A Cluster-Based Hierarchical Approach for Scheduling the Mobile Element in Wireless Sensor Networks

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In Wireless Sensor Networks, recent studies reveal mobility of the sink nodes as a solution for collecting the data from the sensor nodes. The mobile element acts as a mechanical carrier for collecting the data from the sensor nodes. Each sensor node is assigned a buffer for accumulating the sensed data and data loss occurs if the buffer overflows. Therefore, scheduling the mobile element such without any buffer overflow is a major issue. The proposed algorithm incorporates the partitioning of the network into clusters based on the geographical regions. Within each cluster, a hierarchical tree structure is formed such that only the base-level nodes are visited by the mobile element. The collected data flows down the hierarchical tree to the base level nodes until all the collected data reaches the mobile node.

***Index Terms*—sensor networks, mobile sink, scheduling, cluster**

I.INTRODUCTION

There is an increased focus in the field of Wireless Sensor Networks (WSN) which is used for crucial applications such as environmental monitoring , Habitat monitoring, battlefield surveillance, nuclear, chemical and biological attack detection. Sensor nodes can be placed in endangered areas where the data collection becomes a challenging problem.

Each sensor node is assigned a buffer to store the collected data. The deadline of the node is the time up to which the buffer will not overflow. The data sensed by the sensor nodes need to be transferred to a base station, where it can be analyzed by the field experts. A severe drawback in such a scenario is that, in addition to sensing and transmitting their data, the nodes near the base station has to relay the data from the nodes that are farther away which leads to energy drain of the near-by nodes. Researchers have proposed mobility as a solution for this problem of data gathering [1]. The mobile element which acts as a base station visits all the nodes in order to collect the data and this problem of scheduling the visit of the mobile element is called the Mobile Element Scheduling (MES) problem.

We propose a hybrid approach of partial relaying of data by the sensor nodes (a scenario of a static base station) but no energy holes are created because of the partitioning of data into subgroups to the next level nodes. In addition, the base station acts as a mobile element which collects the data from the near-by nodes in a cluster. The bottleneck in this mobile base station is that the mobile element has to visit all the nodes before their deadline and also to visit the nodes in non-reachable regions. To overcome the above problem, we have proposed the solution such that the mobile element will visit only the near-by nodes within the cluster to collect the sensed data and the relayed data.

II.RELATED WORK

This section presents the work related to the scheduling problem in which mobile element (ME) has proved as an alternative to multi-hop communication for WSN. In the literature, various types of mobility such as random mobility, predictable mobility and controlled mobility have been considered for mobile element in WSNs. In our problem we have assumed controlled mobility for the ME to improve the reliability of the WSNs [3]. Using ME in WSNs for MES problem has been proved as NP complete. Some heuristics solutions have been discussed in [1]. The first algorithm, the Earliest Deadline First(EDF) implies the node with the closest deadline is visited first. In EDF with k-Lookahead, instead of going to a node whose deadline is earliest, two earliest deadline nodes are visited so that both of the deadlines are met. But the

Minimum Weighted Sum First (MWSF) is designed which give weights to deadlines and cost and goes to the node which has the minimum weighted sum.

Several classes of Vehicle Routing Problem have been suggested in the literature. They focus on the common issue of efficiently managing the vehicle fleet for the purpose of saving the customers. For our scenario , the vehicle fleet is the mobile element and the serving customers are the sensor nodes. The most basic VRP is the capacitated vehicle routing problem (CVRP) in which a fixed fleet of vehicles are housed in a central depot. The vehicle routing problem with time windows (VRPTW) is a generalization of the CVRP with the further complexity of time windows and other time data. The VRP is extended for multiple vehicles with heterogeneous capacity and further extended to multiple depots. This paper[2] presents a mixed-integer linear mathematical programming formulation(MILP) for the VRPTW problem.

Exploring the spatial correlation of sensing data has been made by dynamically partitioning the sensor nodes into clusters so that the sensors in the same cluster have similar surveillance time series. A generic framework [4] has been developed to address the challenges such as how to schedule the sensors in a cluster, how to dynamically maintain the cluster in response to environmental changes etc. The data collection can be classified into continuous data collection and event detection data collection. More amount of data has to be transmitted for continuous data collection and achieving energy is a challenging issue in such a scenario.

III. CLUSTER-BASED SCHEDULING ALGORITHM

A.. Problem Formulation

The Mobile Element Scheduling (MES) is defined as the scheduling of the ME such that none of the buffers overflow. The nodes communicate within the limited range. The data sensed by the node are stored in a buffer. This data is forwarded to the sink node through the neighboring sensor nodes. The sink node has an unlimited buffer capacity.

B. The Proposed Cluster-Based Scheduling Algorithm (CBS)

The CBS algorithm involves two phases. The first phase entails the cluster formation with reference to the tree structure and the second phase describes the actual data transmission of all the nodes within the cluster to be forwarded to the ME. At the initial stage, the nodes are divided into different clusters based on their geographical region. The nodes that are to be visited by the ME are identified in the following phase. Hence for each cycle, the ME takes the same path irrespective of the number of nodes within a cluster. This classification paves way to categorize the end nodes where the overall collected data has to be relayed by the remaining nodes within that cluster will be relayed. This algorithm partially inherits the static Base Station (BS) where all the nodes relay data to the BS. A major disadvantage of such a approach is that energy hole is created to the nodes-near the sink because they relay all the data from the other nodes apart from the sink nodes. Such a scenario does not occur in our proposed algorithm because the data has been dynamically divided between the next level nodes such that none of the single node is overloaded.

1) Formation of Cluster-Based Hierarchical Tree Structure

1. Group the sensor nodes into different clusters according to their geographical region. Consider one of the cluster as in Fig.1 and within that cluster the nodes form a tree structure.
2. A baseline of nodes along a linear path is found in the cluster. The sink node moves along this line as indicated in Figure1. The sink node broadcasts a value k=0 as it moves through the specified path.
3. Initially the ‘k’ value in the sensor nodes is set to infinity. The sensor nodes on receiving the ‘k’ value which indicates the hop distance from the sink node, it determines its position in the tree as the lowermost nodes. It broadcasts the value ‘**k +1**’ to its neighboring nodes. Sending node is the parent node and the receiving node is the child node.
4. If the received ‘k’ value is greater than its current value then the new value is discarded.

5. If the received 'k' value is equal to its current value it stores the sending (parent) node's ID in the 'parents' list.

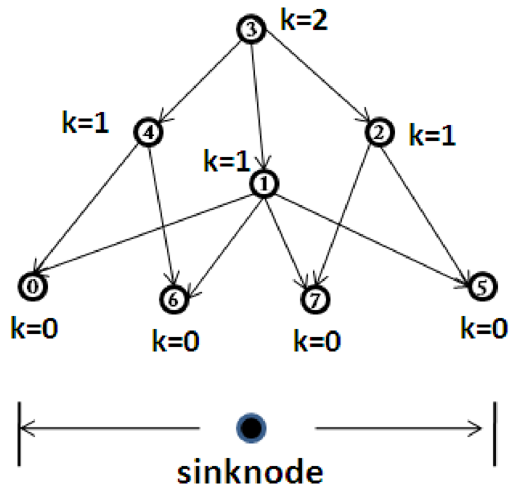

Figure.1: Nodes within a single cluster which represents the tree structure. The mobility of the sink node is only through the base-level nodes (along the line shown).

Nod e ID	'k' value	No. of Parents (m)	Parent Nodes
0	0	1	(Sink Node)
1	1	4	0, 5, 6, 7
2	1	2	5, 7
3	2	3	1, 2, 4
4	1	2	0, 6
5	0	1	(Sink Node)
6	0	1	(Sink Node)
7	0	1	(Sink Node)

Table 1: Tree Representation of Fig.1

The 'k' value (Tab.1) represent the hierarchical structure of the nodes within the cluster with the larger value characterizing the top-level node and the least value (i.e. 0) signifying the nodes that the ME will visit periodically. Since the ME visits only the boundary nodes, the higher level nodes partition their sensed data and forward it to the base nodes. Therefore the ME takes a linear path for collecting the data from all the sensor nodes. Thus, the total distance travelled by ME is minimized.

2) Data transmission to the boundary-near nodes

We have adopted the mechanism of distributing the data to all the nodes in the next lower level to avoid the problem of overloading the data to the near-sink nodes . Thus by scattering the data to the next level nodes, all the boundary nodes receive almost the same amount of data which implies that the near-sink sensors are not exploited thus preventing energy holes.

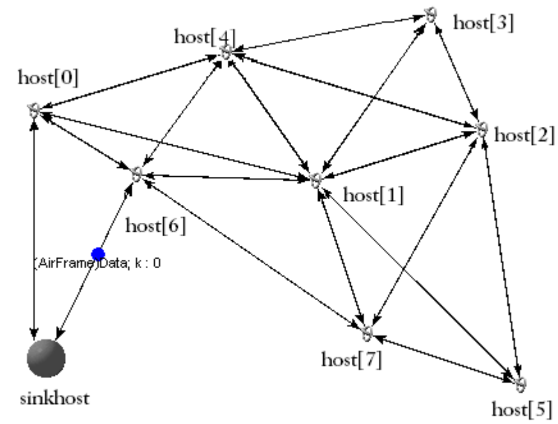

Figure 2. The data packet being relayed to the base node along with the 'k' value. The value of k = 0 indicates that the packet is moving towards the sink node from the base-level node.

Algorithm for dividing the sensor data and forwarding to the next level nodes:-

1. The sensor nodes divide the collected data into 'm' segments where 'm' is the no. of parents of the sensor node.
2. It sends each segment to each one of the parent in the 'parents' list (from prev. algorithm).
3. The parent node on receiving the segmented data from its child, again divides the data further into 'm' segments ('m' implies the no. of its parents) and send them down the tree. This process continues until all the data reach the sink node.

IV.PERFORMANCE EVALUATION

A.Impact of Partial Inheritance of Static Base Station over CBS

The major impact in the static BS is that the nodes near the sink run out of battery due to the relaying of data from the farther nodes. Our proposed algorithm exhibits a hybrid nature by taking over only the positive aspect of the static scenario so that the lifetime of the ME can be enhanced and at the same time none of the nodes create energy hole because of imparting only the partitioned data. Simulation has been done using OMNet++ which demonstrates there is no energy drain in the proposed CBS.

Initial power levels were assigned for each nodes and the energy level have been estimated along with their standard deviation which shows that no energy hole have been created for the proposed algorithm although it inherits some of the positive aspects of the static network and the most specific being the progress in the increasing lifetime of the ME.

B. Analysis of the Lifetime of the ME

In the proposed algorithm the ME visits only the baseline nodes which will avoid the battery drain since the number of nodes to be visited is minimal and also the mobility of the ME can be framed to traverse a linear path along the baseline nodes of all the clusters.

In Table.3, the first column indicates the number of nodes to be visited. The basic scheduling

No. of nodes	Basic Scheduling	CBS
6	6300	6500
8	6000	6670
10	5000	7340
12	5000	6143
14	4300	6075
16	2220	4654
18	2100	3456
20	1920	2400

Table.3 Network Lifetime

algorithm defines the ME visiting all the nodes based upon their deadline in which the energy-level of the ME degrades gradually owing to the visit of the ME to all the nodes. But in the proposed CBS the ME traversal path can be fixed initially and always it takes the same path relative to the time taken to visit all the baseline nodes. This confirms the increase in the lifetime of the ME which in turn improves the lifetime of the network since the frequent battery-drain of the ME is circumvented.

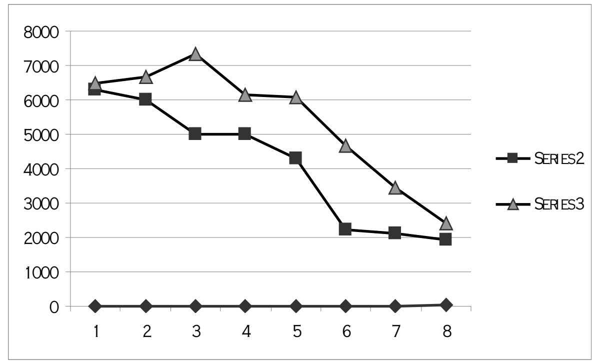

Figure.4 Comparison between a Basic Scheduling algorithm (series2) and the proposed CBS (series 3)

C. Minimum Speed Requirement of the ME

The minimum required speed has to increase with the increase in the node density in order to avoid buffer overflow. Since the ME visits the same set of baseline nodes irrespective of the increase in the node's density. The data loss rate is not affected by the node's density because the algorithm itself reduces the loss rate by periodic relaying of data in an hierarchical fashion. The ME speed will have a variation only if a new node is added at the base-level. This is because the ME has to visit the node which has the forwarded data. Since the ME takes the same path to visit only the baseline nodes, speed does not have a direct impact on the deadline misses. The speed can be chosen as a constant value as the path to be traversed is relative to the time taken to visit the nodes. After one full cycle, the ME will visit the same node at the same time which remains constant since the number of nodes to be visited is minimal

V. CONCLUSION

The dynamic deadlines of the ME have lead to the Mobile Element Scheduling (MES) problem. In the proposed cluster-based approach, the mobile element has to visit only the identified near-sink nodes. This minimizes the number of nodes to be visited by the ME. Relying on the near-sink nodes overrides the behavior of the static network which we have proved in our results. Our CBS algorithm provides higher performance in terms of data loss occurrence rate, data loss rate, minimum speed requirement, node density, lifetime of the ME and network lifetime. The performance of the CBS have been compared with the existing Basic Scheduling algorithm and we saw that CBS gives better results in most of the cases. The ME visits only the baseline nodes and if there is buffer overflow in any one of these nodes with reference to all the clusters, the lost data can be reconstructed since the partitioned data is available in all the remaining baseline nodes.

The current formulation does not include the waiting time of the ME since the ME is always in motion. The problem can be extended in this direction with reference to the speed of the ME. The problem of deadline miss (data loss occurrence) can be totally relinquished if the problem is modeled with multiple MES.

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