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Energy efficiency and network lifetime maximization in wireless sensor networks using improved ant colony optimization

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Abstract

Improving network lifetime is the fundamental challenge of wireless sensor networks. One possible solution consists in making use of mobile sinks. Sink mobility along a constrained path can improve the energy efficiency in wireless sensor networks. However, due to the path constraint, a mobile sink with constant speed has limited communication time to collect data from the sensor nodes deployed randomly. This poses significant challenges in jointly improving the amount of data collected and reducing the energy consumption. This paper proposes a data collection scheme, called the Maximum Amount Shortest Path (MASP), to address this issue that increases network throughput as well as conserves energy by optimizing the assignment of sensor nodes.

MASP is formulated as an integer linear programming problem and then solved with the help of improved ant colony optimization. The residual energy of each node is calculated and the optimal path is selected by considering the shortest path, residual energy, channel noise, and delay. This approach is validated through simulation experiments using NS2

Keywords: *Mobile sinks, constrained path, data collection, sensor nodes, residual energy, channel noise, delay.*

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1. Introduction

Existing work has shown that sink mobility can improve the performance of wireless sensor networks

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[2-5]; mobile sinks are mounted on some people or animals moving randomly to collect information of interest sensed by the sensor nodes where the sink trajectories are random. In the scenarios where the trajectories of the mobile sinks are constrained or predetermined [4-5], efficient data collection problems are often concerned to improve the network performance. The path constrained sink mobility is used to improve the energy efficiency of single-hop sensor networks which may be infeasible due to the limits of the path location and communication power [9-10].

This work focuses on large-scale dense WSNs with path-constrained mobile sinks that may exist in real world applications, such as ecological, environment monitoring and health monitoring of large buildings [10]. Let a mobile sink M installed on a transportation vehicle move along a fixed trajectory L periodically. Assume that sensor nodes are randomly deployed in the neighbourhood of the trajectory. When M arrives at the end point of its path once and returns back to the start point, now it has completed one round. The mobile sink collects data from sensor nodes while moving close to them. According to the communication range of M, the monitored region can be divided into two parts, the direct communication area (DCA), and the multihop communication area (MCA) for far-off sensors. Sensor nodes within the DCA, called subsinks, can directly transmit data to the mobile sink due to their closer proximity of the trajectory. On the other hand, sensors within the MCA, called members, must first relay data to the subsinks which complete the final data transmission to the mobile sink. The communication time (or duration) between each subsink and the mobile sink is assumed to be fixed due to the fixed movement path and constant speed of M. So each subsink has an upper bound on the amount of data that can be transmitted to the mobile sink in one round.

The throughput of the WSN is dependent on the relationship between the upper bound on the data collected and the number of members belonging to each subsink. The main challenge here is to find an efficient assignment of members to the subsinks that improves the data delivery performance as well as reduces energy consumption.

2. Related Work

Based on the trajectory of the mobile sink, existing research on sink mobility can be classified into three categories: random path, constrained path, and controllable path. In sensor networks where the path is random [1], [2], the mobile sinks are often mounted on some people or animals moving randomly to collect interested information sensed by the sensor nodes. Due to random mobility, it is difficult to bound the data transfer latency and the data delivery ratio. On the other hand, it is possible to guarantee the data delivery efficiency with the help of efficient communication protocols and data collection schemes while the trajectories of the mobile sinks are constrained or controllable.

This section reviews the data collection approaches in WSNs with path-constrained mobile sinks and path-controllable mobile sinks, which can be sub classified according to the communication mode (single or multiple hops) and the number of mobile sinks

Predictable sink mobility is exploited in [3] to improve energy efficiency of sensor networks. A mobile sink is installed on a public transport vehicle which moves along a fixed path periodically. However, all sensor nodes can only transmit data to the single mobile sink in one-hop mode. Actually, single-hop communication between all sensor nodes and the mobile sink may be infeasible due to the limits of existing road infrastructure and communication power. An architecture of wireless sensor networks with mobile sinks (MSSN) is proposed in [4] for a traffic surveillance application. However, it is also assumed that all sensor nodes in MSSN are located within the direct communication range of the mobile sink. In this paper, a data collection scheme based on the multi-hop communication is designed to improve the amount of data and reduce energy consumption. In [6], [8], the authors propose mobile sensor networks with a path-constrained sink supporting multihop communication.

A communication protocol and a speed control algorithm of the mobile sink are suggested to improve the energy performance and the amount of data collected by the sink. In this protocol, a shortest path tree (SPT) is used to choose the cluster heads and route data, which may cause imbalance in traffic and energy dissipation. To address the imbalance problem, the MASP scheme proposed in this paper is designed to enhance data collection from the viewpoint of choosing cluster heads more efficiently. Moreover, if a mobile sink is mounted on public transportation, e.g., a bus, the speed cannot often be changed freely to the purpose of data collection. In [7], a routing protocol, called MobiRoute, is suggested for WSNs with a path predictable mobile sink to prolong the network lifetime and improve the packet delivery ratio, where the sink sojourns at some anchor points and the pause time is much longer than the movement time. Accordingly, the mobile sink has enough time to collect data, which is different from our scenario. Moreover, in MobiRoute all sensor nodes need to know the topological changes caused by the sink mobility.

Most of the current work about path-controllable sink mobility has focused on how to design the optimal trajectories of mobile sinks to improve the network performance. Mobile element scheduling problem is studied in [11], where the path of the mobile sink is optimized to visit each node and collect data before buffer overflows occur. The work in [11] is extended to support more complex scenario with multiple sinks in [13]. A partitioning-based algorithm is presented in [12] to schedule the movements of the mobile element to avoid buffer overflow. In [11-13], the mobile sinks need to visit all sensor nodes to collect data and the path optimization is based on the constraint of buffer and data generation rate of each node. In [14], the path selection problem of a mobile device is focused to achieve the smallest data delivery latency in the case of minimum energy consumption at each sensor. It is assumed that each sensor node sends its data directly to the mobile device.

Single-hop communication is not feasible due to the limitation of road infrastructure and requirement on delivery latency. A rendezvous-based data collection approach is proposed in [15] to select the optimal path due to the delay limitation in WSNs with a mobile base station. In this work, the mobile element visits exact locations, called rendezvous points, according to the pre computed schedule to collect data. The rendezvous points buffer and aggregate data originated from the source nodes through multihop relay and transfer to the mobile element when it arrives.

3. Problem Formulation

In this scenario, let n sensor nodes be deployed randomly and let n_s nodes close to the trajectory of the mobile sink be chosen as subsinks. The other n_m nodes away from the mobile sink choose different subsinks as their destinations. The mobile sink moves along a fixed path periodically with constant speed to collect data. Assume that the mobile sink has unlimited energy, memory, computing resources and has enough storage to buffer data. Each sensor node continuously collects data and transmits them either directly to the mobile sinks or to one of the subsinks which finally delivers the data to the mobile sink.

The members within the multihop communication area need to choose one and only one subsink as its destination. A highly dense sensor network is considered, in which all members can reach the subsinks through single-hop or multihop communication. Assume each sensor node transmits and receives data with fixed transmission and reception power, respectively. So the power consumption is independent of the transmission distance between adjacent nodes. To calculate the power consumption [4]:

$$P \approx e\,(k_r + k_t) \quad \text{-·} \qquad (1)$$

Where p denotes the total energy consumption of one node for receiving k_r bits and transmitting k_t bits, and e is a factor indicating the energy consumption per bit at the receiver circuit. Let q denote the total amount of data sensed by each node per traversal round of the mobile sink. Assume that all sensor nodes forward data along the shortest path trees to their destinations.

Equation (2) describes the relationship between the total amount of data received by all nodes and the sum of hops.

$$\sum_{i=1}^{n} K_r^i = \sum_{i=1}^{n} h_i . q \quad \text{------------------------} \qquad (2)$$

Where h_i is the shortest hop from sensor node i to its destination subsink.

The total amount of data, q_{total} collected by the mobile sink in one round consists of the data collected from all subsinks as follows:

$$q_{total} = \sum_{i=1}^{n_s} q_i \quad \text{------------------------} \qquad (3)$$

Where q_i is the amount of data from subsink i per round.

4. Proposed Solution

The proposed solution focuses efficient data collection and network lifetime maximization of wireless sensor networks. Here the predictable mobile sink path is considered. The objective is to improve the energy efficiency for data gathering, which minimizes the energy consumption of entire network under the condition of maximizing the total amount of data collected by the mobile sink. Network lifetime can be improved by optimal subsink selection which depends on the residual energy of the nodes. The problem is solved by using improved ant colony optimization.

Figure.1 denotes the overall design of the proposed system. The physical structure of the network is defined. A sensor network with stationary nodes is considered here and all of them conveying the gathered information to the sink node through singlehop or multihop communication. The sink node is considered as mobile node and the path of the sink node is constrained. All the sensors are homogeneous, i.e., the physical capacity like communication range, antenna type etc of each sensor is same. Sensors can only communicate with the peers within communication range due to limited power. Multi-hop communication is required to communicate with farther ones.

Each sensor is characterized by two operational states: active and sleep. In active state the node is fully working and is able to transmit/receive data, while in sleep state it cannot take part in the network activity. The network model represents the behavior of a single sensor, the dynamics of the entire network, and the channel contention among interfering sensors.

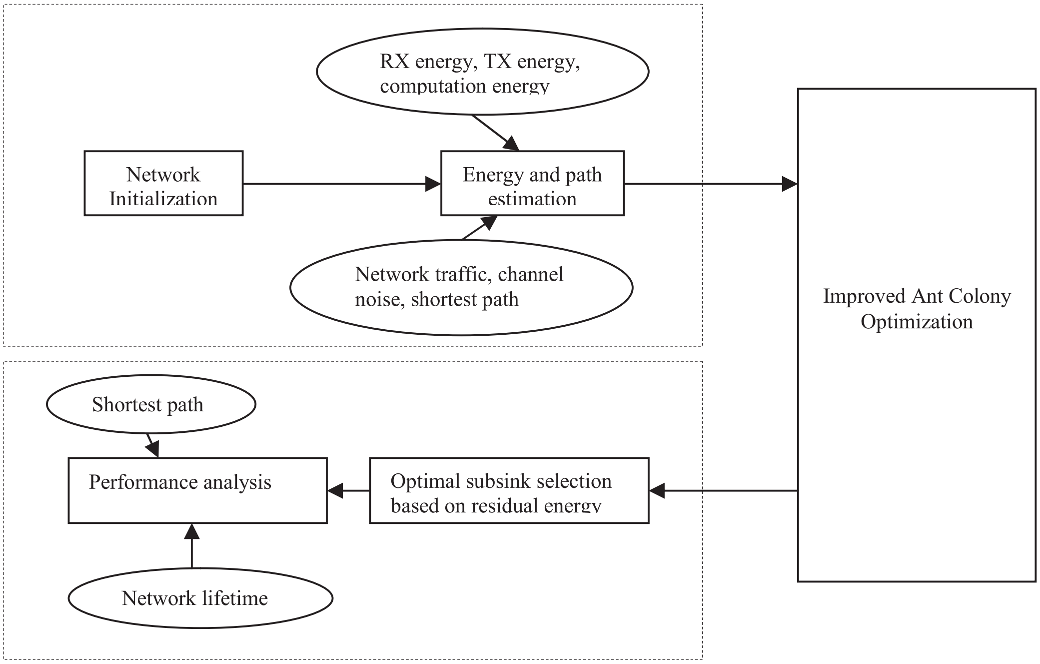

Fig. 1. Design of the proposed system

Output of the energy/path estimation module generates a fitness function, which is the input to improved ant colony optimization module. Communication between sensor nodes consumes most of the available power, so energy estimation can be done by considering the parameters energy for transmission, energy for reception and energy for computation. Estimation of path considers the parameters shortest path, channel noise and network traffic.

Ant Colony Optimization is swarm intelligence based optimization technique widely used in network routing, which is inspired by a behaviour of feeding of ant. The searching on ACO utilizes two evaluations which consist of the static value and the dynamic one. The static evaluation is peculiar information of the target problem. Usually, a reciprocal number of the distance is adopted as the static evaluation value, when ACO is applied to the route searching problem such as TSP. On the other hand, the dynamic evaluation introduces pheromone amount.

In the subsink selection process the output generated by the improved ant colony optimization is compared with the residual energy of the subsinks to select the optimal path.

4.1 Improved Ant Colony Optimization

Ant Colony Optimization, a swarm intelligence based optimization technique, [19] is widely used in network routing. A novel routing approach using Improved Ant Colony Optimization algorithm is proposed for Wireless Sensor Networks consisting path constrained mobile sink. Ant colony optimization (ACO) algorithms simulating the behaviour of ant colony have been successfully applied in many optimization problems such as the asymmetric travelling salesman, vehicle routing and WSN routing.

Let $b_i(t)$, (i = 1... n) be the number of ants in town i at time t and let

m = $\sum_{i=1}^{n} b_i(t)$ be the total number of ants.

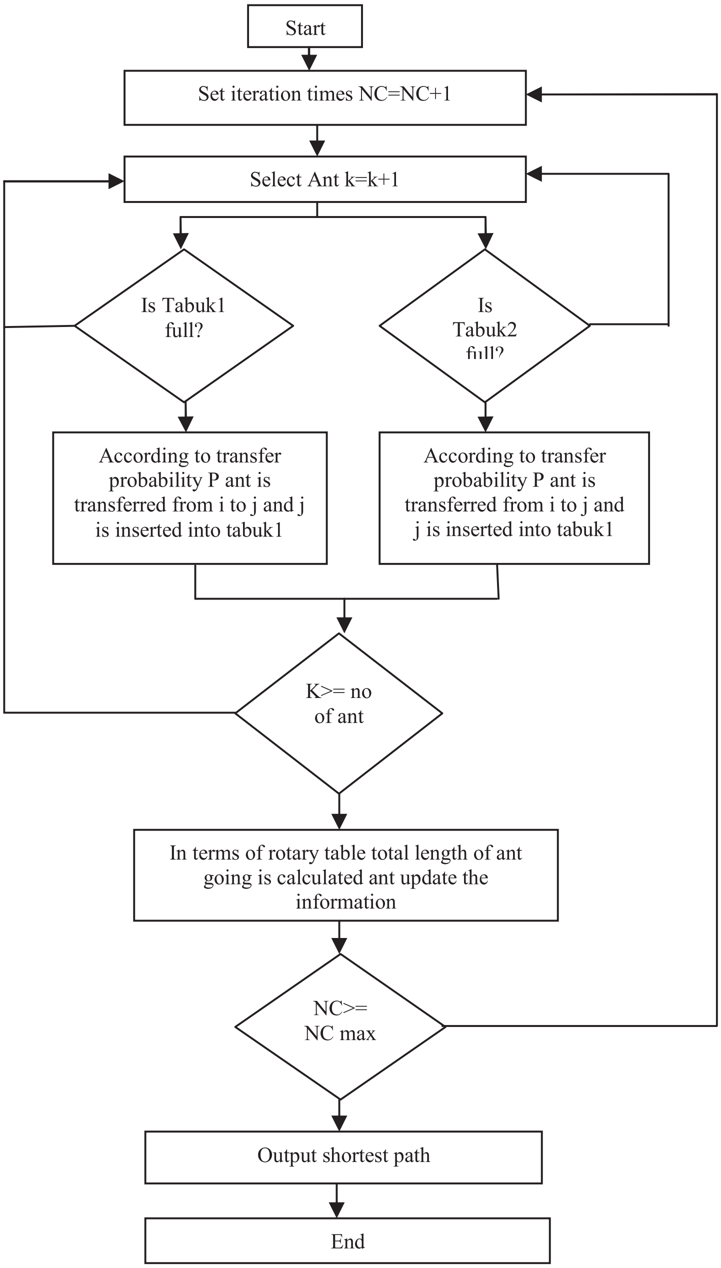

Fig. 2. The flow chart of the improved ACO algorithm

Each ant is a simple agent with the characteristics: it chooses the town to go to with a probability that is a function of the town distance and of the amount of trail present on the connecting edge; to force the ant to make legal tours, transitions to already visited towns are disallowed until a tour is completed (this is controlled by a tabu list); when it completes a tour, it lays a substance called trail on each edge (i,j) visited. Let $\prod_{ij}(t)$ be the intensity of trail on edge (i,j) at time t. Each ant at time t chooses the next town, where it will be at time t+1.

The moves carried out by the m ants in the interval (t, t+1), then every n iterations of the algorithm (a cycle) each ant has completed a tour. At this point the trail intensity of each edge is calculated and which is compared with the residual energy of the node to find the optimal path.

Figure.1 explains the steps in the Improved Ant Colony Optimization, which is proposed for the limitation of the basic ant colony algorithm. In the searching process, two group ants carry out searching separately. One finds the optimal path from the source to destination, and the other finds path from the destination to source. After one search, they alternate information each other. All ants are assigned to two paths so as to avoid stagnating by choosing one. Meanwhile, in every searching process, the previous received optimal path and the probability of the path are saved.

When each ant chooses the next node, the probability of previous search is introduced to speed up the search speed. After a period of time, ants choose the path according to rotary table, which can ensure diverse solution and avoid stagnation. The probability choice and rotary table choice carry on across. The probability choice is carried on several times and then the rotary table choice is carried on. The probability choice can protect the excellent solution and the rotary table choice can produce the opportunity of the better solution.

5 PERFORMANCE EVALUATION

The performance of the proposed data collection scheme MASP using improved ant colony optimization implemented in NS2 is evaluated. In the simulation experiments the sensor nodes are placed in a 600 m × 800 m monitored rectangular area randomly. The initial energy of the each node including the sink, subsink and sensor nodes are set and the mobile sink moves with constant speed.

The following metrics to evaluate the performance

- Total amount of data is the total amount of information collected by the mobile sink in one round.
- Total energy consumption is the total energy consumed by all sensor nodes in one round.
- Network lifetime is defined as the number of movement rounds of the mobile sink from the beginning of the data collection phase to the first nodes energy exhaustion.

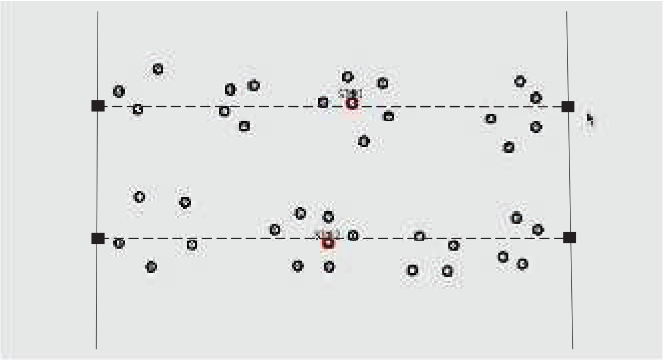

Fig. 3. Trajectories of mobile sink

Multiple sink can gather more data effectively. MASP has stronger data collection ability than SPT with same number of sinks. The amount of data collected by MASP with two sinks is even higher than SPT with three sinks. Due to more sinks, the average hops for each member to its subsinks is decreased and the total energy consumption of the sensor network is reduced significantly. This along with optimal subsink selection improves the network lifetime.

6 CONCLUSION

This paper proposed an efficient data collection scheme called MASP for wireless sensor networks with path-constrained mobile sinks. In MASP, the mapping between sensor nodes and subsinks is optimized to maximize the amount of data collected by mobile sinks and also balance the energy consumption. An improved ant colony optimization algorithm is proposed, Based on the basic ant colony algorithm, two group ants separately search the path and rotary table is used to avoid stagnation, and the searching probability is optimized. The previous search probability of the path is introduced in every search to speed up the search. The optimal path satisfies multi constrains: delay, delay jitter, bandwidth and cost although it increases delay compared with mini delay algorithm and increases cost compared with mini cost algorithm.

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