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Mobile Sink based Data Gathering and Forwarding in WSN

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Abstract: Environment monitoring is performed using the sensor devices. Wireless Sensor Network (WSN) is constructed with a set of data collection units. Base station, sinks and sensor devices are used in the WSN. Power resources, bandwidth and storages are the limitations of the sensor devices. Sink nodes are used to collect data from a group of sensor devices. Many to one traffic pattern based data collection model increases the transmission load to a set of nodes. The traffic pattern based network load problem is referred as hotspot problem. Energy efficient communication protocols and multi-sink systems are used to handle hotspot problems. Static and mobility based sink placement schemes are used to handle data collection process. Mobile sinks are used to increase the network lifetime with delay constraints. Random mobility and controlled mobility models are used in the mobile sinks. In random mobility the sinks are moved randomly within the network. The sinks are deterministically moved across the network is referred as controlled mobility. The network lifetime is managed with the number of nodes and delay values. The Delay bounded Sink Mobility problem is initiated under sensor node allocation to sinks. A polynomial-time optimal algorithm is used for the origin problem. Extended Sink Scheduling Data Routing algorithm is used to schedule sink nodes. The mobile sink scheduling scheme is enhanced to support large size networks. Distributed scheduling algorithm is applied to schedule nodes with high scalability. The scheduling scheme is tuned for multiple sink based environment. Delay and energy parameters are integrated in the sink scheduling process. The decentralized scheduling mechanism achieves high data collection efficiency with low latency values. Region based sink movement is used to manage data collection risk levels.

I. INTRODUCTION

The development of wireless technologies and micro-sensing MEMS has triggered the success of wireless sensor networks (WSNs). A WSN is composed of one or multiple remote sinks and many tiny, low-power sensors, each equipped with actuators, sensing devices, and wireless transceivers. These sensors are massively deployed in a region of interest (ROI) to continuously collect and report surrounding data. WSNs offer a convenient way to monitor physical environments. Many applications such as object tracking, health monitoring, security surveillance, and intelligent transportation have been proposed.

A WSN is usually deployed with static sensors to perform monitoring missions [2]. However, due to the dynamics of events or environments, a purely static WSN could face these challenges: (1) Sensors are often scattered in a ROI by aircrafts or robots. These randomly scattered sensors could not guarantee complete coverage of the ROI and may be partitioned into disconnected sub networks. The existence of obstacles could even worsen the problem. (2) Sensors are usually powered by batteries. As some sensors exhaust their energy, holes could appear and the network could be broken. However, in many scenarios, it is quite difficult to recharge sensors or redeploy nodes. (3) A WSN may need to support multiple missions or have multiple types of sensors. Sometimes, we may need to send a certain type of sensors to particular locations to support particular needs. Without mobility, this is difficult to achieve. (4) While most efforts assume that

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sensors are cheap, some types of sensors may be expensive. Dispatching of those expensive ones from locations to locations may be necessary.

By introducing mobility to a WSN, we can enhance its capability to handle the above problems. Nevertheless, mobile WSN and mobile ad hoc network (MANET) are essentially different. Mobility in a MANET is often arbitrary, whereas mobility in a mobile WSN should be 'intentional', in the sense that we can control their movement to achieve our missions. In this article, we give a comprehensive survey of recent progress in mobile WSNs. Our discussion focus on two types of nodes: mobile sensors and data ferries. With the former, one may change the network topology by moving these mobile sensors. With the latter, one may maneuver these data ferries to collect or relay sensing data. We will cover three topics:

- Mobility management of mobile sensors: First, we introduce deployment methods to organize a WSN. Second, we present relocation methods to improve the coverage and connectivity of a WSN. Third, we discuss how to assign mobile sensors to desired locations.
- Path planning of data ferries: We first introduce path-planning methods to maneuver data ferries in a sparse WSN, and then discuss how to use data ferries to extend a WSN's lifetime.
- Platforms and Applications of mobile WSNs: Some mobile platforms and applications will be introduced.

II. LITERATURE REVIEW

Recently, there is a trend to investigate mobility as a means of relieving traffic burden and enhancing energy efficiency in WSN [1]. 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. Guney et al. also studied the problem and proposed several greedy algorithms. 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 [5]. In our recent research [10], 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. Basagni et al. jointly considered the sink mobility and delay. But they assumed that the routes are predetermined. Wang et al. used multiple controllable sinks to travel among event locations to efficiently gather data. They considered issues like the mobile distance of a sink and time delay. However, only one-hop routing has been used. Recently, Yun and Xia jointly considered the multihop routing, sink mobility, and delay bound to improve the energy efficacy. They still used the fast mobility assumption, so the delay is caused by nodes holding their transmissions until the location of the sink is most favorable for energy saving, not by the movement of the sink.

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 [9], [3]. 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. Recently, there are some interesting results to further improve the performance of a mobile sink in WSNs. For example, Li et al. [7] presented a localized geographic routing scheme to ensure the data delivery to the mobile sink in a WSN. Ota et al. [8] proposed an event prediction scheme to predict an event from collected sensory data by studying the mobile sinks' mobility control in wireless sensor and actor networks. In our previous study [4], we also addressed the problem of lifetime maximization with delay bound in a mobile WSN.

III. QUERY PROCESSING IN SENSOR NETWORKS

Wireless sensor network (WSN), one of the fastest growing research areas, has been attracted a lot of research activities. 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., neighboring 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 [6], multisink 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 behaviors 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 [1]. 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 subproblems, for example, subproblems 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 subproblems 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 on the network lifetime.

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Furthermore, we study the effects of different trajectories of the sink and provide important insights for designing mobility schemes in real-world mobile WSNs.

Static and mobility based sink placement schemes are used to handle data collection process. Mobile sinks are used to increase the network lifetime with delay constraints. Random mobility and controlled mobility models are used in the mobile sinks. In random mobility the sinks are moved randomly with in the network. The sinks are deterministically moved across the network is referred as controlled mobility. The network lifetime is managed with the number of nodes and delay values. The Delay bounded Sink Mobility (DeSM) problem is initiated under sensor node allocation to sinks. A polynomial-time optimal algorithm is used for the origin problem. Extended Sink Scheduling Data Routing (E-SSDR) algorithm is used to schedule sink nodes. The system supports single sink based scheduling scheme. Scheduling overhead is increased in centralized scheduling scheme. The system supports small size networks only. Energy consumption is not managed.

IV. DELAY BOUNDED SINK MOBILITY (DESM) MECHANISM

A mobile sink is used to gather sensed data by traveling around the network. We assume that 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 Vmax (in m/s). We assume that while the sink is moving, sensors1 will buffer their newly generated data. Only when the sink stays at one of sink sites, sensors will start transmitting data to the sink through multihop routing. This could potentially cause a high delay for data packets. Here, we define the delay of data as following,

We model a WSN as a graph $G = \{V \cup V_0, L \cup L_0\}$, where V and V_0 is the set of sensors and sink sites. We define n = |V| as the number of sensors and m = $|V_0|$ as the number of sink sites. $L \subseteq \{V \times V\}$, is the set of wireless links between sensors. $l_{ij} \in L$ if and only if sensor j is within the communication range r_i (in meter) of sensor i. Similarly, $L_0 \subseteq \{V \times V_0\}$ is the set of links between sensors and sink sites. As in most previous proposals, we do not explicitly consider radio interferences, i.e., we assume the data generation rates of sensors can be properly scaled so that underlay MACs like TDMA can eliminate the interference among communications. For a node i, we assume its data generation rate λ_i (in b/s) can be estimated accurately. Its initial energy is E_i (in J).

The total energy consumption of i cannot exceed E_i. Typically, the radio module is the most energy-consuming part, and thus its energy consumption consists of three parts: transmission, receive, and sleep. Since usually the power assumption in sleep state is several orders of magnitude lower than in other states, it has nonsignificant impact on the network lifetime and thus can be ignored.

The energy cost for transmitting one bit data from nodes i to j (or to s_0 at site k) can be determined as follows:

$$e^T_{ij(k)} = \alpha + \beta \cdot d(i, j(k))^\theta, \quad (1)$$

where α (in J/bit) and β (in J=bit=m^3) are constant coefficients, d(i, j(k)) (in meter) is the distance between nodes i and j (or sink site k), and θ is the path loss index, which is typically in the range of 2 to 6 depending on the environment. We denote energy cost for receiving one unit data as e^R (in J/bit), which is constant. Hence, energy consumption at node i is

$$e_i = e^T_{ij}\left(\sum_{l_{ij}\in\mathcal{L}} f_{ij}\right) + e^T_{ik}\left(\sum_{l_{ik}\in\mathcal{L}_0} f_{ik}\right) + e^R\left(\sum_{l_{ji}\in\mathcal{L}} f_{ji}\right) \quad (2)$$

where $f_{ij(k)}$ (in bit) is the amount of data from nodes i to j (s_0 in site k).

For the sink s_0, we assume it has limitless energy compared to sensor nodes.

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V. MOBILE SINK BASED DATA GATHERING AND FORWARDING SCHEME

The mobile sink scheduling scheme is enhanced to support large size networks. Distributed scheduling algorithm is applied to schedule nodes with high scalability. The scheduling scheme is tuned for multiple sink based environment. Delay and energy parameters are integrated in the sink scheduling process. The mobile sink based data collection scheme is improved for multi sink environment. Scheduling schemes are used to estimate the sink movement plans. Data collection intervals are assigned in the scheduling process. The system is divided into five major modules. They are network boundary analysis, data capture process, centralized scheduling, distributed scheduling and data collection process.

Sensor network boundary and node placement details are analyzed in the boundary analysis. Data sensing is performed under the data capture process. Centralized scheduling is used to schedule single sink nodes. Distributed scheduling is used to schedule multiple sink nodes. Data collection process is designed to perform query processing in the network. Node and sink properties are collected from the user. Sensor node placement and coverage analysis is carried out under network boundary analysis. Node location and coverage information are analyzed. Node and sink energy levels are analyzed in the network analysis. Environment monitoring and data sensing is carried out under the data capture process. Captured data values are updated into the local storages. Captured data values are updated with time details. The data values are transferred to the sink node.

Centralized scheduling is used to estimate the data collection process for single sink environment. Extended Sink Scheduling Data Routing (E-SSDR) algorithm is used to schedule single sink node. Sink node and sensor node transmission coverage details are used for the scheduling process. Delay information is used for data update process in sink node.

Distributed scheduling is designed for the multiple sink nodes. Sink movement is planned with sink coverage and network region details. Distributed sink scheduling algorithm is used for sink movement plan. Region based sink movement model is used in the system. Data requests are submitted by the users. Data values are collected by the mobile sinks from the sensor nodes. User query values are processed by the mobile sink nodes. Mobile sink transfers the query results to the requested user.

VI. CONCLUSION

Two tier based sensor network architecture is used to handle query processing in sensor networks. Sink nodes are used in the wireless sensor networks to handle data collection and transmission process. Extended Sink Scheduling Data Routing (E-SSDR) is used to schedule sinks. The Delay bounded Sink Mobility (DeSM) is solved with centralized and distributed scheduling schemes. The scheduling scheme is adapted to support multi sink based data collection mechanism. Energy consumption is minimized in the data collection scheme. The scheduling scheme is suitable for single and multiple mobile sink environments. Scheduling overhead is reduced in the multi sink model. Data collection latency is reduced in the sensor networks. Scheduling process is managed for sink level and network level environments.

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