# Efficient Cluster Organization Method of Zigbee Nodes

Sung-Je Woo[1] and Boek-Duk Shin[2]

*[1]Advanced Power Grid Research Division, Korea Electrotechnology Research Institute, 12, Bulmosan-ro 10beon-gil, Seongsan-gu, Changwon-si, Gyeongsangnam-do, 642-120, Korea.*
*[2] Environmental Energy Dept. Principal Research Engineer, Wooam, Inc., KOAMI Bldg., #13-6, Yeouido-dong Yeongdeungpo-gu, Seoul 150-729, Korea.*
*[1]cliot@wooam.com, [2]objector@wooam.com*

***Abstract***

*The Zigbee communication, based on PHY and MAC of IEEE 802.15.4 standards, is a communication technology to connect local wireless nodes and provides high stability and transfer rate due to data communication with low power. Zigbee is commonly organized with one coordinator and more than one node, as the basic service area and this network is referred to as PAN. In the nodes away from coordinator in one PAN, the signal strength is weak causing the network a shortage of low performance and inefficient use of resources due to transferring delay and increasing delay time and thus cannot conduct seamless communication. This study suggests the grouping method, that makes it possible to perform wide range data transferring depending on the node signal strength in Zigbee node and analyzes the suggested algorithm through simulation.*

***Keywords:*** *zigbee, wireless network, IEEE 802.15.4, repeater, grouping*

## 1. Introduction

The Zigbee, regarded as an important technology which organizes HAN (Home Area Network) in a smart grid, is one of the standards of IEEE 802.15.4 that supports local communication. The communication mode of Zigbee network assigns one device as a coordinator in the network and organizes PAN combining with the other nodes centered by that coordinator (Figure 1). Also, the coordinator of this PAN (Personal Network Network) is able to communicate with neighbor coordinators so that it can organize a wide range network by expansion of network. To compensate for the low transferring speed and support the case that real-time data communication is needed, it is possible to support selective GTS (Guaranteed Time Slots) assignment operation and reduce the resources and costs which are needed in organizations by concentrating most loads for communication into coordinators and thus reducing the function of terminal devices relatively. The Zigbee network organization, which makes star, tree or cluster tree topology using devices that have different roles, has a shortage of reducing the performance of an entire network in the case that data transferring is impossible in a node by network trouble after organizing initial network using nodes, and also has a shortage of reducing network performance if real-time data transferring is needed.

Generally, the data transferred by the node have to be saved in the buffer and transferred to the terminal within the time that satisfies QoS (Quality of Service) Characteristics. However, the receiving status can be widely moved due to variable wireless channel conditions, node movement and several environmental variables. Thus, if the delay of data transfer time is increased, data loss can occur due to increased buffer saved time of data and dissatisfaction of delaying time, which is required by specific data flow or buffer overrun. These data re-transfers and losses can result in the reduced network performance.

The signal strength which is sent by Zigbee coordinators can be weakened as distance from it increases, causing communication with target nodes to become difficult and abuse of the wireless resources. Therefore, it is difficult to perform stable and reliable wireless communication with wide range nodes. It is not easy to use the wireless resources using location data because the coordinator cannot search the location of node [5, 8, 9]. Also, the wireless link can occur to the signal attenuation by distance [6, 7] (Figure 2, and 3) and the wireless signal fading by the transferring media.

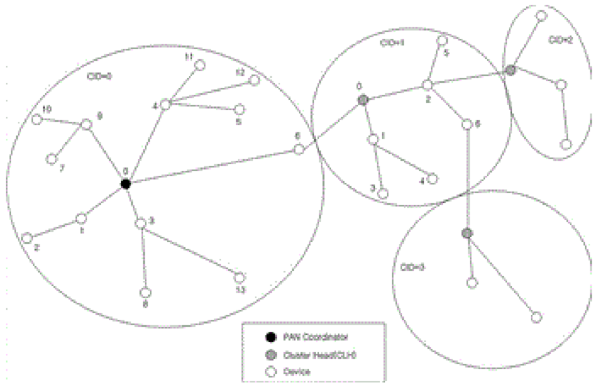

**Figure 1. Zigbee cluster tree organization**

In the case of Zigbee, which is suggested as standard communication protocol of bi-directional power automation service for the home and building in the smart grid that makes it possible to provide high quality power service by combining power technology and IT, smooth service in a multi-hop environment is not easily accomplished due to multipath fading and signal attenuation. For this reason, the network has to be organized by locating the coordinator in each house or each floor of the building so that it is difficult to use the resources efficiently and costs more.

Because Zigbee has characteristics of wireless communication based on a short communication range and low power consumption, it has high communication success variation in accordance with the communication range and organization of structures. To resolve this issue, it is necessary to install a device, such as transit nodes for places with low efficiency of communication. If multi-coordinators exist in this case, performance decreases such as delays can occur due to the wireless idle condition under MAC communication based on CSMA/CA because of transfer synchronization issues.

Networks which are organized using actual Zigbee devices in the real industrial field show performance that is much lower than the expectation for theoretical network organization and communication efficiency. The attenuation phenomenon of wireless signal shows a result that exceeds expectation between theoretical and actual result [5, 6, 7]. We imagine that those issues happened because the actual problems of communication specification and network organization that are mentioned above are not resolved aggressively [1]. For the HAN, the unit of service for home using Zigbee in the smart grid which is aggressively performed and validated at this moment, its service is performed as a form to locate the coordinator in each home due to the issues caused by network organization and wireless signal attenuation. This may cause unreliable coordinator position and signal based service due to the fact that it does not organize the efficient network. In addition, it may require excessive installation costs by only supporting 1 on 1 communication between coordinator and terminal, and may cause greater expenses and service delays as a result of increasing the load for the DCU (Data Concentration Unit) that is in charge of checking the home as the number of coordinators has been increased.

This study suggests the transit node selection algorithm in accordance with the node connection condition to increase the transfer rate and reduce data delay, and the efficiency after analyzing the range of dynamic network configuration by the Zigbee node signal strength and interconnection of included node numbers mathematically using performance analysis of the suggested algorithm. For the method of suggestion, we reduce the consumption of resources by using the method to notify the transit node selection and node information included in each group using a current link status packet to decrease overhead which occurs in organization of networks.

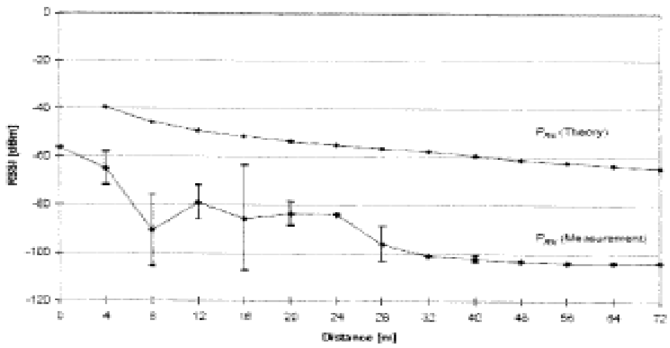


**Figure 2. RSSI value by distance**

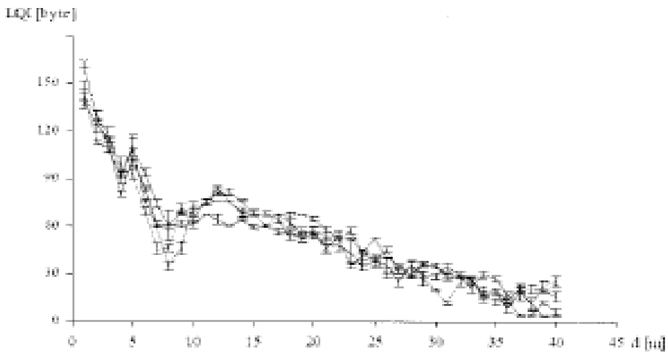


**Figure 3. Relation between distance and LQI in Zigbee node**

## 2. Main Issues

### 2.1. Current study and issues related with current Zigbee network organization

Zigbee has star, tree or cluster tree type network organization using nodes which have different roles. The multi-hop data transferring through router node in tree or cluster tree type network configuration transfers the data using an AODV routing algorithm. However, it does not suggest any standards or corresponding efficient configuration for efficient topology configuration in the Zigbee network structuring algorithm. Even in the Zigbee standard, network configuration type in accordance with signal strength and quality is not mentioned. Although we consider the objective of the Zigbee network that transfers and conducts the simple data or command by nodes which have a type of sensor network with less mobility, those currently used topology configuration methods have issues that may breakdown the network topology due to some issues that occur in any node and may have trouble data transferring in the nodes that have failure. For the home HAN area or more complicated building, the cases for which data cannot be transferred to the target node because of attenuation by obstacles, interference and fading between wireless channels such as Bluetooth, can occur. If the user configures the network using a coordinator and terminal node to avoid those issues, it may cause additional expenses in infrastructure that is connected to a coordinator. Thus, we need a reliable network configuration method to reduce cost and make structure in corresponding to the current standard.

### 2.2. Role of network Zigbee nodes in suggested method

PAN elements in the Zigbee network consist of a coordinator, repeater and end device that has the role of an RFD (Reduced Function Device). The coordinator organizes PAN initially and plays a role to make and manage the neighbor table for the member nodes included in the PAN area. The neighbor table is a set of table of wireless nodes which is located on the communication available range with itself (coordinator, repeater and separated nodes). The coordinator organizes PAN initially and makes the neighbor table. Also select repeater, save selected repeater information on the neighbor table and broadcast this information through the connection status information packet.

The repeater receives information about member nodes from the coordinator and writes coordinator information on the neighbor node. Also, the repeater organizes a group of new member nodes for the repeater and makes and manages a new neighbor table for them. At this time, the repeater manages member nodes which are created by the coordinator and repeater's own member nodes separately and selects sub-group repeaters which send that information to the coordinator. The repeater writes the information received by member nodes from the coordinator as well as repeaters of the upper group so as to exclude the member nodes of the coordinator or upper group in selection of repeater to clarify the possibility of overlap in repeatability and expansion ability of group member as much as possible.

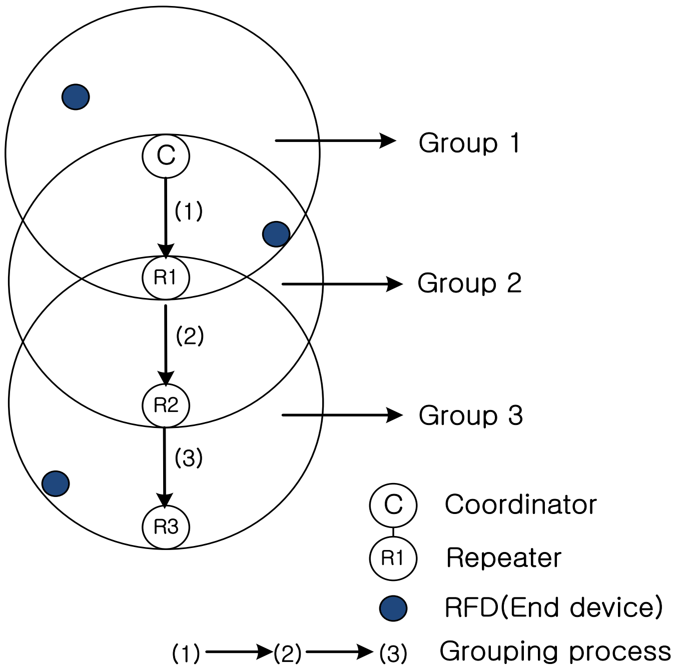


**Figure 4. Role of node and organization process in network configuration**

### 2.3. Network configuration and interlocking process in the suggested method

#### 2.3.1 Network group organization of coordinator

As the first step in the suggested network configuration in this study, the coordinator transfers active scan, detects beacon frame of the nodes which receives it so that it writes the information about these nodes in the neighbor table after process of certification and connection. The coordinator organizes the first group for the nodes which are able to communicate with itself (Figure 4, Group 1 (G1)). The coordinator is able to measure the wireless link quality between itself and the nodes based on the beacon frame, and write the measured RSSI and LQI values on the neighbor table. The coordinator writes the acquired information from the n nodes which are located within the available communication range with itself in its group.

After completion of G1 organization, the coordinator broadcasts the information including G1 member nodes and repeater information in the entry field of the link status packet, which is generated and broadcasted regularly. The link status packet includes repeater information and the coordinator selects the repeater (R1) among nodes which has high quality of wireless linkage within the available communication range and notifies the result to the member nodes using the link status packet. The link status packet, which is a packet that broadcasts the information of surrounding nodes in a regular manner, is able to notify the selected node information as a repeater using an entry field reserved area as "REPEATER' area. 'REPEATER' field has information of group ID and network address (or short address) of the repeater. The node selected as the repeater node can verify the information of repeater terminal selection by receiving the link status packet of the coordinator and registers the member of G1 by writing an entry of link status packet of the coordinator. The link status packet, the information which is broadcasted from node certification and connection process is completed for coordinator and all nodes, can receive the link status packet from all nodes within available communication nodes.

### 2.3.2 Organization of network group in repeater

From the process in Section 2.3.1, R1 which is selected as repeater of G1 organizes the second group (G2) by receiving the beacon frame after an active scan between nodes which is located within the available communication range with R1 to create the transmission of R1. After creating the group, R1 writes the information of G2 member nodes in the neighbor table of R1. R1 selects the second repeater node based on the link status quality for the G2 member nodes for the node that has signal strength over the reference value among nodes that does not overlap with G1 members. R2 information also broadcasts the network address of group ID and sub-group repeater node using the 'REPEATER' field of the link status packet which is generated in the node regularly. As the G2 and R2 information is broadcasted through link status packet, the coordinator can recognize the G2 network organization information without separated overhead

After G1 and G2 organization, these group creating processes keep going until the selected terminal does not have any further transmitting nodes. The information that results during the creating process over G2 transfers to the upper repeater node neighboring with the link status packet and finally the coordinator is able to detect all group information. Figure 3 describes an example for the process.

As a characteristic of wireless media, wireless nodes can detect the connection status packet of nodes within the available communication range. Once the connection status packet is detected, a wireless node writes the measured RSSI and LQI values together with the terminal address on the neighbor table. This process is to acquire the required information in advance when grouping of other nodes around the repeater node if wireless becomes the repeater node. Also, this is to take some information about backup candidates of the repeater against communication trouble or link loss due to an unexpected accident of selected node as repeater.

Because the link status packet is a packet which is generated after connection between two nodes, the method to select repeater using link status packing during group organization is a new method or a method to configure the network without overhead for packet efficiently.

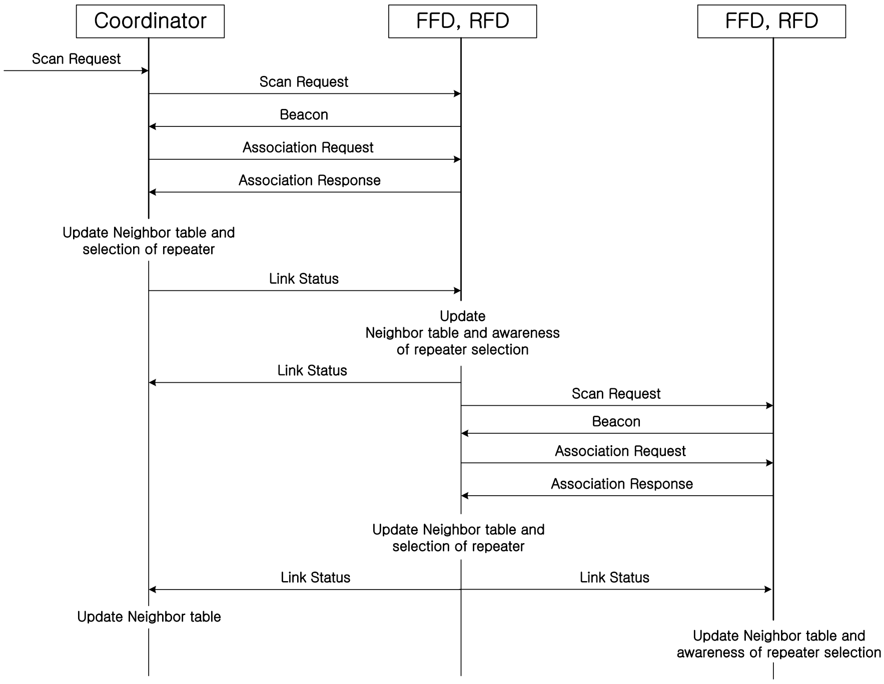


**Figure 5. Repeater node selection process**

## 2.4. Guideline to select Repeater Node

The wireless packet has the signal attenuation phenomenon caused by propagation delay, fading or other similar situations. The RSSI, which represents the signal strength received by wireless signal, can be described by the ratio of measured signal strength in the receiving node and received power, as below. Generally, the value of reference power (Pref) is Pref = 1mW

$$RSSI = 10 \cdot \log \frac{P_{RX}}{P_{ref}}. \qquad (1)$$

The expression of RSSI is organized by transmitting power and received power as shown in Eq. (1). According to Friis' free space transmission equation [3], [6], the received signal strength is inverse proportionally to a decrease for the distance. Therefore, PRX is expressed as below.

$$P_{RX} = P_{TX} \cdot G_{TX} \cdot G_{RX} \cdot \left(\frac{\delta}{\tau}\right)^2. \qquad (2)$$

*$P_{TX}$: Transmission power of sender*
*$P_{RX}$: Receiving power of wave at receiver*
*$G_{TX}$: Gain of transmitter*
*$G_{RX}$: Gain of receiver*
*$\delta$ : Wave length*
*$\tau$ : Distance between sender and receiver*

The propagation of wireless packets has rapid RSSI which decreases according to the transmission distance. This phenomenon obscures accuracy for the location of the transmission node. For this reason, another method to measure the quality of wireless packets was generated, LQI value. LQI value is the strength and quality of the received packet and is measured by combining with RSSI. LQI is measured with the range from 0x00 to 0xff as integer. The minimum and maximum LQI represent the lowest and the highest quality of IEEE 802.15.4 signals which can be found in the receiver. Figure 2 shows the LQI value in accordance with distance, and Figure 3 shows the RSSI value which is interlocked with LQI by distance. The equation for LQI is shown in Eq. (3).

$$LQI = (RSSI\ register\ value + 38) \cdot 4 \qquad (3)$$

The coordinator and each node can calculate the RSSI and LQI values by receiving the wireless packet. If the quality of the wireless link decreases due to movement or removal of repeater, the coordinator and upper repeater are able to set the new repeater node for the nodes with which communication is not available any more based on this value. These methods are suitable for the wireless node characteristic with high variability and high movement.

### 2.5. Packet transmission method

The packet transferring using the suggested algorithm is conducted by multi-hop which has an objective of wide range data transferring through transmitting terminal. If the data transferring node is not the own member's node, the transmitting terminal performs a tunneling function for transmission. The transmitting packet notifies the transmitting frame by describing a 'relay frame' in the packet type of the packet header as well as a source and destination location clearly by describing SA (Source Address) and DA (Destination Address). The repeater node receives this data and searches for a neighbor table to find the routine of the upper repeater node and coordinator to receive and transmit the packet. The coordinator and nodes already know each other's information from the neighbor table using the link status packet. The operating sequence applying suggested method is as follows.

If data transferring is needed to the destination node, the coordinator transfers frame to the first transmitting terminal after searching for transmitting terminal information during routine to the destination location from the neighbor table. The first repeater node inspects the received packet header and transfers the packet by finding destination node or sub-repeater node in the neighbor table. At this time, the tunneling method, shown in Fig. 6 is used. The transmitting frame has a field to notify the transmitting frame inside of the header and the payload data of transmitting frame includes header and data which is sent to the designated node. The repeater node in the final destination which receives the transmitting frame transfers the frame to the destination node of the group which includes itself after removing the transmitting frame header. The destination node which receives data transfers ACK frame to the coordinator to finish the transmission if the data is properly received.

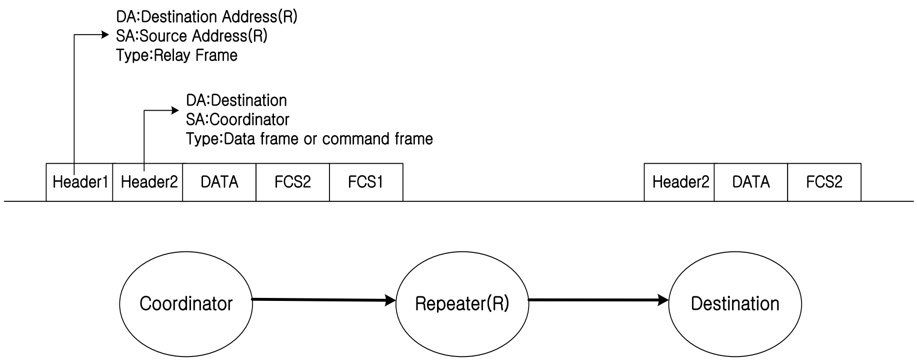


**Figure 6. Tunneling**

## 3. Performance Analysis

Assuming that the repeater node which is selected during grouping is located within the available range of communication with the coordinator and upper group repeater node, and the location is selected with the same location which has the same radius(r) of the group which is created by the coordinator or repeater node. During creation of group, the area of group (σ ) which is newly created using radius r is defined as below Eq. (4).

$$\sigma = -3\pi r^2 + 14r^2 \quad (4)$$

In Eq. (4), which is the area that is generated after creating the first grouping of coordinators, the area of the group which is newly generated excluding the overlapped part with previous groups is represented. Using Eq. (4), the accumulated group area during grouping can be calculated and the equation of the accumulated area($S_n$) during nth grouping process can be defined as below.

$$S_n = 4\pi r^2 - 3n\pi r^2 + 14nr^2 - 14r^2 \quad (5)$$

The group area which is accumulated using Eq. (5) is shown in Table 1. The first process($n$=1) is coordinator generating group and $n \geq 2$ is the area which is generated by repeater generated group.

To analyze the expansion performance and efficiency of the suggested grouping algorithm, we analyze the numerical result for the suggested method. The network environment is 200m x 200m of square area, and the coordinator is located in the center of the area. The coordinator generates the first group in the network, and the wireless nodes are located on the network environment with uniform random distribution. To acquire the result for various environments, the number of wireless nodes is set as 10 to 200 and distributed. Because the signal attenuation affects the communication quality and group generation, we analyze the grouping performance in accordance with the LQI measurement level by dividing 3 LQI values needed in the simulation. The representative LQI value used in the simulation is set as high variation in the range or low variation after setting the value. Table 2 shows the LQI parameters used in the simulation.

**Table 1. Accumulated area in a accordance with grouping process**

| Process($n$) | $S_n$ |
|---|---|
| 1 | $\pi r^2$ |
| 2 | $-2\pi r^2 + 14r^2$ |
| 3 | $-5\pi r^2 + 28r^2$ |
| 4 | $-8\pi r^2 + 42r^2$ |

**Table 2. Used LQI level for performance evaluation**

| Parameter | LQI value(byte) | Distance(m) |
|---|---|---|
| LQI 1 | 90 | 90 |
| LQI 2 | 60 | 40 |
| LQI 3 | 30 | 70 |

Figure 7 shows the accumulated value of the grouping area in accordance with setting values in Table 2. LQI 1, 2 and 3 shows the different accumulated area as the change of grouping process; however, the accumulated area of LQI 3 level shows a wider area expansion than LQI 1 and LQI 2. LQI 1 level value has less effect than 2 and 3 levels during the grouping process and shows less area expansion relatively. In the Figure 7, we can estimate that an LQI value over the reference is needed to show the wanted level of coverage area expansion; even it may be changed in accordance with the configuration and environment of network.

With the result of Figure 7, we can check if the grouping expansion area is different in accordance with LQI level. This result affects the number of nodes which are included in one group during the grouping process. When we set the radius of the available communication range between nodes as $r$, the number of nodes which is included in the group ($N_r$) can be expressed with the function of $r$ as Eq. (6).

$$N_r = 0.5 + \sum_{k=1}^{r-1}(k + 0.5) \qquad (6)$$

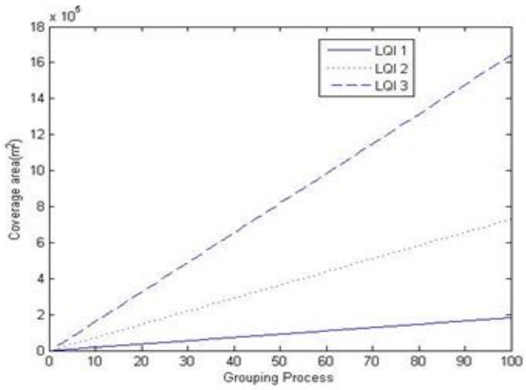


**Figure 7. Accumulated area change during network grouping process(LQI1, LQI2, LQI3)**

$N_r$ may be changed in accordance with the number of entire nodes in network environment, and this represents that the entire number of nodes and numbers included in the group have a certain relation with the ratio($\omega$ ) of the number of nodes for the entire area. $\omega$ is 1 when the number of nodes is 200 in the network. Eq. (6), applying ratio for number of nodes is represented as Eq. (7) as below.

$$N_{r\omega} = 0.5\omega + \sum_{k=1}^{r-1}(k + 0.5)\omega \qquad (7)$$

Using Eq. (7), we can know the number of average nodes and included number of nodes per group for the entire number of nodes distributed on the entire network area. Also, we can calculate the number of generated group in accordance with group radius $r$, using Eq. (5). Where equation for the $\omega$ , the ratio of area and number of nodes is represented as below

$$\omega = \frac{N}{C} \cdot \rho \qquad (8)$$

*N:Number of nodes in network topology*
*C:Coverage Area(m2)*
*$\rho$:Constant integer value, 200*

In Eq. (7), we can recognize that entire number of nodes exit in the network affects the average number of nodes in the group. As shown in Figure 8, the average number of nodes per group, in accordance with the change in the number of nodes in the network, as bigger radius and many the numbers of nodes in topology, as increase the number of nodes included in the group. In LQI 1, the result does not have many changes. In LQI 3, average number of nodes is proportionally increased to the number of nodes and vice versa. As shown in Fig. 8 and Eq. (7), the average number of nodes per group has much greater changes for the group radius and entire number of nodes in network topology. Due to the fact that group radius affects the number of nodes included in the group, we calculate the number of groups that is generated in accordance with group radius as shown in Figure 9. It may be changed in accordance with the entire number of nodes in the network, however, as a result of an increase in the group radius, the number of the generated group is reversely decreased as shown is Figure 8. As a result in Figure 8 and Figure 9, the bigger the group radius and entire number of nodes in the network, the smaller the number of generated group and increase in the number of nodes included per group. In Fig. 10, we can recognize the average number of nodes per group for all nodes in the network. Differing from Figure 8, it shows the value related with radius, the result is increased linearly.

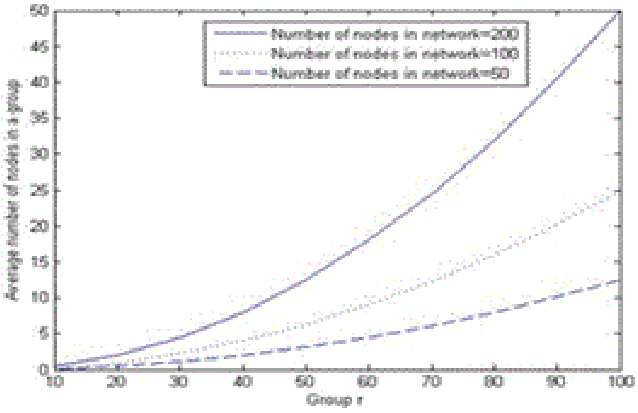


**Figure 8. Number of generated group in accordance with group radius(r)**

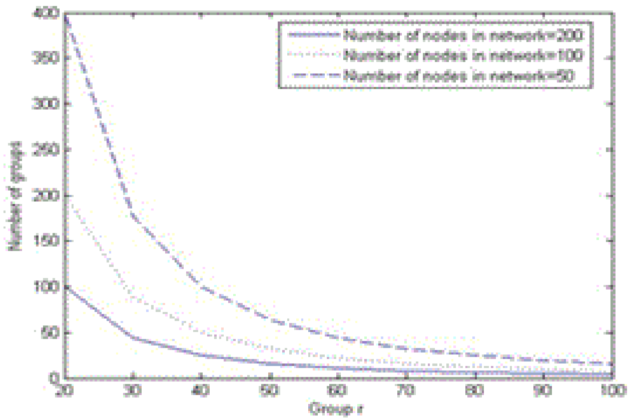


**Figure 9. Average number of nodes per group in a accordance with group radius(r)**

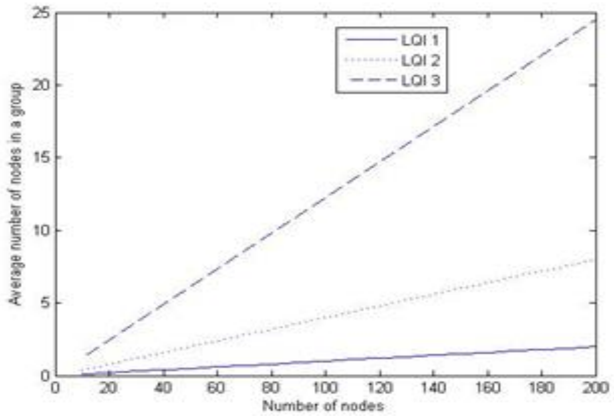


**Figure 10 Average number of nodes for the change in number of nodes in network topology**

## 4. Conclusion

This study suggests the grouping algorithm that is able to transfer data reliably to the destination node using the repeater node from coordinator through grouping between coordinator and transmitting terminal and wireless nodes under the Zigbee network environment. The suggested algorithm is a method that is able to select the repeater node by signal strength and to organize a network which is able to transfer the multi-hop data more reliably than the current network organization method in data transfer.

Also, due to the new method transfer the selection of repeater nodes using the current link status packet to prevent from overhead of new method, it does not have trouble modifying standard and performance decreases from overhead. We also verify entire number of nodes in the network and signal strength mathematically as an important element to organize and expand the PAN in the suggested algorithm and represent the result of the verification. As a result, we can recognize that the result is different in accordance with the signal strength and the number of nodes in the network. These results represent the method to achieve the transferring efficiency of wide range data transferring and reduce network configuration costs by organizing a reliable network under the variable wireless network environment. We represent this as a result of an experiment.

The method suggested in this study can improve the time occupation ratio for the data to be transferred throughout the entire system because it can be used with the objective not to reduce the transfer rate due to data transferring failure from the coordinator to a distant wireless terminal by introducing a grouping concept under the condition that the location and coordinates of wireless nodes cannot be recognized. Also, it makes it easy to satisfy the required QoS because of reduced saving time for the saved data in the buffer.

The suggested method can prevent costs to install the coordinator in each location because of failure in effective routine setting due to signal attenuation when organizing the network in a HAN area of the Smart Grid. In addition, this method can save costs by using the repeater node to transfer data between floors in data transferring in a building so that the method is able to organize the network with a lower cost than current method. Also, because this method follows the packet and scheduling method that is used in the current method, it makes the group and manages the network without overhead. Therefore, it can be used for effective resource distribution and cost conservation in various wireless environments.

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## Authors

**Sung-Je Woo**

Master degree of electrical and electronic engineering in Sungkyukwan University.

Advanced Power Grid Research Division, Korea Electrotechnology Research Institute

**Bok-Duk Shin**

2000-2002 STX Postec R&D team leader

2005 Ph.D, Computer Science in Kyungnam Univ.

2009 Wooam Inc. Director