



MULTI SINK SCHEDULING SCHEME FOR WIRELESS SENSOR NETWORKS

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Abstract: *In wireless sensor networks WSN increasing the network lifetime, where the information delay caused by moving the sink should be bounded. Some of the combinational complexity of this problem, most previous proposals focus on heuristics and provable optimal algorithms remain unknown. By build a unified framework for analyzing this joint sink mobility, routing, delay, and induced sub problems and present efficient solutions for them. We generalize these solutions and propose a polynomial-time optimal algorithm for the origin problem. Furthermore, we developing with multiple sink for the network and study the effects of different trajectories of the sink and provide important insights for designing mobility schemes in real-world mobile WNNs.*

Index Terms—*Wireless sensor networks, delay-constrained mobility, network lifetime*

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1. INTRODUCTION

In the past decades, wireless sensor network (WSN), one of the fastest growing research areas, has been attracted a lot of research activities. Due to the maturity of embedded computing and wireless communication techniques, significant progress has been made. Typically, a WSN consists of a data collection unit (also known as sink or base station) and a large number of sensors that can sense and monitor the physical world, and thus it is able to provide rich interactions between a network and its surrounding physical environment in a real-time manner.

The capacity-limited power sources of small sensors constrain us from fully benefitting from WSNs. Due to the unique many-to-one (converge-cast) traffic patterns, the traffic of the whole network will be converged to a specific set of sensor nodes (e.g., neighbouring nodes of the sink) and results in the hotspot problem. Much research effort has been dedicated to resolve this issue, for example, energy efficient communication protocols, multi-sink systems. However, as long as the sink and sensor nodes are static, this issue cannot be fully tackled. Therefore, there is a recent trend to exploit mobility of the sink as a promising approach to the hotspot problem.

By the way of using sink mobility, we can classify them into two categories: random mobility based and controlled mobility based. For the first category, the sink is designed to move randomly within the network. For example, Rahul et al. presented an architecture on which mobile entities (named MULEs) pick up data from sensors when in close range in sparse sensor networks. Schemes based on random mobility are straightforward and easy to implement. However, they suffer from shortcomings like uncontrolled behaviours and poor performance. Hence, recent research resorts to controlled mobility to improve the performance.

For the controlled mobility, the key problem is to deterministically schedule the sink to travel around the network to collect data. It is shown that by properly setting the trajectory even limited mobility would significantly improve the network lifetime. However, the mobility also brings new issue, i.e., the delay of the data delivery caused by the movement of the sink. Some previous proposals tried to avoid this issue by considering the so-called fast mobility, whereas the speed of the sink is sufficiently high so that the resulting delay



can be tolerated. While others address this delay-bounded mobility problem by heuristics with little theoretical understanding.

To this end, we study the delay-bounded sink mobility problem (DeSM) of WSNs in this paper. We assume that WSNs are deployed to monitor the surrounding environment and the data generation rate of sensors can be estimated accurately. We constrain the mobile sink to a

set of sink sites. First, we propose a unified framework that covers most of the joint sink mobility, data routing, and delay issue strategies. Based on this framework, we develop a mathematical formulation that is general and captures different issues. However, this formulation is a mixed integer nonlinear programming (MINLP) problem and is time consuming to solve directly. Therefore, instead of tackling the MINLP directly, we first discuss several induced sub problems, for example, sub problems with zero/infinite delay bound or connected sink sites (sink sites are connected if for any two sites there exists a path that connects them and each edge of that path meets the delay

constraint). We show that these sub problems are tractable and present optimal algorithms for them. Then, we generalize these solutions and propose a polynomial-time optimal approach for the origin DeSM problem. We show the benefits of involving a mobile sink and the impact of

network parameters (e.g., the number of sensors, the delay bound, and so on.) on the network lifetime. Furthermore, we study the effects of different trajectories of the sink and provide important insights for designing mobility schemes in real-world mobile WSNs.

Our main contributions are the following:

1. We provide a unified formulation of DeSM, which is general and practical. We discuss sub problems of DeSM and offer efficient algorithms for them to guide the design of our algorithm for the origin DeSM.
2. We generalize algorithms for sub problems and present an optimal algorithm with polynomial complexity for the DeSM.
3. We study the effects of different trajectories of the sink and provide important insights via extensive simulations.

2. RELATED WORK

Mobility management is one of the most important issues in wireless networks, and it has



received extensive research efforts in different areas of wireless networks such as mobile ad hoc network (MANET), wireless mesh network, vehicular ad hoc network.

Recently, there is a trend to investigate mobility as a means of relieving traffic burden and enhancing energy efficiency in WSN. We can classify sink mobility into two categories: random mobility and controlled mobility. Sinks in the first category move randomly within the network. Schemes based on random mobility are easy to implement, but they suffer from shortcomings like uncontrolled behaviors and poor performance. Recent research tends to use controlled mobility to improve the performance. The hardcore is to jointly schedule different issues (e.g., sink mobility, data routing, information delay, and so on.) to optimize the network lifetime.

For this paradigm, Gandham et al. first challenged this problem and proposed a heuristic algorithm. Wang et al. relaxed the problem by doing the sink scheduling and data routing separately, and their proposed routing scheme can work only in a grid network topology.

Recently, Shi and Hou developed the first algorithm with performance guarantee with a single sink. Liang et al. extended Shi's work by considering issues like multiple sinks and the maximum number of hops from each sensor to a sink. A three-stage heuristics has been developed to find high-quality trajectory for each sink as well as the actual sojourn time at each sojourn location. In our recent research, we proposed a generalized column generation-based algorithm that can be applied to a set of sink mobility problems with near-optimal performance.

In above proposals, they assume that sinks are high-speed so that information delay caused by moving the sink can be ignored. However, on the one hand, mobile sinks in physical worlds usually have limited speed. On the other hand, underlay applications like the real-time surveillance demand a delay upper bound. Therefore, it is natural to take the delay issue into consideration.

Keung et al. studied the message delivery capacity problem in delay-constrained mobile sensor networks where the sink nodes are static while sensor nodes are mobile. They focused on maximizing the percentage of sensing messages that can be successfully delivered to sink nodes within a given time constraint. Their network model is fundamentally different with ours and is somehow similar to the DTN.

In our previous study, we also addressed the problem of lifetime maximization with delay bound in a mobile WSN. The major improvements of this paper over the previous one are twofold. First, we present some new theoretical results like the connectivity analysis of a WSN. Second, we design a set of new simulations to study the effects of different trajectories of the sink and provide important insights for designing mobility schemes in real-world mobile WSNs.

3 DeSM PROBLEM

Fig. 1 shows reference architecture for a WSN with a mobile sink (i.e., s_0). Sensor nodes, which are stationary, keep monitoring the surrounding environment and generating data. A mobile sink is used to gather sensed data by traveling around the network. We assume that

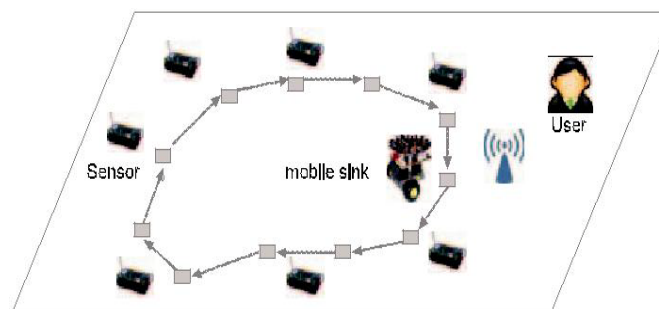


Fig. 1. Reference architecture for a WSN with a mobile sink.

Only at certain locations, the sink can communicate with the outside network and then deliver cached data to users. For example, due to interference and security issues, for a sensor network deployed in the battle field for the surveillance mission, it is reasonable that the sink can connect with the headquarters only at certain locations using wireless techniques like WiMAX or LTE. These locations are represented by squares in the figure. The sink has a maximum speed V_{\max} (in m/s). We assume¹ that while the sink is moving, sensors¹ will buffer their newly generated data, as in. Only when the sink stays at one of sink sites, sensors will start transmitting data to the sink through multi-hop routing. This could potentially cause a high delay for data packets. Here, we define the delay of data as following,

Definition 1 (Delay of data).

The delay of data is defined as the time spent by the mobile sink moving from one sink site to the next sink site.



To limit such delay, a delay bound is set according to the underlay applications. Moreover, as pointed out in the previous study, whenever a sink has been relocated to a new site, it will take some time to rebuild the routes of sensors. Thus, we set ϵ as the minimum residual time of any sink site.

4 EXTENDED SDR (E-SSDR) ALGORITHM FOR DESM

4.1 E-SSDR Algorithm

To solve the origin DeSM problem, we prove the following conclusion:

For an instance of DeSM, if its sink site graph

G^0 is not connected, we can divide G^0 into connected subgraphs, each of which can be solved optimally by the SDR. The overall optimal solution for this instance is the same solution of the sub graph with the longest network lifetime.

The proof is based on contradiction. Assume that for an instance of DeSM, we have an optimal solution which involves two sites from two different sub graphs. This means that we find a sink path including these two sites that meets the delay constraint. Thus, these two sites are connected and should be in the same sub graph.

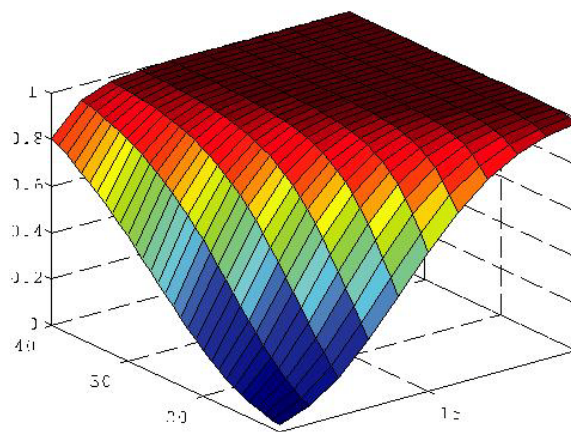


Fig. 2. Probability of the full connection

we propose an E-SSDR approach to solve the origin DeSM optimally:

Step 1. Divide G^0 into connected sub graphs.

Step 2. Apply the SDR approach to each sub graphs and obtains the optimal sink path as well as corresponding routes.

Step 3. Choose the solution of the sub graph with the longest network lifetime as output.

5 NUMERICAL RESULTS

In this part, we evaluate the proposed algorithms using three typical trajectories of the sink,



namely:

1. Linear trajectory. This case simulates that the sink travels along one predefined path, for example, a vehicle carrying a sink moves along the only path across the forest to gather sensed data daily.
2. Boundary trajectory. Luo and Hubaux suggested that it is the most efficient way to collect data in a dense network.
3. Arbitrary trajectory. In this case, we have little control over the distribution of sink sites, for example, in a battle field. Due to page limit, we prepare a supplement file, available online, for the simulation results the arbitrary trajectory.

6 CONCLUSION AND FUTURE WORK

We proposed a unified framework to analyze the sink mobility problem in WSNs with delay constraint. We presented a mathematical formulation that jointly considers different issues such as sink scheduling, data routing, bounded delay, and so on. The formulation is general and can be extended. However, this formulation is a MINLP and is time consuming to solve directly. Therefore, we discussed several induced subproblems and developed corresponding optimal algorithms. Then, we generalized these solutions and proposed a polynomial-time optimal approach for the origin problem. We show the benefits of involving a mobile sink and the impact of network parameters (e.g., the number of sensors, the delay bound, and so on.) on the network lifetime. Furthermore, we study the effects of different trajectories of the sink and provide important insights for designing mobility schemes in real-world mobile WSNs.

As for the future work, we plan on extending current work to accommodate networks with multiple sinks. Furthermore, using the centralized optimal algorithm developed in this paper as performance benchmark, we want to design distributed online algorithms for fast execution in large-scale networks and test them in real-world experiments.

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