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Particle Swarm Optimization-Based Routing Protocol for Clustered Heterogeneous Sensor Networks with Mobile Sink

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ABSTRACT

In Wireless Sensor Networks (WSN) sensor nodes with sensing, computing and communication infrastructure are randomly deployed and organized as clusters. Most of the existing sensor networks focus on homogeneous in which the cluster heads are changed periodically. To improve the lifetime of energy constraint battery powered WSN and to avoid energy sink-hole problem; Clustered Heterogeneous Sensor Networks (HSN) are analyzed with mobile sink. Our proposed method combines load balanced clustering, transmission power control over normal nodes present in the cluster and mobile sink over HSN. PSO is used to find the optimal path for mobile sink to collect data from cluster heads. The experimental results show that the proposed system has lower energy consumption and improved lifetime over static sink, without load balancing and power control approaches. The optimal path algorithm based on PSO is more robust and easy to reach the solution for real world environmental monitoring and data aggregation problems.

Keywords: Heterogeneous Sensor Networks, Clustering, Mobile Sink, Power Control, PSO

1. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of large number of nodes, having sensing, computation and wireless communication capabilities. WSN consist of large number of tiny sensor nodes, which are usually operated by battery and are unattended after deployment. Sensor nodes life time depends on the life time of battery power (energy). Hence battery power (energy) utilization is a critical issue in WSN. WSN is an emerging technology and have wide range of applications, such as environment monitoring, home and assisted living medical care, industrial automation, agriculture, vehicle monitoring, animal tracking, habitat monitoring and numerous military applications, (Chong and Kumar, 2003; Zhao and Guibas, 2004). They also collect information from the environment, where they deployed and reports to the remote base station.

Normally stationary sink is used in WSN and is more energy efficient when compared to the nodes present in the network. Each sensor node communicates wirelessly with a few other local nodes within its radio communication range. The existing homogeneous wireless sensor networks have sensors with equal capacity and hence they become application specific. In this study, heterogeneous sensor network is analyzed, which consists of different compositions of sensors with different capabilities such as collection of image data, collection of audio signal. The clustering method is used for communication between nodes and sink, since it is energy efficient when compare to single and multi hop routing. The cost of transmitting a bit is higher than a computation (Chong and Kumar, 2003) and hence it is advantageous to organize the sensors into clusters. In clustering, one of the sensor nodes in the cluster will be elected as Cluster Head (CH) and which is responsible

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for relaying data from each sensor to the remote receiver. In addition, data fusion and data compression can occur in the cluster head by considering the potential correlation among data from neighboring sensors. This clustering approach is preferred because it localizes traffic and can potentially be more scalable (Bandyopadhyay and Coyle, 2003; Karl and Wilig, 2005; Santi, 2005; Wei and Chan, 2005).

In HSN there is no need of cluster head selection algorithm and network life time can be increased by reducing the energy consumption for communication and load balancing (Gupta and Younis, 2003). In the large scale HSN, as the sink is far away from the sensor nodes, each node needs more energy to send the data. The energy consumption of nodes in HSN can be reduced by introducing mobile sink. In this study, the network life time is increased by:

- Clustering of nodes
- Performing load balancing over clustering
- Applying adaptive transmission power control over sensors in clustered load balanced HSN
- Applying adaptive transmission power control over sensors in clustered load balanced HSN, Instead of static sink, mobile sink is introduced, which could improve coverage and localization
- PSO is used to determine the optimal path

1.1. Related Work

Wireless sensor networks have gained increasing attention from both the research community and actual users. Many clustering algorithms in various contexts have also been proposed in the past by (Baker and Ephremides, 1981; Das and Bharghavan, 1997; Lin and Gerla, 1997; Amis and Prakash, 2000; Heinzelman *et al*., 2000; Chiasserini *et al*., 2002; McDonald and Znati, 1999; Gerla and Tsai, 1995; Basagni, 1999a; 1999b; Chatterjee *et al*., 2002; Amis *et al*., 2000). Many of these algorithms aim at minimizing the energy spent in the homogeneous system.

Mhatre and Rosenberg (2004) gives guidelines about the modes of propagation, clustering and battery energy of normal and CH nodes. Cheng and Shi (2009) analyzed the heterogeneity with new clustering algorithm which decides the cluster head according to the node energy. CH selection algorithm was needed as LEACH. Hur and Kim (2008) explains about adaptive clustering and power control for homogeneous sensor networks. A survey on energy efficient scheduling mechanisms for WSN is given by (Wang and Xiao, 2005).

Yin *et al*. (2007) presents energy consumption analysis over clustering and it was concluded that optimum transmission range was necessary to make network active and compatible. Jayashree *et al*. (2006) proposed load balancing over heterogeneous sensor networks and stability of the network was analyzed.

Gao *et al*. (2010) have studied power control in WSN by changing the network topology to optimize network routing through adjusting transmission power. Lin *et al*. (2006) addresses the issue of feedback based transmission power control algorithm to dynamically maintain individual link quality over time. Kawadia and Kumar (2005) have studied power control over Ad-hoc networks.

Also most of the WSN systems adapt network level transmission power control. Most of the approaches are used for homogeneous non cluster WSN systems. In many practical applications of WSN, the mobile sink tends to move around within the sensor fields and receive data (Ye *et al*., 2002; Hamida and Chelius, 2008). Tracking and data delivery to sink node is discussed in Oh *et al*. (2010). Constructing a proper routing takes a very important role in homogeneous sensor networks, which periodically changes cluster heads. The different network topologies with mobile sink is analyzed in Yang *et al*. (2010).

Al-Karaki and Kamal (2004) addresses different routing techniques for WSN. Ammari and Das (2008) analyzed heterogeneity mobility and mobile sink in homogeneous using veronoi diagram. Yang *et al*. (2010) introduced mobile sink instead of static sink and it was compared with two different topologies.

2. MATERIALS AND METHODS

2.1. Contribution and Organization

- Energy utilization is a very critical issue in WSN. In this work, energy efficiency is obtained by considering two different sensors (Heterogeneous in terms of energy) in the network. Compared to flat and multi hop communication cluster based architecture provides long life time, hence it is preferred. In homogeneous, CH selection algorithm is needed to select CH periodically, which in turn increases the overhead. In this system CH are fixed
- If few CH nodes are heavily loaded, will consume their energy soon. To get uniform energy depletion, load balancing (equal number of nodes to each cluster) is introduced over clusters

- To send data to the cluster heads low energy sensors (normal nodes) adjust their communication ranges according to the distance with its corresponding CHs (Adaptive Transmission Power is introduced)
- Frequent re-clustering, long distance communication from CH nodes to farthest located static sink, which in turn increase the energy consumption. To avoid energy whole problem and to prolong the network life time mobile sink is introduced. Mobile sink travels through the CHs and collect data from them with sojourn time. Communication is taken over single shared channel using TDMA which prevents radio interference and reduces energy consumption
- PSO is used to find the shortest path between the CHs through which sink travels, hence neighbours of sink changes which avoids energy hole as well as CH life time gets increased hence network life time
- Hence energy efficiency of CH nodes and normal nodes present in the clusters gets increased

2.2. Network and Energy Models

Assume uniformly deployed sensor nodes (Low energy and High energy nodes) within a LxL area with node density d. After deployment, nodes are unattended. Both the L-nodes and H-nodes are stationary and uses single hop communication to sink. The battery energy of L and H- nodes are E_0 and E_1 respectively. H-nodes are less energy constraint.

2.3. Energy Model

Energy consumption in WSN is mainly divided into two parts, based on energy consumption for processing, computation and transmission of collected data. The energy required for data transmission will be more compared to data collection. The power dissipation of radio module is given by Equation 1and 2:

$$E_{tx}(k,d) = E_{elc}(k) + E_{amp}(k,d) = kE_{elc} + k\varepsilon_{fr}d^2 \quad d \le d_0 \tag{1}$$

$$= kE_{elc} + k\varepsilon_{fr}d^4 \quad d > d_0 \qquad E_{rx}(k) = kE_{elc} \tag{2}$$

E_{elc} is the electronics energy. E_{amp} is the amplifier energy, depending on the distance to the receiver. As the distance between sources to sink plays a major role in energy consumption, the sensor nodes that transmit data over a long distance will drain energy soon. Reducing the node transmission radius will lead to less energy consumption (Mhatre and Rosenberg, 2004).

2.4. Radio Model

The two ray ground propagation model is used for communication. The minimum transmission power of sending node P_{min} is given by Equation 3:

$$P_{min} = \frac{P_t P_{thr}}{P_r} \tag{3}$$

P_{thr} is the minimal threshold power of received signal.

2.5. Heterogeneous Sensor Network Model

Clustering is one of the most important approaches used in WSN to save energy. Heterogeneous Sensor Network (HSN) modeled by both Low (L) as well as High (H) Energy sensors are distributed uniformly and randomly in the environment. The powerful H sensors form clusters around them and act as cluster heads, since CH nodes are predetermined. The cluster formation is depicted in **Fig. 1**, consists of L sensors, H sensors and the Base Station (BS). H sensors provide longer transmission range, higher data rate than L sensors and also facilitates better protocols, algorithms and secure schemes in sensor networks.

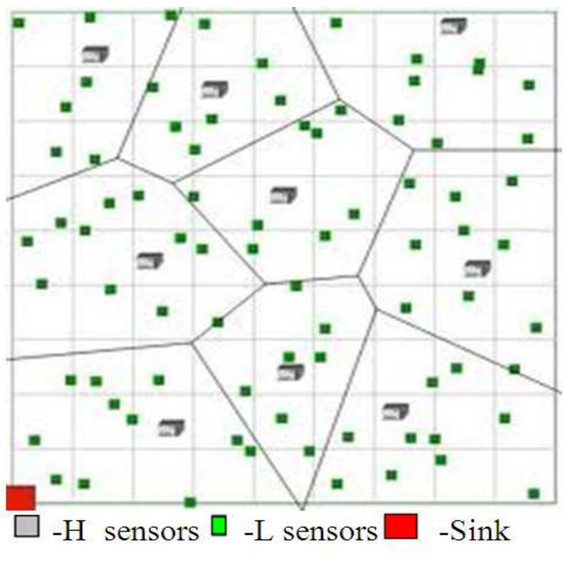

Fig. 1. Heterogeneous sensor network formation

As an efficient and robust cluster formation scheme is adopted in HSN the sensor nodes provide coverage of the region with a high probability (Amis and Prakash, 2000). Cluster heads are responsible for data aggregation and transmission of the aggregated data to a base station.

2.6. Energy Model of HSN

In this model number of L nodes and H nodes are fixed that is ten percentage of population of node is act as H nodes and equipped with additional battery energy. H-nodes have higher software and hardware complexity. Direct communication is taken place between L-nodes to the concerned H-node. In multi hop communication, if any node expires the network loses connectivity. But in the proposed system, if any of the nodes in the cluster dies it does not affect the network operation. The total energy consumption of heterogeneous sensor networks is obtained by combining the energy consumed by cluster heads and non cluster heads. The total energy consumed by heterogeneous sensor networks (Mhatre and Rosenberg, 2004) is given by Equation 4-12:

$$E_T = E_{HE} + E_{LE} \tag{4}$$

$$E_{HE} = T\left(\tfrac{L}{H}\left(l_1 + E_f\right) + \left(l_2 + \mu_2 d^4\right)\right) \tag{5}$$

$$E_{LE} = T\left(l_1 + \frac{\mu_1 A^2}{H}\right) \tag{6}$$

Where:

E_f = The computational energy spent on fusion of each packet
l_1 = The amount of energy spent in the transmitter electronics circuitry within a cluster
l_2 = The amount of energy spent in the transmitter electronics circuitry from the cluster head to the base station
μ_1 = The energy spent in the RF amplifier within the cluster
μ_2 = The energy spent in the RF amplifier from the cluster head to the base station
A = The radius of the region
T = The data gathering cycles
n_0 = The number of low energy nodes
n_1 = The number of high energy nodes
$\frac{A}{\sqrt{n_1}}$ = The radius of the cluster region

2.7. Load Balancing Over Clustering

Main objective of this study is to reduce energy consumption hence it gives increased life time. Load balanced clustering gives uniform energy depletion of all nodes present in the network by making communication with closer nodes by balancing load among the H sensors.

In a hierarchical sensor network, the H nodes transmit hello packets to all the nodes and the nodes in turn acknowledge (it consist of node locations) the receipt of it. Upon receipt of acknowledgment all H sensors compares the distance between itself to L sensors with the threshold distance. All Clusters are formed on the basis of shortest distance between H and L nodes:

$$\begin{aligned} &D_{LH} = \sqrt{\left(H_i(x,y) - L_j(x,y)\right)^2} \\ &\text{where i -1,2,3,...10\%of total nodes} \\ &\text{where j -1,2,3,...90\%of total nodes} \\ &D_{LH} < D_{th} \end{aligned} \tag{7}$$

It will be linked with particular H node else it is omitted until the counter associated with each H node reaches zero:

Algorithm: CH advertisement

H sensors announcement
L Sensors acknowledgment
Set counter value to (N/H)-1 for all H nodes
IF H sensors receives *ack* with in a stipulated period (to avoid collisions TDMA is used)
It calculates distance between itself to all L sensors one by one and compares it with threshold distance
IF the calculated distance is less than threshold distance,
Decrement the counter value
ELSE
Do not change the counter value
IF Counter value is zero
Stop comparing
END IF
END IF
Load balanced Clusters are formed, corresponding H sensors will give further details to thbe corresponding members.
END IF.

Figure 2 explains about the procedure involved in getting load balancing over HSN.

2.8. Adaptive Transmission Power Level Based Communication

Initially all L nodes use the maximum transmission radius and power to communicate. All nodes in the network use its maximum communication range.

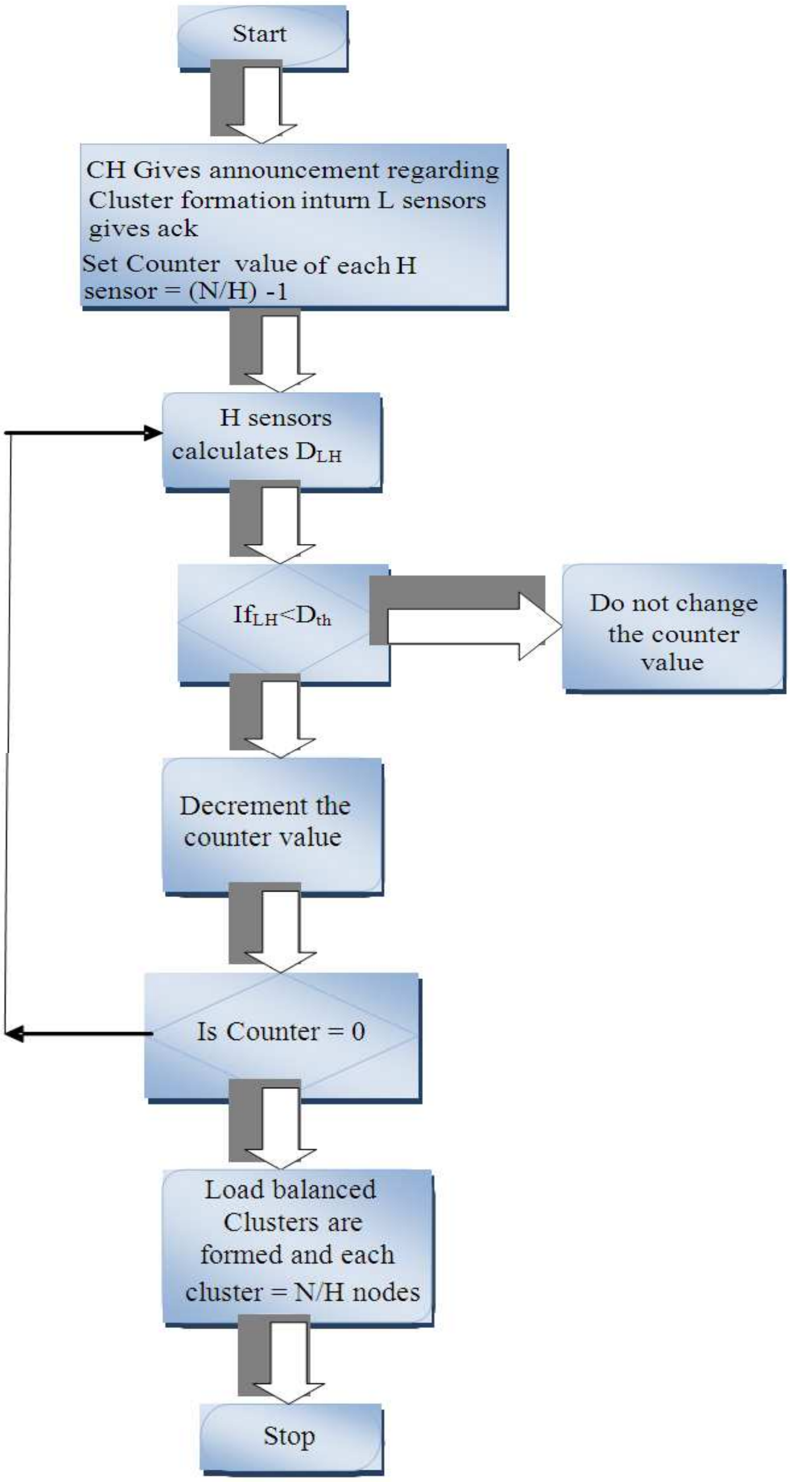

Fig. 2. Flow chart for load balancing over clustering

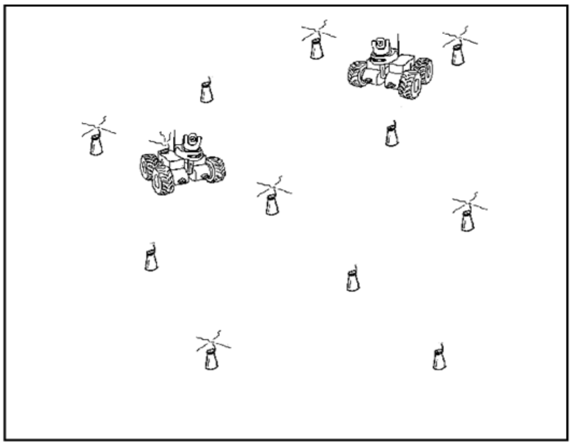

Fig. 3. HSN with mobile sink

Table 1. Various transmission ranges and corresponding power levels

Pt (mW)	Transmission range (m)
281.8	250
225	200
169	150
112	100
56	50
28	25

As a result of node distribution maximum transmission radius is usually longer than the distance between CH nodes and L nodes present with the clusters, which causes the waste of energy. To save energy, an L node adjusts its transmission radius to reach the corresponding CH alone. Initial transmission range of all nodes is to be R. After cluster formation all L sensors reduces its transmission range according to the radius of cluster it belongs to, it is to be r, where r<R.

Mapping **Table 1** shows the distance between L and H nodes and the corresponding transmission power level.

2.9. Sink Mobility

Sensor nodes which are far away from the sink relay their data using maximum transmission power level, hence nodes loses its energy soon. Introducing mobile sink will increase the lifetime and avoids sink whole problem,the HSN with mobile sink is shown in **Fig. 3**. Initially Random way point mobility model is assumed and speed of mobile sink to be '*v*'. Locally sensed data is buffered at each cluster and sink collects the data from the subset of nodes (CH nodes) only. The aggregated data is buffered at the H-sensors until the sink enters its contact area. The procedure to collect data by mobile sink is:

- Sink transmits hello packets to all CHs
- All CHs registers with sink with in a defined period
- Sink travels through the definite path calculated by shortest path routing and PSO
- When it enters the CH vicinity it gives beacon message
- CH transmits buffered data to sink after receiving message
- Sink travels and collects the data within the sojourn time

2.10. Energy Model

Total energy of the network is equal to sum of the energy of H-sensors for data aggregation and transmission of the data to sink and energy spent by sink to collect data from all H-sensors and sink movement energy. Energy of cluster head is:

$$E(H_i) = \text{area of each cluster} \times \text{number of nodes in the cluster} = \pi r^2 \times \frac{N}{H} \tag{8}$$

$$S_e = \sum_{k \in C_i} Tl_k \tag{9}$$

$$\text{Totalenergy} = E(H_i) + S_e \tag{10}$$

- l_k is an integer variable which represents the number of times when the sink is located at node k,. $k \in C_i$ at time T
- C_i is the possible set of cluster heads
- T is the sojourn time in which the sink has to collect data from all CHs and it includes the travelling and waiting time also

2.11. Particle Swarm Optimization (PSO)

Different routing techniques have been proposed in the literature for the mobile nodes, they are proactive, reactive and flooding schemes. In the above methods link breaks occur because of node mobility, hence route discovery becomes an energy consuming issue due to overhead. Simultaneously mobility increases more chances of energy degradation; hence efficient methods are needed for routing (Jung *et al*., 2011).

In this study two different routing methods have been implemented and compared in an effective manner. The methods are:

- Shortest path routing
- PSO based routing

In the shortest path routing mobile sink finds the nearer CH with respect to its present position, through which it travels and collects the data from high energy nodes only.

PSO is a bio-inspired (Kennedy and Eberhart, 1995) computational method, which is a population based optimization technique which performs a parallel search on a solution space. Optimum solution is obtained from the set of randomly generated initial solutions by moving particles around in the search space, which finds the optimum solution by swarms following the best particle. Each particle has particular velocity and position, at each iteration a new velocity value is calculated and it is used to update the particle's position. The process iterates until reaching a stopping condition (optimum one).

In the classical PSO algorithm:

- Each particle has a position and a velocity
- Knows its own position and the value associated with it
- Knows the best position(pbest) it has ever achieved and the value associated with it
- Knows its neighbors, their best positions(gbest) and their values

The move of a particle is a composite of three possible choices (Onwubolu and Clerc, 2004):

- To follow its own way
- To go back to its best previous position
- To go towards its best neighbor's previous or present position

A general framework of a particle swarm optimization algorithm is given below:

Algorithm:
procedure PSO
Initialize a population of particles
Do
for each particle p with position xp do
if (x_p is better than $pbest_p$) then
$pbest_p \leftarrow x_p$
end_if
end_for
Define $gbest_p$ as the best position found so far by any of p's neighbors
for each particle p do
$v_p \leftarrow$ Compute_velocity(x_p, $pbest_p$, $gbest_p$)
$x_p \leftarrow$ update_ position(x_p, v_p)
end_for
while (a stop criterion is not satisfied):

$$v_p(t) = v_p(t-1) + c_1 rand_1 (pbest_p(t-1) - x_p(t-1)) + c_2 rand_2 (gbest_p(t-1) - x_p(t-1)) \quad (11)$$

$$x_p(t) = x_p(t-1) + v_p(t) \quad (12)$$

The algorithm to find the shortest path has been taken from Niasar *et al*. (2009).

3. RESULTS AND DISCUSSION

3.1. Simulation Environment

Network simulator ns-2 is used for simulation. Two ray ground reflection model is used and 100 nodes are uniformly spread in a square region with a dimension of 200×200 m, out of which 10% are H nodes.parameters used in the simulation are given in **Table 2**. Initially less energy constraint sink is located far away from the network area.

As the residual energy of HSN with ATPC is more compared to the HSN as shown in **Fig. 4**, the life time of HSN with ATPC is longer compared to HSN. Simulation is carried out for calculating energy consumption by varying the number of L nodes. The plot of the number of L nodes Vs energy consumption is shown in **Fig. 5**. It shows that the energy consumed by HSN with ATPC is less when compared to HSN. Hence optimization of life time as well as energy consumption is achieved in the case of HSN with ATPC. Application of Load balancing leads to more residual energy than HSN with ATPC. When more packetes are transmitted the energy is saved, hence life time is also increased is shown in **Fig. 6 and Fig. 7** shows the comparison graph for residual energy in HSN with mobile sink and without mobile sink.

The sink covers a distance of 685 m in the coverage area by the HSN nodes to cover the entire H nodes using shortest path method and it travels a distance of 432 m only using PSO (**Table 3 and 4**). During the sink movement the transmission energy of nodes will be minimum and the mobility factor will have very less impact because the speed of mobile sink is to be 4 m sec^{-1}. Thus the energy consumption by sink is minimum when compared to the static sink and it collects data from all nodes in a periodic manner.

When speed of the mobile sink increases, the round trip time gtes reduced, hence loss of data occurs. Frequent retransmission are needed by all CHs, energy consumption gets increased. So,optimum speed is requied to collect data without loss, hence 4 m sec^{-1} is fixed as speed of sink.

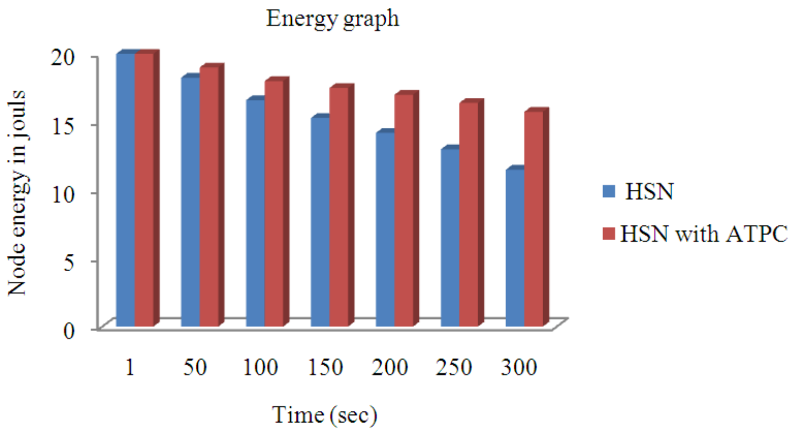

Fig. 4. Comparison graph of Energy depletion rate

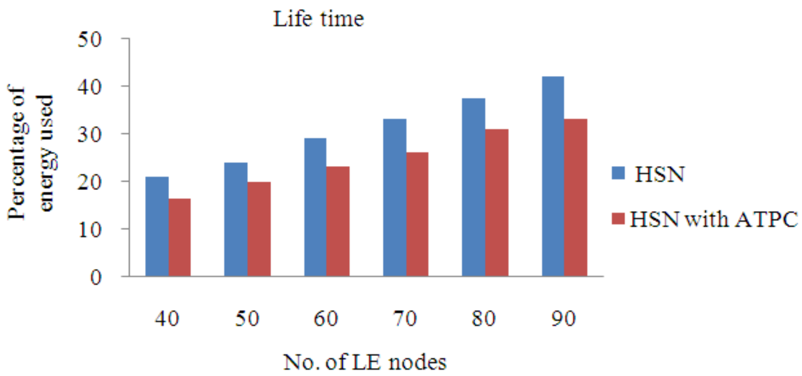

Fig. 5. Network Life time

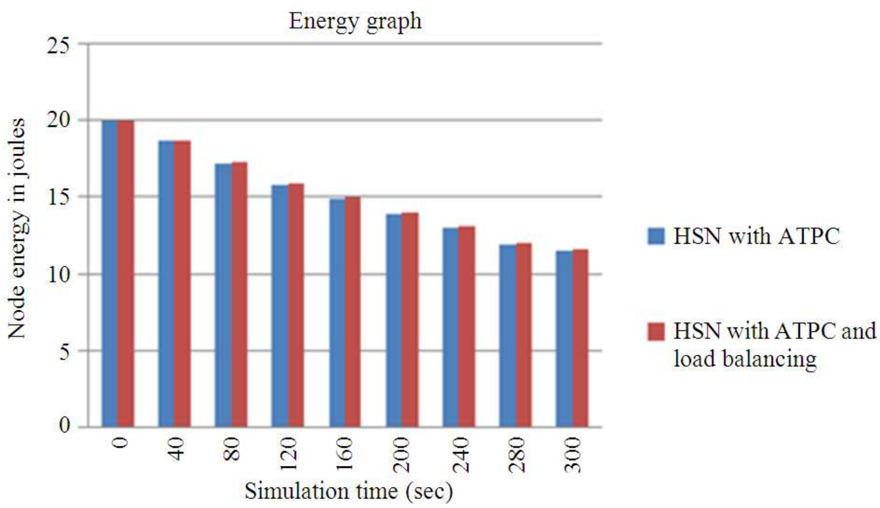

Fig. 6. Residual Energy comparison graph of HSN with ATPC and load balancing and HSN with ATPC only

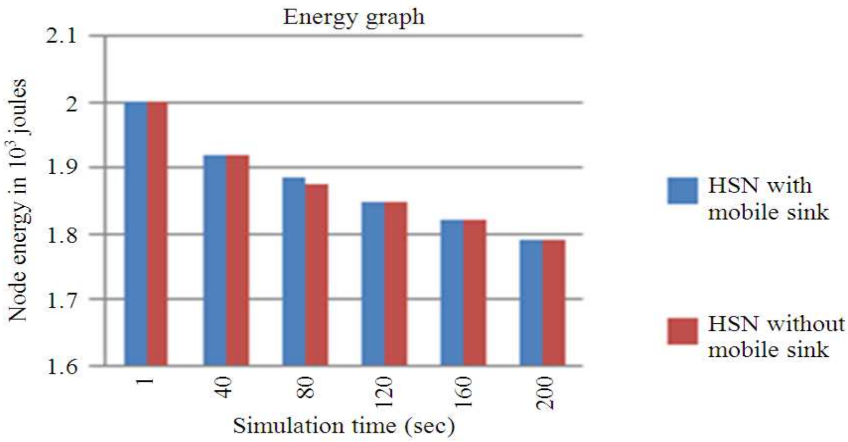

Fig. 7. Comparison graph for residual energy in HSN with mobile sink and without mobile sink

Table 2. Parameters used in the simulation

Parameter	Value
Size of field	200×200 m^2
Total no. of nodes	101
Distribution type	Random distribution
Propagation model	Two ray ground propagation model
Traffic load	Constant bit rate
Length of data packet	200 bytes
Initial communication Range (R)	200m
Initial energy of H sensors	20 J
Initial Energy of L sensors	10 J
Energy to transmit a packet	0.264
Energy to receive a packet	0.158

Table 3. Comparision table for travelled transmission distance by two proposed methods

Proposed Method	Transmission distance (m)
Shortest path method	685
PSO	432

Table 4. Gives the relation between speed of mobile sink Vs time period by which it completes one trip distance

Speed (m/s)	PSO (distance in m)	Shortest (distance in m)
2	219.18460	342.62480
4	109.59230	171.31240
6	73.06153	114.20830
8	54.79615	85.65620
10	43.83692	68.52496

4. CONCLUSION

Heterogeneous sensor network with ATPC is implemented and compared with heterogeneous sensor network with non ATPC for energy consumption and network life time. H sensors have longer transmission range, hence number of hops to reach receiver is reduced at the same time L sensors reduces its transmission range and thus energy optimization is obtained. The life time maximization is done by introducing mobile sink and it follows the optimum path which is found by PSO. The proposed method over load balanced, adaptive transmission power control HSN, the mobile sink travels a distance 1.5 times shorter than shortest path method. Hence mobile sink life time also gets increased, simultaneously HSN life time.

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