A Balanced Energy Dissipation Scheme for Enhanced Performance in Data Gathering Wireless Sensor Networks

Ayan Acharya, Anand Seetharam, Abhishek Bhattacharyya and Mrinal.K.Naskar

***Abstract*—Wireless sensor nodes, being highly energy constrained, must function in an energy-efficient manner in order to enhance network lifetime. Thus suitable protocols must be defined in order to minimize the energy dissipated by the individual nodes in the network. The LEACH and PEGASIS protocols are elegant solutions to the problem. While the LEACH protocol randomizes cluster heads for equal energy dissemination, the PEGASIS protocol forms a chain of cluster heads taking rounds in transmitting to the base station. In this paper, we propose a Balanced Energy dissipation scheme for Enhanced Performance (BEEP) which shows enhanced performance over PEGASIS. As the individual nodes are deployed randomly in the area under surveillance, the base station is located at variable distances from them. Further the inter-nodal distance also being variable, the amount of energy dissipated by each node is considerably different after each node has taken a turn in transmitting to the base station. This energy difference between the various nodes increases as time elapses resulting in degraded network performance. In BEEP we increase the network performance by ensuring equal energy dissipation of the individual nodes despite their random deployment. BEEP further employs ant colony optimization for constructing the chain instead of the greedy algorithm used in PEGASIS to increase network lifetime. Extensive simulations have been carried out which shows that significant improvement is achieved.**

***Keywords*—Wireless sensor network, data gathering cycle, equal energy dissipation, Ant Colony Optimization(ACO), BEEP.**

I. Introduction

RECENT advancements in the field of digital signal processors, short range radio electronics, MEMS based sensor technology and low power RF design have enabled the development of inexpensive low power sensors with significant computational capability [1-3]. Applications of sensor networks vary widely from climatic data gathering, seismic and acoustic underwater monitoring to surveillance and national security, military and health care. The sensor networks are required to transmit gathered data to the base station (BS) or sink. It is often undesirable or infeasible to replace or recharge sensors. Network lifetime thus becomes an important parameter for sensor network design and efficiency.

In case of WSNs, the definition of network lifetime is application specific [4]. It may be taken as the time from inception to the time when the network becomes nonfunctional. A network may become non-functional when a single node dies or when a particular percentage of nodes perishes depending on requirement. However, it is universally acknowledged that equal energy dissipation for equalizing the residual energy of the nodes is one of the keys for prolonging the lifetime of the network [4].

Sensor nodes are constrained by limited battery power. Each node is provided with transmit power control and omni-directional antenna and therefore can vary the area of its coverage [2,5]. Since communication requires significant amount of energy as compared to computations [1], sensor nodes must collaborate in an energy-efficient manner for transmitting and receiving data so that lifetime enhancement is achieved. In this paper, we consider a wireless sensor network where the base station is fixed and located far off from the sensed area. Furthermore all the nodes are static, homogenous and energy constrained and capable of communicating with the BS. Communication between the nodes and the base station is expensive and the network being homogenous, no high energy node is available for data bypassing [1]. Moreover all nodes have information about their respective distances from the BS in the static environment as stated in [2]. Often, the sensor network is burdened with redundant data during the process of systematic data gathering from the field. One of the means to avoid energy loss by transmitting unreliable data to the distant base station is to accomplish data fusion [1] which packs the data into meaningful sets of information. Individual nodes thus take rounds in transmitting to the base station which also distributes the dissipated energy more or less uniformly amongst the nodes.

The LEACH protocol [1] presents an elegant solution to this energy utilization problem where nodes are randomly selected to collaborate to form small number of clusters and the cluster heads take turn in transmitting to the base station during a data gathering cycle. It improves energy cost per round by a factor of 4 for a 100 node network as compared to a direct approach where individual nodes transmit directly to the base station. The PEGASIS protocol [2] is a further improvement upon the LEACH protocol where a chain of

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nodes is formed which take rounds in transmitting data to the base station.

BEEP on the other hand attacks an issue which has still not been addressed. In BEEP a chain is formed in a way similar to PEGASIS but instead of making all nodes transmit to the base station the same number of times, the network lifetime is increased by allowing the individual nodes to transmit unequal number of times to the base station depending on the energy dissipated by them. An enhanced network performance is achieved by ensuring equal energy dissipation by all the individual nodes in the network.

The rest of the paper has been arranged in the following manner. Section II illustrates the energy dissipation model used. In Section III we define the BEEP protocol proposed by us. In Section IV we describe how the Ant Colony Optimization tool is used in our scheme for chain construction. In Section V the simulation results showing the improvement of our protocol over the existing ones have been laid down. Section VI concludes our work and also states the scope of improvement.

II. ENERGY DISSIPATION MODEL

We consider the first order radio model as discussed in [1,2,5] with identical parameter values. The energy per bit spent in transmission is given by

$$e_{tx}(d) = e_{t1} + e_{d1} * d^n \quad (1)$$

where e_{t1} is the energy dissipated per bit in the transmitter circuitry and $e_{d1}*d_n$ is the energy dissipated for transmission of a single bit over a distance d, n being the path loss exponent (usually $2.0 \leq n \leq 4.0$). For a first order model we assume n=2 for simulation purposes. However as channel non-linearity increases and the value of n enhances, our model would then gain even greater relevance as BS transmission would then require greater energy dissemination. Thus the total energy dissipated for transmitting a K-bit packet is

$$E_{tx}(K,d) = (e_{t1} + e_{d1} * d^2) * K$$

$$= e_t + e_d * d^2 \quad (2)$$

where $e_t = e_{t1} * K$ and $e_d = e_{d1} * K$

If e_{r1} be the energy required per bit for successful reception then the energy dissipated for receiving a K-bit packet is

$$E_{rx}(K) = e_{r1} * K$$

$$= e_r \quad (3)$$

where $e_r = e_{r1} * K$

In our simulations we take e_{t1} = 50 nJ/bit, e_{d1} = 100 pJ/bit/m2 and $e_{r1} = e_{t1}$ as mentioned in [5] with K = 2000 bits. It is assumed that the channel is symmetric so that the energy spent in transmitting from node i to j is the same as that of transmitting from node j to i for any given SNR .

III. BEEP: BALANCED ENERGY DISSIPATION SCHEME FOR ENHANCED PERFORMANCE

$$\begin{array}{c} c0 \rightarrow c1 \rightarrow c2 \leftarrow c3 \leftarrow c4 \\ \downarrow \\ \text{BS} \end{array}$$

Figure.1.

In the proposed scheme, we aim at building a system in which each node dissipates an equal amount of energy. The nodes are at first distributed randomly in the playfield. PEGASIS employs chain formulation by greedy algorithm assuming the availability of global knowledge about the network. Likewise, BEEP too uses the chain formation. However the chain in our scheme is formed using the ant colony algorithm which is described in detail in Section IV. Data gathering starts after the chain is formed. In each data gathering cycle, every node in the network forms a data packet of its own. Also for each data gathering cycle, a leader is chosen among all the nodes in the network. For gathering data in each round, every node receives data from its neighboring node, fuses it with its own data packet and transmits it to its other neighbor in the network. As in PEGASIS, a simple token passing approach is initiated by the leader to start data transmission from the ends of the chain. The token passing approach used is illustrated in Figure1. Suppose a network has only 5 nodes and after chain formation if the node denoted by c2 is elected as the leader in a particular cycle then the token passing approach would be as demonstrated in Figure 1. The set of nodes from which an individual node will receive data packets during a particular cycle will constitute its neighbors during that cycle. The leader elected in a particular cycle receives the fused data packets of the nodes in the network from its two neighbors, fuses it with its own data packet and finally this single data packet is transmitted to the sink. In PEGASIS, the nodes are successively selected as leaders. For example, if there are 'N' nodes then each node will become a leader once every 'N' data gathering cycles or one data gathering round. This results in unequal energy dissipation of the nodes because of variable distances of the individual nodes from their neighbors and the non-uniformity of their distances from the base station. To iron out these factors which result in degraded network performance, our scheme allows the individual nodes to become leader variable number of times depending on their residual energies.

Let us assume that there are 'N' nodes in the network. We assume that 'C' cycles constitute a round and that the i^{th} node is selected as the leader x_i number of times in one data gathering round. Now let d_i be the inter-nodal distance. Each node, except the ones at the end of the open chain has two neighbors. But as the distances between a node and its two neighbors are usually quite close to each other, for mathematical formulation, we take d_i as the average of distances of the i^{th} node from its two neighbors. Let d_{Bi} denote the distance of the i^{th} node from the base station. Thus making use of relations (2) and (3) we have, the energy dissipated (Esi) by the i^{th} node in each cycle as,

$$Esi=(e_t+e_r+e_d d_i^2)(C-x_i)+(e_t+2e_r+e_d d_{Bi}^2)x_i$$
$$=(e_t+e_r+e_d d_i^2)C+x_i e_d(d_{Bi}^2-d_i^2)+e_r x_i$$
$$=A_i C+B_i x_i$$

with $A_i=(e_t+e_r+e_d d_i^2)$ and $B_i=e_d(d_{Bi}^2-d_i^2)+e_r$

Since it is desired that every node should spend an equal amount of energy in each around we assume Esi=Ess for all i. This would not only ensure 100% energy utilization but would also make sure that all the nodes in the network die simultaneously, ensuring no degradation in performance as long as the network is alive.

Therefore from equation (4), we have

$$x_i = (Ess - A_i C)/B_i$$
$$\therefore C = \sum_i x_i = Ess\sum_i 1/B_i - C\sum_i \frac{A_i}{B_i}$$
$$\Rightarrow C(1+\sum_i \frac{A_i}{B_i}) = Ess\sum_i 1/B_i$$
$$\Rightarrow Ess = C(1+\sum_i \frac{A_i}{B_i})/(\sum_i 1/B_i)$$
$$\therefore x_i = (C/B_i)[(1+\sum_i \frac{A_i}{B_i})/(\sum_i 1/B_i) - A_i]$$

Now for the system to be realizable, we should have,

$$C > x_i \geq 0$$

$x_i \geq 0$ is only possible if

$$[(1+\sum_i \frac{A_i}{B_i})/(\sum_i 1/B_i)-A_i] \geq 0$$
$$\Rightarrow (1+\sum_i \frac{A_i}{B_i}) \geq A_i\sum_i 1/B_i$$

As $B_i=e_d(d_{Bi}^2-d_i^2)+e_r$ is positive for all i as $d_{Bi} > d_i$ in all cases. Further under most circumstances the relation $d_{Bi} >> d_i$ is also valid except for the last few nodes forming the chain which tend to become widely separated due to random distribution. This discussion helps us to write the above inequality as,

$$A_i \leq (1+\sum_i \frac{A_i}{B_i})/(\sum_i 1/B_i) \quad (5)$$

The parameter values are $e_t=e_r=0.0001$ and $e_d = 2*10^{-7}$ for 2000 bits. Therefore, A_i can be approximated as (e_t+e_r) and B_i as $e_d d_{Bi}^2$ which is evident from the earlier explanations. However in order to ensure that $x_i \geq 0$ is valid for all values of i we need to estimate an upper limit on the inter-nodal distance from the above inequality expressed in (5). The inequality in (5) now takes the form

$$(e_t+e_r+e_d d_i^2) \text{ (}A_i\text{ corresponding to maximum possible } d_i\text{)}$$
$$\leq e_d/\sum_i(1/d_{Bi}^2)+(e_t+e_r) \text{ (After Approximation)}$$
$$\therefore d_i^2 \leq (d_{Brms}^2/N) \quad (6)$$

with d_{Brms} as the root mean square of distances from the base station of the nodes and $\sum_i(1/d_{Bi}^2)=N/d_{Brms}^2$. The other condition $x_i < C$ with identical approximations also gives the same inequality as found in (6). Therefore our system will be always viable if condition (6) is ensured. To assess the performance of our system we introduce a parameter Performance Analyzer (PA) which is defined as,

$$PA=\frac{\textit{Number of nodes alive}}{\textit{Total Number of Nodes Deployed}}$$

IV. Chain Formation: Ant Colony Algorithm

In this section we discuss the optimization algorithm used by us. We abandon the greedy algorithm used in PEGASIS for chain construction. Ant Colony Optimization (ACO) [9], a meta-heuristic based on the Ant System introduced in the early nineties of the last century, is a very useful optimization tool. Further using the greedy algorithm adopted in PEGASIS, the condition encountered in (6) cannot be satisfied always because this approach causes the inter-nodal distances to become larger towards the end of the chain. However, ACO can be used to ensure that (6) is always satisfied. This fact is illustrated by simulations in Section V. Ant Colony Optimization is inspired by the behavior of real ants searching for food. The main objective of ACO is to utilize both local information (visibility) as well as information about good solutions obtained in the past (pheromone), when constructing new solutions. In particular this memory is exploited in two ways. First, intensification is achieved by a strong bias towards the best choice in each decision process, based on both pheromone and visibility. Second, diversification is driven by making frequently used paths less desirable to choose.

Our problem here of finding a chain through the nodes is exactly similar to the Travelling Salesman Problem (TSP) [10]. The only exception in our problem is that the inter-nodal distance in the chain can never exceed a specified value as shown in (6). Also, we don't need to come back to the starting node ie. an open chain is formed.

To apply ant algorithm in our problem, we place ants arbitrarily on the nodes. N nodes are numbered from 1,2,…,N and (i,j) is defined as the link connecting node i and j. Every ant is a simple agent with certain memory attributed. According to probability, an ant chooses next node to move into. This probability is a function of inter-nodal distance and pheromone deposited upon the link. Every ant has a taboo table recording nodes which ant has already accessed. Taboo table forbids ant to move into previously visited nodes. At the end of travelling an ant deposits pheromone on the paths it has travelled through. Pheromone deposited by k^{th} ant on $(i,j)^{th}$

link is given by

$$\Delta\tau_{ij}^{k}=\begin{cases} Q/L_k & \text{if (i,j) is part of the path} \\ 0 & \end{cases}$$

with L_k as the length of the path travelled by the k[th] ant and Q is a constant. The basic pheromone updating rule is then given by

$$\tau(i,j,t)=(1-\rho)\tau(i,j,t-1)+\sum_{k=1}^{m}\Delta\tau_k(i,j,t),$$

where $1>\rho>0$ is called the evaporation rate responsible for further path exploration. An ant's choice of a node from its neighborhood N_i^k is governed by the equation given below:

$$P_i^k(j)=\begin{cases} (\tau_{ij}^{\alpha}).(\eta_{ij}^{\beta}) / \sum_{k \in N_i^k} (\tau_{ik}^{\alpha}).(\eta_{ik}^{\beta}) \text{ if } q<q_0 \\ 1 \text{ if } (\tau_{ij}^{\alpha}).(\eta_{ij}^{\beta})=\max\{(\tau_{ik}^{\alpha}).(\eta_{ik}^{\beta}):k \in N_i^k\} \\ \qquad \text{with } q>q_0 \\ 0 \text{ if } (\tau_{ij}^{\alpha}).(\eta_{ij}^{\beta})\neq\max\{(\tau_{ik}^{\alpha}).(\eta_{ik}^{\beta}):k \in N_i^k\} \\ \qquad \text{with } q>q_0 \end{cases}$$

with $P_i^k(j)$ as the probability of selecting node j after node i for ant k. A node $j \in N_i^k$ if j is not already visited and length of link (i,j) satisfies condition (6). η_{ik} is the visibility information generally taken as the inverse of the length of link (i,k), q_0 is a pseudo random factor deliberately introduced for path exploration and α, β are the weights for pheromone concentration and visibility. Ants stop moving if they find a dead end or complete visiting all nodes. This completes the entire chain construction.

V. Simulation Results

To evaluate the performance of BEEP extensive simulations were performed on several random 100 node networks in a 50m*50m field like in PEGASIS. For performing simulations we have used the MATLAB as well as C++. In Figures 2 and 3 the chains formed by the greedy algorithm and ACO respectively have been illustrated and by observing them one can clearly see how ACO helps to bring about a uniformity in inter-nodal distances thereby preventing certain particular nodes from dissipating greater amount of energy. In Figure 2 the links marked in red show that for some nodes the inter-nodal distance obtained by the greedy algorithm increases greatly thereby resulting in increased energy dissipation by the nodes. However Figure 3 shows that in case of the chain formed by ACO none of the inter-nodal distances become very large thereby resulting in balanced energy dissipation.

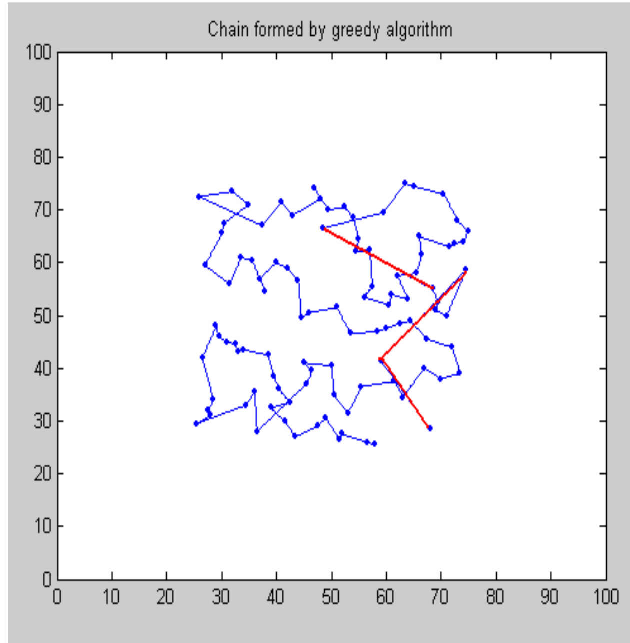

Figure 2: Chain formed by Greedy Algorithm

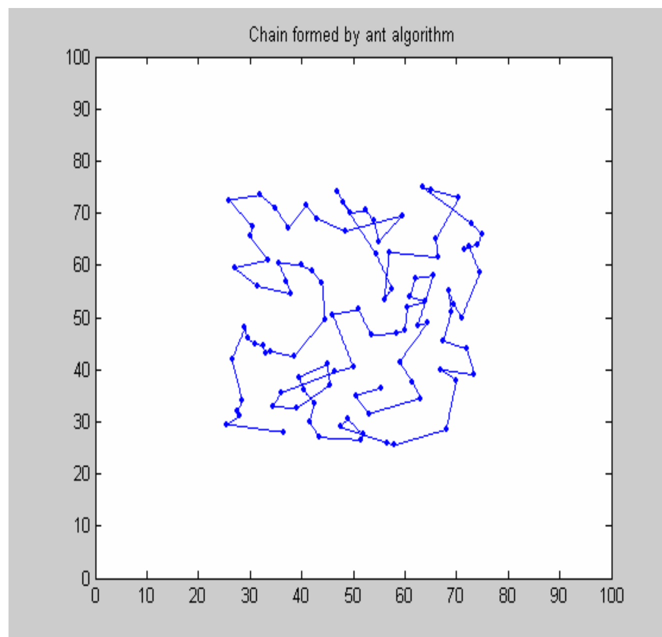

Figure 3: Chain formed by Ant Colony Optimization

Simulation results also show that BEEP outperforms PEGASIS which in turn implies that our scheme would show a major improvement over LEACH. In Set I of simulations, the base station was kept fixed at (25,150) and energy per node was varied. In Set II, the base station distance was varied by keeping the energy per node fixed at 1J. While comparing BEEP with PEGASIS, care was taken to ensure that the nodes which have distant neighbors in the chain were not allowed to become leaders in PEGASIS. The threshold on the inter-nodal distance required for this purpose was tactically chosen to be the same as that given by (6) for first set of simulations so that PEGASIS and BEEP can perform on the same ground.

Set I: Table I

Energy (J\node)	Protocol	1%	10%	20%	30%	100 %
0.25	PEGASIS	813	1003	1021	1034	1124
	BEEP	1040	1040	1040	1040	1040
	% improvement	27.96	3.74	1.91	0.63	
0.50	PEGASIS	1880	2009	2048	2065	2236
	BEEP	2078	2078	2078	2078	2078
	% improvement	10.59	3.47	1.50	0.66	
1.00	PEGASIS	3632	4006	4073	4132	4489
	BEEP	4141	4141	4141	4141	4141
	% improvement	14.02	3.37	1.67	0.23	

The above table corresponding to simulation Set I shows the improvement both in terms of number of cycles and percentage. % impr. actually indicates the percentage of improvement of BEEP over PEGASIS. Our objective from the very beginning is to ensure that performance remains unaffected as long as the network is alive. This is validated in Table I from where one can observe that in BEEP all nodes die simultaneously. BEEP gives better result compared to PEGASIS until a considerable amount of nodes die. Moreover it is also evident from Table I that in PEGASIS 100% of the nodes die shortly after that in BEEP. Hence it can be said that although the last node in PEGASIS dies at a later stage as compared to BEEP but the network performance is so highly degraded that it is of little importance. This is depicted in Figure 4 with the help of PA or the Performance Analyzer parameter. Table I also clearly illustrates the fact that BEEP shows considerable improvement even when more than 30% of the nodes in PEGASIS are dead. In Figure 5 we represent the one set of results obtained in form of a bar diagram for clearer understanding.

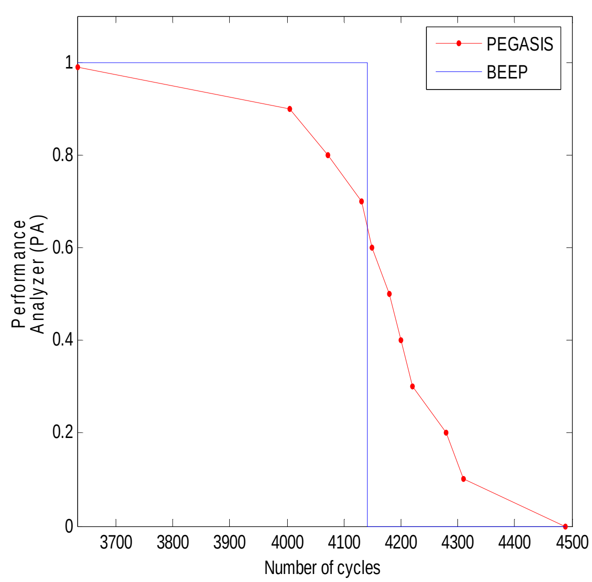

Figure 4: A Comparative Study of PEGASIS and BEEP

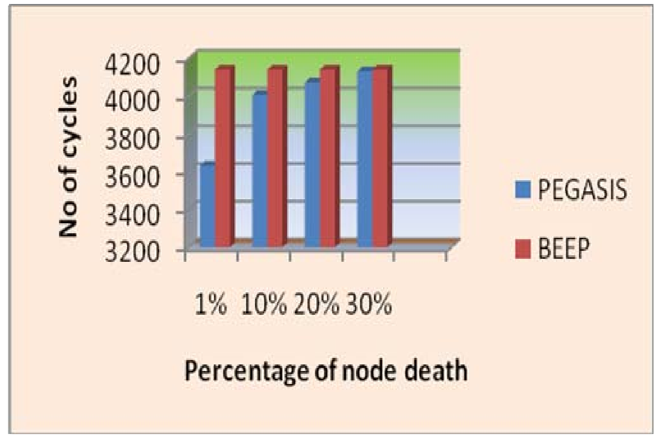

Figure 5: Performance Result for 50m*50m network with initial energy 1 J/node and base station at (25,150)

Set II: Table II

Base Station Location	Protocol	1%	10%	20%	30%	100%
(25,170)	PEGASIS	3515	3749	3869	3917	4318
	BEEP	3927	3927	3927	3927	3927
	% improvement	11.71	4.75	1.50	0.26	
(25,190)	PEGASIS	3102	3655	3695	3725	4154
	BEEP	3742	3742	3742	3742	3472
	% improvement	20.63	2.38	1.27	0.46	
(25,220)	PEGASIS	3176	3332	3397	3409	3950
	BEEP	3417	3417	3417	3417	3417
	% improvement	7.62	2.57	0.61	0.33	

Set II is performed by keeping energy per node at a constant value of 1 J. The base station distance is varied as given in above table and percentage improvement in different stages was observed. As the base station is moved away, the restriction upon BEEP as per condition (6) is relaxed. We find that BEEP still performs better over PEGASIS. In our simulation we keep the upper limit on inter-nodal distance in case of PEGASIS as constant throughout. A comparison corresponding to Table II has been presented in Figure 6.

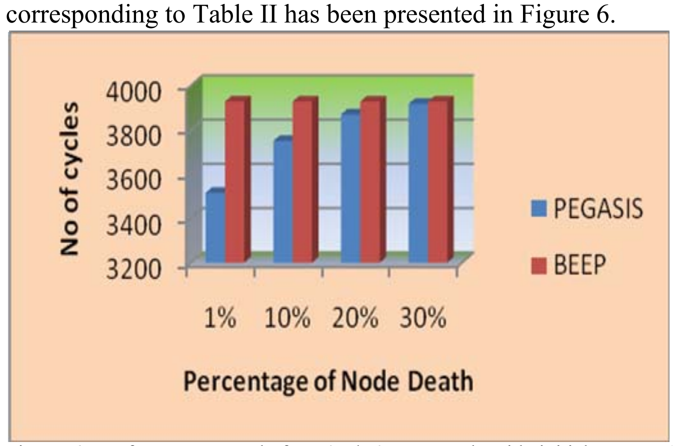

Figure 6: Performance Result for 50m*50m network with initial energy 1 J/node and base station at (25,170)

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VI. CONCLUSION

The BEEP protocol considered in this paper ensures that 100% energy utilization occurs thereby increasing network lifetime. The Ant Colony Optimization scheme also helps to enhance the performance of our scheme. The simulation results also help to understand and appreciate the facts stated in the paper. In future we would also like to form the chain using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques and observe how these optimization tools perform as compared to ACO and the greedy algorithm. The future works also include analyzing the network performance considering packet losses and fading multipath channels and modifying the existing model to provide desired results under these circumstances.

VII. APPENDIX

Proof For Inequality (6) :

$$(e_t + e_r + e_d d_i^2) \text{ (}A_i\text{ corresponding to maximum possible }d_i\text{)}$$
$$\leq [1 + \sum_i \frac{(e_t + e_r + e_d d_i^2)}{e_d(d_{Bi}^2 - d_i^2) + e_r}] / [1/e_d(d_{Bi}^2 - d_i^2) + e_r]$$
$$\approx [1 + (e_t + e_r)/e_d * \sum_i (1/d_{Bi}^2)] / [1/e_d * \sum_i (1/d_{Bi}^2)]$$
$$= [e_d + (e_t + e_r)\sum_i (1/d_{Bi}^2)] / \sum_i (1/d_{Bi}^2)$$
$$= e_d / \sum_i (1/d_{Bi}^2) + (e_t + e_r)$$
$$\therefore e_d d_i^2 \leq e_d / \sum_i (1/d_{Bi}^2)$$
$$\Rightarrow d_i^2 \leq 1/\sum_i (1/d_{Bi}^2)$$
$$\therefore d_i^2 \leq (d_{Brms}^2 / N)$$

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IX. BIOGRAPHIES

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