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Data harvesting with mobile elements in wireless sensor networks

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Abstract: *In Wireless Sensor Networks, mobile elements (MEs) as powered carriers to convey data has been shown to be an actualway of persisting sensor network life time and transmitting information in segregated networks. As the data generation amounts of sensors may vary, some sensors need to be visited more recurrently than others. In this paper, a partitioning-based algorithm is presented that schedules the activities of MEs in a sensor network such that there is no data loss due to buffer excess. Simulation results show that the proposed Partitioning-Based Scheduling (PBS) algorithm performs well in terms of dipping the minimum required ME speed to prevent data loss, providing high predictability in inter-visit durations, and minimizing the data loss rate for the cases when the ME is controlled to move slower than the minimum required ME speed.*
Key word: *Mobile Element, wireless sensor network, Scheduling, Data collection, Base station*.

I. Introduction

A typical Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion, at different locations. The development of WSNs was motivated by military applications. However, WSNs are now used in civilian applications, including environment, traffic and habitat monitoring, healthcare and home automation. The use of wireless sensor networks (WSNs) have been proposed for critical applications such as battlefield surveillance, habitat monitoring, traffic monitoring, and nuclear, chemical and biological attack detection. Habitat and environmental monitoring represent a class of sensor network applications with enormous potential benefits for scientific communities and society as a whole. Instrumenting natural spaces with numerous networked micro sensors can enable long-term data collection at scales and resolutions that are difficult, if not impossible, to obtain otherwise. The intimate connection with its immediate physical environment allows each sensor to provide localized measurements and detailed information that is hard to obtain through traditional instrumentation. The integration of local processing and storage allows sensor nodes to perform complex filtering and triggering functions, as well as to apply application-specific or sensor-specific data compression algorithms. The ability to communicate not only allows information and control to be communicated across the network of nodes, but nodes to cooperate in performing more complex tasks, like statistical sampling, data aggregation, and system health and status monitoring. Increased power efficiency gives applications flexibility in resolving fundamental design tradeoffs,e.g. between sampling rates and battery lifetimes. Low-power radios with well-designed protocol stacks allow generalized communications among network nodes, rather than point-to-point telemetry. The computing and networking capabilities allow sensor networks to be reprogrammed or re-tasked after deployment in the field.

1.1 RELATED WORK:

The use of mobile essentials to harvest data has newly been considered in the nonfiction. Data MULES focuses on exploitation of mobile elements (called MULEs) in sparse sensor networks. The MULEs move randomly and collect data unscrupulously from sensor nodes. The movements of data gathering elements are not precise in this framework. In the message ferrying (MF) approach, message ferries are used to path data from one node to another in a spare ad hoc network. Based on a given traffic matrix, the aim of message ferrying approach is to find the best route of a ferry so that the average delay from source to destination is minimized while meeting the bandwidth obligation of flows. Associated to the MES problem are the Orienteering Problem (OP), the Prize Accumulating Traveling Salesman Problem (PC-TSP), as well as the original TSP. These problems deal with routing a vehicle to visit each city at most once. However in our problematic, a node may need to be stayed more than once before all other nodes are stayed because of the difference in buffer excess deadlines. In OP and Prize Collecting TSP, each city has an associated non-negative prize and the vehicle aims to collect the maximum total prize.

Though the mobile part in the MES problem also collects data that can be considered as prize, the value of the prize is forceful and depends on the time of the visit. The Vehicle Routing Problem (VRP) is defined as result a route for a vehicle that diminishes the total travel cost to deliver cargo between a siding and customers. Unlike TSP, VRP considers more than one vehicle and nodes can be visited more than once. Among many variants of VRP, VRP with deadline and Intermittent VRP(PVRP) are relevant to the MES problem. The aim of VRP with Deadline is to program a vehicle to visit as many nodes as possible by their deadlines. Diverse from our problem, each node in Target VRP is visited at most once. Furthermore, the target of the visit to a node in Deadline VRP is static, whereas the deadline of a node changes enthusiastically in our case. Periodic VRP is the problem of conniving routes for delivery vehicles for a given T-day retro where not all customers require transfer on every day in the period. Customers are linked with a set of feasible schedules that are some amalgamations of days they can be visited.

In PVRP, the realistic solution set consists of a finite number of potentials. However, in MES, the feasible solution set consists of an unlimited number of possibilities such that thetime difference between any two successive visitsplanned to the same node is smaller than the associated buffer excess time. Moreover, in the MESproblematic, the vehicle does not need to go back to acertain node at the termination of every cycle whereas thevehicles in PVRP go back to the garage every day.Although the MES problem can be discretized inthe time territory, the resulting size of the practicablesolution set does not scale well with the range ofdata cohort rates.The MES problem in wireless sensor networks isverified to be NP-complete and three empirical algorithms are presented in. The first one is the Earliest Deadline First (EDF) algorithm, where thenode with the neighboringtarget is visited first. Toimprove EDF, the second algorithm, EDF with klookahead, is proposed. Instead of staying a nodewhose limit is the earliest, this algorithm considers thek! Permutations of the knodes with leastdeadlines, and chooses the next node which indications tothe earliest finish time. Accordingly, the EDF withk-lookahead algorithm achieves better than pureEDF. The third algorithm is the Minimum WeightSum First (MWSF) algorithm, which accounts forthe weights of deadlines as well as detachments betweennodes in defining the visiting schedule. TheMWSF algorithm achieves the best among thethree projected algorithms.Even though the MWSF solution considersboth deadlines as well as distances, ''back-andforth'' movement between far absent nodes occursregularly. In our proposed PBS algorithm, we consider the target and distances ofall nodes instantaneously and utilize a two-layer scheduling approachto diminish the back-and-forth movement behavior.This is achieved by separating the set of allnodes rendering to deadlines as well as their geographic locations. The resulting agendas andpaths are usually shorter, which diminishes the minimum required speed of the ME to avoid bufferexcess.

1.2 PARTITIONING-BASED SCHEDULING ALGORITHM

Partitioning-Based Scheduling (PBS) algorithm is intended to resolve the MES problem, and aims to schedule the visits of the mobileelement to each sensor to avoid data loss due to sensor buffer overflow. With the PBS algorithm, wefirst screen all nodes into several groups, calledbins, such that nodes in the same bin have similartargets. Then each bin is extra divided intosub-bins with respect to physical locations ofthe nodes. To decide the ME path within a singlesub-bin, we solve the Traveling Salesman Problem, which figures a minimum cost tour that stayseach node exactly once. Finally, the agendas forindividual groups are concatenated to form theentire schedule. While calculating the schedules, the data transfer time between the sensor nodesand the ME is also considered. We first planour system and problem formulation and thenpresent a detailed explanation of our solution to the MES problem. Problem formulation and notation and then present a detailed explanation of our solution to the MES problem in the remainder of this section.

1.3 PROBLEM FORMULATION AND NOTATION

Wireless sensor networks poised of standardized sensor nodes are considered. Thenodes are fortified with wireless communicationborders with limited ranges. Sensor nodes capturethe events in their surrounds and record them totheir buffers. The following conventions are alsomade regarding the sensor nodes and the mobile element.

•The somatic sizes of sensor nodes and the mobileelement are insignificant.
•The mobile element can move in any directionwithout any dormancy of making any turns.
•Data transmission time between sensor nodes and themobile element is not insignificant compared to the delay due
to ME movement. Data transmission rate is denoted by.r_{tr}
•All sensors have the same finite buffer size, and attime t= 0, all sensor node buffers start in anvacant state. The mobile element has suitablylarge data storage and it does not suffer fromthe buffer excess problem.We denote the number of nodes in the networkby N and the set of nodes by $\{n_i\}$, wherei=1,...,N. Let W_{ij} denote the distance amidnodes$n_i$andn_j. The buffer excess time and datageneration rate of each node are meant by $o_i$andr_g^i, respectively. For a buffer of size b$O_i = \frac{b}{r_g^i}$. We assume that the data generationrate is directly related to event incidence rate.The MES problem ($\{W_{ij}\}$,$\{O_i\}$) is to find asequence of visits to nodes $\{n_i\}$, for i,j=1,...,N, and calculate the minimum speed V_{min} of the ME so that no node buffer excess occurs. We attack the problem by

first overlooking the broadcast timebetween the sensor nodes and the mobile element, then including it appropriately into our calculations.

II. Proposed Method

2.1 THE PROPOSED MODIFIED PBS ALGORITHM

LetB_j, j=1,...,M, denote bin j, where M is the whole number of bins. In PBS, nodes are first segregated into bins in such a way that excess timesof the nodes in binB_i is smaller than those in B_j,forj>i> 0. Moreover, the variety of excess timesfor nodes in$B_{i+j}$is twice that ofB_i. This allows thenodes inB_i to be visited twice more frequently thanthe nodes in B_{i+1}during generation of the visitschedules. Then, each bin further is divided intosub-bins so that nodes in the same sub-bin are physical close to each other. This two-level dividing results in clusters of nodes with alikelimits and positions. Therefore, in each subbin, node visit schedule of the ME can be computed using a TSP solution. Finally, timetables fordiscrete sub-bins are concatenated to form theentire schedule that guarantees all deadline constraints are satisfied. In the following, we designate the details of the PBS algorithm outlined in Algorithm 1.

2.2 Modified Bin partitioning according to overflow times

Minimum and maximum excess times in thenetwork are defined asO_{min}= $min_i\{O_i\}$ and O_{max}= $max_i\{O_i\}$, respectively, for i=1,2,...,N. Then nodes are assigned to bins according to the following equation:

$$n_i \in B_j, \quad \begin{cases} \text{if } 2^{j-1}o_{\min} \leqslant o_i < 2^j o_{\min}, & j = 1, \ldots, M-1; \\ \text{if } 2^{j-1}o_{\min} \leqslant o_i \leqslant o_{\max}, & j = M. \end{cases}$$

It shows an example of segregating nodesinto three bins. The overflow times of nodes in B_1range from $O_{min}$to $2O_{min}$, the overflow times ofnodes inB_2range from $2O_{min}$into $4O_{min}$, and the excess times of nodes inB_3range from 4omintoomax.As far as PBS algorithm is concerned, there is nodiscrepancy between nodes in the same bin in termsof their excess times. Therefore, all nodes in abin$B_j$are considered as if they are allotted an excess time of $2^{j-1}1O_{min}$. Every bin is then visited at dissimilaroccurrences: all nodes in $B_1$are visited everycycle, nodes in $B_2$are visited every other cycle,and nodes in $B_3$are visited every four cycles, wherewe define acycleas a closed path among a set ofnodes, such that no node is encompassed more than oncein the same cycle. We also define a supercycleas aclosed path composed of concatenated cycles such that every node is comprised at least once in a supercycle. In our algorithm, the duration it takes for theME to complete a supercycle is defined as the periodof the ME schedule. The notions of cycle and super cycle in this context will be enlightened further in the following sections.

Algorithm 2. [2D-tree(S, *cutonx*, depth, d)]

if d=depth **then**
  return
endif
if *cutonx* **then**
  $S_1 = \left\{ n_i | x_i \leqslant \frac{1}{|S|} \sum_{n_j \in S} x_j \right\}$
else
  $S_1 = \left\{ n_i | y_i \leqslant \frac{1}{|S|} \sum_{n_j \in S} y_j \right\}$
endif
$S_2 = S - S_1$
cutonx ← !*cutonx*
KD-tree(S1, *cutonx*, depth, d + 1)
KD-tree(S2, *cutonx*, depth, d + 1)

2.3 Sub-bin partitioning according to locations

Each bin obtained is then segregatedinto sub-bins according to the node locations suchthat the nodes in the same sub-bin are geographically close to each other.

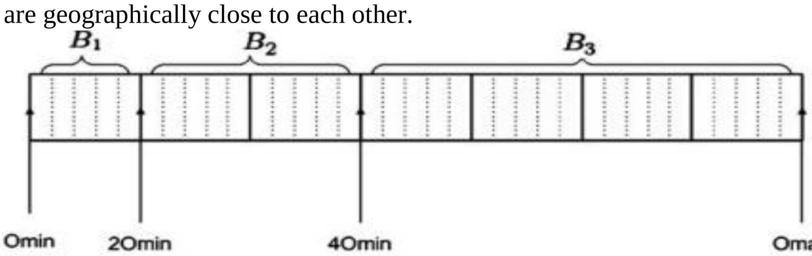


Fig1: The diagram of step 1: Partition according to overflow times

The number of sub-bins of a bin B_j is calculated based on the index j. As an example, the nodes in B_2 need to be visited only half as recurrently as the nodes inB_1. Hence, B_2 is segregated into two sub-bins: B_2^1andB_2^2, where $B_2^1$is visited every even cycle, and $B_2^2$is visited everyodd cycle. Following the same rule,B3 is subdivided into four sub-bins: B_3^1;B_3^2;B_3^3andB_3^4, and in general, binB_i is subdivided into B^{2i-1}sub-bins: B_i^1;...;B_i^{2i-1}I .In our case, we use the2D-tree where the two proportions are the lengthand width of the sensor deployed field.
In each procedure call, the nodes are subdivided into two, based on the cut criteria decided by cut on x. Then, cut on x flag is negated and the route is called recursively on resulting panels untilthe desired 2D-tree depth is reached.

An example of 2D-tree dividing for 16 randomly deployed nodes in the givenregion. As shown in the figure, the nodes are firstgeometrically divided into two composed parts bythe cut Awith respect to theirx-organizes. Thenodes havingx-coordinates smaller than the average of the x-coordinates is assigned to one partand rest to the other.As the cutApartitions the region vertically, cutsBand C flatscreen the ensuing twoparts since they-coordinates of the nodes.This process is recurring alternately until the desirednumber of barriers is obtained. The number of screens, which is also the number of sub-bins in forming a TSP explanation on each sub-bin. The two-level separating results in clusters of nodes with similar targets and locations. Therefore, the ME arrangement problem is reduced to

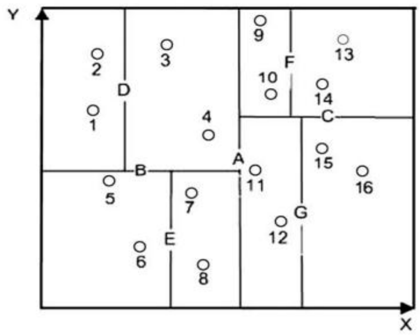


Fig. 2: Nodes in a 2 dimension space cut by KD-tree.

The Traveling Salesman Problem (TSP) for each subbin. In the fiction, several algorithms to calculateTSP paths are projected such as the nearest neighbor, LKH, and Prim's algorithm. In oursolution, we adopt Prim's process to calculatethe TSP path. While any TSP algorithm can bemerged into PBS, we adopted Prim's algorithm for its satisfactory TSP path length performance at the reasonable time complexity of O(N2). In PBS, the path of the ME is slightly differentfrom the computed TSP path such that the ME doesnot return back to the first visited node after stayingthe last node in the sub-bin. In its place, the ME visitsthe first node of the next sub-bin. Then, it follows the computed ME path in that sub-bin andproceeds to the following sub-bin. As a special case,in B_1, the node with the smallest overflow time istaken as the start node.

2.4 Forming the super cycle:

After the ME paths within the sub-bins are deliberate, the visit order of the sub-bins should bedecided to form the comprehensive ME path. At theend of partitioning, there are B^{2i-1}sub-bins of binB_i, each collected of nodes with deadlines at leasttwice the goals of the nodes in sub-bins of B_{i-1}, i=1,...,M. Therefore, in a rational MEschedule, sub-bins in the same bin should be visitedwith the same occurrence and a sub-bin inB_{i-1}should be visited twice more regularly than asub-bin of binB_i. This heuristic choice results in asub-bin ofB_i to be visited 2MI times for each visitto a sub-bin of bin BM. Remembrance that in a supercycleeach sub-bin, hence each node, is stayed at leastonce. In other words, each sub-bin in the least commonly visited binBMis stayed at least once. Without loss of simplification, let the ME visit each sub-bin in BM exactly once in a super cycle. Then, a sub-binof binB_i should be stayed exactly 2MI times in a super cycle according to our heuristic choice. Let $I_{i,j}$ be defined as the supreme period between two consecutive visits to a node in subB_j I . Then, the sufficient illness to avoid bufferexcess for all nodes ofBj I can be stated as $I_{i;j}$ 6omin——————————————2i1. ð3ÞLetLi,j denote the longest ME path between tworepeated visits to a node of sub-bin B_j I , i.e.,$l_{i,j}$=$I_{i,j}$ ·v, where vis the speed of the ME. Hence, to evade buffer overflow inB_jI, vPL_j; j$O_{min}2^{i-1}$should besatisfied. This can be achieved by either swellingthe ME speed or decreasing$L_{i,j}$.
Our objective ofdiminishing the ME speed for a lossless schedulecan be realized by minimizing $L_{i,j}$for each sub-bin and setting v to the largest compulsory value to satisfy Inequality (3) for every sub-bin.Since all sub-bins are fashioned according to environmental proximity as well as excessaims,the TSP tours of sub-bins $B_{ji}$of binB_i of similar dimensions. In order to have a probable visiting schedule of sub-bins, we form cycles such that only onesub-bin from each bin is contained in a cycle. Furthermore, all cycles preserve the order of bins Bifrom

which sub-bins are selected. In particular, sub-bins are visited starting from B_1 in increasingbin number order and a sub-bin in$B_i$is always stayed after the same sub-bin inB_{i-1}. This guarantees thatin every cycle that a sub-bin B_j I is visited, the protuberancesinB_j are visited at precisely the same time as theywere stayed in the earlier cycle qualified to the starttimes of the cycles. The foundation behind this choicewill be debated in more detail in.There are two times more sub-bins in bin Bi than$B_{i-1}$and each sub-bin inB_i is always visited after the same sub-bin in B_{i-1}. For each sub-bin of B_{i-1} , we greedily timetable the closest two sub-bins from B_i to follow it. Note that more intricate concatenation algorithms can be used to further minimize thedistances between consecutively visited sub-bins.a visiting classification example of sub-bin sin a super cycle is given for M= 3. The supercycle inthis case consists of four cycles and the visit calendars of the sub-bins are as follows:$B_1$is visited every cycle,$B_{12}$is visited in cycles 1 and 3, and $B_{22}$is visitedin cycles 2 and 4 and the sub-bins of the last bin, B_3, are visited in cycles 1, 2, 3, and 4, one at a time

2.5 Data transfer time considerations:

Let f_i denote the smallest visit incidence for node $n_i$to avoid sensor buffer excess. Withoutconsidering the data program time and assuming a lossless schedule, the supreme durationbetween two consecutive visits to n_i is O_i. Thus,fi ¼1O_i. Considering the broadcast bandwidth, f I is determined by n_i's data cohort rate r I g, transmission ratertr and buffer size b.

$$t_{\rm tr}^i = \frac{\beta b + t_{\rm tr}^i r_g^i}{r_{\rm tr}}, \quad (4)$$

$$t_{\rm tr}^i = \frac{\beta b}{r_{\rm tr} - r_g^i}, \quad (5)$$

$$= \frac{\beta b o_i}{o_i r_{\rm tr} - b}, \quad (6)$$

Then where b (b61) is the proportion fill level of the buffer of the sensori. The maximum duration between

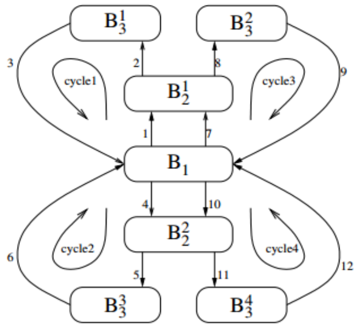


Fig. 3: An example of the visiting sequence of sub-bins in a 'super cycle'

Two repeated visits is o O_i +tt_r. Therefore, usingonewi ¼O_i þttr as the new excess time in PBS step1 (bin partitioning) will generate a schedule for MES with communication time attention. Note that b is node precise and is not known before.The case ofb= 1 refers to completely full buffersand the transmission time is the maximum. Therefore, a bvalue of 1 is chosen in our process aswe are involved in the lowest ME speed whichcan promise a lossless schedule.

2.6 Discussion of minimum required speed:

To minimize the power drinking of the ME,any solution to the MES problem should abatethe ME speed. In this paper, we calculate a lowerbound for the PBS results on the ME speed, denoted asy_{min}, such that no buffer excessbefallsin the network nodes. Considering an arbitrary node n_i in bin B_j, let Li, kand Ci, k denote the path that ME has voyaged and the set of nodes ME has stayed between the k^th visit and (k+ 1)^th visit to n_i, respectively. The broadcast time at node n_i is denoted by tri. To avoid buffer overflow at node n_i, the following condition should be pleased:

$$2^j o_{\min} \geqslant o_i \geqslant \frac{L_{i,k}}{v} + \sum_{n_s \in C_{i,k}} tr_s, \quad (7)$$

Where$L_k$vis the time ME spends on roaming between nodes and Pns2Ci;kt_rs is the total data communication time. To security no data loss at ni, the sum of these two terms should be less than or equal tothe excess time of n_i. According to Eq. (1),we haveo_i62jo_{min}. Note that it is hard to find the databroadcast time for each node, but we can easilyfind the upper bound, which is the program time for a full buffer by setting b= 1 in Eq.(6)

$$tr_i \leqslant \frac{bo_i}{o_i r_{tr} - b}. \quad (8)$$

With Eqs. (7) and (8), we have

$$v \geqslant v^i_{min} = \frac{L_{i,k}}{2^j o_{min} - \sum_{n_s \in C_{i,k}} \frac{bo_i}{o_i r_{tr} - b}}, \quad (9)$$

$$v_{min} = \max_{\forall n_i} v^i_{min}. \quad (10)$$

As stated in, the PBS procedureproduces a periodic schedule. Therefore, there isno need to keep track of all visits to the nodes. For a node in binB_j, if there is no excess during2^{j-1}repeated visits, which occur during a singlesupercycle, no surfeit condition is definite.
In general, $L_{i,k}$, i=1,2,...,N, k=1,2,...,2_{j-1},cannot be approached easily except for positivespecial distributions of sensor nodes. Once an MEcalendar is generated by the PBS algorithm, $L_K$and v I min, therefore V_{min}, can be added numerically. If the ME is controlled to move at a smaller speed than V_{min}, there may be data losses due to buffer overflow. Although not discussed in this paper, furtheroptimizations can be done for the laterdetached bytrading off performance of the former one. In theperformance study section, we also present thepresentation of our PBS algorithm as a function of the ME speed.

III. Time Complexity Analysis

Let N and M denote the amount of sensor nodesand number of bins, individually. Then, the complexity of PBS algorithm steps (Algorithm 1) areas follows:
•Step 1: Segregating with respect to excess times can be reached by relating the overflowtime of each node with the bin restrictions resulting in complexity of O(NM).
•Step2: In the topographicalseparating phase,the number of times a node in binB_i is processedand assigned to a sub-partition is upper boundedby i-1. Since project is done by simplylinking the entreated coordinate of the nodewith the average, it is O(1). In the worst case,all nodes except the one with the smallest overflow time are in binB_M, therefore the intricacyof the 2D-tree algorithm is O(NM).
•Step3: The complexity of manipulative TSP pathby Prim's algorithm for N nodes is O(N2).Assume that each sub-bin is assigned a singleidentity from the set U= {1,2,...,2M1}.Recall that $2^M - 1$ is the total number of subbins. LetK_i denote the quantity of nodes in thesub-bin with identity i2U.

$$k_1^2 + k_2^2 + \cdots + k_{2^M-1}^2$$
$$\leqslant (k_1 + k_2 + \cdots + k_{2^M-1})^2 \quad (11)$$
$$= N^2 \quad (12)$$

Step4: In concatenation step, first the epicenter ofgravity for each sub-bin is considered in O(N) time. For each sub-bin B^i_j, two sub-bins in $B^{i+1}$with epicenter of flagrancies closest to that ofB_j I areparticular to be visited after Bj I . If a selected sub bin is already decided to be visited after another sub-bin in Bi, the next closest sub-bin toB_j I is measured. Since there are 2^{i-1}sub-bins in B_ii, it takes $2^{i-1}\cdot 2^i = 2^{2i-1}$comparisons for each bin.Therefore, the time intricacy of the concatenation step is O(N+4M).Accordingly, the PBS algorithm has an general time complexity of O(N2+4M).

3.1 Performance evaluation:

To evaluate the presentation of our projectedPBS algorithm considering transmission time, wehave run an extensive set of imitations. In this simulation study, the following scenarios are measured for performance evaluation.
•Simulation I: We observe the data injury rate as afunction of the mobile division speed.
•Simulation II: We observe the consequence of the nodedensity on the smallest required ME speed to prevent data loss in the PBS algorithm.
•Simulation III: The consequence of number of bins onthe presentation of PBS algorithm is evaluatedfor different network sizes and properties.
•Simulation IV: We perceive the impact of sensor buffer size in sensor nodes on the routineof the PBS algorithm.
•Simulation V: The effect of wireless communicationrate between sensor nodes and ME on the dataloss rates is analyzed.
•Simulation VI: Sensor visit obviousness is investigated as a function of extratime and nodedensity through inspection of the standard unconventionality of inter-visit times.All reproductions except for Simulation III are alsorun for the MWSF algorithm to compare the presentation of the procedures. The details of thesimulation setup as well as the comprehensive discussionof the results are presented in the following sections.

3.2 Metrics and methodology:

We observe the following metrics to evaluate thepresentation of the PBS algorithm. Data loss occurrence rateis definite as the ratio ofthe number of sensors absent their deadlines to the total number of nodes visited. It presentsthe recital in terms of the number of sensors absenttheir deadlines rather than theamount of data lost.

•Data damage rateis defined as the ratio of the datalost due to buffer excess to the total amountof data generated.

•Minimum compulsory speedis defined as the minimum speed of the mobile element to thwartany buffer overflow.

•Certainty is defined as the standard eccentricityof the inter-visit duration which is the durationbetween two visits of the ME to the same node.

The simulator is developed in C++ language. Agraph generator forms the accidental sensor networktopology and regulates the sensor data generationrates and excess times according to the scenarioat handThen, we pretendthe visits of the ME to each sensor node in a distinctmanner by keeping track of the time. After eachvisit, the existing time is incremented by the timethat ME spends wandering from the previous nodeto the current node. If the time between two succeeding visits of the ME to the same node exceeds thenode's deadline, then data loss occurs. In such acase, the loss is recorded in the simulation.In our simulations, we use the following defaultsettings unless specified otherwise. Each simulationis run on a network with 200 sensor nodes randomlyplaced following the uniform distribution on a200 m·200 m area. Each sensor node is armedwith same size buffers (10 Mb). Data broadcastrates between sensor nodes and the ME is 500 kb/s. To pretend this, we assume that eventsare powerful at certain locations, which we call Eyes. The nodes in the eye meridians have the highestdata cohort rates, which drops radially outward. Four topologies,1A, B, C, and D, are considered in our imitations. Topologies A, B, and Chave one, four, and nine eyes, correspondingly. Topology D corresponds to regularly distributed datacohort rates over the sensor network. It can alsobe considered as having infinite number of eyes. Theradius of each concentric circle is denoted byR1,R2,R3,...,Rn, where R1= 20 m. The value ofeach range is calculated as Ri ¼i R1; i¼1;...;n.

The nodes in the deepest region are assignedtheminimum overflow time, which is called the base_time, and excess times for nodes in regions radially superficial are calculated as:

Overflow Time i =base_time+(i1)Æ step, i=1,...,n,

Where excess Time i is the overflow time allotted to nodes inRegioni andstep is the size of the increments. In our simulations, we take base_time as 500 s and500 s forstep. Similarly, we consider the grids withfour eyes and nine eyes as shown. We shoulder the data size is 16bits.Therefore, for a node with specimen frequency of100 Hz, the data cohort rate is 1.6 kb/s andthe corresponding buffer overflow time is 6250 s.We have run the experiments for both PBS andMWSF algorithms on all four topologies to makethe assessments. The MWSF procedure is run with weight a= 0.1, where a is the weight of deadline, and 1ais the weight of coldness. According tothe experimental effects in [17], MWSF algorithmyields the best recital when the value of a is around 0.1. We measured PBS with the default bin number M= 3 unless specified otherwise.

3.3 Impact of the ME speed on data loss:

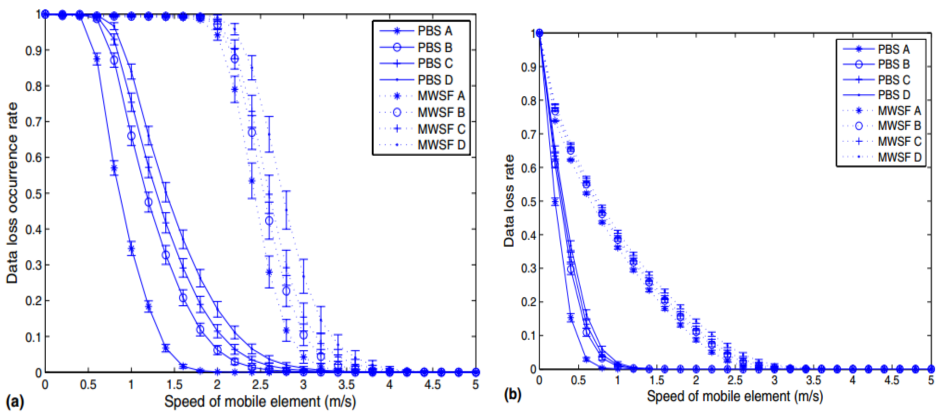


Fig.4:

It show data loss incidence ratesand data loss rates for reproductions run with bothPBS and MWSF procedures on topologies A, B, C,and D. We have composed experimental results fordifferent speeds of the mobile component ranging from0 m/s to 5 m/s. Loss rates range from 0 to 1, whichresemble to the no loss and complete loss cases, respectively. In both figures, loss rates decrease with the increased speed Compared to MWSF, the loss rate of PBS procedure decreases at a higher rate as the speedincreases. Therefore, we conclude that the PBS procedure is more effective in terms of plummeting the loss rate.

3.4 Impact of node density on minimum required ME speed:
In this section, the impression of the node compactness isappraised to observe the scalability of the PBS algorithm. In this reproduction the number of nodesdeployed on a 1 km2 area is varied between 150 and 200. With the increasing node density, we amount the smallest required speed of the ME to evade buffer excess. Figure shows the results of running this simulation on four topologies.

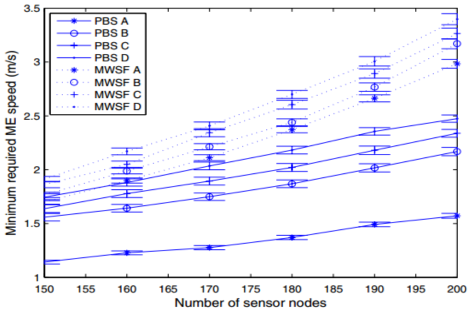


Fig 5:

As expected, the least required speed upsurgeswith the increasing node compactness. When the nodecompactnessincreases, the path length in a super cycle upsurges, as well. This leads to a higher ME speed.The least required speed by the PBS procedureis in general inferiorthan the MWSF procedure on thesame topology. The minimum required speed for Topology A is lower than B, which is lower thanC. The minimum required speed for Topology Dis the maximum. The path that ME covers in a super cycle is longer when the number of eyes is larger.

3.5 Impact of number of bins on data loss:
In this section, we study how the number of bins M disturbs the presentation of the PBS algorithm .M = 1 resembles to the case where all the nodesare delimited in one bin and are visited every cycle.No physicalsegregating is used in this case. When M> 1, nodes are first partitioned accordingto overflow times and then separated geographically. When M= 1, the super cycle is corresponding to the TSP solution overall nodes. On the other hand, if M> 1, the super cycle consists of TSP responses in each sub-bin, andthe trackspresented due to concatenation step.

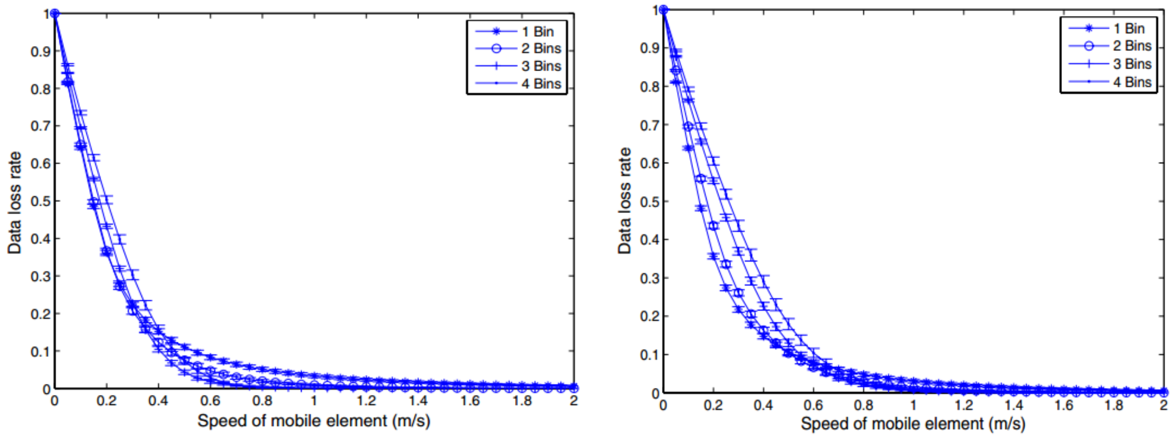


Fig 6:

Therefore, it is predictable that with M= 1, the ME visits a larger amount of nodes within a given time period compared to M> 1. If the ME hurry is verysmall, almost every node buffer will be full at thetime the ME visits them. Hence, by staying a largeramount of nodes in a given time period, data lossrate is smaller with M= 1. As the ME speed getslarger, visiting nodes with high excess times asregularly as those with low overflow times willannounce redundancy for M= 1 case. It can also be observed that a large number ofbins provides much smaller minimum speed toavoid buffer overflow. As an example, when the data loss rate for M= 4 case drops to zero, the curve for M= 1 case still asymptotically approaches x-axis. Scheduling with small numberof bins sacrifices performance on nodes with lowoverflow times severely. Therefore, although the presentation of scheduling with one bin schemehas smaller data loss when movable element movesat lower speeds, its advantage disappears for moderate and high hurries.

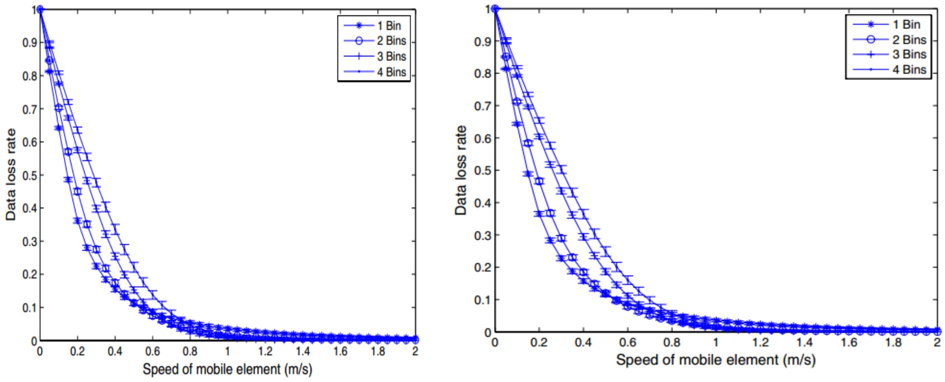


Fig 7:

3.6 Impact of buffer size:

Figure the influence of buffer size on datadamage rate for both PBS and MWSF on differenttopologies. The buffer size varieties from 1 Mb to 80 Mb. The ME is running at a speed of 1 m/s.We observe figurethat the data loss rates ofboth PBS and MWSF drop as buffer sizeupsurges. With the larger buffer but the same datacohort rate, all sensors have more volume tocarry data and have larger overflow time. Whenthe ME is running at the same rapidity as before, itcan gather more data. Thus the data loss rate decreases with swelling buffer size. We also noticethat the routine of PBS is much better thanMWSF except when the buffer size is awfullylow. When the buffer size goes toinfinity, there should not be any data loss in theideal case. Therefore, all curves converge to zero.

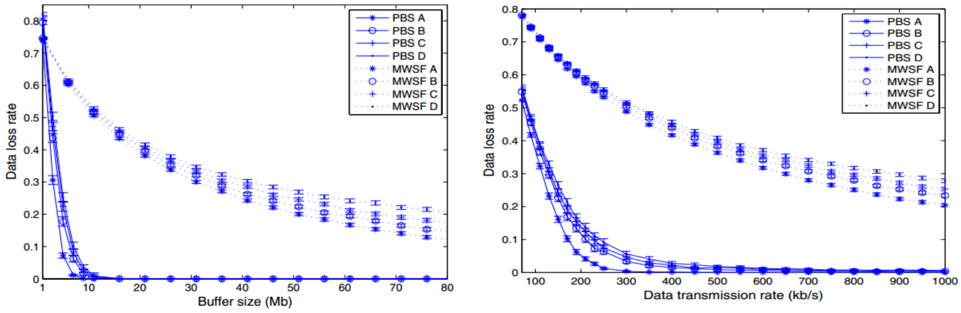


Fig 8:

3.7 Impact of transmission rate:

The wireless transmitter on the sensor nodes alsohas impact on the trade-off between cost and performance. The transmission rate affects the power consumption at each sensor node, which is the currentmajor bottleneck of WSNs.shows theimpact of transmission rate on the performance ofPBS and MWSF on four topologies. Transmissionrate ranges between 0.1 Mb/s and 1 Mb/s. Thespeed of the ME is chosen as 1 m/s. For both PBSand MWSF, the data loss rate is decreasing withthe increasing transmission rate. When the transmission rates are the same, performance of PBS inTopology A is better than Topology B. Performancein Topology B is better than Topology C, which isbetter than Topology D. On same topology, dataloss rate for PBS is less than MWSF. Larger transmission rates lead to smaller transmission times.Spending smaller portion of time on data transmission, the ME visits more nodes before their buffers overflow. Thus, the data damage rate decreases astransmission rate upsurges. When the data transmission rate goes to infinity, the ME actually visitsone sensor node, then moves to the next node immediately without stopping. Hence, all curves in Fig.12 are expected to converge to non-negativevalues.

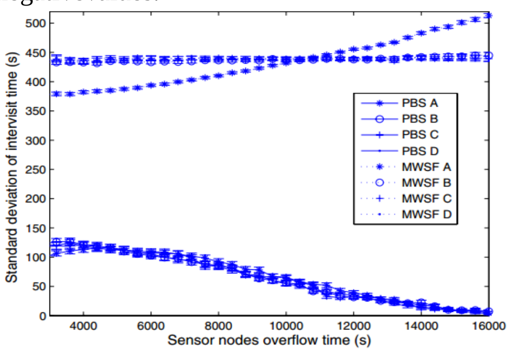


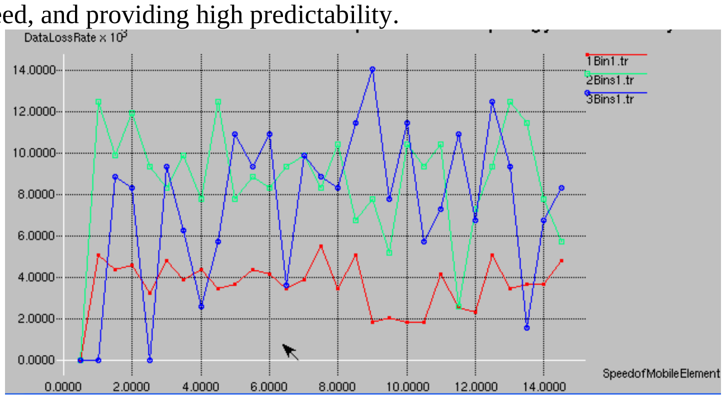
Fig 9:

3.8 Sensor visit predictability:

We claim that our PBS proceduredelivers periodic supercycle scheduling. While thisin correct, the inter-visit times for a given sensor ina supercycle are not essentially equally spaced. Inthis section, we analyze the difference between intervisit times of the ME to a given sensor node for dissimilar sensor excess times. The standard deviationof inter-visit periods is used to amount the certainty of visits to sensor nodes, which shows the periodical feature of our arrangement scheme. We observethe predictability of sensor node visit times as a function of different data generation rates. We focus onthe standard deviations of inter-visit periods andgroup the falloutsaccording to runoff times.shows the results of running PBS and MWSFprocedures on Topologies A, B, C and D. To pledge the sureness interval, each result is the averagevalue of 5000 independent runs. We choose 1 m/s asthe speed of the mobile element, where buffer overflows still occur. As expected,shows thatthe ordinarynonconformity of inter-visit times for PBSis much smaller than MWSF for all excess timevalues. Likened with the MWSF algorithm, PBS provides higher predictability for the visits to sensornodes due to higher periodicity.Furthermore, note that the ordinaryaberration ofinter-visit times of PBS decreases as the excesstime of sensor nodes growths in general. Especiallyfor nodes with high excess times, the standardeccentricity is nearly zero. Therefore, the PBS procedurefavoritisms nodes with high excess times withhigh predictability. This is due to the statistic that thenodes with high excess times are visited less frequently and more periodically. Especially the nodesof the past bin are visited once every supercycle. Thelength of the supercycle is always the similar. But dueto dissimilar length of cycles the broadcast times for nodes are not always the same. Therefore, theperiod of supercycles are almost the same with somesmall differences. The standard nonconformity of inter appointment times for these nodes is close to zero. Notice that for MWSF in Topology A, the standard eccentricity of inter-visit period increases asoverflow time increases, while Topology B, C andD do not reflect such behavior. Exploratory the MWSF scheme with topology A, since nodes in the central region have smaller excess times, mobilecomponent would visit this region more normally. Thisleads the ME to visit nodes with small excess times with more unsurprisingly. Because of the long distancebetween the authority areas and the center of the eye intopology A, the mobile element's visit is more volatile for the nodes in the edge area. However, intopology B with four eyes and topology C with nineeyes, nodes with high stayingincidences is morebinge over the entire region and the expectednessis more composed for all nodes.

IV. Simulation Result:

We assume that UMs are generated infrequently, and therefore, multi-hop transmission of UMs does not have significant impact on the network lifetime. Even if multi-hop transmission is allowed, network partitioning and increased transmission delay to reach farther nodes may prohibit some UMs to be delivered before their deadlines.In such cases, MRME selects a set of nodes to reduce their overflow times before scheduling the ME path using PBS. Although such reductions guarantee the worst case delay to be below a threshold, it also results in an increased ME speed for lossless schedule since selected nodes will be visited more frequently than before. Therefore, MRME aims to minimize the ME speed while reducing overflow times to meet the specified UM delay. We compare our algorithm with Minimum Weighted Sum First algorithm and showed that our PBS algorithm provides higher performance in terms of decreasing loss rate, reducing the minimum required speed, and providing high predictability.



V. Conclusion

The sensor nodes may have unalike data cohort rates, which pointers to theMobile Portion Scheduling Problem. In this paper, we proposed a Partitioning-Based Scheduling (PBS) procedure to report this problem. We comparedourprocedure with Least Weighted Sum Firstalgorithm and showed that our PBS algorithm provides higher performance in terms of decreasing lossrate, dipping the leastcompulsory speed, andproviding high predictability. Our future workincludes investigation of methods to utilize morethan one mobile element for data collection and tocater to the needs of vital real-time announcement events.

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