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Optimal Cluster Head Selection and Clustering for WSN Using PSO

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***Abstract:** Nowadays, Wireless Sensor Network is the promising and booming technology used in a variety of applications like disaster monitoring, health care, environmental monitoring, agriculture, industrial automation, etc. However the main drawback of the wireless sensor network is the limited energy source of the sensor nodes. Consequently, efficient utilization of the energy becomes essential for increasing the lifetime of network. Clustering protocol is one of the best energy efficient approach for saving the energy and maximizing the network lifetime. But the improper selection of cluster heads (CHs) may lead to the death of the CHs which deteriorate the performance of the network. Therefore the proper selection of cluster head becomes important for the energy conservation of sensor nodes and to maximize the lifetime of network. In this paper, we have presented PSO based optimal cluster head selection algorithm, in which the best possible CHs are chosen on the basis of parameters like residual energy, intra-cluster distance, and inter-cluster distance of the sensor node. With the effective scheme of particle encoding and fitness function, the proposed PSO algorithm is implemented for reducing the energy consumption and improving lifetime of network. The proposed algorithm also ensures the uniform distribution of the energy over network, by changing the role of CHs after each round. We extend our research to cluster formation approach where the sensor nodes are joined to the CH on the basis distance and energy of cluster head. The proposed algorithm is simulated extensively under various conditions like number of sensor nodes in the field, number of CHs, the position of the base station, constant energy and random energy, etc. and the simulation results are analyzed with the extant algorithms. Under all the circumstances the proposed algorithm outperforms the existing LEACH and SEP protocols in terms of average residual energy, the network lifetime and number of data packets received by the base station. Because of the improvement in the lifetime of the network, the proposed algorithm can be used in the applications like environmental monitoring, agriculture etc.*

***Keywords :** Wireless Sensor Networks, energy saving, Particle Swarm Optimization, Lifetime of Network.*

I. INTRODUCTION

Nowadays, wireless sensor network (WSN) plays an indispensable role in most of the applications like disaster monitoring, health care, environmental monitoring, agriculture, industrial automation, smart homes, etc [1]. The main aim of the WSN is to collect physical entities from the environment and transfer it to the base station (BS) via wireless links. WSNs have limited resources like battery power, memory size, and processing speed. The sensor nodes have limited battery power and because of that the lifetime of the WSN is also restricted. Replacement and recharging of batteries of sensor nodes are impossible due to environment complexity and huge numbers of sensing nodes in the network field. Therefore energy saving in the wireless sensor network becomes very essential. The conventional communication protocols, direct transmission protocols and minimum transmission energy protocol do not guarantee the balanced distribution of energy over the network. Hence it demands to design the powerful energy aware multihop routing algorithm for WSN [2].

Clustering protocol is one of the best energy efficient approach for saving the energy and increasing the lifetime of network . In the clustering protocol, the sensor nodes are partitioned into groups. Every group has one master node, called a cluster head. All the sensor nodes sense the data and transfer it to the corresponding CH. Then the CH aggregates and transmits the data received from sensor nodes to the base station. The cluster heads have to work more than the normal sensor node and because of that, they may die out fast. Improper cluster head selection may affect the performance of the network. Therefore the proper selection of CH plays a indispensable role in the clustering.

This paper is arranged as follows: introduction is covered in Section I. Section II is a literature survey. Section III concisely describes Particle Swarm Optimization. Section IV describes proposed work and section V describes the experimental setup and simulation results in detail and lastly, the paper is concluded in section VI.

II. LITERATURE SURVEY

There are many researchers who are working on the different problems of wireless sensor network like clustering, routing, node placement, data aggregation etc. Here we presented the review of papers related to clustering of wireless sensor network using the nature inspired approach. Md. Azharuddin and P. Jana presented a PSO based algorithm for clustering and routing. These algorithms not only take care of the consumption of energy of the sensor nodes but also the balancing of energy distribution over the network. Algorithms also take care of the cluster head failure. Experimental results proved that the performance parameters of the proposed algorithm are superior to the existing algorithm in terms network lifetime and energy consumption of the number of data packets received [3].

Elhabyan and Yagoub proposed PSO based protocol to find out the optimal number of CHs
in order to maximize the lifetime of network.

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The protocol also considers the network coverage and link quality. Simulation results proved that the performance of the proposed PSO based protocol amended in terms of the energy efficiency of the network [4].

Akila et al. presented a clustering algorithm in which the number of clusters is decided by Leaped Frog Optimization algorithm. The main aim of the protocol is to form the clustering in a non-overlapping way [5].

Garg et al. presented a new approach based on PSO for clustering the sensor nodes. Here the authors tried to meliorate the performance of existing LEACH algorithm using PSO. The proposed LEACH-P algorithm selects the cluster heads nearer to the BS which reduces the power consumption of CH and thus improved the lifetime of the network. The proposed LEACH-P algorithm outperforms the existing LEACH protocol in terms of stability period, lifetime of network and transmission of data[6].

Sharma et al. proposed a PSO based approach to select the CHs based on the reselection mechanism. Experimental results show that the proposed PSO based algorithm works better than the existing LEACH algorithm in terms of the stability period [7].

Rao et al. have presented a PSO based algorithm for energy efficient cluster head selection in which cluster heads are selected on the basis numerous parameters like residual energy, inter-cluster distance and intra-cluster distance of the sensor nodes. Here the clusters formation is done on the basis of weight function. The experimental results demonstrate that the proposed algorithm works better than the existing algorithms [8].

Singh and Lobiyal have proposed an energy-aware PSO based clustering algorithm. The algorithm intends to maximize the lifetime of network and reduce the consumption of energy of sensor nodes. The fitness function for PSO was suggested by authors, based on node degree, residual energy, distance and density of sensor nodes in the cluster [9].

Rostami and Mottar have introduced clustering algorithm based on PSO for minimizing consumption of energy and maximizing the lifetime of network . The algorithm uses fitness function which considers the parameters like residual energy, intra-cluster distance and inter-cluster distance. The simulation results show that the proposed clustering algorithm outperforms the existing algorithms [10].

Ahmed et al. have presented a hierarchical routing technique for saving of energy and maximizing the network lifetime. Authors focused on Artificial Fish Swarm Algorithm (AFSA) technique and hierarchical routing. Algorithm selects the optimal CHs on the basis of distance and residual energy of the nodes. In this technique, artificial fish swarm optimization is used for the best possible cluster head location. The experimental results show that the proposed AFSA technique is stable and more energy efficient compared to existing protocols [11].

III. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization is most simplest, nature-inspired, computationally efficient metaheuristic optimization technique. The main goal of using the Particle Swarm Optimization is to find out the best possible position of particle which gives the best valuation of the fitness function. During each generation, the velocity of every particle is modified based on current velocity, the preceding local best and global best position of the particle. Updated velocity and position of the particle can be calculated based on the past values. A similar procedure is followed for each iteration. The mathematical formulae to update the velocity and position of particles are specified by equation 2.1 and 2.2.

$$V_j(t) = w_j \times V_j(t-1) + ac_1 \times rn_1 \times (X_{pbestj} - X_j(t-1)) + ac_2 \times rn_2 \times (X_{gbest} - X_j(t-1)) \quad (2.1)$$

$$X_j(t) = X_j(t-1) + V_j(t) \quad (2.2)$$

Where w_j = inertial weight, $0 < w_j < 1$,
ac_1 and ac_2 = acceleration factors, $0 \le ac_1, 2 \le ac_2,$
rn_1 and rn_2 are random numbers in the range of [0,1].
Similar procedure is followed for every iteration till either an appropriate G_{best} is reached or a set amount of iterations t_{max} is reached.

$$P_{bestj} = \begin{cases} P_j & If\left(Fitness(P_j) < Fitness(P_{bestj})\right) \\ P_{bestj} & otherwise \end{cases}$$

$$G_{bestj} = \begin{cases} P_j & If\left(Fitness(P_j) < Fitness(G_{bestj})\right) \\ G_{bestj} & otherwise \end{cases}$$

Flowchart for the PSO algorithm is shown in Fig.1

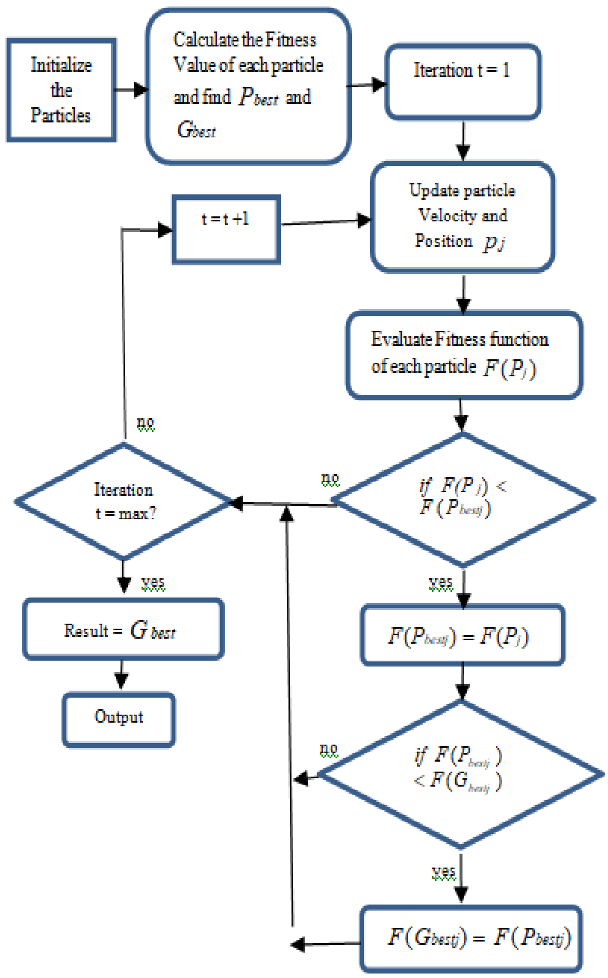

Fig. 1 Flowchart of PSO

IV. PROPOSED WORK

4.1 Energy Model

The energy model referred here is same as the radio model employed in [2]. The transmitter utilizes its energy to operate the radio electronics and the amplifier. Similarly, the receiver utilizes its energy to operate the radio electronics. Sensor nodes dissipate their energy based on the number of the bits to be transferred over the distance. If the propagation distance d is greater than the threshold distance d_0, the energy consumed by a sensor node is directly proportional to d^4 else energy consumed by sensor node is directly proportional to d^2 [2]. The total amount of energy exhausted for transmission of the n bits data over distance by each sensor node in the network field is given by the following equations.

$$E_{TX}(n,d) = nE_{elect} + nE_{fs} \times d^2 \ (if \ d < d_0) \tag{4.1}$$

$$E_{TX}(n,d) = nE_{elect} + nE_{mp} \times d^4 \ (if \ d > d_0) \tag{4.2}$$

Where, E_{elect} is the energy exhausted to operate the receiver or transmitter, E_{fs} is amplification energy for free space model and E_{mp} is for multi-path model which is mainly reliant on the transmitter amplifier model. d_0 specifies the threshold transmission distance which is expressed by the following equation

$$d_o = sqrt(E_{fs} / E_{mp}) \tag{4.3}$$

Similarly, energy consumed to receive n bits of data by the receiver circuit is expressed by

$$E_{RX}(n) = n \times E_{elect} \tag{4.4}$$

Where E_{elect} depends on various parameters like modulation, filtering, digital coding, and the signal spreading.

4.2 Proposed Algorithm

The proposed algorithm is split into two stages

1. Optimal cluster head selection using PSO algorithm

2. Formation of clusters

Sensor nodes are scattered randomly on the sensor network field. Once the sensor nodes are placed on the network field, they are treated as stationary nodes. All sensor nodes are considered homogeneous.

The algorithm goes through the following steps.

Step 1: Optimal cluster head selection algorithm using PSO is applied for proper selection of cluster heads in the network. In the optimal cluster head selection algorithm phase, all sensor nodes transmit the information like residual energy and their location to the base station. In order to find optimal cluster heads, cluster head selection algorithm using PSO is runs at the base station. PSO announce the optimal cluster heads based on different parameters like residual energy, intra-cluster distance and inter-cluster distance.

Step 2: After finalization of the cluster heads, clusters are formed on the basis of residual energy and distance of cluster head from the sensor nodes. Every sensor node joins to their nearest cluster head. If the distance between the sensor nodes and the CH is less than the distance between that sensor node and the base station, then the data will be sent to the cluster head. Otherwise data will be directly transmitted to base station. This helps to reduce the consumption of energy of the sensor nodes as well as the burden on the cluster heads.

Step 3: If the transmission distance is greater than the threshold distance then the multipath energy model is applied. Else, the free space energy model is used.

The execution steps of the proposed algorithm is as follows

1. Initialize the Particles.
2. Calculate Fitness value of each particle and find P_{best}, G_{best}
3. For t = 1 to max

- Update the particle velocity and particle position p_j Using equations 2.1 and 2.2.
- Calculate fitness value of each particle $F(P_j)$
- $If \ fitness(P_j) < fitness\ (P_{bestj})$
- $P_{bestj} = Pj$
- $if \ fitness(P_{bestj}) < fitness\ (G_{bestj})$
- $G_{bestj} = P_{bestj}$

V. EXPERIMENTAL SETUP AND RESULT

The proposed algorithm was demonstrated in MATLAB. Area of the sensor network is considered as 200 m × 200 m. The initial energy of all the sensor nodes is considered as 0.2J. Simulation experiments were executed by varying the number of sensor nodes from 100 to 500 with 5% or 10% cluster heads. We examined the performance of the proposed algorithm at the different positions of the BS and at various number of sensor nodes. Sensor nodes are considered to be static and homogeneous. The simulation results are compared with the existing protocol to validate the diminution in consumption of energy and improvement in the network lifetime. The PSO parameters considered for the simulation is as follows.

w_j=0.7, $ac_1 = ac_2 = 2$, rn_1 = 0.5 and rn_2 =0.7.

The other parameters considered to run the simulation is shown in Table 1.

Table 1 Network Parameters

Algorithm	Number of Nodes	Position of Base Station	FND	HND	LND
LEACH	100	Centre of the field (100, 100)	268	411	614
SEP			283	413	596
Proposed PSO Based			315	610	996

SIMULATION RESULT

Performance measures:

The performance of the proposed algorithm is evaluated by considering the following measures.

Network Lifetime: It is the time duration from the beginning of sensor network operation until the last alive node died.

First Node Dead (FND): The number of rounds till the first node dead.

Half Node Dead (HND): The number of rounds till the death of half number of nodes.

Last Node Dead (LND): The number of rounds till the last node dead.

Energy Consumption: It is the total energy utilized by cluster heads and sensor nodes for data transmission.

Packets received by Base Station: It is the number of data packets that Base Station receives during the network's lifespan.

Experiment 1

The simulation considers the sensor network field size of 200 m × 200 m consist of 100 homogeneous sensor nodes scattered randomly with an initial energy of 0.2J. The 5% of the cluster heads are considered for simulation. The base station is considered at the centre of the network field i.e. at (100, 100). Here the network for the LEACH and SEP protocol is also considered as homogeneous. Table 2 shows the comparative readings of the proposed algorithm with other protocol LEACH [2], SEP [12] for residual energy, first node dead, half node dead and all node dead.

Table 2: Performance comparison of three Clustering Algorithms

Parameter	Value
Channel	Wireless Channel
Sensor Network area	200 m × 200 m
Number of sensor node	100 - 500
Number of Clusters	5 - 10%
Initial Energy of node	0.2J
E_{elect}	50 nJ/bit
E_{fs}	10 pJ/bi/m2
E_{mp}	0.0013 pJ/bi/m4
Length of packet	4000 bits
Massage size	500 bit

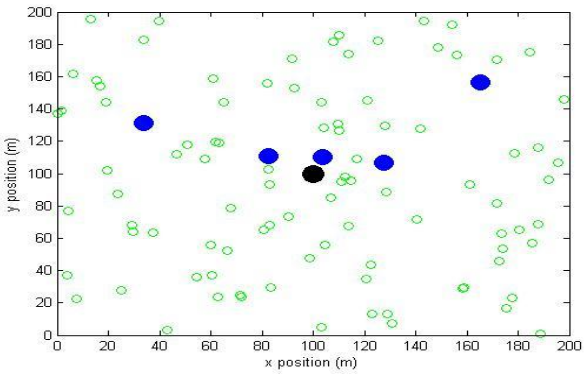

Fig. 2 Sensor Network field with 100 nodes and 5 CHs

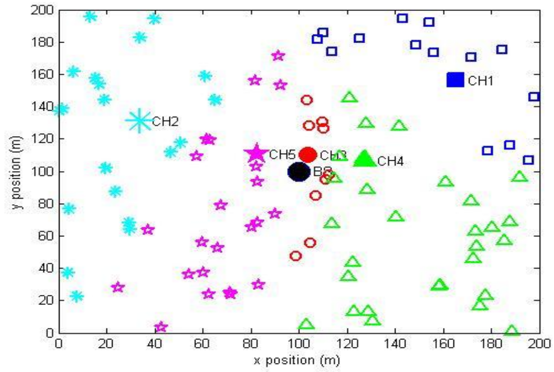

Fig. 3 Clustering of the Sensor nodes

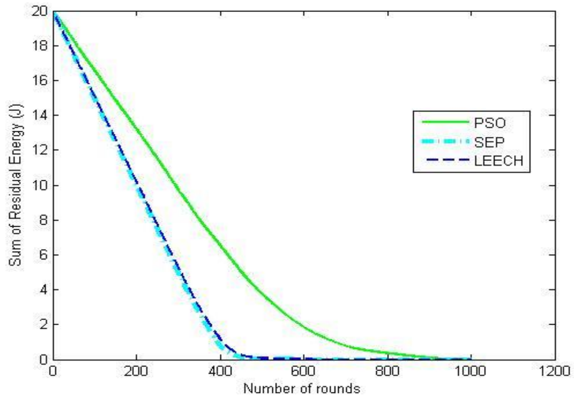

Fig. 4 Sum of Average Residual Energy

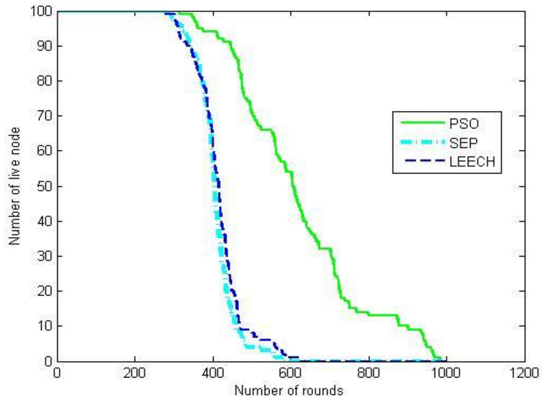

Fig. 5 Live nodes per round

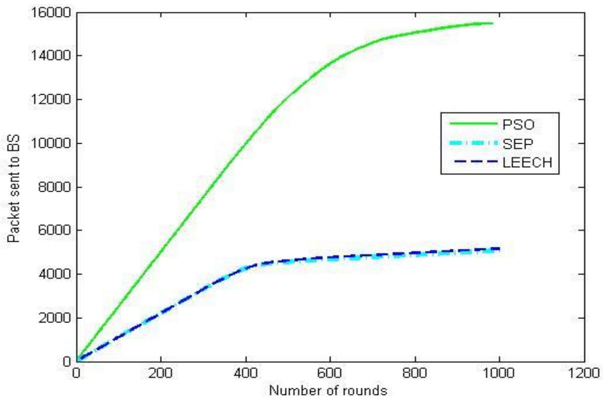

Fig. 6 Packets sent to Base Station per round

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From the figures, it is observed that for the proposed algorithm first node died at 315 and all nodes died at 996 rounds. On the other hand for SEP first node died and all nodes died is at 283 and 596 respectively whereas for the LEACH it is 268, 614 respectively. Thus from the results it is observed that the network lifetime of the proposed algorithm is increased by 62.2% and 67% than LEACH and SEP respectively.

It is also observed that after the 100 rounds residual energy of proposed PSO based algorithm is 33% more than LEACH and SEP. Similarly after the 500 rounds residual energy of proposed PSO based algorithm is 58% more than LEACH and SEP. The main reason for increasing the lifetime of the network for the proposed algorithm is the optimal selection of the CH. The proposed PSO based algorithm selects the cluster heads on the basis of residual energy of sensor nodes. The selection of CH with low energy can hamper the network lifetime. Thus the proposed PSO based algorithm maximized the lifetime of the network by selecting the sensor nodes with higher residual energy as cluster heads. The role of CHs are changed after the each round which ensures the uniform distribution of energy over the network.

Experiment 2

The proposed algorithm has been extensively run under various conditions and scenarios like number of sensor nodes in the field, number of CHs, the position of the base station, constant energy and random energy, etc. The sensor network field size is considered the same i.e. 200 m × 200 m. The LEACH, SEP and proposed PSO based algorithm were executed for 1000 rounds.

Table 3: Performance comparison of three Clustering Algorithms

Algorithm	Number of Nodes and E0	Position of the Base Station	FND	HND	LND
LEACH	100 E0= Random	At the Centre (100, 100)	21	157	520
SEP			13	147	508
Proposed PSO Based			52	218	985
LEACH	200 E0=0.2 J	Right Corner (200, 200)	62	254	537
SEP			73	198	504
Proposed PSO Based			106	593	989
LEACH	400 E0=0.2 J	Left Corner (0, 200)	63	248	566
SEP			71	201	552
Proposed PSO Based			525	768	982
LEACH	500 E0=0.2 J	Out of the field (100, 300)	31	131	324
SEP			42	123	311
Proposed PSO Based			90	197	569

From Table 3, it is clearly observed that the performance of the proposed algorithm improves as the size of network increases and the number of rounds increases. The proposed algorithm works better at high node density and at a large number of rounds.

Experiment 3

In this simulation 200 sensor nodes are scattered randomly over the network with the initial energy of 0.2J. The size of the network is considered the same as in previous experiments. For the comparison of consumption of energy, we executed the algorithms for 400 rounds and the total energy consumed by the sensor nodes in the network is measured at the end of 400 rounds.

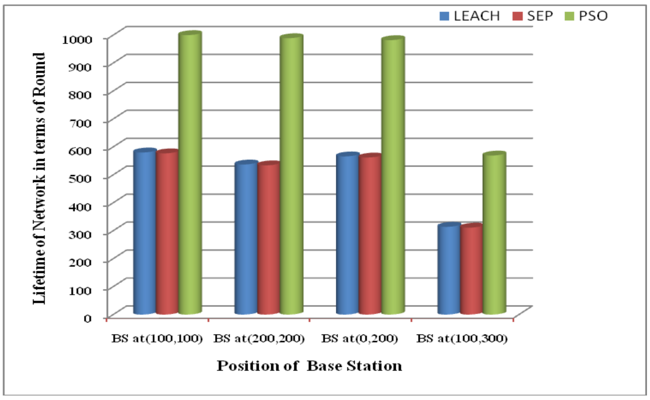

Fig. 7 Lifetime of Network at various positions of BS

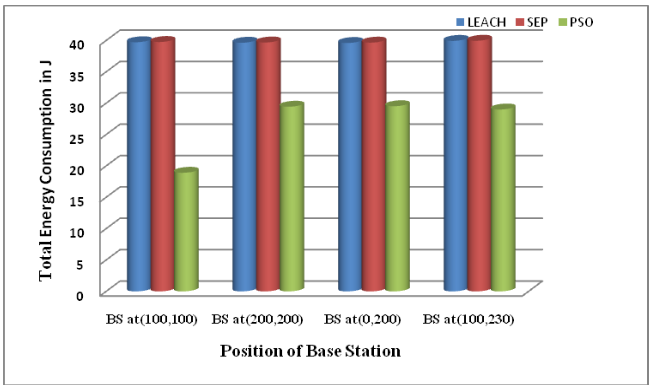

Fig. 8 Total Energy Consumption at various positions of BS

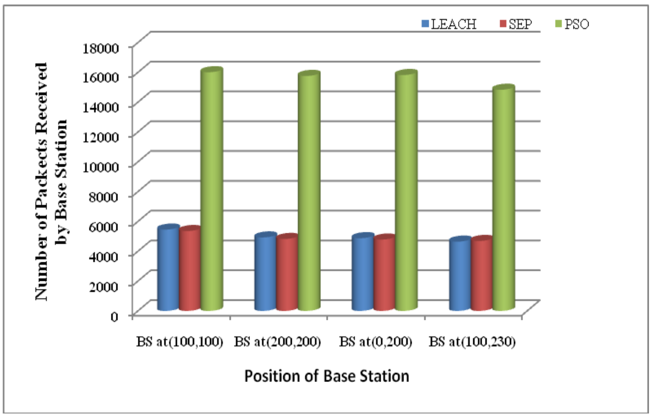

Fig. 9 Packets received by BS at various positions

Fig. 7, 8 and 9 show the comparative results of a network lifetime, consumption of energy of sensor nodes and number of packets received by the base station at the various positions for LEACH, SEP and proposed PSO based algorithms. The performance of the proposed algorithm is examined on the basis of lifetime of network, consumption of energy and number of data packets delivered to the base station and compared with both the existing LEACH and SEP protocol. From the simulation results, it is clearly observed that the proposed algorithm outperforms both LEACH and SEP protocols in terms of network lifetime, consumption of energy and the number of data packets delivered to the base station. It is possible with the proposed algorithm because the algorithm selects the cluster heads which are nearer to sensor nodes as well as base station, which minimizes the transmission distance and hence there is reduction in the power consumption. It is observed from the results that the lifetime of network of the proposed algorithm is more when the BS is placed at the centre of the network field and it decreases as the BS is placed at the corner or out of the network field.

VI. CONCLUSION

The challenging issues in the development of WSNs are proper energy utilization of sensor nodes and the lifetime of network. Therefore for minimization of consumption of energy and prolongation of lifetime of network, we have proposed the PSO-based optimal cluster head selection algorithm in which the CHs are selected on the basis of residual energy, inter-cluster distance, and intra-cluster distance of the sensor nodes. The proposed algorithm is implemented with effective scheme of particle encoding and fitness function. The proposed algorithm is also ensure the uniform distribution of the energy over network, by changing the role of CHs after each round. We extend our research to cluster formation approach where the sensor nodes are joined to the CHs on the basis of energy and distance from the cluster head. The proposed algorithm has been extensively run under various conditions and scenarios like number of sensor nodes in the field, number of cluster head, the position of the base station, constant energy and random energy, etc. For the performance comparison of proposed algorithm, LEACH and SEP algorithms, we have considered the measures like first node dead, half node dead and last node dead. From the results it is observed that the improvement in first node dead for proposed algorithm is from 70% to 700% compared to LEACH and SEP algorithms. Similarly there is 38% to 209% and 73% to 89% improvement in half node dead and last node dead respectively. The experimental results show that the proposed PSO based Optimal cluster head selection and clustering algorithm outperforms under all conditions as compared to the existing LEACH and SEP protocols in terms of average residual energy, the network lifetime and number of data packets received by the base station.

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