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# AOMDV의 특성과 진동 센서를 적용한 이동성과 연결성이 개선된 WSN용 LEACH 프로토콜 연구

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## 요 약

유비쿼터스 서비스의 성장과 함께 여러 종류의 애드 혹 네트워크가 등장하게 되었다. 특히 애드 혹 네트워크에는 무선 센서 네트워크와 모바일 애드 혹 네트워크가 많이 알려져 있는데, 앞서 서술한 두 가지 네트워크의 특성을 혼합한 무선 애드 혹 네트워크도 존재한다. 본 논문은 LEACH 라우팅 프로토콜을 혼합 네트워크 환경에 적합하도록 개선한 변형된 LEACH 프로토콜 제안한다. 즉 제안한 라우팅 프로토콜은 대규모 이동 센서 노드로 구성된 네트워크에서 노드 검출과 경로 탐색 및 경로 유지를 제공하며, 동시에 노드의 이동성, 연결성, 에너지 효율성을 유지할 수 있다. 제안한 라우팅 프로토콜은 멀티-홉(multi-hop) 및 멀티-패스(multi-path) 알고리즘을 적용하고, 토폴로지 재구성 기법으로는 이동 중인 대규모 노드에 대한 노드 이동 평가, 진동 센서, 효율적인 경로 선택과 데이터 전송 기법을 이용하여 구현하였다. 실험에서는 제안한 프로토콜과 기존의 전통적인 LEACH 프로토콜을 비교하여 성능을 나타내었다.


**키워드 : 애드 혹, 모바일, 라우팅 프로토콜, 센서 네트워크, LEACH**

# A Research of LEACH Protocol improved Mobility and Connectivity on WSN using Feature of AOMDV and Vibration Sensor

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## ABSTRACT

As the growth of ubiquitous services, various types of ad hoc networks have emerged. In particular, wireless sensor networks (WSN) and mobile ad hoc networks (MANET) are widely known ad hoc networks, but there are also other kinds of wireless ad hoc networks in which the characteristics of the aforementioned two network types are mixed together. This paper proposes a variant of the Low Energy Adaptive Cluster Hierarchy (LEACH) routing protocol modified to be suitable in such a combined network environment. That is, the proposed routing protocol provides node detection and route discovery/maintenance in a network with a large number of mobile sensor nodes, while preserving node mobility, network connectivity, and energy efficiency. The proposed routing protocol is implemented with a multi-hop multi-path algorithm, a topology reconfiguration technique using node movement estimation and vibration sensors, and an efficient path selection and data transmission technique for a great many moving nodes. In the experiments, the performance of the proposed protocol is demonstrated by comparing it to the conventional LEACH protocol.


**Keywords : Ad hoc, Mobile, Routing Protocol, Sensor Network, LEACH**

## 1. Introduction

In recent years, ubiquitous services that make use of wireless sensor nodes have been developed and used in a variety of domains. An architectural approach to service access for a network environment with sensor nodes is characterized by a lack of established infrastructure. Mobile clients may invoke services by their descriptive names, and a temporary multi-hop ad hoc network is dynamically established between the client and the host offering the requested service. Existing routing protocols for sensor networks usually take stationary sensor nodes for granted, and thus their main interest has been energy efficiency. Nowadays, there are many applications

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exploiting mobile sensor nodes in which traditional fixed node-based routing protocols do not fit very well. For example, node mobility and the new mode of communication must be considered in applications such as environmental pollution surveillance, habitat monitoring, harbor cargo control, sensor network systems using nanotechnologies, etc.

Two well-known wireless ad hoc networks, wireless sensor networks (WSNs) and mobile ad hoc networks (MANETs), exhibit specific characteristics, and routing protocols for those networks are naturally built to take into account such characteristics. Thus, routing protocols for MANETs focus mainly on node mobility and network connectivity, and routing protocols for WSNs seek to minimize energy consumption and to provide node detection and path management for a large number of spatially distributed nodes. Previous routing protocols suited to either WSN or MANET might be effective in their targeted environment, but their effectiveness is limited in a combined environment that requires the properties in both network types — i.e., node mobility, network connectivity, energy efficiency, and large scale node detection.

This paper proposes a routing protocol that takes into account the basic requirements for both WSN and MANET. Existent WSN routing protocol is doing energy efficiency by center network metric and MANET is doing connectivity about node mobility by center metric. But, research for routing protocol that consider two network metric at the same time is lacking real site. In this paper, we consider this point that existent LEACH protocol's centric metric is energy efficiency so we design and proposed additionally routing protocol that consider node mobility and connectivity. To do this, we inserted AOMDV's special feature in LEACH protocol to consider two network metrics, and node movement are notified beforehand to LEACH through use shock sensor in sensor node, did so that network topology renewal and preservation may can quickly. Additionally, achieved an experiment to find suitable Trade-off of two point metrics and reflect the result in proposed protocol.

The proposed protocol detects and manages a large number of mobile sensor nodes and supports node mobility, network connectivity, and energy efficiency at the same time. Basically, the proposed protocol adopts a well-known sensor network protocol called Low Energy Adaptive Cluster Hierarchy (LEACH), so the advantages of energy efficiency and large-scale node management that LEACH already offers can be obtained without any extra effort. The adopted LEACH protocol is complemented by adding techniques that minimize network reconfiguration time and packet flooding in a network with moving nodes. In the proposed protocol, the probability of node movement is mathematically modeled, and events advertising node movement are generated by the vibration and moving speed of a node. The experiment results show that the designed protocol outperforms the standard LEACH protocol in several aspects.

The rest of the paper is organized as follows. Section 2 briefly describes related works, and Section 3 states the techniques adopted in the proposed routing protocol that is a modified version of the standard LEACH protocol. Section 4 describes the experiments performed to evaluate the effectiveness of the proposed protocol by comparing it to the conventional LEACH protocol. Finally, conclusions and future research directions are given in Section 5.

## 2. Related Work

As far as the authors are aware, there is no previous work that develops a routing protocol addressing the features in MANETs and WSNs at the same time. This section thus describes the existing routing protocols for each network type separately.

### 2.1 Sensor network routing protocols

#### 2.1.1 Flat routing protocols [1]

In flat routing protocols, no effort is made to organize the network or its traffic. All routers are considered sitting on a flat geometric plane, and the best route to a destination is discovered hop by hop by any path. Unlike traditional wired networks, in which each node is identified by a unique address (which is used for routing), sensor networks are data centric, i.e., the interest is in "what is the data" rather than "where is the data," so they do not generally require routing between specific nodes. Minimizing the energy consumption to extend the network lifetime has been the main interest of routing protocols in WSNs. Two well-known flat routing protocols are described below.

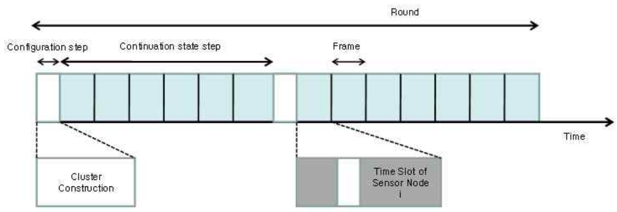
- Directed Diffusion [2]: Directed diffusion is data centric in that all communication is for named data, not named nodes. Query handling is another additional feature (i.e., users should be able to request data from the network). All nodes in a directed diffusion-based network are application-aware. This enables diffusion to achieve energy savings by selecting empirically efficient paths and by caching and processing data in-network (e.g., data aggregation).

- Sensor Protocols for Information via Negotiation (SPIN): SPIN, a family of negotiation-based information dissemination protocols in a WSN, is designed to solve the shortcomings of conventional data dissemination approaches like flooding using data negotiation and resource-adaptive algorithms. A sensor node advertises data and waits for the request from the sink node. Nodes running SPIN assign a high-level name to their data, called meta-data, and perform meta-data negotiations before any data is transmitted to eliminate the transmission of redundant data throughout the network.

#### 2.1.2 Clustering techniques [3]

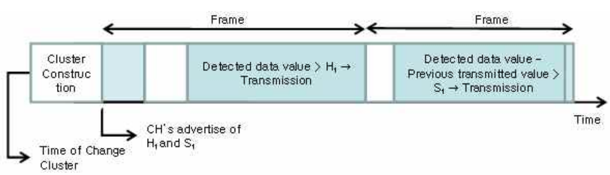
A cluster is composed of a cluster head (CH) and other nodes that are within the direct transmission range of the CH (i.e., distance by one hop). In each cluster, the nodes that are distant from other cluster heads by 1 hop (i.e., the nodes belong to more than one cluster as a non-cluster-head) are called gateway nodes. To carry out flooding for route discovery using clusters, clustering that organizes a sensor network into clusters must be previously performed [4][5][6]. Two representative cluster routing protocols are described below.

- LEACH: LEACH organizes the nodes into clusters, with one node acting as a cluster head. All non-cluster-head nodes transmit their data to the cluster head (CH). The cluster head then aggregates the received data and forwards the aggregated data to the sink node. LEACH randomizes rotation of the cluster heads. Since the cluster heads consume more energy than cluster members in radio transmission, the rotation of cluster heads makes energy consumption evenly distributed across all sensor nodes in the network. Moreover, CHs locally collect and aggregate data to reduce global communication. As a consequence, the overall energy consumption is reduced and the sensor network can last longer. LEACH operates in a sequence of rounds, as shown in (Fig. 1). Each round consists of a setup phase and a steady-state phase. In the setup phase, the clusters are organized and the cluster heads are selected. In the steady-state phase, the CH creates TDMA frames, i.e., channel allocation in time. The nodes determined to become a CH for the current round broadcast messages to their neighbors. Non-cluster heads that receive the messages join a cluster by choosing the CH based on their received signal strength and the residual energy, and reply to the chosen CH.




(Fig. 1) Round Time of LEACH

- TEEN (Threshold sensitive Energy Efficient sensor Network protocol): TEEN operates very similarly to LEACH, but sensor nodes here do not have data that is transmitted periodically. The nodes will transmit data in the current cluster period only when certain conditions are true. While LEACH is appropriate for proactive networks, TEEN is an efficient protocol for reactive networks, as its nodes react to changes in the value of the time threshold. TEEN determines whether or not to transmit the sensed data based on a hard threshold (HT) and a soft threshold (ST) broadcasted by the cluster head at every cluster change time. If the current value of the sensed attribute exceeds HT for the first time, the node that senses this value switches on its transmitter and sends the sensed data. The sensed value is stored in an internal variable, called the Sensed Value (SV). Afterwards, when the current value of the sensed attribute differs from the SV by an amount equal to or greater than the ST, the node will transmit data in the current cluster period (see Fig. 2). Like LEACH, a TDMA schedule is used and each node in the cluster is assigned a transmission slot.




(Fig. 2) Processing of TEEN

### 2.2 Existing Mobile ad hoc network routing protocols

Mobile ad hoc network related routing protocols can be classified broadly via three methods [7][8][9][10].

First, the Proactive method is usually called the table-driven method; and it is a technique in which all the moving nodes within the network maintain the most up-to-date routing information on all of the nodes except themselves. In this method, whenever periodic changes are made in the routing information or in the network topology, each node updates the routing information on itself after the changes are propagated throughout all the nodes. The strongest point of such a prior route configuration method is that if a packet has to be transferred, the route can always be organized along the most optimal route without delay. The weak point of this method is that when the network topological changes are large, the overhead of the routing protocol message required to propagate the routing information throughout the entire network also becomes large. Some of the major protocols are DSDV and CGSR, etc.

The Reactive method, which is also called the on-demand method, is a technique by which routes are searched when the node is requested of data transfer. Its strong point is that it can reduce the control message overhead that occurs in the Proactive routing method. Its weak point is that, as routes are searched at the point at which the traffic occurs, additional time is needed, which can cause delay of transfer for traffic. Among some of the major protocols are DSR, AODV, and TORA, etc.

The Hybrid method is a technique that has adopted the strong points of both the Proactive method and the Reactive method. Within certain domains, routing is carried out by IARP, which is based on the Proactive routing method. Searching for routes to the nodes belonging to the outside domains is carried out by IERP, based on the Reactive routing method.

In addition to these classes of methods, other classes also exist, such as protocol research into raising efficiency in the MAC layer, protocol research into maximizing the efficiency of the routes organized by carrying out the operation of protocol routing, and researched into maximizing node energy efficiency [11][12][13][14].

## 3. Proposed Routing Protocol

Application areas such as environmental pollution surveillance, habitat monitoring, and traffic control employ a WSN consisting of spatially distributed devices using sensors to monitor physical or environmental conditions cooperatively at different locations. Sensor nodes in WSNs are generally characterized by mobility and limited resources (energy, memory, computational speed, and bandwidth). Since a great number of nodes are deployed in a WSN, preserving node detection, path selection, and network connectivity are challenging issues.

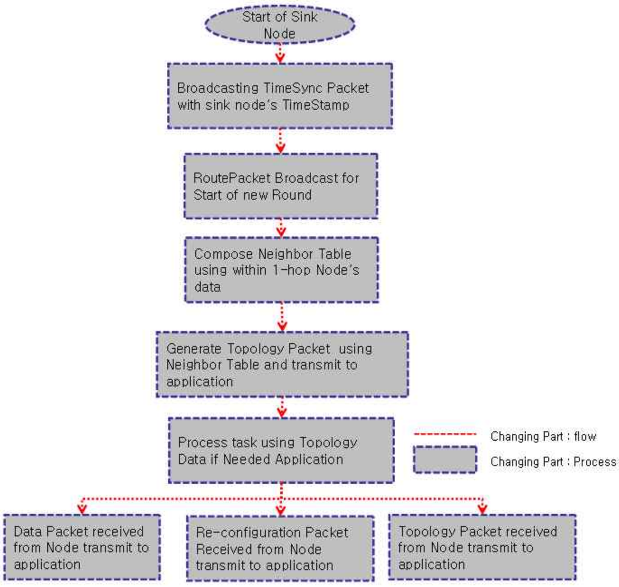
One of the most important issues in wireless ad hoc

〈Table 1〉 Processing step of Sink Nodes

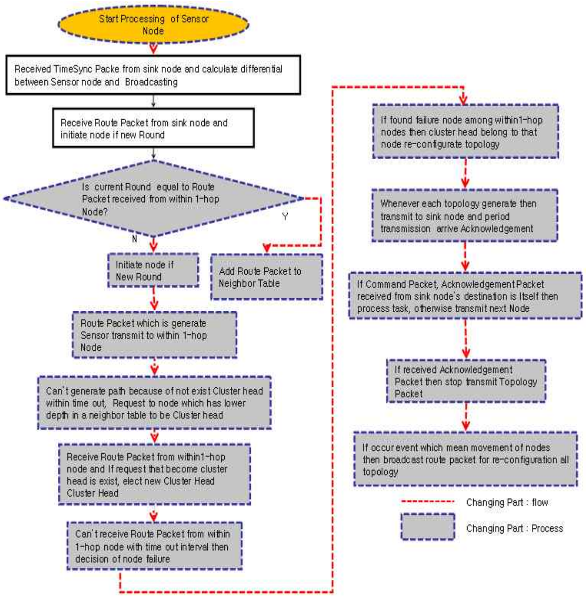
| Algorithm | [Processing step of Sink Nodes] |
|---|---|
| step 1 | Broadcasting of TimeSync Packet that is including TimeStamp itself |
| step 2 | Broadcasting of RoutePacket for notify new round |
| step 3 | Configure Neighbor Table with node's information of within 1-hop |
| step 4 | Make Topology Packet using Neighbor Table and transmit this packet to Application |
| step 5 | If application require information than process this task using Topology information |
| step 6 | step 6-1 Transmit Data Packet that is received from node to application<br>step 6-2 Transmit ReConfiguration Packet that is received from node to application<br>step 6-3 Transmit Topology Packet that is received from node to application |

〈Table 2〉 Processing step of Normal Nodes

| Algorithm | [Processing step of Normal Nodes] |
|---|---|
| step 1 | Broadcasting TimeSync Packet that is received from Sink Node after difference calculate between Itself TimeStamp from other's TimeStamp |
| step 2 | Receive Route Packet form Sink Node and Initialize node if that is new round |
| step 3 | step 3-1 Receive Route Packet from Nodes less than 1-hop and attach Neighbor Table if that is current round<br>step 3-2 Receive Route Packet from Nodes less than 1-hop and Initialize node if that is new round |
| step 4 | Transmit Route Packet that is make itself within 1-hop Nodes |
| step 5 | Because there is no ClusterHead for Time out, so does not path create case, In neighborhood table, selecting of node that has the smallest depth request to become ClusterHead |
| step 6 | Receive Route Packet from node within 1-hop, If there is request that become ClusterHead than election as new ClusterHead |
| step 7 | step 7-1 If any Route Packet does not come to node within 1-hop for Time out than decision is disable node<br>step 7-2 If disable node are find within 1-hop nodes than ClusterHead that this node is belonged reconfigure topology |
| step 8 | Whenever Topology is created, transmit to sink node and until Acknowledge comes, periodic transmission |
| step 9 | In case the destination of Command Packet, Acknowledge Packet that is passed from Sink node is own than processing this Packet, otherwise pass a Packet to next node |
| step 10 | If receive Acknowledge Packet than stop transmission of Topology Packet |
| step 11 | If event occur that it means transfer of node than broadcasting of Route Packet for whole Topology reconfiguration |




(Fig. 3) Step of Sink Node's processing




(Fig. 4) Step of Normal Node's processing

networks is to minimize the "flooding packet." The protocol proposed in this paper divides the communication area into grids, determines communication directions, and applies clustering within a grid as a means to minimize the flooding packet. The proposed protocol adopts the conventional LEACH protocol that is a cluster-based routing protocol, and modifies it to provide smooth topology reconfiguration and enhanced connectivity for moving nodes. Moreover, in order to facilitate network topology reconfiguration and to reduce the flooding packet, a mathematical model to estimate node movement is developed. Sensor nodes can dynamically join or leave the network by generating events based on the mathematical movement estimation model. The Processing step and mechanism for Sink node and Normal node are displayed in <table 1> and <Table 2>. The modifications made to the conventional LEACH protocol are marked with dotted lines and shades in (Fig. 3) and (Fig. 4).

### 3.1 Multi-hop algorithm for topology configuration of mobile ad hoc sensor network [12]

A multi-hop configuration is required for preserving the connectivity of moving nodes. To address this issue, the proposed protocol adds a few modules to the conventional LEACH protocol. Multi-hop configuration facilities provided by the LEACH routing system implemented in TinyOS 1.x [15] are used, and additional modules are also implemented to facilitate routing. In particular, requests for duplicate routes are stored by applying AOMDV (Ad hoc On-demand Multipath Distance Vector)[16][17][18][19], a duplicate route selection technique used in mobile ad hoc networks, to the LEACH protocol.

$$
\begin{aligned}
& if\,(seqnum_i^{\,d} < seqnum_i^{\,d})or \\
& ((seqnum_i^{\,d} < seqnum_j^{\,d})and \\
& (energy_i^{\,d} > (energy_j^{\,d} + energy_i\ ))then \\
& seqnum_i^{\,d} := seqnum_j^{\,d}; \\
& hopcount_i^{\,d} := hopcount_j^{\,d} + 1; \\
& energy_i^{\,d} := energy_j^{\,d} + energy_i \\
& nexthop_i^{\,d} := j; \\
& endif
\end{aligned}
$$

(Fig. 5) Reception Rule of redundant requests

The stored requests for duplicate routes are examined later, based on the residual energy and the number of hops. If necessary, the request packet for duplicate routes is accepted and the corresponding duplicate route is configured (see Fig. 5).

In the conventional LEACH protocol, the depth of a cluster hierarchy is determined randomly in a multi-hop configuration. The modified LEACH protocol proposed in this paper is designed to have a uniform depth level (5 hops basis) by considering communication delay and the deployment of sensor nodes. That is, a field Hop_Count is added to a cluster head, which decreases by 1. When the value of Hop_Count is 0, nodes are directed to other cluster heads. The MHLeachPSM module initializes each node, and performs three operations: Status Timer, Tilt Timer, and Round Timer.

Status Timer carries out the following actions for each period.

- The broadcasting nodes state information to the neighboring nodes: They advertise whether or not the node is alive, the node's depth from the sink node, whether or not the node has chosen its cluster head, request for the cluster head, whether or not a new communication round has started, etc.
- When a neighboring node is out of order or out of energy, it removes the node and adds a new node.
- When the parent nodes of a node of interest are changed, a “New Topology” packet is created and transmitted.

### 3.2 Analysis and Verification of Modified-LEACH protocol.

The path set up using AOMDV and LEACH has the following characteristics: First, it adds the alternative paths setup by default through duplicate RREQs. Second, the multiple paths setup using Redundant Node Existence Message (RNEM) function as additional paths that pass through an alternative node for each node in a 2 hop interval on the primary path. Lastly, the alternative paths that pass through the additional node have the same number of hops as if they were passing through the primary path.

Here, we checked the number of alternative paths added through RNEM and reviewed the survival rate of alternative paths when the same probability value as the possibility of node movement is added. If h is the length of a path, i.e., the number of hops, the number of nodes n = h + 1. If the number of alternative paths using k alternative nodes is $A_n(k)$, this can be expressed as a recursion formula as follows:

$$\begin{cases} A_n(0) = 1, & n > 1 \quad (1) \\ A_n(k) = 0, & k > \lfloor n/2 \rfloor \quad (2) \end{cases}$$

From Eq. (1) and (2), the number of alternative paths using k alternative nodes can be obtained in (3).

$$A_{n+1}(k) = A_n(k) + A_{n-1}(k-1), \quad k > 1,\ n > 2 \qquad (3)$$

Eq. (4) represents the total number of alternative paths in the proposed protocol. Eq. (4) includes both the number of paths using RREQ in consideration of energy levels, and the number of alternative paths obtained by applying modified LEACH and RNEM.

Using the Eq. (4) and following Eq. (5), the number of alternative paths in a network of h = 10, i.e., with up to 10 hops, can be obtained with the recursion formula, as shown in <Table 1>. Here, k is the number of alternative nodes.

$$\begin{aligned} S_{n+1} &= \sum_{k=0}^{\lfloor \frac{n+1}{2} \rfloor} A_{n+1} + \mathrm{AOMDV}_{E\text{-path}} \\ &= \sum_{k=0}^{\lfloor \frac{n}{2} \rfloor} A_n(k) + \sum_{k=0}^{\lfloor \frac{n-1}{2} \rfloor} A_{n-1}(k) + \mathrm{AOMDV}_{E\text{-path}} \\ &=> S_n + S_{n-1} + \mathrm{AOMDV}_{E\text{-path}} \end{aligned} \qquad (4)$$

$$P(n) = (1-x)^n \sum_{k=0}^{\lfloor \frac{n}{2} \rfloor} A_n(k) x^k * P(EL) \qquad (5)$$

〈Table 3〉 Number of alternative paths using k alternative nodes

| k \ h | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | $S_n$ |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 4 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 5 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| 6 | 1 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 8 |
| 7 | 1 | 5 | 6 | 1 | 0 | 0 | 0 | 0 | 13 |
| 8 | 1 | 6 | 10 | 4 | 0 | 0 | 0 | 0 | 21 |
| 9 | 1 | 7 | 15 | 10 | 1 | 0 | 0 | 0 | 34 |
| 10 | 1 | 8 | 21 | 20 | 5 | 0 | 0 | 0 | 55 |

The probability of the maintenance of alternative paths using k alternative nodes can be calculated by Eq. (5), where P(n) is the probability of maintenance. Further, when Eq. (5) is used, if we assume a case of 2 hops and a case of 10 hops using <Table 3>, the survival rates of the general protocol and the proposed protocol are shown in <Table 4>.

〈Table 4〉 Probability calculation result

| h \ Protocol | Conventional Protocol | Proposed Protocol |
|---|---|---|
| 2 | 0.0375 | 0.05 |
| 10 | 0.0005368 | 0.0021106 |

### 3.3 Module for reducing topology reconfiguration time based on node movement estimation and vibration sensors [15][20]

The modified LEACH protocol can predict topology changes based on the mathematical model that estimates node movement. This allows reduction of topology reconfiguration time, thereby complementing the shortcoming of the conventional LEACH protocol with regard to node mobility.

In the proposed protocol, the possibility of node movement is predicted in advance based on the probability theory and event triggering, so that the network can react more promptly to its topology change caused by node movement. The possibility of a node falling out of the communication range is calculated using a formula that considers collectively the waiting time of mobile or sensor nodes, the node's location, movement direction, movement speed, and the residual energy. If the calculated value exceeds a certain threshold value, an event used to advertise node movement is generated, and the topology of the cluster concerned is reconfigured. Refer to Eq. (6) is a part of the formula that calculates the probability of node movement. The network topology reconfiguration can be controlled by changing the threshold values for the node movement probability.

Important metric are $t_m$, $N_{dir}$, $E_{remain}$.

$t_m$ is accumulates time that node does not move and because supposed environment is node moves around after setting time, probability of node movement if specification time passes.

$N_{dir}$ is moving direction of node, that is confirmed the by two methods. First, node notifies leave signal on cluster header when move and Node that move passes other cluster header neighborhood. If cluster head that pass becomes more than 3, position of node and moving direction can confirm by triangular measurement method. Second, in case cluster head that can receive signal from moving node is below 2, Cluster head calculates signal strength and if signal is increased gradually, consider that approach to own otherwise consider node are receded if signal is decrease so that calculation is available about for moving direction of node.

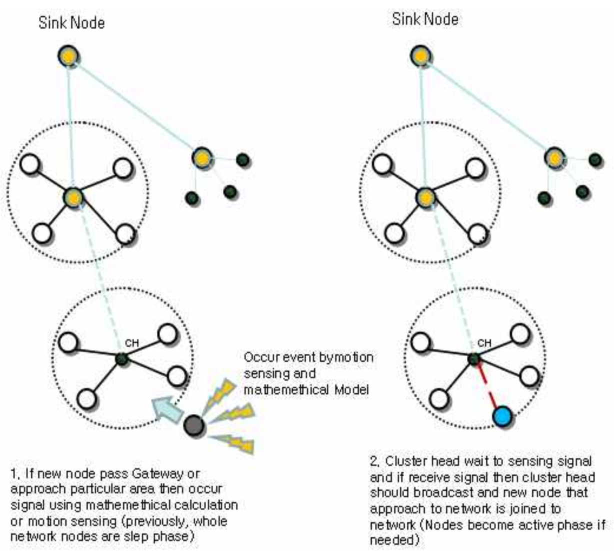
In the case of $E_{remain}$, node does not move actually. Node is come in Frozen if node consumes all energies; in this case, node's behavior is same effect as leave from network. Therefore, $E_{remain}$ is included as parameter in possibility of movement calculation formula.

$$P_m = t_m + N_{pos} + E_{remain} + N_{stat} + N_{msig} + N_{sp} + N_{dir} \qquad (6)$$

$P_m \geq P_{th}$ : Node of Corresponded are exclude, Whole Network does not change, Case by Case re-configuration topology within cluster (occur event)
$P_m < P_{th}$ : No change from Network topology

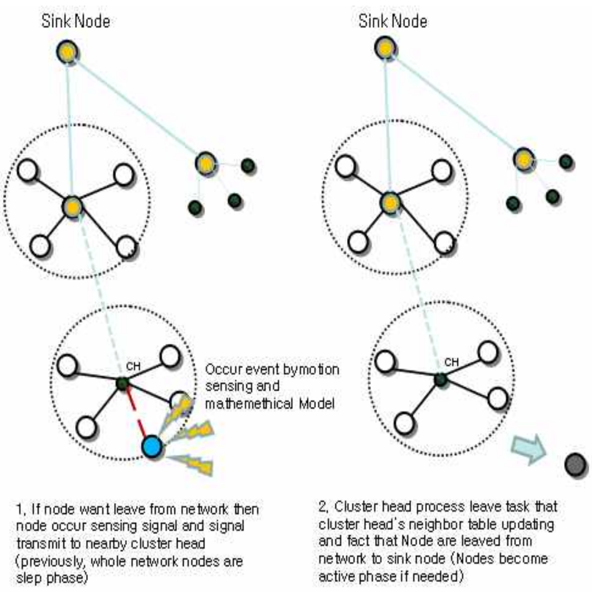
- $P_m$ : Possibility of Node move
- $P_{th}$ : Threshold value of Node move
- $t_w$ : Accumulation Time that Node don't move
- $N_{pos}$ : Node Position(Configuration according to weighted value)
- $N_{stat}$ : Node Status (Configure value to + or − according to move or stop)
- $E_{remain}$ : Remaining Energy(Configure value according to critical vlaue)
- $N_{Dir}$ : Node Direction (where if nodes move)
- $N_{msig}$ : Movement signal of Node (Notify start itself)
- $N_{sp}$ : Node Speed

In addition, the technique to perform the operations "Join" and "Leave" for a sensor node based on a vibration (or shock) sensor is introduced for energy conservation. The principal idea is including a shock sensor in a node to figure out whether or not the node is stationary.



(Fig. 6) Join action of new Node

If an event indicating the node is on the move is generated, the network topology is reconfigured immediately without waiting for the timeout signal. When there is no event regarding node movement, nodes are placed in Sleep mode to save power. (Fig. 6) and (Fig. 7) show the Join and Leave operations of a new node.



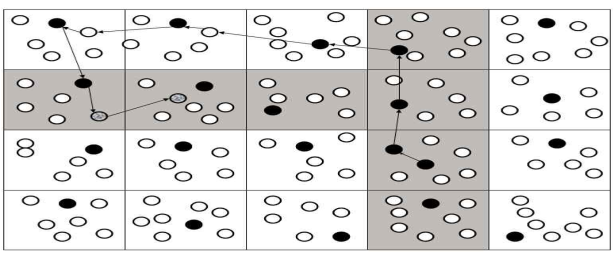
(Fig. 7) Leave action of Node

### 3.4 An efficient path selection and data transmission technique for a large number of nodes [14]

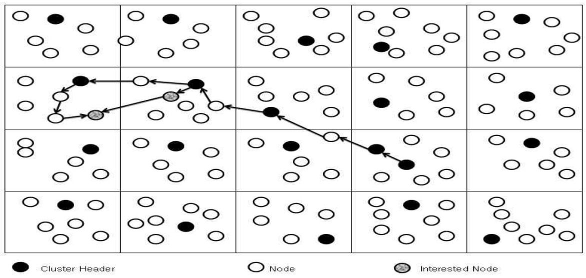
The proposed protocol includes a technique to provide an efficient path selection and data transmission in a network with a great many moving nodes. The core of the technique is to adopt the concept of grid topology and clustering in order to detect mobile nodes and manage their address system. The communication area is divided into equally spaced grids. The objective is to reduce the protocol overhead effectively for network management, with the assistance of position information. Within a grid, there might be more than one cluster. Once the grids and clusters are established in a network area, an efficient communication path selection is possible with the aid of the grids. That is, an algorithm to find the shortest path to transmit data by calculating the gradients of the destination from the source node is implemented. In addition, a technique to aggregate data on the selected path when the data is actually transmitted is also employed.

In general, a wireless network consists of set of mobile nodes that are free to communicate in any direction. The introduced grid technique can be effective and energy efficient when the communication direction of a node is limited to a certain direction. The conventional grid technique allows communication only in a vertical or horizontal direction from the grid cell in which an event of interest occurs. That is, identified paths are links over vertical/horizontal hops, and communication is performed only via cluster heads within a grid. Under such constraints, an inefficient path, as shown in (Fig. 8), is selected by establishing a reverse path from the sink to the source.

Instead of letting communication start in a vertical or horizontal direction from a grid cell and then forming a reverse path, using node IDs that are stored in a node cache when communication starts for the first time makes it possible to find a shorter and more efficient path, as shown in (Fig. 9)[14]. In this approach, the mathematical model used to determine the communication direction when the first communication starts plays a significant role.

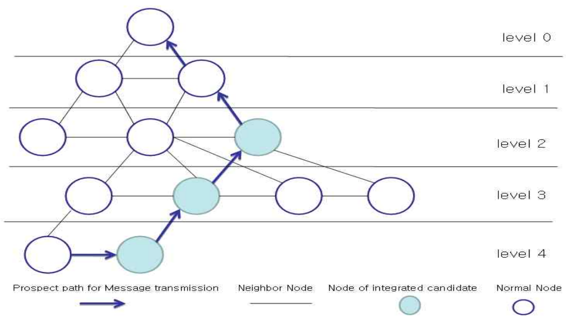


(Fig. 8) Inefficient Data transmit path




(Fig. 9) Establishment of Efficient Data transmit path

When the path selection is completed, nodes other than cluster heads might also need to transmit data. If every node in the network sends data to the cluster heads, more energy is consumed. As shown in (Fig. 10), paths are considered as a tree structure, and a technique to aggregate data between parent and child nodes and between child and child nodes at each phase is employed. The conditions for data aggregation can be mathematically modeled using a node's residual power and the amount and type of data to be transmitted.




(Fig. 10) Data transmit path and Data aggregation

## 4. Experiments

The experiments designed to evaluate the proposed protocol are performed in terms of four factors – *network configuration time, topology reconfiguration time, transmission success rate, and routing overhead.* The first factor is used to examine whether the proposed protocol that enables partially reactive routing for network connectivity and node mobility can provide network configuration time equivalent (or similar) to the conventional LEACH protocol that offers proactive routing. In terms of the second factor, the experiment aims to verify that the proposed reactive routing can reduce the reconfiguration time of network topology. The factor routing overhead is examined because the proposed protocol is likely to increase routing overhead due to the use of topology information for maintaining the configuration of moving nodes.

### 4.1 Experiment environment

<Table 5> presents the experimental environment. The number of nodes used to measure the time taken to configure a network is 200, and the number of nodes used to measure the time taken to reconfigure the network topology is 50. As described earlier, the elements measured for the experiments are network configuration time (initial configuration time), network topology reconfiguration time (full-scale reconfiguration), transmission success rate, and routing overhead.

The reason why 10 times experiments are used is that this model is random way. The result in each experiment can be different. Thus more detailed conclusion can be drawn from one which has a lot of experiment. During 10 times experiments, it did not have any change of parameters. Meaning of (Figure 12) experiment is measurement of how fast the network topology can be restructured, when nodes are moved or disappeared due to energy exhaustion and arithmetic operation of JOIN and LEAVE is generated. Experiment of (Figure 13) is that while 200 nodes were fixed and a node was moved, the rate of communication success between an appointed node and a destination node was measured. Experiment of (Figure 14) is that after 200 nodes are fixed, it is the result that the number of packets for routing is counted purely, by using random way point model.

〈Table 5〉 Environment of Experiment

| Item | Value |
|---|---|
| Platform | Pentium 4 core 2 Duo 2GHz |
| O.S. | TinyOS 1.15 based on cygwin in Windows XP |
| Simulator | Tinyviz |
| Number of Nodes | 200 nodes(Incremental Configuration),<br>50 nodes (Time of Network Re-configuration) |
| Range of RF | 10m |
| Mobility Model | Random way point, node speed : 30km/h |
| Number of Experiment | Incremental Configuration, Time of Network Re-configuration (each 5 times, Measurement of average value)<br>Transmission Ratio, Routing Overhead (each 10 times) |

### 4.2 Comparison of network configuration time

In this experiment, network configuration times of the proposed protocol and of the conventional LEACH protocol are measured by increasing the number of nodes. Even though the proposed protocol provides reactive routing, its network configuration time is similar to that of the conventional LEACH protocol. (Fig. 11) shows the times taken to configure networks. The configuration time of the conventional LEACH protocol is shorter than that of the proposed protocol by 2.697 seconds. Considering that the proposed protocol offers certain features that are not available in the conventional LEACH protocol, such as node movement estimation based on the mathematical model and active network configuration using vibration sensors, the time gap of about 3 seconds in the network configuration does not undermine the proposed protocol. (Fig. 11) shows the advantage of the proposed protocol in a network environment where node mobility and real-time monitoring of nodes are vital. Little performance difference between a proposed technique and existing LEACH protocol can be confirmed in an experiment comparing network restructure time by increasing nodes. The reason why a proposed technique is relatively faster than a existing LEACH protocol is that run rate is faster than a existing LEACH protocol, when nodes try to JOIN or LEAVE with a formula of a vibration sensor and a movement possibility. Computing speed of JOIN and LEAVE of LEACH protocol which does not consider nodes′ movement cannot be faster than a proposed protocol because the number of nodes increase and the network can be changed. However, the reason why a great performance difference is not detected is that overhead for a movement probability calculation exits.

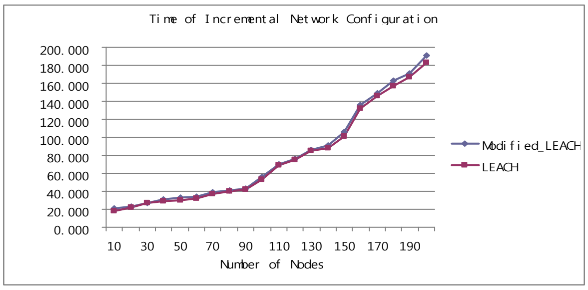
### 4.3 Comparison of network topology reconfiguration time

Network topology reconfiguration time means the time taken from the beginning of reconfiguring the network topology owing to the changes of node location, till the beginning of the normal operation of the reconfigured network. Reconfiguration is launched when nodes, including cluster heads, move out of the communication range, or when cluster heads receive an event message that advertises the node's movement. The events advertising node movement are generated based on the vibration sensor attached to a node, or on the mathematical estimation model of node movement. The goal of this experiment is to examine whether or not the proposed protocol allows for a faster topology reconfiguration than the conventional LEACH protocol. In the experiment, the number of nodes considered to measure reconfiguration time is 50.

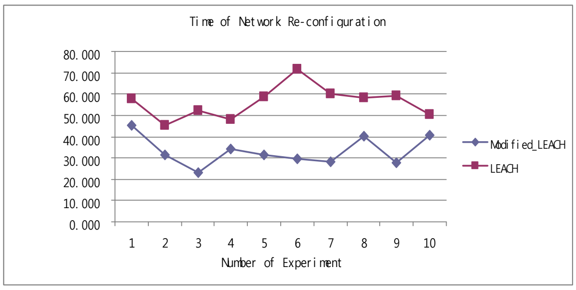
As shown in (Fig. 12), the proposed protocol reconfigures the network topology more quickly than the conventional LEACH protocol throughout the experiments, which were repeated 10 times. On the average, the reconfiguration time of the proposed protocol is faster than the convention LEACH protocol by 23.069 seconds.

In the conventional LEACH protocol, a new node joins the cluster head immediately, but an existing node should wait for a timeout or round update when it leaves the network. On the other hand, topology reconfiguration of the proposed protocol is more prompt; it performs dynamic and reactive node join/leave operations based on the mathematical movement estimation model and vibration sensors providing information about node movement. When nodes′ movement probability calculation is finished and changes are occurred in a network topology due to nodes′ movement or exhaustion of energy, the network topology should be reconstituted. In this case, a proposed technique has better performance than an existing LEACH protocol because a node which has the best chance of movement is removed from a cluster head and alternative pathway which can make topology with multi-channel, one of AOMDV′s characteristic, in advance exists. Additionally, node movement status information can be gotten earlier than a existing LEACH technique because a vibration sensor is loaded in each node. Thus, it is possible to save time as much as a existing LEACH protocol waits for a certain period to restructure topology.

The factor *topology reconfiguration* is very important in the complex network environment where the requirements for real-time monitoring, node mobility, network connectivity, and energy efficiency are appearing together. (Fig. 12) shows that the proposed protocol performs better than the conventional LEACH protocol in terms of network topology reconfiguration.




(Fig. 11) Time of Incremental Network Configuration



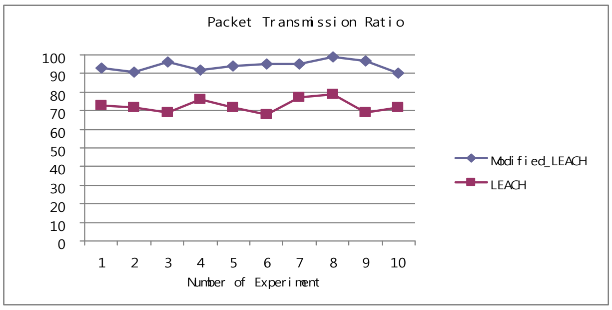

(Fig. 12) Time of Network Re-Configuration

4.4 Comparison of transmission success rate

This experiment investigates the ability of the proposed protocol to discover paths for data transmission using the multi-hop routing scheme. That is, when nodes are not within each other's radio range, the performances of the conventional LEACH protocol and the modified LEACH protocol proposed in this paper, in terms of finding communication paths hop by hop, are compared. The number of nodes used in this experiment is 200. Each packet is given a sequence number. If a packet sent arrives at the intended destination, the transmission is considered as "success." If the packet does not arrive at the destination or its sequence number is changed due to retransmission after the failure of the first attempt to transmit, that transmission is considered as "failure." For each experiment round, 50 packets are randomly transmitted to a destination node. (Fig. 13) shows the experiment results. The transmission success rate of the proposed protocol is higher that of the conventional LEACH protocol by 21.5%.

In this experiment, a proposed technique can achieve an excellent rate of transmission success because it maintains information of multi pathway like AOMDV. Additionally, a existing LEACH protocol using cluster-based single hop has a disadvantage; however, the farther a node is from a destination node, the higher performance a proposed technique in this thesis can show because a proposed technique in this thesis applies multi pathway setup, an advantage of AOMDV, to communication between hops in LEACH protocol. But, there is no performance difference in a single hop communication.

This result shows that the proposed protocol designed to support the mobility of mobile sensor nodes offers more efficient multi-hop routing than the standard LEACH protocol. Although it is not included in the experiment results, there appear to be some areas where communication is not possible in the network that is operated using the conventional LEACH protocol.

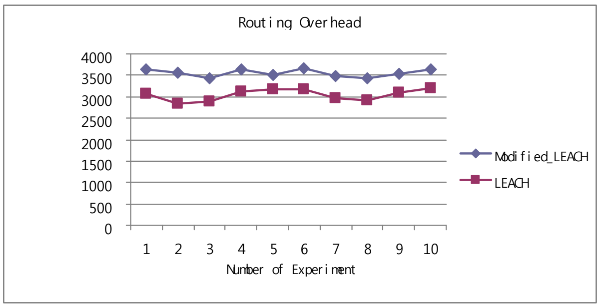



(Fig. 13) Packet Transmission Ratio

### 4.5 Comparison of routing overhead

Routing overheads of the conventional LEACH protocol and the modified LEACH protocol are measured by accumulating the created control packets and comparing the number of the accumulated packets. Control packets are generally created for routing purpose, for example, to deliver and maintain topology information of mobile sensor nodes. In the experiment, the number of created control packets is measured by randomly transmitting 50 packets over the network, consisting of 200 nodes. (Fig. 14) shows the experiment results. In the proposed protocol, the number of the created control packets increases by 14.3% (511 more control packets are created), as compared to the conventional LEACH protocol. This is because the proposed protocol requires more control packets in order to form and maintain the topology of moving sensor nodes reactively. It is presumed that routing overhead increases as the number of nodes in the network increases. Substantive routing overheads increased instead of getting a fast network topology recovery function by reducing a network reconfiguration time and considering a node movement. This experiment also reflects this part. Compared with an existing LEACH protocol focusing on energy efficiency, routing overheads increase because an active time of nodes is long and an exchange of information is occurred frequently. If the number of nodes increases, that this phenomenon will occur more frequently is anticipated. Moreover, there are some parts which are not noticed in this thesis, experiment result of lifespan of a network which can be operated without disconnection of network. If it is anticipated logically, lifespan will be shorter in reverse proportion of routing overheads.

Overall, the experiments show that the proposed protocol outperforms the conventional LEACH protocol in terms of network configuration, topology reconfiguration, and transmission success rate, but in return for routing overhead.




(Fig. 14) Routing Overhead

## 5. Conclusion

This paper has presented a routing protocol that is a variant of the conventional LEACH protocol. That is, the conventional LEACH protocol is modified to be more suitable to a network environment where real-time monitoring of a larger number of moving sensor nodes is required, such as pollution surveillance applications, habitat monitoring applications, and traffic control. LEACH is a proactive routing protocol with minimum communication delay. The proposed protocol modifies the conventional LEACH protocol in a way that makes reactive routing possible. The modified LEACH protocol offers reactive routing by predicting a situation in which network topology change is required (i.e., the operations Join/Leave are needed), based on the mathematical estimation model of node movement and vibration sensors attached to the nodes that are used to sense their movement. Furthermore, additional modules used to perform efficient node detection and path selection for a large number of mobile nodes are implemented in the modified LEACH protocol.

The experiments have been performed to evaluate the performance of the proposed protocol in terms of four factors - network configuration time, topology reconfiguration time, transmission success rate, and routing overhead. The experiment results show that the initial network configuration time of the proposed protocol is similar to the conventional LEACH protocol and that the full-scale topology reconfiguration time of the proposed protocol is faster than the conventional LEACH. The transmission success rate of the proposed protocol is also higher than the conventional LEACH, but it has increased routing overhead as compared to the conventional LEACH. Overall, the modified LEACH protocol proposed in this paper can perform better than the conventional LEACH protocol in a network environment in which real-time node monitoring, mobility of sensor nodes, network connectivity, and energy efficiency should be collectively taken into account.

For future work, the algorithms and techniques implemented in the proposed protocol will be optimized in order to minimize flooding packets and routing related packets, which in turn lead to reduced routing overhead.

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