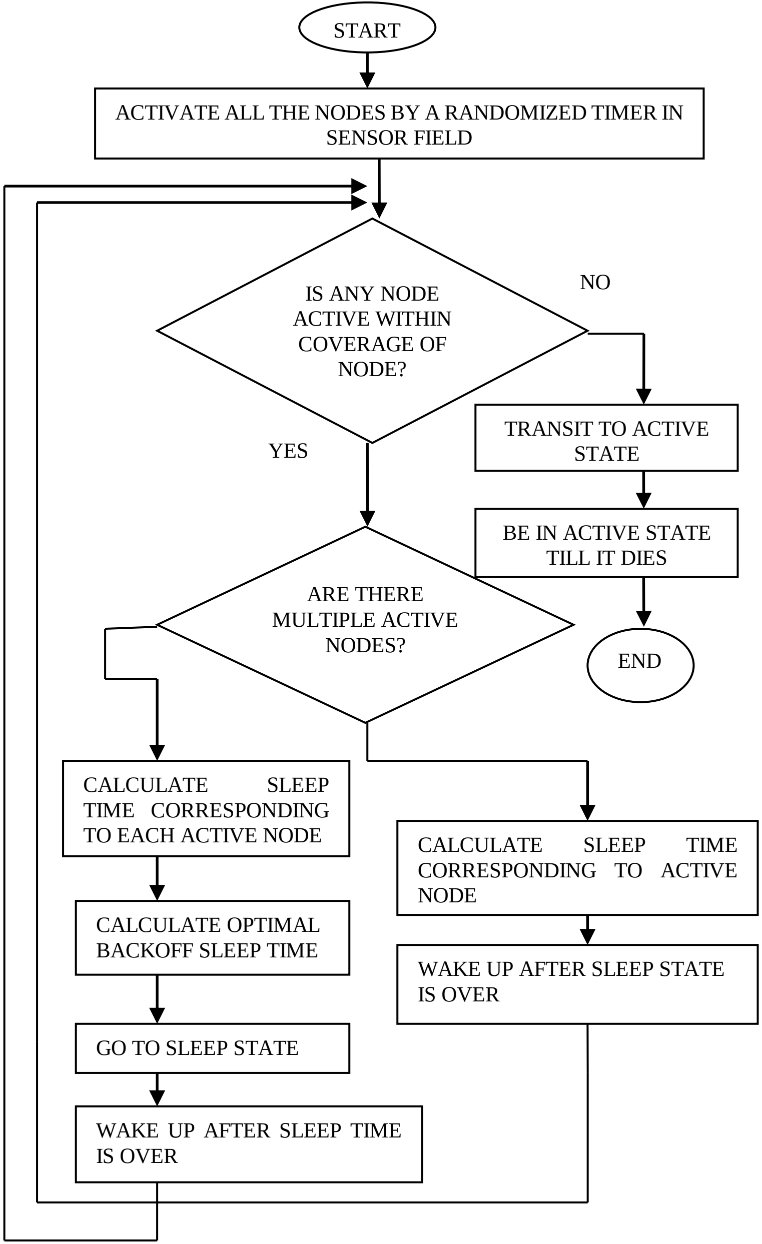

Fig.2. Flowchart of Optimal Backoff Sleep Time Protocol

Thus, the protocol prevents presence of redundant active nodes in sensor field which causes wastage of the power and reduces the coverage life of a node. The unnecessary activity of nodes is avoided and substantial amount of power is saved.

The important terms to understand the protocol are listed and explained below.

i. *Active state:* In this state, the node will work like a full functioning device, the transducer will sense it's surrounding; the sensed parameter will be processed and transmitted to the desired location. All the functions including sensing, processing, transmitting & receiving i.e. communication will take place.

ii. *Probing state:* In this state, the node which is active will continuously transmit some packets to check whether any other node is active within its coverage and if yes it will transit to sleep state which is explained below.

iii. *Sleeping state:* This state is like a standby mode in which the transducer will sense the phenomenon but its output will not be processed and transmitted. Unless any active node interrupts, the wireless module will also not communicate. Thus, the power is saved.

iv. *Dead state:* If the battery is fully drained or the external power supply is cutoff then the node will die. This state is called as dead state.

The nodes deployed in the sensor field will be activated by a randomized timer. Once the nodes are active, they will continuously probe their environment to check if any other neighbor node is active within its coverage. If no, the node itself will remain active otherwise it will decide its sleep time and transit to sleep state.

The sleep time is computed based on the following equation:

$$\text{Sleep Time} = \text{Rand}\,(M - N) \text{ x } (1\text{-PNF}) \qquad \text{Eq. (1)}$$

Where M: Statistical mean of life of a node observed at different number of runs in min

N: Life of active node at the time of probing in min

PNF: Probability of Node Failure (of active node)

PNF is obtained by mapping or curve-fitting the average of the values of the life of node observed at multiple trials of the experiment [stated in Section IV]. The bathtub curve is shown in the Fig.3 shown below.

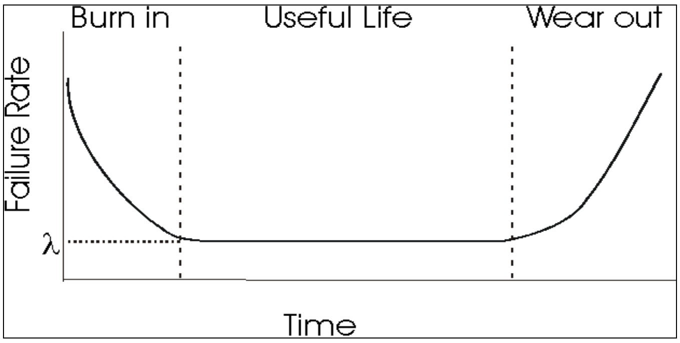

Fig.3. Bathtub curve for obtaining PNF [14]

In case, if there is more than one node active within the coverage of probing node, then the sleep time corresponding to each of the active node will be calculated and the mathematical average of it will be considered as optimal backoff sleep time. The term backoff sleep time means the time for which node will back itself from being active and continue to be in sleep state. The word optimal indicates the value is neither maximum nor minimum; the mid or average value is taken.

The state transition diagram of Optimal Backoff Sleep Time Protocol is shown in Fig.4.

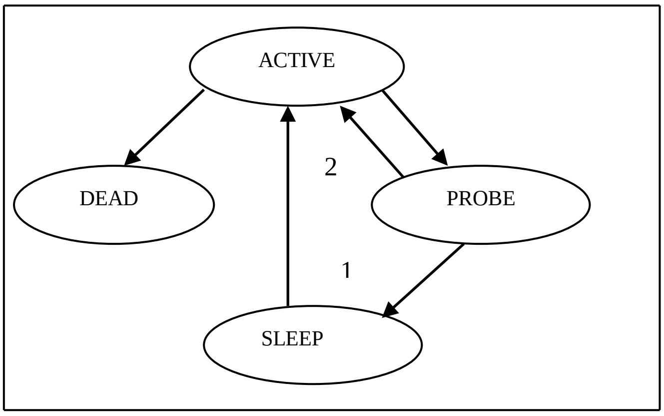

Fig.4State Transition Diagram of Optimal Backoff Sleep Time Protocol

1-means active present and 2-otherwise in Fig.4.The nodes deployed in sensor field are activated by a randomized timer. Once the nodes become active, they will enter into the PROBE state. In this state, the node will probe its surrounding to check whether any other node is active within its range. If any node is active within the range, there is no need of it to remain active till the presently active node times out. Thus, the PROBE state is the one where the node will continuously probe some messages i.e. broadcast the packets to detect the presence of any other node active within its coverage. In the ACTIVE state, all the functional units of the node will be ON. In this case, the node will make a transition to the SLEEP state. In the SLEEP state, the sensor will sense the phenomenon but its output will not be processed, the wireless module will also hear any packets from active node. The sleep time of a node based on Optimal Backoff Sleep Time Protocol for runtime implementation is calculated by using Eq. (2)

$$SD_{runtime} = \alpha \times p(s) \times SF \qquad \text{Eq. (2)}$$

The terms used in the Eq (2) are described below.

1. $SD_{runtime}$ is the Sleep Duration (SD) for the runtime implementation.
2. $\alpha$ is the equivalent quantitative value of the data read at the software serial port of the microcontroller.
3. p(s) is the probability of success of the node.
4. SF is the Scaling Factor.

The time for which the node should sleep is decided by using Eq. (2). After the sleep time gets over, the node will undergo a transition to the ACTIVE state. In this state, it will again check if any other node is active within the range of it; if yes it will go back to the SLEEP state, otherwise it will remain in the ACTIVE state till it times out. After the node times out or the external power supply to it is cut, it goes into the DEAD state i.e. not functioning at all. The relative energy consumption of nodes in the four states is given by Table.1.

Table.1 Percentage of node energy in different states

| STATE | NODE ENERGY CONSUMPTION |
|---|---|
| ACTIVE | 70% (Maximum) |
| PROBING | 15% (Moderate) |
| SLEEP | 4% (Very less) |
| DEAD | 1%(Negligible) |

The next section discusses the results of the runtime implementation of Optimal Backoff Sleep Time Protocol.

## VII. EVALUATION OF THE PROTOCOL

The virtual runtime implementation of the protocol was carried out and the following observations were recorded:

*i. Practical average life of the node*

To each of the unit of the prototype of a mote, an external power was given and was kept ON till the battery fully drained out. This experiment was performed for multiple times and the results obtained are shown in Fig.5.

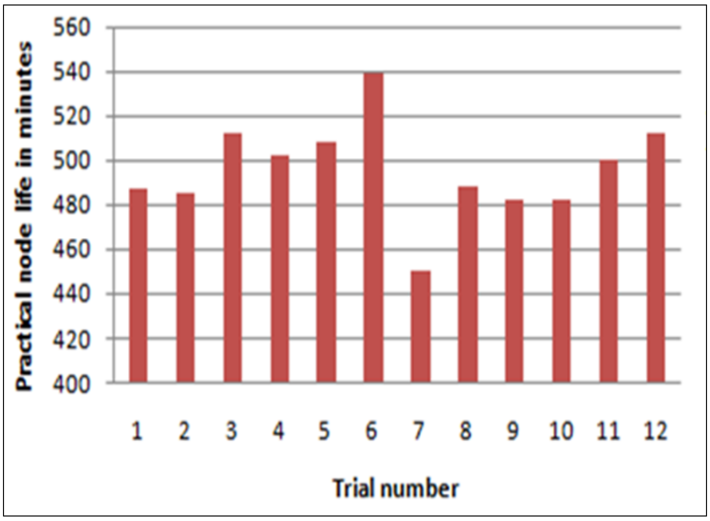

Fig.5. Practical average life of the node

The statistics are as follows: Mean = 495.58 min, Variance = 484. 44 and Standard Deviation (SD) = 22.01. The statistics needs to be calculated to determine the accuracy of the observed values.

*ii. Indoor/ NLOS/ Short haul radio range of the protocol*

The radio range of the protocol was found out in the indoor environment (residential building) where there is no clear Line of Sight (LOS) radio path. The results of this experiment for multiple trials are shown in Fig.6.

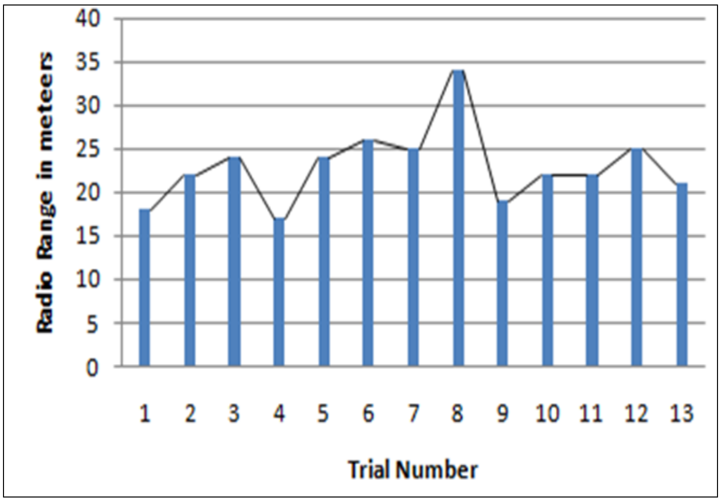

Fig.6. Indoor or NLOS radio range of the protocol

The statistics are as follows: Mean = 23 m, Variance = 18.66 and SD = 4.32

When the same experiment has been performed in the open ground, where clear LOS (Line of Sight) radio path is available, the range is termed is *free space or LOS /Long haul radio range*. This value observed was approximately 32 m.

The reasons for difference in the two ranges are listed below:

a. There are obstacles like wall due which to which the electromagnetic waves will be reflected in the indoor environment.

b. The medium of propagation is air or free space but due to a multiple factors like condition of weather, the dielectric constant changes and there is an attenuation of EM waves.

c. The time required for the data transmission by 802.15.4 XBee [15] is given by Eq. (3).

Tx Time = Time on air + Time for CSMA-CA + Time for retries Eq. (3)

The last two factors add delay in the zigbee communication known as *zigbee latency time* which introduces an error in the range calculation.

The RSS was observed at different points by changing the position of one XBee module from another which is shown in Fig.7.

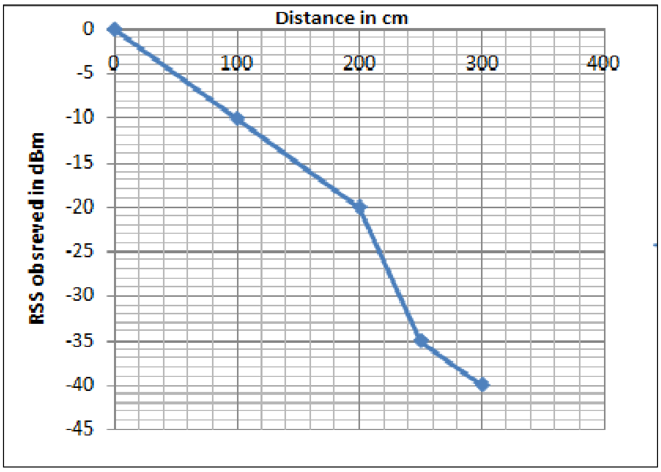

Fig.7. RSS observed by changing the distance

*iii. Probing time of the node*

The time taken by a probing node to detect the presence of any active node within its range is known as the probing time of a node. The time elapsed since power supply is applied and the occurrence of first probe observed for multiple times is shown in Fig.8.

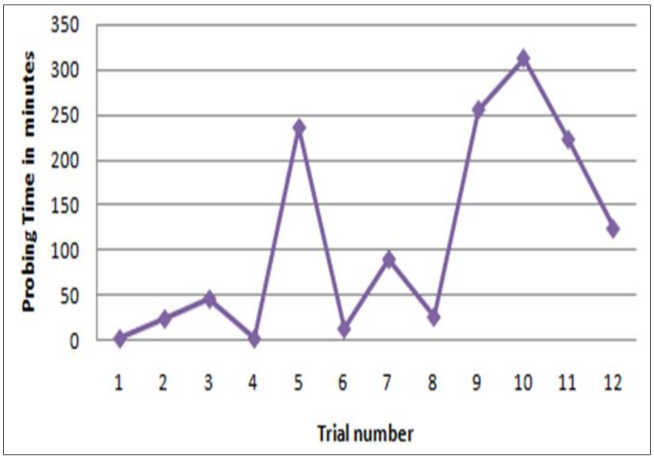

Fig.8. Probing time of the node

The statistics are Mean = 111.91 min, Variance = 12995. 36, Standard Deviation (SD) = 113.99.

*iv. Probing frequency of the node*

The probing frequency is the number of times a node will undergo probe when any active node is present within its coverage. The ideal probing frequency is one but the probe may occur two or three times as sleep time is decided by using random function and PNF varies as per the remaining life of active node within the range of probing node.

The probing frequency was observed by keeping one node active within the range of other. The results obtained are shown in Fig.9.

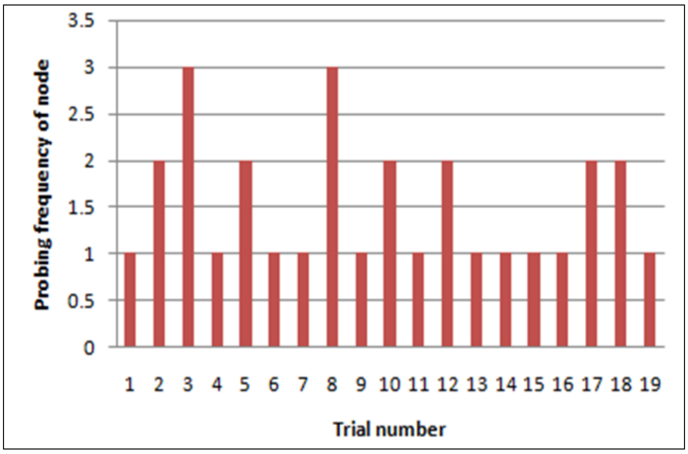

Fig.9. Probing frequency of the node

The Coverage Lifetime (CL) was observed without and with implementation of the protocol. The observations are shown in Fig.10.

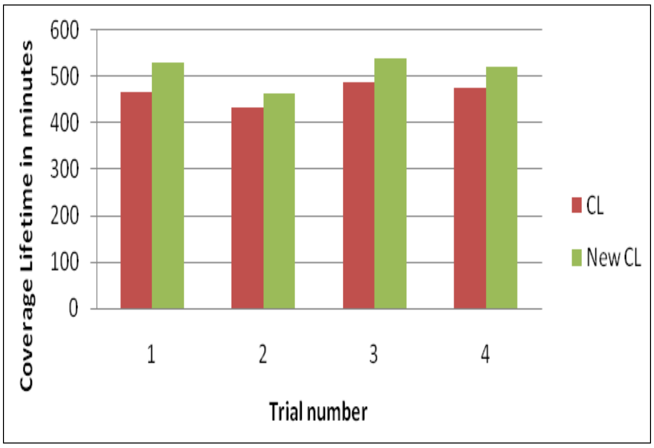

Fig.10. Practical Coverage Lifetime (CL) of the network

The calculation shows there is a 10.2% increase in the Coverage Lifetime (CL) of the network observed after implementation of the protocol.

## VIII. CONCLUSION AND FUTURE SCOPE

Optimal Backoff Sleep Time Protocol for coverage improvement of randomly deployed WSN was implemented at runtime using the hardware developed by us. The various parameters like practical average life of node, radio range of protocol, its communication coverage, probing time and probing frequency of the node were observed by performing the experiment for multiple times. The statistics of the observations were calculated. The Coverage Lifetime (CL) of the network was observed practically. The implementation of the protocol shows that there is a 10.2% increase in the CL of network.

This protocol is applicable only for static nodes and not able to tackle the *moving node problem*. For mobile nodes, the Doppler shift i.e. the apparent change in frequency due to the motion of nodes needs to be taken into account. Moreover, at some trials there are two to three probes. Any suitable technique to get ideal probing frequency will certainly improve the efficiency of the protocol. The future work can be carried out on these lines.

The observations and results presented in this paper are obtained using the original program, without adding scaling. However, practically the working of the protocol can be demonstrated by scaling so that much time is not wasted.

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