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Research Article

Dynamic Path Planning Design for Mobile Sink with Burst Traffic in a Region of WSN

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In mobile wireless sensor networks, priori-trail planning for the mobile sink is a commonly used solution to data collection from the whole network, for its low protocol overhead. However, these trail-based approaches lack efficient load balance mechanism to handle burst WSN traffic, which needs to be sent to the base station correctly with low delay. This paper proposed a dynamic path planning for mobile sink to balance load and avoid traffic bottleneck. It contains grid partition of the network, priori-trail creation, burst-traffic awareness and estimation, resources collaborative strategy, and dynamic routing adjustment. Experiments on NS-2 platform show that the proposed algorithm can efficiently balance the regular and burst data traffic with a low-delay and low loss rate performance of the network.

1. Introduction

In recent years, Wireless Sensor Networks (WSN) have been used in various fields, such as ocean exploration, battlefield target location, physiological data collection, and intelligent transportation systems [1]. When there is link-quality degradation or data throughput instability in WSN, Deterministic Routing Strategy (DRS) fails to deal with energy efficiency and network performance problems [2]. Although Opportunistic Routing based methods could overcome the disadvantage of DRS by using potential-relay mechanism to some degree, they also introduce another flooding problem, where packets are repetitively forwarded among multinodes across the network [3]. Incidental data often suddenly occur in such cases, like water pollution detection or wildlife monitoring, and their information transmission would lead to burst traffic in WSN. To quickly respond to these affairs and meanwhile improve energy efficiency and network performance, we propose a novel algorithm named Dynamic Path Planning for Mobile Sink with Burst Traffic (DPPMSBT).

The main contributions of this paper are three aspects:

(1) Dynamic path planning for mobile sink node, which could quickly respond to emergent data collection.

(2) Reducing packets loss rate by waking up neighboring nodes to cache data when burst traffic occurs.

(3) Prolonging network's lifetime by re-electing cluster heads based on the balance between residual energy and center location of nodes.

The rest of the paper is organized as follows. In Section 2, previous researches on mobile sink network are given in detail. In Section 3, grid partition of WSN network and priori-trail creation of mobile sink based on this grid partition is presented. In Section 4, burst traffic-awareness and estimation are described and a collaborating transmitting model on neighboring resources is also established. Finally, in Section 5, dynamic route adjustment algorithm of this paper is presented and experimental results are also given, showing that it is efficient in lowing the packet loss rate and delay and balancing nodes' energy to extend the network life cycle.

2. Related Works

In regular data collecting, a mobile sink needs to move back and forth along some predesigned paths across the whole WSN network. Hot spot strategy has been proved to be an effective method for data collection so far, and it needs grouped nodes gather their information on hot spots for mobile sinks' visit in sequence [4, 5]. Many studies on algorithms about hot spot locating [4, 6–10] and mobile sinks trail predesigning [11–21] have been reported.

In literature [9], Z. Pooranian et al. used the Queen-Bee algorithm to create energy efficient clusters in wireless sensor networks. Based on Genetic Algorithm (GA), Queen-Bee (QB) could reproduce more children than GA algorithm by using the crossover operator, so it could overcome the premature convergence problem existing in GA algorithm. With QB algorithm, number of clusters, cluster heads, cluster members, and the transmission schedules were determined, and the results of the simulation showed that the energy consumption of the nodes had been decreased and the lifetime of the network was increased. Habib Mostafaei [20] proposed a Distributed Learning Automaton (DLA) algorithm to dynamically plan a path from the source to the destination by considering several QoS routing constraints like end-to-end reliability, and energy cost and packets delay. However, burst traffic caused by incidence was not discussed in these literatures.

In literature [12], Lin and his team proposed a mobile node with WSN energy-saving mobile routing algorithm named an Energy-Efficient Mobile Routing Algorithm to extend the life of wireless sensor network. The cluster head is selected according to the residual energy, which avoids a node of the low residual energy be selected as a cluster head. Another mobile sink is added as relay station for data collection especially when there is burst traffic occurring. However, the article did not discuss this problem of burst data traffic furtherly.

In literature [14], the HexDD (Honeycomb Architecture and Hexagonal Tiling-Based Data Dissemination) protocol was proposed for the emergent data transmission in wireless sensor network, which partitioned network into independent hexagonal meshes and then stored the emergent data on nodes of hexagonal grid boundary. The mobile sink moved randomly to collect the emergent data from the boundary nodes by sending query packets. However, HexDD protocol was designed to cruise across the whole network for burst data collection, and it was short of dealing with the periodic data gathering work.

Based on studies mentioned above, we saw that periodic collection of data on the network and burst traffic were usually done separately, and we tried to integrate these two works by changing mobile sink's path dynamically to collect burst data in one of our previous study [21]. In this study, we are going to further study of improving the balance of energy consumption between sudden data flow and the whole network's periodic node data collection and meanwhile meet the performance requirement of the network.

3. Network Model and Problem Description

3.1. Problem Description. In this paper we will focus on the after-mentioned situation. In a dense wireless sensor networks, we need to collect the whole network data regularly, and in a round of data collection process only one area may produce burst traffic. In order to solve this problem, this paper proposes a dynamic node movement strategy. Firstly, the monitoring area is divided into independent virtual grids. Each node selects a node as a cluster head, and each cluster head position is an alternate position for mobile sink node movement. Then we can transform the moving position of the mobile sink node into a classic traveler problem (Traveling Salesman Problem, TSP). If an area has an unexpected event, it is necessary to ensure that burst traffic data is collected in the shortest possible time and that the delay of collecting other nodes is reduced as much as possible, also, saving node energy at the same time.

3.2. Network and Channel Model. N sensor nodes are distributed in the square monitoring area evenly. The sensor nodes, battery-powered, have limited energy, storage, and computing power. The mobile sink node starts moving from the point of a certain point of departure and moves along the planning path at constant speed V_s and collects periodic data of the monitoring area. When the sink node moves to the communication range of the cluster head node, the node of the monitoring area communicates with it in a single hop mode.

Communication between nodes is set over a single shared channel to avoid multichannels inter-coordination, which would lead to nodes' end-to-end time delay. In order to cover the bandwidth limitation due to mutual interference between neighboring nodes, we introduce a neighbor interference degree aware algorithm for local links allocation [22]. When packets arrive at each cluster head, they are accepted in time-slot strategy to improve the channel utilization.

In a regular round, mobile sink node moves along with predesigned path to reach each cluster head node to collect data.

3.3. Network Assumptions. The following assumptions are given:

(1) The nodes in the network are evenly distributed, with unique ID and no longer moved after deployment.

(2) All nodes in the network have the same initial energy and communication radius and transmit and receive power.

(3) Sink nodes, whose energy is not restricted, move at a constant speed v_s, that is, slower than the frequency of the data sent from sensor node so as not to affect the data transceiver.

(4) Each sensor node can obtain its own location information through GPS or other positioning algorithm.

(5) The mobile sink node can access the existing network wirelessly, in addition to being able to communicate freely with the sensor node in the detection area.

In this paper, a simple energy consumption model is used, assuming that all nodes in the network use fixed transmit power and receive power. A round of data collection is completed when the mobile sink node moves back to the original position.

4. Path Optimization Algorithms

4.1. DPPMSBT Algorithm Flow. When no burst traffic occurs, a shortest route L for mobile sink node is originated. When

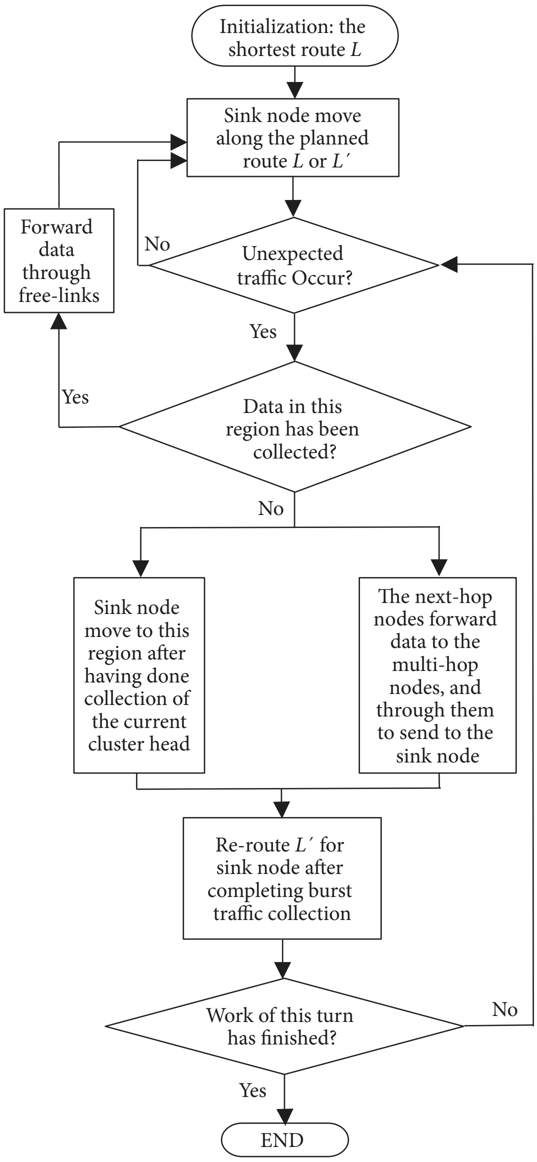

Figure 1: DPPMSBT algorithm flow chart.

it occurs, there are two schemes depending on whether the emergent region's data have already been collected.

(1) If yes, nodes in this region are rather idle and we can forward burst traffic data through these nodes to the mobile sink node.

(2) If no, the mobile sink node will temporarily change its way for quick response to the emergency. This will interrupt originally planned routine work, and we readjust the original plan and route, whose detailed description is shown in Figure 1 and Step 3, Section 4.2.

4.2. DPPMSBT Algorithm Implementation

Step 1. In the initial planning of the mobile sink node path, we refer to the MREEMRP algorithm [12] to divide the monitoring region into a number of square grids, where each node is grouped into the corresponding grid depending on its location. Each grid forms a cluster, whose center node named cluster head is selected by the balance between the residual energy of nodes and the sum of the distances from all nodes to the cluster head, avoiding low residual energy node from being selected as a cluster head. Suppose that the maximal communication distance between any two nodes is R, and the grid side length is r. In order to fulfill the requirements of communicative distance of any two nodes between any two neighboring grids, grid side length r of division needs to meet the formula (1).

$$r^2 + (2r)^2 \leq R^2 \Longrightarrow \\ r \leq \frac{R}{\sqrt{5}} \tag{1}$$

In each cluster, only cluster head node remains active to collect data from its cluster and send data to the mobile sink node, while the others stay in the sleeping state.

Step 2. Before the start of the data collection, the mobile sink node can obtain the shortest travelling path L with an improved TSP path planning algorithm, whose time complexity is described in formula (2).

$$\sum_{k=2}^{n-1} k\,(k-1)\binom{n-1}{k} + n - 1 = O\left(2^n n^2\right) \tag{2}$$

where n is number of cluster heads, whose sequence number is k.

After that, the mobile sink node can calculate the total time required to reach each cluster head for data collection as Original planned path time. The mobile sink node collects the data of each cluster head within one hop, with a combination of static collection and dynamic movement alternative mode. Suppose the mobile sink stays t_s seconds to gather cluster head's data, which can be adjusted according to the data amount of each grid.

When no burst traffic occurs, the mobile sink node moves according to the Original Planned Path L to collect the cluster heads' data, as shown in Figure 2.

Step 3. Suppose, at a moment, a node labelled with Z has burst traffic data; there are two different schemes for the mobile sink node's next work.

(1°) The mobile sink node has already visited the cluster which node Z belongs to, meaning that its data has been collected just now.

In this case, node Z forwards its burst traffic data directly to the mobile sink node through a shortest route. Firstly, it broadcasts a route request packet (ReqP) to neighboring nodes. One of the neighboring nodes accepts this ReqP and adds the last hop information to the routing table with the corresponding hop count plus 1, and then it forwards this ReqP to its neighboring nodes, ..., and so on until this ReqP reaches the mobile sink node. The mobile sink node will select the route with the smallest number of hops after it receives all ReqPs, then it returns a route reply packet,

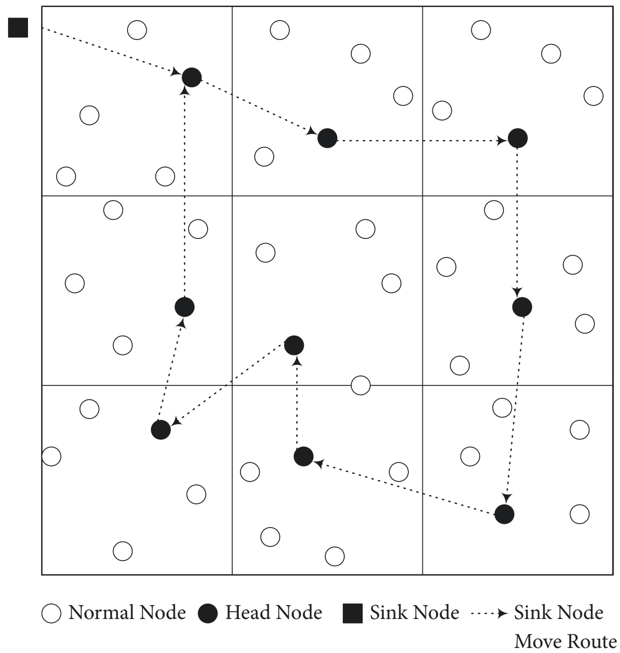

Figure 2: Sink Data Collection Path Planned Model Based on Grid.

Destination node	Source node	Last hop	Next hop	Number of hops

Figure 3: Routing Table Format.

establishing a reverse route according to the hop information. After Node Z receives this route reply packet, it sends its burst traffic data to the mobile sink node along this route. The routing table format is shown in Figure 3.

(2°) The mobile sink node has not yet visited the cluster which node Z belongs to, and node Z needs to wait for the mobile sink node coming to collect burst traffic data.

Firstly, node Z wakes up other node within the same grid to help it cache the data, preventing packets loss due to excessive volume. Then, the mobile sink node will respond according to its different current state. If it is collecting data from a cluster head now, it will come straightly to the grid of node Z after it finished the collection of current regions. Otherwise, the mobile sink node will come to the region of node Z immediately to collect burst traffic data. Thirdly, we assume that each cluster head node needs the same time t_s for sending data to the mobile sink node, and the time t for the mobile sink node takes from now to finishing data collection of node Z is calculated according to formula (3), where (X_Z, Y_Z) and (X_S, Y_S) are coordinates of node Z and mobile sink node, respectively. V_S is the moving speed of mobile sink node.

$$t = t_s + \frac{1}{V_s}\sqrt{\left(Y_Z - Y_S\right)^2 + \left(X_Z - X_S\right)^2} \quad (3)$$

Fourthly, we subdivide the unvisited clusters into two sets, where set V_1 is for the clusters which are originally planned to be visited by the mobile sink node within time t and set V_2 is for the clusters which are originally planned to be visited by the mobile sink node beyond time t. While the mobile sink node moves to node Z, it will inform nodes in set V_1 to forward their periodic data through nodes in set V_2.

Fifthly, clusters in set V_1 send data forwarding request packet (DFReqP) to nodes in set V_2 and then wait for their returns to determine a minimum hop route to forward data. Nodes in set V_2 return DFResP back after received it. Then, cluster head in set V_1 selects a smallest number hop route based on returned DFResP packets. If there are multiple-routes with the smallest number of hops as candidate, we select the one on which DFResP is firstly sent back and along it return a data forwarding confirmation packet (DFAP) back. Considering that volume of a single node is limited, we also wake neighboring node within the same grid up to help the current node forward data, and this will reduce the packet loss rate. The awakened node returns the data forwarding route message packet (DFRMP) to the DFReqP source in set V_1, and the latter will forward its data to the mobile sink node through the awakened node. After forwarding, the awakened node will go back into sleep mode again. In order to improve the network's lifetime, we make a rule that if a cluster head in set V_2 has received DFAP once, meaning it has taken charge of a data forwarding task, then it can reject all other DFRefP, so that the data forwarding burdens in set V_2 can be distributed evenly in different nodes to prevent single node premature death due to losing energy.

After collecting the burst traffic data of node Z, the mobile sink node re-establishes its remaining path L' for the nodes in set V_2, to continue this round of data collection.

An example of this burst traffic data transmission is shown in Figure 4. Suppose that node 8 has burst traffic data occurring when mobile sink node is collecting data from node 3 and node 8 is a cluster head which is waiting for mobile sink node coming to collect its data. Node 8 sends message to notify mobile sink node to come and neighboring node 8' to help cache its burst traffic data. The mobile sink node rushes to node 8 after completing data collection for node 3.

At the same time, the time t for data collection at node 8 is calculated by the formula (3) and compared with the expected visiting time of the rest cluster heads originally planned to visit in this round. At this point, the expected visiting time of node 6 and node 9 is within time t. Accordingly, we add node 6, 9 to set V_1. The remaining nodes 4, 5, and 7 are added to set V_2. The mobile sink node informs two nodes in set V_1 to forward their data through nodes in set V_2. Nodes 6,9 broadcast DFReqP to find the smallest hops routing and then get the routing information in DFResP returned by each node in set V_2. Suppose node 5 firstly receives the returned DFResP from node 6, so it sends a DFAP to node 6 and refuses node 9 forwarding request. After receiving the back message from node 6, node 5 uses an AwaP to wake up node 5', and the latter sends a DFRMP to node 6 according to the routing information contained in the wakeup packet, preparing to help node 6 forward data. Then, node 6 can send its data to node 5' to forward to the mobile sink node. On the other

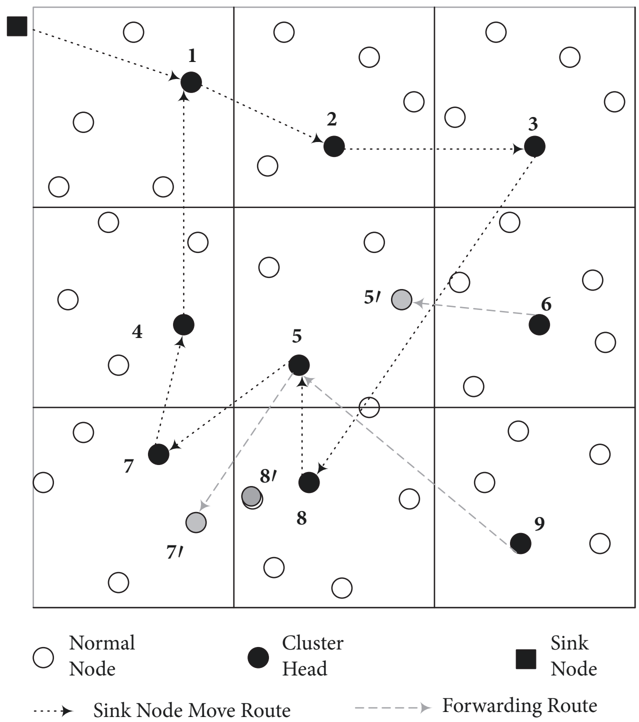

Figure 4: An Example of Data Collection with Burst Traffic.

hand, node 9 chooses node 7 as the minimal-hop routing according to the information in DFResP, and the remaining steps are the same as those of node 6.

After all, the mobile sink re-establishes its remaining path L' for the nodes in set V_2 and moves according to path L' to continue the data collection in this round. One round of data collection is completed after the mobile sink node move back to the starting location, and the network will re-elect cluster head within each grid, according to the balance between the residual energy of nodes and the sum of the distances from all nodes to the cluster head. This procedure is iterated until network is 20% disconnected due to nodes' death, meaning the network's life ends.

5. Simulation and Results Analysis

5.1. Simulation Platform. In this paper, we simulate the DPPMSBT algorithm and analyze the results by using the object-oriented network simulation platform NS2 (Network Simulator version 2), which must run on UNIX/LINUX platform.

Running environment of NS2 is described as follows:

(1) On windows 7 operating system, virtual machine software VMware workstation with version 12.5.9 is installed.

(2) On virtual machine, ubuntu operating system with version 14.04LTS is installed.

(3) On ubuntu14.04 platform, NS2 application with version ns-allinone-2.35 is downloaded and unzipped to directory /usr /ns-allinone-2.35, and then NS2 environment is setup by using installation procedure one by one.

Simulation is setup according to the following:

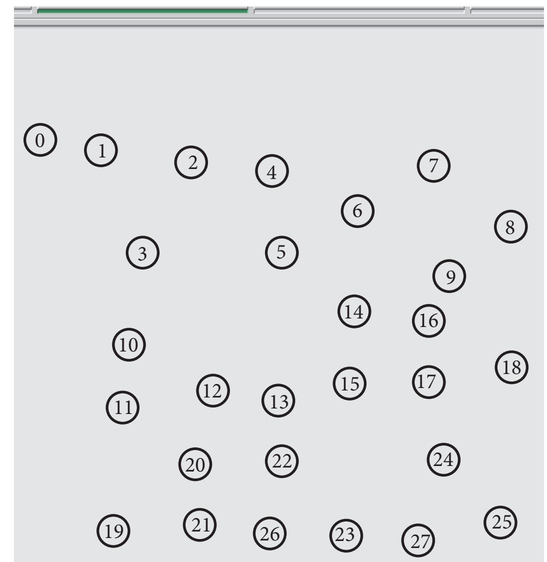

Figure 5: Network Topology for Simulations.

(i) The network size is set to 100m ∗ 100m

(ii) The number of nodes is 27

(iii) The nodes' location is randomly and evenly distributed

(iv) The start position of mobile sink node is at the left top of the monitoring area, which is marked with number '0' in Figure 5.

The simulation environment parameters are shown in Table 1.

A round of data collection is completed when the mobile sink node returns to the first cluster head node, and then we re-elect cluster head and plan the next travelling path according to the node's survival energy. At this point, if the first cluster head node has run out of energy, mobile sink node needs to move to the newly elected cluster head node.

5.2. Simulation Results and Analysis. We conduct simulation experiments with 3 different methods, which are Original Path Planning, Queen-Bee routing algorithm, and DPPMSBT algorithm presented in this manuscript. Topology of the simulation network is shown in Figure 5, where node 0 is the mobile sink node starting position.

5.2.1. End-to-End Delay. Here end-to-end delay refers to a network latency metric, which is the time difference between expected arriving and actual arriving of packets. Figure 6 shows an average end-to-end delay curves of network with three methods, labelled with "Original_delay," "Queen-bee_delay," and "DPPMSBT delay," respectively. From it we can see that end-to-end delay of DPPMSBT algorithm is the smallest one among that of three methods.

In Figure 6, unit of vertical and horizontal ordinate are both second (s), and we can find peak value of end-to-end delay is near 3 seconds, meaning that without emergent response to burst traffic, like in Original Path Planning and

Table 1: Simulation environment parameters setting.

Parameter name/value	Remarks
S/100m∗100m	Size of the monitored area
N/27	Number of nodes
MAC_p/IEEE802.15.4	MAC layer protocol
E_{sink}/∞	Energy of the sink node
Ei/1J	Ordinary node energy
Tmax/200s	Maximum simulation time
ts/5s	cluster head data collection time
vs/10m/s	sink node moving speed
R/25m	node communication radius

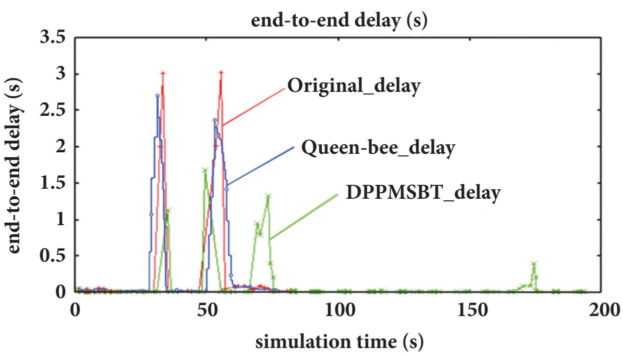

Figure 6: Delivery curve of the data packet.

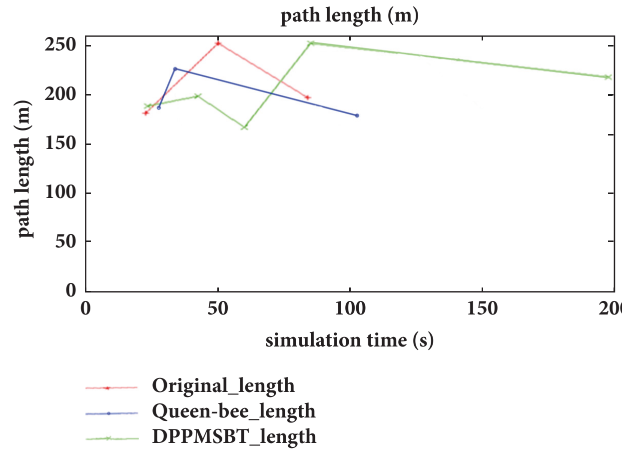

Figure 7: Path length comparison.

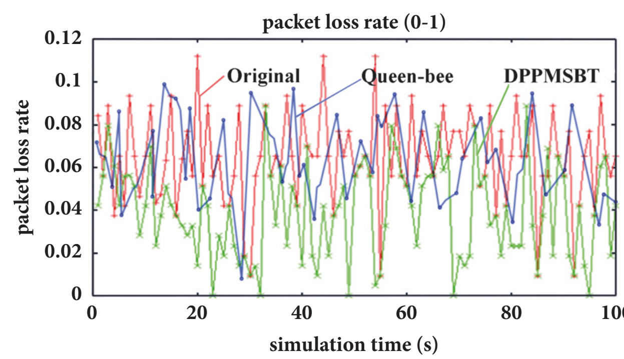

Figure 8: Packet loss rate comparison.

Queen-Bee algorithm, the instantaneous time delay of packets transmission is relatively big. However, our DPPMSBT algorithm makes use of dynamic path planning for quick response to unexpected data delivery, and it performs better than other methods in this metric.

5.2.2. Path Length and Network Lifetime. Path length refers to the total length of route that mobile sink node travels along with. Network lifetime refers to the survival time of the entire network, especially in this manuscript, we define it as the time from starting until network is 20% disconnected due to nodes' death. In Figure 7, there are three curves labelled with "Original_length," "Queen-bee_length," and "DPPMSBT_ length," corresponding to the path length of sink node moving on Original Path Planning, Queen-Bee Routing algorithm, and DPPMSBT algorithm, respectively.

From Figure 7, we can see that, in the first 70 seconds of simulation, "DPPMSBT_length" is the shortest one among three methods. This is because when burst traffic occurs, nodes on the original path may turn to forward their packets to other nodes and no longer wait for sink node's visit, which will implicitly shorten the path length of mobile sink node. After 70 seconds of simulation, "DPPMSBT_length" increases gradually to overturn this sequence, meaning sink node return to work after emergent response to burst traffic.

It also can be seen that "DPPMSBT_length" curve holds on until the end of 200s simulation time, while other two methods last not more than 120s, meaning that network lifetime in our DPPMSBT algorithm is much longer than that in other two methods. The reason is because energy on several related nodes rapidly reduce when burst traffic occurs, and their early death leads to network's breakdown. However, in our proposed DPPMSBT algorithm, we wake up other nodes to help forwarding the burst traffic data, balancing the energy consumption of nodes, and gain longer lifetime for network.

5.2.3. Packet Loss Rate. Packet loss rate is the percentage of dropped packets during transmission from cluster heads to the mobile sink node. This paper takes simple Bernoulli loss model to simulate network losing packets and leverages DE- (Direct-Estimation-) MLE algorithm to estimate packets loss rate from terminal node data. In Figure 8, experimental results are presented, with three curves corresponding to three different methods we use for simulation. These three methods we have mentioned above and their packet loss rate curves are labelled with "Original," "Queen-bee," and "DPPMSBT," respectively.

From Figure 8, we can see that packet loss rate of "Original" and "Queen-bee" is bigger than that of "DPPMSBT." This is because in comparison with other two methods, our proposed DPPMSBT algorithm introduces load sharing mechanism among nodes in the same grid, to cache cluster heads' data when burst traffic occurs and wait for the visit of mobile sink node. This efficiently reduces the packet loss rate, while other two methods choose to send burst traffic data directly to the sink node through multihops, resulting in poor performance in percentage of dropped packets.

6. Conclusions

In this paper, a dynamic mobile sink node moving path planning algorithm (DPPMSBT) is proposed for the intensive wireless sensor networks that collect periodic data of the whole network and a single area may generate burst data. From the analysis of the end-to-end delay, the path length and the network lifetime, and the packet loss rate, the proposed algorithm DPPMSBT has a greater advantage; it can guarantee the periodic collection of the whole network data and make dynamic sink path planning to collect accurate burst traffic data when there is an incident. And it can also reduce the packet loss rate and extends the network lifetime.

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

The absence of author Chang Jie in this paper is due to work transfer.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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