Survey on Communication for Mobile Sinks in Wireless Sensor Networks: Mobility Pattern Perspective

Sangdae Kim[1], Beom-Su Kim[2], Babar Shah[3], Sana Ullah[4], Ki-Il Kim[2]
[1] Division of Computer Science and Engineering, Kongju National University, Korea
[2] Department of Computer Science and Engineering, Chungnam National University, Korea
[3] College of Technological Innovation, Zayed University, UAE
[4] Department of Computer and Software Technology, University of Swat, Pakistan
sdkim.cse@gmail.com, bumsou10@cnu.ac.kr, babar.shah@zu.ac.ae, sanajcs@gmail.com, kikim@cnu.ac.kr

Abstract

Mobile sinks are being exploited for various purposes for solving the hotspot problem. Thus, the mobility support technique of mobile sinks is important, and it has been studied steadily. A survey was conducted of studies of mobile sinks in sensor networks having different movement patterns depending on the applications. The related techniques were divided into three main categories according to mobility pattern: predefined, random, and control. In addition, communications for mobile sinks are strongly affected by whether there is a single mobile sink or multiple ones. Based on this two-level categorization, an overview is presented of some state-of-the-art mobility support techniques researched during the past three years, and then the technique are analyzed according to various criteria. Finally, this survey concludes with a summary and a discussion of some future research challenges.

Keywords: Wireless Sensor Networks (WSNs), Mobile sink, Mobility pattern

1 Introduction

Wireless sensor networks (WSNs) are a promising type of network for collecting information in a region of interest. The network consists of sensor nodes for sensing information and sink nodes for collecting sensed data. Traditionally, sensor nodes deployed throughout the network disseminate the sensed data to the sink node in a multihop fashion. In this process, sensor nodes located around the sink node are used more intensively than other nodes. Thus, they are depleted of energy faster than other nodes, and this phenomenon could lead to the isolation of the sink node and the problem that the network cannot operate normally. It called the "hotspot problem."

To alleviate the hotspot problem caused by data concentration around of the sink node, studies related to mobile sinks have been conducted. Early studies focused primarily on solving the aforementioned hotspot problem only. However, as WSNs gradually became widely exploited as the technology developed, the amount of research on utilizing mobile sinks has increased. Many studies on the use of mobile sinks for various objectives in various fields have been conducted in recent years [1]. These studies can be categorized into various movement patterns depending on the application. Therefore, in this in-depth survey, state-of-the-art studies from the past three years are classified according to the movement pattern.

The mobility patterns of mobile sinks can be largely categorized into three types: (1) predetermined mobility patterns in which the mobile device moves along a predetermined path, (2) random mobility patterns in which the mobile device moves along an arbitrary path, and (3) controlled mobility patterns in which the trajectory of the mobile device is determined by various factors. In addition, one can classify the studies based on the number of mobile devices. The purpose of this classification-based survey is to help readers easily find the latest research trends in terms of the number and pattern of mobile devices in any target application.

The remainder of this article is organized as follows. In Section 2, the taxonomy criteria and requirements of mobile sinks are described. In Section 3, state-of-the-art studies of mobile sinks are surveyed. The open issues and research challenges are discussed in Section 4. Finally, this survey is summarized and concluded in Section 5.

2 Classification and Requirements of Mobile Sinks

In this section, taxonomy criteria and the requirements of mobile sinks are presented. In Section 2.1, the taxonomy criteria presented in this survey are described. In Section 2.2, the main research objectives of the mobile sink studies are discussed.

*Corresponding Author: Ki-Il Kim; E-mail: kikim@cnu.ac.kr
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2.1 Classification

In this section, a classification table for the mobile sink studies is provided, and each classification is described. The classification of the mobile sink studies is shown in Figure 1.

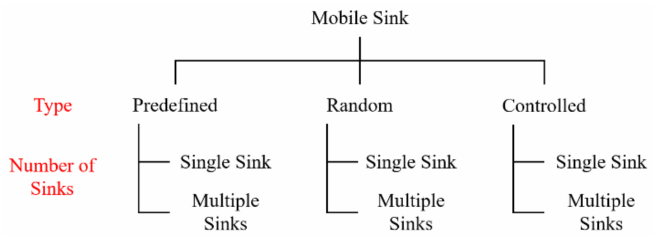

Figure 1. Classification of mobile sinks in WSNs

The mobility pattern of a mobile sink is a criterion that is clearly classified according to the application. Therefore, the mobility pattern of the mobile sink was selected as the primary classification basis.

The predetermined mobility pattern is defined as when the mobile device moves along a predetermined path with a constant speed or variable speed to gather the data from sensor nodes near the path. Sometimes, mobile sinks can stay for a while at any point at any time. Sinks that traverse certain areas according to their purposes, such as buses and patrols, are examples of mobile sinks with typical predetermined mobility patterns. The random mobility pattern is defined as that of a mobile device moving along an arbitrary path with random speed to gather the data from sensor nodes near the sink. Sinks in situations where a sink has to move according to momentary decisions, such as disaster evacuation and a search for enemies, are examples of mobile sinks with typical random mobility patterns. The controlled mobility pattern is defined as a pattern in which the trajectory of a mobile device is determined. In this pattern, the trajectory and sojourn time of the mobile sink are calculated according to network requirements, and they can be recalculated by changes in the network.

The number of mobile devices was selected on a second classification basis because the efficiency or purpose could vary depending on the number of mobile sinks, even if the application exploits a mobile sink with the same mobility pattern. In other words, the network operation policy could change according to the number of mobile sinks.

For example, in the case of a predetermined or a random mobility pattern, if there is only one mobile sink, sensed data must be sent on the trajectory of the mobile sink. However, if there are multiple mobile sinks, the sensor nodes could deliver sensed data by selecting a sink that is advantageous to sensor nodes — for example, because of low delay or low cost. In the case of the controlled mobility pattern, because one sink must cover the entire network when there is one mobile sink, it inevitably involves such problems as transmission delay. However, if there are multiple mobile sinks, the problem that occurs when there is only one mobile sink can be alleviated by appropriately partitioning the network for each mobile sink.

2.2 Performance Requirements

In this section, some performance requirements of the mobile sink are described. Because the mobile sink is exploited for a variety of purposes in many applications, the performance requirements of users are also quite diverse.

(a) Average path (tour) length: This refers to the total length of the trajectory of a mobile sink node. It is one of the requirements that is measured primarily in controlling the trajectory of the mobile sink to collect data efficiently. In particular, it has a direct effect on end-to-end delay in the method using the store-and-forward principle.

(b) End-to-end delay: This is the total time for transmitting data from the source node to the sink node, including propagation delay, transmission delay, queuing delay, processing delay, and so on. This requirement is particularly important in applications that must provide real-time service.

(c) Energy consumption: This is the total energy consumption of each sensor node caused by transmission, reception, listening for the data packet, and using standby power in an idle state. It is directly related to network lifetime, and many studies have focused on equalizing or reducing energy consumption.

(d) Network lifetime: This requirement is diversely defined [2]. When the first sensor dies, a certain percentage of the sensor nodes die, the network partitions, or a loss of coverage occurs. Network lifetime is directly related to the transmission and reception of messages exploited to maintain the network and collect sensed data. In particular, excessive use of unnecessary control messages could cause network wide lifetime shortening.

(e) Packet delivery ratio: This is defined as the ratio of the data packets received at the sink to the data packets sent by the sensor nodes. This is one of the most important requirements in WSNs used for collecting information of interest. It is especially important in such applications as monitoring.

3 Survey of State-of-the-Art Mobile Sink Studies

In this section, the state-of-the-art mobile sink studies that were classified according to the criteria mentioned earlier are reviewed. The mobile sink studies focusing on the predetermined mobility pattern are described in Section 3.1. Then, mobile sink studies employing a random mobility pattern are discussed in Section 3.2. Finally, the mobile sink studies utilizing the controlled mobility pattern are explained in Section

3.3.

3.1 Predetermined Mobility Pattern

In this section, state-of-the-art mobile sink studies based on the predetermined mobility pattern are introduced. An operation overview of a mobile sink based on the predetermined mobility pattern is shown in Figure 2.

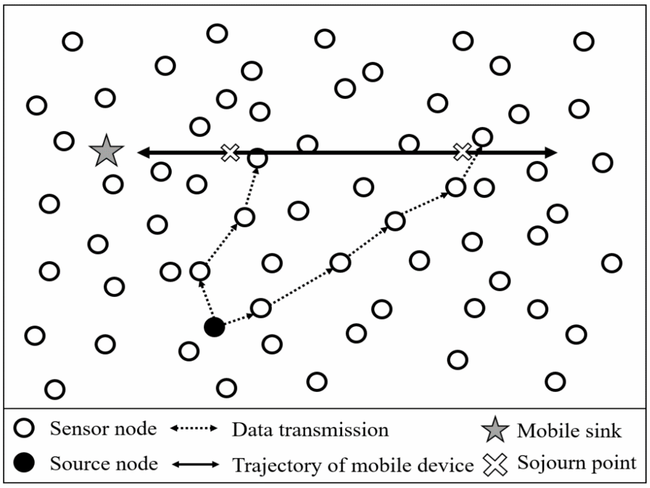

Figure 2. Operation overview of a mobile sink based on predetermined mobility pattern

As previously described, the mobile sink travels along a predefined path. If the mobile sink stays at a sojourn point for gathering data, the source node delivers the sensed data near the sojourn point, and the mobile sink can gather the data while stationary at the sojourn point. However, in the case of a mobile sink moving constantly at the sojourn point, the source node exploits various schemes, such as footprint chaining, to establish a transmission path to the mobile sink. Here, a brief summary and comparison of each of the studies on the predetermined mobility pattern from the past three years are provided.

3.1.1 Single Mobile Sink

Yue et al. [3] proposed a fault-tolerant routing algorithm based on an artificial bee colony particle swarm optimization algorithm. The algorithm considers the optimal recovery strategy of an alternate route. When the mobile sink loses a connection, the path is adapted with optimal fitness values using sensor nodes near the original path. This process enhances overall fault tolerance and reliability.

Donta et al. [4] proposed an ant colony optimization-based mobile sink path determination (ACO-MSPD) algorithm for enhancing the network lifetime under nonuniform data constraints. When the sensor node generates data unevenly in different time periods, such problems as memory overflow can occur. To prevent such problems, the proposed scheme finds several appropriate rendezvous points to prevent the mobile sink from visiting all the sensor nodes. First, a directed spanning tree is constructed to find a forwarding node for each sensor node. Through an ant colony optimization algorithm, the proposed scheme selects an optimal set of rendezvous points and the traveling path of the mobile sink. Thus, the proposed scheme can minimize the delay in the data collection process. In addition, to maximize the network lifetime, a rendezvous point reselection strategy is exploited. The ACO-MSPD approach can minimize the data collection delay and maximize the network lifetime in a WSN under nonuniform data constraints.

Wang et al. [5] proposed an asynchronous clustering and mobile data gathering based on timer mechanism (ACMDGTM) to enhance the network lifetime by mitigating the hotspot problem. The ACMDGTM divides the network into a couple of virtual grids, and the size of each grid is determined by the range of communication of the sensor. The cluster head is elected by the location and residual energy of the node, and the member nodes build an appropriate route for data transmission to the cluster head. Afterward, the rendezvous points, which are covered by as many cluster heads as possible, are defined. They play the role of the junction of clusters. The mobile sink visits each cluster head to collect data and record the visit time. At this time, based on the data overflow time of the cluster head, it determines the best moving path of the mobile sink. Through this process, the ACMDGTM outperforms other methods in terms of minimizing energy consumption and maximizing the network lifetime.

Wang et al. [6] proposed an empower Hamilton loop based data collection algorithm. The proposed scheme adopts a nonuniform clustering method to alleviate the energy hole problem. To elect the cluster heads, the competitive radius of the candidate cluster head is set. When the distance between candidates is less than their competitive radius, the node that has more residual energy is elected as a cluster head. After the cluster heads have been selected, the proposed scheme constructs the trajectory of the mobile device by the empower Hamilton

loop optimization algorithm. This algorithm not only finds the loop for the mobile sink trajectory, but also reduces the total traversing cost of the mobile sink. Figure 3 shows an overview of the data collection process of the proposed scheme. Based on the constructed trajectory, the proposed scheme has excellent performance in terms of network lifetime, energy consumption, and transmission delay.

In a previous study [7], a delay-aware energy-efficient routing algorithm (DERM) was proposed. The source node relays packets to a destination region where the mobile sink is expected to arrive within the delay constraint. The algorithm can address the sink location errors caused by unexpected errors by using track routing. When the destination has received the

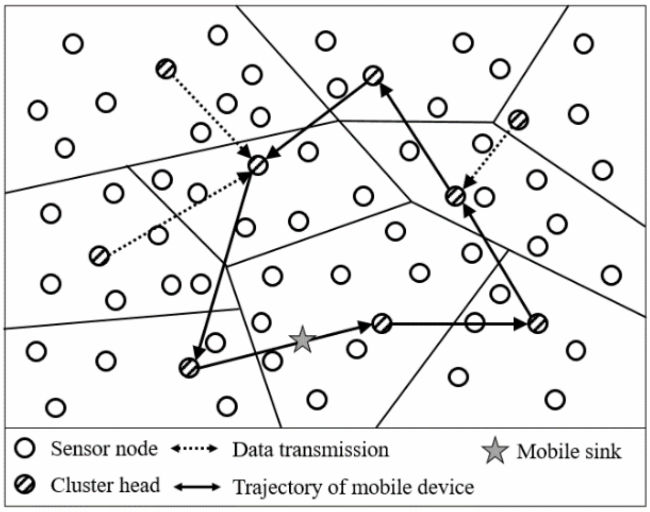

Figure 3. Operation overview of data collection scheme based on empower Hamilton loop [6]

packet but the mobile sink has not arrived at the region, it can track the sink along the trajectory and complete the last-mile delivery.

3.1.2 Multiple Mobile Sinks

Gharaei et al. [8] proposed collaborative mobile sink sojourn time optimization (CMS2TO) to optimize the sojourn time of mobile sinks. The CMS2TO approach divides the network into K adjacent coronas, and there are a control region and a centroid point in each cluster. The cluster heads are elected based on residual energy and the distance to the centroid point. The cluster heads are responsible for intercluster communication. If the mobile sink is sojourning in its cluster, it sends its data packet directly to the mobile sink. The proposed scheme for calculating the sojourn time consists of three phases: (1) energy, (2) threshold calculation using the lifetime of the next residence cluster, and (3) sojourn time optimization based on the deviation of the threshold time and suggested sojourn time. Through this process, CMS2TO can overcome the problem caused by unpredictable mobility patterns, and it enhances the network performance in terms of network lifetime and other metrics.

Cluster-chain mobile agent routing (CCMAR) [9] was proposed as an energy-efficient routing algorithm for prolonging network lifetime based on a clustering approach. First, the scheme divides the entire network into same-sized clusters, and then a cluster head is elected through a weight calculated by residual energy and the distance between a source node and the cluster head. The elected cluster heads are connected by a reasonable chain for intercluster communication, and then they report their ID and location information. The mobile sink that received the information chooses the closest cluster head as the leader. The leader cluster head can transmit the data to the sink directly, and the data are relayed to the leader cluster. Through this process, the approach can reduce the total energy consumption and prolong the network lifetime.

Wang et al. [10] proposed a trajectory scheduling method based on the coverage rate for multiple mobile sinks (TSCR-M) for large-scale networks. Traditional multihop transmission, which is widely exploited in WSNs, requires a large amount of energy to transmit packets. Therefore, TSCR-M exploits single-hop-based trajectory scheduling for collecting data. First, the proposed scheme utilizes a particle swarm optimization algorithm to search the park positions that could cover as wide a range as possible while minimizing overlapping coverage. Then, the optimal trajectory of the mobile devices is scheduled by a genetic algorithm. Through this algorithm, the total energy consumption of the network is reduced, and the network lifetime increases.

3.1.3 Comparison of Mobile Sink Studies Based on Predetermined Mobility Pattern

Here, the mobile sink studies based on predetermined mobility patterns are compared. Table 1 shows a comparison of the studies introduced in Section 3.1.

Table 1. Comparison of mobile sink studies based on predetermined mobility pattern

Protocol	Key feature	Performance requirements				
		Average path length	End-to-end delay	Energy consumption	Network lifetime	Packet delivery ratio
Yue et. al. [3]	Optimal route recovery of mobile sink based on particle swarm optimization algorithm			○	○	○
Donta et al. [4]	Minimize the dealy in data collection process & maximize network lifetime based on an Ant Colony optimization		○		○	
Wang et al. [5]	Minimizing energy consumption and maximizing network lifetime based on asynchronous clustering			○	○	
Wang et al. [6]	Hamilton loop based Prolonging network lifetime and reducing energy consumption and delay		○	○	○	

Table 1. Comparison of mobile sink studies based on predetermined mobility pattern (continue)

Protocol	Key feature	Performance requirements				
		Average path length	End-to-end delay	Energy consumption	Network lifetime	Packet delivery ratio
DERM [7]	Energy-optimal anycast to time-varying destination regions based on a location-based forwarding technique tailored		○	○		○
Gharaei et al. [8]	Sojourn time optimization of mobile sink based on network clustering				○	
CCMAR [9]	Network clustering based on weight to energy-efficient routing			○	○	
Wang et al. [10]	Trajectory scheduling based on particle swarm optimization			○	○	

According to Table 1, most studies focused on the main proposed of WSNs such as reducing energy consumption and prolonging the network lifetime. In the case of Yue et al. [3], packet delivery ratio is improved by optimal route recovery of mobile sink based on particle swarm algorithm. Donta et al [4] minimize the end-to-end delay based on ant colony optimization. Wang et al. [5] and [6] achieved reducing end-to-end delay using Hamilton loop and anycast, respectively. In the case of DERM [7], the end-to-end transmission delay is reduced by tracking the current location of the mobile sink in real time or by predicting the movement of the mobile sink and transmitting the packet to the expected destination in advance. Gharaei et al. [8] optimize the sojourn time of mobile sink to prolong the network life time.

3.2 Random Mobility Pattern

In this section, state-of-the-art mobile sink studies focusing on the random mobility pattern are introduced. An operation overview of the mobile sink based on a random mobility pattern is shown in Figure 4.

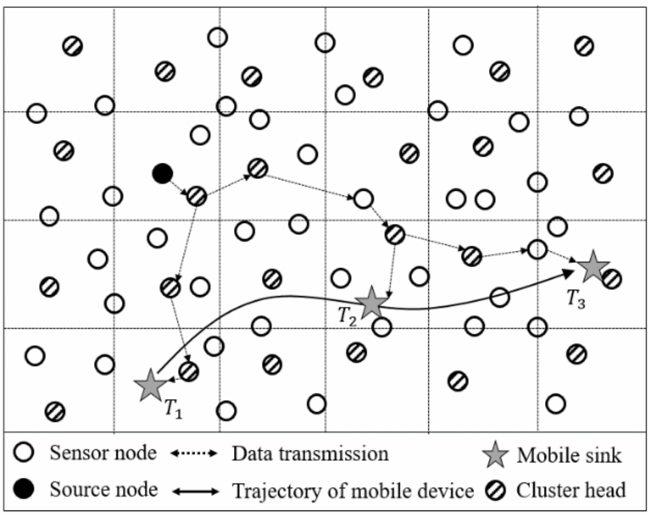

Figure 4. Operation overview of the mobile sink based on random mobility pattern

As previously described, the mobile sink travels with random speed and direction. To enable the source node to locate the mobile sink, the mobile sink should announce its location to the network whenever its location changes. The simplest scheme is to secure the connectivity between the network and the mobile sink on a node-by-node basis. However, this scheme causes excessive control overhead. Therefore, most schemes for mobile sinks based on random mobility patterns divide the network into a certain scale, as shown in Figure 4, and notification is provided when the mobile sink moves to another region. This secures connectivity between the mobile sink and the network with a relatively low control overhead. Here, studies on the random mobility pattern from the past three years are briefly summarized and compared.

3.2.1 Single Mobile Sink

The energy efficient clustering scheme (EECS) [11] is a clustering algorithm for enhancing the network lifetime and packet delivery ratio. To achieve these objectives, the cluster head is elected considering the residual energy of the node, the distance, and the overhead. In addition, a waiting time of a mobile sink in a particular area and the maximum number of packets that could be sent to the mobile sink within the time are considered. Because the process is repeated to balance the residual energy, the EECS has resistance to the energy hole and hotspot problems.

Habib et al. [12] constructed a backbone tree following the principle of the water vascular system of a starfish. Because the tree is constructed in consideration of the transmission ranges of sensors and the size of the network, all sensors can communicate with the backbone tree with a single hop. The sink node also updates its position instantly to the starfish routing backbone. The sink node periodically broadcasts its location, and the backbone nodes are periodically updated with the current sink location. Through communication based on the starfish backbone tree, the proposed scheme increases the network lifetime and throughput and reduces the energy consumption.

3.2.2 Multiple Mobile Sinks

Biased trajectory dissemination of uncontrolled mobile sinks (BTDUMS) [13] was proposed to reduce the average path length, delay, and energy consumption. First, in the proposed scheme, grid clusters of the same size are constructed. Because the mobile sink shows biased movement, the biased clusters (BCs) are discovered when an uncontrolled mobile sink moves randomly for a long time. Then, a biased loop (BL), which consists of all BCs and some non-BCs (NBCs), is constructed to disseminate the mobility message (MM) of the mobile sink. Figure 5 shows an operation overview of BTDUMS and the BL construction. When the mobile sink moves to another cluster, it sends an MM to each BC on the BL. A source node transmits a packet to the BC or NBC closest to itself, and the packet is relayed to the BC closest to the mobile sink. The BC transmits the packet to the mobile sink. Through this process, the proposed scheme achieves its objectives.

3.2.3 Comparison of Mobile Sink Studies Based on Random Mobility Pattern

Here, mobile sink studies focusing on a random mobility pattern are compared. Table 2 shows the comparison of the studies introduced in Section 3.2.

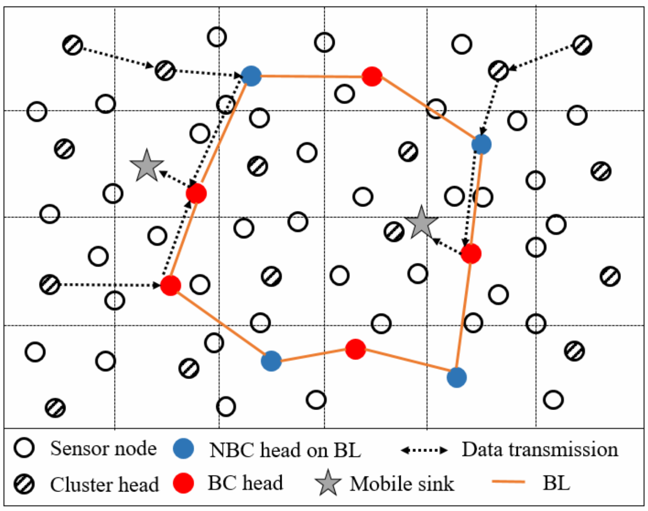

Figure 5. BL construction and an operation overveiw [13]

It was found that the number of mobile sink studies based on random mobility patterns has decreased.

Previously, it had been actively studied to secure the connectivity of the mobile sink to the network. This is probably because of not only the large number of studies in the past, but also a change of interest in the direction of efficiently controlling the mobile sink to collect information from the network.

Table 2. Comparison of mobile sink studies based on random mobility pattern

Protocol	Feature	Performance requirements				
		Average path length	End-to-end delay	Energy consumption	Network lifetime	Packet delivery ratio
EECS [11]	Network clustering considering residual energy, distance between nodes, and data overhead			○	○	
Habib et. al. [12]	Single-hop access to backbone network of sensor node based on Starfish-shaped tree		○		○	○
BTDUMS [13]	Routing path establishment based on biased cluster loop	○	○	○		

According to Table 2, as for the mobile sink based on a predetermined mobility pattern discussed in Section 3.1, the mobile sink studies focusing on a random mobility pattern also focused on reducing energy consumption. In the case of the approach of Habib et al. [12], the location update for the movement of the mobile sink is performed through such structures as a tree or grid. Thus, the source node can secure connectivity with the mobile sink and reduce end-to-end delay. In the case of BTDUMS [13], a BC loop is constructed through a connection between clusters mainly visited by a mobile sink that has biased movement. Because the constructed loop is used as a rendezvous area, the packet from the source can be transmitted quickly to the mobile sink.

3.3 Controlled Mobility Pattern

In this section, state-of-the-art mobile sink studies based on the controlled mobility pattern are discussed. The controlled mobility pattern, which encompasses the majority of mobile-sink-related studies in the past three years, determines the trajectory of the mobile sink according to network conditions or requirements. The objectives of the controlled mobility pattern are to prolong the network lifetime, collect data efficiently, and improve the packet delivery ratio. In many studies, the network is divided into several clusters to reduce the transmission hop count of the sensor node and to optimize the trajectory of the mobile sink to collect sensed data in each cluster.

As illustrated in Figure 6, the network is divided into clusters of certain sizes (each cluster size can be different depending on the requirements of the application). Thereafter, a cluster head for collecting sensed data in each cluster is elected. The trajectory of the mobile sink is determined according to a graph consisting of cluster heads. In addition, the trajectory can be changed in any order according to the requirements of the application. Here, studies on the controlled mobility pattern from the past three years are briefly summarized and compared.

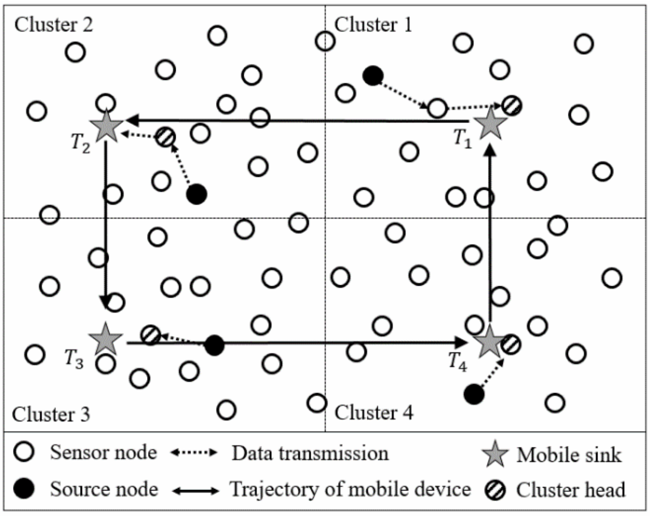

Figure 6. Operation overview of the mobile sink based on controlled mobility pattern

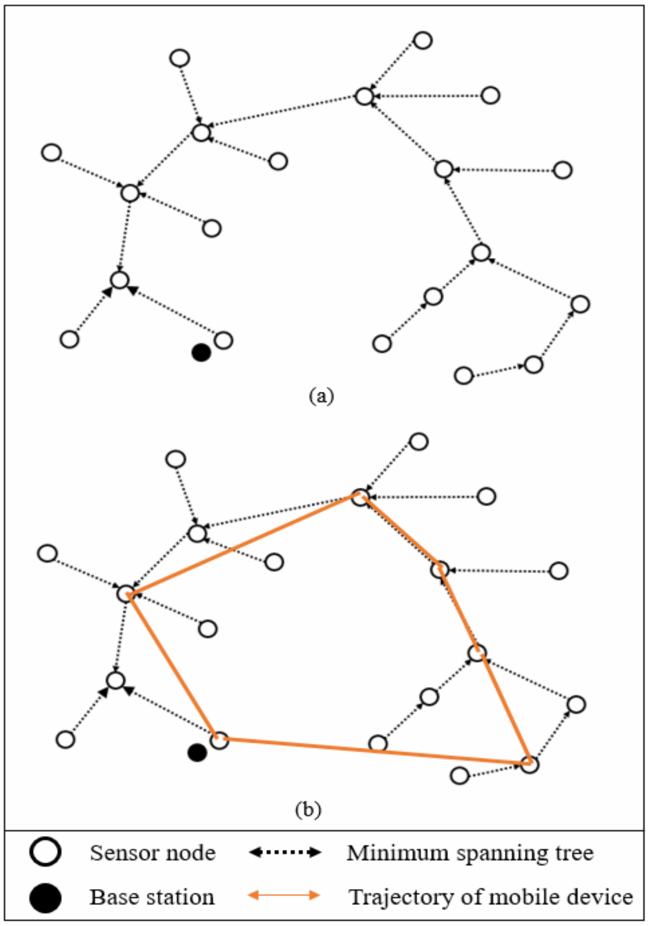

Figure 7. Example of EAPC operation: [14] (a) the minimum spanning tree construction and (b) trajectory construction result

3.3.1 Single Mobile Sink

Energy-aware path construction (EAPC) [14] was proposed as an energy-efficient path construction algorithm. In the initialization phase, it constructs a minimum spanning tree rooted at the base station. After constructing the minimum spanning tree, it elects the collection points according to the number of packets collected by the sensor node, including the packet generated. Finally, it constructs a convex polygon based on the elected collection points and connects the remaining collection points located on the inner side of the convex polygon. When the process is finished, the collection points are renumbered, and the mobile sink visits each region in order. Figure 7(a) shows the minimum spanning tree based on the initial network. Figure 7(b) shows the trajectory construction results based on EAPC. Through this process, an efficient moving path is constructed to prolong the network lifetime.

Ang et al. [15] proposed a scheme to minimize the energy consumption in multicluster-based large-scale WSNs. The proposed scheme uses analytical approaches to determine the node energy consumption and partitions the network into multiple clusters prior to data collection. In addition, it utilizes multicluster network models for determining the optimal number of clusters for minimizing energy consumption. Initially, each network is represented by one cluster, and the sink node traverses the centroid of a cluster to collect data. When the sink arrives at the centroid, it broadcasts a data request (DREQ) message. The sensor nodes that received the DREQ broadcast the DREQ message and deliver the data to the sink node. In this process, the energy consumption of each sensor and the optimal number of clusters are calculated. Furthermore, the proposed scheme shows that increasing the number of clusters might not always provide the best solution to reduce energy consumption.

Soni et al. [16] proposed controlling the trajectory of a mobile sink to collect data efficiently using reinforcement learning. First, the proposed scheme divides the network into several clusters to reduce the data delivery hop count using reinforcement learning. Every sensor node calculates the cost of a route that goes to the cluster head node, and reward R is derived to make the proper decision. After a few rounds have been repeated, the network clustering is completed. The mobile sink advertises its current location to all cluster heads. The cluster head with the data sends a request to the sink. As the sink moves to that cluster, it advertises its altered location. If a sink receives requests from several cluster heads, it determines the priority according to the distance between itself and the clusters. Through this process, the proposed scheme improves network lifetime and the packet delivery ratio, and it reduces the average delivery delay.

Mitra et al. [17] proposed a virtual-grid-based hierarchical routing protocol suitable for delay-bound applications. The proposed scheme selects a mobile sink trajectory by considering hop counts and data generation rates. In addition, data aggregation at each level of the hierarchy aims to reduce data traffic and increase throughput. First, the proposed scheme constructs a virtual grid according to the transmission radius of a sensor node. In each grid, the candidate subsinks that could be visited by the mobile sink are elected. Each candidate subsink finds the shortest path to its immediate neighboring candidate subsink. One of the candidate subsinks is selected as the starting point of the mobile sinks, and the mobile sink comes back to that candidate subsink within the time period. Then, the mobile sink computes the Euclidean distances between each pair of candidate subsinks and finds the subset of candidate subsinks that would be actually visited by the mobile sink that could provide the minimum total energy.

Nitesh et al. [18] proposed an algorithm for finding an efficient path for a mobile sink. The algorithm was designed to determine rendezvous points selected from a Voronoi graph to reduce the total path length of the mobile sink. It also has a local recovery process for orphan sensor nodes. Through this process, it could design a delay efficient path for the mobile sink.

The mobile-sink-based path optimization artificial bee colony (MSPO-ABC) [19] scheme was proposed for trajectory optimization of mobile sinks to minimize the total hop count based on the artificial bee colony algorithm. First, the network is divided into grids of uniform size. The initial random fitness is calculated to perform the travel path optimization process for the mobile sink through the artificial bee colony algorithm. Then, up to maximum number of iterations, all employed bees try to find a better individual. If the individual found is more fit, it replaces the existing individual with the new one. Based on the optimal individual, the proposed scheme finds the optimal solution for minimizing of hop counts between all subnodes and the rendezvous points of the mobile sink.

Particle swarm optimization based selection (PSOBS) [20] was proposed to obtain near-optimal rendezvous points based on particle swarm optimization to manage network resources efficiently. Initially, the proposed scheme constructs a cluster structure in which no node performs multihop routing. Each sensor node can communicate with its cluster head with a one-hop range. After the initial solution is obtained, a fitness value is calculated for each particle. Each particle in the particle swarm optimization algorithm is compared and updated using two values: (1) the best position the particle has ever experienced and (2) the best position ever achieved in the population. Through this process, the proposed scheme can identify the rendezvous points and find the optimal route of the mobile sink. The mobile sink can collect the data by visiting each point along the route. As a result, the proposed scheme has advantages in terms of throughput, energy consumption, and hop count.

Jerew et al. [21] proposed a trade-off between energy consumption and data collection latency. The scheme consists of two major algorithms: (1) the adjacent tree-bounded hop algorithm (AT-BHA) to construct adjacent collection trees by finding the closest nodes to the last constructed collection location and (2) the farthest node first-bounded hop algorithm (FNF-BHA) to exploit the farthest node from the mobile sink in the construction of the collection tree. Through these algorithms, it was possible to prolong the network lifetime and reduce the moving path of the mobile sink and total hop count for data gathering.

Dynamic path planning for mobile sink with burst traffic (DPPMSBT) [22] was designed to respond quickly to emergent data collection. Because the existing studies with a controlled mobility pattern usually focus on reducing the path length, they have difficulty dealing with unexpected traffic. If excessive traffic occurs in some area, the cluster head calls the mobile sink to the area. The data of the other cluster in which the visit is omitted by the call of the mobile sink are relayed to the changed travel path of the mobile sink. Figure 8 shows an example of data collection with burst traffic. If burst traffic occurs near node 8 when the mobile sink is located near node 3, node 8 sends a message to notify the mobile sink to come, and neighbor node 8′ caches some of the traffic to help. The mobile sink moves to node 8 to handle the burst traffic without going through nodes 6 and 9. To enable the mobile sink to collect the data of nodes 6 and 9, they send their data to node 5′ and node 5 on the trajectory of the mobile sink, respectively. Thus, the mobile sink collects the data of all clusters. Through this process, the mobile sink can guarantee the data collection without loss despite unexpected excessive traffic.

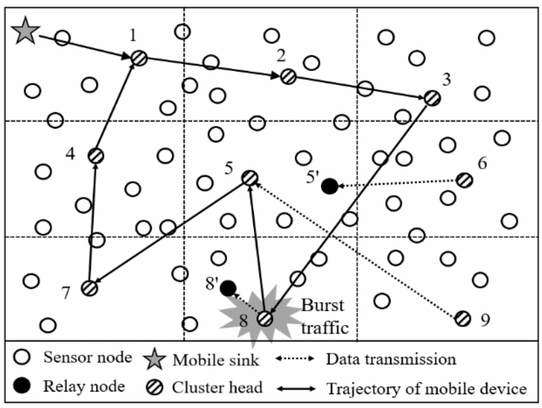

Figure 8. Example of data collection with burst traffic [22]

Energy-balanced tree-based data collection (ETDC) [23] was proposed to reduce energy consumption in communication and end-to-end delay based on an energy-balanced tree. To construct the tree, the node closest to the center of the network is regarded as the root, and it broadcasts packets to its one-hop neighbor nodes. The nodes that received packets become the first child nodes of the root. Then, the first child nodes broadcast packets to their one-hop neighbor nodes, and the nodes become the second child nodes. All nodes join the tree as this process is repeated. After the tree construction process, the tree is divided into several subtrees to find optimal traversal points. The trajectory of the mobile sink is optimized based on curve fitting. Through tree construction and trajectory optimization, the proposed scheme can reduce the path length and enhance the packet delivery ratio and network lifetime.

The mobile seink based energy aware clustering (MSEAC) [24] cluster head selection strategy was proposed to prolong the network lifetime and reduce packet delay by overcoming the energy hole issue. The network is initially divided into a number of rectangular regions, and each region has one cluster head. Because the cluster head is randomly selected initially, the fitness function is evaluated to find the best fitness value. The average node-to-node distance and distance between the node and the sink node are the decisive parameters of the process. The sink moves in the observing field after estimating the centroid location of the cluster heads. The proposed scheme improves network lifetime and packet delivery and reduces packet delay.

The hyper-heuristic framework (HHF) [25] was proposed to maximize the network lifetime. To design the training network, several factors should be considered: the number of sensors, deployment of sensors, number of candidate sink sites, etc. Moreover, to obtain a heuristic framework, the approach considers the following factors: minimum residual energy, maximum residual energy, local simulated network lifetime, average sensor energy, and average consumption rate of sensors. First, the proposed scheme initializes the population according to the above-mentioned factors. Then, it evaluates the fitness of all training networks and selects the higher fitness value. When the maximum number of iterations is reached, the highest fitness value can perform better than the predefined heuristics. By finding the network with the highest fitness value, the proposed scheme can maximize network lifetime.

3.3.2 Multiple Mobile Sinks

Improved mobile-sinks-based energy-efficient clustering algorithm (IMECA) [26] was proposed to improve energy conservation and to increase load balancing. The proposed scheme divides a network into three rhombi, and each rhombus is considered as a cluster. The mobile sink moves across the cluster, stopping for data collection at several stopping stations. Each sensor finds communication paths to send data to the closest mobile sink with minimum cost. If the sensor exploits multihop routing toward the closest sink or its cluster head, the sensor node selects the best relay node considering the balancing of its energy consumption. When the remaining energy of the relay node does not satisfy the threshold, the other node should be selected as a new relay node. Based on the trajectory control of mobile sink and reducing the average transmission distance, the proposed scheme can reduce the energy consumption and achieve load balancing.

Mobile multi-sink node path planning algorithm with energy balance (hexHPSO) [27] is a mobile multiple-sink-node path-planning algorithm with energy balancing. In this scheme, the network is divided into several virtual regular hexagonal grids. The grids are divided into two categories, with the sensor node located in the common area or in a special area. If the sensor is located in the common area, it can calculate information about the grid to which it belongs. However, if it is located in the special area, it cannot obtain information about the grid using only simple information. The sink node can park on two positions: the center point of the grid and the centroid point of the distributed sensor nodes. To obtain a path with an optimal grid traversal and parking position, the proposed scheme exploits particle swarm optimization. Figure 9 shows the trajectory of three mobile sink nodes planned by the hexHPSO algorithm. Through the optimization, the proposed scheme can find the optimal order to traverse the grids and obtain the path of the stop positions selected by using improved crossover and mutation operations.

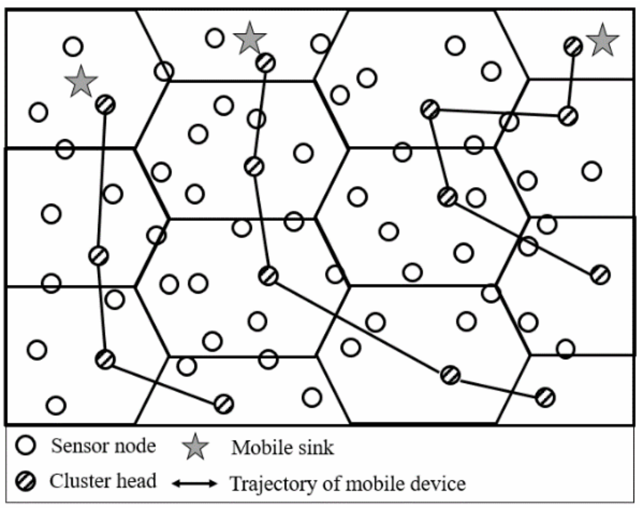

Figure 9. Trajectory of mobile sinks [27]

3.3.3 Comparison of Mobile Sink Studies Based on Controlled Mobility Pattern

The mobile sink studies based on a controlled mobility pattern are compared. Table 3 shows the comparison of the studies introduced in Section 3.3.

Mobile sink studies based on a controlled mobility pattern are being conducted more than studies of the predetermined mobility and random mobility patterns. It is thought that this is because the application of WSNs is increasing with the development of technology, and collecting information on the network efficiently is required; thus, the demand for control of the mobile sink is increased.

According to Table 3, as in the previous sections, the mobile sink studies based on the controlled mobility pattern have focused on reducing energy consumption and prolonging network lifetime. However, unlike the previous studies, most studies based on the controlled pattern divided networks into grids [17, 19, 27], clusters [15-16, 20, 22, 24, 26], trees [14, 21, 23], and so on, and they selected representatives of each structure (for example, the cluster head or root of a subtree). After the structure has been constructed, studies on schemes to enable the mobile sink to traverse the cluster efficiently are conducted. As a result, the average length and end-to-end delay are significantly reduced compared with the previous studies based on predetermined and random mobility patterns.

Table 3. Comparison of mobile sink studies based on controlled mobility pattern

Protocol	Feature	Performance requirements				
		Average path length	End-to-end delay	Energy consumption	Network lifetime	Packet delivery ratio
EAPC [14]	Energy-aware path construction based on graph of collection points			○	○	
Ang et al. [15]	Determining the optimal number of clusters for minimizing the energy consumption			○		
Soni et al. [16]	Trajectory changes in real-time according to demand/request from cluster heads		○	○	○	
Mitra et al. [17]	Efficient virtual grid structure for delay bound applications	○		○	○	
Nitesh et al. [18]	Delay-efficient trajectory design based on Voronoi diagram	○	○	○	○	
MSPO-ABC [19]	Minimization of total hop counts based on artificial bee colony algorithm	○	○	○		
PSOBS [20]	Energy-efficient trajectory finding based on particle swarm optimization algorithm	○		○		
Jerew et al. [21]	Balancing between hop count and tour length based on heuristic algorithms	○	○	○		
DPPMSBT [22]	Dynamic path planning for load balancing and traffic bottleneck avoiding based on grid structure	○	○		○	○
ETDC [23]	Sink trajectory optimization based on energy-balanced tree	○	○		○	○
MSEAC [24]	Alleviate the issue of energy hole based on nature-inspired firefly optimization algorithm		○		○	○
HHF [25]	Scheduling the trajectory for network lifetime maximization based on hyperheuristic framework		○		○	
IMECA [26]	Trajectory control for minimizing average distance based on hexagonal-shaped cluster	○		○	○	
hexHPSO [27]	Energy balanced grid trajectory planning based on hybrid particle swarm optimization algorithm		○	○	○	

In addition, unlike the case in which the movement of the mobile sink cannot be controlled, because the movement of the mobile sink can be controlled, reducing the number of transmission hops in data transmission leads to a reduction in energy consumption and an increase in network lifetime [18-19, 21-23].

Furthermore, by controlling the movement of the mobile sink, it is possible to respond to the deflected data in real time. Finally, the utilization of particle swarm optimization to optimize the trajectory of the mobile sink (that is, a nature-inspired algorithm) is being exploited more actively than in other mobility patterns [19-20, 23-24, 27].

4 Open Issues and Research Challenges

Although many studies have been performed to support the mobile sink with various mobility patterns, issues and challenges remain.

4.1 Number of Multiple Sink Studies

Surveying the mobile sink studies from the past three years confirmed that there have been relatively few studies using multiple sinks. However, because the applications in which WSNs are utilized are gradually increasing, the field in which multiple sinks are exploited is gradually increasing, and additional studies for multiple sinks should be conducted. Furthermore, research is needed in accordance with the movement of multiple sinks, such as the case where multiple sinks move sporadically or collectively depending on the application.

4.2 Utilization of Particle Swarm Optimization Algorithm

The particle swarm optimization algorithm is known as a simple wide-area optimization algorithm that enables the candidates to improve simultaneously through iterative calculations, thereby finally optimizing. Various methods of particle swarm optimization have already begun to be exploited to deal with mobile sinks. However, because iterative calculation is required in this wide-area optimization process, the algorithm has more computational cost than other algorithms. Thus, research is needed to alleviate the problem. In addition, in a situation where frequent network changes occur, the above-mentioned problem is aggravated each time a network change occurs, which as a disadvantage. Therefore, research on this problem also should be studied.

4.3 Mobile Sink Studies Based on Random Mobility

As mentioned in Section 3.2, there have been relatively few studies based on random mobility. Many studies have already been conducted, and it is clear that handling uncontrolled mobile sinks is difficult. However, in applications where WSNs are actively utilized, such as smart cities, there are numerous uncontrollable mobile devices, such as people and smart vehicles, that must be considered. Thus, real-time and reliable data delivery is an important research area. In addition, recent methods, such as machine learning and artificial intelligence, are expected to improve the previous mobile sink studies based on random mobility.

4.4 Network Structure

Most of the surveyed studies constructed a network structure using clusters, grids, and trees to achieve their objectives. This way of structuring the network has various advantages, including extending the network lifetime. The network structuring has less computational cost than the particle swarm algorithm, but there is still a high cost to construct and maintain the structure, and it causes such problems as energy imbalance of the representative node. Although many studies have proposed compensating to solve the problem, the construction and maintenance of the entire network structure is fundamentally vulnerable to changes in the network. The problem is exacerbated as the size of the applied network increases. Therefore, it is necessary to study the scalability and flexibility in the process of constructing a network structure to respond to the network size and changes.

4.5 Security

As mentioned earlier, it is expected that WSNs will be exploited in various applications, such as smart factories and cities, in the near future, and users will want to collect information from the network. In this scenario, various kinds of information, including personal information from different users, are transferred over the network, so confidentiality must be ensured for the information. Therefore, unlike in the previous research on the number of multiple sinks, each of the multiple sinks should be identifiable, and studies should be conducted to provide differentiated services for each mobile sink.

5 Conclusion

In this survey, the importance of mobile sinks in WSNs was explained. Mobile sink studies conducted during the past three years were investigated. The studies were classified based on the fact that the mobility pattern and the number of sinks differ by application. In addition, the operation processes of the studies were briefly described and compared. Finally, open issues and research challenges were discussed to provide research direction based on recent research trends.

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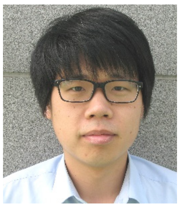
Biographies



Sangdae Kim received his B.S. and Ph.D. degrees in computer engineering from the Chungnam National University, Daejeon, Republic of Korea in 2013 and 2019, respectively. He is a post doctoral researcher at the Software Research Center (SOREC), Chungnam National University. His research interests include the routing protocols for real-time and reliable communication, mobility support strategy for seamless communication.

Beom-Su Kim received his M.S degree in Gyeongsang National University, Korea. He is currently working toward Ph.D. degree at the ChungNam National University, Daejeon, Korea. His research interests include wireless sensor networks and body area networks, routing for MANET.

Babar Shah received M.SC. degree from the University of Derby, UK and Ph.D. degree from Gyeongsang National University, South Korea. He is currently with the College of Technological Innovation at Zayed University, Abu Dhabi. His research interests include wireless and mobile networking.

Sana Ullah received the Ph.D. degree in information and communication engineering from Inha University, Incheon, South Korea, in 2011. From December 2011 to March 2014, he was an Assistant Professor with the College of Computer and Information Science, King Saud University, Riyadh, Saudi Arabia. He is with the Department of Computer and Software Technology, University of Swat, Mingora, Pakistan, and as a Senior Researcher at Gyeongsang National University, Jinju, South Korea. Dr. Ullah is currently an Editor for the Springer Journal of Medical Systems (JOMS), KSII Transaction of Internet and Information Systems, Wiley Security and Communication Network, Journal of Internet Technology, and International Journal of Autonomous and Adaptive Communications Systems. He was a Guest Editor for many top journals including Elsevier's Journal of Information Science, Springer's Journal of Medical Systems, and Springer Journal of Telecommunication Systems. He was also the Co-Chair/TPC member for a number of international conferences including BodyNets, IEEE PIMRC, IEEE Healthcom, IEEE Globecom, and IEEE WCNC.

Ki-Il Kim received the M.S. and Ph.D. degrees in computer science from the Chungnam National University, Daejeon, Korea, in 2002 and 2005, respectively. He is with Department of Computer Science and Engineering, Chungnam National University, Deajeon, Korea. Prior to joining, he has been with the Department of Informatics at Gyeongsang National University since 2006. His research interests include routing for network security, fog computing, machine learning, and sensor networks.