DFVGWRP: A Data Fusion Virtual Grid-Based Weighted Rendezvous Planning for Mobile Sink-Based Wireless Sensor Networks

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Abstract

Literatures have already suggested about different of delay-sensitive applications where all sensed data must be collected within a specific time constraint using data fusion. Due to the numerous advantages, mobile sink has been considered in the field of virtual grid-based wireless sensor networks. Researchers focused on the time restricted efficient routes for delivering all sensed data from each grid to the rendezvous points (RPs) and those data is collected by the mobile sink while visiting these rendezvous points. It is an NP-hard problem to compute an optimal tour that visits all these RPs within the specific time limit. To resolve this challenge, a data fusion virtual grid based weighted rendezvous planning (DFVGWRP) has been proposed for optimizing tour between only selective RPs where mobile sink collects the sensed data within a given threshold time and by this time non-RPs forward their data to the nearest RPs, so that all data is drained by the mobile sink. Simulation results demonstrate improved network lifetime and reduced energy consumption as compared with existing algorithm.

Keywords: Data Fusion, Data Collection, Mobile Sink, Rendezvous Points (RPs), Wireless Sensor Networks (WSNs).

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are composed of a large number of spatially distributed autonomous sensor nodes. Nowadays sensor nodes have been widely used in various applications, such as environment monitoring [1], military [2]
and agriculture applications [3], forest fire detection system [4], home automation system [5], and health monitoring system [6] and Internet of Things (IoT) based smart technologies [5], [6]. In order to implement these applications, sensor nodes have to be capable of sensing and processing data from specific environment and forward the intended information to one or more sink nodes. In addition, all sensor nodes are equipped with battery and energy inefficient routing strategy may require better battery power. Therefore designing energy-efficient algorithm [7] always is order of the day. The traditional static sink is now obsolete as nodes that are near to the sink are mainly responsible for forwarding data from source to sink node that leads to non-uniform consumption of energy. Therefore the sink becomes disconnected from other nodes in WSN. As a result, sink mobility introduced in [8] helps to balance energy depletion of sensor nodes in WSN. In WSNs with mobile sink, the primary goal of the researchers is to determine a specific tour for collecting sensed data from all sensor nodes [9]. The well-known travelling salesman problem (TSP) [10] is already proposed in this area but when the sensor nodes are increasing in number, the TSP problem becomes impractical and intractable. In addition some real-time applications like fire detection system [4] and health monitoring system [6], environmental data collected by the mobile sink on or before the time bound. To solve this problem researcher proposed a tour where mobile sink traversed only the designated rendezvous points (RPs) and the non-RP nodes simply forward their data to RPs [11], [12]. To minimize the energy consumption and uniform energy distribution among the all sensor nodes, a priority based weighted rendezvous planning (WRP) is proposed in [13]. This paper embeds this WRP scheme along with data fusion, which is a heuristic method in Virtual Grid (VG) based sensor field [14]. Initially, sensor field is partitioned into uniform sized cell based on the number of sensor nodes. This uniform partition can balance the network lifetime of overall network and incorporates WRP scheme for this sensor field where mobile sink traverse only the selected cluster heads which act like designated RPs within the specific time bound and deselected cluster heads as like non-RP nodes simply forward the data to RPs by one hop or multi-hop communications. The generic data fusion model can be applied to real life scenario for generation of better decision support system for that application [15], [16]. As single filter sensor model does not deploy reference mechanism, it will incur some data loss or transposition which can be removed by multi filter sensor structure based on Community Model [15].

The rest of the paper is organized as follows. Section 2 describes the state of the art review of data delivery to the mobile sink in WSN. Section 3 presents elaborately the DFVGWWRP scheme. Section 4, compares the performance of DFVGWWRP with the previous work. Finally, Section 5 concludes the paper.
2. LITERATURE SURVEY

Mobile sink in WSN be categorized into two categories named direct method where a mobile sink visits all sensor nodes and collect data via one hop data communication and rendezvous method where a mobile sink only visits the designated RPs and collect data via one hop communication. The non-RP nodes send to the nearest RPs by one hop or multi-hop communication.

2.1. Direct Method

A sink device is attached to a mobile unit and that visits sensor nodes random manner. For delay tolerant applications random mobility gives long network lifetime [17], [18]. To reduce this network latency TSP based data collection by mobile sink (called M-collector) was proposed in [9]. To improve this random mobility researcher have proposed different controlled mobility patterns in WSN [19], [20].

2.2. Rendezvous Method

When there are large numbers of sensor nodes, periodical collection of data from all the sensor nodes becomes impractical and intractable. To solve this problem, researchers have proposed a rendezvous-based model [11]-[13], [21]. In this method mobile sink only visits the subset of the sensor nodes called as RPs and the other sensor nodes send the data to their nearest RPs via one or multi hop data communication. According to the mobile sink’s trajectory, the rendezvous method is categorized into two major types viz. mobile sink moving along a fixed path or the path is unconstrained by any external factors.

Xing et al. [11] proposed two different rendezvous planning algorithms RP-CP and RP-UG. When the mobile elements (MEs) moves along the data routing tree, it is considered as a RP-CP and otherwise RPs are selected based upon maximum saving to energy distance ratios. Almi’ani et al. [12] discussed a novel algorithm where mobile element (ME) move only the subset of sensor nodes considered as cache points and other nodes send their data to the cache points wirelessly.

In [13], the authors proposed a weighted rendezvous planning (WRP) scheme where each sensor node is selected based on their weight and weight of a particular node can be determined based on the number of data packets that a sensor node need to forward and hop distance from the tour. This proposed heuristic method has overcome the problem of delay-aware energy efficient path (DEETP) which is considered as NP-hard problem [13]. The paper partition the area into smaller areas where a mobile sink moves through the area and their proposed method WRP scheme run on these areas. It considers uncontrolled sink mobility environment where the next move of the sink is defined autonomously and controlled by an external observer. In this context, the use of virtual infrastructure that supports mobile sink is important. Here cluster-head defines
rendezvous regions for storing and retrieving data from the sensor nodes in absence of the mobile sink. When the mobile sink crosses the regions, the stored data is collected by the mobile sink. Some related works are as follows. Virtual Circle Combined Straight Routing (VCCSR) is a converge-cast tree based routing algorithm for collecting data from sensors to sink [22]. When a mobile sink needs to collect data from sensors, a dynamic tree is constructed for collecting data in WSN. When the location of the mobile sink is updated the cluster-heads are capable to reconstruct the route efficiently.

Hexagonal cell-based Data Dissemination (HexDD) [23] constructs a hexagonal grid structure for delivering real-time data. In the dynamic condition, HexDD considers multiple mobile sinks. In the proposed scheme, nodes send their data to the nearest border line and disseminate towards the centre cell. When the sink moves one cell to other cell, it informs the current location of the mobile sink to the centre nodes as well as border nodes along the route. As a result energy consumption becomes high for higher sink’s mobility condition causing early hot-spot problem.

Backbone-based Virtual Infrastructure (BVI) is a single-level multi-hop clustering scheme that aims to minimize the total number of clusters using multi-hop clusters and inform the current sink’s location to all the cluster head (CH) nodes. To send the data to the mobile sink, the data is to send to the CHs via a tree. So In high sink’s mobility condition location registration of a mobile sink to the all CHs also become high. To remove this problem a rendezvous CH is used. In the proposed scheme a path with fewer hop-counts between CHs were used where the source node and the mobile sink are located in and collect the data accordingly. This paper proposes a novel scheme called Data Fusion Virtual Grid-Based Weighted Rendezvous Planning for periodic data collection from WSN. At first the sensor fields are uniformly partitioned into a virtual grid where total number of cells is a function of the number of sensor nodes. Here Virtual Grid-Based Dynamic Routes Adjustment (VGDRA) [14] scheme is employed for clustering the virtual grid. A node close to the centre of the cell is designated as cell-header of that the specified cell of the virtual grid. The cell-header is responsible for keeping track of the latest location of the mobile sink. Then VGDRA scheme is called for initial route setup in WSN depending upon the latest position of the sink. Unfortunately in VGDRA scheme, mobile sink moves only the around the sensor field and collect data via closest border line cell header using one hop multi-hop data communication between cell-headers. To reduce the multi-hop data communication and to address different delay-sensitive applications, the extended version of the VGDRA scheme named DFVGWRP method is proposed where mobile sink establishes a route using selective cell-headers of specified cells whose node density and hop counts from the mobile sink are higher than other cells. To constructing the route, Travelling Salesmen Problem (TSP) is called and mobile sink moves along the path and collects the data from those cell-headers directly via one hop communication within the specified time limit and the mobile sink again returns back to the
initial position and forwards along the border line of the sensor fields like VGDRA scheme.

### 3. THE DFVGWRP SCHEME

Suppose the sensor nodes generate data periodically and each data packet must be delivered to the sink node within a specified time limit. To allow maximum packet delivery, a set of cell-headers are elected which act as RPs where a mobile sink roam only those cell-headers and collect data within given deadline. The non-elected cell-headers deliver their packet to the nearest cell-header via one hop or multi-hop data communication.

#### 3.1. Network Characteristics

The network characteristics are assumed as follows:

1) All the sensor nodes have homogeneous architecture and know their location information.

2) All the sensor nodes are deployed randomly.

3) The mobile sink is aware of the location of the cell-header.

4) Each cell-header act as RP and has sufficient storage to buffer all sensed data.

5) The sojourn time of the mobile sink at each cell-header is sufficient to drain all stored data.

6) Nodes adapt their transmission power based on the distance to the cell-header.

7) Each sensor node produces and transmits one data packet of \( d \) length of bits to the corresponding cell-header within time interval \( T \).

8) After setting up the route between mobile sink and the set of cell-headers, mobile sink moves towards the cell-header and collects data from the cell-header directly and return back to the starting position within time interval and moves along the periphery of the sensor field like VGDRA scheme.

#### 3.2. The Virtual Grid Structure Construction

To construct virtual grid structure, initially the sensor field is partitioned into different uniform sized cells based on the number of sensor nodes in the sensor field. These uniform partitioning overcome the network lifetime in WSN. To obtain the optimal number of cluster-heads and those cluster-heads belong to the specified cells, the heuristics in LEACH [24], [25], TEEN [26], and APTEEN [27] is used that consider 5% of the total number of sensor nodes. Let us consider \( N \) number of nodes which are randomly deployed in the sensor field and uniformly partition the sensor field into the \( K \) number of uniform sized cells where \( K \) is a squared number. Equation (1) shows the different number of
uniform sized cells based on the number of sensor nodes ($N$) where $N = 100/200/300$ presented in Figure 1 (a), (b) and (c) respectively.

$$k = \begin{cases} 4 & N \times 0.05 \leq 6 \\ 9 & 6 < N \times 0.05 \leq 12 \\ 16 & 12 < N \times 0.05 \leq 20 \\ \vdots & \end{cases}$$

After partitioning the sensor field, DFVGWRP scheme performs to elect cell-header from each cell of the virtual grid. Initially all sensor nodes are of uniform energy level, so the sensor nodes which are relatively close to the centre of the cell elected as a cell-header to act as a RP for collecting data from other sensor nodes and transmit the data to the mobile sink directly. After election, cell-header floods a notification-alert message which contains the location information of the cell-header and sent it to the other sensor nodes within the cell.

**Figure 1.** Different virtual grid structure
Similarly all the cell-header also aware the location information about their neighbor cell-headers and form a virtual backbone structure which is shown in Figure 2. Figure 3 shows an example of virtual infrastructure after setting up the initial route based on the initial position of the mobile sink.

The mobile sink moves with a constant speed $v$. So the maximum distance $l_{\text{max}}$ is covered by the mobile sink within the time interval $T$ is:

$$l_{\text{max}} = T \times v$$

(2)

Total number of data packets that sensor nodes within a cell $j$ forward to the closest cell-header $CH(j)$ before the time interval $T$.

$$NDP(j) = P_{\text{max}}$$

(3)

$P_{\text{max}} =$ Total number of data packet is received by $CH(j)$ within time interval $T$
A mobile sink starts its movement from the latest position of sink node and before the time $T$ returns to its starting position. In VGDRA scheme, each cluster heads forward the received data packets to the mobile sink via multi-hop data transmissions. To reduce this multi-hop data transmission mobile sink moves towards the cluster-head and collect the data directly. Here the weight of the cluster-head $W_j$ of the cell $j$ is calculated as

$$W_j = NDP(j) \times H(j, RP)$$  \hspace{1cm} (4)

Where $H(j, RP)$ is a function that returns the hop count between the cluster-head $j$ and the RP, where $RP$ is the set of selected cluster-heads that act as a rendezvous point. Here mobile sink is also considered as a rendezvous point. The energy consumption is proportional to the hop count and number of forwarded data packets from source to destination. Therefore visiting highest weighted cluster-head will reduce the multi-hop data transmission and also minimize the energy consumption. The algorithm 1 shows how DFVWGWRP works. Input $G(V, E)$ defines a graph which signifies the virtual infrastructure after setting up the initial route based upon the latest position of the mobile sink and $l_{max}$ is the maximum distance a mobile sink covers within time $T$. At first DFVWGWRP adds the sink node as the first RP, each cluster-head $CH(j)$ receives data packet from all the active sensor nodes within the cell $j$. Each $CH(j)$ acts as Reference Sensor (RS). Each $RS(j)$ calls the four component modules of community model viz. Provider Preprocessing (PP), Goal Identification (GI), Situation Filtration (SF) and Impairment Minimization (IM) [15]. Let total $NFD(j)$ numbers of packets are received by the cluster-head $j$ before the time interval $T$. After that, DFVWGWRP calculates the weight of each the cluster-head. Then DFVWGWRP calls $TSP(\cdot)$ to calculate cost of the tour. If the cost of tour is less than the length $l_{max}$, the selected cluster-head act as a RP. Otherwise it is removed from the tour. Cluster-heads which are not selected as RP named $RP_{NON}$, forward their data packet to the closest RPs via single or multi-hop data transmission.

**Algorithm 1:** Data Fusion Virtual Grid-Based Weighted Rendezvous Planning (DFVWGWRP) Algorithm.
Input: $G(V, E)$, $l_{\text{max}}$
Output: $\text{RP} = (\text{rp}_1, \text{rp}_2, \text{rp}_3, \ldots, \text{rp}_n, \text{rp}_0) = \text{NULL}$, where $\text{rp}_i \in V \cup \text{Sink}$

1. Begin
2. int $V_n \leftarrow 0$
3. int $W_{\text{max}} \leftarrow 0$, flag $\leftarrow 0$
4. float $\text{cost} \leftarrow 0$
5. Boolean mark[$V$] $\leftarrow$ false
6. $\text{RP} = \text{RP} \cup \text{Sink}$
7. $V_n \leftarrow V_n + 1$; $K_{\text{CH}} \leftarrow |\text{CH}|$ //Total number of cluster heads
8. for $j \leftarrow 1$ to $K_{\text{CH}}$
9. $N \leftarrow \text{count}(S_i)$; $\text{CH}(j) \leftarrow N$
10. Each sensor $S_i$ send data $S_i(d)$ to corresponding $\text{CH}(j)$
11. The $\text{CH}(j)$ receives data = $(d_1, d_2, \ldots, d_N)$ before time $T$
12. Each $\text{CH}(j)$ acts as a Reference Sensor (RS)
13. Each RS$(j)$ calls PP(RS$_i$), GI(RS$_i$), SF(F$_1$, F$_2$) and IM(RS$_i$) which are the component modules of Community Model, each RS$_i$ represents different input parameters
14. end
15. while $V_n \leq K_{\text{CH}}$ do
16. $W_{\text{max}} \leftarrow 0$
17. for $i \leftarrow 1$ to $K_{\text{CH}}$
18. for $j \leftarrow 1$ to size($\text{RP}$) do
19. if mark$(i) == $ false do
20. total hop count $\leftarrow$ shortest path $(i, \text{RP}(j))$
21. $W_k \leftarrow \text{CH}(i) \ast \text{total hop count}$
22. end
23. end
24. end
25. maxw = max$(W_k)$; index = k
26. if (mark(index) == false) and maxw $> W_{\text{max}}$ do
27. $\text{CH}_{\text{rp}} \leftarrow$ index; $W_{\text{max}} \leftarrow$ maxw; flag $\leftarrow$ 1
28. if flag $== 0$ do break end
29. $V_n \leftarrow V_n + 1$
30. mark($\text{rp}$) $\leftarrow$ true; $\text{RP} \leftarrow \text{RP} \cup \text{CH}_{\text{rp}}$; cost $\leftarrow$ TSP($\text{RP}$) //Calculate cost of the tour
31. if cost $> l_{\text{max}}$ do
32. $\text{RP} \leftarrow \text{RP} - \text{CH}_{\text{rp}}$; //Remove CH$_{\text{rp}}$ from $\text{RP}$ ; $W_{\text{max}} \leftarrow 0$; flag $\leftarrow 0$
33. $\text{RP}_{\text{NON}} \leftarrow \text{RP}_{\text{NON}} \cup \text{CH}_{\text{rp}}$; //Add CH$_{\text{rp}}$ to $\text{RP}_{\text{NON}}$
34. Mobile sink initiates all CH$_{\text{rp}}$ (where CH$_{\text{rp}}$ $\in$ $\text{RP}_{\text{NON}}$) to forwarding data packet to their closest $\text{RP}$ before time interval $T$
35. end
36. end
37. end
An example of how DFVGWRP finds a travelling tour for the mobile sink which is shown in Figure 4. The maximum tour length is $l_{\text{max}} = 400$ m. At first DFVGWRP starts from the latest location of sink node and it to the tour, i.e, $\text{RP} = [\text{Sink}]$. Figure 4 (a) shows, the mobile sink which is located at cell 1 and marked by numbered ‘17’. In the first iteration, DFVGWRP adds cluster-head 16 to the tour because it has the highest weight. Figure 4(a) shows the tour length of $\text{RP}$ is 215.9 which is smaller than 400, so cluster-head 16 stays in the final tour i.e. $\text{RP} = [\text{Sink}, 16]$. In the second iteration, DFVGWRP selects cluster-head 11 as the next RP. The tour length of $\text{RP} = [\text{Sink}, 16, 11]$ is 216.6 which smaller than required tour length 400. Therefore cluster-head 11 also stays in the final tour. In the third iteration cluster-head 13 is selected as the next RP. The TSP function returns the tour length 263.1 and which is also smaller than required length 400. Therefore, cluster-head 13 is added to the tour. Now tour is $\text{RP} = [\text{Sink}, 13, 16, 11]$ (Figure 4).

![Figure 4](image1.png)

**Figure 4.** Example of DFVGWRP after adding cluster-heads 11, 13, and 16

The process continues and cluster-head 15, 7, 12, 14, 8, 3, 10 and 9 are added according their weight value, yielding a tour is $\text{RP} = [\text{Sink}, 7, 3, 8, 12, 15, 16, 11, 10,
14, 13, 9]. In the next iteration, DFVGWRP adds cluster-head 4 as the next RP because cluster-head 4 has the height weight. Now as Figure 5(b) shows the tour length \( RP = [\text{Sink, 3, 7, 8, 4, 12, 16, 15, 14, 10, 9, 11, 13}] \) is larger than required tour length \( (456.1 > 400) \), therefore cluster-head 4 is discarded from the tour. Similarly after adding cluster-head 6, 5, 1, and 2, the tour length becomes larger than the required length. So, the mentioned cluster-heads are not added to the final tour. Thus the final tour is \( RP = [\text{Sink, 7, 3, 8, 12, 15, 16, 11, 10, 14, 13, 9}] \) with tour a length of 382.3 m, which is less than required tour length [see Figure 5(a)]. Now Non-RP cluster-heads 2, 4, 5, 6, and 1 (which are not selected to the tour) send data to the nearest RP before time \( T \). For this approach cluster-heads 2, 4, 5, 6, and 1 send the data packet to the nearest RPs Sink, 8, Sink, 7, and Sink respectively.

![Figure 5. Example of DFVGWRP after adding cluster-heads 9 and 4](image)

**4. SIMULATION AND RESULTS**

This section explains the simulation results of the proposed scheme using Matlab R2012b. Here total numbers of sensor nodes are varied from 100 to 400 which are deployed in the \( 200 \times 200 \) m\(^2\) sensor field. A mobile sink moves around the sensor...
field counterclockwise and also broadcasts hello packets within a given transmission range up to 20 m. It is assumed that all the sensor nodes have a fully charged battery with initially 1 mJ of energy. Each sensor nodes generates one data packet in every $T$ time and it also sends the packet to the specified cluster-head. In this context the energy model is used [28], [29], [30]. Energy consumption for transmitting and receiving data of a node is computed by the following equations:

$$T_x = (E_{elect} \times K) + E_{amp} \times K \times d^2$$  \hspace{1cm} (5)

$$R_x = E_{elect} \times K$$  \hspace{1cm} (6)

In (5) and (6), $K$ is the message length, $E_{elect}$ is the energy dissipation of the node to run its radio electronic circuitry and $E_{amp}$ is the energy dissipation of the amplifier to suppress the channel noise and $d$ is the distance between sender and receiver. Here $E_{elect} = 50 \text{ nJ}$, $E_{amp} = 10 \text{ nJ/bit/m}^2$ and $K = 8 \text{ bits}$. The comparison of proposed our proposed DFVGWRP scheme and VCCSR scheme is as follows.

### 4.1. The Virtual Backbone Structure Construction Cost

In virtual backbone structure, construction cost is determined by an amount of energy consumption for electing the cell-headers and forming the virtual backbone network. In spite of network size, the VCCSR always considers fixed number of cluster-heads. Whereas the proposed DFVGWRP scheme uses virtual network infrastructure where the total number of cluster-heads is the function of the total number of nodes and the number of cluster-heads varies from 4 to 25 when the number of sensor nodes varies from 100 to 500. Figure 6 shows DFVGWRP incurs less virtual construction cost compared to the VCCSR schemes.

![Figure 6. Comparing the virtual structure construction cost for different network sizes](image)

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4.2. The Network Lifetime

The network lifetime is represented in terms of first nodes death due to energy depletion. Figure 7 shows that the proposed of DFVGWRP surpasses the VCCSR schemes at different network sizes. In VCCSR method, cluster-heads are located at the central-point of the sensor field and it has more energy depletion than the DFVGWRP schemes. The DFVGWRP scheme periodically keeps track of the residual energy level of the cluster-head and elects new cluster-head to prolong the network life time. But the proposed DFVGWRP method clusters the sensor field with uniform cell on the basis of the total number of nodes; as a result it gives better performance than the VCCSR method.

![Network Lifetime Graph](image)

**Figure 7.** Comparing the network lifetime in terms of number of rounds around the sensors field

4.3. Number of Rendezvous Points

The total numbers of rendezvous points are investigated with different network density condition. Figure 8 demonstrates that the proposed method out-perform VCCSR method.
Figure 8. Comparing the number of rendezvous points for different network size

Because, in VCCSR method fixed number of cluster-heads nodes select regardless of the network sizes whereas the proposed DFVGWRP method uses number of cluster-heads elects as 4 to 25 when the number of sensor nodes varies from 100 to 500. This manuscript considers 81 cluster-heads in VCCSR methods.

5. CONCLUSION

This paper presents Data Fusion Virtual Grid based Weighted Rendezvous Planning (DFVGWRP) scheme, which is a novel algorithm for restraining the mobile sink in virtual grid based wireless sensor network. The DFVGWRP scheme uniformly partitions the sensor field into a virtual grid and constructs a virtual backbone infrastructure. To reduce the multi-hop communication, a mobile sink moves towards the rendezvous points and collects the data directly from the dense cluster. Thus, energy expenditure of the sensor nodes is minimized and also the formation of energy-holes is prevented. The simulation results show that the proposed DFVGWRP scheme perform VCCSR scheme by different metrics. This approach can be implemented in grid based localization technique for air pollutants monitoring which is one of the approaches towards future smarter world [31].

ACKNOWLEDGMENTS

All Authors gratefully acknowledge to Computer Science & Engineering Department of University of Kalyani, Kalyani and Brainware University, Kolkata, India, for providing lab and related facilities for do the research.
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