Routing Algorithm for Automatic Metering of Waterworks Data

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***Abstract*—Real-time acquisition of water meter data is very difficult owing to the expensive and difficult environment for installing sensors and wired or wireless communication systems. In this study, a wireless network algorithm that takes into consideration technical and economic factors is proposed. Cluster-based ZigBee communication method is applied to transmit the sensing data without disruption regardless of environmental situations. In addition, it is designed to select the cluster head considering the minimization of battery power consumption. Through this study, data pertaining to the characteristics and the economical efficiency of water meters can be collected and analyzed. This study shows that the system can be widely used to enhance the water distribution networks for stable water supply system.**

Keywords- formatting; water data, automatic metering, meter reading system, block system

I. INTRODUCTION

The data collected from water meters are used basically to ensure stable water supply. The data is very important because it is used to determine the tap water fare for individual consumers. However, until now, inspectors have had to directly visit meters rather than real-time data acquisition because of cheap water fare. The irregularity of data collection could result in inefficient manufacture and supply of water and equitable water allocation might not work in a country which experiences water shortages. In addition, many complaints are associated with water supply charges that are based on irregular data.

With the development of information and communication technologies, the reliable information to the general public is provided by realization of a ubiquitous environment in the field of electricity, gas, and water utilities. In general, providing accurate and up-to-date information pertaining to water usage is very difficult and costly.

In Korea, most of the water meters have been installed in poor environments, such as basements or underground areas that are hard to access. Also, most of the water meters are of the inexpensive mechanical type. Mechanical water meters can only be read by visiting the household where it is located. In addition, because the meters do not support remote automatic meter transmission, there are various problems associated with individual visits, such as errors relating to minimum flow, consumer privacy, recording errors, and re-visits due consumer absence.

In Europe, most of the water meters are installed in easily accessible spaces. However, as opposed to Korea, a water meter can stably transmit real-time data if a ubiquitous sensor network is used. But mechanical water meter types are being used due to economic factors in Europe.

The real-time remote automatic meter reading system, i.e., Automatic Meter Reading (AMR), has so far been unable to be introduced in Korea due to poor installation sites and water cost [1-3].

Networks for real-time transmission of data can be designed using telephone networks, Cable Television (CATV) networks, Code Division Multiple Access (CDMA) networks, Radio Frequency (RF) networks, and Power Line Communication (PLC) networks, but the Industrial Scientific and Medical (ISM) band RF communication network for short distances and the CDMA for long distances have been proposed considering cost and reliability. RF repeaters for short-range communication are required depending on the propagation environment, but there are challenges such as installation conditions and power management.

Therefore, the cluster-based routing algorithm is proposed to enable real-time data transfer considering the power consumption in this study. The status of the water meter data transmission is explained in Section 2 of this study, and the proposed routing algorithm is described in Section 3. The performance of the proposed method is measured and analyzed through NS-2 simulation in Section 4 and finally, Section 5 comprehensively analyzes the feasibility and applicability of the algorithm.

II. DATA TRANSMISSION SYSTEM FOR WATER METERS

There are a variety of data collection methods that are used in the field. Meter reading can be done through direct readings taken during home visits. In outdoor readings, the same data are sent to an external display device from indoor water meters. Meter inspectors obtain data with the help of wireless communication device by walking-by or driving-by the properties. Water meters can be automatically read from a fixed communication network. A typical real-time data transmission system used by public utilities, such as electric, gas, and water, consists of the sensor unit, the transmission unit and data management part as shown in Figure 1. The function of each component is as follows. At first, the sensor unit measures the object and converts the mechanical data into electrical data that can be delivered. Then, they are sent to a transmission unit to transfer them to data management systems, which store the transmitted data simultaneously.

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The transmission unit that collects data from a large number of sensors has the ability to send certain data on a regular basis and to manage their storage. All the data are transferred into a database and used for performing fare management, finding abnormal measurements, data analysis and supply forecasting for management systems.

The meter measures water usage as the key component in the sensor unit. The meter of each home has a diameter of 50 mm or less. Measurement methods could be classified into direct and indirect method. The indirect method depends on the rotation speed of the actual flow. The direct method, which is used primarily for testing, measures a constant volume of water. In order to transmit real-time data, a digital meter having a microprocessor and a memory is required.

Although a partial digital meter has a mechanical type of sensor, the meter can convert mechanical signals into electrical signals. However, the meter does not have an internal microprocessor for data processing. There are two kinds of partial digital meters. One is a pulse counting method that uses a lead switch, and the other is the camera method which has the ability to take and send photos for image processing. The camera method should be equipped with a microprocessor and a memory to transmit real-time data.

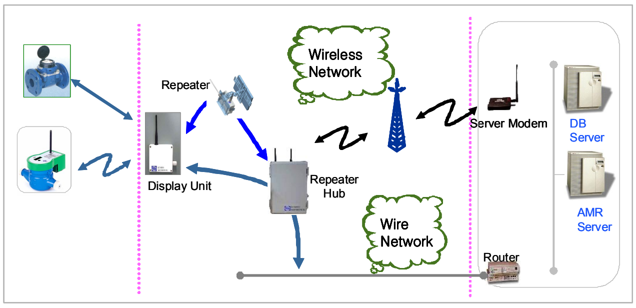

Figure 1. Schematics of Water Data Transmission

Data transmission methods can be divided into the wired and the wireless method. The latter has the advantage of affordability in terms of installation, equipment and communication circuit, but it has the disadvantage that data is unreliable because of communication interference. So, the wireless communication and the power line communication are being widely adopted using ubiquitous environment. As such, communication environments and meter reading methods should be considered not to lose water meter data.

III. CLUSTER-BASED ROUTING ALGORITHM

Pattern of a residential area shown in Figure 2 must be considered to make a plan for sensor distribution. Because the operation units for water supply and management are generally divided into blocks, the block can be divided depending on block's size. The shape of the block can be split into squares, rectangles, triangles, polygons, etc. In this study, a suitable transmission algorithm for a variety of patterns is proposed.

An environment for the installation of repeaters cannot always be located in the middle of the block for obtaining meter data remotely. They are located in various locations, such as center, corners or edges under the terms of the block. Thus, the nodes are not always generated with configuration of a star network. It is not economical to install each repeater for these nodes, since it will be an obstacle for optimization of transmission environment. Therefore, it is more efficient to transfer after collecting data through cluster formation.

Figure 2. Pattern of a Residential Area

The nodes can be divided into a small area of the sensor field called clusters. Each cluster has a cluster head which collects data from the cluster members and the data is delivered to the different clusters or the relay station [4-7].

In particular, the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol, which is most commonly used to maximize the survival time of the network, adopts the probability function as the following equation, which keeps energy consumption evenly between the network nodes.

$$P_i(t) = \begin{cases} \dfrac{k}{N - k^*\left(r \bmod \dfrac{N}{k}\right)} & : C_i(t) = 1 \\ 0 & : C_i(t) = 0 \end{cases} \quad (1)$$

Here, i is the identifier of the node, t is the time, N is the total number of nodes, k is the number of clusters and r represents the round. This protocol consists of advertisement, cluster setup, schedule generation and data transfer step. If the head is selected at least once during r mod (N / k) rounds in the above equation, the chance of re-selection is zero. In case that selected cluster head cannot be delivered to sink node via one-hop, it is difficult to expect a high transmission rate. In this study, the following cluster head selection method is proposed.

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In order to determine the environmental diversity of remote water meter reading like the distribution pattern of a residential area, such as in Figure 2, the network should be initialized as shown in Table 1. First, the repeater broadcasts an advertisement message to characterize the entire node. Second, it gives the node IDs according to each node type, and third, it performs the function of a cluster head selection and change. The whole network becomes ready to start.

TABLE I. CHARACTERISTICS OF ADVERTISEMENT MESSAGES

Node_ID	Unique ID assigned to a node
Hops	Hop depth
Energy_Data	Residual energy of the node
SN_Limit	Signal level limits

Hops mean the hop depth from the repeater station, which is represented by the number of hops. The procedure to create the table about their neighbor nodes is done by knowing the depth of each node. Their repeater station sets zero for hop depth, and then advertisement message is transmitted to the network. The node to receive an advertisement message from the repeater sets its own hop to 1, and then it locally broadcasts an advisement message including hop information, residual energy, and Node_ID. If the node is not yet able to secure the depth of the hop among received nodes, it adds one to the value of the received hop set. If the node knowing the depth of hop receives an advertisement message, it stores the nodes less than the depth of its hop information in the parent node table, such as in Table 2. If the hop depth of the received message is the same, this information should be stored in the neighbor node table.

The parent node table is used to transmit data from the cluster node to the cluster head on the top. If there is no parent node table with their lower-hop value than their own table, it can be transmitted by searching for a detour route to refer to the neighbor node table with the same-hop value.

TABLE II. NODE TABLES

Table name	Relationship between value of hops
Parent node table	My hop < Received nod hop
Neighbor node table	My hop = Received node hop
Child node table	My hop > Received node hop

After the child node table has stored the paths of higher nodes than their own hops, it refers to the reverse path to send messages such as advertisements, broadcast and a control messages between random nodes.

In addition, it is transmitted by specifying a range of signal levels in the advertisement message to distinguish the type of node due to the level of the signal repeater. The configuration of the network is desirable to have the composition of a star and cluster to obtain real-time data. Thus, the node and repeater with a star topology can transmit data directly without the other nodes. However, nodes outside the range of the signal level of any node in the cluster are composed of local-based clusters to transmit data to repeaters through a cluster head. Repeater gives the information of node types based on the signal levels of all nodes to distinguish the specifications of such transmission methods. The node type is specified in the repeater signal level and has the attribute value of Table 3.

TABLE III. CHARACTERISTIC VALUES OF NODES

Size of signal level	> -50 dBm	< -50 dBm
Attribute value of node type	Inside	Outside

Nodes with inside attribute values collect node data with outside attributes and they play a role as a cluster head to send to repeaters or send their own data directly to repeaters. Outside nodes will form a local based cluster to receive and transmit data to nodes selected as the cluster head in the transmission path.

Among the nodes with inside property, any node with a large signal level intensity and within one hop to a repeater is chosen as a cluster head. Locally distributed 2 to 3 cluster heads are selected considering the number of nodes and positions, which are then registered as cluster head members in the node.

The nodes registered in the cluster head members will have the property value of activity and standby cluster headers, such as in Table 4. An active cluster head will be selected by calculating the probability among cluster members in each round. The node working as the active cluster head aggregates data in a cluster to be sent to the repeater, and the rest of the cluster members have the property value of a standby cluster head to send only their own data to the repeater.

TABLE IV. CONFIGURATION OF CLUSTER MEMBER

Activity cluster head	Transmission of aggregated data in the cluster
Standby cluster head	Transmission of their own data

Any number of the nodes with the outside attribute value become one cluster considering geographic location with a cluster member, such as in Table 5.

The cluster heads broadcast their own state to all nodes in the scope of the area. The node to receive the broadcasting message checks which node is selected as the cluster head among cluster members. Then the node prepares for sending data to the selected head.

Each cluster member node is required to have a routing table to send a message to the sensor node. Repeater node, which sends data messages to the cluster head, stores lower

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node information in the child node table. It can be used as routing information when sending data to the header. At the same time, repeaters replace the value of their own ID and hop depth with the Destination_ID and Destination_Hops of the data message before sending them to the heads.

TABLE V. CLUSTER MEMBERS

Cluster member	Cluster division	Nodes configuration in the cluster
CMember1	1# cluster	Node0, Node1, ..., Node24
CMember2	2# cluster	Node25, Node26, ..., Node49
CMember3	3# cluster	Node50, Node51, ..., Node74
CMember4	4# cluster	Node75, Node76, ..., Node99

Data refer to the parent node and neighboring node table to do flooding in the direction of the lower node in hop depth. If a routing node receives a data message, it first compares its depth and Destination_Hops, and if the hop depth is smaller than its depth, it transmits the data in the direction of the cluster head. The cluster head finally obtains the data through these processes.

TABLE VI. TRANSMISSION DATA FIELD

Destination_ID	Address of destination node.
Destination_Hops	Hop of destination node
DATA	Sensing data
Energy_Data	Amount of residual node energy

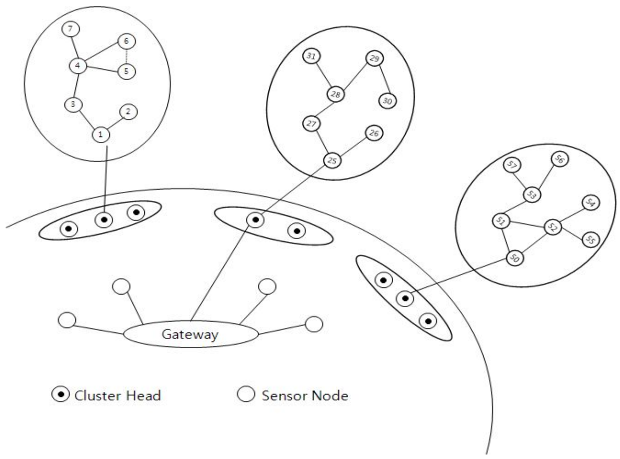

Figure 3. Routing topology

As shown in Figure 3, the topology is proposed for optimal routing algorithm. The algorithm selects a node with the best amount of residual energy.

IV. SIMULATION AND ANALYSIS

The network simulator, NS-2, was used to validate the proposed algorithm in this study [8]. 100 sensor nodes were randomly distributed in the area of 100m x 100m. The sink node was placed in the center of simulation area and the maximum transmission distance of the nodes was assumed to be 10m. In addition, the average packet transmission rate was set to 98% to consider the error rate of the local communication. Sensor nodes, except the sink node, were set to transmit the data packets during 2,030 seconds. The first 30 seconds is allotted to select cluster creation and cluster head and then the data packet is transmitted for the experiments five times at intervals of 400 seconds. The 100 sensor nodes were divided into four groups - 25 sensor nodes per each group. The sensor node that can transfer data to sink node by one hop was selected as the cluster head. To monitor the energy variances of each cluster head, the cluster head was set to change every 50 seconds.

Among Zigbee communications, the most widely used routing algorithm is the Ad-hoc On demand Distance Vector(AODV). The characteristic of this algorithm is the distance vector routing for each node to search the most optimal route from a source node to a destination node. Thus, this study compared the proposed algorithm with the AODV routing algorithm [9-12].

Data transmission interval of static type was set to 10 seconds. Those of multiple type were set to 1, 3, 5, 7 and 10 seconds for every 5 nodes in each cluster. Packet transmission rate is the ratio of the finally reached data packets to the generated data packets at the source node. Figure 4 shows that the packet transmission rate of the static type of 10-second cycle is higher than that of multiple type of various cycles. The proposed routing algorithm showed over 4% increased result in both static and multiple types comparing with AODV.

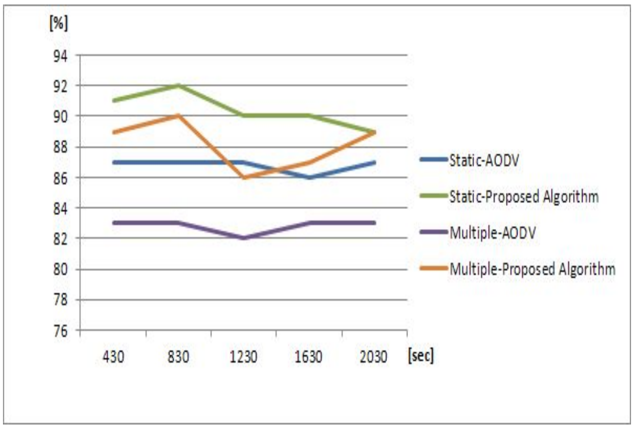

Figure 4. Packet transmission rate

In this simulator, the initial energy of each node was set to 20J. Each node transmits data to gateway through the cluster head at the transmission cycle. Transmit power and

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received power were set to 0.0756J and 0.0828J, respectively, and the remaining energy was obtained after the transmission of 2,030 seconds. As shown in Figure 5, the nodes simulated by proposed algorithm had more remaining energy than those simulated by AODV algorithm by about 50%. The result shows that the proposed algorithm performs better in both static and multiple type cases.

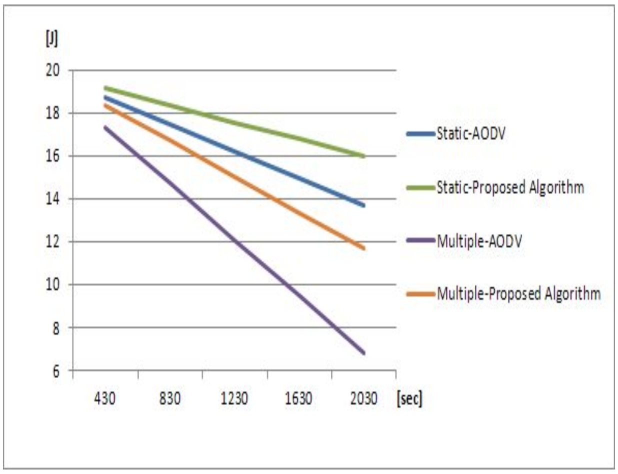

Figure 5. Minimum remaining energy

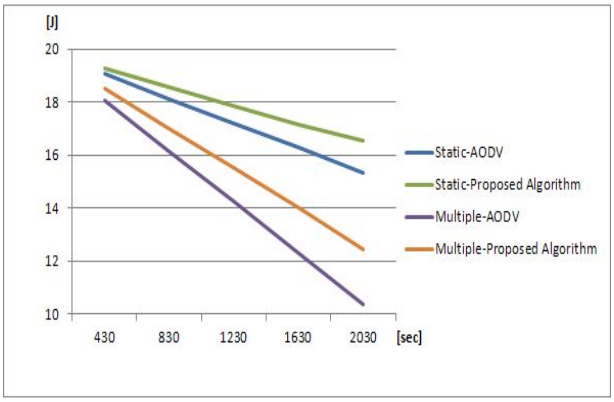

Figure 6. Average remaining energy

Figure 6 shows the average value of the remaining energy in all nodes after the simulation. The average remaining energy of proposed algorithm is about 20% more than that of AODV algorithm. We can notice that the static type has more remaining energy because the transmission cycle of static type is longer than that of multiple type.

V. CONCLUSION

This study proposed a cluster-based routing algorithm to obtain the real-time waterworks data. In particular, we considered the environment of communication and power with priority. Among the sensor nodes that transmitted to the sink node, each cluster's head was selected by checking the reference receiver signal level and remaining energy level.

The experimental results show about 4% improvements in packet transmission rate as compared to AODV algorithm. Because batteries are essential in waterworks data transmission environment, effective use of energy is very important. Compared to the existing AODV, the proposed method for effective use of energy shows improvements of more than 50% at maximum. The results of this study can be applied in realization of water reading system where real-time waterworks data transmission is possible.

In the future, the proposed algorithm may be applied to the implementation of the water management system through the expansion of water reading system.

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