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Anchor Point Based Data Gathering with Energy Provisioning In Wireless Rechargeable Sensor Network

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Abstract: Several studies have demonstrated in Wireless Sensor Network for reducing the energy consumption of nodes However, these benifits are dependent on the path taken by the SenCar, particularly in delay-sensitive applications, as all sensed data must be collected within a given time constraint. An approach proposed to address this challenge is to form a hybrid moving pattern in which a mobile-sink node only visits anchor points, as opposed to all nodes. Sensor nodes that are no anchor point forward their sensed data via multihopping to the nearest anchor point. The optimal TSP nearest neighbour algorithm is used for finding the optimal path taken by the SenCar . The new method is proposed for energy transfer mobile collector to sensor nodes by using WerMDG. The simulation result show that the energy consumption is reduced when comber with the existing method.

***Index Terms*—**Data collection, mobile sinks, scheduling, wireless sensor networks (WSNs).

I .INTRODUCTION

Wireless sensor networks (WSNs) are composed of a large number of sensor nodes deployed in a field. They have wide ranging applications, some of which include military environment monitoring, agriculture home automation, smart transportation and health. Each sensor node has the capability to collect and process data, and to forward any sensed data back to one or more sink nodes via their wireless transceiver in a multihop manner.

The recent breakthrough in wireless energy transfer technology due to Kurs, et al. [6] has opened up a new dimension to prolonging sensor network lifetime. It was shown in [6] that by exploiting coupled magnetic resonance, it is feasible to transfer energy wirelessly between two coils. Their experiment showed that with this technology it is capable of transferring 60 watts with about 40% efficiency over a distance of 2 meters. Intel has also demonstrated [7] that wireless recharging is effective for transferring 60 watts of power over a distance of up to two to three meters with efficiency of 75%. On the other hand, recent advances in Radio Frequency (RF)-based wireless energy transfer can also increase sustainability of WSNs [8]–[10]. Clearly, wireless energy transfer will have a profound impact on the design of WSNs, which is attributed to its following advantages: (1) it can provide reliable energy without being affected by the dynamics of environments; (2) it eliminates wires or plugs between the charger and receiver; (3) it does not interfere with the normal operations of sensors such as sensing, packets delivering and receiving.

The objective of this paper is to provide a distributed and adaptive solution that jointly selects the sensors to be recharged, finds the optimal data generating and uploading rates and the optimal scheduling and routing paths for each node, and determines the optimal sojourn time for the mobile collectorat each anchor point, such that the overall network utility can be maximized.

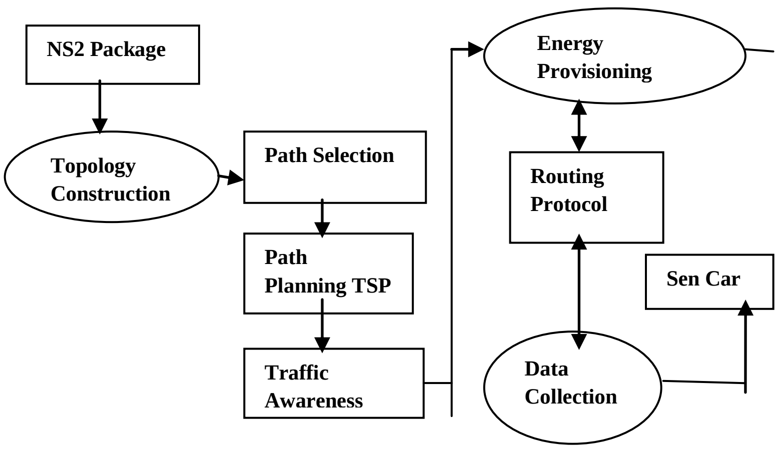
II.RELATED WORK

A. Energy Harvesting Networks and Data Collection

Prolonging sensor lifetime in energy harvesting/rechargeable networks has recently attracted considerable attention in the wireless networking research community. In [1], [2], the authors proposed solutions for fair and high throughput data extraction in the presence of renewable energy sources, which aims to compute the lexicographically maximum data collection rate for each node. Chen, et al. [3] considered the problem of maximizing throughput over a finite-horizon time period for a sensor network with energy replenishment. Liu, et al. [7] studied the problem of joint energy management and resource allocation in rechargeable sensor networks to maximize network utility while maintaining perpetual operation. In addition, energy harvesting techniques have been considered along with the traditional data collection with a static data sink.

In [4], a transmission scheduling algorithm was studied for wireless sensor networks with high node densities, where a mobile sink is responsible for gathering the data packets from the sensor nodes with similar observations. However, these works do not consider the current battery energy of sensor node in energy balance constraint and the energy consumptions in receiving and sensing data. In this paper, we account for the node's battery energy in energy constraint and energy consumptions comprised of transmission/reception/sensing.

Architecture Diagram



B. Wireless Energy Transfer

Recently, there have been great research efforts in the area of wireless energy transfer. It was shown that wireless energy residing in the radio frequencies can be effectively captured to power small devices such as sensors in [9]–[11]. In order to achieve timely and efficient charging, Erol-Kantarci and Mouftah [15] proposed a sustainable wireless rechargeable sensor network (SuReSense) which employs mobile chargers that charge multiple sensors from several landmark locations. In [16], Chiu, et al. studied mobility aware charger deployment for wireless rechargeable sensor networks with an objective of maximizing the survival rate of end devices. In [17], He, et al. considered reader (energy provider)deployment, point provisioning and path provisioning in a wireless rechargeable sensor network to ensure the WISP tags (energy receivers) can harvest sufficient energy for continuous operation. In addition to wireless energy transfer via radio frequencies, energy transfer through magnetic coupling can usually support higher amount of energy transfer in short time with high efficiency. Its application in WSNs was envisioned in [18] and [8]. Shi, et al. [18] considered the scenario of a mobile charging vehicle periodically traveling inside a sensor network with static data collection and recharging each sensor node's battery wirelessly. Zhao, et al. [5] combined wireless energy transfer with mobile data collection and formulated the problem into a utility maximization problem. However, mobile data collection was not considered in [12], while the energy consumptions in receiving data and the time-varying nature of recharging process were not reflected in the analysis in [5]. Moreover, the works overlook the fact that the recharge process brings the energy gradually to the level of battery capacity. In [13], wireless charging and mobile data collection in WSNs were jointly studied and distributed algorithms on how to select data rates, adjust link flow and recharge sojourn time were proposed. However, only results on individual nodes were provided. In this paper, we further improve the algorithms in [13] by exploring various features of the network and evaluating the algorithms in a network-wide environment, to deliver a more comprehensive and in-depth solution to fully capture the practical aspects missing in
[5], [12], [13].

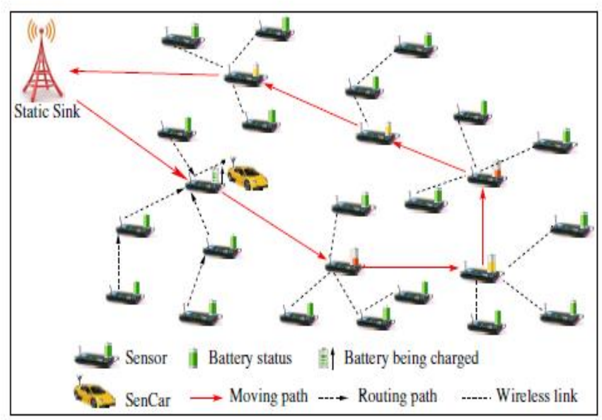


Fig 1: Wireless energy replenishment and mobile data gatherin

III.NETWORK MODEL AND ANCHOR POINT SELECTION

A. Network Model

We consider a network consisting of stationary rechargeable sensor nodes and a static sink. In the sensing field, as shown in Fig. 1, we deploy a multi-functional mobile collector, called *SenCar*, which could be a mobile robot or vehicle equipped with a powerful transceiver to gather data. The SenCar is also equipped with a resonant coil as energy transmitter as well as a high capacity battery to store sufficient energy. The SenCar periodically visits some pre-defined sensor positions called *anchor points* in the field and stays at each anchor point for a period of *sojourn time*. Let Bi denote the battery capacity of node i and N be the set of all the nodes in the network. All sensors in the coverage area of anchor point a form a neighboring set of the anchor point, denoted by Na. The neighboring set is determined in away that nodes can communicate with the sensor node at the anchor point in l hops. The choice of l will have an impact on energy consumption of sensor nodes, i.e., a larger l can cover more sensor nodes from an anchor point location with higher energy consumption on intermediate nodes, whereas a smaller l can save energy on intermediate nodes but cover fewer sensor nodes. In practice, l is chosen such that the anchor points can cover all the sensor nodes in the network. The SenCar starts from the static sink (starting position) and roams over the entire sensing field in a predetermined sequence of anchor points, at a certain traveling speed Vs (in m/s). The SenCar gathers data directly from sensors by visiting the anchor points in a periodic data gathering tour. When the SenCar moves to an anchor point a, it will stay at the anchor point for a period of sojourn time τa to replenish battery energy of the node at the anchor point and gather the data uploaded by sensors in l hops. After τa time, the SenCar leaves anchor point a and travels to the next anchor point.

For data gathering, we consider a simple interference model in this paper, the *node-exclusive interference model*, in which any two links are not allowed to share a common node to transmit at the same time. Otherwise, a collision occurs and the transmission is discarded. We assume the network is sparse so that the impact of channel access and packet collision on the optimal solution is minimum.

We also assume the energy replenished into sensor's battery is much larger than the energy consumed due to transmission, sensing activities and the amount of energy consumed at the anchor points would be compensated by wireless recharge. Thus, when the SenCar finishes recharging and leaves an anchor point, the node at the anchor point is recharged to a high energy level. Since nodes closer to the anchor points consume more energy, these nodes are more likely to be the candidates of anchor points in the next interval.

A. Anchor Point Selection

In wireless rechargeable sensor networks, as each sensor has different energy status at different time, it is desirable to recharge as many sensors with low energy as possible to ensure the perpetual operation of sensors. Accordingly, the sensors located at the selected anchor points should be those with the most urgent needs of energy supplement. In the meanwhile, to better enjoy the benefit of the energy supply provided by the SenCar, more anchor points should be selected. However, this would prolong the traveling tour length and increase the data gathering latency. Thus, it is an inherent tradeoff between the number of sensors to be recharged in a tour and the data gathering latency. Based on these observations, when determining the sequence of anchor points to visit, we jointly consider the remaining energy levels of sensors and the traveling tour length of the SenCar. Our anchor point selection algorithm can be described as follows.

Algorithm

```
Input: Sensor list , battery status , and tour bound ;

Outputs : Anchor point list ;

Sort sensor list  in an ascending order according to
battery status

And record the result in



While true do

If



Calculate the shortest tour length by TSP Nearest
Neighbor Algorithm (TSP-NN) for anchor points in
  and let TSP-NN ( denote its tour length;

Case

   TSP-NN(

   TSP-NN(

   TSP-NN(

end case

end while
```

When the SenCar completes data gathering for the sensors in its neighbor set Na at anchor point a during a tour, each sensor i in Na will report its current battery status or remaining battery energy bi to the SenCar. The SenCar then will utilize this information to determine the sequence to visit anchor points at the beginning of the next tour.

After the SenCar receives the current battery energy status {bi} of all the sensors, it sorts the sensors in an increasing order according to their battery energy {bi}, and records the sorted sensor list by S′, where S′(i) denotes the i-th element in list S′. Thus S′is a sorted list of all sensor nodes containing battery information in the network. The SenCar searches for the maximum number of anchor points for the next tour in the sorted sensor list such that the tour length is no more than a threshold Ltsp, i.e., finds a target sensor (candidate anchor point) S′(n) such that by visiting the sensors with an index no more than n, i.e., S′(1), S′(2), ..., S′(n),the tour length of the SenCar is no more than a bound Ltsp.

IV. DISTRIBUTED ALGORITHM FOR WERMDG PROBLEM

1. Joint Scheduling And Routing Subalgorithm

Scheduling and routing sub algorithm aims to schedule link activation and determine routing of data from sensor i to the SenCarso as to allocate the optimal flow amount on scheduled links destined to anchor point a during τa. In practice, there could be some control messages generated in the process of scheduling and routing such as link gain message, matched/drop message, and the messages on energy balance prices and link capacity prices in sojourn time allocation sub algorithm, however, compared to data packets, these messages are of much smaller sizes and are transmitted less frequently. Thus, the control messages can be ignored at the flow level characterization of the problem. The objective can be achieved by solving the following maximization problem at sensor i.

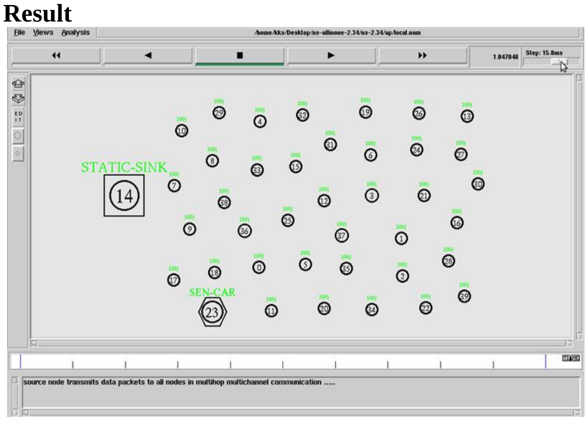
max (1)

subject to

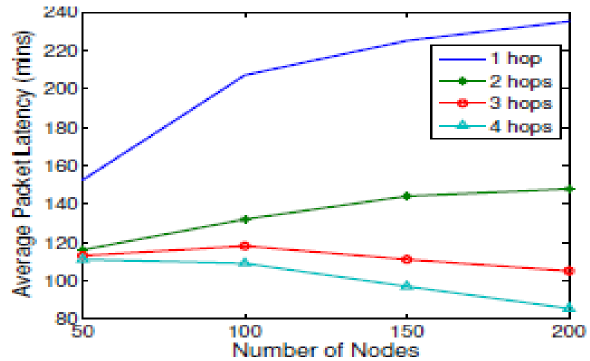
(2)

where constraint is the combination of constraints (9) and, which specifies that the energy consumption for delivering and receiving at node i cannot exceed its maximum available energy budget, and constraint (24) is due to the fact that the total so journ time at all the anchor points is bounded by T as indicated in ,and (λai − λaj − vai µtxij − vaj µrxj − ξaij) can be regarded as thegain of link (i, j) scheduled to transmit data. It is clear that for the optimal solution to , sensor i should spend all its energy budget Ebi = Bi − ζi on the traffic flows over the link with the largest positive gain.

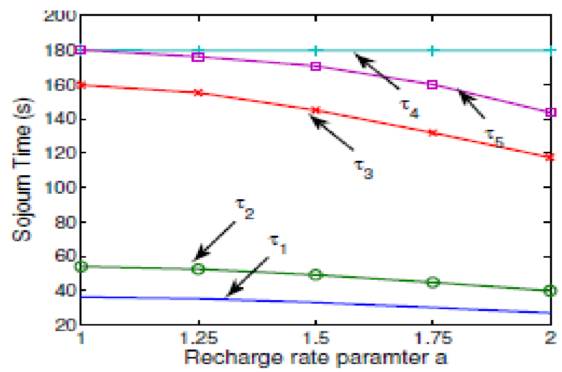
Result



Combarison of Average data collection latency



Impact of recharge rates on sojourn time



CONCLUSIONS

In this paper, we have studied the problem of joint wireless energy replenishment and mobile data gathering (WerMDG) for rechargeable sensor networks. In particular, a multi-functional SenCar is deployed in the sensing field to charge the visited sensors via wireless energy transfer and simultaneously collect data from near by sensors via multi-hop transmissions. We first present an anchor point selection algorithm to determine the sensors that should get recharged in priority and the sequence of the anchor points that the SenCar visits. We then formulate the WerMDG problem into a network utility maximization problem by taking into account the overall energy consumption and the time-varying recharging rate. Furthermore, we propose a distributed cross-layer WerMDG algorithm, through which each sensor adaptively tunes its optimal data rates and routing paths based on the current energy replenishment status while the SenCar dynamically adjusts its optimal sojourn time at each anchor point such that the entire network utility can be maximized. Last, we provide extensive numerical results to demonstrate that the proposed WerMDG algorithm converges, and verify the impact of utility weight and recharging rate on network performance in terms of the amount of data gathered, network utility, link flow rate and sojourn time allocation. The simulation results also show that the WerMDG algorithm can work well in real network settings and environment tand can converge fast even if it suffers from sudden node failures.

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