A Mixed-Integer Cost Estimation Model for Scheduling the Mobile Element in Wireless Sensor Networks

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Summary
In Wireless Sensor Networks, recent studies reveal mobility as a solution for collecting the data from the sensor nodes in a wireless sensor network. The mobile element acts as mechanical carriers 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 of the mobile element such that none of the buffer overflows is a major issue involved in collecting the data from the sensor nodes. The proposed problem incorporates the partition of the sensor nodes into clusters according to their geographical regions. Within each cluster, a hierarchical tree structure is formed such that the base-level nodes are the nodes visited by the mobile element. The remaining nodes within this region form a tree structure so that these nodes relay the data to the next hop nodes. The data is segregated to the next level nodes depending upon the number of nodes in that level. The grouping of data is dynamic since it is based upon the number of nodes in the next level. This occurs as a recursive relay process until it reaches the boundary nodes (i.e. nodes near the mobile element). Data collection of all the nodes from these boundary nodes by the mobile element implies the following: i)the visit of the mobile element is minimized ii) the lifetime of the mobile element is increased iii) occurrence of the loss of data will be reduced because at least a part of the data can be recovered due to the splitting up of the data between the next level nodes iv) the deadline for the collection of data from the sensor nodes will not be missed since there is a periodic relay of the collected data from the high-level to the boundary nodes. Further, this paper presents the mobile element scheduling problem (MES) as a mixed-integer programming (MIP) model and optimizes the cost by scheduling with earliness-tardiness penalties. The objective is to optimize the cost of the earliness-tardiness penalties and also to reduce the buffer overflow so that the capacity constraints are also taken into consideration. Also the MES-MIP modeling structure can be exploited to analyze the penalty cost involved in the scheduling of the ME which can be further employed for larger set of sensor nodes.

Index Terms: *cluster, mobile element, scheduling, sensor networks, mixed-integer problem*

1. 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. We can also foresee scenarios in which the frequent visit to the mobile node is not possible with reference to the deployed regions. Also the sensing rate of the sensor nodes will be different for different nodes for example, if we consider a traffic scenario, the data rate will have larger variations when the urban areas are compared with rural areas. The problem becomes even more complex if the sensor network is heterogeneous where the sensing rate will be different for the sensor nodes.

Each sensor node is assigned a buffer to store the collected data. The deadline of the node is the sampling rate of the sensor node within 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.

In this paper, we have extended our earlier work in which we have proposed a cluster-based algorithm in which the sensor nodes are clustered according to their geographical region and within each cluster they form a hierarchical tree structure. The nodes at the top level of the tree structure relay their collected data to the nodes in the next level within the cluster. The data relayed to the next level will lead to energy drain of the next-level nodes which will be even more intricate when it reaches the leaf node. To overcome this, at each level the collected data is divided according to the nodes in the next level and send to the next level nodes. Therefore the collected data will be periodically relayed to the next level nodes which imply that there will be no data loss. The data will be further relayed to the next level nodes until it reaches the lowest-level. The mobile element [ME] need not visit all the nodes in a cluster because it can collect the data from the leaf

Manuscript received May 5, 2010
Manuscript revised May 20, 2010

level nodes which will be the boundary nodes for that cluster. We can define similar clusters and the mobile element will visit only the boundary nodes of the cluster. This increases the lifetime of the mobile element since the number of nodes to be visited is minimal.

Also the accumulated data at the near-boundary nodes can be segregated based upon the node's identification and collected by the mobile element. There will be no deadline miss which will lead to data loss because the relaying of data acts in a recursive fashion until it reaches the base-line nodes. This problem proposes a hybrid approach of partial relaying of data by the sensor nodes (a scenario of a static base station) but no energy hole created because of the partitioning of data into subgroups to the next level nodes. In addition to that, the base station acts as a mobile element which collects the data from the near-by nodes in a cluster. Another 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.

Our approach also identifies that an early arrival of the ME will also make the ME to wait unnecessarily because an early arrival implies that no sufficient data has been collected in the buffer. Therefore the idle time of the ME leads to unnecessary energy consumption. Hence the ready time of the sensor node is also taken into consideration in order to identify the arrival time of the ME so that the penalty cost can be calculated. Obviously the penalty cost for the ME will be more for the first node to be visited and the last node to be visited compared to the other set of nodes in the network. While the former node will incur an early penalty cost(the cost for the energy consumption of the ME), the later will acquire a late penalty cost(the cost including the energy consumption of the ME and the data loss due to the late arrival of the ME). Since the MES problem has been proved to be a LP problem, a mathematical model has been proposed to optimize this incurred cost. The problem can also be extended to multiple MEs so that an optimal plan can be to visit as well as to minimize the penalty cost.

2. 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. Large amount of data has to be transmitted for continuous data collection and achieving energy is a challenging issue in such a scenario.

Our method is described as follows. First we define the clustering of the sensor nodes and how the nodes within the clustering will formulate a hierarchical tree structure. Further the data from the top level nodes are relayed to their direct link nodes. The data is being grouped and relayed to the next level according to the number of nodes in the next level. The ME has to visit only the edge nodes which have been framed initially for each cluster. The lifetime of the ME can also be increased in such an approach because the ME need not visit all the nodes in that cluster.

3. 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. The following assumptions are made regarding the sensor nodes and the ME.

- The sensor nodes represent a graph from 1… n.
- The ME can move in any direction without any latency of making any turns.
- The buffer size of the sensor node is indefinite.
- Data transfer between the ME and the sensor node is negligible.

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

The CBS algorithm involves two phases which we have initiated in our earlier work and we are further exploring in the same direction. The first phase involves 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) framework where all the nodes relay data to the BS. A major disadvantage of such an approach is that energy hole is created to the nodes-near the sink [1] 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 'n' number of nodes within 1 cluster. Similarly clusters are formed according to the total number of clusters.
2. Consider one of the clusters as in Fig.1 and within that cluster the nodes form a tree structure.
3. A baseline of nodes along a linear path is found in the cluster.
4. The sink node moves along this line as indicated in Figure1.
5. The sink node broadcasts a value k=0 as it moves through the specified path.
6. 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.
7. If the received 'k' value is greater than its current value then the new value is discarded.
8. If the received 'k' value is equal to its current value it stores the sending (parent) node's ID.
9. The Table.1 shows the final values in the nodes after the tree formation.

The 'k' value 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 mobile node visits only the boundary nodes of the cluster the next challenge is the data collection of all the nodes within that cluster.

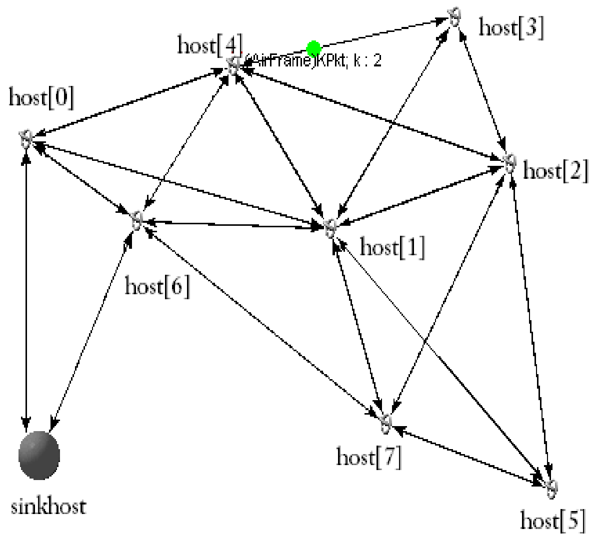

Figure.1: nodes within a single cluster which represents the tree structure.

The mobility of the sink node is only on the base-level nodes. The sink host is the mobile element which collects data from host0, 6, 7 & 5.

Similarly the ME visits only the boundary level nodes of all the clusters. Therefore it takes a linear path for collecting the data from all the sensor nodes. This is possible only because the data has been relayed from the top-level nodes to the boundary-level nodes.

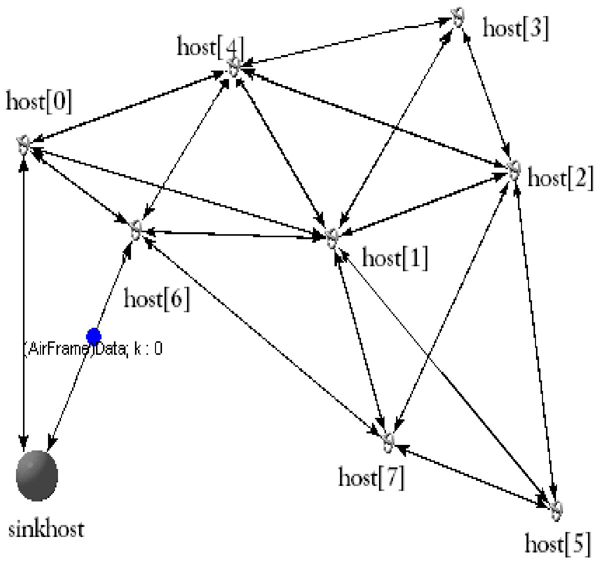

Figure2. Data being relayed to the base nodes 0, 6, 7 & 5 along with the 'k' value. The value of k = 0 states that the packet has reached the baseline node.

2) Data transmission to the boundary-near nodes
We have considered the mechanism of dividing the data to all the nodes in the next level in order to avoid the problem of overloading the data to the near-sink nodes. This proves that starvation will not occur for the boundary-level nodes because the data has been sub-grouped and only a part of the actual data has been relayed to the next-level nodes. The ME will segregate the data after the data collection has been completed for one full cycle (i.e. the ME visits all the nodes in the different clusters which has been defined in the following phase.

1. The sensor nodes divide the collected data into 'm' segments where 'm' is the no. of nodes in the next-level.
2. It sends each segment to each one of the next-level nodes.
3. The nodes that received the segmented data from its previous level divides the data further into 'm' segments ('m' implies the no. of nodes in the next level) and transmits to the next level until it reaches the baseline nodes. This process continues until all the data reaches the sink node.

After establishing all the clusters, the tree structure formation within each cluster determines the number of levels for the data traversal. The number of levels is the value of the 'k' which will be passed from the first level. When the data traverses each level the k value is decremented and the sink node will have the value of 'k' as zero. The decrement of the 'k' value is shown in Fig.3

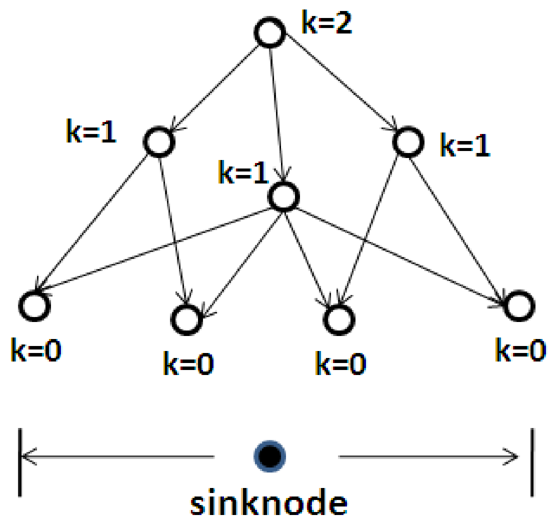

Figure.2 illustrates the value of 'k' being used to indicate the identification between the sink and the top-level node. This transmission of data along with the control packets which determines the traversal of data to the edge nodes is depicted in Figure.2.

4. 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 in Omnett++ which proves 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.

TABLE.2 Power level after simulation

Node ID	*CBS*	*Static n/w*
0	7689	900
1	9800	5500
2	9900	4026
3	9900	6076

4	9900	9900
5	6589	6589
6	6439	6439
7	6239	6239
8	8522	3330
9	8472	-2220
10	9800	9800
11	4206	4206
Std. Dev	1898.529	3409.127

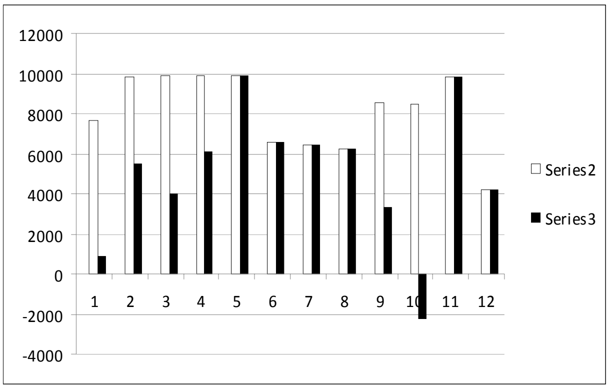

Figure.3 illustrates the power-level after the simulation.

In Fig.3 the x-axis represents the node ID and the y-axis represents the energy-level. Series 2 stands for the energy-level in the proposed algorithm and series 3 stands for the energy level in the static network. Also the static network creates an energy hole for node 10 which is depicted in the graph.

D. 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.

TABLE.3Network Lifetime

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

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

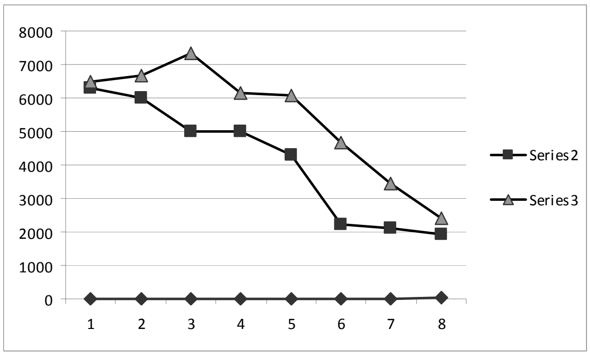

Figure.4 shows the comparison between the Basic Scheduling algorithm (series2) and the proposed CBS (series 3)

The number of nodes to be visited is well ahead in the Basic Scheduling algorithm when compared with CBS which forces the ME to run out of battery in the former method.

B. Minimum Speed Requirement for the Mobile Element

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 a 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 fixed since the number of nodes to be visited is minimal.

C. Uncertainty in the motion of the ME

In a dynamic mobile system, there will be uncertainty in the mobility of the ME [1]. One of the main reasons is the obstacle on the path of the ME. This may lead to incorrect prediction of the cost to visit a node which will give way for buffer overflow. Since the number of nodes to be visited is marginally decreased in the proposed CBS ,the uncertainty rate of the ME to visit the appropriate node before the deadline can be missed will also be less when compared with the Basic Scheduling algorithm. An uncertainty value has to be imposed on the mobility of the ME to avoid data loss. This additional overhead is necessarily not required in the proposed problem because the ME will take only a linear path to visit all the baseline nodes.

D. Impact of Buffer Overflow in the Baseline nodes

Since then, we have discussed only the problem of collecting the data from the baseline nodes. Consider a scenario in which the ME misses the deadline of any one of the baseline nodes. Even then the data can be recovered from the other baseline nodes because the data has been partitioned and relayed to the baseline nodes. In such circumstances the problem can also be extended as a data correlation model in which the data can be recovered even if the ME misses the deadline of any one of the node. Also the data loss occurrence rate will be minimal because the data can be recovered from the other baseline nodes using any of the existing correlation techniques.

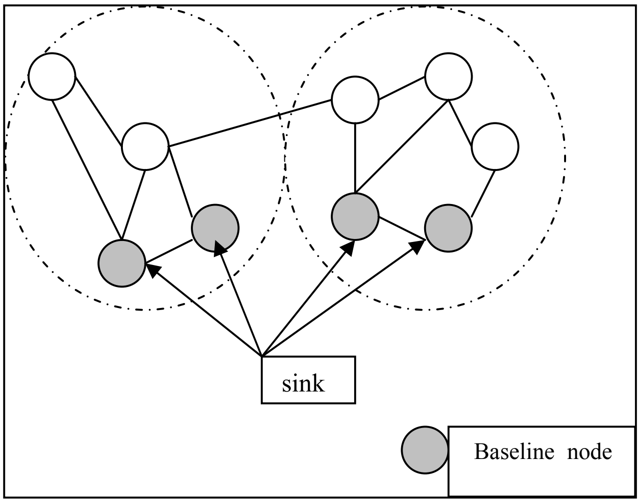

Figure.5 The sink node visits only the baseline nodes.

From Fig.5, the sink node visits only the baseline node and collects the accumulated data from these nodes. Similarly the ME visits only the baseline nodes of the different clusters. If there is a possibility of the ME to miss any one of these baseline nodes that can be recovered from the part of the data that has been relayed in the other edge nodes. Hence the data loss occurrence rates (the ratio of the number of sensors missing their deadline) and the data loss rate (the ratio of the data loss due to buffer overflow) will be less in the proposed CBS.

E. Mobile Element Scheduling with Multiple Mobiles

The MES with single mobile can also be extended to multiple mobiles provided the initial assumption of assigning the number of mobiles for the clusters should be made clearly. This is not impossible because the MEs take only a linear path to visit the nodes. And also the number of baseline nodes to be visited can be predicted at the preliminary stage itself in CBS. The issue of any of the baseline nodes missing the deadlines can also be overcome if multiple MEs are used. The number of ME can be assigned easily since we have a specific number of baseline nodes unless otherwise a new node is being added at the edge of the cluster.

5. MES-MIP Model Formulation

The pre-planning and scheduling of the ME can be used as a reference to optimise the scheduling of the ME in terms of cost. The sampling rate of the sensor node may be varied and the ready time of the sensor which is also taken as the input to find the minimum penalty cost.

Figure.2 illustrates the pre-planning and scheduling of the ME based upon the cost incurred for the ME's periodic visit.

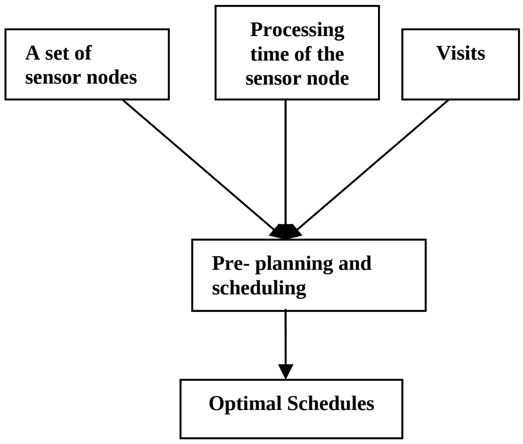

Figure.2. Pre-planned scheduling through MIP model

The planning and scheduling has to be performed so as to minimize the penalty cost of the Mobile Element (ME) which in turn implies maximum utilization of the mobile element. Maximum utilization of the ME is also equivalent to minimizing the idle time of the ME. This focuses on two areas, minimizing the power consumption of the ME, reducing the deadline misses. The objective is to find an optimal schedule with all the sensor nodes visited prior to their deadline, which is predicated on the fact that either early or late arrival of the ME results in an increase in the costs. If the ME visits the node earlier before it's due (i.e. not enough data to be collected from the buffer of the node) and hence incurs an earliness penalty. On the other hand, if the ME visits the node after the buffer is full, it incurs a tardiness penalty because of the data loss due to buffer overflow. Hence the Pre-planned MES problem is characterized as the optimal scheduling of the ME which incurs minimization in energy consumption of the ME, minimization the penalty cost subject to buffer constraints.

In order to formulate the pre-planned MES model, the following variables are introduced.

P_t - processing time of the sensor node
R_t - ready time of the sensor node
E_t - early arrival time of the ME
L_t - late arrival time of the ME
E_c - penalty cost for early arrival (α- energy consumption of the ME)
L_c - penalty cost for late arrival (2α- energy consumption of the ME and data loss)

Now, we have the following formulation

Minimize

$$Z = \sum (P_{ti} + (E_{ti} - R_{ti}) * E_{ci} + (R_{ti} - L_{ti}) * L_{ci}) \quad (1)$$

subject to

$R_{ti} \leq S_{ti}$ (2)
$D_i \leq L_i$ (3)
where i = 1,2,…. n which represents the number of nodes.
$E_t \leq R_t$ (4)
$L_t \geq R_t$ (5)

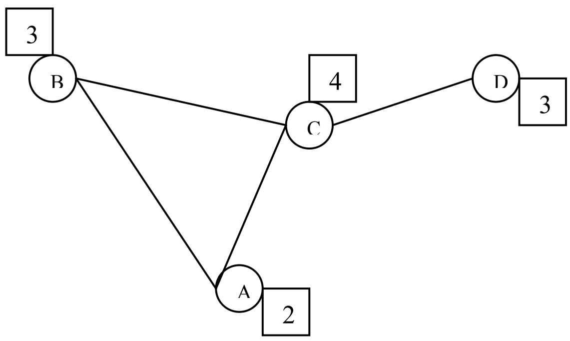

Figure.6 An example set of nodes along with their deadline for which the cost is to be calculated in pact with the proposed model.

The processing time of the node is considered to be 0.6 seconds. The ready time of each and every individual node is considered to be half of the deadline assigned to the respective nodes. Thus for Fig.6, the ready time is assumed as in the following table.

Table.4

Start time of node	*Ready time of the node*
1	1
2	1.5
3	2
4	1.5

From equations 1, 2 & 3, the cost incurred for each node can be calculated as follows. Initial assumption is α =50.

For node A,
0.6

For the next adjacent node (B)
0.6 + (1.5 − 2) * 50 + (2 − 1.5) * 100 = 25.6

For the next adjacent node (C)
0.6 + (2 − 3) * 50 + (3 − 2) * 100 =50.6

For the next adjacent node (D)
0.6 + (1.5 − 4) * 50 + (4 – 1.5) * 100 = 244.6

Hence our objective is to

Minimize
Z =0.6X1 + 25.6X2 + 50.6X3 + 244.6X4 (6)

The ME path will be A, B, C, D where the deadline is not taken into account. The ME just traverses the adjacent nodes in the path.

If the deadline is also taken into account, then the heuristic approach combined with the optimal solution to minimise the cost will be as follows

- Start with the node with the minimum deadline.
- Calculate the cost as the ME visits the node with the next consecutive minimal deadline.
- The solution will identify the cost that has been acquired by each individual node.

Now the visit of the node can be scheduled based upon their deadline and as well as the cost can be calculated imposing the constraints on equation.1.substituting the equation with values obtained when the scheduling is performed along with the deadline, we obtain

Minimize
Z = 0.6X1 + 25.6X2 + 75.6X3 + 100.6X4 (7)

Hence the visit of the ME based upon their deadline can be scheduled as node A,B,D,C. Note that the first two values remain the same in both equations (6) and (7) but the schedule changes in the next two nodes since node D has a least deadline when compared to node C.

The performance can also be compared with a different set of nodes with different set of deadlines. This optimal cost can be used to determine an optimal solution for a larger network with a larger number of sensor nodes. The graphical representation of Fig.3 in Fig.1 depicts a sharp increase in the cost value when the ME visits the last node because there is a deadline miss and this affects the cost value. But when the travelling cost is also accountable then that will validate the increase in cost. since only the adjacent set of nodes are visited in this approach, the last node to be visited irrespective of it's deadline has to admit this sharp increase in the cost value this approach will prove advantageous when travelling cost is also accountable since from Fig.3 it is clear that the ME element although it traverses the same path to reach C through D, the ME does not collects the data irrespective of the readiness of the node C

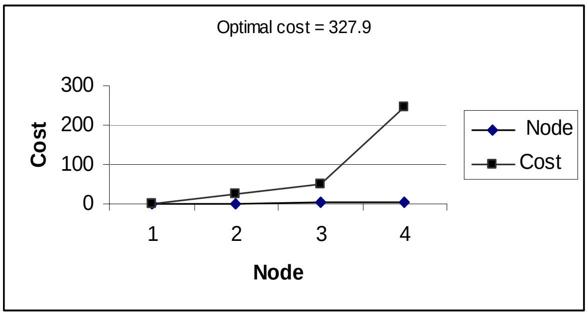

Figure.4 Illustration of the cost value for Figure.3 The optimal minimized cost is evaluated as 327.9 for this approach since the deadline is not taken into consideration.

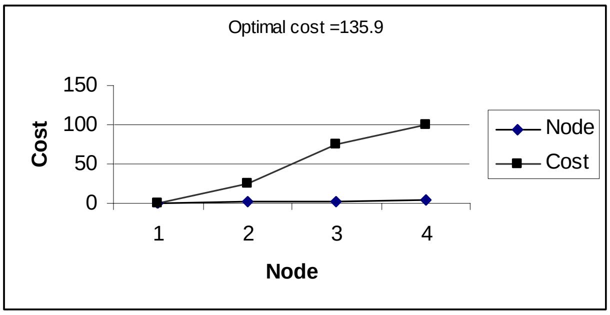

Figure.5 minimizing the cost with an additional constraint of the deadline of the nodes

The optimal cost with reference to the deadline shows the effectiveness of the model. The increase gives a good idea of how the cost can be estimation along with the deadline will prove its efficiency. The ME visit in the second approach will be according to its deadline. Therefore the ME visit will start with the smallest deadline in an increasing order. This implies that the proposed model to calculate cost will confirm that it can be applied to any set of algorithms and the cost can be evaluated accordingly. The heuristic algorithm available in the literature has its own advantages and limitations which can be analysed by evaluating the cost for these algorithms for different set of nodes. Simulation results have been performed through optimization solver for mixed integer programming and the results have been verified for the same number of nodes with different deadlines, for different set of nodes with different deadlines, by varying the processing time of the sensor node and the results proved to be optimal irrespective of the number of nodes.

D. Pre-planned Scheduling with multiple Mobile Elements

The problem can also be extended to multiple MES in which case, when the network grows larger, it can be divided into clusters and each ME can be assigned to each cluster. In such circumstances, our formulation can be indulged in individual clusters and finally the optimal cost can be computed for the whole network. The processing time may also be varied for each cluster which can also be imposed in the constraint (1) defined. The cluster formation can be depending upon the processing time, the geographical region in which for both the cases the proposed pre-planned scheduling model defined will be ideal.

E. Impact of Node Density

Since a pre-planning can be made for cost incurred in the visit of the ME, the number of nodes to be deployed can also be estimated .If the number of nodes is more than the estimated cost may be more depending upon the transmission range.

Fig.6.a densely deployed Fig.6.b sparsely deployed

An analysis can be performed between the cost acquired by a densely deployed set of nodes and a sparsely deployed set of nodes through this pre-planning scheduling model. The cost value estimation will give an outlook to whether increase or reduce the number of nodes to be deployed since the problem formulation generates an optimised cost.

F. Impact of Travelling Cost Constraint

In the problem formulation, the travelling cost is not considered which will also have a major impact particularly in minimizing the cost in the first approach of visiting the adjacent node irrespective of their deadlines. In Fig.3, the

ME visits the adjacent node and the graphical illustration shows the optimal cost is larger compared to the ME's with reference to the deadline. But in the latter approach, the ME's travelling cost will be much higher because the ME visits node A, B skips node C then visits node D due to their deadlines. But the travelling cost will be doubled for the visit of node D in this approach. Hence, an analysis can be performed between these two approaches (with deadline and without deadline) through the pre-planned scheduling problem formulation.

6. CONCLUSION

The dynamic deadlines of the ME lead to the Mobile Element Scheduling (MES) problem. In the proposed cluster-based approach, the near-sink nodes have been identified by determining a cluster within which a hierarchical tree structure is outlined. 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.

Also an initiative approach to determine the cost in scheduling has been projected. An MIP model of pre-planning the scheduling of the ME with the objective of minimizing the cost of the earliness and lateness penalty cost which in turn reduces the idle time of the ME has been formulated. The model explicitly considers the deadline, penalty cost, the processing time and the capacity constraints for a larger set of nodes in the wireless sensor network environment and generates useful scheduling for the ME. This model also proposes a novel approach to determine cost involved in the ME scheduling problem.

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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