Sink Node Mobility in Covering Monitoring Area for Data Collection in WSNs

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Abstract *- Communication in Wireless Sensor Networks (WSNs) plays an important role in relaying data collected by sensor nodes to reach an intended destination (a sink or an in-situ user). However, communication is the dominant energy consumer that must be minimized in order to sustain network lifetime. Several mechanisms that exploited mobile sink have been devised to reduce sensor's communication, however, they do not consider coverage area problem. We proposed a design of a simple mobility pattern of a sink node in covering a monitoring area of interest in collecting data for a specific mission by traversing the entire area from an entry point and finish at an exit point on the square grid. By employing simultaneous equation technique, the square roots of linear and non-linear equations are calculated which will be used to change the traversal direction of the mobile sink. In addition, two types of traversals are compared – the horizontal and vertical traversals.*

Keywords: Wireless Sensor Networks, mobility, and area coverage.

1 Introduction

Wireless ad hoc sensor networks (WSNs) provide critical supports in allowing human to observe and control physical environments remotely as well as for in-situ users. They are envisioned to play a key role in sensing, gathering, and disseminating information. Typically, large numbers of sensor nodes are organized to sense, process the data and forward the data to a base station or a sink node. Although WSNs have gained popularity for their potentially low-cost solution to a variety of real-world challenges [1,2,3], but maintaining connectivity and maximizing network lifetime remain the primary concerned in designing WSNs and protocols [4,5].

For long distance communications, data must be transported in mult-hop fashion. Communication is the main consumer of energy [5] that must be minimized in order to sustain WSNs' lifetime due to limited and unreplenish energy supply. Several research activities have been carried out in addressing the issue. Approaches such as reducing global flooding [6], sleep when idle [7], and varying transmission range [8] were employed. Unlike clustering [9], those approaches cannot reduce communication relay. However, clustering require complex procedures – cluster formation, leader election and maintainance. Another approach used in reducing communication relay in WSNs is to utilize mobility through mobile sensor or mobile sink.

This paper focuses on coverage problem whereby mobile sink is employed within sensor field for data collection from a specific area of interest. To cover the field, a powerful device called aggregation and forwarding node (AFN) is defined as in [10]. The AFN is employed as a mobile sink that will collect sensors reading, which are relayed to a particular location along the grid that AFN traverses. The AFN will only visit the area once, in a particular order in satisfying a one-shot query of a specific mission such as providing locations of an dangerous objects e.g. land mines. Based on the gathered information, in-situ user can plan its' safe path.

The organization of the paper is as follows: Section 2 discusses the existing solutions of mobile sink in maximizing WSNs lifetime. In each subsection we also point out their inadequacy. Section 3 provides a proposed design of AFN mobility in collecting data from the entire monitoring area and Section 4 presents concluding remarks

2 Mobile-assisted sink in WSNs

This section is devoted on literature review of related works which provides an insight of various mechanisms in sustaining WSNs lifetime by exploiting mobile sink or base station. According to [4], the various mechanisms are broadly classified as mobile base station (MBS), mobile data collector (MDC), and rendezvous. This classification is based on two criteria – mobility pattern, and communication method during data transfer.

2.1 Mobile base stations

Stationary sink is the final destination of data forwarding, thus sensor nodes that are close to sink's vicinity will deplete their energy sooner than the rest and worst, the sink is disconnected from the WSNs [11]. Although aggregation results in fewer transmissions [12,13,14], but it will not eliminate sinks' disconnection problem.

To reduce energy consumption per message delivered and ensuring even distribution of energy expenditure, mobile sink was exploited. Shashidhar Rao et al [15] proposed a multiple base stations. These base stations are relocated during operation time, periodically called rounds. In each round the base stations are stationary, at the end of each round they are moved to another feasible site. The computation of new location is based on inductive logic progamming (integer linear programming), which the author found to be time consuming. Simulation result showed that system yields longer network lifetime compared to single static base station.

In the work of Jun Luo et al [16], several movement strartergies of a single base station were explored – arbitary movement, optimum mobile strategies along periphery for circular sensor deployment, and circular trajectory inside deployment area. An analytical model for each was provided and corroborate with simulation, which showed results of significant network lifetime improvement. Circular deployment is not considered a general representation of monitoring area, while the movement pattern was not discussed in depth but the concept of appears everywhere with the same frequency was used. For one-short mission application, multiple visit to the monitoring area is not required.

2.2 Mobile data collector

For large area with sparse sensors deployment, data must be relayed via long multi-hops to reach destination which can be costly in maintaining connectivity. By utilizing a mobile sink, relaying is reduced to one-hop whereby the mobile sink will visit individual sensor node to collect data reading. Mobility pattern of a sink node under this category can be sub-classified as randomized, predictable, and controlled [17,18,19].

2.2.1 Randomized movement

In [20] three-tier architecture is proposed. The mobile sink nodes are modelled as the middle-tier that collect data reading from sensor nodes at bottom-tier. Two-dimensional grid is used to place the nodes in creating network topology. Mobile sinks can move to any four direction from its current grid position, with equal probability. Due to randomized mobility of equal probability, it cannot guarantee an in-order traversal.

2.2.2 Predictable movement

Mobility of sink node is not computed on demand, sink node follow a predetermine path such as bus route to collect data from sensor field [21,22]. Sensor nodes that are not within range will not be able to communicate with mobile sink to deliver data reading. Thus, this type of mobility is not suitable for a critical application.

2.2.3 Controlled mobility

Mobility of mobile sink in the work of [17,18] were controlled differently. In the work of [17], mobile sink slows down when sensor nodes density is low and increase its speed otherwise. Mobile sink follows a simple path to reduce number of hops in relaying data. The paper did not discuss in detail the movement pattern. Mobility of sink is based on deadline [18], whereby mobile sink visits sensor node before sensor's buffer becomes full. The sensor nodes may be revisited based on frequency of data sampling, which influence the deadline. As mobile sink visits the sensor, it will be updated on the next deadline. Earliest Deadline First (EDF) is used to controlled sink movement whereby node with closest deadline will be visited first. The simple algorithm may cause a missed deadline, thus EDF variant with k-look ahead is employed. However, it falls short to the same problem, thus weighted sum is applied in deciding next node to visit. Missing deadline causes miscollection of data reading, which could be a critical data.

Optimized mobile data collector [21] tries to minimize data loss (similar to the work of [18]) but consider a situation when mobile sink moves slowly. To avoid buffer overflow, an algorithm called Partitioning Based Scheduling will initially groups nodes that have similiar buffer overflow times into bins B^i and then the grouped nodes are partition into 2^{i-1} sub-bins using 2-d tree in such a way they are closely located. Computation of visiting schedule is performed in two steps – path for sub-bin is calculated using TSP for single travesal, and each sub-bin path of B^i, is concatenated with every bin of B^i which relate to frequency of visits called cycles. Calculation of the minimum speed of mobile sink depends on number of cycles. Simulation result shows the performance of the algorithm in [23]. Multiple visits to the same nodes causes unnecessary redundant visit, which does not satisfy one-time traversal.

2.3 Rendezvous

Rendezvous is a hybrid solution which combine both methods – mobile base station and mobile data collector[4]. Data are accumulated at designated sensor nodes, which buffer the data as in MDC and relayed multihops as in MBS. This approach cause data latency because generated data are buffered before they are relayed multi-hops to mobile sink. In addition, buffer must be large enough to store the data. To the best of our knowledge, none literature are available for this category.

3 AFN mobility

Characterics of the one-short mission query application are – in-order traversal, one time visit, and ability to collect all data reading. These requirements cannot be fully satisfied by the approaches discussed as above. This section presents design characteristics mobility pattern for data collection focusing on the coverage problem to ensure that all data reading are collected. To achieve the goal, coverage problem by employing mobile AFN must address the following issues:

i. How would the monitoring area is represented mathematically?
ii How does AFN computes its' trajectories in ensuring the entire area is covered?
iii. Which traversal algorithm provides an optimized movement?

In this work, the following assumptions are made:

i. Single AFN is considered for data collection.
ii. Movements of AFN is controlled and restricted/confined to simple directions – left, right, up and down along the square grid.
iii. Data reading from phenomena are already available in sensor nodes
iv. An existing routing algorithm [24] supports relaying sensor reading to AFN.

3.1 Monitoring area

In-situ user selects the area of interest by inscribing the map on the monitor screen. The request is send to an AFN, which will satisfy the user request called a mission. The area of interest is the region signified as an ellipse. The AFN maps the ellipse into square grid with a relative coordinate, as illustrated in Figure 1. Equation (1) is a general form of an ellipse with a center at (h,k) [25]:

$$\frac{(x-h)^2}{a^2}+\frac{(y-k)^2}{b^2}=1 \tag{1}$$

In this work, a titled ellipse is considered. A generalized equation for a tilted ellipse as expressed by equation (2), applies [25]:

$$\frac{\left((x\cos(\theta)+y\sin(\theta))-h'\right)^2}{a^2}+\frac{\left((y\cos(\theta))-x\sin(\theta)-k'\right)^2}{b^2}=1 \tag{2}$$

where h' and k' are as follow:

$$h'=\sqrt{(h^2+k^2)}\cos(\theta+\alpha)$$

$$k'=\sqrt{(h^2+k^2)}\sin(\theta+\alpha)$$

An ellipse represents a more generalize shape compare to a circle, which poses symmetric quadrants [25] (value of a is equal to b as in equation (1)). An ellipse is normally used is determining a monitoring area of interest. U.S. Environmental Protection Agency in Detroit, Michigan is conducting a study, named the Detroit Exposure and Aerosol Research Study (DEARS) [26]. In the study, some of the monitoring areas are indicated by ellipses labeled from 1 to 6 on map of Detroit. Hence, referring to figure 1, this study adopted an ellipse to represent an area of interest, while a circle represent the omni-directional antenna attached to the AFN with limited radius of transmission R.

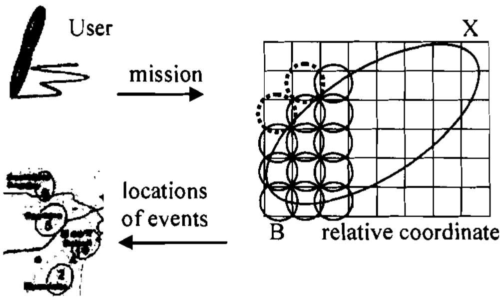

Figure 1. Query of a monitoring area

3.2 Covering an area and trajectories computation

Mathematically, the circle which represents the AFN will have to cover the ellipse. Figure 1 illustrates a partial traversal of AFN beginning at entry point B moving vertically upward along the grid then move one step to the right and start moving downward. The traversals continue until the entire area is covered.

To provide in-order traversal, the system computes the trajectories of AFN's movement by employing simultaneous equations method in determing the roots. Two equations considered are linear equation (straight line) and non-linear equation, which is the ellipse. Initially, the square grids that cover the region boundary which are – starting point, and exit point are determined. The following algorithm describes procedure in computing the mobility pattern:

i. Compute B and X
ii. Begin at starting grid B
   a. Find the intersections (y_{nlow}, $y_{(n-1)high}$) of the ellipse and straight line x_n and x_{n-1}. $x_{n+1} \leftarrow x_n + grid\_size$. Range of n $\{B\ldots X\}$. These can easily be computed by employing simultaneous equations solving technique.
   b. The AFN on x_n will traverse upward from y_{nlow} to $y_{(n-1)high}$ and then change its direction to the right (i.e moves from x_n to x_{n+1}). Thus, AFN that cover the beginning

square move upward until it reaches the square at the same height of the next right square intersection and change its direction to right ($x_n \leftarrow x_{n-1}$)

c. The AFN then start moving downward until it reaches the lowest square grid of intersection (y_n) and change its direction to the right ($x_n \leftarrow x_{n-1}$).

d. The process continues until step ii is satisfied.

iii. to exit grid X

Figure 2 illustrates the traversal algorithm, which shows the traces of AFN mobility in detail.

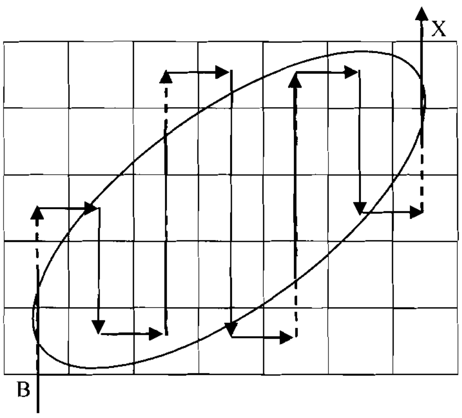

Figure 2. Vertical traversal

3.3 Vertical vs horizontal traversal

Section 3.2 describes the algorithm in computing the trajectories of AFN when it follows vertical traversal. For horizontal traversal the same algorithm applies but the directions of traversal differ. Table 1 summarizes the differences.

Table 1. Directions of traversal

Direction/ Traversal	**Vertical**	**Horizontal**
Upward	Up	Right
Downward	Down	Left
Right	Right	Upward

In this paper, the following specifications are used for the experiment:

i. Equations for the titled ellipse

Various ellipses are created by changing the value of semi-minor and semi-major axes, and angle of rotations as shown in figure 3a and figure 3b.

ii. A straight line equations for vertical and horizontal traversals ranges from 0 to window size.

iii. A circle with a radius R that cover the square grid.

Figure 3a and Figure 3b depict initial results of AFN traversals using the simple proposed algorithm. The figures show the number of steps required in covering the monitoring area for vertical and horizontal traversals. Figure 3a shows results of fixed semi-major axis, which is set to 6 (six) and three different values of semi-minor axis (i.e 10, 25 and 40). Figure 3b the value of semi-major axis varies but the value of semi-minor axis is fixed. The graphs from both figures show that the numbers of steps required are in the range of 80-90s, 60-50s and 20-30s for axes of 40, 25 and 10 respectively. For a small size of semi-axes (10), as the angle increases the number of steps increases slowly, drop at angle 45^0 but then increases again and return to original count. The numbers of steps are the same for an angle 0^0 and 90^0. Additionally, the results indicate that covering the ellipses require almost the same amount of circles when traversing is performed either horizontally or vertically, even for cases when the ellipses are skewed at various angles.

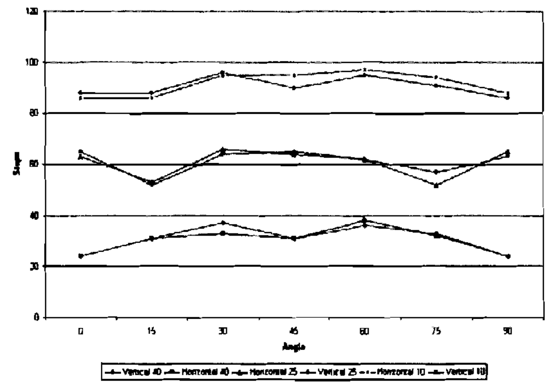

Figure 3a. Traversals comparison – fix *a*

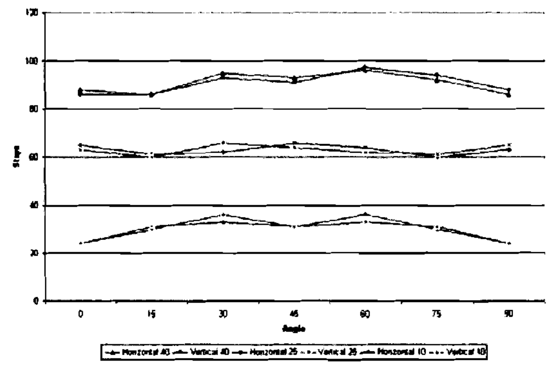

Figure 3b. Traversals comparison – fix *b*

4 Conclusions and future works

In this paper we proposed a simple, in-order, and one-time visit of mobile sink for area covering problem. The result gathered from the experiments demonstrated that rotating an ellipse has some effect on the number of steps of traversal. However, the number of steps required by AFN is almost the same when traversing the monitoring area irrespective of traversal directions – horizontally or vertically.

Due to the simple horizontal and vertical movement along the square grid, the algorithm requires the AFN to traverse outside the boundary of monitoring region which add unnecessary steps to the AFN movements. It is desired that these extra steps (dotted circles as depicted in Figure 1 or dotted line in Figure 2) are eliminated. The direction of next reserach is to explore other technique that can optimize the AFN traversal. Several future works have been set – device an algorithm to determine sensor nodes that reside outside of ellipse but covered by the circle, data aggregation, and observe the performance of the algorithm for network longevity.

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