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Mobile Sink Nodes for Energy Efficient Wireless Sensor Networks using Gravitational Search Algorithm

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ABSTRACT

A novel method of data aggregation mechanism using mobile sink nodes in Wireless Sensor Network (WSN) is proposed to improve the lifetime of the sensor nodes. The sink nodes are used in WSNs to gather the sensed data from the Cluster Heads; those are located far from the Base Station. Network lifetime is improved with the help of sink nodes by eliminating the overload of Cluster Heads. In the proposed work, nodes are allowed to form as clusters and no Cluster Head election is being done. Whereas, the operation of Cluster Heads is being taken care by the newly added mobile sink nodes to perform gathering the sensed data, aggregating it and communication operations. This results in improved lifetime of the sensor nodes. Gravitational Search Algorithm (GSA) is an optimization algorithm which is used for cluster formation and routing the data to achieve better throughput and network lifetime. Network Simulator too is used to simulate the existing as well as the proposed system. Results are compared for the proposed system of Mobile Aggregator Sink Nodes with the existing system in terms of packet delivery ratio, total energy consumption, control overhead and throughput. The results shows better performance of the proposed system and is discussed.

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INTRODUCTION

Wireless Sensor Network (WSN) belongs to Low Range Wireless Personal Area Network (LR-WPAN) (Sabitha and Thyagarajan, 2009). It consists of hundred to thousand sensor nodes in the sensing region. These sensors are capable of sensing, computing and communication. WSN gets its popularity, because of various attractive characteristics of sensor nodes. The characteristics of sensor nodes are: robustness, reliability, flexibility, adaptability, tiny, low cost, less weight, self configuring and can withstand in any harsh environment. This makes the sensor nodes to be applied in various real-time applications including (1) health monitoring of patients in hospitals, (2) habitat monitoring, (3) environmental monitoring, (4) structural monitoring, (5) military applications etc.

Sensor nodes in the sensing region can be stationary nodes or mobile nodes based on the application. These sensor nodes can be placed manually in a pre-defined position or can be scattered randomly over the sensing region using helicopter. As each sensor node is equipped with a limited battery, proper handling of such sensors always plays a vital role for enhancing the network lifetime. Clustering method of data aggregation and transmission improves the network lifetime. Many cluster based protocols have been developed for achieving the same. In clustering method, sensor nodes are allowed to form into many groups called clusters and a Cluster Head (CH) is elected for each cluster. These CHs gather the sensed data from the respective cluster nodes for performing data aggregation. Data Aggregation is the process of finding the average, maximum, minimum value etc. from the cluster nodes. This process eliminates the data redundancies and a single data is being transmitted to the sink node or Base Station (BS).

LEACH (Low Energy Adaptive Clustering Hierarchy) (Lindsy and Raghavendra, 2002) is the first cluster based protocol. It has two phases namely: setup phase and steady state phase. In setup phase, clusters are formed and Cluster Heads are elected and in steady state phase data is transmitted (Lindsy and Raghavendra, 2002). In LEACH, Cluster Head election takes place in random manner. Each node in a cluster gets a chance to become Cluster Head. This results, in maintaining an average energy level of all nodes (Abbasai and Younis, 2007) (Heinzelman *et al*, 2000). The election of Cluster Head in LEACH is based on the probability function. Here, all

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nodes are allowed to select a random number in between 0 and 1. Then the threshold value T (n) is calculated using the formula,

$$T(n) = \begin{cases} P/[1-P(r \bmod 1/P)] & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

If the selected value is less than T (n), then the corresponding node becomes the Cluster Head for that particular round (Mihail *et al*, 2005). From Eq. 1, the value of P is the desired % of Cluster Head (CH), r is the current round and *G* is the set of nodes not as CH in 1/P rounds. Using threshold, each node becomes a CH in 1/P rounds.

PEGASIS (Power-Efficient GAthering in Sensor Information Systems) is an improved version of LEACH (Lindsy and Raghavendra, 2002). PEGASIS is a chain based protocol in which, the nodes those are far from the BS initiates the chain formation. It allows a single node to start the chain formation for transmitting the data to BS. This protocol eliminates the cluster formation, as the chain initialization takes place by a single node (Akkaya and Younis, 2005).

In clustering, the CHs those are farthest from the BS can either transmit the aggregated data directly to the BS or can forward it to the neighbor node until it reaches the BS. Probability of occurrence of failure such CHs in former case is more when compared to the later one. In the later case also, the energy consumption of the exit node (node nearer to the BS) is higher, as it acts as a forwarding node. This leads to an early node failure for the exit node. This drawback can be overcome by introducing mobile sink nodes in the sensing region (Suganthi *et al*, 2011). The role of such sink is to move around the network to collect the aggregated data from the farthest CHs. This reduces the energy consumption of CHs, by avoiding the long distance communication. The lifetime of battery in the sensor node is inversely proportional to the communication distance (Mihail *et al*, 2005). So it is always necessary to choose the next hop with a minimum distance (d_{min}) for transmitting the data to the Base Station.

The Mobile Robots (MRs) (Tzung *et al*, 2011) are used in the sensing region to collect the data from the partitioned nodes which are not able to communicate with other nodes. These methods motivated to further extend the lifetime of sensor nodes by applying the concepts of mobile sink nodes in the sensing region. In this proposed approach, sink nodes are allowed to perform computation and also communication operations with fewer modifications are proposed.

In this paper, a hierarchical level of clustering mechanism is considered. Nodes are allowed to form as clusters and no Cluster Head election takes place. Mobile Aggregator Sink (MAS) nodes are introduced in the sensing region. The purpose of MAS is to perform data processing (called data aggregation) and communication (called transmission and reception) operations. In the proposed approach, all sensor nodes are allowed to perform sensing and communication to the nearby MAS node. Gravitational Search Algorithm (GSA) is used for cluster formation and routing. The introduced Mobile Aggregator Sink nodes are highly powered nodes which are non stationary nodes. These nodes are similar to that of the sink node outside the sensing region. The functions of MAS are to collect the sensed data from cluster nodes, aggregate it and transmit to the Base Station.

The rest of this paper is organized as follows: In section II, work related to the sink nodes and mobile robots are discussed. In section III, proposed work with design considerations with Gravitational Search Algorithm is described in detail. Simulation Results are discussed in sections IV and Conclusion with future enhancement are discussed in section V.

Related work:

A protocol or a model which is developed for routing or aggregating the data in sensor networks should be energy efficient in such a manner to improve the lifetime of the sensor nodes. Clustering way of data aggregation and transmission reduces the energy consumption when compared to the traditional data transmission model (one hop model and multi hop model) (Anahit, 2008). Research is being carried out to further increase the lifetime of the network. Two methods related to the proposed work are briefly described below.

A. Mobile Robot (MR) in Wireless Sensor Networks:

In a hierarchical method of sensor networks, when a parent node dies, children nodes belong to that particular parent are separated. This leads to island/partitioned node formation in the sensing region, as those children nodes are unable to communicate with the other parents or to the BS (Gu *et al*, 2005). Sensed data from those nodes are wasted due to communication failure, even though they may have some useful data. This problem can be overcome by using Mobile Robot (MR) (Tzung *et al*, 2011). These Mobile Robots move around the region to collect the sensed data from those islands. This improves the data gathering mechanisms in WSN. To find the location of those sensor nodes, two control approaches are used namely global approach and local approach (Tzung *et al*, 2011). And three scheduling schemes like time based, location based and dynamic moving based schemes are used for navigation.

B. Mobile Sink Nodes in Wireless Sensor Networks:

The energy consumption of a sensor node for the communication (transmission and reception) process is more when compared to computation (aggregation) (Esmat, 2009). Cluster Heads are those are far from the Base Station having only its own data to transmit. But the Cluster Head nearer to the Base Station has to forward all Cluster Heads data to the Base Station. It leads to early node failure of such Cluster Heads (Suganthi *et al*, 2011). This can be overcome by introducing the mobile sinks in the WSN to avoid such Cluster Heads failure. Such mobile sink nodes move around the network either in linear or circular or in rotation basis to collect the data from the farthest Cluster Heads. The Cluster Heads can transmit the aggregated data to the nearest available mobile sink using shortest path algorithm by considering the energy level of link and selects the link which consumes minimum energy to route data. So this method eliminates the forwarding mechanism of Cluster Head far from the Base Station.

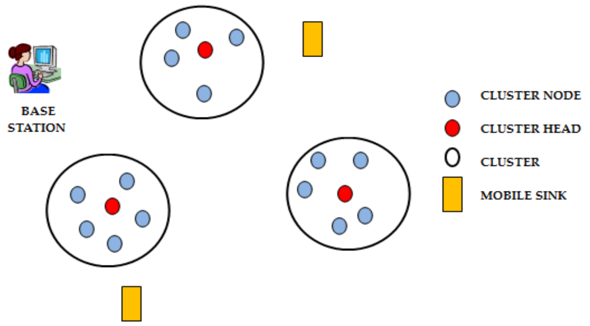

Fig. 1: Mobile Sink nodes in WSN.

Figure 1 shows the clustering scenario in WSN. The network scenario is constructed with the following assumptions: Here, the number of sensor nodes nearer the Base Station is considered lesser than the farthest distance. Mobile Sink Nodes are introduced in the sensing region to collect the aggregated data from the Cluster Heads which are located far from the Base Station. Usage of these sink nodes results in reducing the communication overload of CHs in the existing system and improves the network lifetime. In the above existing techniques (Suganthi *et al*, 2011)(Tzung *et al*, 2011), researches proposed a method to maximize the lifetime of the senor nodes (Tzung *et al*, 2011) as well as improving the data gathering mechanism in WSN (Suganthi *et al*, 2011). In the proposed system, further network lifetime is improved by making the use of Mobile Aggregator Sink Nodes to perform data aggregation operation by eliminating the Cluster Head's role. With the help of Gravitational Search Algorithm, cluster formation is being done based on the fitness value.

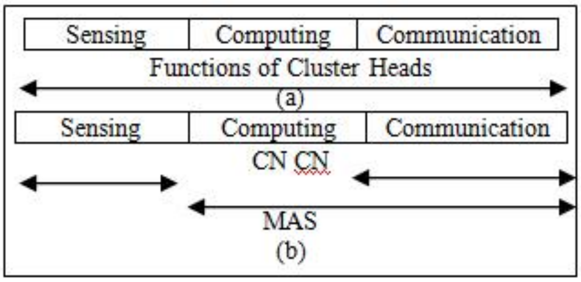

Fig. 2(A): Functions of Cluster Heads in WSN and 2(B). Functions of Cluster Nodes (CN) and Mobile Aggregator Sink (MAS) nodes in WSN.

METHODS AND MATERIALS

In the proposed approach, Gravitational Search Algorithm (GSA) is used. GSA is an optimization algorithm which is applied in the proposed approach for performing cluster formation and routing the data. As the major functions of Cluster Heads in the sensing region are sensing, computation and communication. Due to such huge workload, the CH dies earlier. For improving the network lifetime further, Mobile Aggregator Sink (MAS) nodes are introduced in the sensing region. Here nodes are allowed to form as clusters and no Cluster Head election takes place. The functions of Cluster Heads are taken over by the introduced MAS nodes.

Figure 2(a) shows the operation of CHs in general clustering mechanism and Fig. 2 (b) shows the functions of Cluster Node (CN) and MAS in the proposed approach. In the proposed approach, all sensor nodes are allowed to just sense and communicate to the nearby MAS sink node. The functions of MAS nodes are computation (data aggregation) and communication (transmission and reception) of aggregated data to the Base Station.

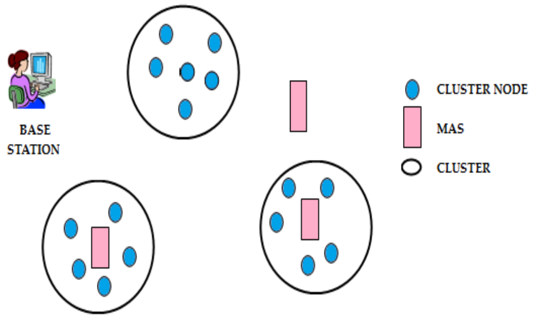

Fig. 3: Mobile Aggregator Sink (MAS) nodes in WSN.

Figure 3 shows the architecture of the proposed WSN model with Mobile Aggregator Sink (MAS) nodes in the sensing region. Nodes are arranged in a hierarchical manner (three levels are considered for hierarchy). The schematic diagram is shown in Fig 4. The introduced mobile aggregator sink nodes keep on rotating in the network. Form Fig.2, the mobile sink nodes can be seen either in between the cluster to gather the sensed data or revolving around to reach the Base Station. Wireless Sensor Network scenario is created in hierarchical manner with the following considerations. Set of nodes which are around 30m distance from the BS are considered to be level 1. Nodes in next 30m as level 2 nodes and another 30m as level 3 nodes. Number of nodes in level 1 is lesser than the number of nodes in level 2 and level 3. Once the nodes are deployed in the sensing region, nodes are allowed to form into group of clusters. Each node updates its own location and communicates it to the BS. Based on the received information, the BS makes MAS to move around the region to collect the cluster nodes data. The reason behind the non Cluster Heads in the proposed approach is, to avoid the early CH nodes failure.

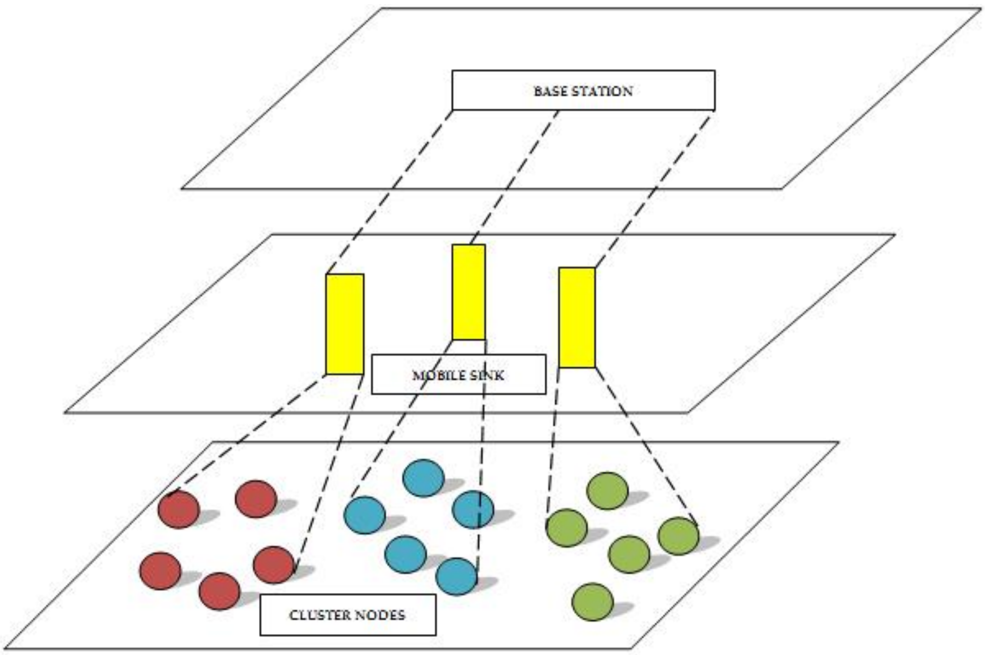

Fig. 4: Hierarchical Level of Data Aggregation and Transmission.

The Mobile Aggregator Sink (MAS) nodes are highly powered nodes similar to the sink nodes or Base Station located away from the sensing region which replaces the CH in the existing method. The purpose of introducing MAS nodes is to reduce the computation and communication capabilities of the sensor nodes act as CHs in the existing approach. In this proposed approach, all sensor nodes play the same role of sensing and transmitting to the nearby available MAS node using Shortest Path Algorithm.

A. Gravitational Search Algorithm (GSA):

Gravitational Search Algorithm is an Optimization algorithm which is based on Newton's Law of Gravity (Holliday and Resnick, 1993). It states that: "*Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of distance between them R^2*".

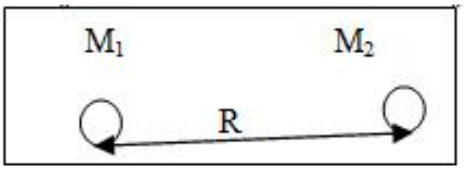

Fig. 5: Newton's Law of Gravity.

Consider that, there are two masses $M_1$and M_2 separated by the distance R which is shown in Fig. 4. By the definition of Newton's Law of Gravity, the Gravitational force (Esmat, 2009) can be given by the Eq. 2.

$$F= G \{M_1M_2/R^2\} \quad (2)$$

where F is the Magnitude of the Gravitational Force, M_1 and M_2 are masses of particle 1 and particle 2 respectively, G is the Gravitational constant ($G = 6.8x10^{-11}\ m^3\ kg^{-1}s^{-2}$) and R is the distance between the two particles. Consider that there are three particles having masses M_1, M_2 and M_3 respectively which is shown in Fig. 6.

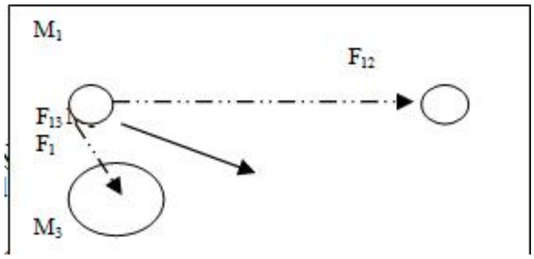

Fig. 6: Forces acting on the masses by Newton's Law of Gravity.

The forces acting on masses M_1, M_2 and M_3 are F_1, F_2 and F_3 respectively. The force acting on masses M_1 by M_2 is represented as F_{12}.The force acting on masses M_1 by M_3 is represented as F_{13} and similarly forces are calculated for all other masses. The force of attraction of mass with a heavier mass is higher than the attraction between smaller masses. In the above diagram, the attraction between M_1 and M_3 is higher when compared to the force of attraction between M_1 and M_2. In the proposed approach, the concept of Gravitational Search Algorithm is applied in the following two phases.

1) *For Cluster Formation Phase and*
2) *Path Establishment Phase for routing the data.*

B. Design Considerations and Cluster Formation Phase:

In the proposed approach, sensor nodes in WSN are arranged in the hierarchical manner. Here nodes are formed into group of three levels. Nodes are in the range of 30m distance length from the Base Station is considered to be level 1 and another 30m as level 2 and next 30m as level 3. Using the Global Positioning System, the location of each node (x,y) coordinate is identified and communicated to the Base station.

Four parameters namely, min(x), min(y), max(x) and max(y) are considered to construct the area of each level. The number of nodes in such, each level is identified with the help of the constructed area having min and max values of *x* and *y* which is shown in Fig. 7.

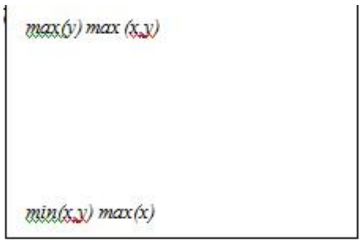

Fig. 7: Area of each level in the sensing region.

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Mass is calculated for each and every coordinate in each level of the sensing area. A sample area of a level is shown in Fig. 7. The formula used for calculating the mass of each point is given by,

$$Mass\ (x,y) = \frac{D_{\sum rni\,(x,y)}}{n_i} + \frac{E_{((x,y),ri))}}{n_i} + \frac{E_{norm}}{D_{norm}} \quad (3)$$

where,

$D_{\Sigma rni}$ – Distance of all reachable sensor node from (x,y) coordinate
n_i - Number of sensor nodes which are reachable/ accessible from (x,y)
$E_{((x,y),ri))}$ - Energy Consumption for transmitting data to the reachable sensor nodes from (x,y)
E_{norm} - Normalized Energy to transmit a packet
D_{norm} - Normalized Distance to reach the sensor node

Let us consider the max(x) and max(y) be (30, 30). So there will be a total 9000 coordinates that are obtained. Mass of each and every coordinate is calculated using the formula given in the Eq. 3. There are three types of masses (Esmat, 2009) described in the Theory of physics.

1) *Active Gravitational Mass M_a:* It is defined as the strength of Gravitational field due to a particular object.
2) *Passive Gravitational Mass M_p*: It is defined as the strength of interaction of object with the gravitational force.
3) *Inertia Mass M_i:* When a force is applied, there will be change in state is called Inertia Mass.

The Active Gravitational Mass and Passive Gravitational Mass are considered in the proposed approach for cluster formation. The force between any Active and Passive Gravitational mass can be represented as,

$$F_{kl} = G\ \{(M_{ak}M_{pl}/R^2)\} \quad (4)$$

where M_{ak} is the active gravitational masses and M_{pl} is the passive gravitational masses, k and l represent the masses M_k and M_l respectively. So, Eq. 4 represents the force acting on mass M_k by M_l.

Suppose, if force is to be calculated for mass M_1 by M_2, this can be calculated using the formula given in the Eq. 5 shows the formula for calculating the force on mass M_1 by M_2. Here M_1 refers to an Active Gravitational Mass and M_2 refers as a Passive Gravitational Mass.

$$F_{12} = G\ \{(M_1M_2/R^2)\} \quad (5)$$

where R is the distance between M_1 and M_2. Similarly, the force acting on all masses is calculated using the formula specified in the Eq. 3. On summing all the forces acting on the masses, the cumulative force can be obtained. This is given in the Eq. 6.

$$\sum F_{kl} = G\ \{(\sum M_{ak}M_{pl}/\sum R^2)\} \quad (6)$$

C. Fitness Calculation:

For finding the fitness value, two parameters are considered namely; best (t) and worst (t). The term best (t) refers to the heaviest mass which is having the highest force and worst (t) is the least mass which is having lowest force value. Eq. 7 shows the formula for calculating the fitness (Esmat, 2009).

$$F_a(t) = \frac{fit_a(t) - worst\ (t)}{best\ (t) - worst\ (t)} \quad (7)$$

where $fit_a(t)$ is the fitness value of the point 'a' at time't'. The values of best (t) and worst (t) can be calculated (Esmat, 2009) using the equations Eq. 8 and Eq. 9 respectively.

$$best\ (t) = \max fit_n\ (t) \text{ where } n€\{1,2…N\} \quad (8)$$

$$worst\ (t) = \min fit_n\ (t) \text{ where } n€\{1,2…N\} \quad (9)$$

The normalized fitness value can be calculated as,

$$F_{normalized}(t) = \frac{F_a(t)}{\sum_{n=1 to N} [F_n(t)]} \quad (10)$$

The point where the best fitness is acquired is considered as a reference point and a circular is constructed from that point with d_c (d_c=30m) as a radius. And this cluster distance can be increased to another 5m (d_c = 40 m) to cover the uncovered nodes. This is shown in the Fig. 8.

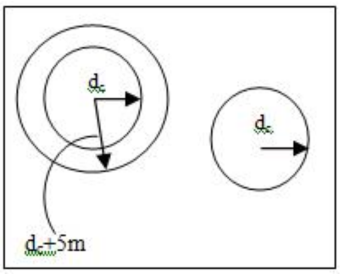

Fig. 8: Clusters in each level of hierarchy with a radius d_c.

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The sensor nodes belong to the constructed circle which becomes the member of that particular cluster. In such a way, all clusters are formed. The same process is repeated until all nodes become a member of any one of the cluster.

The fitness value is updated by allowing all nodes to choose a random value between 0 and 1. The sum of all sensor nodes random value is calculated. The calculated sum is added with the existing fitness value. The resultant value is the fitness value for the next round.

D. Path Establishment Phase for routing the data:

GSA is applied for routing the sensed data to the Mobile Aggregator Sink nodes as well as the aggregated data from the Mobile Aggregator Sink node to the Base Station . If any cluster node in a cluster is not reachable to any of Mobile Aggregator Sink (MAS) node, then the corresponding cluster node sends a *broadcast- message* to the neighbor nodes requesting to forward its data. Once the node receives a *broadcast-reply* from the nearest neighbor, it starts transmitting the sensed data. The same procedure is repeated until it reaches the nearby available MAS node. Three parameters are considered before establishing a path between two nodes. This path establishment can be either between the sensor node and the MAS node or between MAS node and the Base Station. The parameters are as follows.

1) Traffic Load of the neighbor nodes:
2) Energy Consumption for transmitting data to the neighbor node:
3) Distance between the current node and the neighbor node:

The node which satisfies the above three criteria is considered to be the best neighbor node and path is established for data transmission. The same procedure is repeated until path is established up to MAS or Base Station. The proposed technique mainly focused on improving the network lifetime with the help of mobile sink node in wireless sensor networks. This can be achieved by applying the concept of Gravitational Search Algorithm to perform data aggregation and routing the sensed data.

Simulation Results and Discussions:

Wireless Sensor Network scenario is created using GSA algorithm. The proposed scheme is simulated using Network Simulator, version 2.32 (NS-2.32). The initial network parameters considered for simulation is given in the Table. I.

Table 1: Network Parameters.

Parameter	Value
Simulator area	100*100
Initial Energy of Node	100 Joules
Transmitted Power	0.02mw
Receiving Power	0.01mw
Packet Size	512 bytes
Buffer size	50
Level Distance	35m
No of MAS nodes	10

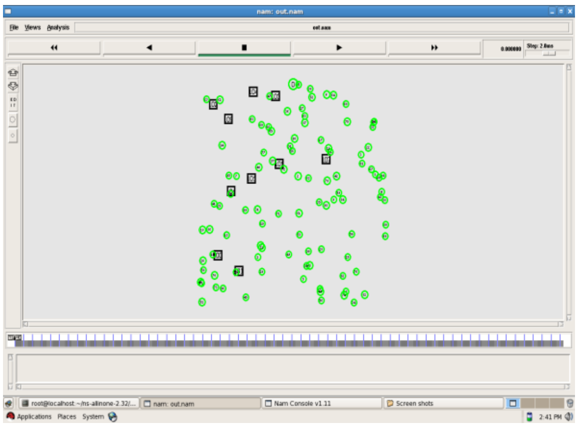

Fig. 9: WSN scenario with Sensor Nodes and MAS nodes.

Figure 9 shows the created WSN scenario with 100 numbers of nodes. The sensor nodes are initially fully energized node which shown in Fig. 9. With the sensor nodes, mobile sink nodes are introduced in the sensor network. The proportion of MAS nodes and sensor nodes are in the ratio 1:10. Here all the sensor nodes are kept stationary and MAS movable. The reason behind the mobility of MAS is, to move around the sensing region to gather the sensed data. Also, if the sensor nodes die in some particular region, can make use of these MAS nodes to move to gather the sensed data from some other sensor within the sensing region. This improves the data aggregation operation of live sensor nodes, and also lifetime to the rest of the sensor nodes can be increased.

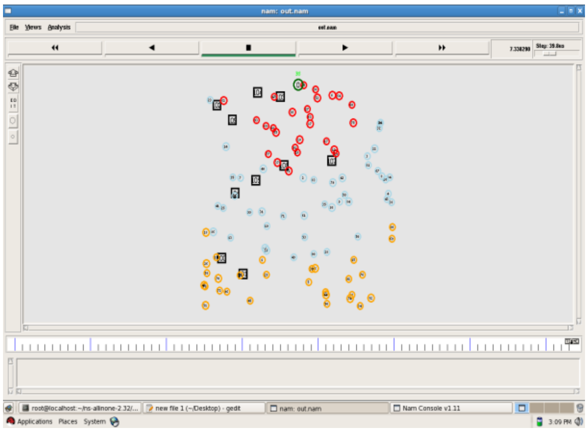

Fig. 10: Hierarchical Level of Sensor Nodes.

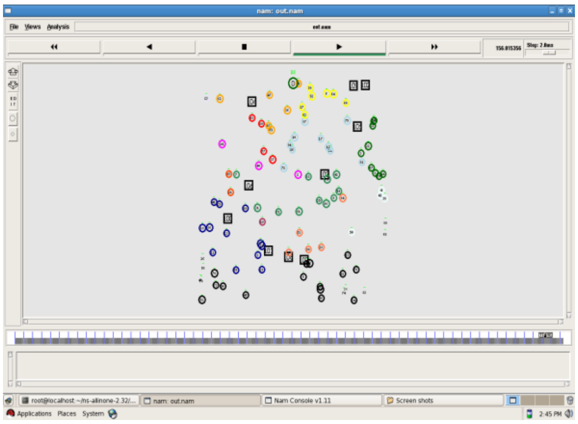

Fig. 11: Clusters Formation in WSN.

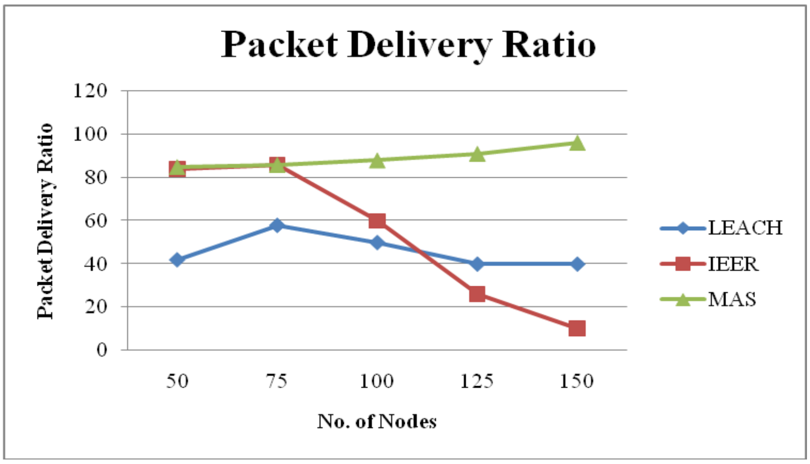

Fig. 12: Packet Delivery Ratio.

After some particular period of time, the level of each sensor node is computed. Three hierarchical levels are considered and this is shown in Fig. 10. The three colors of sensor nodes shows three hierarchical levels. The nodes are in green color represents the Base Station. The set of nodes in red color indicates the sensor nodes at level 1. And those that are in blue represents sensor nodes in level 2 and in yellow indicate level 3 sensor nodes. The number of nodes considered in level 1 is lesser than level 2 and 3.

The mass of each and every coordinate is calculated for three levels using the formula given in the Eq. 3. And forces are calculated for each and every coordinate and clusters are formed by constructing a circle with a cluster distance d_c. Figure 10 shows the created WSN scenario after cluster formation. Each cluster is differentiated using different colors. The movement of MAS can be seen clearly in Fig. 11 when compared to Fig. 10. The cluster nodes use shortest path algorithm to find the nearby MAS to transmit the sensed data for aggregation. Simulations are carried out for 50, 75,100, 125 and 150 numbers of nodes and results are compared for the proposed approach with the existing two approaches LEACH and Mobile Sink nodes (IEER) (Suganthi *et al*, 2011).

Figure 12 shows the output comparison graph between Packet Delivery Ratio (PDR) and the No. of Nodes. The proposed MAS are compared with the two existing techniques LEACH and Mobile Sinks (IEER). The formula for calculating the Packet Delivery Ratio is given in the Eq. 11.

PDR = No. of packets Received
No. of packets Sent (11)

From the graph, it is clear that the Packet Delivery Ratio (PDR) of the proposed MAS is better than the existing approaches.

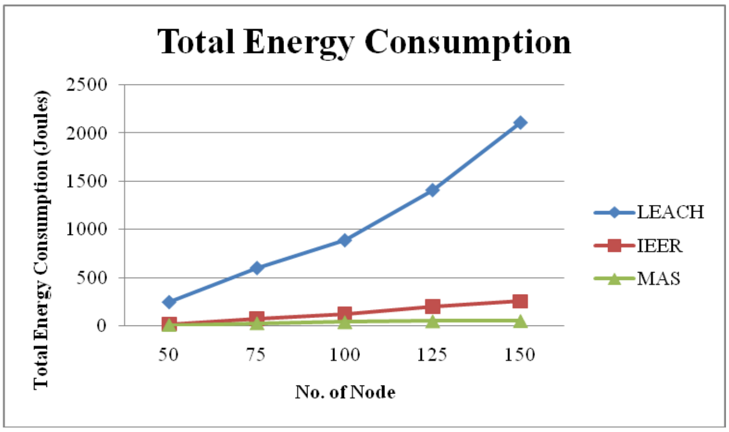

Fig. 13: Total Energy Consumption.

Figure 13 shows the output comparison graph between the Total Energy consumption of all sensor nodes and the No. of Nodes. It is compared with the existing approaches. The Total Energy Consumption is calculated by adding the consumed energy of all sensor nodes in the WSN. From the Fig. 13; it is clear that the Total Energy consumption of sensor nodes in the proposed approach is lesser than the two existing approaches. The value of the Total Energy Consumption is calculated using the formula given in the Eq. 12.

Total Energy Consumption = $[\sum_{n=1 \text{to } N} (E_{initial}(n))] - [\sum_{n=1 \text{to } N} (E_{remaining}(n))]$ (12)

where n = {1,2… N} is the total number of sensor nodes in the sensing region. $E_{initial}$ is the initial energy of each sensor node and $E_{remaining}$ is the remaining energy of all sensor nodes after the simulation.

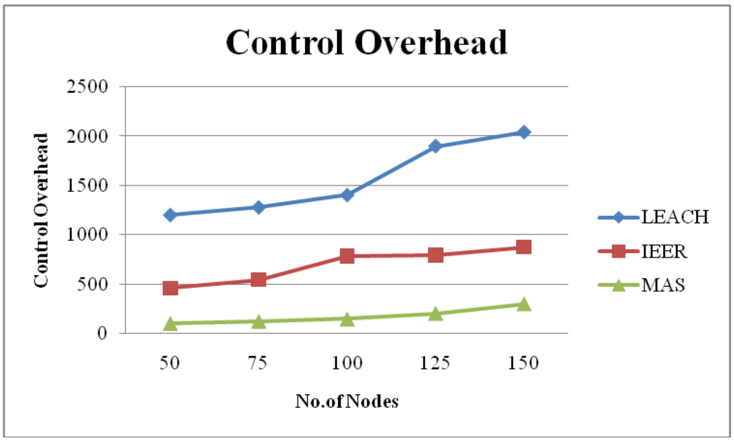

Fig. 14: Control Overhead.

From Fig.14, it is observed that the control overhead messages of the proposed system are lesser when compare to the existing systems. Lesser the control overheads make the system more effective as it reduces the additional information related to the original information.

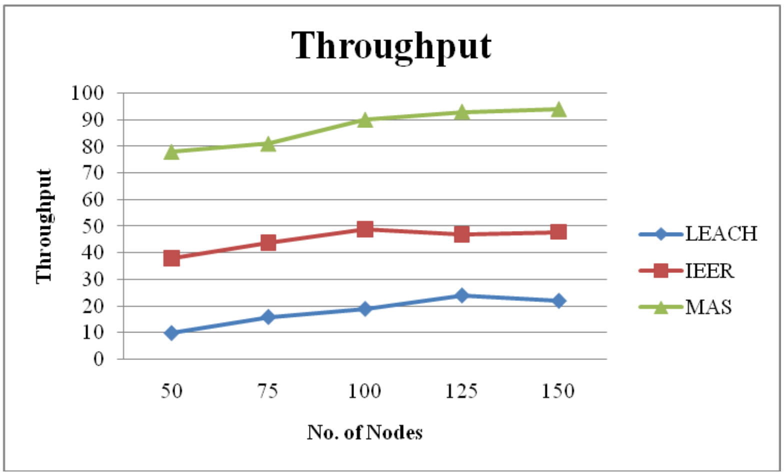

Fig. 15: Throughput.

For the proposed work, it shows better throughput when compare to the existing system and is shown in Fig.15. It is observed from the results, with the help of mobile aggregator sink nodes in the overall network performance is increased as well as the overall network lifetime time is increased.

Conclusion and Future Enhancement:

This paper proposes a novel method of clustering to perform data aggregation using Mobile Aggregator Sink nodes in the sensing region. Gravitational Search Algorithm is an optimization algorithm which is used for cluster formation and path establishment for routing the data. Shortest path algorithm is used by sensor nodes to access the nearest Mobile Aggregator Sink nodes. Fitness function is calculated by considering the best and the worst forces in the sensing region. The simulation results show better performance of the proposed work than the existing works. The same work can be enhanced for tracking single as well as multiple numbers of objects in the Wireless Sensor Networks.

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