Exploiting Mobility for Efficient Data Dissemination in Wireless Sensor Networks

Euisin Lee, Soochang Park, Fucai Yu, and Sang-Ha Kim

Abstract: **In this paper, we introduce a novel mobility model for mobile sinks in which the sinks move towards randomly distributed destinations, where each destination is associated with a mission. The novel mobility model is termed the *random mobility with destinations*. There have been many studies on mobile sinks; however, they merely support two extreme cases of sink mobility. The first case features the most common and general mobility, with the sinks moving randomly, unpredictably, and inartificially. The other case takes into account mobility only along predefined or determined paths such that the sinks can gather data from sensor nodes with minimum overhead. Unfortunately, these studies for the *common mobility* and *predefined path mobility* might not suit for supporting the random mobility with destinations. In order to support random mobility with destination, we propose a new protocol, in which the source nodes send their data to the next movement path of a mobile sink. To implement the proposed protocol, we first present a mechanism for predicting the next movement path of a mobile sink based on its previous movement path. With the information about predicted movement path included in a query packet, we further present a mechanism that source nodes send energy-efficiently their data along the next movement path before arriving of the mobile sink. Last, we present mechanisms for compensating the difference between the predicted movement path and the real movement path and for relaying the delayed data after arriving of the mobile sink on the next movement path, respectively. Simulation results show that the proposed protocol achieves better performance than the existing protocols.**

Index Terms: **Data collection place, mobile sink, next movement prediction, random mobility with destinations, wireless sensor networks.**

I. INTRODUCTION

Wireless sensor networks consist of a large number of sensor nodes and sinks [1]–[3]. The sensor nodes are low cost wireless devices and they are densely distributed over a desired sensing region. The sensor nodes generate sensing data of stimulus and forward them to sinks via wireless multi-hops communication. In typical wireless sensor network, the sensor nodes are equipped with irreplaceable batteries, i.e., unattended mode operation. Therefore, minimizing the energy consumption of the sensor nodes and thus maximizing the lifetime of sensor networks is one of the most important research issues [1].

In many practical applications of wireless sensor networks, the sinks might be defined as mobile users to move around within the sensor fields and collect data during their movement or mission [2]–[7]. Also, exploiting mobility of the sinks, i.e., the mobile users, could be considered as an interesting concept to enhance the network lifetime by avoiding excessive relaying overhead at nodes close to the static sinks [8]–[10]. Up to now, many protocols have been proposed for supporting data dissemination from sensor nodes to mobile sinks [2], [4]–[6], [11]–[15]. These mobility support protocols are studied within two categories that are according to two extreme cases of sink mobility. The first type of studies investigates efficient data dissemination for mobile sinks that move around randomly, unpredictably, and inartificially [2], [4]–[6], [11], [12]. Namely, they take into account the most common and general mobility of sinks, such as human and animals, as target mobility models. On the contrary, the other type of studies restricts the mobility models of sinks to artificial movement that sinks only shift via predefined or determinded paths by periods [13]–[15]. They exploit such sink mobility model in order to minimize energy consumption during the data collection and thus maximize network lifetime.

In this paper, we consider a novel sink mobility in which a mobile sink travels towards specific destinations related to its task rather than wandering randomly without any destination. Only, the mobile sink does not move along a straight line to the destination, but deviates for a random angle towards left or right of the line. For example, firefighters in disaster area should save life of randomly distributed victims and sensor nodes are deployed to detect the victims. In this application, a firefighter gathers information about the location of a victim and then the firefighter moves toward the victim location. Also, while moving, the fire fighter should be able to gather data about other victims. We define this sink mobility as *random mobility with destinations*. In order to support random mobility with destinations, the above mentioned two case studies, i.e., *common mobility* and *predefined path mobility*, have problems and limitations. In the next subsection, we address the problems and the limitations as background of our study and describe our contributions through the some basic ideas for overcoming them in order to support the random mobility with destinations.

A. Background and Contribution

As shown in Fig. 1, the data dissemination approach based on the common mobility [2], [4]–[6], [11], [12] requires generally three additional processes to deliver data to a mobile sink: 1) The first one is that the mobile sink informs all source nodes (A, B, C, and D) of its current location (U) as a data collection place, 2) the second one is that the mobile sink constructs and manages data forwarding path from the data collection places (U) to its new location (U' and U'') and 3) the third one is that the mobile sink avoids the long forwarding path caused by its movement. However, these three processes of the data dissem-

Manuscript received December 15, 2008.

The authors are with the Department of Computer Engineering, Chungnam National University, Republic of Korea, email: {eslee, winter, yufc}@cclab.cnu.ac.kr, shkim@cnu.ac.kr. S.-H. Kim is a corresponding author.

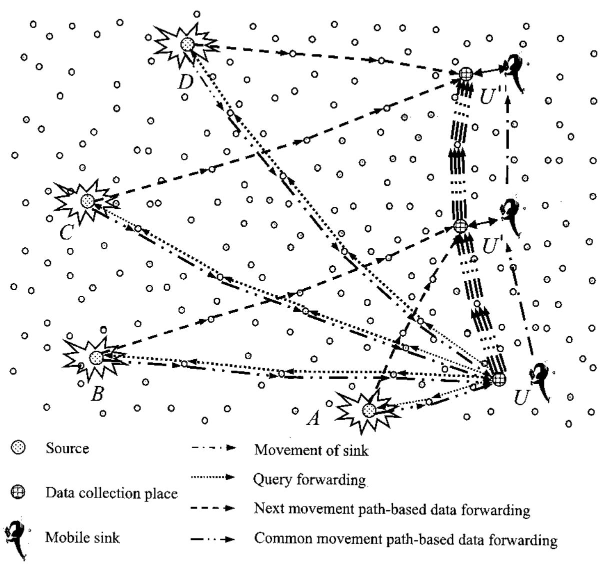


Fig. 1. A mobile sink in data dissemination protocols based on common movement path uses its current location (U) as a data collection place for gathering data from sources and receive data from paths constructed for data relaying due to its movement (U' and U''). In contrast, a mobile sink in data dissemination protocols based on next movement path uses its next movement path (U' and U'') as data collection places and receives data at the path.

ination approach based on the common mobility have the following five problems [16]:

- Path construction problem: When the mobile sink moves to new locations (U' and U''), it must construct communication paths from the data collection place (U) to the new location (U' and U'') [2], [4]–[6], [11], [12]. This incurs energy consumption to additional sensor nodes.
- Data detour problem: Data of sources (A, B, C, and D) are not directly disseminated to the mobile sink (U' and U''), instead, they are disseminated to the new locations of the mobile sink (U' and U'') via the data collection place (U) [2], [4]–[6], [11], [12] in detour manner. Due to the increased wireless hop-counts, there is an increase in the energy consumption of sensor networks, latency as well as degradation of the data delivery ratio.
- Hot-spot problem: A disproportionate amount of data from many sources (A, B, C, and D) is concentrated into the data collection place (U) [2], [4]–[6], [11], [12]. This increases rapidly energy consumption of the sensor nodes in the area around the data collection place [3], [7], [8].
- Report congestion problem: A disproportionate amount of data from many sources (A, B, C, and D) is congested in one path connected between the data collection place (U) and new locations of the mobile sink ($U^{'}$ and $U^{''}$) [2], [4]–[6], [11], [12]. This significantly increases energy consumption of sensor nodes on the path.
- Global or local flooding: If the moved distance of the sink is far from the data collection place (U) to new locations (U' or U''), it disseminates its new location to every source node through global [2] or local [6] flooding to avoid the long forwarding paths from sources (A, B, C, and D).

As shown in Fig. 1, the next movement path-based data forwarding allows source nodes to forward their data on the next movement path of a mobile sink and thus avoid the five problems of the data dissemination approach based on the common mobility. To address this issue, many data dissemination protocols have been proposed in wireless sensor networks [13]–[15]. However, they fundamentally require the source nodes to know the next movement path of the mobile sink. Hence, they consider only predefined path mobility. In [13], the mobile sink repeatedly moves only along a fixed route such as public transportation vehicles, thus being predictive for the source nodes. In [14], a mobile sink floods a route construction packet while moving along a linear path before the data gathering phase in order to construct routes from all sensor nodes to the linear path. In [15], a mobile sink calculates its movement path through the obtained location information of all source nodes and informs back the source nodes about the movement path.

In this paper, we consider random mobility with destinations. For supporting the random mobility with destinations, exploiting the data dissemination approach based on the common mobility is inefficient and exploiting the data dissemination approach based on the predefined path mobility has a mobility limitation. Therefore we propose a new protocol. Similar to the data dissemination approach based on predefined path mobility, the proposed protocol also allows source nodes to forward their data on the next movement path of a mobile sink. However, a mobile sink in the random mobility with destinations does not move along predefined path, but randomly toward the destination. To implement the proposed protocol, we first propose a mechanism for predicting the next movement path of the mobile sink based on its previous movement path, current location, speed, and geographical feature. With the information of next movement path included in a query, we next present a mechanism by which the source nodes send their data to the next movement path before arriving at the mobile sink. We last present mechanisms for compensating the difference between the next movement path and the real movement path, as well as for relaying the arrived data later than the mobile sink at next movement path.

The proposed protocol can solve the five problems of the data dissemination approach based on the common mobility by exploiting the next movement path of mobile sinks. First, the proposed protocol can solve the path construction problem. Because the data collection places become the locations where the sinks will move, the proposed protocol has no opportunity to create additional paths from the sensor node according to the movement of the sink and do additional communications to receive data through the paths. Second, the proposed protocol can solve the detour problem. Because the sensor nodes in the proposed protocol can know locations to which the sink will move, they can forward their data directly to the sink. Third, the proposed protocol can solve the hot-spot problem. The sinks can have multiple and dynamic data collection places if the next movement path of the sink moves to various locations. This can decentralize a disproportionate amount of traffic centralized in single data collection place [3], [7], [17]. Fourth, the proposed protocol can solve the report congestion problem. Because the data collection places, which become the locations where the sinks will move, are also final data destinations, the data at the data collection place does not need to be forwarded. Fifth, the proposed protocol can avoid the global or local flooding problem. Because the proposed protocol enables data to directly route from the source nodes to the new locations of the mobile sink, the mobile sink does not have to flood its new locations. The solution of the five problems leads to a decrease in the energy consumption of sensor nodes and hence an increase in the lifetime of sensor networks. It also leads to an increase in the data delivery ratio and a decrease in latency. Simulation results show that the proposed protocol has better performance than the existing protocols.

B. Paper Organization

The remainder of this paper is organized as follows. Section II explains related works about data dissemination protocols exploiting mobility and mechanisms for movement prediction. We describe the system model and the mechanism for predicting the next movement path in Section III and present the proposed protocol in Section IV. Simulation results are presented in Section V to evaluate the effectiveness of the proposed protocol. Section VI concludes the paper.

II. RELATED WORKS

In this section, we explain related works about data dissemination protocols exploiting mobility and mechanisms for movement prediction.

A. Data Dissemination Protocols Exploiting Mobility

A number of approaches exploiting mobile sinks (called also mobile base stations and mobile collectors) for efficient data collection in wireless sensor networks have been proposed recently [2], [4]–[6], [8]–[15]. To solve the quick energy exhaustion problem of nodes near the fixed sinks due to relaying of large amount of data, authors in [8], [9] propose mechanisms that choose locations of sinks on the perimeter of the sensor network and change their location in optimal way in order to maximize the lifetime of a sensor network through load balancing. These mechanisms ensure uniform energy consumption across the sensor nodes, but there still must be multi-hop communications with long path that consume much energy because the sinks are located on the perimeter of the sensor network. Moreover, they are not suitable for applications presented in this paper, in which mobile sinks moves freely inside the sensor network, because the sinks move only on the perimeter of the sensor network.

In [10], authors consider common mobility and introduce a mobile collector called Data Mule which moves randomly in a sensor field. To reduce energy consumption through avoiding multi-hop communications, the mobile collector visits sensor nodes and gathers data from them via one-hop communication. This approach does not require any path construction to the mobile collector because it visits each individual sensor node. However, it has high delay for data gathering from the whole sensor field. Moreover, it is also difficult to guarantee visit of all sensor nodes because of the random movement of the mobile collector.

For common mobility, in order to achieve low delay for data gathering from all source nodes, authors in [2], [4]–[6], [11], [12] propose protocols that use multi-hops communications to a mobile sink. The mobile sink reconstructs the data dissemination paths from all source nodes by updating the topology change according to its movement. Authors in [11] use global update for reconstruction of the whole path from all source nodes to the mobile sink, while authors in [2], [4]–[6] use local update for the reconstruction of local path from initial location for data gathering to its current location. In [12], authors compare performance between the global update and the local update. However, these protocols have the five problems mentioned in Section I because they consider the common mobility for data gathering.

We describe two-tier data dissemination (TTDD) [2] and energy-efficient data-dissemination (EEDD) [6] in detail, since we compare the proposed protocol with TTDD and EEDD in the simulation. In TTDD, a mobile sink floods locally its query within a local cell of a grid constructed by each source proactively. The nearest dissemination node on the grid point that has received the query disseminates the query upstream through other dissemination nodes toward the source. The source disseminates requested data to the mobile sink via the reverse path. In TTDD, the mobile sink renews its location to the dissemination node for moving within a cell and reselects a new nearest dissemination node via a local flooding for moving between cells. EEDD exploits a virtual grid which is constructed in network initialization stage. In EEDD, a mobile sink floods its query across the whole grid. With diagonal-first routing path, sources forward their data to the mobile sink by multi-hop communications, using only grid heads. In EEDD, if the mobile sink moves into new grid cell, it constructs data dissemination path from the previous grid cell to the new grid one and if the mobile sink moves more than the threshold movement, it floods the query across the whole gird again.

To reduce the delay for data gathering via one-hop communications [2], [4]–[6], [11], [12] and the energy consumption for data gathering via multi-hops communications [10], authors in [13]–[15] propose data gathering protocols based on rendezvous points between the data sent by source nodes and the path of a mobile sink. So, they also do not require any path reconstruction as in [2], [4]–[6], [11], [12] due to the movement of the mobile sink. In [13], a mobile sink moves repeatedly along fixed route such as, for example, public transportation vehicles. Then, source nodes, which can predict its moving path and timing, send their data to the moving path and the mobile sink gathers the data while moving along the path. In [14], a mobile sink moves along a linear path. Sensor nodes send their data to the nodes close to its path. The mobile sink then picks up the cached data when it passes by. However, to make all sensor nodes know the data dissemination route to the linear path of the mobile sink, it must flood a route construction packet while moving along the linear path before the data gathering phase. In [15], based on location information of all source nodes, a mobile sink calculates rendezvous points to which the sensor nodes send their data, and moves along the path between the rendezvous points in order to gather the cached data from the other rendezvous points. However, in practice, a mobile sink may not always be able to know the location information of all source nodes. Note that the mobile sinks in [13]–[15] consider only predefined mobility path, where in a given period the movement path is known, and thus it is not difficult for applying to applications for random mobility with the destination introduced in this paper.

In this paper, we consider the model of random mobility with destinations and proposed a new protocol suited for that model. As the data dissemination approach based on predefined path mobility [13]–[15], the proposed protocol also allows source nodes to predict the next movement path and forward their data to the sink towards the predicted path. Thus, the proposed protocol eliminates the five problems of the data dissemination approaches based on the common mobility [2], [4]–[6], [11], [12]. The proposed protocol also does not have the mobility limitation of the predefined path mobility. In order to predict the next movement path, the proposed protocol requires the mobile sink to move proactively the predefined path [13], [14] and to know the location information of all source nodes [15].

B. Mechanisms for Movement Prediction

There are many previous works [18]–[27] on movement prediction in the literature. In ATM and cellular networks, many works focus on performance enhancement of the resource reservation [18]–[21], quick handoff management [19] between base stations to provide QoS support, or location management [22], [23], through the movement prediction of a mobile user. Authors in [18] propose an algorithm based on movement history to determine the motion of a user. However, they consider movement consisting of regular and random components, which can be either circle or track patterns. Authors in [19] design user mobility model based on movement history, but require instantaneous RSSI measurements from the surrounding cells. Authors in [20] introduce the shadow cluster concept that represents probability that every mobile user will move into the vicinity cells in its current location at future times. However, the probability is calculated by the base station of the current cell of the mobile user by using the user's requirements, position, and movement history. Authors in [22] derive user mobility model by using vehicular traffic activity data. However, the vehicular traffic activity data are collected over a period of several months in order to derive user mobility model. Authors in [21], [23] propose user mobility modeling using the accumulated movement behavior history of the specific mobile user but require data compression techniques for the user mobility modeling.

Many works have the objective to restrict flooding for route discovery [24] or to enhance performance such as the energy consumption [25], data delivery ratio [26], or end-to-end delay [27] in ad hoc networks. Authors in [24], [26] define the region that is likely to contain a mobile node located in a position D, called the *expected region* in order to forward the packet to all one-hop neighbors in the direction of the node and to restrict the flooding for route discovery to a certain area. The expected region is a circle around the node and its radius is set to $(t_1 - t_0)v_{\max}$ where t_1 is the current time, t_0 is the timestamp about the position D, and $v_{\max}$ is the maximum speed of the node. Authors in [25] propose a mechanism delaying data communication until a mobile node moves close to its target peer node. However, for mobility prediction, they consider only two locations, called home and work, and a parameter called regularity that represents degrees of diversions. Authors in [27] propose a mechanism that forwards the data packets via those intermediate nodes that are faster in approaching the destination node. However, they utilize Gauss-Markov mobility and constant speed mobility to predict the movement of a mobile destination node. Furthermore, in all of them [24]–[27], it predicts the mobility of its target peer mobile node for communication instead of its own mobility. In practice, it is difficult to predict the mobility of a target peer mobile node because obtaining its mobility information is not easy and has much communication overhead.

III. SYSTEM MODEL

This section presents the system and network model and describes the mechanism for predicting the next movement path of a mobile sink.

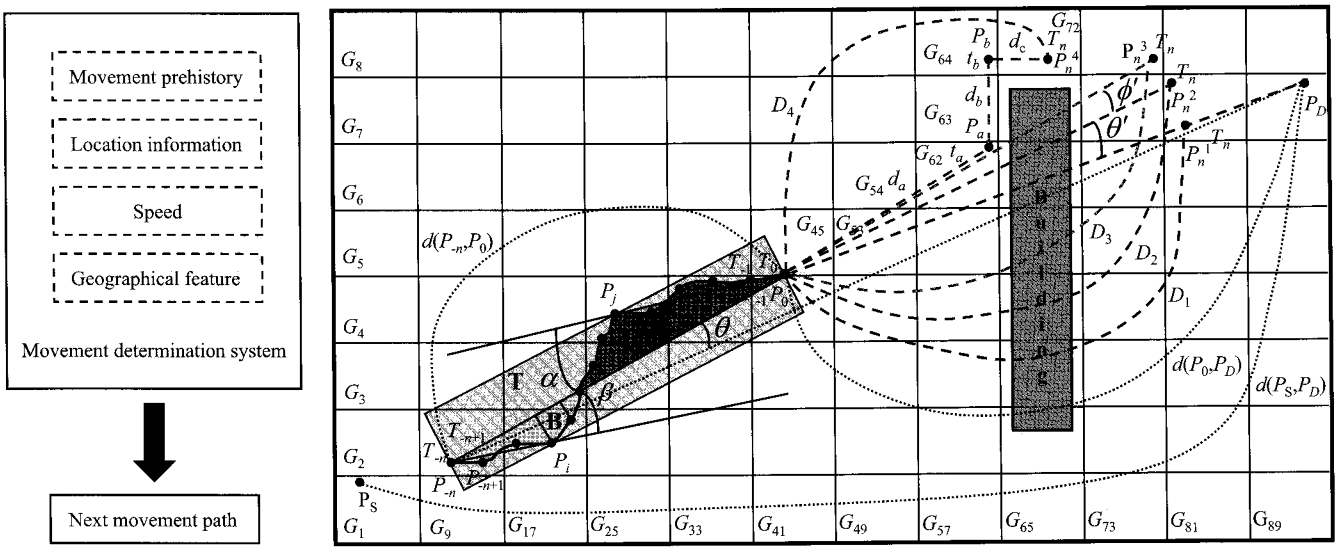
A. System and Network Model

The sensor network is divided into a virtual grid of cells, where each pair of nodes in neighboring grid cells can communicate directly with each other. Each node is aware of its own location $(x,\ y)$ by using the global positioning system (GPS) [28], [29] or other techniques such as triangulation [30], [31] and hence is aware of its own grid cell ID when the location $(x_0,\ y_0)$ of the virtual origin and a grid cell size are given. To ensure that every node in a grid cell can communicate directly with all the nodes in its neighbor grid cells, the grid cell size is set to less than $1/2\sqrt{2}R$, where R is the transmission range.

We assume that the sensor nodes are densely deployed and there may be many sensor nodes in a grid cell. Each sensor node can be in active mode or sleep mode. Only the grid head is required to be awake in each grid cell. If a grid head detects an event, it becomes source and generates data. To save power, other nodes stay in sleep mode most of the time based on the geographical adaptive fidelity (GAF) protocol [29] and only need to wake up periodically to detect death of their grid head. If a grid head exhausts its energy, another node in the grid cell is selected as a new grid head.

B. System and Network Model

A mobile sink introduced in this paper has a device, such as PDA, that can be assumed to have unlimited energy, computing, and memory capability. So, the mobile sink can execute mechanism for predicting its next movement path. Hence, we propose mechanism by which a mobile sink can predict its next movement path. We consider applications for the random mobility with the destination that in general in which the mobile sink usually travels with a specific destination for its task rather than wandering randomly without any destination. So, its next movement path is likely to be correlated to its previous movement path towards the specific destination. The mobile sink does not move along a straight line to the destination but deviates randomly to the right or left, as shown in Fig. 2(b). Thus, the mechanism for movement path prediction of the mobile sink, proposed in this paper, is motivated by the fact that its next movement path is influenced by its previous movement path. In



(a) (b)

Fig. 2. Prediction of next movement path: (a) Sink movement prediction system and (b) an example of predicting next movement path of a mobile sink during future time T_n.

other words, its next movement path during the future time T_n could be determined by that during previous time T_n. The mobile sink records the movement history in its profile, indexed by time slots. The next movement path of the mobile sink is also influenced by its current location, its moving speed, and the local geographical features. Fig. 2(a) shows a processing system which can predict the sink movement path.

Fig. 2(b) demonstrates an example of predicting the next movement path at the current time T_0 of a mobile sink at the point P_0 for a future time T_n, where the mobile sink starts from the point P_S and moves toward the destination point P_D. If the proposed prediction mechanism considers only the destination P_D, the next movement path of the mobile sink is a straight line $P_0P_n^1$ and the moving distance is $D_1=T_nv$, where the average speed of the mobile sink is v.

We consider sink mobility that deviates randomly to the right/left of the line P_0P_D and has correlation between previous and next movement paths with the destination P_D. The proposed prediction mechanism considers that a movement path of the sink during the previous time T_{-n}, that is, from T_{-n} to T_0, is described by a sequence of location points ($= P_{-n}P_{-n+1}P_{-n+2}\cdots P_{-1}P_0$). Here, we recalculate the moving direction and distance of the sink during the future time T_n considering both the movement direction, that is, the straight line $P_{-n}P_0$ of the sink during the previous time T_{-n} and the straight line $P_{-n}P_D$ to the destination P_D when the mobile sink is located at the point P_{-n}. The included angle θ between the two straight line $P_{-n}P_0$ and $P_{-n}P_D$ means that the movement direction $P_{-n}P_0$ of the sink during the previous time T_{-n} inclines the angle θ from the straight line $P_{-n}P_D$ toward the destination P_D at the point P_{-n}. The proposed prediction mechanism reflects the angle θ in the moving direction, that is, the straight line P_0P_D. However, the correlated mobility with the destination has a property that the moving direction of the sink inclines more toward the destination if the sink gets near the destination point from the starting point. Thus, we reflect the angle θ in proportion to the distance $d(P_0,\ P_D)$ between the current point P_0 and the destination point P_D for the distance $d(P_S, P_D)$ between the starting point P_S and the destination point P_D. We recalculate the new angle θ' for the moving direction of the mobile sink as follows:

$$\theta' = \theta\frac{d(P_0, P_D)}{d(P_S, P_D)}. \tag{1}$$

Therefore, the recalculated next movement path of the sink during the future time T_n is that the moving direction is the dotted line $P_0P_n^2$ and the moving distance is $D_2 = T_nv$.

Here, we recalculate moving direction and distance of the sink during the future time T_n considering a strayed degree in the straight line $P_{-n}P_0$, for example, each dimension A and angle α up the line $P_{-n}P_0$ and each dimension B and angle β down the line $P_{-n}P_0$ as shown in Fig. 2(b), when the sink moved during the previous time T_{-n}. The dimension $\sum A$ is a sum of each dimension A between the straight line $P_{-n}P_0$ and each straight line of location points of two serial time slots above the straight line $P_{-n}P_0$. Here, an expression of a straight line of two location points with coordinates $(x,\ y)$ and a dimension between two straight lines are calculated analytically. The dimension B and $\sum B$ is calculated as like as the dimension A and $\sum A$. The angle α is the included angle between the straight line $P_{-n}P_0$ and the straight line P_0P_j consisting of P_0 and one point P_j in the dimension $\sum A$. $\sum\alpha$ is summation of each angle α of each point in the dimension $\sum A$. The angle β and $\sum\beta$ are calculated as analogously, as shown in Fig. 2(b). Hence, the moving direction of the sink is inclined towards the larger dimension between the dimension $\sum\alpha$ and $\sum\beta$. We recalculate the inclination degree ϕ from the dotted line $P_0P_n^2$ as follows:

$$\phi = \frac{|A - B|}{A + B}\left(\sum\alpha - \sum\beta\right). \tag{2}$$

We also bias the inclination degree ϕ in proportion to the distance $d(P_0, P_D)$ between the current point P_0 and the destination point P_D for the distance $d(P_S, P_D)$ between the starting point P_S and the destination point P_D. We recalculate the new inclination degree ϕ' for the moving direction of the mobile sink:

$$\phi' = \phi \frac{d(P_0, P_D)}{d(P_S, P_D)}. \tag{3}$$

As shown in Fig. 2(b), the recalculated moving direction of the sink is the dotted line $P_0 P_n^3$ with the inclination degree ϕ' from the dotted line $P_0 P_n^2$. Recalculated moving distance D_3 of the sink may be shorter than the distance vT_n by reflecting its strayed movement and is defined as

$$D_3 = vT_n - \frac{\sum A + \sum B}{T} d(P_{-n}, P_0) \tag{4}$$

where the dimension T is a dimension of a rectangular constructed by a straight line $P_{-n}P_0$ through two location points P_{-n} and P_0, the longest distance point P_j up the line $P_{-n}P_0$, and the longest distance point P_i down the line $P_{-n}P_0$.

Here, we consider another factor, a geographical feature such as a building, a bridge, or a hill, to recalculate the next movement path during the future time T_n because the geographic feature affects the next movement paths of the mobile sink. In this paper, we assume that the mobile sink has the map of the sensor field and thus knows the location information of the geographic feature. As shown in Fig. 2(b), if the mobile sink is aware of location information of the building, it will move towards the location point P_n^3 while detouring the building. We recalculate the moving direction and the distance of the mobile sink during the future time T_n considering the building. We decide location points P_a and P_b to detour the building as shown in Fig. 2(b). As a distance between two location points P_0 and P_a is d_a and a distance between two location points P_a and P_b is d_b, each elapsed time t_a and t_b to move the two distance d_a and d_b is $\frac{d_a}{v}$ and $\frac{d_b}{v}$, respectively. If $T_n \leq t_a$, then $D_4 = T_n v$. If $t_a < T_n \leq t_a + t_b$, then $D_4 = d_a + (T_n - t_a)v$. If $t_a + d_b < T_n$ as shown in Fig. 2(b), $D_4 = d_a + d_b + (T_n - t_a - t_b)v$. As $(T_n - t_a - t_b) = t_c$, $d_c = t_c v$, and $D_4 = d_a + d_b + d_c$. Hence, recalculated moving direction of the sink is from P_0 to P_n^4 via P_a and P_b, and recalculated moving distance is D_4.

Therefore, a series of grid cell IDs, where the sink will move during the future time T_n through the calculated next movement path, is a series of grid cell IDs $(= G_{45}G_{53}G_{54}G_{62}G_{63}G_{64}G_{72})$ as shown in Fig. 2(b). The proposed mechanism for predicting the next movement path of a mobile sink provides a series of grid cell IDs as an output. Thus, if an error range of predicting next movement path is not larger than the size of a grid cell, our next movement path prediction mechanism may provide path that is close to the real movement path. The small error range of predicting next movement path may not significantly affect the performance. We describe a protocol to disseminate effectively the data by using the series of grid cell IDs during the future time T_n in the Section IV.

IV. PROPOSED PROTOCOL

In this section, we present a protocol that source nodes send their data to a rendezvous point on the next movement path of a mobile sink. The proposed protocol consists of three phases as shown in Fig. 3: Query dissemination, data dissemination, and data acquirement.

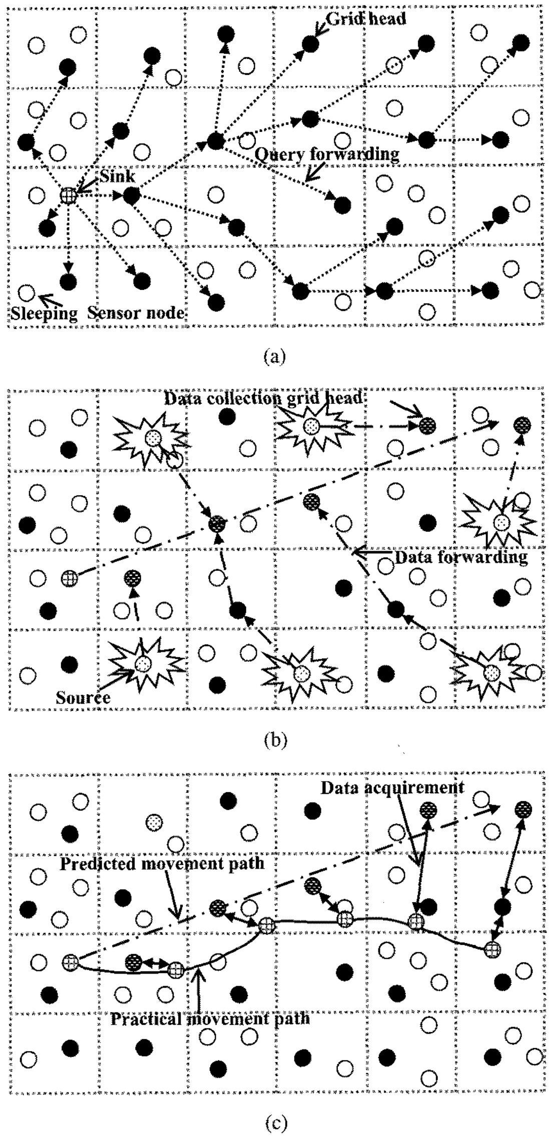


Fig. 3. Three phases of the proposed protocol: (a) Query dissemination, (b) data dissemination, and (c) data acquirement.

A. Query Dissemination

A mobile sink disseminates a query to acquire information from the sensor field. The query contains six fields: *Query_Content, Query_Duration, Current_Grid_Cell, Moving_Gird_Cells, Sink_Speed,* and *Query_Dissemination_Time.* First, the *Query_Content* is information that the sink wants to collect from sensor field. Second, the *Query_Duration* means duration of time, that is, a query lifetime that the sink wants to collect data from the sensor nodes. In other words, it is the lifetime of the query. Third, the *Current_Grid_Cell* symbolizes a grid cell ID where the sink is located when it disseminates the query. Fourth, the *Moving_Gird_Cells* is a series of grid cell IDs where the sink will move during the *Query_Duration.* The *Moving_Gird_Cells* is calculated by the mechanism for predicting the next movement path in the Section III-B. The

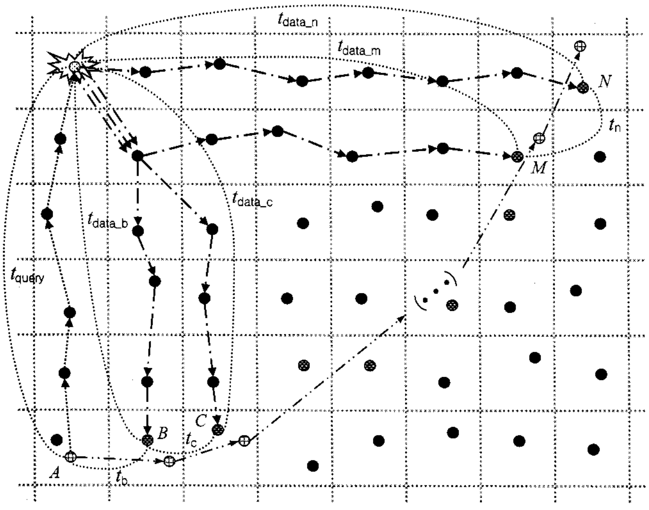


Fig. 4. Three time values that a source needs when it determines a data collection grid to disseminate its data.

grid cell IDs become data collection grid cells for gathering data from sources. Each grid head in the grid cell IDs collects data from the source nodes, and aggregates and saves them until the mobile sink requests them. Fifth, $Sink\_Speed$ represents the average speed of the mobile sink. Finally, the $Query\_Dissemination\_Time$ stands for the elapsed time during which the query is propagated from the sink to the source. The sink sets the $Query\_Dissemination\_Time$ to 0. The scheme to calculate the $Query\_Dissemination\_Time$ at each grid head is presented in Section IV-B. If the query is completed, the sink disseminates the query to the whole sensor field as shown in Fig. 3(a).

B. Data Dissemination

If a mobile sink disseminates query as described in Section III-A to the whole sensor field, each grid head receives the query. Then, as shown in Fig. 3(b), it can determine whether it is a data collection grid cell or not, as well as determine where the data collection grid cells are, by checking the $Moving\_Gird\_Cells$ field of the query. A grid head becomes a source if it has detected a stimulus about the query. Then, the source disseminates its data to a data collection grid cell and the grid head in the data collection grid cell saves the data received from other grid heads as shown on Fig. 3(b).

Fig. 4 shows three time values that a source needs when it determines the data collection grid cell to disseminate its data. The three time values are *Query_Dissemination_Time*, *Sink_Arrival_Time*, and *Data_Dissemination_Time*. First, the $Query\_Dissemination\_Time$ t_{query} means the elapsed time that the query is propagated from the sink to the source. However, after the query packet is disseminated within the sensor field, determining t_{query} at the source is not trivial due to the lack of global time synchronization. To measure the t_{query}, we borrow a part of the idea of the paper [32] which does not use any time synchronization. If the sink at any grid cell disseminates the query packet to its all neighbor grid heads, each node received the query packet measures its t_{query} and disseminates the query packet updated the $Query\_Dissemination\_Time$ field to its all neighbor grid heads. This process is continued until the border of the sensor network. The current node m can calculate $Query\_Dissemination\_Time$ as follows:

$$t_{\text{query}}(m) = t_{\text{query}}(m') + t_{\text{elapsed}}(m') + t_{\text{propDelay}} \tag{5}$$

where $t_{\text{query}}(m')$ is *Query_Dissemination_Time* t_{query} in the query packet of a previous node m' which disseminates it to the node m. $t_{\text{propDelay}}$ is the propagation delay between the two nodes m and m', which is negligibly small. $t_{\text{query}}(m')$ is the elapsed time measured at the previous node m' and is piggybacked on the query packet disseminated by the previous node m'. The previous node m' can measure $t_{\text{query}}(m')$ as follows:

$$t_{\text{elapsed}}(m') = t_{\text{departure}} + t_{\text{transDelay}} - t_{\text{arrival}} \tag{6}$$

where t_{arrival} is the time when the previous node m' receives the last bit of the query packet from its previous node, and is tagged by its MAC-layer. $t_{\text{departure}}$ is the time when the previous node m' disseminates the first bit of the query packet by the physical link to the current node m. $t_{\text{transDelay}}$ is the transmission delay of the query packet which can be computed using the transmission rate and the query packet length. The mobile sink disseminates a query packet that has *Query_Dissemination_Time* t_{query} set to 0, and tags its t_{arrival} as the time that it generates its query packet, because it does not receive the query packet. Every grid head received the query packet calculates its t_{query} and disseminates it updated with its t_{query} to its all neighbor grid heads.

Second, the *Sink_Arrival_Time* means each time that the sink arrives at each grid cell in the *Moving_Grid_Cells* field of the query, which is calculated in Section III-B. As shown in Fig. 4, the *Sink_Arrival_Time* at B is t_b and the *Sink_Arrival_Time* at C is $t_b + t_c$. The source can calculate them through the $Current\_Grid\_Cell$, the $Sink\_Speed$, and the $Moving\_Gird\_Cells$ field in the query.

Third, the *Data_Dissemination_Time* t_{data_i} means the elapsed time that the data of the source is propagated from the source to the data collection grid cell i. However, the source can not know the t_{data_i} from its grid cell to the data collection grid cell i. So, in order to derive the t_{data_i}, the proposed protocol uses a forwarding time t_{1_hop} for one hop communication. The t_{1_hop} is calculated by using the *Query_Dissemination_Time* t_{query} and hop counts from the sink to the source. Since the proposed protocol exploits a virtual grid, the source can calculate the hop counts from the sink to its grid cell through its grid cell ID and the *Current_Grid_Cell* field in the query. Here, in order to calculate the t_{1_hop}, the proposed protocol assumes that every t_{1_hop} for one hop communication with all neighborhood grid heads is equal in every grid head. Accordingly, the t_{1_hop} can be calculated by dividing the *Query_Dissemination_Time* t_{query} into the hop counts. So, the source can get the *Data_Dissemination_Time* t_{data_i} through multiplying the t_{1_hop} by hop counts from its grid cell ID to the data collection grid cell ID.

As shown in Fig. 4, the source can determine a data collection grid cell to forward its data by using the three timing values obtained through the methods mentioned above. The data collection grid cell is the one where the data of the source can arrive earlier than the mobile sink. Fig. 5 shows an algorithm for determining that data collection grid cell, where t is the time that the

```
Algorithm Data_Dissemination($t$)
1   if($t$ > Query_Duration)
2       then source does not disseminate data
3   else
4       for($B \le i \le N$) {
5           if ($\sum_{j=B}^{i} t_j < t + t_{query} + t_{data\_i}$)
6               then source disseminates data to $i$
7                   or nearest data collection grid after $i$
9               break;
8           else if ($i$==$N$)
10              then source does not disseminate data
11          else
12              $i$ = next data collection grid
13      }
```

Fig. 5. The algorithm that a source calculates a data collection grid to where it disseminates its data.

source perceives an event and then generates data after receiving the query.

At 6 line in Fig. 5, the source disseminates its data to the data collection grid cell i or nearest data collection grid cell from its grid cell after i. What the source disseminates its data to i is dependent on the real time delivery and what the source disseminates its data to nearest data collection grid cell after i is dependent on the energy saving. The two methods are interchanged according to the actual application of the wireless sensor network.

C. Data Acquirement

After the mobile sink disseminates a query, it keeps on moving along a sequence of grid cells, specified in the *Moving_Grid_Cells* field of the query and determined through the sink mobility model. If the sink arrives at a data collection grid cell, it requests and receives the collected data from the grid head through one hop communication as shown in Fig. 3(c).

While moving along the sequence of grid cells, it is possible that the sink cannot move to some data collection grid cells due to various reasons. In this case, the sink acquires the collected data through multi-hop communications in the current location as shown in Fig. 3(c). Here, the number of data collection grid cells which are not visited represents the accuracy of our mechanism for predicting the next movement path of the sink. We evaluate the performance of the proposed protocol for various accuracies through a simulation in Section V.

D. Overtime Data Dissemination

In Section IV-B, we have described how the sources send their data to data collection grid cells. However, it is possible that the data arrive later than data acquirement by the mobile sink due to delay of propagation time. In this paper, this data is referred to as '***overtime data***.' We introduce a simple scheme to disseminate the overtime data to the sink. We implement the scheme by using the *Moving_Grid_Cells* field of the query.

The grid head in the data collection grid cell forwards the overtime data toward the next data collection grid cell. As a result, a destination direction of the overtime data and the moving direction of the sink become identical. Because the propagation delay of the overtime data may be relatively small and can be shorter than movement time of the sink, the overtime data may reach the sink quickly through few hops. If the moving direction of the overtime data is different from that of the sink, the overtime data can reach the next data collection grid cell. Then, if the sink does not acquire data from the grid head of that grid cell, the grid head stores the overtime data together with the data of other sources in its buffer and delivers the overtime data to the sink when the sink requires data. However, if the grid head has already delivered the data to the sink, the grid head forwards the overtime data to next data collection grid cell, in the manner described above.

E. Multiple Mobile Sinks

The proposed protocol can also support multiple mobile sinks. If another sink acquires data from sensor field, the considered sink inquires of the grid head in current located grid cell whether other sinks disseminated the same query with its query. If the same query is already disseminated in sensor field, the sink obtains location information (grid cell IDs) of the data collection grid cells from the grid head. Thus, the sink moves to the data collection grid cells and acquires data via one hop communication from each grid head of the data collection grid cells. If the sink can not move to the data collection grid cells, the sink requires data to each grid head of the data collection grid cells and acquires the data via multi-hop communication.

F. Multiple and Dynamic Data Collection Grid Cells

Grid cell IDs of the *Moving_Grid_Cells* field in a query refers to the data collection grid cell IDs. The proposed protocol is able to have multiple data collection grid cells if the *Moving_Grid_Cells* during next movement path include various grid cell IDs. The sink contains the *Moving_Grid_Cells* with the various grid cell IDs in a query and disseminates the query to the sensor field. The sink visits the grid cell IDs sequentially and thus acquires data. It is able to solve the hot spot problem, created by a disproportionate amount of traffic to the sensor nodes near a single data collection grid cell [3], [7], [8], [17]. The advantage of having multiple data collection grid cells is verified in our earlier paper [3] and is also one of advantages of the proposed protocol.

The proposed protocol is able to diversify the data collection grid cells because the *Moving_Grid_Cells* for the next movement path is different in each query. That is, sequence of data collection grid cells changes dynamically in each query. Since the sequence of data collection grid cells is dynamically selected at each grid cell based on a movement path of the sink, the energy consumption is distributed across the whole network and hence the network lifetime is prolonged. The advantage of having dynamic data collection grid cells is verified in our paper [7]. This is also one of advantages of the proposed protocol.

V. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed protocol through simulations. We first describe our simulation model and performance evaluation metrics. To evaluate the performance of the proposed protocol, we compare it to two protocols, the well known TTDD [2] protocol for mobile sinks and the EEDD [6] protocol, which is more efficient than TTDD by using diagonal-first routing path.

A. Simulation Model and Performance Evaluation Metrics

We have implemented the proposed protocol in the Qualnet ver. 3.8 [33]. In the simulation, the sensor network consists of 1000 sensor nodes, which are uniformly deployed in a 1000 m × 1000 m field. The energy model of the sensor nodes is applied in reference to the MICA specification [34]. All sensor nodes have the same energy, and their transmitting/receiving power consumption rate is 42 mW and 29 mW, respectively. Their transmission rang R is 150 m. And a grid cell size is set to 50 m × 50m to make sure that it is less than $1/2\sqrt{2}\cdot R$. In other words, the grid cell size ensures that provides that each sensor node in a grid cell can communicate directly with all sensor nodes in its neighbor grid cells. Only one sensor node in each grid cell becomes the grid head based on GAF protocol [29]. The grid head that has exhausted its energy is changed into another sensor node from the same grid cell. The number of sinks is one and the default speed of the sink is set to 10 m/sec. We use random waypoint mobility model with a movement position file, in which the sink moves toward the destination via positions that are reflecting random movement. The random movement with position file is provided in the Qualnet ver. 3.8. The next movement path of the mobile sink is predicted by the mechanism proposed in the Section III-B. The sink disseminates the query in an interval of 50 second and all grid heads receive the query. Five sensor nodes among them are selected randomly as sources and generate only one sensing data for the query. The simulation lasts for 1000 seconds. Simulation results are average values obtained through simulations with other seeds of 50.

We use three metrics to evaluate the performance of the proposed protocol. ***The number of living sensor nodes*** are defined as the number of sensor nodes which can become active state because the energy remains. ***The energy consumption*** is defined as the communication (transmitting and receiving) energy the network consumes. ***The data delivery ratio*** is the ratio of the number of successfully received reports at the sink to the total number of reports generated by each sensor node.

B. Performance Evaluation for Simulation Time

Fig. 6(a) shows the number of living sensor nodes during the simulation time. If the movement location of the sink is different from the data collection place, TTDD requests additional paths and communications within a grid cell or local flooding out of the grid cell and EEDD requests additional paths and communications through grid heads. The energy consumptions of sensor nodes are increased in both TTDD and EEDD. As a result, dead sensor nodes are quickly generated and their number of dead sensor nodes increases rapidly over time. But, the proposed protocol does not need additional paths and communications in accordance with the movement of the sink, because the movement location of the sink is same with the data collection grid cell. As a result, the energy consumption of sensor nodes decreases. The energy consumption of the sensor nodes in the proposed protocol is more evenly distributed because the proposed protocol solves the hotspot problem due to addition of data collection grid cells. Therefore, generation of dead sensor nodes is slower.

Fig. 6(b) shows the data delivery ratio. Both TTDD and EEDD must create additional paths from a data collection place according to the movement of the sink. Hence, in both TTDD and EEDD, data from the source are delivered to the final destination of the sink via the paths passing along the data collection grid cells. Therefore, it decreases the data delivery ratio due to communications through more sensor nodes because wireless sensor networks generate many data failures due to the low quality of wireless technology. On the other hand, the proposed protocol does not make data detour and delivers data to the sink because each data collection grid cell is the moving grid cell for the sink. Hence, the data delivery ratio increases because the data are delivered via communications through fewer sensor nodes.

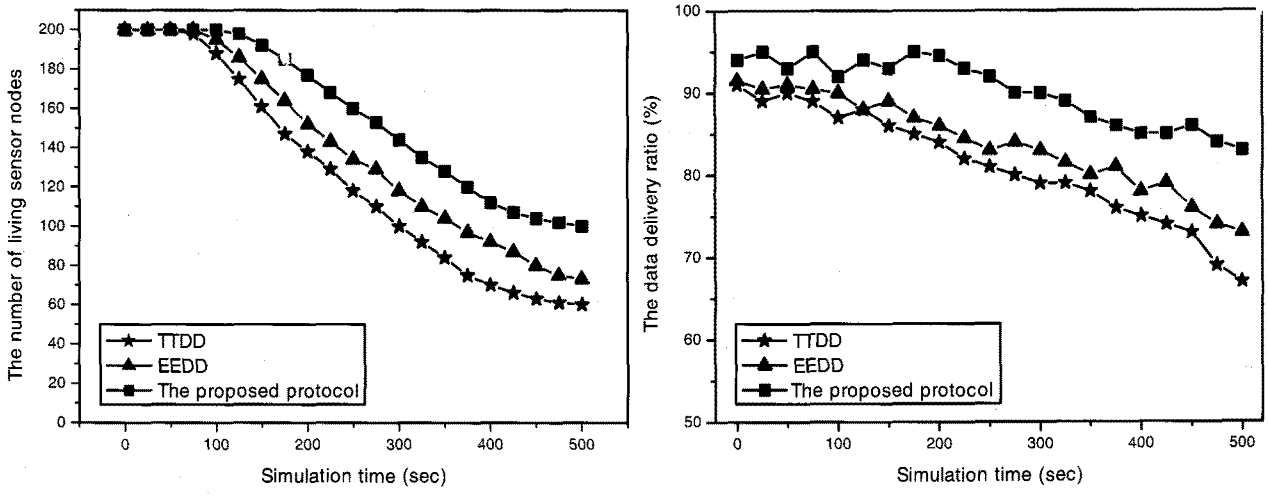
C. Performance Evaluation for the Number of Sources and Data Collection Grid Cells

Fig. 7(a) shows the energy consumption for the number of sources and data collection grid cells (DCGC). The number of sources varies from 2 to 20 and the number of data collection grid cells (DCGC) varies from 2 to 10 in the proposed protocol. If the number of sources increases, the energy consumption increases in all TTDD, EEDD, and the proposed protocol because the sensor nodes must disseminate data from many sources. But, the proposed protocol has a slowly increasing energy consumption if the number of data collection grid cells increases. This is because the sources deliver data to the nearest data collection grid cells through short-hops communication if the number of data collection grid cells increases.

Fig. 7(b) shows the data delivery ratio for the number of sources and data collection grid cells (DCGC). The data delivery ratio decreases in all TTDD, EEDD, and the proposed protocol if the number of sources increases. This is because the increase of the number of sources causes the hot spot problem. However, the proposed protocol decreases slowly the data delivery ratio if the number of data collection grid cells increases. This is because the sources deliver data to the nearest data collection grid cell from their own grid cells through short-hops communication, in case the number of data collection grid cells increases. The proposed protocol also solves the hot spot problem because the data collection grid cells are decentralized.

D. Performance Evaluation for Accuracy of Predicting Next Movement Path

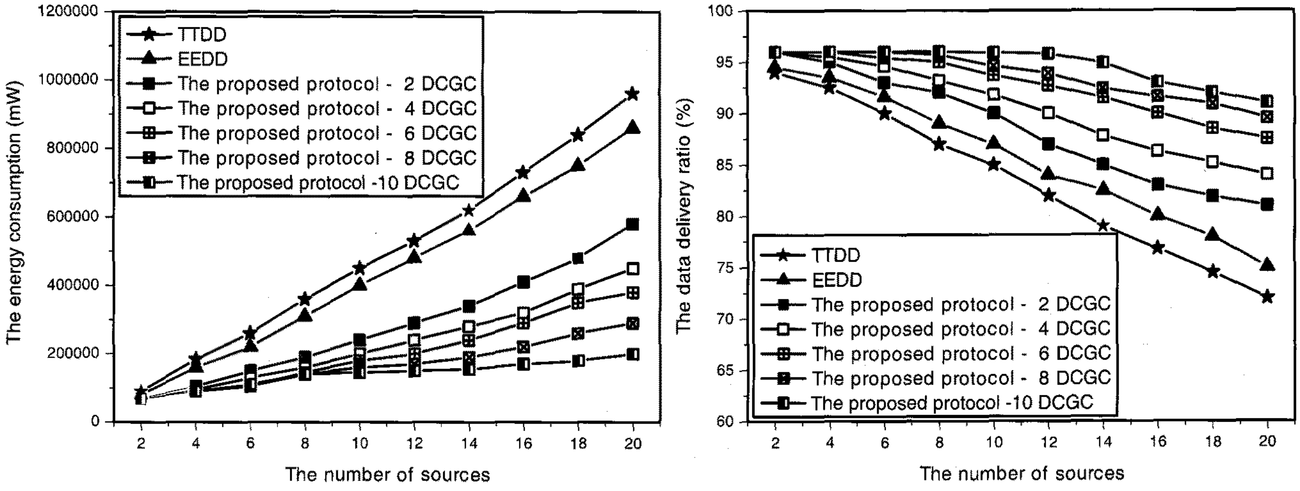
Figs. 8(a) and 8(b) show the energy consumption and the data delivery ratio versus the accuracy of predicting next movement path of a mobile sink. The accuracy is derived as the average angle that in each time slot, the real moving grid cell IDs from time T_0 deviates from the predicted moving IDs from the time T_0 through the sink mobility model. When the angle is 0 degrees, the accuracy is 100 percent and for an angle of 90 degrees,



(a)

(b)

Fig. 6. Performance evaluation for simulation time: (a) The number of living sensor nodes and (b) the data delivery ratio.



(a)

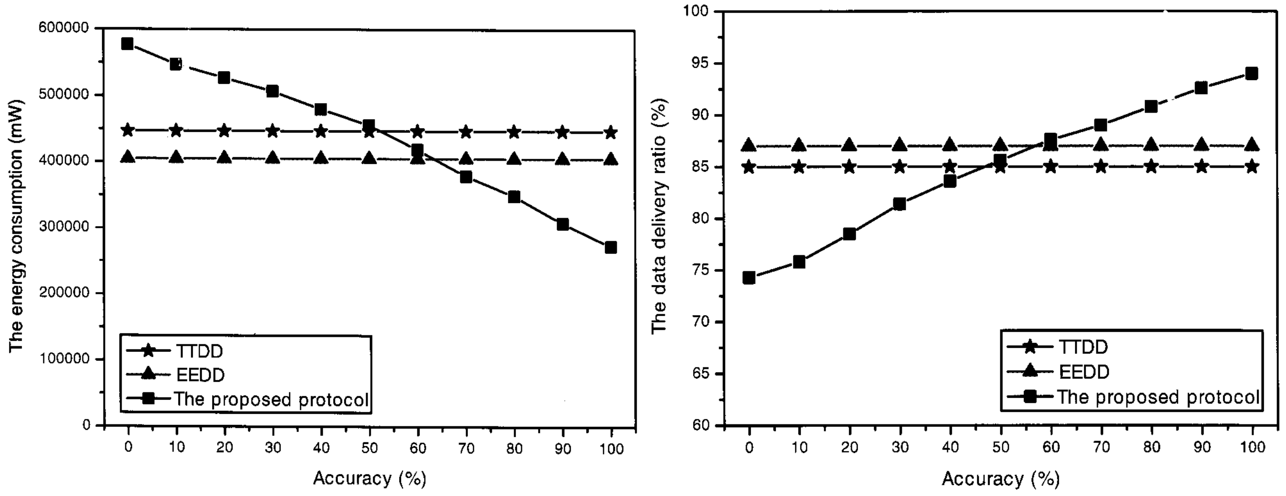
(b)

Fig. 7. Performance evaluation for the number of sources and data collection grids: (a) The energy consumption and (b) the data delivery ratio.

the accuracy is 0 percent. In the sink mobility model considered in this paper, when moving toward the destination, the mobile sink does not move along a straight line to the destination, but randomly deviates within the half plane towards the destination and does not move to the opposite direction of the destination. For accuracy of 100 percent, the proposed protocol decreases the energy consumption and increases the data delivery ratio because the mobile sink receives data from each data collection grid cell through one hop communication. However, if the accuracy goes down, the proposed protocol increases the energy consumption and decrease the data delivery ratio because the mobile sink requests and receives data through multiple hops communication in each grid cell far away from each data collection grid cell. Nevertheless, if the accuracy of our sink mobility model is higher than 55 percent and 65 percent, respectively, the proposed protocol is better than TTDD and EEDD in terms with the energy consumption, respectively, and if the accuracy of our sink mobility model is higher than 50 percent and 60 percent, respectively, the proposed protocol is better than TTDD and EEDD in terms of the data delivery ratio, respectively. In other words, if an accuracy of our sink movement prediction mechanism is higher than 65 percent, the proposed protocol has better performance in terms of energy consumption and the data delivery ratio than TTDD and EEDD. Accuracy of 65 percent means that the mobile sink moves within 31.5 degree of right and left from the predicted movement path.

E. Performance Evaluation for the Sink Speed

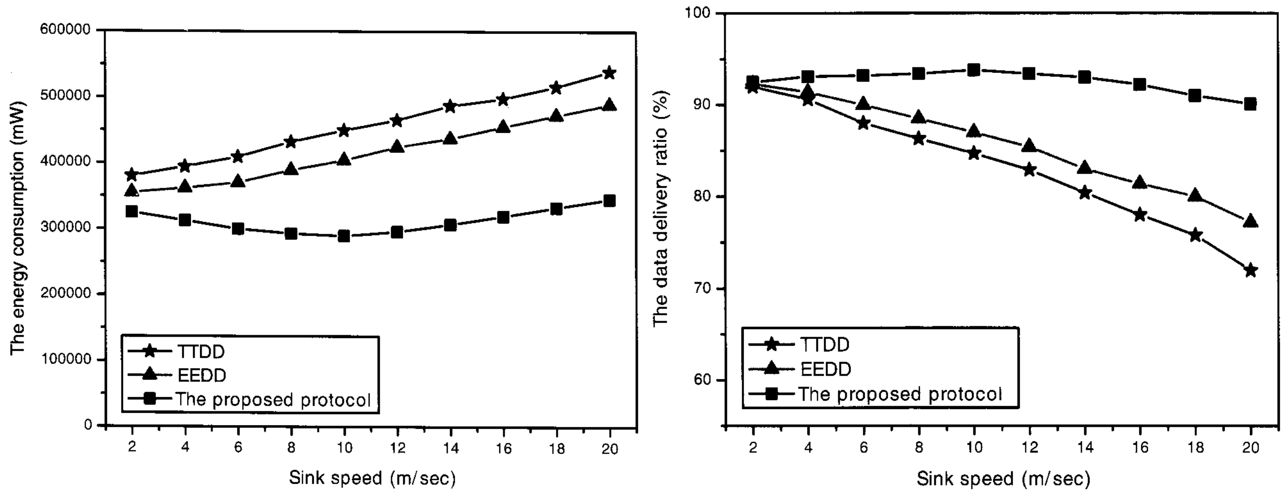
Fig. 9(a) shows the energy consumption versus the sink speed. If the sink speed increases, both TTDD and EEDD need more paths from the sensor node according to movement of the sink and do more communications to receive the data. As a result, their energy consumption increases with the sink speed. However, if the sink speed increases, the energy consumption of the proposed protocol decreases slowly before the speed of 10 m/sec and increases slowly after the speed of 10 m/sec. This is because the proposed protocol increases the number of data collection grid cells in the calculated *Moving_Grid_Cells* field of the query due to the increase of the sink speed. If the number



(a)

(b)

Fig. 8. Performance evaluation for accuracy of sink movement prediction: (a) The energy consumption and (b) the data delivery ratio.



(a)

(b)

Fig. 9. Performance evaluation for sink speed: (a) The energy consumption and (b) the data delivery ratio.

of data collection grid cells increases, the energy consumption reduces because the sources disseminate their data to the nearest data collection grid cell. However, if the number of data collection grid cells is relatively large with respect to the number of source nodes, the data collection grid cells which do not collect data from sources occur more often and hence the sink requires unnecessarily data from the data collection grid cells.

Fig. 9(b) shows the data delivery ratio for sink speed. If the sink speed increases, both TTDD and EEDD need more paths from the sensor node according to the movement of the sink and require more communication to receive data through the paths. As a result, their data delivery ratio decreases with the sink speed because communications through more hop counts are subject to more transmission failures. However, although the sink speed increases, the proposed protocol increases only the number of data collection grid cells and there is no change in the data delivery ratio. This is because the data collected in the data collection grid cells are delivered to the mobile sink through one hop communications.

VI. CONCLUSION

In this paper, we have introduced the model of random mobility with destinations, followed by a mobile sink that has specific destinations for its task rather than wandering randomly without any destination. We also propose a new protocol for supporting mobile sinks that move according to the model of random mobility with destinations. The proposed protocol allows the source nodes to forward their data towards the next movement path of a mobile sink. However, a mobile sink in the random mobility with destinations does move not along the predefined path, but rather randomly toward the destinations. Thus, we first propose a mechanism for predicting the next movement path of the mobile sink based on its previous movement path, current location, speed, and geographical features. With the information of next movement path included in the query, we present a mechanism by which the source nodes send their data on the next movement path before arriving at the mobile sink. Last, we present mechanisms for compensating the difference between the next movement path and the real movement path , as well as for relaying the data that arrives later than the mobile sink at the next movement path. The simulation results show that the proposed protocol has better performance in terms of the energy consumption and the data delivery ratio compared to the the existing protocols.

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," *IEEE Commun. Mag.*, pp. 102–114, Aug. 2002.

[2] H. Luo, F. Ye, J. Cheng, S. Lu, and L.Zhang, "TTDD: Two-tier data dissemination in large-scale wireless sensor networks," in *Proc. ACM MOBICOM*, Sept. 2002.

[3] E. Lee, Y. Choi, S. Park, D. Lee, and S. H. Kim, "A novel mechanism to support mobility of users in wireless sensor networks based on multiple static sinks," in *Proc, IEEE CCNC*. Jan. 2007.

[4] H. Kim, T. Abdelzaher, and W. Kwon, "Minimum-energy asynchronous dissemination to mobile sinks in wireless sensor networks," in *Proc. ACM SenSys*, Nov. 2003.

[5] A. Visvannathan, J. Youn, and J. Deogun, "Hierarchical data dissemination scheme for large scale sensor networks," in *Proc. IEEE ICC*, May 2005.

[6] Z. Zhou, X. Xiang, and X. Wang, "An energy-efficient data-dissemination protocol in wireless sensor networks," in *Proc. IEEE WoWMoM*, Jun. 2006.

[7] S. Park, D. Lee, E. Lee, Y. Choi, and S. H. Kim, "A communication architecture to reflect user mobility issue in wireless sensor fields," in *Proc. IEEE WCNC*, Mar. 2007.

[8] S. Gandham, M. Dawande, R. Prakash, and S. Venkatesan, "Energy efficient schemes for wireless sensor networks with multiple mobile base stations," in *Proc. IEEE GLOBECOM*, Dec. 2003.

[9] J. Luo and J.-P. Hubaux, "Joint mobility and routing for lifetime elongation in wireless sensor networks," in *Proc. IEEE INFOCOM*, Mar. 2005.

[10] R. Shah, S. Roy, S. Jain, and W. Brunette, "Data MULEs: Modeling and analysis of a three-tier architecture for sparse sensor networks," *Ad Hoc Networks* 1, pp. 215–233, 2003.

[11] J. Luo, J. Panchard, M. Piorkowski, M. Grossglauser, and J. Hubaux, "MobiRoute: Routing toward a Mobile Sink for Improving Lifetime in Sensor Netowrks," in *Proc. IEEE/ACM DCOSS*, Jun. 2006.

[12] G. Wang, T. Wang, W. Jia, M. Guo, H. Chen, and M. Guizani, "Local update-based routing protocol in wireless sensor networks with mobile sinks," in *Proc. IEEE ICC*, Jun. 2007.

[13] A. Chakrabarti, A. Sabharwal, and B. Aazhang, "Using predictable observer mobility for power efficient design of sensor networks," in *Proc. ACM/IEEE IPSN*, Apr. 2003.

[14] A. Kansal, A. Somasundara, D. Jea, M. Srivastava, and D. Estrin, "Intelligent fluid infrastructure for embedded networks," in *Proc. ACM MobiSys*, Jun. 2004.

[15] G. Xing, T. Wang, W. Jia, and M. Li, "Rendezvous design algorithms for wireless sensor networks with a mobile base station," in *Proc. ACM MOBIHOC*, May 2008.

[16] E. Lee, S. Park, F. Yu, Y. Choi, M. Jin, and S. Kim, "A predictable mobility-based data dissemiantion protocol for wireless sensor netowrks," in *Proc. IEEE AINA*, Mar. 2008.

[17] H. Dai and R. Han, "A node-centric load balancing algorithm for wireless sensor networks," in *Proc. IEEE GLOBECOM*, Dec. 2003.

[18] G. Liu and G. Maguire Jr., "A Class of Mobile Motion Prediction Algorithms for Wireless Mobile Computing and Communications," *ACM/Baltzer MONET*, 1(2), pp.113-121, 1996.

[19] T. Liu, P Bahl, and I. Chlamtac, "Mobility modeling, location tracking, and trajectory prediction in wireless ATM networks," *IEEE J. Sel. Areas Commun.*, vol. 16, no. 6, pp. 922–936, Aug. 1998.

[20] D. Levine, I. Akyildiz, and M. Naghshineh, "A resource estimation and call admission algorithm for wireless multimedia networks using the shadow cluster concept," *IEEE/ACM Trans. Netw.*, vol. 5, no. 1, pp. 1–12, Feb. 1997.

[21] F. Yu and V. Leung, "Mobility-based predictive call admission control and bandwidth reservation in wireless cellular networks," *Comput. Netw.* vol. 38, pp. 577–589, 2002.

[22] J. Jannink, D. Lam, N. Shivakumar, J. Widom and D. Cox, "Efficient and flexible location management techniques for wireless communication system," *ACM/Baltzer Wireless Netw.*, vol. 3, no. 5, pp. 361–374, 1997.

[23] A. Bhattacharya and S. Das, "LeZi-update: An information-theoretic approach to track mobile users in PCS networks," in *Proc. ACM MOBICOM*, Aug. 1999.

[24] Y.-B. Ko and N. H. Vaidya, "Location-aided routing (LAR) in mobile ad hoc networks," *ACM/Baltzer Wireless Netw.*, vol. 6, no. 4, pp. 307–321, 2000.

[25] S. Chakraborty, Y. Dong, D. Yau, and J. Lui, "On the effectiveness of movement prediction to reduce energy consumption in wireless communication," *IEEE Trans. Mobile Comput.*, vol. 5, no. 5, pp. 157-169, Feb. 2006.

[26] S. Basagni, I. Chlamtac, V. Syrotiuk, and B. Woodward, "A distance routing effect algorithm for mobility (Dream)," in *Proc. ACM MOBICOM*, Oct. 1998.

[27] K. Feng, C. Hsu, and T. Lu, "Velocity-assisted predictive mobility and location-aware routing protocols for mobile ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 57, no. 1, pp. 448–464, Jan. 2008.

[28] B. Karp and H. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks," in *Proc. ACM MOBICOM*, Aug. 2000

[29] Y. Xu, J. Heidemann, and D. Estrin, "Geography-informed energy conservation for ad hoc routing," in *Proc. ACM MOBICOM*, Jul. 2001.

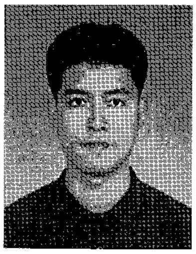
[30] N. Bulusu, J. Heidemann, and D. Estrin, "Gps-less low cost outdoor localization for very small devices," *IEEE Pers. Commun. Mag,*, vol. 7, no. 5, pp. 28–34, Oct. 2000.

[31] J. Albowicz, A. Chen, and L. Zhang, "Recursive position estimation in sensor networks," in *Proc. IEEE ICNP*, Nov. 2001.

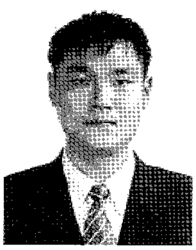
[32] E. Felemban, C. Lee, and E. Ekici, "MMSPEED: Multipath multi-speed protocol for QoS guarantee of reliability and timeliness in wireless sensor networks," *IEEE Trans. Mobile Comput.*, vol. 5, no. 6, pp. 738–754, Jun. 2006.

[33] Scalable Network Technologies, Qualnet. [Online] Available: http://www.scalable-networks.com

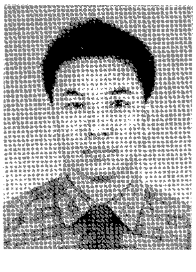
[34] J. Polastre, R. Szewczyk, and D. Culler, "Telos: Enabling ultra-low power wireless research," in *Proc. ACM/IEEE IPSN*, Apr. 2005.



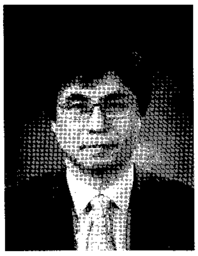
Euisin Lee received the B.S. degree in computer science and engineering and the M.S. degree in computer engineering from the Chungnam National University, Daejeon, Korea, in 2005 and 2007, respectively. Since 2007, he has been pursuing the Ph.D. degree in computer engineering at the Chungnam National University. His research interests are in the areas of computer communication and networking. He is mainly intrested in mobility management in IPv4 and IPv6 including host-based and network-based, and routing, mobility management, multicast, QoS, geographic routing,and location service in Mobile Ad hoc Networks (MANETs) and Wireless Sensor Networks (WSNs). He is Student Member of ACM, IEEE Communications Society, and IEEE Computer Society, and Member of KICS.



Soochang Park received the B.S. degree in computer science and engineering and the M.S. degree in computer engineering from the Chungnam National University, Daejeon, Korea, in 2005 and 2007 respectively. Since 2007, he has been pursuing the Ph.D. degree in computer engineering at the Chungnam National University. His research interests are in the areas of computer communication and networking. He is mainly intrested in IP routing with AS level configuration, mobility management in IPv4 and IPv6 including host-based and network-based, and routing, mobility management, and QoS in Mobile Ad hoc Networks (MANETs) and Wireless Sensor Networks (WSNs). He is Student Member of ACM, IEEE Communications Society, and IEEE Computer Society, and Member of KICS.



Fucai Yu received the B.S degree in communication engineering from Lanzhou Jiaotong University, Lanzhou, China, in 1999 and M.S degree in computer science from Chungnam National University, Daejeon, Korea, in 2006. He is currently a Ph.D. candidate of computer science of Chungnam National University. His current research interests include routing for MANET and sensor networks. He is Student Member of IEEE Communications Society and IEEE Computer Society, and Member of KICS.



Sang-Ha Kim received the B.S. degree in chemistry from Seoul National University, Seoul, Korea, in 1980. He received the M.S. and Ph.D. degrees in quantum scattering and computer science from University of Houston, Houston, TX, in 1984 and 1989, respectively. From 1990 to 1991, he was with the Supercomputing Center, SERI, Korean Institute of Science and Technology (KIST) as Senior Researcher. He joined Chungnam National University, Daejeon, Korea, as a Professor in 1992. His current research interests include wireless networks, QoS, optical networks, and network analysis. Dr. Kim is Member of ACM, IEEE Communications Society, IEEE Computer Society, and KICS.