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Cluster Based Mobile Data Gathering Using Minimum Covering Spanning Tree in WSN

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Abstract: In Wireless Sensor Networks (WSN), generally sensors closest to the sink or base station tend to deplete their battery energy faster than other sensors and create an energy hole around the sink. In order to overcome this problem, a Cluster based Mobile Data Gathering technique using Minimum Covering Spanning Tree (MCST) is proposed. In this technique, multiple sensors are arranged to form clusters. Two SenCars with multiple antennas are deployed in the cluster location and Space Division Multiple Access (SDMA) technique is applied for data gathering with energy efficiency. The visiting tour of each Sencars among the selected anchors is performed using the MCST algorithm . By simulation results, we show that the proposed technique minimizes the energy consumption and delay, and enhances the network efficiency.

Keywords: WSN; Data gathering; spanning tree; Cluster; MCST.

1. INTRODUCTION

Sensor network is a multihop network which consists of hundreds of sensor nodes. The main resource constraint of the sensor node is the energy. Generally, sensor networks are deployed in the unattended and hostile environment such as wildlife detection, continuous environment monitoring, and military. So it is impossible to replace or recharge the battery [1]. Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes, which consist of sensed and data processing, and communicating components, leverage the idea of wireless sensor networks (WSNs). Considering that battery is the main source of energy for the sensor nodes, how to reduce the high-energy expenditure in multihop routing and extend WSN's lifetime is a major challenge [2]. Generally WSN are deployed as sensor nodes and a base station (sink). Their application areas are to monitor environments or inaccessible regions, such as battlefields, jungles or forests. Nowadays the cost of sensor nodes has been reduced by the advances of semiconductor technology and mass production. Also nodes of WSNs are equipped with expensive sensors such as video, audio, GPS and so on [3].

Every WSN is constrained by low data rates, energy reservations, and usually a many to one communication pattern. Analyzing the performance of such networks has been done with the help of Steiner trees, shortest path trees or greedy heuristic based trees. These topologies have been put to numerous routing protocols and data aggregation methods to optimize energy, load and response time [4].

One important task of WSNs is to collect useful information from the sensory field. For a large-scale, data centric sensor network, it is inefficient to use a single, static data sink to gather data from all sensors. In some applications, sensors are deployed to monitor separate areas. In each area, sensors are densely deployed and connected, while sensors that belong to different areas may be disconnected. Unlike fully connected networks, some sensors cannot forward data to the data sink via wireless links. In some complex terrain environment, especially in noise interference and mobile case, how to effectively gather data is a challenge task with limited power. In general, most data-gathering schemes aim to prolong lifetime of WSNs by saving power consumption and optimized data transmitting scheme. Normally, in WSN, data collected by sensors are transmitted to one or more sink nodes. It was noticed that the sensors closest to the sink deplete their energy faster than other sensors nodes which creates an energy hole around the sink [12].

A data gathering technique uses aggregation methods to reduce the data traffic. Data gathering reflects how efficient the mobile element gather data from the sensors without delay and buffer overflow [5].

One of the energy efficient data gathering techniques is to use a mobile sink which moves within the sensor field, collects the sensed data from source nodes and sends these data to application's users or network administrators. Recent research emphasized the fact that utilizing mobile sinks for data collection led to improving the performance of sensor networks in terms of network life time and the overall energy consumption. However, one of the main challenges of this technique is the difficulty of the mobile sink to traverse all sensor nodes in the network, since data must be collected within a specific time deadline. This deadline is usually imposed by either the network user, the underlying application or even by the mobile sink itself, for example, due to the battery recharging cycle [6].

A mobile-sink scheme offers considerable flexibility in balancing traffic load because it can dynamically adjust the set of bottleneck nodes. Therefore, the trajectory of a mobile sink determines how the traffic load in a network is balanced. Identifying a routing path from a sensor to a mobile sink is challenging, especially in an environment in which the sensors do not possess their location information [7].

In this paper, we propose to develop a scheme for data gathering technique with energy efficiency in WSN.

This paper is organized as follows. Section 2 presents the related works done in this research field. Section 3 presents the proposed Cluster based Mobile Data Gathering using Minimum Covering Spanning Tree (MCST-CMDG). Section 4 presents the simulation results and analysis and Section 5 presents the conclusion.

2. RELATED WORKS

Xinxin Liu et. al., [8] have proposed two energy efficient proactive data reporting protocols, SinkTrail and SinkTrail-S, for mobile sink-based data collection. The proposed protocols feature low-complexity and reduced control overheads. Two unique aspects distinguish our approach from previous ones: (1) we allow sufficient flexibility in the movement of mobile sinks to dynamically adapt to various terrestrial changes; and (2) without requirements of GPS devices or predefined landmarks, Sink Trail establishes a logical coordinate system for routing and forwarding data packets, making it suitable for diverse application scenarios. We systematically analyze the impact of several design factors in the proposed algorithms.

Saim Ghafoor et. al., [9] have proposed a novel approach for mobile sink trajectory in wireless sensor networks. Their proposed approach is based on Hilbert Space Filling Curve, however, the proposed approach is different from their previous work in a sense that the curve order changes according to node density. In their research, they investigated the mobile sink trajectory based on Hilbert Curve Order which depends upon the size of the network. Second, they calculated the Hilbert Curve Order based on node density to redimension the mobile sink trajectory.

Marwa M. Hassana et. al., [10] have introduced the optimal location solution through utilizing the Mixed Integer Linear Programming (MILP) solution to the problem in small scale WSNs. Consequently, maximum reliability of a path may lead to the minimum energy consumed for retransmission along the routing path. However, in large-scale networks, their paper introduced the Genetic Algorithm (GA) as one of the heuristics solution. The Fitness function of the GA calculates the negative value of the log of the reliability of a path and the GA tries to find the sink position with the minimum fitness value to minimize the energy spent by each sensor in the routing towards the sink.

In [11], a data gathering technique with mobile collectors using space-division multiple access (SDMA) technique is proposed. In this technique, the visiting tour of the SenCar to each polling point is determined based on the distance and coverage only. However the polling points should be selected based on connectivity, node degree and SDMA compatibility in addition to the coverage condition. Moreover, the visiting does not consider the buffer overflow problem cause due to the depletion of sensor's energy.

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Junzhao Du et. al., [16] have introduced a technique to optimize the energy consumption on gathering the global data named In-network communication cost. By doing so, the Mobile Element (ME) is able to efficiently collect network wide data within a given delay bound meanwhile the network eliminates the energy bottleneck to prolong its lifetime. For case study, they considered the trajectory planning for both Mobile Relay and Mobile Sink on a tree-shaped network. In the Mobile Relay case an algorithm named RP-MR is proposed. In the Mobile Sink case, an algorithm named RP-MS is proposed.

Miao Zhao et. al., [17] have proposed to utilize mobility for joint energy replenishment and data gathering. In particular, a multi-functional mobile entity, called SenCar is employed, which serves not only as a mobile data collector that roams over the field to gather data via short-range communication but also as an energy transporter that charges static sensors on its migration tour via wireless energy transmissions. Taking advantages of SenCar's controlled mobility, they focused on the joint optimization of effective energy charging and high-performance data collections.

Huan Zhaoa et. al., [18] have proposed a heuristic topology control algorithm and further discussed how to refine their algorithm to satisfy practical requirements such as distributed computing and transmission timeliness.

Jiqiang Tang et. al., [19] have considered a delivery latency minimization problem (DLMP) in a randomly deployed WSN. Their goal is to minimize the travel latency of the mobile sink. They formulated the DLMP as an integer programming problem which subjects to the direct access constraint, the data transmission constraint and the route traverse constraint. They have proven that the DLMP is an NP-Complete (NPC) problem, and then proposed a substitution heuristic algorithm to solve it by shortening the travel route and having the mobile sink move and collect data at the same time.

I. Snigdh et. al., [20] have proposed an Energy Conserving Scheme efficiently and effectively suggests an energy efficient solution to encounter such situations. Absence of such mechanisms could lead to a catastrophe or an irrecoverable loss of data. Buffer overflow problems have been addressed in literature scarcely. Thus, it becomes imperative to provide proficient mechanisms to handle such problems. Proposed algorithm ECS is one of such kind.

Behnam Behdani et. al., [21] have described a inear programming and column generation approaches and also for a version in which data can be delayed in its transmission to the sink.Their column generation approach exploits special structures of the linear programming formulations so that all sub problems are shortest path problems with non-negative costs.

Yu GU et. al., [22] have developed a novel notation Placement Pattern (PP) to bound time varying routes with the placement of sinks. This bounding technique transforms the problem from time domain into pattern domain, and thus, significantly decreases the problem complexity. Then, they formulated this optimization in a pattern-based way and create an efficient Column Generation (CG) based approach to solve it.

3. CLUSTER BASED MOBILE DATA GATHERING USING MINIMUM COVERING SPANNING TREE

A. Overview

In order to overcome the problems discussed in the previous section, in this paper, we propose to develop a Cluster based Mobile Data Gathering Using Minimum Covering Spanning Tree (MCST-CMDG) technique. In this technique, multiple sensors are arranged to form clusters. The anchor points are selected for intermediate data collection based on the connectivity and node degree, node compatibility and the distance between the sensors of two adjacent clusters parameters. After determining the anchor points, the average residual energy of each cluster is determined by the cluster head (CH). Then the clusters are classified into two categories as clusters with residual energy less than a threshold and clusters with residual energy more than the threshold. Two SenCars with multiple antennas are deployed which applies SDMA technique [17] for data gathering. One Sencar is responsible for gathering data from the high energy clusters and the other one gathers the data from clusters of lower energy. The visiting tour of each Sencar among the selected anchors is performed using the MCST Algorithm [14]. Figure 1 shows the block diagram of the proposed MCST-CMDG technique.

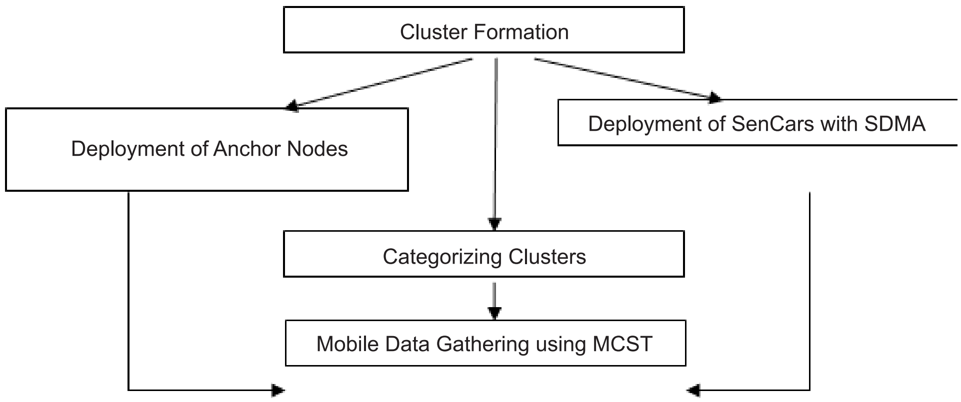

Figure 1: Block Diagram of the Proposed Technique

B. System Design

We consider a network with two mobile SenCars and static sensor nodes randomly deployed. Each SenCar is equipped with two antennas, while every sensor has a single antenna and is statically scattered over the field.

In SDMA, multiple receive antennas are used in the uplink transmission. Each sensor's signal can be demodulated by using a linear decorrelator receiver at the Sencar.

Each Sencar is equipped with two antennas and normal sensors nodes acting as the source nodes are equipped with a single antenna to transmit the sensed data to their corresponding Sencar. Figure 2 shows the transceiver architecture of SDMA with the linear decorrelator.

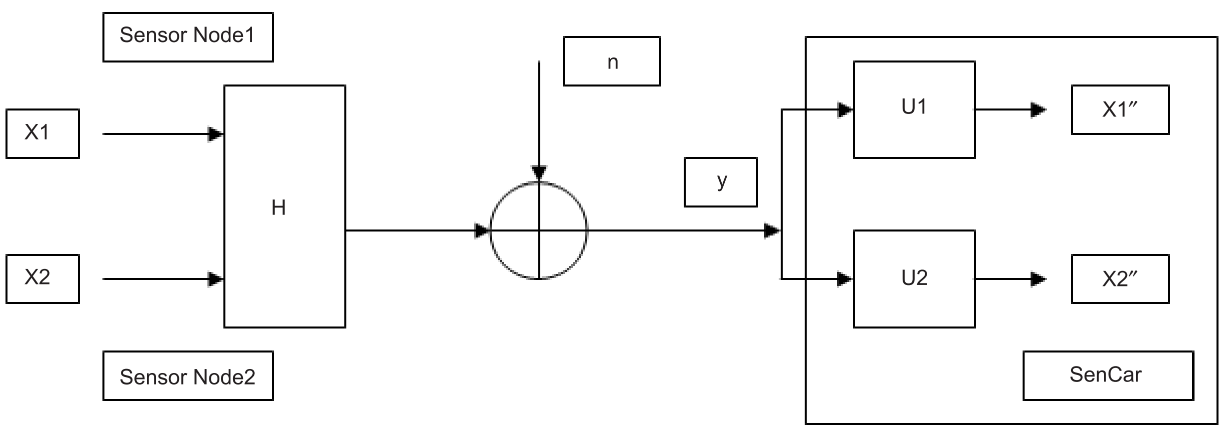

Figure 2: SDMA with linear decorrelator strategy

C. Transmission using SDMA

Notations:

i	sensor
i_1, i_2	two receive antennas of Sencar
H	channel co-efficient matrix
h_1 and h_2	two columns of H
h_i	complex channel coefficient vector between i and i_1, i_2

x_1, x_2	Data sensed by sensors S_1 and S_2
u_1, u_2	Filter vectors for sensors S_1 and S_2
P_t	Transmit power of S_1 and S_2
Pr_1, Pr_2	Received power at S_1 and S_2
SNR_1, SNR_2	SNR of the data from S_1 and S_2
n	Channel noise
δ_0	Receiver Sensitivity
δ_1	SNR threshold to correctly decode the received data

Algorithm:

1. Let $h_i = [h_{i1}, h_{i2}]^T$
2. If S_1 and S_2 want to transmit x_1 and x_2 to Sencar, the received vector at Sencar is given by

$$y = h_1 x_1 + h_2 x_2 + n \tag{1}$$

3. In order to remove the inter flow interference among the sensors, the received signal y is projected onto the subspace orthogonal to the one spanned by the other channel vector.

   Choose u_1 and u_2 as such that

$$u_1 \times h_2 = 0$$

   and

$$u_2 \times h_1 = 0$$

   Hence, the received signal can be decoded as

$$\dot{x}_1 = u_1^* y = u_1^* h_1 x_1 + u_1^* n$$

$$\dot{x}_2 = u_2^* y = u_2^* h_2 x_2 + u_2^* n \tag{2}$$

4. Using (11), x_1, x_2 are separated from each other to cancel the inter flow interference.
5. u_1 and u_2 can be chosen as vectors that in lie in the same direction as the projection of h_1 onto v_1.
6. To successfully decode the received signal by the Sencar, the following criteria should be satisfied:

$$Pr_1 = P_t \left| u_1^* h_1 \right|^2 \geq \delta_0, SNR_1 = P_t \left\| u_1^* h_1 \right\|^2 / \sigma^2 \geq \delta_1$$

$$Pr_2 = P_t \left| u_2^* h_2 \right|^2 \geq \delta_0 \ SNR_2 = P_t \left\| u_2^* h_2 \right\|^2 / \sigma^2 \geq \delta_1 \tag{3}$$

7. Any two S_1 and S_2 that satisfy (3) can successfully make concurrent data uploading to Sencars.

D. Cluster Formation and Anchor Point Selection

Let NS_k be the set of nodes

1. When the nodes are deployed in the network, it is initially grouped into clusters based on connectivity factor.

   That is, each node within the cluster must be located within the communication range of all nodes in the same cluster.

$$NS_k = \{i, j | q_{i,j} = 1 \text{ for } i \neq j\} \tag{4}$$

where, S_k denotes number of sensor in the set NS_k

M denotes number of clusters in the network

Q denotes connectivity matrix,

$k = 1, 2, \ldots, M$ and $i, j = 1, 2, \ldots, N_k$

$$Q = \begin{cases} q_{i,j} = 1, & \text{if nodes } N_i \text{ and } N_j \text{ are connected} \\ q_{i,j} = 0, & \text{Otherwise} \end{cases}$$

If S_k is low for a cluster, then the sensor node will be removed from the relevant cluster and moved to the cluster with high S_k.

The anchor points are selected for intermediate data collection based on the connectivity and node degree, node compatibility and the distance between the sensors of two adjacent clusters.

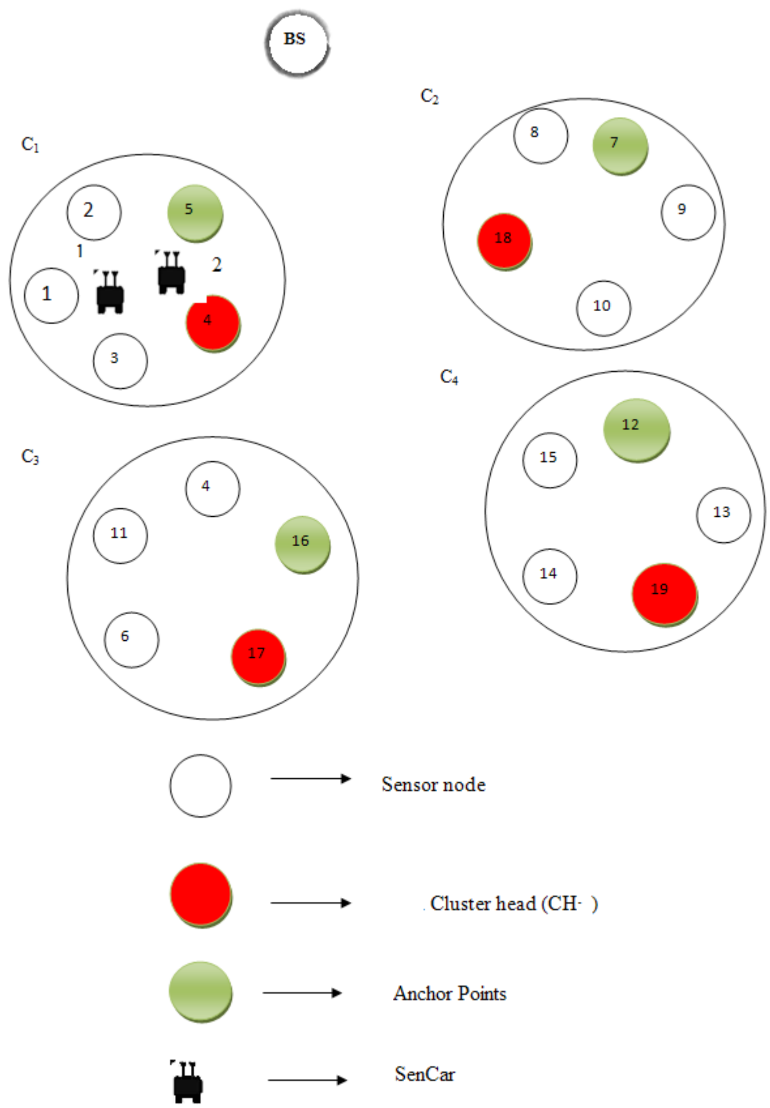

Figure 3: Cluster Formation and Anchor node deployment

E. Categorizing the Clusters

Let C_i be the cluster with CH_i, $i = 1, 2, \ldots, m$.

The residual energy (E_{res}) of each node (N_i) after performing one data communication is estimated using following formula.

$$E_{res} = E_i - (E_{tx} + E_{rx}) \tag{5}$$

where, E_i is the Initial energy of the node

E_{tx} & E_{rx} are the energy utilized at the time of transmission and reception of data.

Then the average residual energy of C_i determined by CH_i is given by

$$AE_{res} = \frac{1}{k}\sum_{j=1}^{k} E_{res}(j) \tag{6}$$

where, k is the number of cluster members in C_i

$E_{res}(j)$ is the residual energy of j^{th} cluster member.

Then C_i can be categorized as

$$C_i = \begin{cases} CL_1, | AE_{res} < T_{RE} \\ CL_2, | AE_{res} \geq T_{RE} \end{cases} \tag{7}$$

F. Mobile Data Gathering Using MCST

Let SC_x, $x = 1, 2$ be the two SenCars to be deployed.

The sensor nodes move into sleep mode when the data gathering process in the respective cluster is completed.

z represents the number of remaining SenCars at each iteration.

After determining the anchor points, the data gathering can be performed using the following steps:

1. CH estimates the average residual energy of each cluster using (6).
2. The threshold value for residual energy (T_{RE}) is maintained in route cache.
3. Each cluster is categorized into CL_1 or CL_2 according to (7).
4. SC_x are deployed in the middle of the network area.
5. Each CH_i transmits the information to SC_x which contains its location, id and category.
6. The anchor points are organized into tree structure assigned with weight as the metric for partition.
7. The minimum spanning tree T(V, E) is detected among selected polling points at the static data sink.
8. The weight of each selected anchor point is calculated using the following criteria:

$$q(a) = \sum_{b \in V(subT(v))} \zeta(|r_b| - |C_u|) + \sum_{e \in E(subT(a))} \eta X_e, v \in A' \tag{8}$$

ζ and η = constant co-efficient representing the time taken by the sensor to upload its data and for a SenCar to move a unit distance.

sub T(a) = sub-tree of T rooted at a

V(.) and E(.) = vertices and edges on a tree.

r_b = set of associated sensors with selected anchor point a.

C_u = compatible pairs among the sensors related with selected anchor point a.

X_e = length of edge e.

Note that the root has maximum weight when compared to all other vertices.

9. The spanning tree is split into N parts by iteratively finding a sub-tree t based on the weight of each vertex on T and t.
10. Initially, the farthest leaf vertex v on T with the minimum weight has been detected.
11. If $q(a) = Q_T/z$,

    Then

        Parent vertex (K(v) on T is detected

    End if
12. The weight of the parent is detected and Step 8 is repeated until $q(v) \geq Q_T/z$
13. This vertex v is recorded and considered as the root of the subtree t.
14. All the vertices on t are removed from t. That is, relevant anchor points on t will be assigned to a SenCar.
15. Q_T, z and $q(v)$ are assigned for each vertex is updated.
16. The above process is repeated to find another sub-tree.
17. SC_1 selects the clusters $C_j \in CL_1$ and SC_2 selects the clusters $C_j \in CL_2$
18. SC_x fetch the anchor points corresponding to $C_{j.}$
19. When a SC_x reaches the first anchor point, the cluster members within the relevant cluster are scheduled to communicate with SC_x.
20. If the two cluster members within C_j are compatible (i.e. they are connected by a link), they will upload the data simultaneously using SDMA at time t (as explained in section 3.3).

4. SIMULATION RESULTS

A. Simulation Parameters

We use NS2 to simulate the proposed Cluster based Mobile Data Gathering Using Minimum Covering Spanning Tree (MCST-CMDG) technique. In this simulation, the area size is 500 meter × 500 meter square region. The proposed MCST-CMDG technique is compared with the mobile data gathering using MCST [14] technique. The performance is evaluated in terms of delay, packet delivery ratio and average energy consumption.

The simulation settings and parameters are summarized in Table 1.

Table 1
Simulation parameters

Number of Nodes	100
Area Size	500 X 500m
MAC protocol	802.11
Simulation Time	50 sec
Traffic Source	CBR
Number of SenCars	2
Propagation	Two Ray Ground
Antenna	Omni Antenna
Initial Energy	25.0 Joules
Transmission Power	0.66 watts
Receiving Power	0.396 watts
Transmission Range	250, 300, 350, 400 and 450 m
Speed of SenCars	20, 25, 30, 35 and 40 m/s

B. Results and Analysis

The simulation results are presented in the next section.

A. Based on Transmission Range

In order to analyze the impact of clustering on various transmission ranges, the transmission range is varied as 250, 300, 350, 400 and 450m.

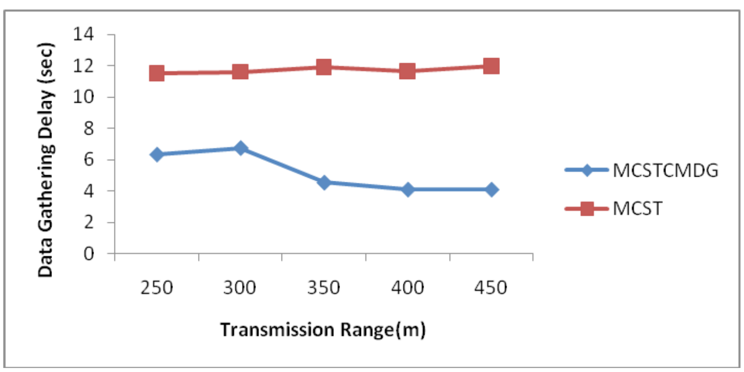

Figure 4: Data Gathering Delay Vs Transmission Range

Figure 4 shows the data gathering delay occurred for MCSTCMDG and MCST techniques. When the range increases, the number of clusters formed will be less and hence the data gathering time tend to reduce. As seen from the figure, the delay of MCSTCMDG reduces from 6.3 to 4.0 seconds. Since in MCST, polling points are considered based on coverage constraint only without clustering, more polling points are needed, resulting in the increase of data gathering delay. Hence MCSTCMDG has 55% reduced delay, when compared to MCST.

Figure 5 shows the packet delivery ratio measured for MCSTCMDG and MCST techniques. When the range increases, data will be gathered from more number of nodes and hence the packet delivery ratio tends to increase.

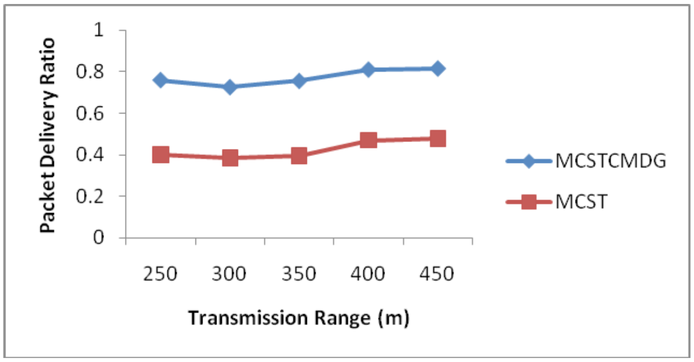

Figure 5: Packet Delivery Ratio Vs Transmission Range

As seen from the figure, the delivery ratio of MCSTCMDG increases from 0.75 to 0.81 whereas for MCST, it increases from 0.39 to 0.47. Since MCSTCMDG handles the buffer overflow problem by gathering data from the energy draining clusters separately using SenCar1. Hence MCSTCMDG has 45% increased delivery ratio, when compared to MCST.

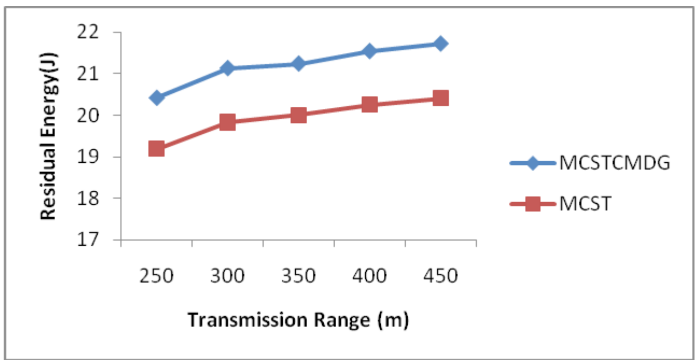

Figure 6: Residual Energy Vs Transmission Range

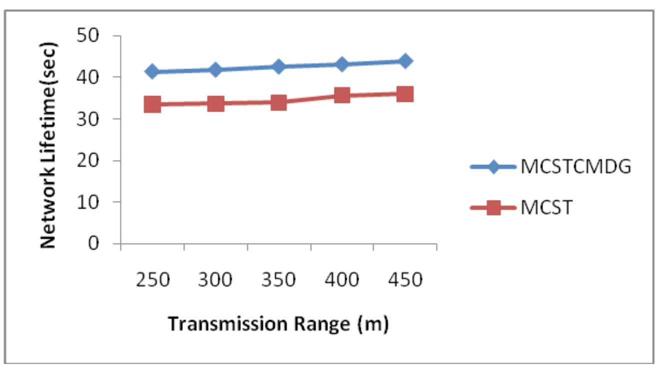

Figure 7: Network Lifetime Vs Transmission Range

Figure 6 and 7 show the results residual energy and network lifetime for MCSTCMDG and MCST techniques. When the range is increased, the transmitting power of sensors becomes less thereby increasing the average residual energy and network lifetime. When comparing the performance of the two techniques, we infer that MCSTCMDG outperforms MCST by 6% in terms of residual energy and 18% in terms of network lifetime. This is due to the fact that, in MCSTCMDG, each SenCar gathers the data based on the average residual energy of clusters.

B. Based on Speed of SenCars

In order to analyze the effect of SenCar's mobility on data gathering, the speed of the SenCars is varied as 20, 25, 30, 35 and 40m/s.

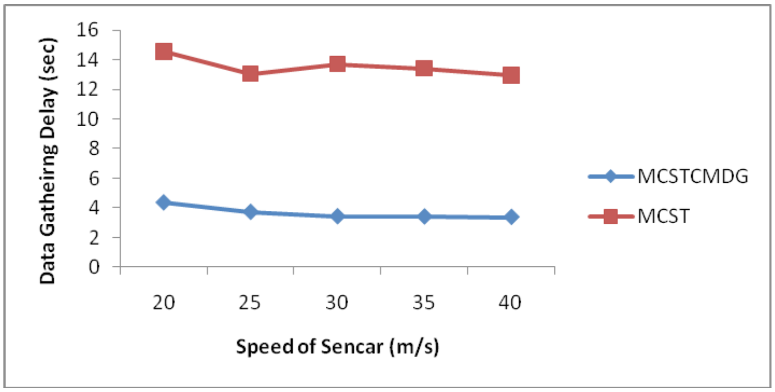

Figure 8: Data Gathering Delay Vs Speed of SenCars

Figure 8 shows the data gathering delay occurred for MCSTCMDG and MCST techniques. When the speed of the SenCar increases, the length of its visiting tour decreases, leading to decrease in data gathering time. As seen from the figure, the delay of MCSTCMDG reduces from 4.3 to 3.3 seconds. Since in MCST, polling points are considered based on coverage constraint only without clustering, more polling points are needed, resulting in the increase of data gathering delay. Hence MCSTCMDG has 73% reduced delay, when compared to MCST.

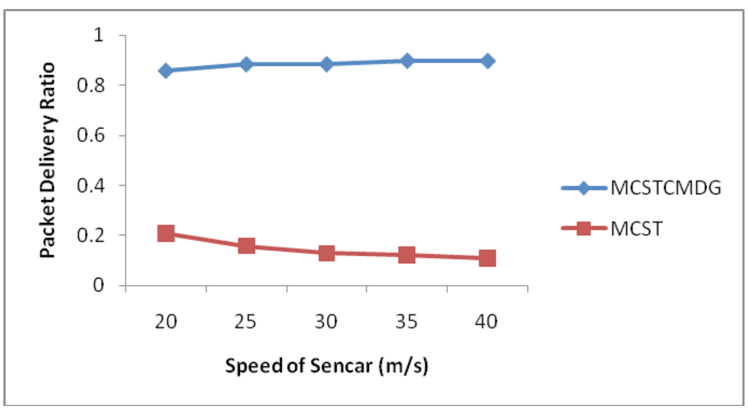

Figure 9: Packet Delivery Ratio Vs Speed of SenCar

Figure 9 shows the packet delivery ratio measured for MCSTCMDG and MCST techniques. When the range increases, data will be gathered from more number of nodes and hence the packet delivery ratio tends to increase. As seen from the figure, the delivery ratio of MCSTCMDG increases from 0.75 to 0.81 whereas for MCST, it increases from 0.39 to 0.47. Since MCSTCMDG handles the buffer overflow problem by gathering data from the energy draining clusters separately using SenCar1. Hence MCSTCMDG has 45% increased delivery ratio, when compared to MCST.

Figures 8 to 11 show the results of delay delivery ratio and energy consumption by varying the SenCar speed from 20 m/s to 40 m/s for MCSTCMDG and MCST techniques. When comparing the performance of the two protocols, we infer that MCSTCMDG outperforms MCST by 73% in terms of delay, 83% in terms of delivery ratio, 3% in terms of residual energy and 22% in terms of network lifetime.

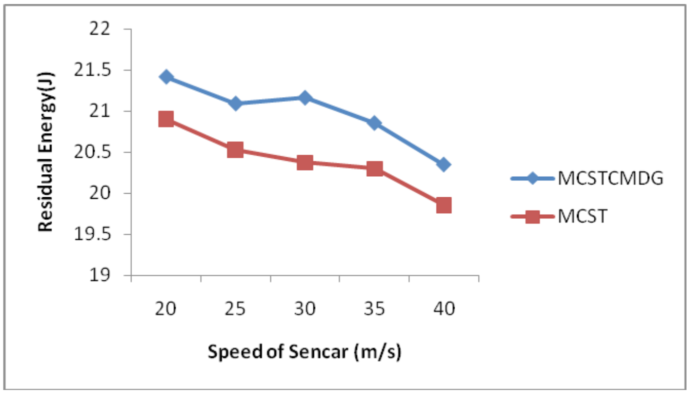

Figure 10: Residual Energy Vs Speed of SenCars

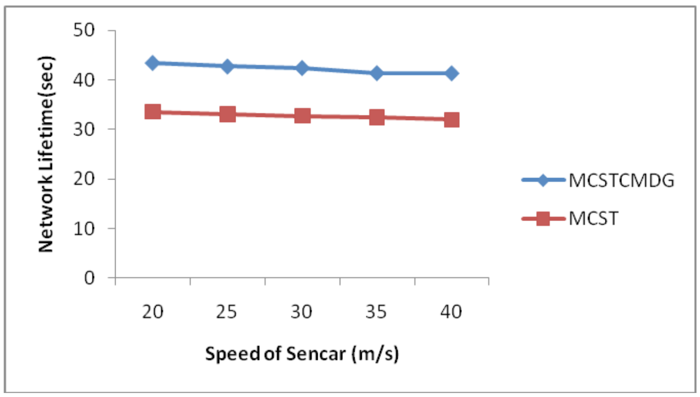

Figure 11: Network Lifetime Vs Speed of SenCars

5. CONCLUSION

In this paper we have proposed to develop a cluster based Mobile Data Gathering Using MCST technique in WSN. In this technique, multiple sensors are arranged to form clusters. The anchor points are selected based on the connectivity and node degree, node compatibility and the distance between the sensors of two adjacent clusters. After determining the anchor points, the average residual energy of each cluster is determined by the CH. Then the clusters are classified into two categories as clusters with residual energy less than a threshold and clusters with residual energy more than the threshold. Two SenCars with multiple antennas are deployed which applied SDMA technique for data gathering. One Sencar is responsible for gathering data from the high energy clusters and the other one gathers the data from clusters of lower energy. The visiting tour of each Sencar among the selected anchors is performed using the Minimum Covering Spanning Tree (MCST) Algorithm. By simulation results, we have shown that the proposed technique minimizes the delay while improving the network efficiency.

REFERENCES

[1] Suraj Sharma and Sanjay Kumar Jena, "Data Dissemination Protocol for Mobile Sink in Wireless Sensor Networks", *Journal of Computational Engineering*, pp. 1-10, 2014.

[2] Rongbo Zhu, Yingying Qin, and Jiangqing Wang, "Energy-Aware Distributed Intelligent Data Gathering Algorithmin Wireless Sensor Networks", *International Journal of Distributed Sensor Networks*, pp. 1-13, 2011.

[3] Djuraev Mamurjon and Byoungchul ahn, "A novel data gathering method for large wireless sensor networks", *International Conference on Electronic engineering and computer science,* pp. 288-294, 2013.

[4] I. Snigdh, D. Gosain and N. Gupta, "Optimal sink placement in backbone assisted wireless sensor networks", *Elsevier, Egyptian Informatics Journal*,2016.

[5] B. Sivakumar and B. Sowmya, "An Energy Efficient Clustering with Delay Reduction in Data Gathering (EE-CDRDG) Using Mobile Sensor Node", *Springer, Wireless Personal Communication*, 2016.

[6] Abdullah I. Alhasanat, Khaled D. Matrouk, Haitham A. Alasha'ary and Ziad A. Al-Qadi, "Connectivity-Based Data Gathering with Path-Constrained Mobile Sink in Wireless Sensor Networks", *Wireless Sensor Network*, Vol 6, pp. 118-128, 2014.

[7] Wei-Cheng Chu and Kuo-Feng Ssu, "Sink discovery in location-free and mobile-sink wireless sensor networks", *Computer Networks*, Vol 67, pp. 123-140, 2014.

[8] Xinxin Liu, Han Zhao, Xin Yang, and Xiaolin Li, "Sink Trail: A Proactive Data Reporting Protocol for Wireless Sensor Networks", *IEEE TRANSACTIONS ON COMPUTERS*, Vol. 62, No. 1, JANUARY 2013.

[9] Saim Ghafoor, Mubashir Husain Rehmani c, Sunghyun Cho and Sung-Han Park, "An efficient trajectory design for mobile sink in a wireless sensor network", *Computers and Electrical Engineering*, Vol 40, pp. 2089–2100, 2014.

[10] Marwa M. Hassana, Rabie A. Ramadan and Hatem M.El Boghdadic, "Finding the Best Sink Location in WSNs with Reliability Route Analysis", *International Workshop on Wireless Networks and Energy Saving Techniques*, 2014.

[11] Miao Zhao, Ming Ma, and Yuanyuan Yang, "Efficient Data Gathering with Mobile Collectors and Space-Division Multiple Access Technique in Wireless Sensor Networks", *IEEE Transactions On Computers*, Vol. 60, No. 3, March 2011.

[12] Yimin Yu, Chao Song, Ming Liu and Haigang Gong," Energy-Efficient Algorithm for Sensor Networks with Non-Uniform Maximum Transmission Range", *Sensors* 2011, Vol. 11, pp. 6203-6213.

[13] Marwa M. Hassana, Rabie A. Ramadan and Hatem M.El Boghdadic, "Finding the Best Sink Location in WSNs with Reliability Route Analysis", *International Workshop on Wireless Networks and Energy Saving Techniques*, 2014.

[14] Miao Zhao, Ming Ma, and Yuanyuan Yang, "Efficient Data Gathering with Mobile Collectors and Space-Division Multiple Access Technique in Wireless Sensor Networks", *IEEE Transactions On Computers*, Vol. 60, No. 3,2011.

[15] Yimin Yu, Chao Song, Ming Liu and Haigang Gong,, "Energy-Efficient Algorithm for Sensor Networks with Non-Uniform Maximum Transmission Range", *Sensors*, Vol. 11, pp. 6203-6213, 2011.

[16] Junzhao Du,Hui Liu, Longfei Shangguan, Luo Mai, Kai Wang and Shucong Li, "Rendezvous Data Collection Using a Mobile Element in Heterogeneous Sensor Networks", *IEEE INTERNATIONAL JOURNAL OF DISTRIBUTED SENSOR NETWORKS*, 2012.

[17] Miao Zhao,and Yuanyuan Yang, "A Framework of Joint Mobile Energy Replenishment and Data Gathering in Wireless Rechargeable Sensor Networks", *IEEE TRANSACTIONS ON MOBILE COMPUTING*, Vol. 13, No. 12, 2014.

[18] Huan Zhaoa, Songtao Guoa, Xiaojian Wanga and Fei Wang, "Energy-efficient topology control algorithm for maximizing network lifetime in wireless sensor networks with mobile sink", *Applied Soft Computing*,Vol 34, pp. 539–550, 2015.

[19] Jiqiang Tanga, Hongyu Huanga, Songtao Guoa and Yuanyuan Yang, "Dellat: Delivery Latency Minimization in Wireless Sensor Networks with Mobile Sink", *J. Parallel Distrib. Comput*., Vol 83, pp. 133–142, 2015.

[20] I. Snigdh and D. Gosain, "Energy Analysis for Trajectory based Sink Mobility in WSN", *Procedia Computer Science*,Vol-54, pp. 118 – 126, 2015.

[21] Behnam Behdani, Young Sang Yun, J. Cole Smith and YeXi, "Decomposition algorithms for maximizing the lifetime of wireless sensor networks with mobile sinks", *Computers & Operations Research*, Vol 39, pp. 1054–1061, 2012.

[22] Yu Gu, Yusheng Ji, Jie Li, Fuji Ren, Baohua Zhao, "EMS: Efficient mobile sink scheduling in wireless sensor networks", *Ad Hoc Networks*, Vol 11, pp. 1556–1570, 2013.