Improving Energy Efficiency Using Wireless Sensor Network

DR. P. SIVAKRISHNA
Department of CSE, Sree Rama Engineering College

Abstract— Energy is the major constraint in Wireless Sensor Network. In multi-hop network, the nodes consume high energy due to data forwarding to the nodes that are present far away. This leads to quick draining of battery within a short time. In the proposed system, multiple mobile sink nodes are used for gathering data from the Cluster Head (CH) i.e. Rendezvous Points (RP) and each cluster contain only one RP. Initially Rendezvous Point (RP) is identified in the network in random manner. The proposed system makes a hybrid moving pattern in which mobile-sink nodes solely visits RP's, as hostile. Sensor nodes that are not the Rendezvous Points forward their detected knowledge via single hopping to the closest RP. The basic drawback is the computation of a tour that visits the Rendezvous Points (RP), among a given delay. Finding the distinctive best path is considered as an NP-hard problem. To overcome the problem, Weighted Rendezvous Planning (WRP) is projected thereby every sensing node is appointed a weight equivalent to its hop distance from the tour. WRP is a valid intensive technique which helps in better energy preservation. Localization of node is included in which movement of the sink node can be tracked by all the nodes. WRP increase the network lifetime and reduce energy consumption when compared with the existing system. The simulation-based performance evaluation is performed in the output.

Index Terms- Wireless Sensor Network, Cluster Head, Rendezvous Point, Weighted Rendezvous Point, NP-hard problem.

I. INTRODUCTION

Wireless Sensor Networking is an emerging technology that consists of collection of nodes that are selforganized into a cooperative network and the nodes communication takes place using radio signals. WSN is otherwise called as Motes.WSN are spatially distributed autonomous sensors to monitor physical or environmental conditions such as temperature, sound, pressure etc and to cooperatively pass their data through the network to the Base Station. WSN is composed of hundreds or even thousands of small, cheap sensor nodes which communicate with one another wirelessly. A sensor network consists of multiple detection stations called sensor nodes. Every sensor node is equipped with a transducer, microcomputer, transceiver and power source. The power transceiver effectively used for gathering data's from various applications like environment monitoring, civil application etc and finally, transmit the data's to the Base Station.

There are several important considerations that enable the successful operation of the network. The considerations are network lifetime and energy consumption. The lifetime of the WSN depends upon the energy consumption of the sensor nodes. In WSN, Data Collection and Aggregation is considered as an important and necessary to save the energy and to prolong the network lifetime. The energy consumed by each sensor node is done in two major ways namely sensing the field and routing the data's to the Static Sink (or) Base Station. The deployed sensor nodes are left unattended then it is difficult to recharge (or) replace the battery. After the sensor nodes are grouped into autonomous organization, the sensor nodes near the Base Station deplete in their batteries much faster than other nodes. Due to the depletion of energy, the network lifetime is not guaranteed.

Energy consumption is considered as critical factor because of limited power supply. To achieve high scalability, energy efficiency and prolong network lifetime, the Cluster-Based scheme is considered. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding.

Energy consumption is the core issue in Wireless Sensor Network (WSN). To generate a node energy model that can accurately reveal the energy consumption of sensor nodes is an extremely important part of protocol development, system design and performance evaluation in WSNs. Sensor nodes have a limited supply of energy. This energy is used for three purposes: sensing data, manipulating data and data communication. Sensor nodes are deployed mostly in uninhabited areas where there is no power supply. Hence the energy lifetime of sensor nodes strongly depends on battery lifetime. To increase network lifetime, energy must be saved in every hardware and software solution composing the network architecture. The hop distance strategy in Wireless Sensor Networks (WSNs) has a major impact on energy consumption of each sensor node.

In single-hop network, the data packets are transmitted from the source station to the Base Station which consists of only one hop between them as shown in Fig 1.3. If the nodes are present close to each other than the energy consumption by the nodes gets reduced. Thus the nodes present in the Clusters will communicate with the ClusterHead in a single-hop fashion in order to increase the energy efficiency.

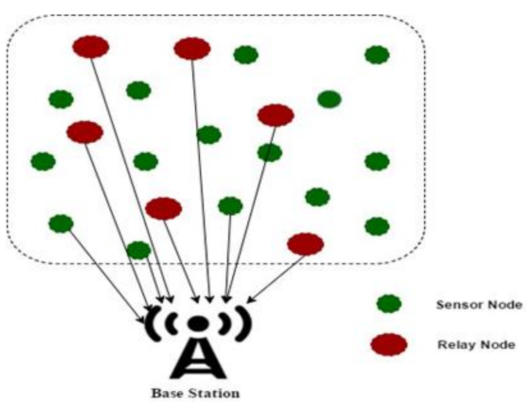

Fig 1.3 Single-hop network

Fig 1.4 shows the multi-hop network, when the distance between the nodes is large and the communication between the nodes is carried out through the number of intermediate nodes placed in the network. The distance between the Cluster Head and the Base Station may be large and the Cluster Head may consume lot of energy. In order to reduce the consumption of energy, an intermediate node called Mobile Sink is placed between them and the Mobile Sink will collect the aggregated data's and transmit it to the Base Station.

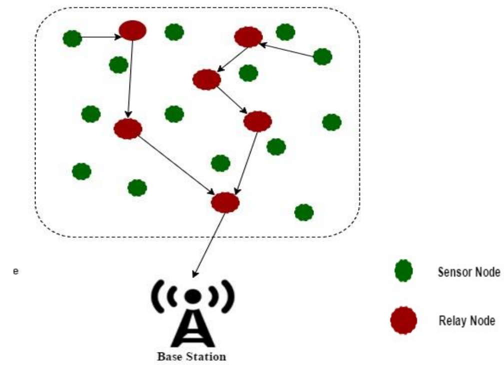

Fig 1.4 Multi-hop network

II. RELATED WORKS

In [1] Gedik B., Liu L. and Yu P. S. proposed an adaptive sampling approach for data collection in sensor networks. One of the most prominent and comprehensive ways of data collection in sensor networks is to periodically extract the raw sensor readings. This way of data collection enables complex analysis of data, which may not be possible with in-network aggregation or query processing. ASAP, which is an adaptive sampling approach was developed for energy efficient periodic data collection in sensor networks. The main idea behind ASAP is to use a dynamically changing subset of the nodes as samplers such that the sensor readings of the sampler nodes are directly collected, whereas the values of the non sampler nodes are predicted through the use of probabilistic models that are locally and periodically constructed.

ASAP is effectively used to increase the network lifetime while keeping the quality of the collected data high. The ASAP approach consists of three main mechanisms namely sensing driven-cluster construction was used to create clusters within the network such that nodes with close sensor readings are assigned to the same clusters. Correlation-based sampler selection and model derivation were used to determine the sampler nodes and to calculate the parameters of the probabilistic models that capture the spatial and the temporal correlations among the sensor readings as needed. Adaptive data collection and model-based prediction were used to minimize the number of messages used to extract data from the network.

In [3] Konstantopoulos C., Pantziou G., Gavalas D., Mpitziopoulos A. and Mamalis B. proposed a rendezvous-based approach for enabling energyefficient sensory data collection with mobile sinks. A large class of Wireless Sensor Networks (WSN) applications involves a set of isolated urban areas covered by sensor nodes for monitoring environmental parameters. Mobile sinks mounted upon urban vehicles with fixed trajectories provide the ideal infrastructure to effectively retrieve the sensory data from such isolated WSN fields. Existing approaches involve either singlehop transfer of data from SNs or heavy involvement of network periphery nodes in data retrieval, processing, buffering, and delivering tasks. These nodes run the risk of rapid energy exhaustion resulting in loss of network connectivity and decreased network lifetime. The aim of the paper in to minimize the overall network overhead and energy expenditure associated with the multihop data retrieval process while also ensuring balanced energy consumption among SNs and prolonged network lifetime. A cluster structure is built and consists of member nodes that route their measured data to their assigned Cluster Head (CH). CHs perform data filtering upon raw data exploiting potential spatial-temporal data redundancy and forward the filtered information to appropriate end nodes with sufficient residual energy, located in proximity to the MS's trajectory. Simulation results confirm the effectiveness of the approach as well as its performance gain over alternative methods.

In [4] Lee E., Park S., Yu F. and Kim S.-H. focused on the data gathering mechanism with local sink in geographic routing for the Wireless Sensor Networks. Most existing geographic routing protocols on sensor networks concentrates on finding the ways to guarantee data forwarding from the source to the destination, and not many protocols concentrate on gathering and aggregating data in a local and adjacent region. The data generated from the sources are often redundant and highly correlated. Gathering and aggregating data from the region in the sensor networks Is important and necessary to save the energy and wireless resources of sensor nodes. Thus the concept of local sink was introduced. The local sink is a sensor node in the region, in which the sensor node is temporarily selected by a global sink for gathering and aggregating data from sources in the region and delivering the aggregated data to the global sink. Data funneling technique was considered and by using this technique the border nodes with shortest distance from the global sink are selected as local sink. Single local sink model was used for determining the optimal location of the single local sink because the buffer size of the local sink is limited and the deadline of the data is constrained. Single local sink is capable of carrying out many sources in a large-scale local and adjacent region. The multiple local sink extension was also considered. This mechanism improves the energy efficiency, data delivery ratio and reduces the deadline miss ratio.

In [7] Ma M., Yang Y. and Zhao M. proposed the tour planning for mobile data-gathering mechanisms in Wireless Sensor Networks. A mobile data collector called M-Collector is a mobile robot or a vehicle equipped with a powerful transceiver and battery and work like a mobile Base Station for gathering data while moving through the field. An M-collector starts the datagathering tour periodically from the static data sink, polls each sensor while traversing its transmission range, then directly collects data from the sensor in single-hop communications, and finally transports the data to the static sink. Since data packets are directly gathered without relays and collisions, the lifetime of sensors is expected to be prolonged. The paper mainly focuses on the problem of minimizing the length of each datagathering tour and refers as the Single-Hop DataGathering Problem (SHDGP). The SHDGP was formulized into a mixed-integer program and then a heuristic tour-planning algorithm was presented for the case where a single M-Collector was employed. The single hop mobile data gathering scheme can improve the scalability and balance the energy consumption among sensors. It can be used in both connected and disconnected networks. The data gathering algorithm greatly shorten the moving distance of the collectors compared with the covering line approximation algorithm. The data-gathering scheme significantly prolong the network lifetime compared with the static data sink or a network in which the mobile collector a=can only move along a straight line.

In [11] Xu K., Hassanein H., Takahara G. and Wang Q. proposed relay node deployment strategies in heterogeneous Wireless Sensor Networks. In a heterogeneous Wireless Sensor Network (WSN), Relay Nodes are adopted to relay data packets from Sensor Nodes to the Base Station. The deployment of the Relay Nodes can have a significant impact on connectivity and lifetime of a WSN system. The first discussion is based on the biased energy consumption rate problem associated with uniform random deployment. This problem may leads to insufficient energy utilization and shortens the network lifetime. To overcome this problem, two random deployment strategies was proposed and they are lifetime-oriented deployment and hybrid deployment. The lifetime-oriented deployment is also called as weighted random deployment. The network is divided into two regions i.e. one region is far away from the Base Station and another region is close to the Base Station. The former solely aims at balancing the energy consumption rates of Relay Nodes across the network, thus extending the system lifetime. However, this deployment scheme may not provide sufficient connectivity to Sensor Nodes when the given number of Relay Nodes is relatively small. The latter reconciles the concerns of connectivity and lifetime extension. Both single-hop and multi-hop communication models are considered. It provides guideline for efficient deployment of Relay Nodes in a large-scale heterogeneous WSN.

A three layer framework was proposed for the mobile data collection in the Wireless Sensor Network, which include Sensor Layer, Cluster Head Layer and Mobile Collector (SenCar) Layer. In Sensor Layer, the sensor nodes are self-organized into Clusters and each Cluster contains multiple Cluster Heads. Relay routing transmission was considered and other factors considered are load balance, schedule pattern and data redundancy. In Cluster Head Layer, multiple Cluster Heads within the Cluster cooperate with each other to perform energy saving inter-cluster communication. The Cluster Head takes the responsibility for forwarding the data's to the data sink. In the Mobile Collector (SenCar) Layer, mobile collector was considered to reduce the burden of data routing from the Cluster Head. SenCar is equipped with two antennas, which enables two Cluster Heads simultaneously upload data to the SenCar at a time by utilizing Multi-User Multiple-Input and Multiple-Output (MU-MIMO) technique. In cluster- based schemes, cluster heads will inevitably consume much more energy than other sensors due to handling intra-cluster Aggregation and inter-cluster data forwarding. Due to the presence of single mobile sink and multiple Cluster Head in each Cluster, the latency gets increased during data transmission.

III. MULTIPLE MOBILE SINK ROUTING

To overcome the drawbacks of the existing system, Multiple Mobile Sink is considered for gathering the data's from the Cluster Head and transmit it to the Base Station. Single Cluster Head is generated for each Cluster in random manner by using K-Means algorithm and the Cluster Member transmit the data's to the Cluster Head in Single-Hop fashion. Weighted

Rendezvous Planning is a valid intensive technique used to find the nearest optimal travelling path. WRP is the process of assigning weights to the Cluster Head by considering the path distance and the no of packets that they need to transmit. When the multiple Mobile Sink emerge from the Base Station they split the network according to the mobile sink number and the mobile sink collect the aggregated data's only from the assigned area. Thus Multiple Mobile Sink will not approach same Cluster Head at a time. The Beacon Frame is transmitted from the Mobile Sink to the Cluster Head to verify the network condition and check whether the data's are ready for transmission. AOMDV routing protocol is used to determine the routes for transmitting the data packets. The location of the mobile sink is traced by the sensor nodes present in the network.

By the usage of multiple Mobile Sink Node the Network Lifetime gets increased. Single-Hop transmission reduces the energy consumption. The packet delivery between the Cluster Head and the Base Station get increased. Transmission of Beacon frame reduces the packet loss. Increase throughput. Finally the performance is improved and energy efficiency is achieved.

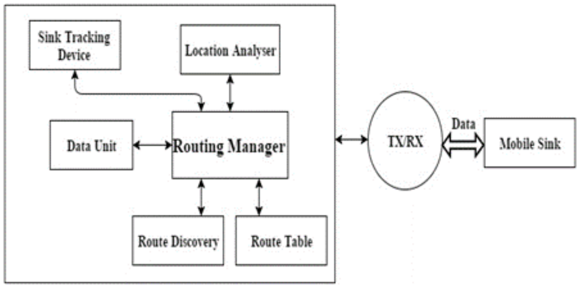

Fig 1 System architecture

In Route discovery, the WRP algorithm is used to find the shortest route through which the mobile sink must move for gathering the data's from the Cluster Head as shown in Fig 3.1. The Routing table incorporates the combination of Routes and the data's that are involved in transmission. The data's which are involved in data transmission are stored in the Data Unit. The position of the Sink Node is traced by all the nodes present in the Clusters in order to avoid the arrival of the Mobile Sink to same Cluster Head at a time by the usage of Sink Tracking Device. The Location Analyzer provides guidelines that which sink should move to which Cluster Head for gathering the data's. The routing table information and the details about the data's transmitted are managed by the Routing Manager.

A. Cluster Formation

In this module, to achieve high energy efficiency sensor nodes that are present in the network are grouped into Clusters. The main idea of clustering is to reduce the network traffic from sensor node to sink and improve the energy consumption. Here the sensor nodes are located in the region in static manner. For Cluster Formation, K-Means Clustering Algorithm is considered.

K-Means Clustering Algorithm

K-Means is one of the simplest

Unsupervised learning algorithms that solve the wellknown clustering problem as shown in fig 4.1. K-Means clustering aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean value. This algorithm has a close relationship with the K-Nearest Neighbor classifier which is a popular machine learning technique. The procedure follows a simple and easy way to classify a given data set through a certain number of clusters. The main idea is to define k centers for each cluster. These centers should be placed carefully because different locations cause different result. Consider each point belonging to a given data set and associate it to the nearest center. In the proposed system, each cluster contains single Cluster Head.

The Clustering activity Involves the following steps:

- Data Point Representation
- Data Points similarity measurement
- Clustering or grouping
- Data Abstraction

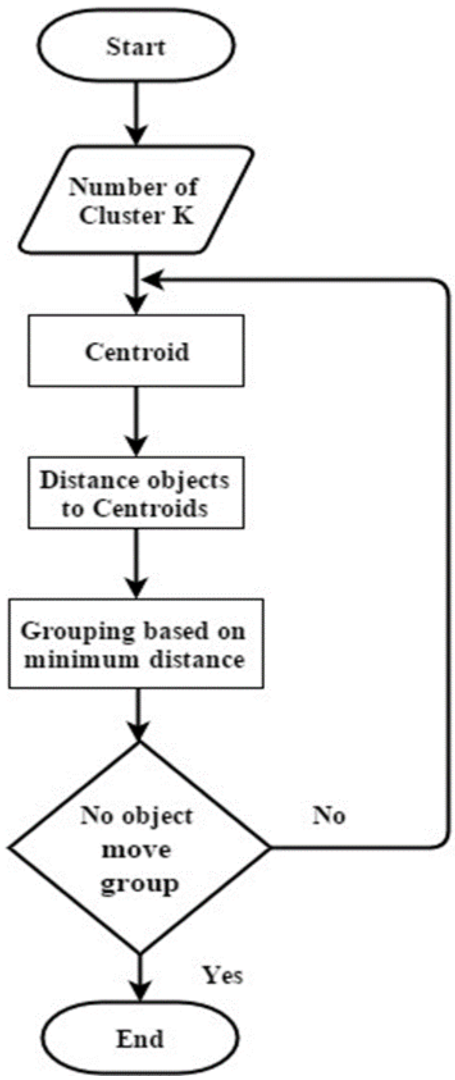

Fig 2 K-means flowchart

K-Means Algorithm Steps

Let X = {x1,x2,x3,……..,xn} be the set of data points and V = {v1,v2,…….,vc} be the set of centers.

1) Randomly select 'c' cluster centers.
2) Calculate the distance between each data point and cluster centers.
3) Assign the data point to the cluster center whose distance from the cluster center is minimum of all the cluster centers
4) Recalculate the new cluster center using

$$V_i = (1/c_i) \sum_{j=1}^{c_i} (x_i)$$

Where ci represents the number of data points in the ith Cluster.

5) Recalculate the distance between each data point and new obtained cluster centers.
6) If no data point was reassigned then stop, otherwise repeat from step 3.

Advantages

- Fast, Robust and easy to understand.
- Gives best result when data set are distinct or well separated from each other.

B. Cluster Head Selection

The random selection of Cluster Head is considered throughout the transmission. All the Cluster Member transmits the data's to the Cluster Head. If the Cluster Head Energy gets drain, then the node with the highest energy is considered as the Cluster Head. The Clustering Techniques consists of two phases: Setup Phase and Steady State Phase. In the Setup Phase, Cluster Formation and Election of Cluster are preformed and In the Steady State Phase, sensor nodes transmit the data's to the Cluster Head and the Cluster Head transmit the aggregated data's to the Base Station.

C. Mobile Sink Node

The mobile sink nodes gather the aggregated data's from the Cluster Head and transmit it to the Base Station. The Mobile sink nodes are emerged from the Base Station and they contain buffers to store the collected data's. When the buffer value reaches zero, then the stored data's are transmitted to the Base Station. During pause time, the mobile sink sends a Beacon Frame to the neighboring Cluster Head in order to check the network condition.

D. Scheduling the Mobile Sink Node

The Scheduling is the process of planning to how the sink node operates. Weighted Rendezvous Planning (WRP), a heuristic method finds a near-optimal travelling tour for the mobile sink, such that it minimizes the energy consumption of sensor nodes. WRP assigns a weight to Cluster Head (CH) based on the number of data packets that they forward and hop distance. The multiple Mobile sink communicates with each other in order to avoid the arrival of the mobile sinks to the same Cluster Head.

IV. RESULTS

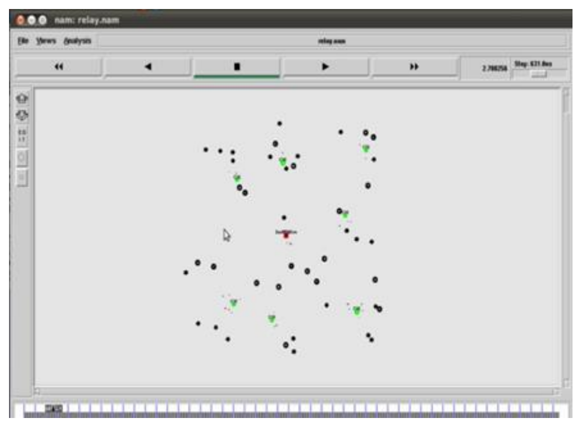

Fig 3 Node creation and data transfer

Fig 3 represents node creation in the network. The nodes that are placed in the network are grouped into clusters and each cluster contains one Cluster Head. The node 50 is considered as Base Station. The data's are transmitted from the Cluster Member to the Cluster Head in a single-hop fashion. The nodes present near the Base Station transmit the data's directly to the Base Station.

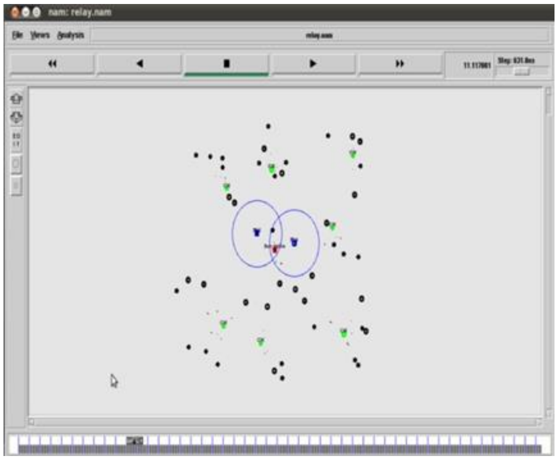

Fig 4 Multiple mobile sinks emerge from the base station

Fig 4 represents the emergence of multiple Mobile Sinks from the Base Station. The nodes 51 and 52 are considered as Mobile Sink. The Cluster Heads which are nearer to the Base Station are selected by the Mobile Sinks for gathering the data's. In order to avoid the arrival of the Mobile Sinks to same Cluster Head, the network is partitioned according to the number of the emerged mobile sink and the mobile sink gather data's only from the allocated Cluster Head.

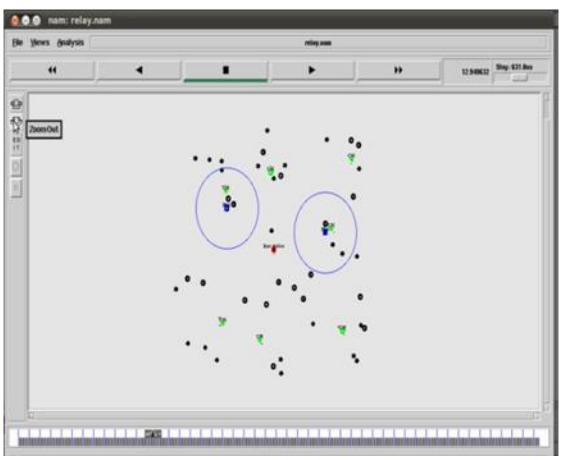

Fig 5 Mobile sinks visit cluster head 27 and 41

Fig 5 represents the Mobile Sinks gathering data's from the Cluster Heads. Mobile Sink 1 gathers the data from the Cluster Head 41 and Mobile Sink 2 gathers the data from the Cluster Head 27. The Mobile Sinks while gathering the data's from the Cluster Heads 41 and 27 they send Beacon frame to the nearby Cluster Head to verify the condition of the network. Further, the Mobile Sinks 1 and 2 visits the remaining Cluster Heads that are present in the allocated network.

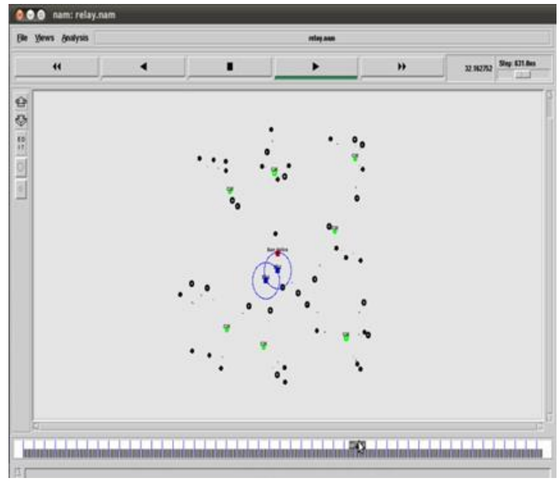

Fig 6 Both the mobile sink reaches the base station

Fig 6 represents the arrival of the Mobile sinks to the Base Station. After collecting the data's from the allocated Cluster Head, the Mobile Sinks deliver the data's to the Base Station. The multiple Mobile Sink visits all the allocated Cluster Head in a single stretched manner. The delay for delivering the data's are reduced and the Cluster Head energy will not be drain quickly.

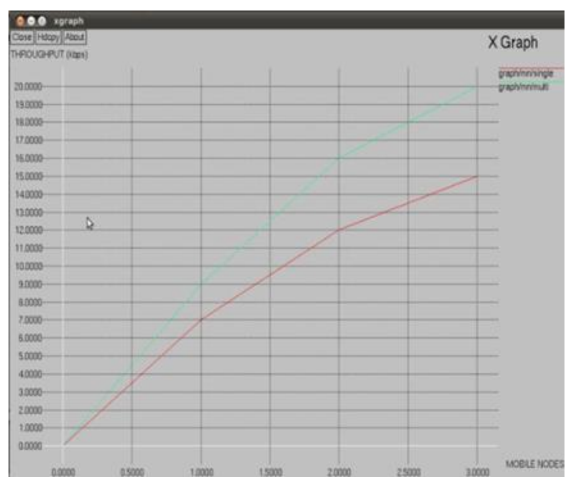

Fig 7 Comparison of throughput

Fig 7 represents the comparison of throughput for both single Mobile Sink and multiple Mobile Sinks. Mobile nodes are plotted along x-axis and throughput is plotted along y-axis. The throughput gets increased by the usage of multiple Mobile Sinks when compared to the usage of single Mobile Sink. The throughput depends upon the number of mobile nodes used in the network.

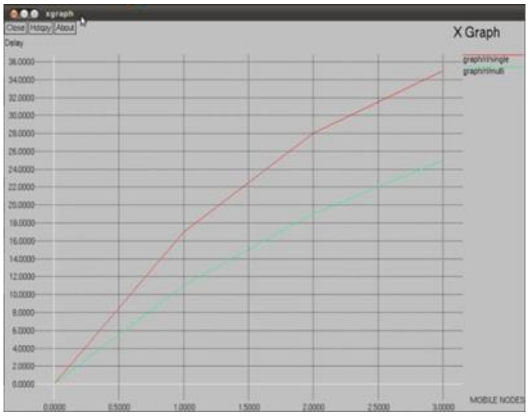

Fig 8 Comparison of delay

Fig 8 represents the comparison of delay for both single Mobile Sink and multiple Mobile Sinks. Mobile nodes are plotted along x-axis and delay is plotted along yaxis. The delay gets reduced by the usage of multiple Mobile Sinks when compared to the usage of single Mobile Sink. The delay depends upon the number of mobile nodes used in the network.

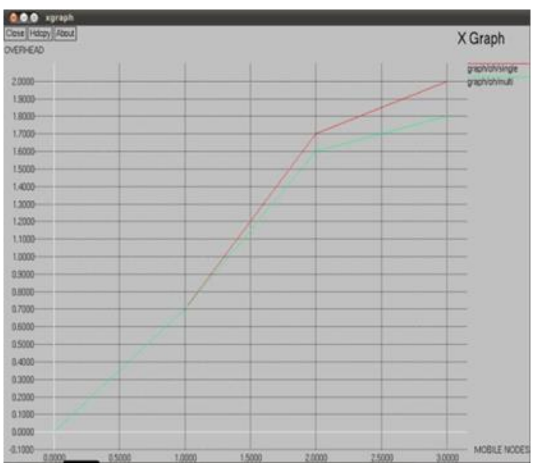

Fig 9 Comparison of overhead

Fig 9 represents the comparison of overhead for both single Mobile Sink and multiple Mobile Sinks. Mobile nodes are plotted along x-axis and overhead is plotted along y-axis. The overhead gets reduced by the usage of multiple Mobile Sinks when compared to the usage of single Mobile Sink. The overhead depends upon the number of mobile nodes used in the network.

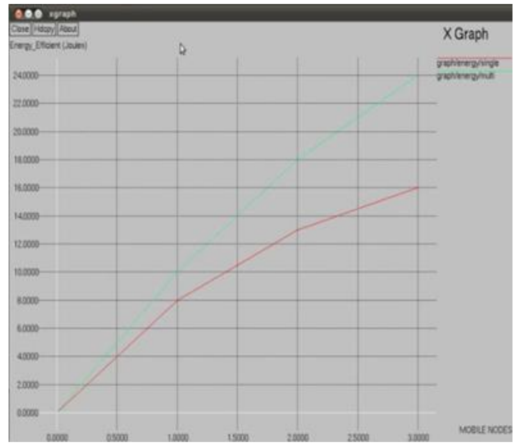

Fig 10 Comparison of energy efficient

Fig 10 represents the comparison of energy efficiency for both single Mobile Sink and multiple Mobile Sinks. Mobile nodes are plotted along x-axis and energy efficient is plotted along y-axis. The energy efficient gets increased by the usage of multiple Mobile Sinks when compared to the usage of single Mobile Sink. The energy efficient depends upon the number of mobile nodes used in the network.

V. CONCLUSION AN" FUTURE ENHANCMENT

In the proposed system, Multiple Mobile Sinks is used for data gathering between the Cluster Head and the Base Station to improve the energy efficiency and to prolong the network lifetime. The Cluster Head need not wait for long time for the arrival of the Mobile Sink node. Thus the delay of data packets gets reduced. The Cluster Head gather the data's from the Cluster Head in a single stretched manner. By the usage of Multiple Mobile Sink, the Communication Overhead is reduced. Location awareness Multiple Mobile sinks is considered and the sensor nodes present in the Cluster must keep track of the position of the Mobile Sink Node. WRP algorithm is used to find the shortest distance from the Cluster Head to the Base Station and the Mobile Sink will travel in the detected shortest path.

In the enhanced future work, for each round of data gathering, the Cluster Head gets changed and every Cluster Member will be activated as Cluster Head during data collection. The Cluster Head selection is done using Highest Energy First algorithm. The node with highest energy will be selected as Cluster Head. The energy of the Mobile Sink may drain due to large amount of data gathering. The aim of the project is to save energy and speed up the data transmission. Thus Back-Up sensors and speed Mobile Sink may also be another consideration for collecting the data's and to achieve high energy efficiency. The speed Mobile Sink also reduces the delay of the data packets.

REFERENCES

[1] Gedik B., Liu L. and Yu P. S.(2007), 'ASAP: An adaptive sampling approach to data collection in sensor networks', IEEE Trans. Parallel Distrib. Syst., vol. 18, no. 12, pp. 1766–1783.

[2] Karenos K. and Kalogeraki V. (2010), 'Traffic Management in Sensor Networks with a Mobile Sink', IEEE Trans. Parallel and Distributed Systems, vol. 21, no. 10, pp. 1515-1530.

[3] Konstantopoulos C., Pantziou G., Gavalas D., Mpitziopoulos A. and Mamalis B. (2012), 'A rendezvous-based approach enabling energyefficient sensory data collection with mobile sinks', IEEE Trans. Parallel Distrib.Syst., vol. 23, no. 5, pp. 809–817.

[4] Lee E., Park S., Yu F. and Kim S.-H. (2010), 'Data gathering mechanism with local sink in geographic routing for wireless sensor networks', IEEE Trans. Consum. Electron., vol. 56, no. 3, pp. 1433–1441.

[5] Liu C., Wu K. and Pei J. (2007), 'An energyefficient data collection framework for wireless sensor networks by exploiting spatiotemporal correlation', IEEE Trans. Parallel Distrib. Syst., vol. 18, no. 7, pp. 1010–1023.

[6] Ma M. and Yang Y. (2007), 'SenCar: An energy-efficient data gathering mechanism for large-scale multihop sensor networks', IEEE Trans. Parallel Distrib. Syst., vol. 18, no. 10, pp. 1476–1488.

[7] Ma M., Yang Y. and Zhao M. (2013), 'Tour planning for mobile data gathering mechanisms in wireless sensor networks', IEEE Trans. Veh. Technol., vol. 62, no. 4, pp. 1472–1483.

[8] Tang S., Yuan J., Li X., Liu Y., Chen G., Gu M., Zhao J. and Dai G. (2010), 'DAWN: Energy efficient data aggregation in WSN with mobile sinks', in Proc. IWQoS, pp. 1–9.

[9] Tang X. and Xu J. (2008), 'Adaptive data collection strategies for lifetime-constrained wireless sensor networks', IEEE Trans. Parallel Distrib. Syst., vol. 19, no. 6, pp. 721–7314.

[10] Wu Y., Mao Z., Fahmy S. and Shroff N. (2010), 'Constructing maximum-lifetime data-gathering forests in sensor networks', IEEE/ACM Trans. Netw., vol. 18, no. 5, pp. 1571–1584.

[11] Xu K., Hassanein H., Takahara G. and Wang Q. (2010), 'Relay node deployment strategies in heterogeneous wireless sensor networks', IEEE Trans. Mobile Comput., vol. 9, no. 2, pp. 145–159.

[12] Yun Y. and Xia Y. (2010), 'Maximizing the Lifetime of Wireless Sensor Networks with Mobile Sink in Delay-Tolerant Applications', IEEE Trans. Mobile Computing, vol. 9, no. 9, pp. 1308-1318.

[13] Zhang Z., Ma M. and Yang Y. (2008), 'Energy efficient multi-hop polling in clusters of twolayered heterogeneous sensor networks', IEEE Trans. Comput., vol. 57. No. 2, pp. 231–245.

[14] Zhao M., Ma M. and Yang Y. (2008), 'Mobile data gathering with space-division multiple access in wireless sensor networks', in Proc. IEEE Conf. Comput. Commun., pp. 1283–1291.

[15] Zhao M., Ma M. and Yang Y. (2011), 'Efficient data gathering with mobile collectors and spacedivision multiple access technique in wireless sensor networks', IEEE Trans. Comput., vol. 60, no. 3, pp. 400–417.

[16] Zhao M. and Yang Y. (2012), 'Bounded relay hop mobile data gathering in wireless sensor networks', IEEE Trans. Comput., vol. 61, no. 2, pp. 265–271.