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Performance Evaluation of Spatial Diversity of Wireless Sensor Networks

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Abstract*— Wireless sensor networks (WSNs) have become very popular in the fields of industry and academic. Node deployment is an essential issue to ensure the full network coverage and lengthen overall system lifetime. Previously in [1], we have studied the effect of grid node deployment in total power consumption of the network. The first part of this work is conducted to investigate the effect of random node deployment with different path lose exponent values based on LEACH protocol. It is concluded that, LEACH protocol with 100 randomly node deployment perform well for free space areas with packet rate 5 pkt per sec to achieve about 98% of PDR but while increasing the number of obstacles between transmitter and receiver also increasing the area of the field we notice that PDR decrease to reach about 38%.The second part of this work is a linear network, Where nodes are deployed in a line and the sink node located at the end of that line, we have studied the effect of path lose exponent in two deployment area (i.e. free space and an urban area),the result shows that when the path lose exponent increases the total power consumption decreases and the system lifetime improved.

***Index Terms*—Random node deployment, LEACH protocol, linear node deployment.**

I. INTRODUCTION

Sensor nodes deployment is an important issue in terms of coverage, connectivity, cost and lifetime [2] [1]. Long distance transmission by sensor nodes is not energy efficient, since energy consumption is a superlinear function of the transmission distance [3]. One of the methods to prolong the overall network lifetime is done by perfect sensor nodes deployment topology. Nodes can be deployed randomly or pre-determined locations. One of the most important issue that should be taken into account is how should the sensors be deployed in the monitored region? [4]. In order to monitor the desired field of interest for the sensor network, every point of the monitored field must be covered by at least one sensor. Therefore, sensor deployment strategies play a significant role in determining the appropriate placement of sensor nodes to meet certain coverage requirements [5]. Things that should be taken in account while designing a wireless sensor networks are (1) Ease of deployment, Sensor networks may contain hundreds or thousands of nodes and they may need to be deployed in remote or dangerous environments (2) System lifetime, These networks should function as long as possible, System lifetime can be measured using generic parameters such as the time until the nodes die [6] (3) Latency, Data from sensor networks are typically time sensitive o it is important to receive the data in a timely manner Long delays due to processing or communication may be unacceptable [6]. There are different ways to deploy sensor nodes in a field to achieve a desired coverage and prolong system lifetime. Here we classify node deployment method to random, and linear node deployment, each of them can be used according to their need. the paper is organized as follows: section II express the random node deployment, section III show the linear node deployment, simulation results, conclusions is given in section IV,V, respectively.

II. RANDOM NODE DEPLOYMENT

The wireless sensor networks (WSNs) consist of individual nodes that are tiny, battery-powered devices which can process, compute and communicate various information in order to interact with their environment. They also contain sensors and actuators to control the physical characteristics of the world. With these enhancements, a sensor node is often responsible for data collection and fusion of its own sensor data and data collected from other sensor nodes. They usually consist of processing unit with limited computational power and limited memory. In many potential working environments, such as remote harsh fields, disaster areas and toxic urban regions, sensor deployment cannot be performed manually. To scatter sensors by aircraft is one possible solution. The nodes organized in a random way as shown in figure 3.1 following their self organizing method to communicate with each other, gathering information sensed from the physical world and transmitting it to the sink node where a final decision is taken place [7]. Low-Energy Adaptive Clustering Hierarchy (LEACH) is a clustering based protocol that collects data from wireless sensor nodes and sends the collected data to the cluster head, which in turn send the data to the sink node. For random node deployment, the hierarchical based routing is the best choice [7]. LEACH is a hierarchical based or cluster based routing methods. For a microsensor network the following assumptions are made [8]:

- The base station (BS) is located far from the sensors and is immobile
- All nodes in the network are homogeneous and energy constrained
- All nodes are able to reach the BS
- Nodes have no location information
- The propagation channel is symmetric
- Cluster-heads perform data compression

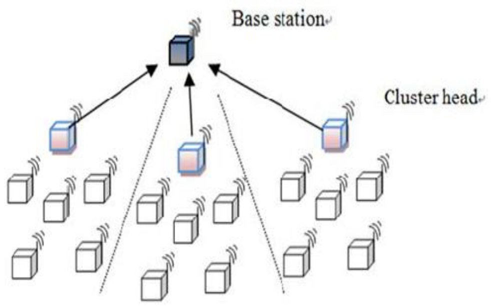

Fig.1 Clustering Concept

Clustering process as shown in fig.1 involves dividing the sensor nodes into clusters and each cluster has a cluster head node that is responsible to gather the data from its members and send it to the base station. This approach has the following advantages:

1) Non-CH sensor nodes can save the energy consumption because the nodes can avoid long-distance communication and have only to send data to its own CH being nearby.

2) The amount of data to be send to the sink node can be reduced, which also saves the energy consumptions. In addition LEACH performs local data fusion to “compress” the amount of data being sent from the clusters to the base station, further reducing energy dissipation and enhancing system lifetime [11]. When a cluster head node dies (i.e. use all of its battery energy) all the nodes that is included in the cluster will loss communication capability, Thus LEACH incorporates randomized rotation of the high energy cluster head position such that it rotates among the sensors in order to avoid draining the battery of any one sensor in the network [6]. Following this way the total energy of the system is evenly distributed among the sensor nodes. Each cluster head create a TDMA media access protocol to tell its members when to transmit their data, In this way other nodes in the same cluster that are not transmitting can enter into a sleep state which reduces the total energy consumption and prevent collision with other transmitting nodes. LEACH protocol operation is divided into rounds, each round begin with setup phase followed by steady state phase. In order to minimize the set up overhead the steady state phase is long compared to the set up phase [9] [10] [6].

III. LINEAR NODE DEPLOYMENT

Wireless Sensor Networks (WSN) are composed by a large number of tiny nodes that are able to sense the environment, process the gathered data, and send information to other nodes of the network [12]. A WSN is considered linear if one of the following conditions are true: (1) if all the nodes are aligned on a straight line, strictly forming a line, or thin LSN; (2) if all of the nodes exist between two parallel lines that extend for a relatively long distance as compared to their transmitting range and the distance separating them constitute a semi-linear or thick LSN [13]. A sensor network can be deployed along the borderline or the boundary of a restricted area. Any irregular activities will be monitored by sensor nodes and reported to a control center [14]. Several methods have been proposed recently to minimize power consumption in [15-20]. Two categories of transmission techniques are used by wireless sensor nodes to deliver event reports: (1) direct transmission and (2) multi-hop transmission. With the former model, sensor nodes transmit data directly to sinks, while with the latter event reporting is based on multi-hop relaying between nodes and the sink [20]. In this paper, we assume a linear wireless sensor network; consist of homogeneous sensor Nodes that are sending data to a single sink node located at the end of the network.

IV. SIMULATION RESULTS

A. Part 1: Random node deployment

We have tested random node deployment with different scenarios to show the performance of LEACH. LEACH protocol is more preferable with random node deployment than other deployment strategies as we have shown in [7]. The following parameters were used in our simulations.

Table I Parameters Used in Our Simulations

parameter	value
Simulation time	20 sec
Field size (meter)	10x10, 30x30, 50x50, 70x70, 100x100
Number of nodes	100 node
Deployment type	random
Sigma σ	0
Path lose exponent	2.0,2.2,2.4,2.6,2.8,3
Chipcon transceiver	CC 2420
Packet rate (packet per sec)	1 , 5
Routing protocol	LEACH
Time slot (sec)	0.2
Percentage P	0.05
Round length (sec)	20

Case 1:

- Field size 10x10
- Packet rate = 1 pkt per sec
- Path lose exponent = 2.0, 2.2, 2.4, 2.6, 2.8, 3

Cluster heads gather the data from their members and send it to the sink node as explained in chapter three. Figure 2 shows The total transmitted packet from the cluster heads to the sink node which is equal to 58 packet summed from four cluster heads when path lose exponent equal to 2.0 . The total received packets as shown in figure 3 is equal to 53 pkt out of 58 pkt where 5 packets is lost due to wireless channel loses.

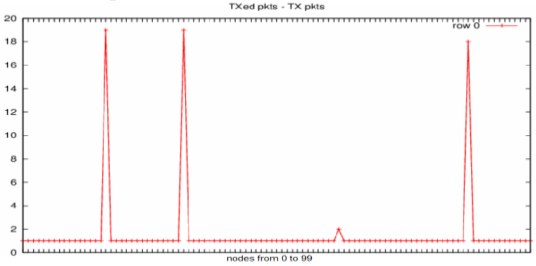

Fig.2 Total Transmitted Packets from Cluster Heads to the Sink Node When Path Lose Exponent = 2.0

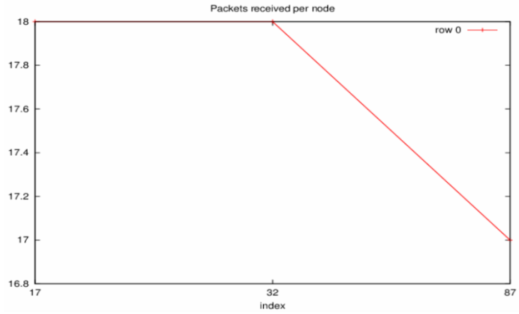

Fig.3 Total Received Packets at Sink Node from Cluster Heads When Path Lose Exponent = 2.0

The other case when increase the path lose exponent to 2.2 which means a slight increase in the obstacles between transmitter and receiver, we tested the effect of these obstacles with the same scenario as shown in fig.4. Fig. 4 and 5 show the total transmitted packets from cluster heads to the sink node, the total received packets at the sink side, respectively.

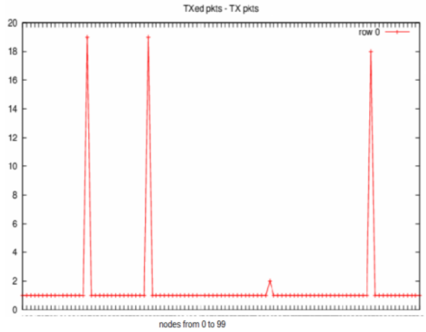

Fig.4 Total Transmitted Packets from Cluster Heads to the Sink Node When Path Lose Exponent = 2.2

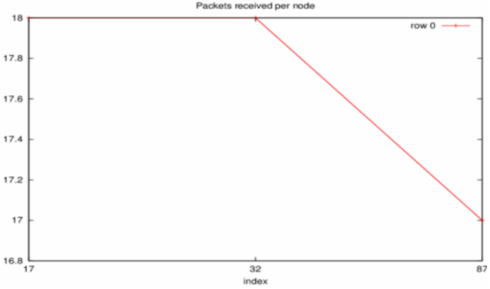

Fig.5 Total Received Packets at Sink Node from Cluster Heads When Path Lose Exponent = 2.0

We continued our stud with the same scenario but with a gradual increasing in the number of obstacles by increasing the value of path lose exponent. Figures below show the total transmitted and received packets each for the values of 2.4, 2.6, 2.8 and 3 of path lose exponent.

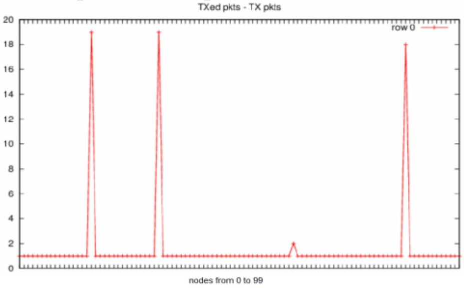

Fig. 6 Total Transmitted Packets from Cluster Heads to the Sink Node When Path Lose Exponent = 2.4

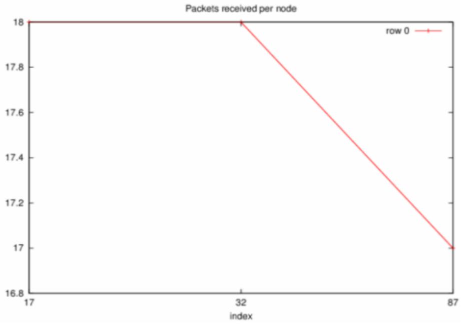

Fig.7 Total Received Packets at Sink Node from Cluster Heads When Path Lose Exponent = 2.4

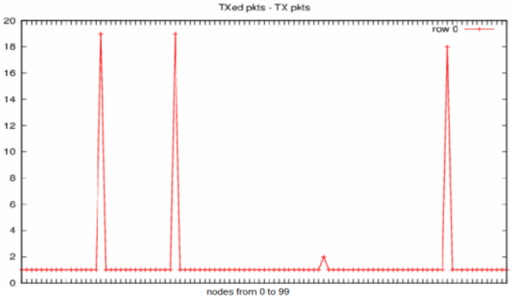

Fig 8 Total Transmitted Packets from Cluster Heads to the Sink Node When Path Lose Exponent = 2.6

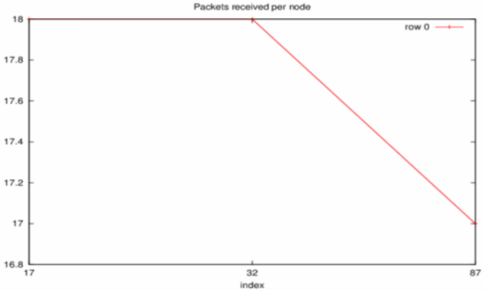

Fig.9 Total Received Packets at Sink Node from Cluster Heads When Path Lose Exponent = 2.6

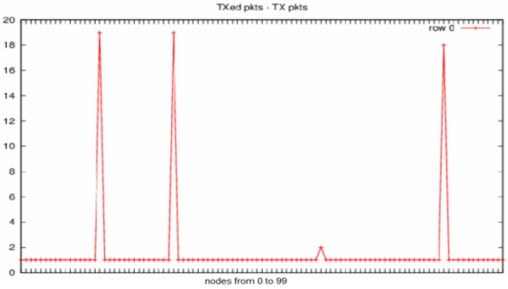

Fig.10 Total Transmitted Packets from Cluster Heads to the Sink Node When Path Lose Exponent = 2.8

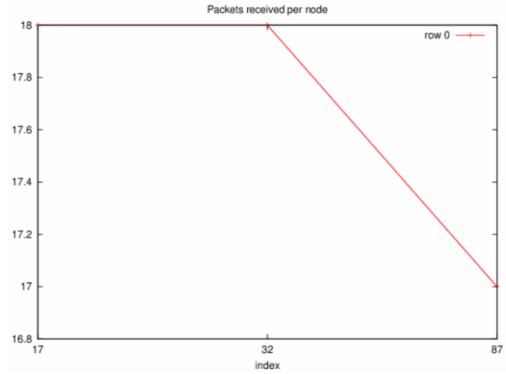

Fig.11 Total Received Packets at Sink Node from Cluster Heads When Path Lose Exponent = 2.8

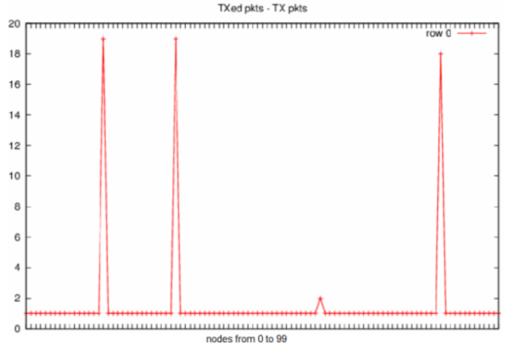

Fig.12 Total Transmitted Packets from Cluster Heads to the Sink Node When Path Lose Exponent = 3

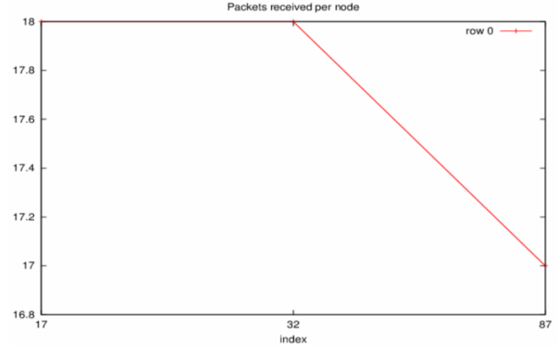

Fig.13 Total Received Packets at Sink Node from Cluster Heads When Path Lose Exponent = 3

It can be noticed here as we used a small size of area 10x10 and deploy large number of nodes, we approximately we get the same amount of transmitted and received data. We calculate the packet delivery ratio (PDR) to show the improvement when increasing the packet rate when packet rate equal 1 and 5 pkt per sec as shown in figure 4.13.

$$\text{PDR} = \frac{\text{Recieved packet}}{\text{Transmitted packet}} * 100\% \qquad (1)$$

Fig.15 shows the packet delivery ratio PDR for a field size of 30x30 meter with different path lose exponent values. We can notice as there is no obstacle between transmitter and receiver the PDR is about 98%in case of 2.0 path lose exponent value. The PDR is about 92% when there are obstacles at 2.6. With increasing the number of obstacles to represent an urban areas we can clearly notice that PDR decreasing to reach about 45% when path lose exponent equal to 3 in case of packet rate is 1 pkt per sec and reach about 62% when packet rate is equal to 5 pkt per sec.

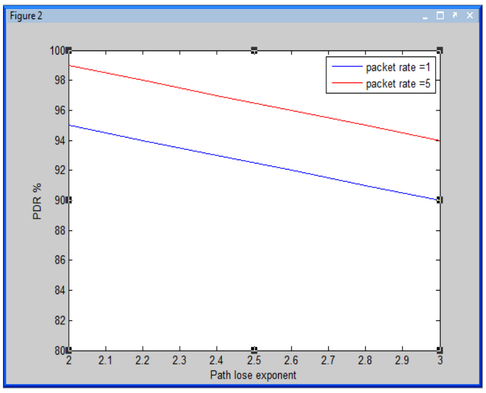

Fig.14 PDR with Packet Rate =1 and Packet Rate = 5 For 10x10 Field Size

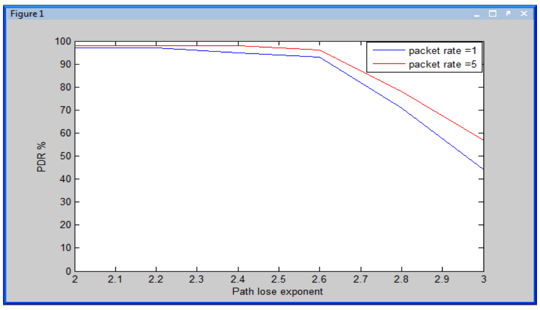

Fig.15 PDR with Packet Rate =1 and Packet Rate = 5 For 30x30 Field Size

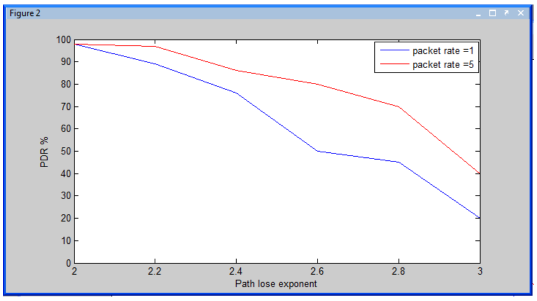

Fig.16 PDR with packet rate =1 and packet rate = 5 for 50x50 field size

It is very obvious that as field size increases with the same amount of nodes there is a big loses in PDR this is because of :

- Large number of died nodes that run out off their energy
- With the increase of distances between nodes LEACH could not perform well functionality

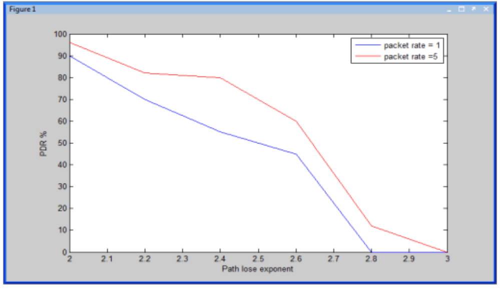

Fig.17 PDR with packet rate =1 and packet rate = 5 for 70x70 field size

Fig. 17 show the PDR while increasing the area of the field. We can see the difference in PDR between the tow cases i.e. when packet rate =1 and packet rate =5 pkt per sec. For the same reasons explained previously in case of 50x50 but here larger amount of nodes run out of their energy before reach their cluster heads due to large distances between each other.

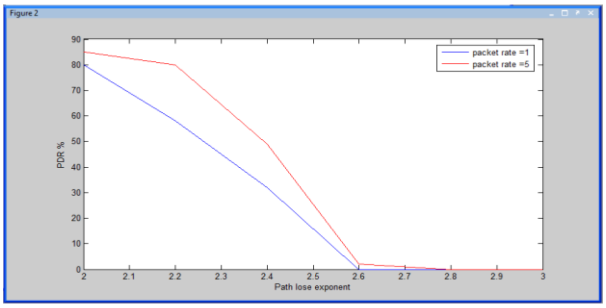

Fig.18 PDR with Packet Rate =1 and Packet Rate = 5 For 100x100 Field Size

Our final scenario of implementing random node deployment and showing the performance of LEACH protocol is done here when increasing the size of the area field up to 100x100 meter. We can see at about 2.7-2.8 the PDR reaches to zero. This is because of very long distance is not preferable with this situation with limited amount of nodes. Finally, we made a simple comparison for the above cases to show the overall average of PDR over different areas, for packet rate =1, we can notice that when increasing packet rate per second will increase the PDR to a good percentage as shown in fig.19.

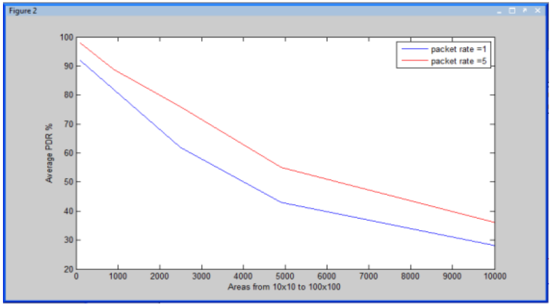

Fig.19 Average of PDR with Different Areas

B. Part 2: Linear node deployment

We assume a uniform placement node, where the sink node located at the end of the network, nodes are equally placed from each other, perfect media access control and thus the background noise is the only interference. It is reasonable to assume that the energy consumed to transmit a data unit is directly proportional to the total energy consumption by a constant number. Hence, we only consider transmission power in this paper. For a sender to transmit a stream of data at rate to a receiver, the corresponding transmission power *P* can be modeled as in[10]:

$$P = R * d^r \qquad (2)$$

Where 2≤ *r* ≤4 is the path loss exponent, here we investigate total power consumption for a path lose exponent in an urban area (i.e. r= 2.7). also system lifetime where investigated for the same parameter. Fig.20 shows the linear network considered in this work where L is the length of the network; di is the distance between two nodes as in [21]. A commonly used approach for deploying sensor networks is the uniform placement in which sensor nodes are placed with equal distance in between. Such a deployment is usually the easiest. Its performance could be modeled as follows:

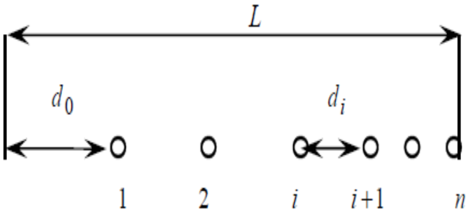

Fig.20. Linear Wireless Sensor Network [21]

$$Pi = i\,\frac{L}{n}\left(\frac{L}{n}\right)^r c \qquad (3)$$

$$T = min\left(\frac{E_0}{Pi}\right) \qquad i=1,2,....,n-1 \qquad (4)$$

Where
Pi: total power consumption of the ith node to relay all the collected data
L: length of the network
N: Total number of nodes
R: path lose exponent
C: node density
T: lifetime
E_0: initial energy

The performance of a linear network with the changes in path lose exponent is analyzed,

We test the uniform placement of nodes with L=10,n=(10,15,20,25,30,35),r= (2,2.7) for free space and an urban area respectively, E_0 =1,c=1.

Fig.21 shows that total power consumption decreases as the path lose exponent increase while in figure 22 the system lifetime increases as the path lose exponent increases.

We have simulated our result with the aid of matlab simulator, we chose the following parameters:

we optimize the linear node placement for a given total number of nodes up to 35 node along length L= 10, node density c = 1, initial energy $_0 = 1$, path lose exponent for free space (i.e. $\eta = 2.0$) and for urban are of path lose $\eta = 2.7.$ we can see in figure 21 that the total power consumption of the network decreases as increasing the path lose exponent value with increasing the number of relaying nodes in the network. Also, we can see in figure 22, the network lifetime increases while increasing the path lose exponent value and also with the increase of relaying nodes in the network.

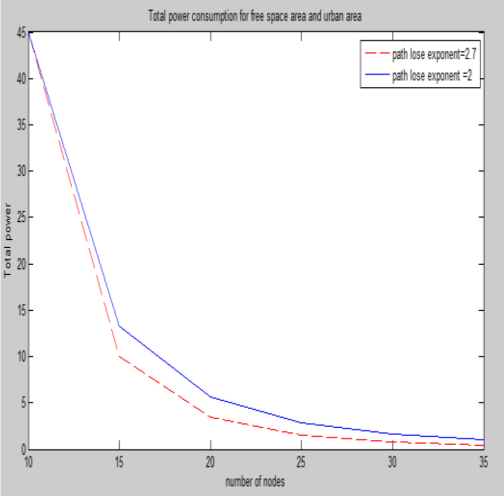

Fig.21 Total Power Consumption for Free Space and an Urban Area

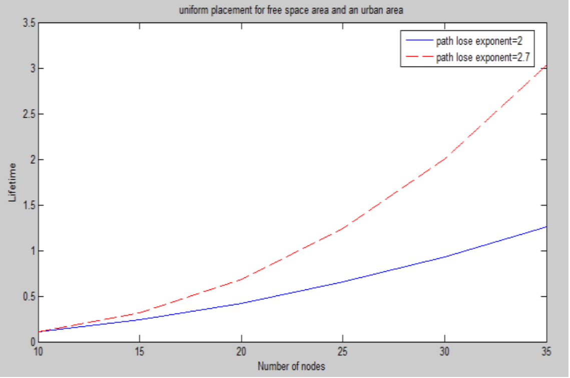

Fig. 22 Lifetime of Linear Node Deployment for Free Space and an Urban Area

V. CONCLUSION

In this paper, we have investigated the effects of spatial diversity of node deployments, different values of path lose exponent were used in random node deployment and linear node deployment. We concluded that, LEACH protocol with 100 randomly node deployment perform well for free space areas with packet rate 5 pkt per sec to achieve about 98% of PDR but while increasing the number of obstacles between transmitter and receiver also increasing the area of the field we notice that PDR decrease to reach about 38%. For linear node deployment, the result shows that when the paths lose exponent increase the total power consumption decreases and the system lifetime improved.

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