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# Efficient Context-Aware Scheme for Sensor Network in Ubiquitous Devices

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## ABSTRACT

Many sensor network applications have been developed for smart home, disaster management, and a wide range of other applications. These applications, however, generally assume a fixed base station as well as fixed sensor nodes. Previous research on sensor networks mainly focused on efficient transmission of data from sensors to fixed sink nodes. Recently there has been active research on mobile sink nodes, sink mobility is one of the most comprehensive trends for information gathering in sensor networks, but the research of an environment where both fixed sink nodes and mobile sinks are present at the same time is rather scarce. This paper proposes a scheme for context-aware by ubiquitous devices with the sink functionality added through fixed sinks under a previously-built, cluster-based multi-hop sensor network environment. To this end, clustering of mobile devices were done based on the fixed sinks of a previously-built sensor network, and by using appropriate fixed sinks, context gathering was made possible. By mathematical comparison with TTDD routing protocol, which was proposed for mobile sinks, it was confirmed that performance increases by average 50% in energy with the number of mobile sinks, and with the number of movements by mobile devices.


**Key words:** Wireless sensor network, Mobile sink, Context gathering

## 1. INTRODUCTION

Wireless sensor networks constitute an emerging technology that has received recently a significant attention both from industry and academia. A sensor network, which is one of the core techniques of the ubiquitous environment, is composed of a number of performance-limited sensor nodes and sink nodes which gather the data sensed by the sensor nodes [1]. Sensor networks were developed as a way to gather and process data in many different environments, and they are used for the military, environmental observation, and for industrial purposes. Because the sensor nodes of sensor networks have limited resources, most of research focused on energy efficiency of context gathering [2]. Furthermore, most of research was done with fixed locations of sink nodes that collect sensed information. However, recently there has been active research on sink nodes that are mobile [3]. If sink nodes are made mobile, then even more practical applications are possible for a sensor network.

Recently there has been various research on the applications, which would make our lives safer and more convenient using the data gathered by sensors [4,5]. In the ubiquitous environment of the future, many new mobile devices will be developed, and location-sensitive information acquisition using them will be made commonplace. Furthermore,

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desire for context-aware service for the improvement of the quality of life that is tailored for each user will increase, and various kinds of information such as information from devices, dispositions and emotions of consumers, and environmental information will be required for the purpose [6]. Such kinds of information and context can be gathered by using sensor networks.

In the future, sensor networks of various purposes will coexist together. Mobile devices recognize specific sensor networks in the area while on the move, role as sink nodes, and gather context easily. In order to realize this, research of sensor networks where fixed sinks and mobile sinks coexist is needed. However there hasn't been much research.

This paper proposes a scheme for context-aware by mobile devices with the sink functionality added, using a sensor network infrastructure that has already been built for various purposes. This paper proposes a mobile device-tier architecture scheme, in which when a mobile device moves into a specific sensor network region, the mobile device finds and selects a nearby fixed sink. Then, context is gathered through the selected fixed sink. In the section 2, a data routing protocol for mobile sinks is studied. In the section 3, the three-tier context-aware scheme for ubiquitous devices is proposed. In the section 4, the performance of the proposed scheme is evaluated for energy efficiency. Lastly, the section 5 states the conclusions.

## 2. A TWO-TIER DATA DISSEMINATION MODEL FOR LARGE-SCALE WIRELESS SENSOR NETWORK

In recent years, many researches have been conducted on routing protocols in WSN [7-17]. Several researchers have shown that moving the sink can balance energy consumption among sensor nodes, thereby prolonging the network lifetime. There are protocols such as Directed Diffusion [18], Declarative Routing Protocol, GRAB [19], however a mobile sink node has to continuously transmit its location to all of sensor nodes; and the sensor nodes, after getting the location information transmitted from the sink node, when there is data to be sent to the sink node, they can decide upon data transfer direction. However the frequent location updates made by many mobile sink nodes waste not only the batteries of sensor nodes, but also a lot of bandwidth of the wireless communication channel. This kind of sink-node-oriented data transfer method is not suitable as a routing protocol for a large-scale sensor network that has many mobile sink nodes. In order to resolve the problem with mobile sink nodes, a two-tier data dissemination approach (TTDD) was proposed [14].

### 2.1 Two-Tier Data Dissemination Routing

Tow-tier Data Dissemination in Large-scale Wireless Sensor Networks (TTDD) [14] suggests that a node sensing events becomes a source node and sends information to several mobile sinks. In TTDD routing protocol, when an event of interest happens, a source node spontaneously makes grids in order to transmit data to a mobile sink node. In each of intersection points of the grids, there exists a dissemination node that has forwarding information. TTDD uses a two-tier system when transmitting data. Transfer in the lower-tier is used for regional communication within a cell, and the transfer in the higher-tier is used for communication between cells. In order to receive data, a mobile sink node floods a cell with data request packets. Once a dissemination node receives a request packet, it retransmits the packet to the upstream dissemination node. The data request packet ultimately is transmitted to the source node. The source node transmits data in the direction opposite to the route of the request packet. The operative process of TTDD is composed of grid construction, two-tier query and data forwarding.

2.1.1 Grid Construction

When an event of interest happens, a source node spontaneously creates a αxα grid with it as the core. In order for the creation of a grid, a source node transmits a data announcement packet to each of the dissemination points of the grid. The sensor node closest to the dissemination point that received the data announcement packet becomes a dissemination node, and the upstream node that sent the message saves the location of its neighbor dissemination node. The dissemination node selects a neighbor dissemination node using the same method employed by a source node, and with repetition of this process, ultimately a grid is constructed for the entire area of a sensor field.

2.1.2 Two-tier Query Data Forwarding

Every time a mobile sink, which needs sense information, is moved, it floods with queries closest sensor nodes in the area that include a dissemination node.

When an immediate dissemination node, which is located in the interior of a local cell, receives a query, it forwards the query to neighboring dissemination nodes which received a data announcement message. Each dissemination node saves the location of the neighbor dissemination node from downstream which sent the query, and with that, two-way channel towards the source is established. When a source node receives a query, it transmits sensed information to neighbor dissemination node from downstream which sent the query. By repetition of this process, sense information is transmitted even to the dissemination node inside the local cell of the mobile sink node that made the query.

In TTDD, a grid structure is constructed every time a sensor node senses current state. The number of control packets, which are used in the construction of the grid structure, is about the same as the number of packets being flooded with for the entire sensor network. If an event of interest happens frequently at many places, then the protocol can't be considered to be an energy-efficient routing protocol.

## 3. EFFICIENT CONTEXT-AWARE SCHEME FOR UBIQUITOUS DEVICES

This section proposes an efficient context-aware scheme for for ubiquitous (or mobile) devices with sink functionality (henceforth as mobile sinks). The efficient context-aware scheme (henceforth as ECAS) allows mobile sinks to make the mobile device tier(see Figure 1), and allows for context to be gathered using a fixed sink. When a mobile sink move around a sensor network region that was constructed for a specific purpose, the fixed sink node which was gathering information in the field is found and a cluster region that has a fixed sink as the core and which is for mobile sinks is entered. The cluster is composed of many different mobile sinks, and they periodically receive fixed sink's announcement messages to verify their location. If the sink's ID is changed, which is in a fixed sink's announcement message, it implies that the mobile sink has moved into a different sink node region. When the fixed sink's announcement message couldn't be transmitted within a period of time, a message can be requested for it. If there is no response even after the announcement request, it implies that the mobile sink has moved beyond the sensor network region, and data can no longer be gathered.

Mobile device tier is constructed for mobile sinks, and Figure 1 shows the process of clustering of mobile sinks with a fixed sink as the core. A mobile sink can request and gather context through a fixed sink. Up to the fixed sink tier of Figure 1, it is a sensor network previously constructed for a particular purpose. A Fixed sink construct a grid, and gathers context from the sensor nodes which are included in the grid, and forwards it up to the

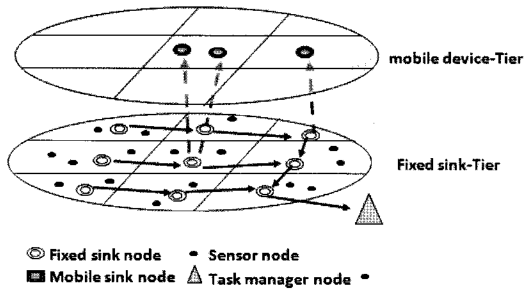


Fig 1. An efficient context-aware scheme for mobile divices through fixed sinks

task manager node. Also, fixed sinks are connected in a tree form that has the task manager node as a root. When a mobile sink is entered, it is clustered in a mobile device tier. The fixed sink provides context to the mobile sink.

### 3.1 Two-Tier Data Dissemination Routing

The proposed mobile sink and sensor network have the following assumptions and requirements.

- Sensor nodes and fixed sinks are not mobile
- The communication between a mobile sink and fixed sink is done in a single hop

#### 3.1.1 Admission into a Cluster

A fixed sink node makes an announcement of its existence periodically for mobile sinks in its area. Also, when it receives a message regarding its existence from mobile sink, it immediately transmits an announcement message. If a mobile sink enters a sensor network region while on the move, then it will receive an announcement message from a fixed sink node. When a mobile sink receives an announcement message from a fixed sink, it realizes that it has entered a sensor network region where context regbe g sensed, and it expects periodic announcement messagesk region weceive an anFixsensmrs , it region while announcement message from a fixed sink as needed. When a mobile sink receives an announcement message from a fixed sink node, it saves the ID of the sink node, and now it enters a cluster that

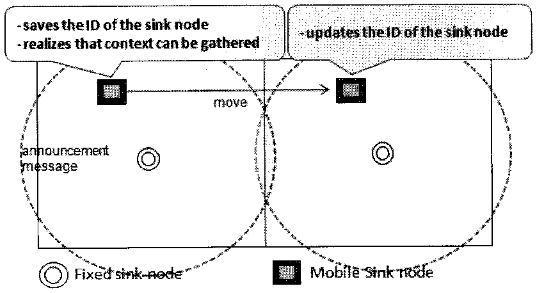


Fig 2. Admission into a Cluster

has the sink node as the core(see Figure 2).

#### 3.1.2 Data Announcement

The sensor node that sensed an interest event in the sensor field becomes a source node. A source node creates data announcement packets and data packets, and transmits them to its associated fixed sink. A data announcement packet is composed of the ID of the associated fixed sink, time of data creation, expiry time for the data and hop-count of the closest dissemination sink node. If many source nodes, which detected the same event of interest, transmit data announcement packets and data packets to a fixed sink, then the fixed sink node merges the data. When a data announcement packet(see Figure 3) and data packet is received by a fixed sink node, it records the node's ID, and forwards them.

##### 3.1.2.1 Transmission of a data packet

The fixed sink($S_2$ in Figure 4) that receives a data packet forwards the data up to the task manager node through an upstream path (in this paper, an upstream path refers to the path from a source node to the task manager node through a routing path, and a downstream path refers to the opposite route). It also forwards the data packet through a downstream path. The fixed sinks in the upstream

| Source sink ID | Data created time | Available time | Dissemination sink node ID | Hop-count |
|---|---|---|---|---|

Fig 3. Data announcement packet

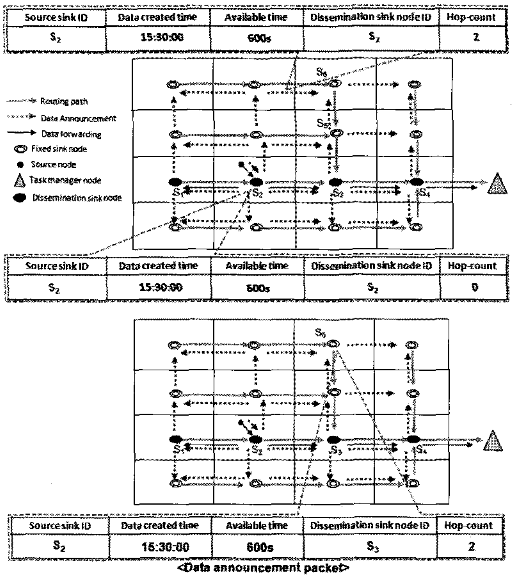


Fig 4. Data announcement

and downstream paths that receive the data packet save the data in their cache until the expiry time is over, and forwards the packet in the appropriate direction. After the process is complete, the fixed sinks on the upstream and downstream path along on the tree($S_1$, $S_2$, $S_3$ and $S_4$ in Figure 4) have all saved the data packet in their cache, and these fixed sinks are collectively known as a dissemination sink node.

3.1.2.2 Transmission of a data announcement packet

The fixed sink that received a data packet($S_2$ in Figure 4) and data announcement packet from a source node transmits a data packet to neighbor fixed sinks which are associated with its own routing path, and immediately transmits data announcement packets to neighboring fixed sinks in the top, down, left, and right directions. When the fixed sink which is not dissemination sink node receives data announcement packets from neighbor fixed sinks, it saves a data announcement packet with smaller value of hop-count field than already saved packet in its cache. The fixed sink increases the value of hop-count field in the packet, and then it transmits the packet to neighbor fixed sinks. The fixed sinks in the sensor field that received announcement packets transmit to its neighboring fixed sinks using the same method as well. The dissemination sink nodes that received data announcement packets record their own ID's in the packet field known as dissemination sink node ID and update in hop-count field as 0, and the packets are transmitted. When this process is complete, the fixed sinks in the sensor field region have received data announcement packets, and they recognize occurrence of an event(see Figure 4 for an illustration). Furthermore, ID of the closest dissemination sink node can be found.

3.1.3 Data Request and Data Forwarding

When there is an event of interest, a mobile sink transmits a data request packet to its fixed sink. The data request packet contains the ID of the fixed sink that was included in the announcement packet(see Figure 5), time of data creation, and ID of a dissemination sink node. Once the fixed sink receives a data request packet, it fills out remaining fields using the ID of self(in this paper, we'll refer to it as destination sink ID) and contents of the data announcement packet that was saved in the cache. Then, it transmits a data request packet to a dissemination sink node.

| Source sink ID | Data created time | Available time | Dissemination sink node ID | Destination sink ID |
|---|---|---|---|---|

Fig 5. Data request packet

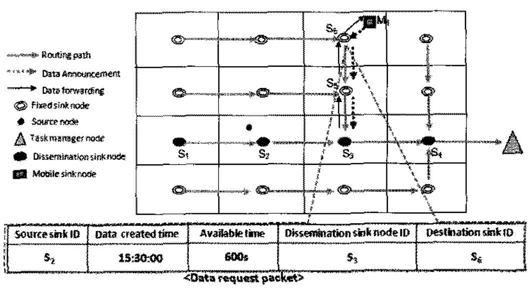


Fig 6. Data request and data forwarding

In Figure 6, the fixed sink $S_6$ transmits a data request packet to $S_3$, which is the closest dissemination sink node. When $S_3$ receives a data request packet, the source sink ID and the time of creation of data are checked against corresponding data in the packet's cache, and if they are the same, and if the data hasn't been expired, then a data packet is transmitted back to $S_6$ and then the mobile sink.

# 4. PERFORMANCE EVALUATIONS

This section evaluates the communication overhead of the proposed efficient context-aware scheme for mobile devices. For the evaluation, an analytical model is defined, and in order to measure the performance of the proposed routing protocol, a comparison is made with another preexisting protocol. In order to simply analyze, the cost for merging of data and query, and the maintenance costs for the routing protocols are not considered.

## 4.1 Evaluation Model and Notations

In this section, the proposed routing protocol ECAS and preexisting routing protocol TTDD are compared. Before the actual analysis, an analysis model is defined first. The analysis model is a sensor network that has width of $A$, uniformly distributed $N$ number of sensor nodes, and about $\frac{d}{m}$ number of sensor nodes on each side. There exists $k$ number of mobile sinks in the sensor network. These mobile sinks pass by $m$ number of cells for $T$ hours at speed of $v$, and they receive $d$ number of data packets from a source node. Therefore the amount of data that a mobile sink can receive while it is on one cell is $\sqrt{N}$ number of data packets. A data packet is of a unit size, and the sizes of a data request packet and data announcement packet are both $l$. In the routing protocols of ECAS and TTDD, a sensor field is divided into cells, of which the length of their sides are $a$. There exists $n(=N\frac{\alpha^2}{A})$ number of sensor nodes in each cell, and the number of sensor nodes that are on one of the sides of a cell can be expressed as $\sqrt{n}$.

## 4.2 Evaluation of Communication Overhead

In this section, the communication overhead from the time of data request made to a source node by a mobile sink, to the time it receives the data is analyzed. In order to simply analyze, the communication overhead used for merging of packets and the cost used in maintaining the grid after its creation are not considered. First, the communication overhead of TTDD is as follows. A mobile sink searches for an immediate dissemination node in order to transmit a data request packet to a source node. To this end, a mobile sink starts to flood a cell with messages, resulting the overhead $nl$. The immediate dissemination node that receives a data request packet transmits the packet up to the source node. The average number of nodes in a straight line from the first sink node to the source node is $c\sqrt{N}(0<c\leq\sqrt{2})$, but because packets are not transmitted in a straight line, a $\sqrt{2}$ must be multiplied

$$nl+\sqrt{2}(c\sqrt{N})l$$

The source node that receives a data request packet transmits the packet up to a mobile sink. The overhead of transmitting a data request packet can be calculated similar to the data request packet delivery process, by $\sqrt{2}(c\sqrt{N})\frac{d}{m}$. The communication cost of TTDD's routing protocol when $k$ number of mobile sinks pass over $m$ number of cells is as follows.

$$km(nl+\sqrt{2}(c\sqrt{N})l+\sqrt{2}(c\sqrt{N})\frac{d}{m})$$
$$=kmnl+kc(ml+d)\sqrt{2N}$$

When the overhead in the creation of a grid $\frac{4N}{\sqrt{n}}l$, is added, the total overhead for TTDD is that of formula (1).

$$CO_{TTDD}=\frac{4N}{\sqrt{n}}l+kmnl+kc(ml+d)\sqrt{2N} \quad (1)$$

Now the communication cost for ECAS will be investigated. The number of fixed sinks in a sensor field is $\frac{N}{n}$, and this corresponds with the number of cells. In other words, for each cell, there exists one fixed sink. A mobile sink transmits a data request packet to the appropriate cell's fixed sink. The farthest distance between a mobile sink and a fixed sink is $\frac{\sqrt{2n}}{2}$, and the average overhead is $\frac{c}{2}\sqrt{n}\,(c<0\leq\sqrt{2})$.

A fixed sink transmits a data request packet up to a dissemination sink node or source sink node. The average overhead that results from this is $c\sqrt{N}-\sqrt{2n}\,(0<c\leq\sqrt{2})$, but because the packet is not sent in a straight line, a $\sqrt{2}$ is multiplied, giving the final formula below.

$$(\frac{c}{2}\sqrt{n})l+\sqrt{2}(c\sqrt{N}-\sqrt{2n})l$$

The dissemination sink node or source sink node that receives a data request packet transmits the packet up to the fixed sink node that requested the data packet, and as the end of the process, the fixed sink transmits to a mobile sink. The overhead that results from this as follows

$$(\frac{c}{2}\sqrt{n})\frac{d}{m}+\sqrt{2}(c\sqrt{N}-\sqrt{2n})\frac{d}{m}$$

The communication cost of ECAS's routing protocol when $k$ number of mobile sinks pass over $m$ number of cells is as follows.

$$(\frac{c}{2}\sqrt{n})l+\sqrt{2}(c\sqrt{N}-\sqrt{2n})l+(\frac{c}{2}\sqrt{n})\frac{d}{m}+\sqrt{2}(c\sqrt{N}-\sqrt{2n})\frac{d}{m}$$
$$=kc(ml+d)\sqrt{2N}+k(c-4)(ml+d)\frac{\sqrt{n}}{2}$$

Formula (2) shows the total overhead result from delivery of data announcement packet is added.

$$CO_{ECAS}=\frac{N}{n}l+kc(ml+d)\sqrt{2N}+k(c-4)(ml+d)\frac{\sqrt{n}}{2} \quad (2)$$

By comparing TTDD's formula (1) and ECAS's formula (2), it can be seen that the overhead of creation of a grid and that of data announcement message delivery has been reduced by $\frac{4n}{\sqrt{n}}$. Furthermore, the number of packets needed for data transmission has been reduced by $k(c-4)(ml+d)\frac{\sqrt{n}}{2}$.

The possible range of $c$ is $(0<c\leq\sqrt{2})$ and accordingly, $(c-4)<0$, so the value of $m(c-4)(ml+d)\frac{\sqrt{n}}{2}$ is always negative. More performance can be expected with the number of mobile sinks and with the number of movements by mobile sinks, when compared with TTDD.

Figure 8 and 9 show the results of TTDD and ECAS when $m$=4 and $m$=16, respectively(The values used are shown in Table 1). The horizontal axis of the graph denotes the number of mobile sinks ($k$). It can be seen that as the number of mobile

Table 1. Values of variable for performance analysis

| $N$ | $n$ | $c$ | $l$ | $d$ |
|---|---|---|---|---|
| 1000 | 100 | 1 | 1 | 100 |

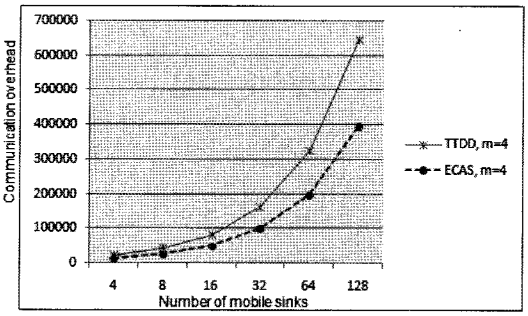


Fig. 8. Communication overhead when the number of movements by a sink node 4, with changing number of sink nodes.

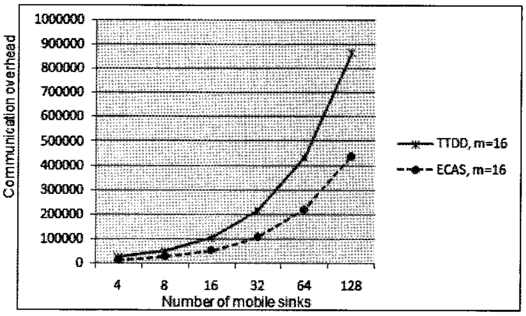


Fig. 9. Communication overhead when the number of movements by a sink node 16, with changing number of sink nodes.

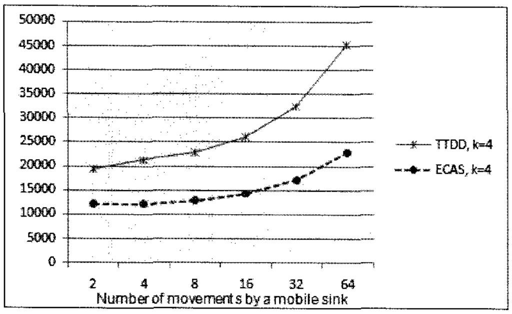


Fig. 10. Communication overhead when the number of mobile sink node 4, with changing number of movement by a sink nodes.

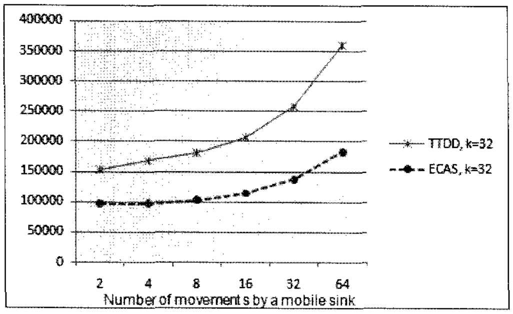


Fig. 11. Communication overhead when the number of mobile sink node 32, with changing number of movement by a sink nodes.

sinks is increased, and as the number of movements by mobile sinks is increased. Figure 10 and 11 show the results of when $k$=4 and $k$=32. The horizontal axis of the graph denotes the number of movements by mobile sinks. It can be seen also that as the number of movements of mobile sinks is increased, and as the number of mobile sinks is increased, ECAS correspondingly shows better performances than TTDD.

## 5. CONCLUSIONS

In this paper the protocol that can be used under mobile sink has been proposed. The proposed protocol is a context-aware scheme for mobile device with sink functionality added. When the mobile device enters a sensor network, it can gather information using a fixed sink. It has been confirmed by comparative mathematical analysis that with increase in the number of mobile devices, and the movements of a mobile device. The performance of the proposed routing protocol increases by average 50% correspondingly, when compared with TTDD routing protocol that supports mobile sinks using the grid concept. However, there exist many limitations because the routing protocol depends on a fixed sink. More research needs to be done in order to make transparent data gathering possible even when the functionality of a fixed sink is dropped.

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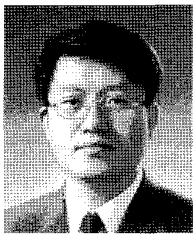

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