Nodes Energy Conserving Algorithms to prevent Partitioning in Wireless Sensor Networks

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ABSTRACT
Joint scheduling method satisfies both necessary requirements of sensing coverage and network connectivity for the successful reporting simultaneously. For the sensing coverage uses randomized scheduling method, which divides sensor nodes to k subsets. Each sensor node randomly joins one predefined subset. Then, this method turns on some sensor nodes in extra subsets for the network connectivity. Some of extra-on nodes are subjected to many transmissions and receptions, in addition to the transmissions of their packets and even some of them should be stay on all the time. These problems can cause rapid battery depletion in extra-on nodes and may lead to network partitioning. In this article, algorithms are proposed to minimize the number of extra-on sensor nodes. The probing mechanism (pbm) algorithm consists of three methods that allow for some nodes to change their working shift assigned by the randomized scheduling algorithm based on different scheduling rules. Matlab simulation proved that the pbm algorithms reduces the number of extra active sensor nodes up to 35% while the sensor nodes still transmit via the shortest path to the sink node. By using the nearly shortest path algorithm, the nodes find paths to the sink node via neighboring nodes instead of turning on extra nodes. Nearly shortest path algorithm can reduce the number of extra-on sensor nodes by 96.85%. Integrating the probing mechanism and nearly shortest path algorithms can also reduce the number of extra-on sensor nodes up to 96.85%. Since the rescheduling process fulfilled by the probing mechanism in the integrated approach covers some blind points by the rescheduled sensor nodes, the integrated approach is preferable.
Key words:
wireless sensor networks, probing mechanism algorithms, joint scheduling method, partitioning, shortest path routing

1. Introduction

Deploying large number of energy restricted sensor nodes makes energy efficiency the most important concern for a Wireless sensor network (WSN). Nodes sleep scheduling [1-5] is a fundamental technique to minimize the number of nodes that remain active, while still achieving acceptable sensing coverage and network connectivity for applications. The most fundamental issues of sensing coverage and network connectivity should satisfy for the successful operation of a WSN. They can be considered as a measure of quality of service [6] and significantly influence the performance of WSNs [7].

Joint scheduling method [8] joins the problems of coverage and connectivity. This method divides sensor nodes to k subsets to achieve sensing coverage and energy efficiency at the same time and then allows one predefined working subset for each sensor node. Some sensor nodes are assigned to be active in more than one subset to ensure network connectivity. Some of those extra-on nodes are subjected to many transmissions and receptions, when they participate in other nodes routing. Moreover, some extra-on nodes are critical for network connectivity, namely the network may be partitioned if they are turned off. Thus, power conservation in extra active nodes is important to prevent network partitioning and extending network life time. In this study, reducing power consumption in extra-on nodes and reducing extra-on nodes' duty cycle will be investigated. Two algorithms are proposed for the joint scheduling method, in order to prevent partitioning the network. Both algorithms will reduce the number of extra-on nodes and eliminate the extra subset assignment of some nodes. Probing mechanism scheduling [9] with three different methods reschedules the working shift of the sensor nodes. Since transmission via more number of hop counts needs more energy, the shortest path for sensor nodes to route their packets are preferred. In the joint scheduling method, using the shortest path will create additional workload for extra-on nodes. The extra energy usage is due to the performance of the additional sensing task and participation in many transmissions and receptions. In the second proposed algorithm, the nearly shortest path will solve the mentioned problem by selecting an alternative path with more numbers of hop counts.

In the scope of this study, the flat communication architecture with regards to both the sensing coverage and the network connectivity issues will be considered. Sensor networks will be stationary and sensor nodes will be randomly distributed in a two-dimensional field. According to [10] random deployment is much easier and cheaper compared to other sensor deployment methods such as deployment in grids or following predefined patterns. The current studied network also does not guarantee full coverage of the area, but provides different degrees of coverage requested by different applications such as the detection of chemical attacks or the detection

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of forest fire. The first proposed algorithm (probing mechanism scheduling) reduces the duty cycle assigned by randomized scheduling algorithm for extra-on sensor nodes. The second algorithm (nearly shortest path) selects an alternative path instead of routing via extra-on nodes. The aim of this article is to reduce the power consumption of the network in extra-on sensor nodes, which will prevent network partitioning and extend the network life time. To achieve this goal, the following parts will be fulfilled:

1. Implementing a new joint scheduling method [11] and comparing its features and performance with the original joint scheduling method.

2. An enhancement of probing mechanism scheduling algorithm [9] consists of three methods, each method reschedules some sensor nodes' working shift based on a different rule. After utilizing the probing mechanism algorithms in the joint scheduling method, the duty cycle of extra-on sensor nodes will be reduced and consequently some of them will not work in extra subset.

3. Employing nearly shortest path algorithm which reduces the number of extra-on sensor nodes effectively. In nearly shortest path algorithm, the nodes route through alternative paths (not the shortest path) to the sink node, instead of turning on extra-on nodes.

4. Integrating implemented joint scheduling method with partition avoidance protocols and measuring the performance of integrated algorithms.

2. Methodology

The proposed algorithms are based on [8]. At first, randomized scheduling algorithm [12] for sensing coverage is used where only a portion of the nodes are in the active mode. The others fall in to sleep mode to save energy. Hence, by using the randomized scheduling algorithm, network sensing coverage and energy efficiency can be achieved at the same time. Secondly, to fulfill other requirements of the WSNs, i.e. to ensure network connectivity, the algorithm turns on extra sensor nodes. Some of those extra-on nodes are critical nodes which can partition the network if their energy discharges. To prevent network partitioning, probing mechanism rescheduling and nearly shortest path algorithms for minimizing the number of extra-on sensor nodes are proposed.

2.1 Conceptual Model

The mechanism to achieve sensing coverage and network connectivity and its related steps are carried out during the establishing interval of the network and in the initializing time. Subsequently, the network will perform the sensing and communicating tasks based on neighboring information acquired by the sensor nodes until the network life time expires.

2.1.1 Sensing Coverage

To solve the sensing coverage problem, randomized scheduling algorithm is utilized which is a distributed algorithm and consequently scalable for large networks. Assume that the sensor nodes constitute a set S. Given a number k, each sensor node randomly joins one of the k disjoint subsets of the set S. Once the k subsets are determined, they work alternatively. At any given time, only one subset works and all the sensor nodes belonging to this subset are turned on. The intuition is that when the network is sufficiently dense, each subset alone will cover most part of the field. Figure 2 shows an example. There are eight sensor nodes (with IDs 0, 1, ..., 7), deployed in a rectangular area randomly. Let's say there are two subsets S0 and S1 (k=2). Each sensor randomly selects 0 or 1 and joins one of the corresponding subsets S0 or S1. Assume that sensor nodes 0, 3, 4, 6 select number 0 and thus join subset S0, and sensor nodes 1, 2, 5, 7 select number 1 and join subset S1. Then subset S0 and S1 work alternatively which means that when sensor nodes 0, 3, 4, 6 (solid circles) are active, sensor nodes 1, 2, 5, 7 (dashed circles), fall asleep and vice versa.

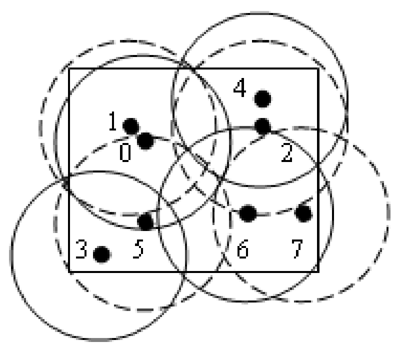
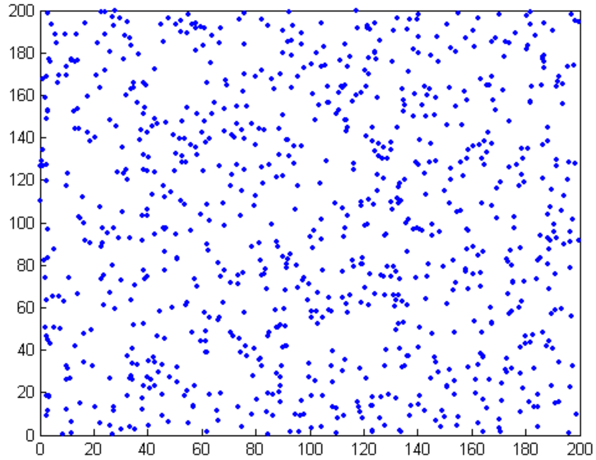


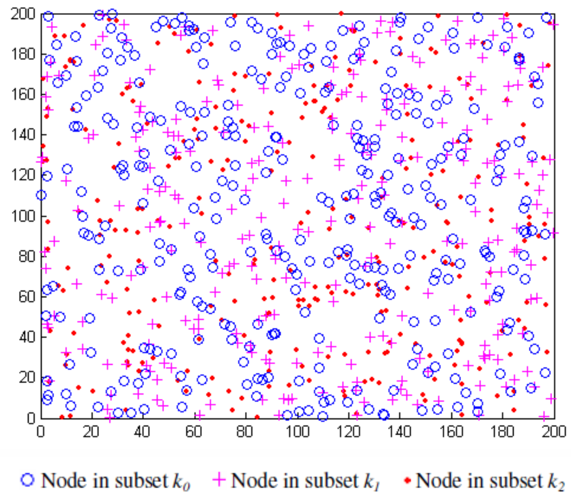
Fig. 2 An example of the randomized coverage-based algorithm

a) Node distribution

Figure 3 shows example of node distribution in the area without and with subset assignments. In Figure 3 (a), the sensor nodes are randomly distributed in the region and Figure 3 (b) shows the same distribution when the nodes are assigned to work in three subsets (k0, k1, k2). Different subsets are shown with different symbols in this figure which will be turned on in different time slots.



(a)



(b)

Fig. 3 Node distributions in the area (a) without (b) with subset assignment

2.1.2 Network Connectivity

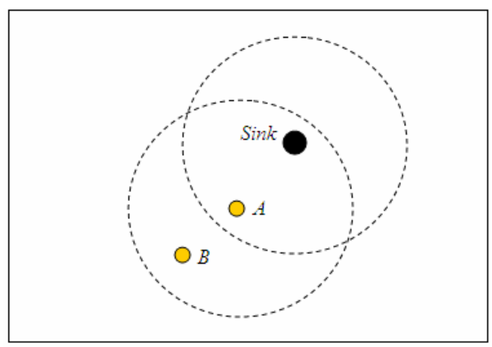
After performing randomized scheduling algorithm, the k sub-networks will be formed in the network, each of which corresponds to a predefined subset and consists of all the nodes assigned to that subset. Using the extra-on rule ensures that each sub-network is connected, given that the original network before scheduling is connected. Besides, it also guarantees that each sensor node has at least one shortest path to the sink node.

a) Extra-on rule

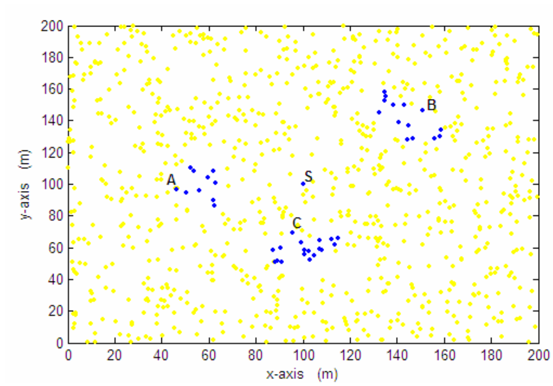
Introducing the concept of upstream and downstream nodes is required for defining the extra-on rule. Assume that each sensor node knows its minimum hop count to the sink node S. A sensor node A is called the upstream node of another sensor node B, if node A and node B are neighboring nodes and the minimal hop count of node A to the sink node is one less than that of node B. Node B is also called node A's downstream node (Figure 4(a)). Figure 4(b) shows another example from the upstream and downstream nodes in a 200 by 200 meters area with 878 deployed sensor nodes (Coverage intensity = 0.9). Upstream nodes for nodes A and B and downstream nodes for node C are highlighted in this figure.

Extra-on rule

When a sensor node A has a downstream node B active in time slot i, and if none of node B's upstream node is active in that time slot, then node A should also work in time slot i. In other words, in addition to working in duty cycles assigned by the randomized scheduling algorithm, node A is required to work in extra subset, for example time slot i in this case (Figure 5). The different color for nodes in this figure indicates different subsets.



(a)



(b)

Fig. 4 Example of upstream and downstream nodes (a) node A upstream of B,node B downstream of A. (b) Nodes A, B and their upstream nodes, node C and its downstream nodes.

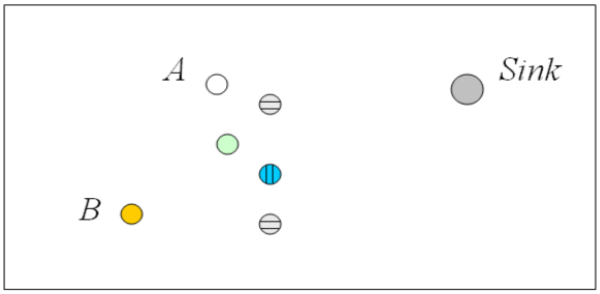


Fig. 5 Example of extra-on rule

2.2 Mathematical Formulation and Derivation

For a given k, the minimum number of sensor nodes n, required to provide a network coverage intensity of at least t is as follows[12]:

$$n \geq \left\lceil \frac{\ln(1-t)}{\ln(1-\frac{q}{k})} \right\rceil \tag{1}$$

where $q = \frac{S_a}{A}$. S_a is the size of the sensing area of each sensor, and *A* is the size of the whole field. For example, for coverage intensity of 0.9, the sensing range of 10 and *k*=4, then $q = \frac{\pi(10)^2}{40000}$ and $n \geq 1171$.

3. Improvement in proposed Algorithm

At the beginning of this section a quick review of Probing mechanism is provided then nearly shortest path algorithms are presented in detail.

3.1 Probing Mechanism Algorithm

After random deployment, each node is randomly joined to one subset. To ensure network connectivity, each node is required to find a route to the sink through its upstream nodes. If the node is not able to find an upstream node working in its subset, one of the upstream nodes should work in extra subset. This implies that to avoid turning on the extra-on nodes, at least one of the upstream nodes should be active in the node's subsets. In the probing mechanism step, one of the upstream nodes with more repeated subsets is selected randomly to change its working subset based on the probing mechanism rules [9]. Only the sensor nodes which are not already rescheduled by this algorithm can participate in the rescheduling process. This step starts from the nodes with a maximum hop count towards the sink node. The steps of algorithm for the network connectivity can be summarized as following:

- Propagation of minimum hop count
- Probing mechanism scheduling
- Creating path to the sink node using extra-on rule

At the end of each step, information is broadcasted to the neighbors.

3.2 Nearly Shortest Path Algorithm

The probing mechanism algorithm can reduce the ratio of EXONs only up to 35% while further reduction of EXONs is required to save energy in each individual node and prevent partitioning. Some of the EXONs should be turned on all the time and some of them are subjected to many transmissions and receptions. Both reasons consume the nodes energy and in some cases may be result in network partitioning. Nearly shortest path algorithm is the second proposed algorithm to reduce the number of extra-on sensor nodes effectively. To measure the performance of the nearly shortest path algorithm the ratio of extra-on sensor nodes has to be determined. Then, the total number of transmissions and receptions for EXONs, number of EXONs always on, and the average number of hop counts for transmission per node (as a measure of transmission time) are investigated and compared to algorithms with and without the pbm. This algorithm will be integrated with routing step in joint scheduling method. That step performs the extra-on rule where if there is no upstream node working simultaneously with the node, one of the upstream nodes is assigned to work in the node's subset. By using the nearly shortest path algorithm, if there is no upstream node working in the node's subset, the algorithm checks the neighboring node's upstream nodes. If the upstream nodes of the neighboring node have the desired condition, the node finds the route via that neighbor. This means the algorithm avoids turning on an extra node in the cost of routing with more number of hop counts. Figure 6 shows an example. Node A has two upstream nodes D and E. None of them is working in node A's working shift but A has a neighbor B with upstream node C active in the same subset with A. Using the nearly shortest path algorithm, node A can relay its information through node B without turning on any upstream nodes such as shown in Figure 6.

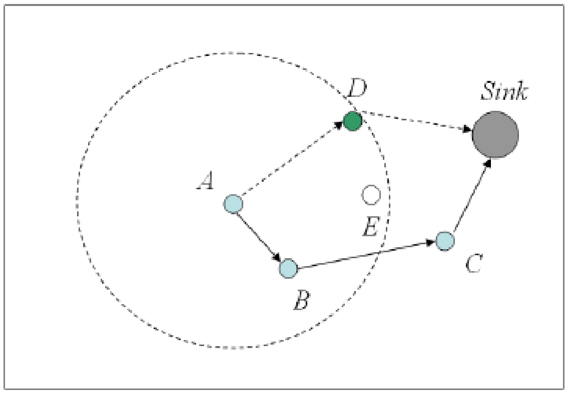


Fig. 6 Example of nearly shortest path algorithm

If the upstream nodes are not active in the same time slot with the node, then by using the nearly shortest path algorithm, the node can send its information via its peer (same hop count) neighbors. Since the information has been broadcasted to the neighbors after any changes, all sensor nodes will have information about their neighboring nodes.

4. Algorithm validation using simulation

In order to validate the correctness of the algorithm, simulation was performed using Matlab simulator. The simulation has been focused on connectivity of network, minimizing the number of extra-on sensor nodes to ensure connectivity, investigating the effect of the number of subsets and network coverage intensity on the number of extra-on sensor nodes. Furthermore, the average number of extra-on nodes always on, average total number of transmissions/receptions, and average number of hop counts for reporting per node were investigated. Five main programs were designed and implemented to simulate the proposed algorithms. All programs and their related functions are shown in Table 1. Typical specification of the wireless sensors for environmental monitoring is presented in Table 2 [13]. The parameters used in the equations and figures are also described in Table 3.

Table 1. List of programs and functions

jnt_sch	Main program to produce joint scheduling method
pbm1	Main program to produce pbm1 algorithm
pbm2	Main program to produce pbm2 algorithm
pbm3	Main program to produce pbm3 algorithm
n_sh_path	Main program to produce nearly shortest path algorithm
Pbm1_near_shp	Main program to run pbm1 and nearly shortest path algorithm
Pbm2_near_shp	Main program to run pbm2 and nearly shortest path algorithm
Pbm3_near_shp	Main program to run pbm3 and nearly shortest path algorithm
Find_route	Function to find route for nodes
SCND_route	Function to find route for nodes
Find_route2	Function to find route for nodes in nearly shortest path algorithm
SCND_route22	Function to find route for nodes in nearly shortest path algorithm
nearshrtstpath	Function to find ratio of EXONs (Extra-On Sensor Nodes) for nearly shortest path algorithm

Table 2. Specification of wireless sensors for environmental monitoring

Parameter	Typical value
Transmission range	2 – 200 m
Transmission power	16 mW
Reception power	14 mW
Battery rating	3 V

Table 3. Simulation setting parameters

Description	Range
The number of disjoint subsets (*k*)	3 – 6
Network coverage intensity (*t*)	0.6, 0.7, 0.8, 0.9
The size of the whole field (*A*)	200 × 200 m^2
Sensing Range (R_s)	10 m
Communication Range (R_c)	20 – 45 m
Communication Range for PDR	20 – 70 m
The size of sensing area of each sensor (S_a)	314.16 m^2

4.1 Simulation Scenario

The simulation for joint scheduling method starts by entering the number of subsets (k), network coverage intensity (t) and transmission range of sensors (Rc) as inputs parameters. A screen captured after the running simulation is shown in Figure 7. Two figures are shown during the simulation running, ‘node distribution’ in the area and ‘node subset assignment’. In this process also the extra-on matrix is built and at the end the ratio of extra-on sensor nodes is calculated.

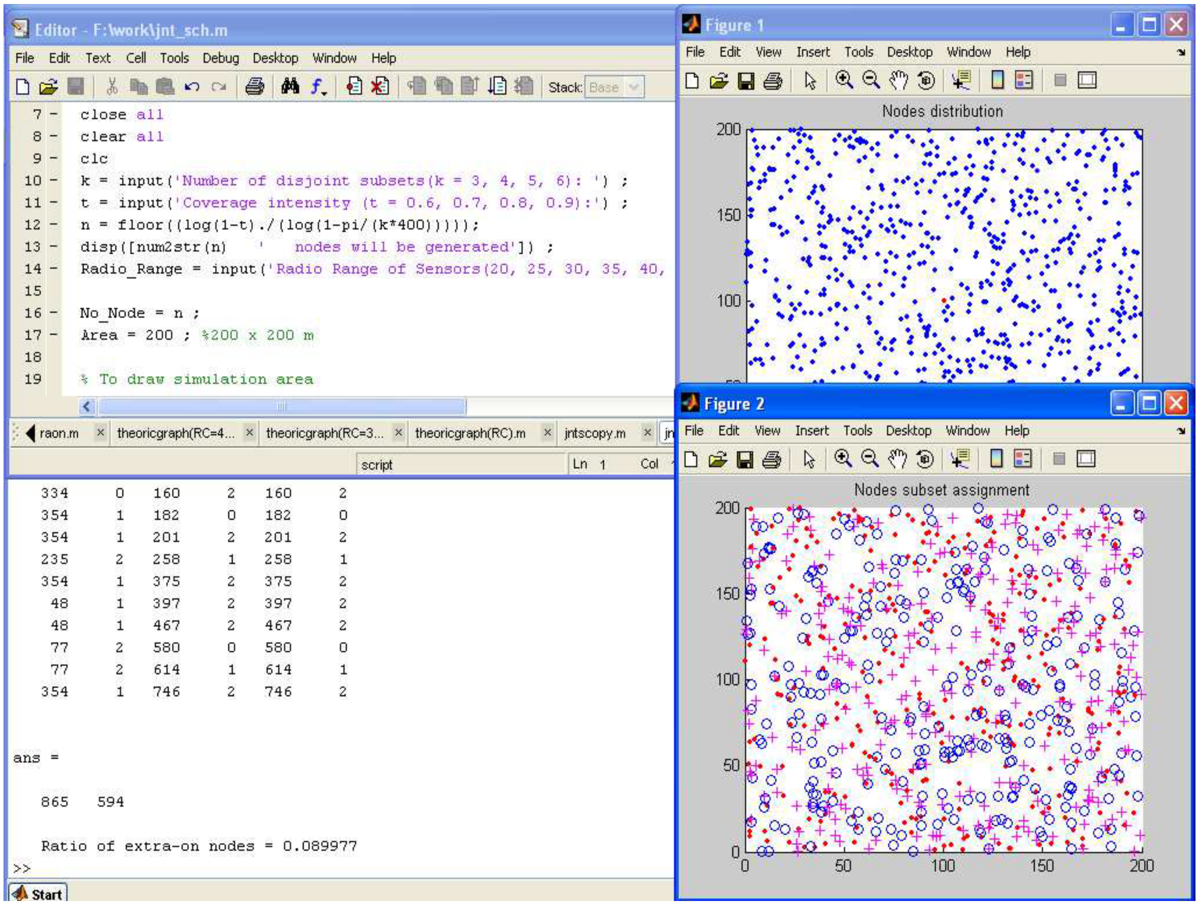


Fig. 7 Graphical User Interface sample

4.2 Simulation Flowchart

The flow chart of the simulation is shown in Figure 8. It can be seen from this flowchart which number of subsets, coverage intensity, and transmission range of sensors are inputs of this simulation. After inputting the data, n nodes are randomly generated based on coverage intensity and number of subsets. Then the nodes' respective x and y coordinates, distance between any two pair of nodes, and distance between each node and sink are calculated. In the next part, neighbors for the sink node are obtained. A random number from 0 to k-1 is assigned for each sensor node as their subset decision. Minimum hop count for each node to the sink node, all nodes' neighbors, and upstream nodes for each node are determined. Then, the probing mechanism scheduling is performed in this part, if the joint scheduling has been integrated with the probing mechanism.

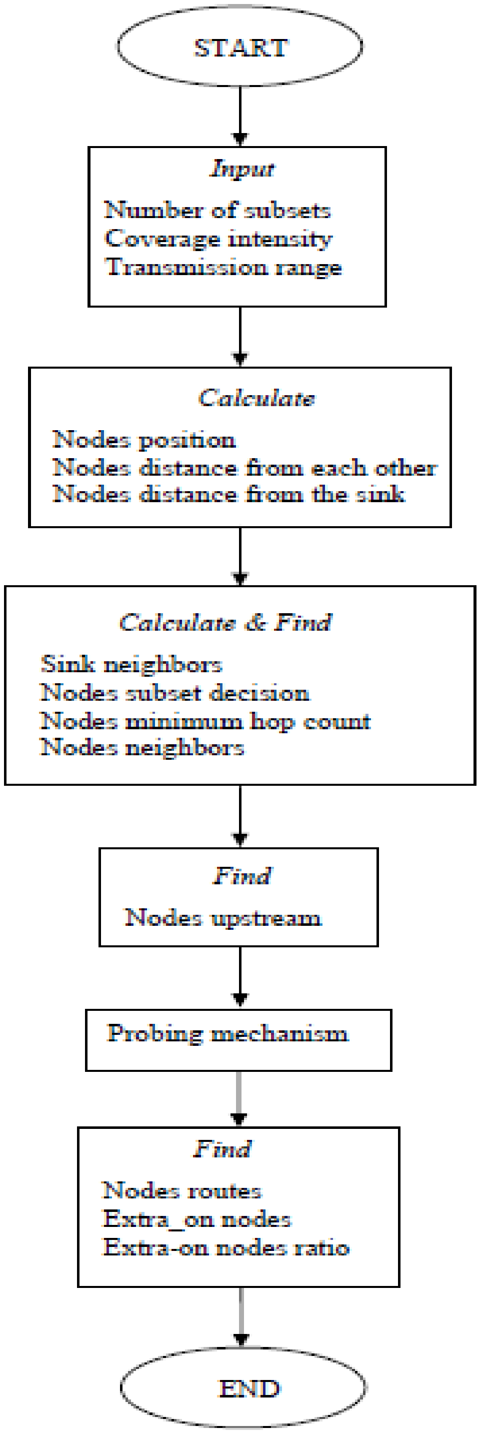


Fig. 8 Simulation flowchart

At the end of simulation one or more routes are determined for each node. At the same time with finding the routes, an extra-on matrix is created. The first and second columns of this matrix include extra-on nodes and their original subset assignments respectively. The first working subsets are already assigned by the randomized scheduling algorithm. Furthermore, the ratio of the extra-on sensor nodes is determined based on the extra-on matrix. The rescheduling process or probing mechanism is explained in the next section. Figure 9 shows the flowchart of the routing part (extra-on rule) in details for the joint scheduling method and probing mechanism algorithms. As mentioned that extra-on rule starts from nodes with maximum hop counts. The first loop in Figure 9 (L1) has a control on the number of hop counts. L1 starts from the nodes with maximum hop counts, and each run reduces the number of hop count (hop = hop – 1), until the number of hop count reaches 1. The second loop (L2) in Figure 9, for any node A, selects eligible nodes among the upstream nodes as a part of the route. It stops finding the route when the last upstream node’s minimum hop count from the sink node is equals to 1. The third loop (L3) manages and checks the finding of the routes for all nodes belonging to a hop count.

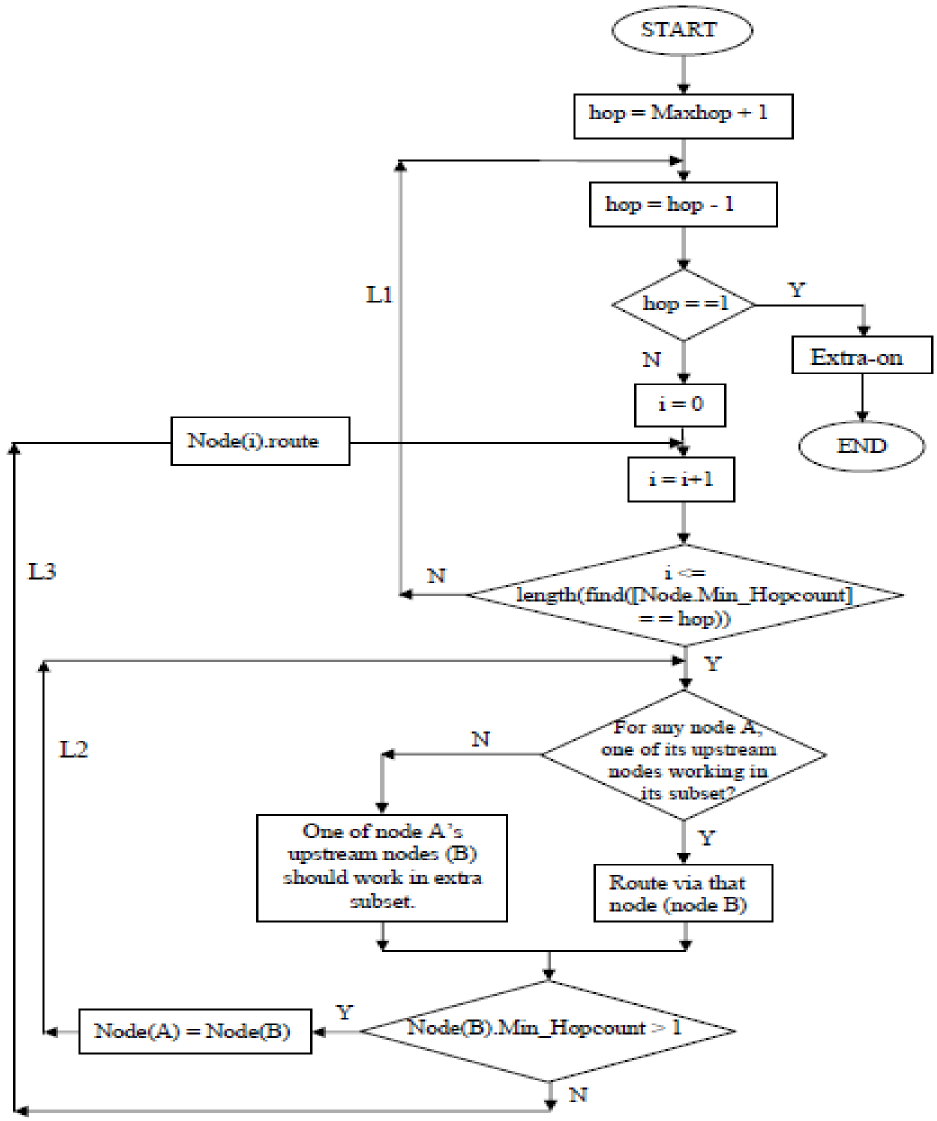


Fig. 9 Routing flowchart

a) Simulation flowchart for probing mechanism algorithms

Figure 10 shows the simulation flowchart for pbm1. As the rescheduling process should be performed before the extra on rule, in the improved algorithm, this flowchart is put before the routing part in Figure 8. Since each node can be only rescheduled by the probing mechanism once, the algorithm selects the node with the repeated subset, which was not rescheduled by the probing mechanism previously. In other words, the algorithm selects those repeated subset nodes in which their sch2 field is equals to 0. To draw a flowchart for the other probing mechanism algorithms, only the decision part (dotted rectangle in Figure 10) changes.

b) Simulation flowchart for nearly shortest path algorithm

Since the probing mechanism and extra-on rule are performed in two separate steps, two separate loops are needed (Figures 9 and 10). But the nearly shortest path and extra-on rule are performed once in broadcasting, from the node with maximum hop count to the sink node. The simulation flowchart for the routing of the nearly shortest path algorithm is shown in Figure 11. From this figure, if there is no upstream node in the same subset with node, the situation of the neighbor is checked. If the node's neighbor has an upstream node working in the nodes' subset, the node routes information via that neighbor, otherwise an extra-on node is turned on.

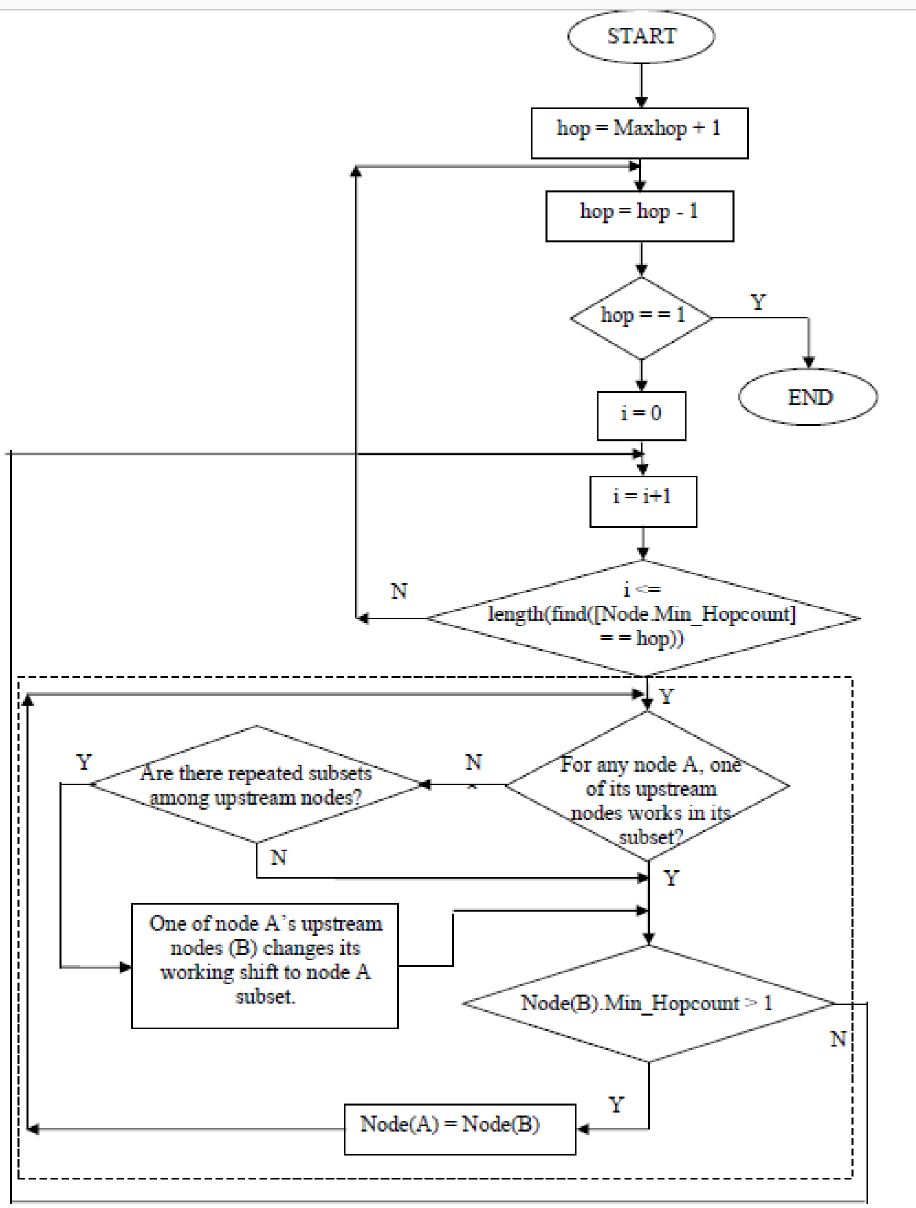


Fig. 10 Pbm1 simulation flowchart, Note: Dotted rectangle shows pbm1

decision part

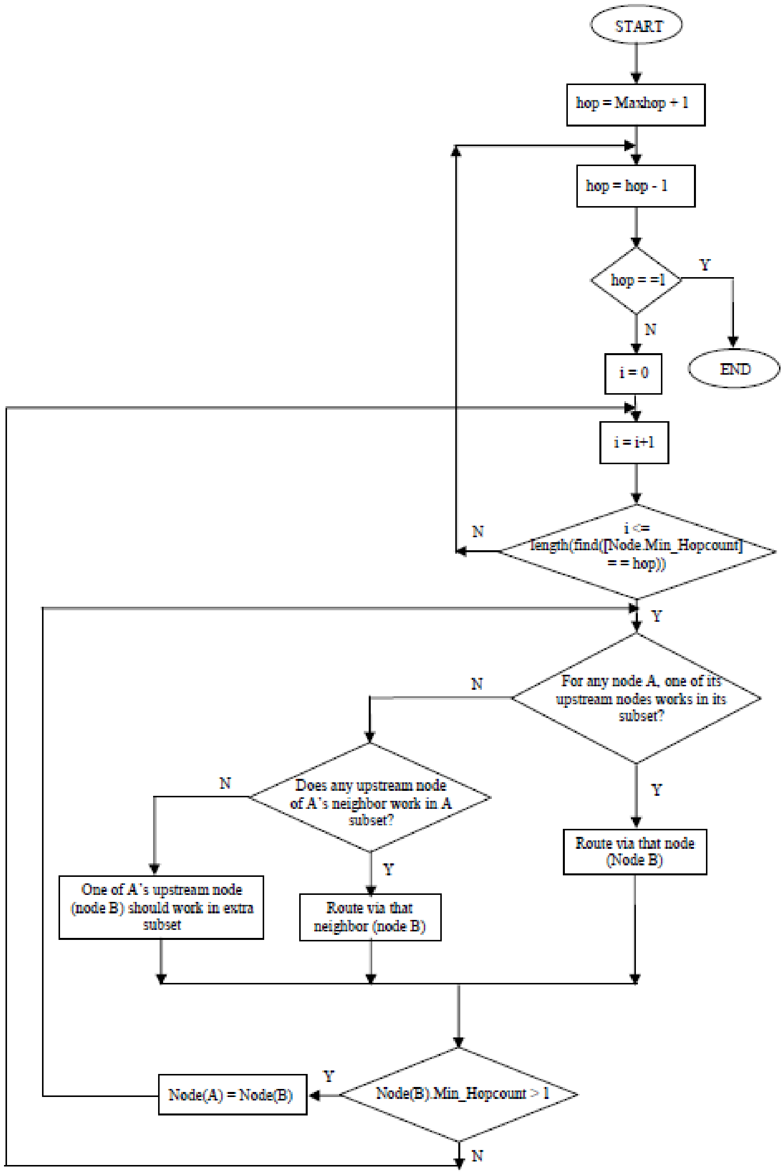


Fig. 11 Nearly shortest path algorithm routing simulation flowchart

5. Integrating probing mechanism scheduling and nearly shortest path algorithms

By utilizing the nearly shortest path algorithm, the ratio of the EXONs was reduced by 96.85%. Integrating the nearly shortest path and probing mechanism algorithms could also reduce the ratio of EXONs up to 96.85%. In other words, either using the nearly shortest path algorithm only or integrated by the probing mechanism scheduling algorithms, the same ratio of extra-on sensor nodes is resulted. On the other hand, in the integrated approach a portion of the EXONs, which were previously rescheduled by the probing mechanism algorithm, could cover some blind points. Hence, the integrated approach is preferable. Figure 12 shows the ratio of EXONs when the joint scheduling method was integrated with both the pbm3 and nearly shortest path at the same time.

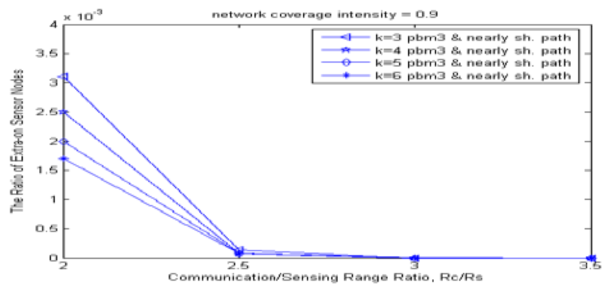


Fig. 12 The ratio of EXONs for integrated pbm3 and nearly shortest path Algorithms

5.1 Comparisons among algorithms

Table 4 shows the ratio of EXONs, number of EXONs always on, total number of transmissions/receptions and the average transmission time per node for the implemented joint scheduling method with pbm1, pbm2, pbm3 and nearly shortest path algorithms. All values in the table are average values after 100 runs for the number of subsets of 3 and coverage intensity of 0.9. The transmission time was measured based on the number of hop counts. From this table, pbm1 and pbm2 had very close values. The minimum values related to the mentioned parameters is desirable and concerning table 4, the nearly shortest path presents the smallest values of ratio of EXONs, average number of EXONs always on and average total number of transmissions/receptions. On the other hand, each node in the nearly shortest path algorithm had sent information to the sink node with 1.15 more number of hop counts which was not much more than the other algorithms. Therefore, concerning the average values of the parameters in the following table, the nearly shortest path appears to be appropriate algorithm to prevent partitioning. To cover the blind points, pbm3 had less average ratio of EXONs among the pbm algorithms. So, pbm3 is performed more number of rescheduling and is selected to integrate with the nearly shortest path algorithm.

Table 4. Comparisons among algorithms

Scheme	Ratio of EXONs (R_c/R_s=2)	Average number of EXONs active all the time	Average total number of transmission reception	Average number of hop counts
Joint Scheduling	9.84%	41.34	1370.2	4.85
Pbm1	7.78%	31.59	1111.3	4.85
Pbm2	7.83%	32.63	1133.9	4.85
Pbm3	6.36%	24.60	956.30	4.85
Nearly Shortest Path	0.31%	0.04	40.23	6

6. Conclusions

Nearly shortest path algorithm has been proposed and simulated for energy saving in each individual node in order to avoid partitioning. By implementing this algorithm some nodes have been reduced workload from other nodes by selecting an alternative path. Probing mechanism scheduling algorithms had been rescheduled the sensor nodes' original duty cycle assigned by the randomized scheduling algorithm. All the sensor nodes in the implemented joint scheduling method without and with probing mechanism used the shortest path to the sink node. Nearly shortest path algorithm does not turn on extra nodes in expense of routing via more number of hop counts.

Using nearly shortest path algorithm, if a node could not find any upstream in its subset, verifies the situation of its peer neighbors whether they have an upstream in the same subset with node. If there was such a neighbor, the node relays its information to the sink via that route. The ratio of the extra-on sensor nodes has been decreased significantly by utilizing the nearly shortest path algorithm. Although, this research study created a big reduction in the ratio of EXONs, but there were still EXONs all the time in some runs of the simulation. Those remaining EXONs all the time did not have alternative routes to the sink node and in the case of their failure, network might be partitioned. Therefore, there is still small probability of partitioning.

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