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A Genetic Approach to Find the Cluster Head and Lifetime Maximization of Mobile Sensor Network

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Abstract: Wireless sensor networks (WSNs) have become an important research area in the field of computers and electronics in the last decade. A WSN in which the sensor nodes are mobile is called a Mobile WSN. Since the sensor nodes are deployed in large numbers in such a network and in environments where human intervention is not possible so it is difficult to recharge their individual batteries. Hence the main challenge in a WSN is the limited energy available to the sensor nodes. A possible solution to maximize energy is to use a mobile agent in a WSN for collecting data. In this work firstly clustering is performed in the network and then a communication forest is created, which is a group of cluster heads visited by the mobile agent. Single hop communication is used between the sensors and the cluster heads. The Genetic Algorithm (GA) is used for choosing the cluster heads. Lastly the data is transmitted from the cluster heads to the mobile agent using Multiple-Input Multiple-Output (MIMO) technique. All the sensor nodes considered in this network are mobile except the base station. The objective is to define the cluster heads, the communication forest and collect the data using mobile agent from the cluster heads. Results are shown for WSN with an instance of 100 nodes deployed over 1000X1000 m2 area. The simulation results showed an increasing network lifetime.

Keywords: Mobile Sensor Networks, WSN, MA, Network Lifetime, MIMO.

I. INTRODUCTION

A wireless sensor network (WSN) is composed of a large number of spatially distributed sensor nodes which are cheap, low power, limited in memory, energy constrained due to their small size. These sensor node work together to monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. There are three main functions of a sensor node-sensing, processing and communication. Before wireless sensor networks became popular, the wired sensor networks were being used for the same purpose but due to high cost of installation, termination, maintenance, upgradation and infeasibility of wired sensor networks in hostile and remote locations, wireless sensor networks became a good alternative [1]. Since the sensor nodes in a wireless sensor network are deployed randomly in large numbers and in difficult to reach areas the major problem lies in the constrained energy resources available to the sensor nodes as it is difficult to recharge their individual batteries. A typical wireless sensor network is shown in figure 1.

A feasible solution to this network lifetime maximization problem is to use a mobile agent (MA) in a WSN for collecting data. A mobile agent is a powerful hardware unit rich in energy and capable of collecting data by traversing through the WSN. The network lifetime is defined as the time until the first sensor node in the WSN dies [3].

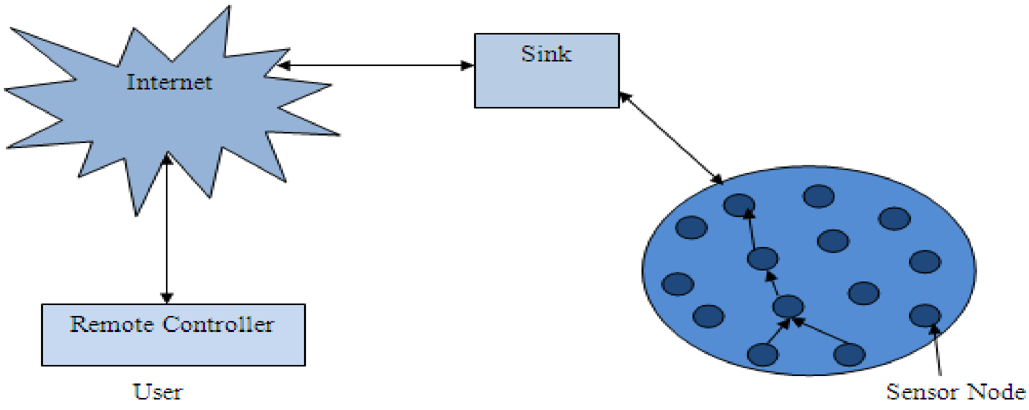

Fig. 1 A wireless sensor network [2]

In this work data collected by sensor nodes is transferred to a central sensor node called the Cluster Head (CH) using single hop communication. The sensor nodes can only communicate with their own cluster head and not with each other. Then a communication forest is created in which the roots of the trees are the cluster heads visited by the mobile agent. After each CH possesses the gathered data, the MA goes to every CH for collecting data. Only the cluster heads can communicate directly with the MA. Lastly the mobile agent transmits the gathered data to the base station. A base station is a node where the information collected by the WSN is processed, for example, a computer or a laptop etc. The network considered in this work consists of one mobile agent and several randomly deployed mobile sensor nodes. The problem is to define the cluster heads, the communication forest and collect the data using a mobile agent from the cluster heads.

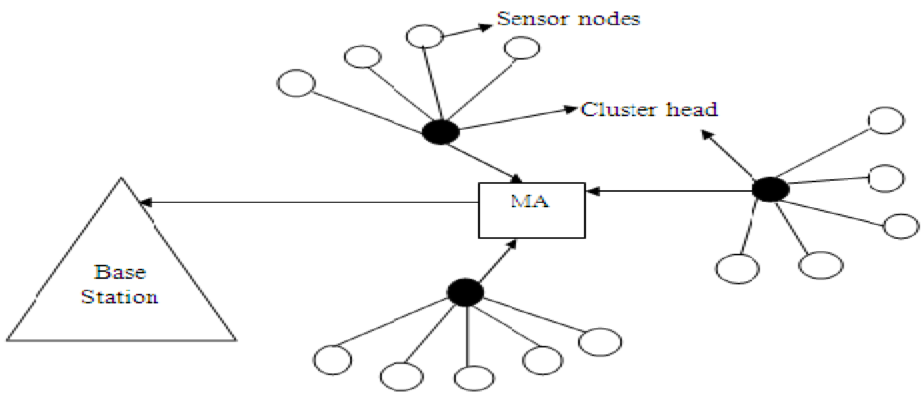

Fig. 2 A wireless sensor network showing a base station, a mobile agent, cluster heads and sensor nodes

The rest of the paper is organized as follows: Section II gives a review of the previously published work on maximizing the network lifetime of the WSN. In Section III the proposed energy metric of the WSN is presented. Section IV introduces the Genetic Algorithm. In Section V the MIMO System is described. Section VI analyzes the experimental results and finally section VII concludes the paper and points out the future work.

II. Related Work

The lifetime maximization problem of the WSN has received a great attention in the research. A short review of the published research on this topic is presented in this section.

Sirdeshpande et al. [4] propose a modified Leach (Low Energy Adaptive Clustering Hierarchy) protocol for network lifetime improvement by developing a cluster based routing in which the cluster heads are selected based on maximum coverage. The clusters are dynamically formed with each transmission.

Ignatius et al. [5] propose a wake-up scheduling protocol in which some nodes stay active while the others enter sleep state so as to conserve their energy. The best shortest path among the nodes in the WSN is taken into account in this protocol.

Genetic algorithm proposed by Cai et al. [6] finds out an optimal itinerary for multiple mobile agents for collecting data from the sensors in the WSN. Their work also addresses the shortcomings of using a single mobile agent.

A solution to the battery allocation problem in WSN with different topologies and heterogeneous power distributions is proposed by Long et al. [7] in which a battery pack selection method is developed based on an energy-cost battery pack model.

An approach for minimizing the total energy consumption within a limited delay is proposed by Romao et al. [8]. The set of cluster heads is defined using GA and the sensors send data to the cluster heads using one or more hops. A communication forest is created in which the roots of the trees are the sensors visited by the mobile agent. Results are shown for different limits of mobile agent tour length to control the delay in the message transmission.

We adapted their work with the changes mentioned above. In this work results are shown for different energy limits given to the 100 nodes.

III. Energy Metric

In this work the energy consumption of the sensor nodes is directly proportional to the amount of data transmitted or received. It is assumed that the sensors are awake only while transmitting or receiving data otherwise they remain in the idle state in which there is negligible energy consumption. In order to transmit a k-bit message over a distance d, the estimate of the energy consumed is given according to the radio energy dissipation model as [10]:

$$d_0 = \sqrt{Efs / Eamp} \tag{1}$$

$$Etx\ (k,d) = k*Eelec + k*Eamp*d^2 \quad \text{if } d < do \tag{2}$$

$$Etx\ (k,d) = k*Eelec + k*Eamp*d^4 \quad \text{if } d \geq do \tag{3}$$

Where Eelec is the energy dissipated per bit for running the transmitter (ETX) or the receiver circuit (ERX). The distance between the sender and the receiver is denoted by d. The free space (fs) model is used if the distance is less than the threshold; otherwise, the multi path (amp) model is used. So the energy consumption of the sensor nodes transmitting data to the cluster heads is directly dependent on the distance between them. More the distance more will be the energy consumption. When the mobile agent visits each cluster head for data collection the distance between the CH and the MA becomes zero so the energy consumption of the cluster heads reduces in comparison to the regular nodes. Like [10] these constants are assumed to be Eelec=5 nJ/bit, Eamp=0.0013 pJ/bit/m^4, Efs=10 pJ/bit/m^2.

IV. Genetic Algorithm

The genetic algorithms (GA) proposed by Holland [12] are random algorithms. In this the process of genetic selection and natural elimination in biological evolution is simulated. Genetic algorithms are search algorithms based on the mechanics of the natural selection process (biological evolution). GAs are based on the principle of the Survival of the fittest. In GA the natural processes of biological evolution i.e. selection, crossover, mutation and accepting are mocked to evolve a solution to the problem. Given a set of initial feasible solutions to a problem, the GA recombines them in a way to guide its search to the most promising solutions for that problem. Each feasible solution is known as a chromosome (string) and a chromosome gives a measure of fitness via a fitness function. The fitness of a chromosome determines its ability to survive and produce offspring.

1	1	0	1	1	1	0	1	1	1	1	0	1	1	1

Fig. 3 Representation of a chromosome

There are basic three genetic operators.

- **Selection:** It is selecting the chromosomes for reproduction.
- **Crossover:** It is combining parent chromosomes to produce new chromosomes i.e. offspring. It combines the fittest chromosomes and passes superior genes to the next generation.
- **Mutation:** It is altering some genes in a chromosome.

Algorithm 1 Genetic Algorithm

1. Generate random population of n chromosomes (i.e. suitable solutions for the problem).
2. Compute the fitness f(x) of each chromosome x in the population.
3. Create a new population by repeating the following steps until the new population is complete.

a. Based on the fitness, select two parent chromosomes from a population.

b. Crossover the parents to form new offspring with a crossover probability p_c.

c. Mutate new offspring in the chromosome with a mutation probability p_m.

d. Place new offspring in the new population.

4. Run the algorithm further using the newly generated population.
5. Stop and return the best solution in the current population when the end condition is satisfied.
6. Go to step 2.

The first problem in this work is to choose the set of cluster heads. For this initially clustering is performed in the network which divides the sensor nodes into various clusters where each cluster has a central node called the cluster head. The initial number of cluster heads and the initial number of cluster members are chosen according to the equations 4 and 5 [9]:

$$nch=N*prob \quad (4)$$

where nch is the total number of cluster heads in the network, N is the total number of sensor nodes in the network and prob is the probability which should be kept minimal so that the total number of cluster heads does not exceed the number of sensor nodes.

$$nm=(N-nch)/nch \quad (5)$$

where nm is the number of member nodes in each cluster. After this initial iteration, the Genetic Algorithm (GA) is used for choosing the cluster heads for subsequent rounds. The initial population consisting of the sensor nodes in the network is modified by the three genetic operators. In the selection phase, the sensor nodes having more energy are chosen as CHs. In the crossover phase, the sensor nodes in the network move to new positions with a crossover probability p_c and lastly the mutation is performed with a probability p_m which generates a new population. Once the cluster heads are formed, a communication forest is created which is a group of cluster heads to be visited by the MA.

V. MIMO SYSTEM

Gerard Foschini and others described multiple input/multiple output (MIMO) systems in the mid-to-late 1990s. Single-in-single-out (SISO) channel is a traditional communications link, which has one transmitter and one receiver. But instead of a single transmitter and a single receiver several of each can be used. This is called a MIMO channel in which there are multiple transmitters and receivers. The MIMO system is shown in figure 4. MIMO has several advantages such as it increases the capacity of the channel, throughput and range. Suppose there are N_R receiving antennas and N_T transmitting antennas. With a MIMO system, the data stream from a single user is demultiplexed into N_T separate sub-streams. The number N_T equals the number of transmitting antennas. The signals are received by N_R receiving antennas. So the MIMO channel can be described as [11]

$$Y = H^{*}X + N \tag{6}$$

where H is called the channel matrix, X is the complex vector for the transmitted signal, Y is the complex vector for the received signal and N is the channel noise. In this work the case of two transmitting antennas and one receiving antenna is considered. The random channel model treated here is the Rayleigh channel model. The Rayleigh channel model assumes NLOS (Non-Line of Sight), and is used for environments with a large number of scatterers. For H (n_R X n_T) channel matrix it has independent identically distributed (i.i.d.), complex, zero mean, unit variance entries [11].

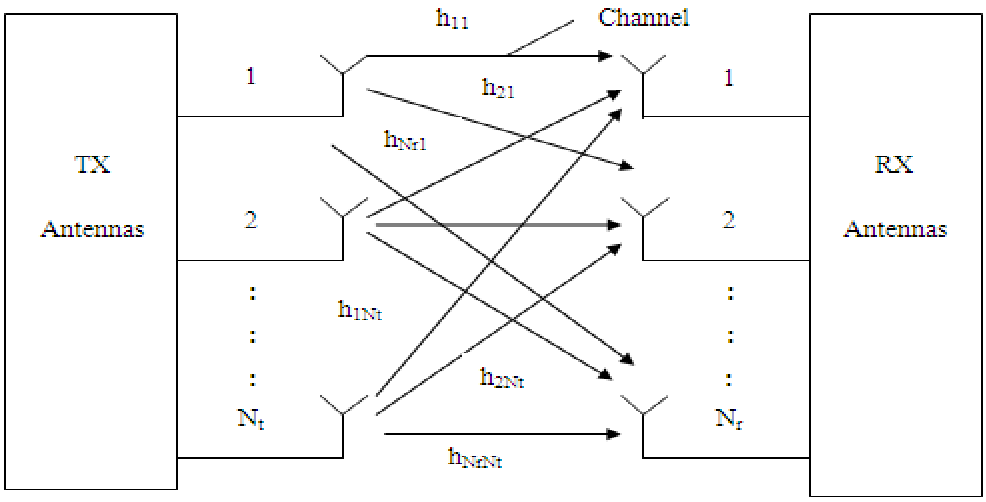

Fig. 4 Multiple-input multiple-output system block diagram [11]

VI. SIMULATION RESULTS

In the simulation, 100 nodes are randomly deployed on a 1000X 1000 m^2 field. The location of the base station is randomly chosen and is kept fixed throughout the simulation. All experiments are performed using MATLAB. The system parameters are summarized in Table 1. Figure 5 shows a 1000 X 1000 m^2 WSN consisting of 100 sensor nodes. The base station is denoted by red box and the sensor nodes are denoted with a blue dot along with their node numbers. After creating a WSN, clustering is performed in the network. Figure 6 depicts the total number of cluster heads formed initially in the network using eq. 4 with their respective node numbers 78, 70, 14, 44 and 49. These cluster heads are denoted with a green box in the figure.

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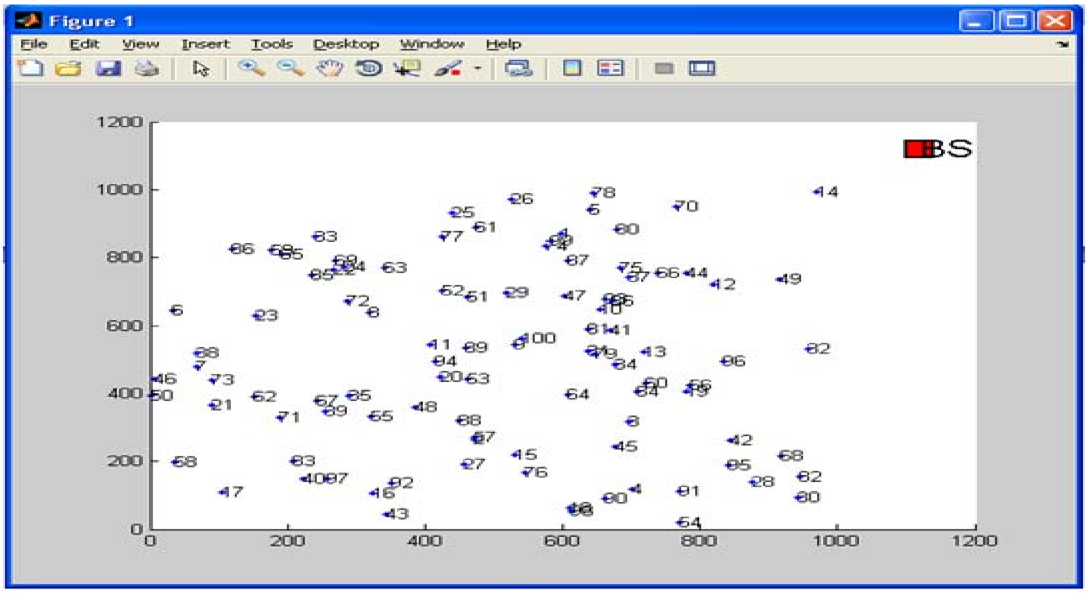

Fig. 5 A wireless sensor network with a base station

After defining the total number of cluster heads in the network the number of member nodes in each cluster are determined using eq. 5. One such cluster with cluster head 14 and 19 member nodes is shown in figure 7.

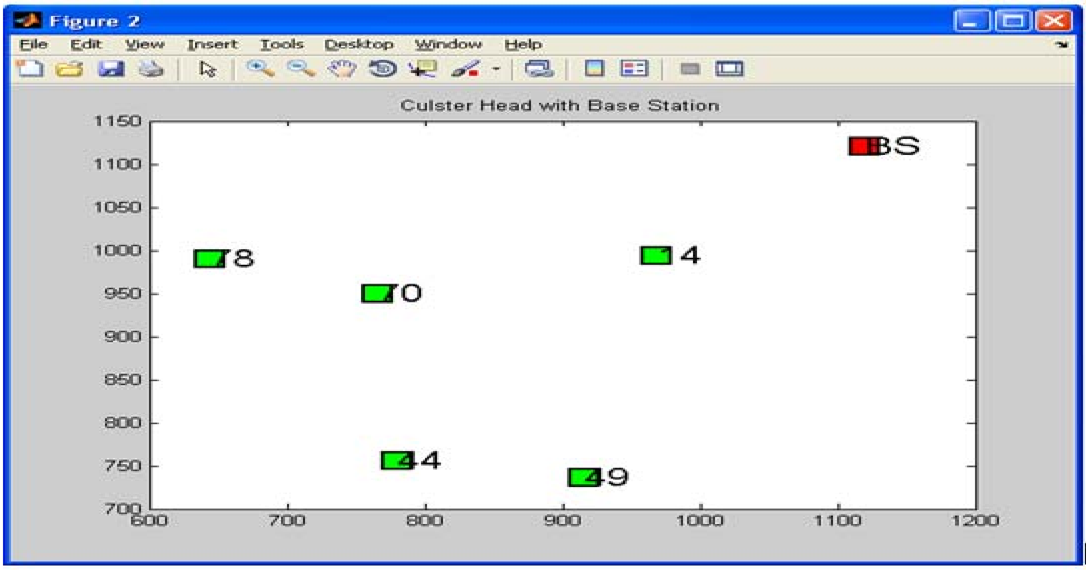

Fig. 6 Initial cluster heads with the base station

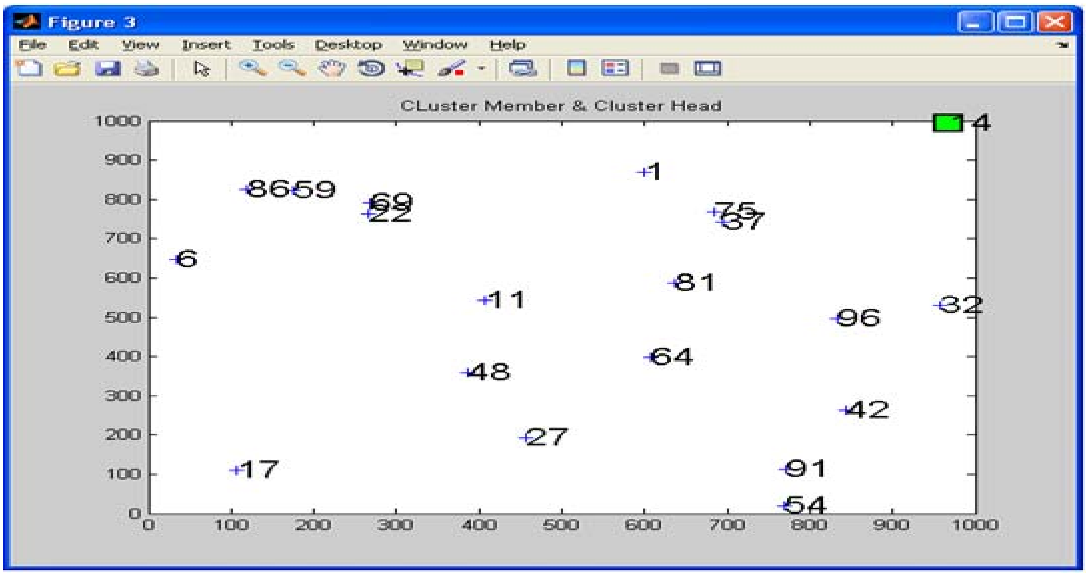

Fig. 7 Cluster head 14 and its members

After choosing the initial cluster heads, the Genetic Algorithm is used for choosing the set of cluster heads for subsequent rounds. One such chosen set of cluster heads is shown in the figure 8.

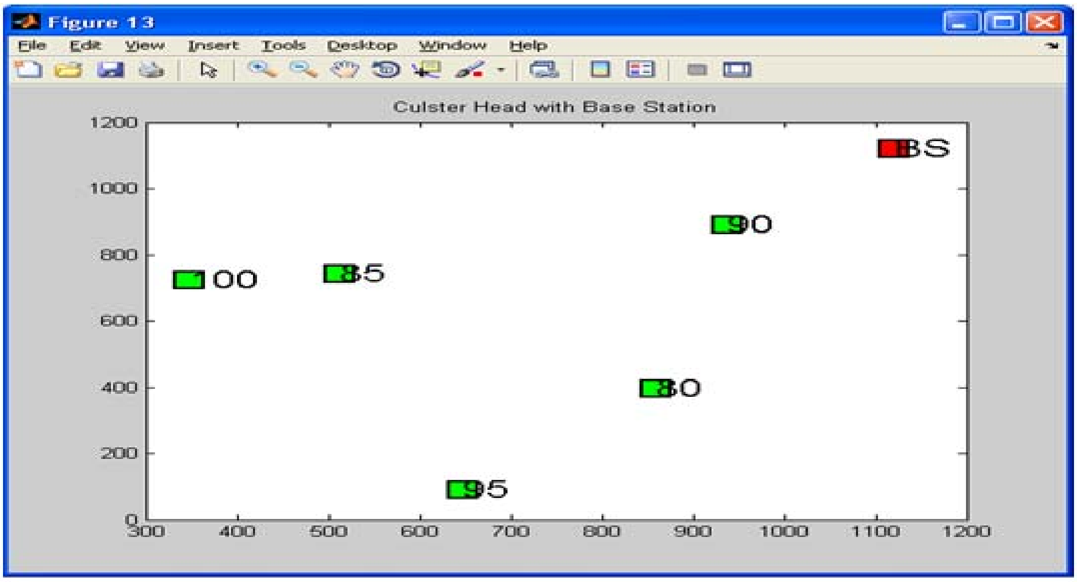

Fig. 8 Cluster heads formed using Genetic Algorithm

Figure 9 shows a communication forest consisting of the set of the chosen cluster heads. The mobile agent then visits only these nodes for collecting data and then finally transmits it to the base station. Figure 10 shows that the symbol error rate decreases with the increase in SNR because of the employed MIMO technique.

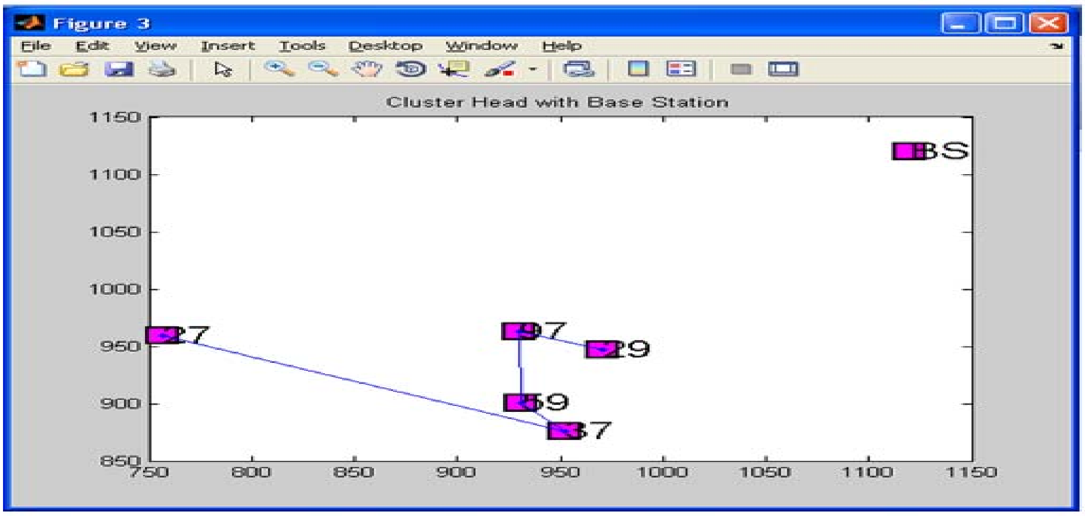

Fig. 9 Communication forest

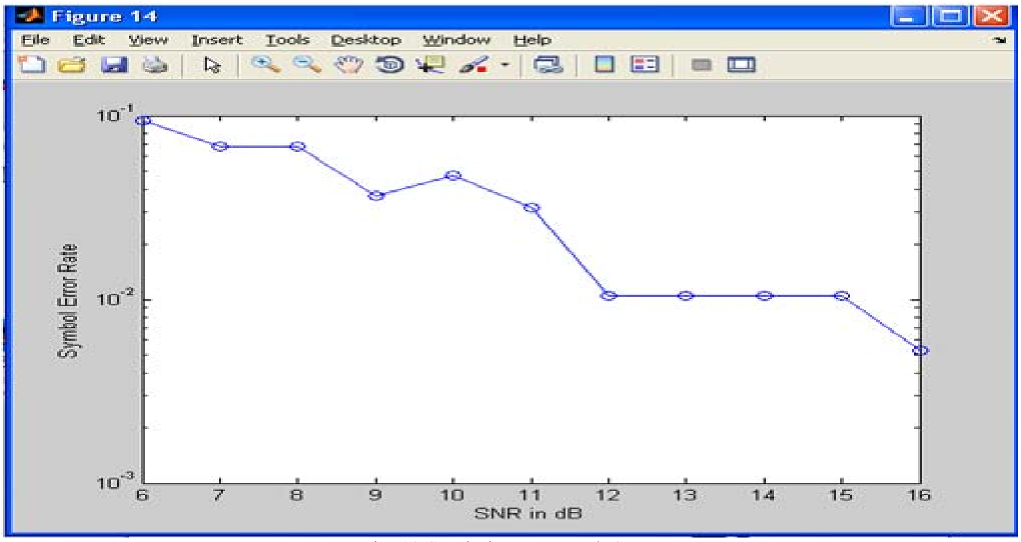

Fig. 10 Symbol error rate v/s SNR

The experimental results in figure11 show as the initial energy provided to the nodes is increased, the number of rounds till the nodes are alive also get increased. Like when the initial energy given to 100 nodes is 5J the nodes remain alive for 11 rounds and when the energy is changed to 10J the nodes remain alive for 12 rounds.

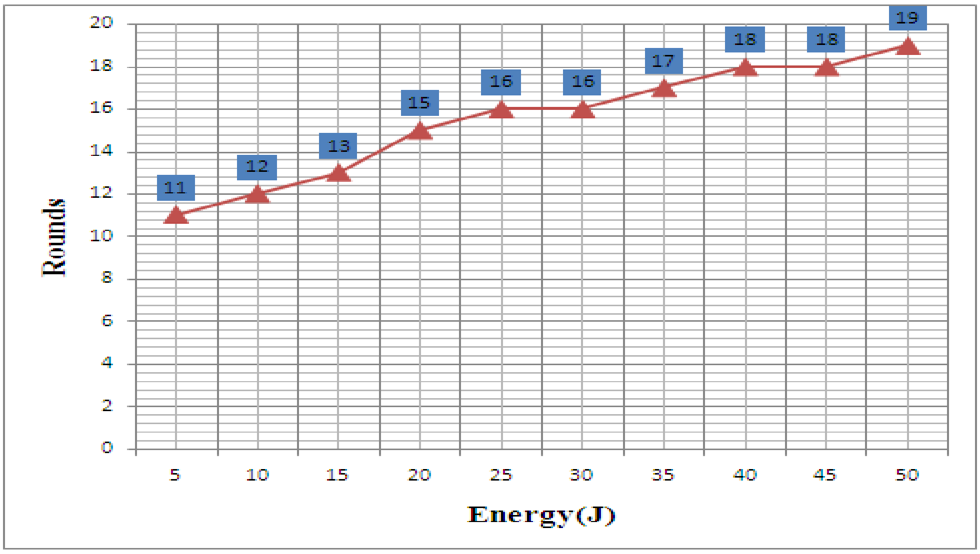

Fig. 11 Number of rounds till the nodes are alive

VII. CONCLUSION

In this work a Genetic Algorithm is presented to define the cluster heads and communication forest in a WSN. The sensors send information collected from the environment to the cluster heads. The energy consumption of the nodes increases or decreases based on the distance between the sensor node and its cluster head. Then the mobile agent collects all information visiting each cluster head using MIMO technique and delivers it to the base station. In this way the total energy consumption of the WSN is minimized. The simulation was done with different energy levels provided to 100 nodes for different number of rounds and the simulation results showed an increasing network lifetime.

Future work include: Obtain the results using Particle Swarm Optimization (PSO) algorithm instead of GA or compare the performance with other algorithms and use multiple mobile agents by making a particular mobile agent visiting only a particular set of cluster heads.

Table I
The System Parameters

S.NO	Parameter Description	Value
1	Total number of sensor nodes (N)	100
2	Area of the WSN (Area)	1000 X 1000 m^2
3	Crossover probability (p_c)	0.5
4	Mutation Probability (p_m)	0.7
5	Characteristic of the transmitter amplifier (Eamp)	0.0013pJ/bit/m^4
6	Energy dissipated per bit to run the transmitter or receiver (Eelec)	5 nJ/bit
7	Characteristic of the transmit amplifier (Efs)	10 pJ/bit/m^2
8	Data size (dsize)	60 bits
9	Antenna gains of the transmitter and the receiver (G_tG_r)	5 dBi
10	Efficiency (α)	0.4706
11	Link margin (Ml)	40 dB
12	Gain Factor (G1)	30 dB
13	Path loss (k)	[3, 5]

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14	Power density (σ)	−134 dBm/Hz
15	Receiver noise figure (N_f)	10 dB
16	Carrier frequency (f_c)	2.5 GHz
17	Bandwidth (B)	20 kHz
18	BER performance (P_b)	10^{-3}
19	Circuit power consumption of the transmitter (P_{ct})	98.2 mw
20	Circuit power consumption of the receiver (P_{cr})	112.6 mw
21	Transmission rate (R)	0.75

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