CHAPTER 3

PRIORITY BASED RENDEZVOUS PLANNING ALGORITHM FOR DATA GATHERING

3.1 INTRODUCTION

Data gathering is a mechanism that can save the energy consumption at each sensor nodes in a network using various techniques discussed in chapter 1.5. In multi-hop WSN with a static sink node, the sensor nodes, which are closer to the sink node tend to become congested and quickly drain their battery since it forwards the data from other nodes which are far away from sink node. This leads to a dead node condition which creates an energy hole in the network through which no sensor data can be forwarded further. This is called as an energy hole problem which in turn cause disconnected network and non-uniform depletion of energy which reduces the lifetime of the network.

Li et al. (2007) discussed about an analytical model for the energy hole problem. Also, due to the static nature of the sink node, the data has to travel long distance consuming more energy which reduces the lifetime of the network. This motivated to apply mobile sink based data gathering in wireless sensor networks to reduce the energy consumption and improve the packet delivery ratio.

The existing mobile data gathering techniques in WSN are broadly grouped into two categories: Direct data collection and Rendezvous data collection. In direct data collection schemes, the mobile sink node visits each node individually and collects their data. The main goal of direct data collection schemes would be to reduce the data gathering length and latency. In
Rendezvous approach, a subset of nodes called Rendezvous Points (RPs) will be selected and the mobile sink node visits them and collects the data from RP nodes and their neighbors within prescribed allowed delay.

In this work, the focus was on a priority based rendezvous planning algorithm for data gathering in delay sensitive WSN applications which incorporates both energy and delay constraints, to reduce the energy consumption and improve the packet delivery ratio.

The outline of the rest of the chapter is as follows: Section 3.2 highlights the problem formulation. Section 3.3 discusses the proposed model. Section 3.4 narrates the proposed design methodology and section 3.5 discusses the simulation results and performance of the proposed system.

3.2 PROBLEM FORMULATION

A delay tolerant WSN is considered in which the sensor nodes sense the pollution or seismic level and generate data regularly at certain interval of time. The data packet must be delivered to mobile sink node when it reaches a particular node or its nearby RP node. Also, it is ensured that the mobile sink must receive all data packets without any packet loss. The mobile sink moves around the deployed WSN to collect data from a set of RP nodes selected. The objective is to determine a set of RPs and to compute the data gathering tour by the mobile sink that will visit all the RP nodes.

Further, in order to improve the packet delivery rate, sojourn time is introduced for the mobile sink that helps to collect all the data from the sensor nodes. The term sojourn refers to ‘waiting time’ in probability and queueing theory. In this work, Sojourn time indicates the amount of waiting time for the mobile sink to wait at each RP to collect their data. The sojourn time is calculated using the number of packets to be transmitted by an RP node and the
data rate. The sink node waits until the sojourn time interval and it starts moving towards the next RP. The architecture for data collection using mobile sink in a WSN is illustrated in Figure 3.1.

The travelling Salesman Problem (TSP) is often used to model the data gathering to find a tour to visit RP nodes and collect their data. The following assumptions were made in the proposed work.

1. The sensor nodes are assumed to be deployed randomly within a square layout region and the all the nodes are assumed to be static in nature except the mobile sink.
2. The RP nodes are assumed to have the unconstrained storage capacity to buffer all sensor data.
3. Base station and the Mobile sink node are assumed to be aware of the location of sensor nodes deployed in a network.
4. Mobile sink is assumed to travel with constant speed and have unconstrained resources.
5. The deployed sensor nodes are assumed to have similar capabilities and have the same radius of coverage.
6. Each sensor node generates one data packet of size of ‘b’ bits at a regular time interval ‘D’.
7. The communication time between the sensor nodes and the sink node is considered negligible when compared to the mobile sink's travelling time.
3.3 PROPOSED MODEL

A WSN is considered as a graph $G(V,E)$, where $V$ is the set of homogeneous sensor nodes, and $E$ is the set of the edges between each pair of nodes in $V$. The mobile sink starts its movement from the node $m_0 \in V$ with a constant speed ‘$v$’, stops at each RP for a sojourn time period ‘$p$’ and can travel a maximum distance of $l_{max}$. Hence, the maximum distance a mobile sink can travel is given by

$$l_{max} = v \cdot D \quad (3.1)$$

where $v$ indicates the speed at which the mobile sink moves and $D$ indicates the maximum amount of delay allowed (includes sojourn time). Each sensor node
transmits its packet to the nearest RP through multi-hop transmission. The mobile sink stops at each RP for a desired sojourn time period ‘p’ and collects their data and move to next RP. The objective of the model is to find a tour \( M = \{m_0, m_1, m_2, \ldots, m_n, m_0\} \) where \( m_i \in V \), such that the tour length does not exceed \( l_{max} \) which increases the data collection efficiency, by using tour refinement procedure.

### 3.4 PROPOSED DESIGN

Priority based Rendezvous Planning (PRP) preferentially designates sensor nodes with the highest priority value as an RP. The priority of a sensor node is calculated as the product of the number of data packets that the sensor node has to forward and its hop distance to the nearest RP on the tour. Thus, the priority of sensor node ‘\( i \)’ is calculated as

\[
P_i = \text{number of packets} \times \text{hop Count}
\]  

where \( P \) indicates the calculated priority of a sensor node. The sensor nodes, which are one hop neighbors from an RP node and sensor nodes which have less number of data packets in their buffer get the minimum priority value. Hence, sensor nodes that are far away from the selected RPs and/or having higher number of packets in their buffer will have a higher priority of being recruited as an RP. In general, the energy consumption in a sensor node is directly proportional to the hop count between source and destination nodes, and the total number of data packets to be forwarded. Hence, by visiting the highest priority sensor node, the energy consumption can be reduced significantly by reducing the number of multi-hop transmissions. This ultimately helps to prevent the formation of energy holes in WSN. Also, in dense areas of the network, the presence of a large number of sensor nodes may cause congestion that results in energy holes. Thus, making a mobile sink to visit these regions will prevent the formation of energy holes in WSN. But visiting the same sensor node again and
again may reduce its battery energy while during multiple rounds of mobile data gathering tour. Hence, it is suggested that, at a regular interval of time, the priority computation has to be repeated, assuming different values for maximum allowable delay during data collection process which helps to change the RP nodes for data gathering.

In this work, initially a priority value is computed for all sensor nodes using equation 3.2. The priority values are calculated based on the number of data packets in a sensor node’s buffer for transmission and the hop count to the nearest RP node. In order to find this, a data forwarding tree is constructed with the sink node as the root node. Initially, the mobile sink starts its tour from the sink node which is the root of the data gathering tree. Next a node ‘a’ with highest priority is selected and added to tour, then the tour length is calculated and checked with $l_{\text{max}}$. If the calculated tour length is less than $l_{\text{max}}$, then the node ‘a’ is added to the tour and labelled as RP, if not the node ‘a’ is removed from the tour. At the end of this iteration, $M=[\text{sink, a}]$. Similarly, the above process is repeated until a set of RP points were selected to satisfy the maximum tour length of $l_{\text{max}}$.

The basic idea to find RPs among the sensor nodes is to first construct a Shortest Path Tree (SPT), rooted at the sink node. The SPT is constructed to find the shortest route between the sink node (root) and other sensor nodes in the network. To improve the data collection efficiency, the mobile sink has to wait near each RP node for a time interval called sojourn time (waiting time). More the number of packets to be pushed, more the sojourn time for the mobile sink. The sojourn time for the mobile sink at each RP node was calculated using the number of packets to be pushed by an RP node and the data rate. The mobile sink sojourns near the RP node for the calculated period of time such that it can completely drain all the data from the RP node. This dynamic sojourn time computation leads to a more reliable data collection with increased packet
delivery ratio. For example, if a packet size is assumed to be 20 bytes (20 x 8 = 160 bits) and data transmission rate is assumed to be 2000 bps, then sojourn time will be 0.08 seconds for a single data packet to be pushed which is considerably smaller when compared to the maximum allowable delay in the data collection process. The sojourn time is calculated as a function of the number of the packet and the data rate as given in Eq. 3.3.

\[ p = \frac{N \times S}{R} \quad (3.3) \]

where, \( p \) is the sojourn time, \( N \) is the number of packets, \( S \) is the size of each packet (in bits) and \( R \) is the rate of transmission (in bits per second). Hence, the mobile sink dynamically calculates the waiting time and moves towards the next RP to pull its data and this behavior helps to make a mobile sink to spare less time with RP nodes which have less number of packets to be pushed which ensures improved data collection.

**Table 3.1 Algorithm for priority based rendezvous planning algorithm**

<table>
<thead>
<tr>
<th>Input: ( G(V, E), l_{max} )</th>
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<tbody>
<tr>
<td>Output: ( M = {m_0, m_1, m_2, \ldots, m_n, m_0} = \text{NULL} ) where ( m_i \in V \cup \text{Sink} )</td>
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<tr>
<td><strong>PROCESS:</strong></td>
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<tr>
<td>Step 1: Assign the sink node as the first RP in the set ( M ).</td>
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<tr>
<td>Step 2: Construct an SPT with the sink node as the root node.</td>
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<tr>
<td>Step 3: For each node in the network</td>
</tr>
<tr>
<td>a. Calculate the hop count to nearest RP and the number of packets to forward.</td>
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<tr>
<td>b. Calculate the priority values for all the sensor nodes.</td>
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<tr>
<td>Step 4: Assign the highest priority node as the RP, and add to the set ( M ).</td>
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<tr>
<td>Step 5: Find the tour length using the TSP solver.</td>
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<tr>
<td>Step 6: If the tour length is less than the ( l_{max} ) value then accept the tour.</td>
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<tr>
<td>Step 7: Else remove the RP from the list ( M ) and search for next RP and iterate.</td>
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</table>
The above procedure to find the travelling tour for a mobile sink using PRP algorithm is illustrated with an example as follows:

![Figure 3.2 Illustration of PRP algorithm](image)

The Euclidean distance between few sensor nodes in the Figure 3.2 were assumed as follows for illustration purpose:

- (Sink, Node 0) – 25m, (Sink, Node 6) – 30m,
- (Sink, Node 7) – 50m, (Node 0, Node 6) – 15m,
- (Node 6, Node 7) – 30m
Initially, the maximum tour length allowed is assumed as $l_{max} = 90$ m. PRP algorithm starts from the sink node and adds it to the tour, so, $M = \{\text{Sink}\}$. After this an SPT is constructed with the sink node as the root node.

During iteration-I, PRP adds node 6 to the tour because it has the highest priority, yielding $M = \{\text{Sink}, 6\}$. The tour length of $M$ is smaller than the required tour length ($60 < 90$), hence node 6 stays in the final tour.

During iteration-II, PRP recalculates the priority values of sensor nodes because node 6 is now part of the tour. PRP selects node 7 as the next RP, which has the highest priority value. As Figure 3.2 (c) shows, the tour length of $M = \{\text{Sink}, 6, 7\}$ is larger than the required tour length ($110 > 90$). Consequently, PRP removes node 7 from the tour $M = \{\text{Sink}, 6\}$.

During iteration-III, the priority value of sensor nodes will not change because node 7 is not selected as an RP but it stays marked and will not be selected. PRP selects node 0 because it has the next highest priority value and is not marked [as shown in Figure 3.2 (d)]. The TSP function returns $70$ m for $M = \{\text{Sink}, 6, 0\}$, which is less than $90$ m.

During iteration-IV, node 0 is added to the tour. PRP recalculates the priority values of sensor nodes because node 0 is added to the tour. The process continued, yielding a final tour of $M = \{\text{Sink}, 8, 6, 0\}$ with a tour length of $85$ m, which is less than the required tour length as shown in Figure 3.2 (e).

As shown in Figure 3.2, the final tour computed by PRP algorithm always includes sensor nodes that have more data packets to forward than other nodes as RPs. This ensures uniform energy consumption and mitigates the energy-hole problem. This is the key advantage of PRP over the other cluster based approach and rendezvous based approaches.
At each round of data collection, the priority values at each node should be calculated and must be communicated to the mobile sink node, which computes the travel plan and makes known to all the other sensor nodes so that each sensor node sends their data to the RP. Based on the travel plan the sink node moves to the RP collects the data and restore its position for the next cycle. In order to decide the priority of the nodes, the other parameter could be current battery energy level so that the alternate RP could be selected. Due to battery drainage over the duration of the transmission in the RP, the role of a node as RP cannot be sustained and hence the adaptive assignment of RP is suggested. In general, the priority of the node is written as:

\[ Pr(N, C, B) \]

where, N is the number of packets to be transmitted from the node, C is the Hop count of the current node to the nearest RP node, and B is the battery energy level. In this thesis, N and C have been considered for the experimental work. The process of fixing the priority, moving to the sensor nodes, collecting the data is repeated over all the selected RP nodes as per the computation of maximum tour length. The distance to BS from each sensor node can also be considered to calculate the priority of sensor nodes. The remaining battery energy level of a sensor node and physical distance between sensor nodes does not contribute significantly to reduce the network energy consumption. Because, giving priority to the sensor node with high residual energy, but less degree and more hop count to RP may not guarantee reduced energy consumption. Hence, in this work we considered only the number of data packets and number of hops for priority computation.

The priority value is calculated using Eq. 3.2 and tour path is computed at the completion of each tour. The tour path information is broadcasted to all the sensor nodes by the base station which intimate the non-
RP node to send its data to the nearest RP nodes which push its data to the mobile sink node when it visits. At the end, the mobile sink node uploads all the data to either a BS or a static sink node for further analysis and starts its next cycle of mobile data gathering. If the maximum allowable delay (D) during the mobile data gathering is fixed, the priority computation has to be done only once. For every change in ‘D’ the priority computation process has to be repeated and the tour construction steps also have to be repeated at the base station which is assumed to be resource intensive in general.

3.5 SIMULATION AND RESULTS

The experimental simulations and analysis are done in Network Simulator NS2. A connected WSN where nodes are placed uniformly on a sensor field of size 200m × 200m is considered in this simulation. PRP is used to interconnect disconnected nodes if the required delivery time for data packets is greater than the shortest travelling tour to visit all sensor nodes. The reason for following uniform sensor-node distribution is energy holes are less likely to form when nodes are distributed uniformly. Each sensor node generates one data packet every T time, which is then forwarded to an RP through an SPT. The sensor nodes are assumed to be aware of the mobile sink’s movement and the arrival time of the mobile sink. The proposed WSN has a maximum of 200 sensor nodes, which is reasonable for most applications. In order to measure network lifetime, all sensor nodes are assumed to have a fully charged battery with 100 J of energy. Other parameters are summarized in Table 3.1.

<table>
<thead>
<tr>
<th>Table 3.2 Simulation parameters</th>
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<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>Number of sensor nodes (n)</td>
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<tr>
<td>Mobile sink speed (v)</td>
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<td>Sensor node’s transmission range</td>
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Table 3.2 Continued

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<tbody>
<tr>
<td><strong>Packet length (b)</strong></td>
<td>20 bytes</td>
</tr>
<tr>
<td><strong>Sensor node’s battery</strong></td>
<td>100 J</td>
</tr>
<tr>
<td><strong>Allowed packet delay (D)</strong></td>
<td>200 s</td>
</tr>
</tbody>
</table>

The scalability of the deployed sensor nodes is compared with the existing algorithms. In WSN, when the number of nodes increases, the consumption of energy should be maintained. Compared to the existing approaches, the energy consumption of the PRP algorithm is very much reduced.

Figure 3.3 shows the effect of increase in number of sensor nodes (x-axis) with the Standard Deviation of the node’s energy consumption (y-axis). The Number of nodes is varied from 40 to 200 deployed in a distributed area of 200m x 200m. The proposed algorithm was compared with a cluster based algorithm, RD-VT and RP-UG algorithms discussed in section 2.2. The
performance of PRP algorithm outperforms the other approaches due to the optimal selection of RP nodes having more number of data packets for transmission and having more number of hop nodes. This leads to minimized energy consumption among sensor nodes when compared to other approaches.

In this approach, visiting a high priority always reduces the amount of energy consumption than visiting a node with low priority. Because, the highest priority node always has more number of packets to be transmitted (including its child node packets) and available at more than single hop distance. This helps to reduce the number of multi hop transmission in turn the amount of energy consumed on each sensor node. Thus, a sensor node with highest priority if get selected as RP helps to reduce the overall network energy consumption by transmitting its child node packets to mobile sink node when it visits.

In a static network with fixed allowable delay and one packet of data being generated within the time interval 'D', the same set of RP nodes will be selected for data gathering. But for variable values of 'D' the RP nodes selection process yields a different set of sensor nodes for mobile data gathering by a mobile sink. Optimum solution can be obtained if all the sensor nodes were selected as RP subjected to the condition that the optimal tour length $l_{opt} \leq l_{Max}$, which results in reduced network energy consumption improving the lifetime of the network.

The performance of the proposed rendezvous algorithm is compared in terms of the Packet Delivery Ratio (PDR) with respect to scalability by varying the number of sensor nodes. Packet Delivery Ratio (PDR) is defined as the ratio of the total number of packets successfully received to the number of packets sent.

$$\text{PDR} = \frac{\text{Total number of packets successfully received}}{\text{Total number of packets sent}}$$  \hspace{1cm} (3.4)
Figure 3.4 shows that the proposed algorithm has high PDR when compared to other approaches. This is primarily due to the proposed algorithm incur less network energy consumption, which increase their lifetime and hence is able to receive a large number of data packets successfully. This improves the overall PDR. When the number of sensor nodes is large, the number of transmitting packets will be more in number that will lead to packet loss due to the constrained tour length and the constant speed of mobile sink. Also, the introduction of dynamic sojourn time helps to improve PDR by forcing the mobile sink to wait near an RP and collect its data, which helps to improve the performance than other approaches.

Figure 3.5 illustrates the performance of the proposed algorithm and is compared in terms of simulation time with respect to scalability of the network by varying the number of nodes. The simulation time is defined as the
time taken for the execution of a particular algorithm. The proposed algorithm takes a nominal amount of time for its execution over other existing approaches.

![Graph](image)

**Figure 3.5 Number of nodes Vs simulation time**

### 3.6 SUMMARY OF CONTRIBUTIONS

A mobile sink data gathering scheme for centralized and distributed sensor networks is proposed in which the mobile sink movement is efficient with high data delivery. An energy efficient movement path is found using the set of rendezvous points and the mobile sink visits them individually by travelling along the path and collects their data and returns to its initial position. This movement path is an optimal path for the mobile sink to reach all the rendezvous points. The proposed energy efficient data gathering approach in wireless sensor networks facilitates for the local data aggregation in each RP node with optimal tour length and improved scalability. The simulation results demonstrate that the proposed mobile sink data gathering scheme greatly reduces the energy consumption and improves the PDR compared to the existing algorithms.