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Energy efficient path selection for mobile sink and data gathering in wireless sensor networks

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ABSTRACT

Mobile sink (MS) has drawn significant attention for solving hot spot problem (also known as energy hole problem) that results from multihop data collection using static sink in wireless sensor networks (WSNs). MS is regarded as a potential solution towards this problem as it significantly reduces energy consumption of the sensor nodes and thus enhances network lifetime. In this paper, we first propose an algorithm for designing efficient trajectory for MS, based on rendezvous points (RPs). We next propose another algorithm for the same problem which considers delay bound path formation of the MS. Both the algorithms use *k*-means clustering and a weight function by considering several network parameters for efficient selection of the RPs by ensuring the coverage of the entire network. We also propose an MS scheduling technique for effective data gathering. The effectiveness of the proposed algorithms is demonstrated through rigorous simulations and comparisons with some of the existing algorithms over several performance metrics.

1. Introduction

Wireless sensor network (WSN) has been a growing technology in the scientific domain due to its various applications such as environment monitoring, health care, target detection, disaster management and so on [1]. In a WSN, the sensor nodes (SNs) close to the base station (BS) are overburdened as they act as a bridge between the BS and the rest of the network for forwarding data to the BS. This results in rapid energy depletion of these SNs and leads to network partitioning. Such adverse circumstance is termed as hot spot problem [2] also known as sink hole or energy hole problem [3]. Studies [4] have shown that for a large WSN, while the SNs nearby the BS exhaust their energy, the far away SNs retain more than 90% of their energy. To overcome this situation, the concept of mobile sink (MS) has been conceived by the researchers [5–7]. Many researches have been carried out to design trajectory of the MS in which random [8] and controlled [9] mobility of the MS are considered. The random mobility suffers from buffer overflow and uncontrolled behavior of the MS. In controlled mobility, some researchers have proposed that the MS visits every SN to collect data [10–12] and thus conserves a considerable amount of SNs' energy. However, it leads to longer path that the MS traverses and thus increases data delivery latency. The other technique is to allow the MS to visit a limited number of positions called rendezvous points (RPs) [13,14] and collect data from the SNs using multi-hop communication [14,15]. A model diagram for an RP based data collection by the MS is presented in Fig. 1.

The RP based trajectory alleviates the problem of longer path of the MS and thus minimizes data delivery latency. However, designing path of the MS is a challenging issue as it has impact on the network coverage, data delivery and network lifetime. For quick data delivery, it is desirable to minimize the path of the MS. To this end, this is worth noting that shorter the path length, larger will be the multi-hop communication, (i.e., higher will be the hop counts and larger will be the multi-hop path lengths). This will result in higher energy consumption of the SNs. On the other hand, larger the tour, lesser will be the hop counts and shorter will the multi-hop path lengths. Therefore, while designing the path of the MS, care must be taken so that there will be a trade-off between the path length of the MS and the multi-hop path lengths.

In this paper, we address this problem and propose two energy efficient algorithms, called reduced *k*-means (RkM) and delay bound reduced *k*-means (DBRkM) for RP based trajectory design of the MS. In the proposed methods, we initially create a set of potential positions using *k*-means clustering [16] over the set of SNs. Then we optimize it to obtain minimum number of RPs by

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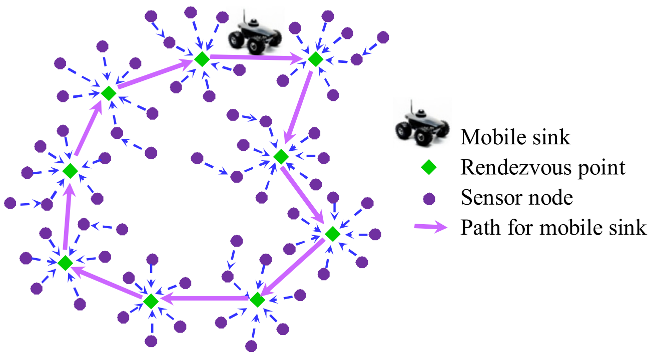

Fig. 1. Wireless sensor network with mobile sink.

applying certain criterion. However, contrary to RkM, DBRkM considers a delay bound parameter for the selection of RPs. The RkM formulates a path for the MS by minimizing overall hop counts and average hop distance. The DBRkM also determines the path by minimizing the same parameters along with delay bound consideration. We perform generous assessment on the proposed algorithms by comparing the results of RkM with *k*-means based approach and DBRkM with WRP [17] and CB [18] algorithms. We evaluate and analyze the performance of the proposed algorithms in terms of network lifetime, number of hop counts, average remaining energy and number of active nodes per round.

There exist several works that address the similar problem. However, contrary to the existing techniques, the proposed algorithms use three parameters which are totally different from the existing schemes. The algorithms emphasize to reduce the overall hop counts by selecting RPs nearby the range of most desirable distance and with highest neighboring SNs. They also minimize the total transmission distance by optimizing the average hop distance between the RPs and the SNs. To the best of our knowledge, none of the existing works have considered all such parameters. The work also provides an efficient data gathering scheme which effectively minimizes the buffer overflow problem.

2. Related works

Researchers have proposed several schemes projecting the utilization of MS [6,19–24] [5] for efficient and fruitful data gathering in WSNs. However, the mobility management of MS is an important issue and can be broadly classified into two categories: random [8] and controlled mobility [9]. Even if the implementation of random mobility based approach is straightforward, they form an unnecessary delay in the data gathering. However, the path in controlled mobility is determined either through some pre-specified points or special locations, i.e. RP [14]. In [14,18], the authors have suggested to plan a stationary path for the MS by employing RPs and subsequently the SNs are organized randomly in the vicinity of the path. Depending upon the distance from the predetermined path SNs are classified into two types. First type incorporates the SNs inside the communication range of the route, while the second type includes remaining SNs. Nodes of the first category hand on their data personally to the MS while rest of the nodes transmit through the nodes of the first category. However, the tour length is not constrained and hence, is not acceptable for delay bound applications. In [6], Ghafoor et al. utilized the Hilbert curve to plan a productive path for MS in a homogeneous WSN. Where the MS travels the proximity of every SN and gathers data via one-hop communication. Nevertheless, this practice presents a much extended path which is not practical for many crucial applications. In [25], numerous sinks are employed to travel in predetermined paths. However, the tour length of the MSs is not considered which my result in increased data delivery latency. In [18,17] the authors have addressed the concern of path length during the MS path design. In [17], a delay limited scheme is presented as weighted rendezvous planning (WRP) for path formulation, in which every SN is given a weight that depends upon hop distance from the closest RP and the amount of data packets transmitted by the node. However, the algorithm has a very high running time complexity, i.e., $O(n^5)$, where n is the total number of SNs in the network which is not suitable for any large sized WSNs. In [18] a cluster based (CB) algorithm is planned, which uses a binary search method to determine the minimum number of RPs. Once the clusters are obtained, CB begins from the sink location and chooses a node from all clusters as an RP, which is the neighboring node to the respective cluster center. These techniques have successfully formulated the path for MS by considering some of the parameters affecting their performance. In contrast to the above methods, the proposed technique considers three new parameters, i.e., number of one hop neighboring SNs, distance from MDD and average hop distance to formulate an efficient path for the MS.

3. System model and terminologies

3.1. System model

We consider a homogeneous WSN that consists of SNs deployed randomly in the area of interest. The sink is assumed to move around the target area with a constant speed. The following are some additional assumptions.

- Two nodes communicate each other if and only if they are within their communication range and the communication is carried out over a wireless link.
- The SNs once deployed, remain stationary throughout their life span.
- It is considered that the sojourn time (data collection time) of the MS is sufficient to gather data from the SNs.
- The network assumed to be functional until certain percentage of the total number of SNs die.
- We assume the same energy model as described in [26]. We also assume that there is no retransmission of data and the transmission speed along the path of MS is also constant.

The notations used to develop the proposed algorithms are shown in Table 1.

Table 1
Notations used.

Terms	Definition
n	Number of SNs
S	Set of SNs denoted as $\{s_1, s_2, s_3, \ldots, s_n\}$
k	Number of potential positions of RPs
r	Communication range of SNs
C	Set of initial k-means centers as potential RPs denoted as $\{c_1, c_2, c_3, \ldots, c_k\}$
$dist(x_i, x_j)$	Euclidean distance between two nodes x_i and x_j
OHN_i	Set of one hop neighboring SNs for potential RP c_i denoted as $\{nb_1, nb_2, nb_3, \ldots\}$
D	Delay limit
tourcost	Path length of the MS tour
max()	A function that returns the maximum value
mod()	Modulo operator
sizeof()	Number of elements in a set
indegree()	A function returning number of SNs within r of a potential RP
$\|Q\|$	Cardinality of any set Q