Energy efficiency improvement based on optimal buffer thresholds model for wireless sensor devices

Yoonkyung Jang
Dept. of Computer
Science and Engineering
Kyung Hee University
Gyeonggi-do, Korea
jokjjs0216@khu.ac.kr

Ahreum Shin
Dept. of Computer
Science and Engineering
Kyung Hee University
Gyeonggi-do, Korea
ashin@khu.ac.kr

Intae Ryoo
Dept. of Computer
Science and Engineering
Kyung Hee University
Gyeonggi-do, Korea
itryoo@khu.ac.kr

***Abstract*— In Wireless Sensor Networks(WSNs), energy efficiency is important because it is difficult to replace battery of sensor nodes frequently. To apply suitable MAC protocol to WSNs, it is essential to maximize the battery power of sensor devices. Group Management MAC(GM-MAC) is one of the MAC protocols that can greatly save sensors' battery power. However, there may be data loss and bottleneck phenomenon with original buffer threshold scheme of GM-MAC. In this paper, we have proposed a new buffer thresholds model. In order to verify performance improvement of the proposed scheme, it has been simulated and compared with original buffer threshold method. In addition, it is compared with mathematical theory. A new buffer thresholds model has been verified to improve energy efficiency and have no data loss at all. It can be used in wide range of WSNs topologies with mobile sensor nodes.

Keywords— Wireless Sensor Networks(WSNs), MAC protocol, stability, buffer threshold, sensor node, sink;

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are used in many areas like environment monitoring, healthcare program, industrial management and so on. WSNs are useful because it can be used in situation that sensors that have mobility without cable.[1]

WSNs consist of sink and sensor nodes.[2] Sensor nodes collect data. Sensor nodes send data to sink. Because sensor nodes have limited information processing capability and limited energy, data is processed at sink with enough computation ability.[3] It is provided to users regardless of time and place.

Battery of sensor node must be replaced because sensor node has limited energy. However, changing battery is difficult because sensor nodes are mostly deployed in hostile environment like mountaintop and underground. Energy is most important resource in WSNs.[4] A situation where one of the sensor nodes consumes all energy and cannot operate can have a bad influence on the operation of the whole WSNs system. Applying suitable Medium Access Control (MAC) protocol to WSNs system is essential to save energy and send data stably.

Studies on MAC protocols are actively being carried out. In the past, sensor node and sink do not have mobility. After that, the sensor nodes have mobility, and now research on the mobility of sensors node and the one of sinks is underway. The mobility of sink can be a solution to the problem of energy consumption imbalance between sensor nodes. [5]

Group-Management MAC (GM-MAC) can be applied to WSNs system with mobile sink and mobile sensor nodes. All sensor nodes have its group number based on distance from sink. A sensor node sends data to its upper sensor node. The upper sensor node means sensor node that has 1 smaller group number.

Sensor nodes in GM-MAC have buffer threshold. A buffer threshold is specified according to group number of each sensor node. A buffer threshold is useful to save energy, but it has bottleneck phenomenon. Also, as a group number increases, the buffer threshold rapidly decreases.

To resolve these problems, a new equation of buffer threshold is suggested in this paper. Numerous experimental results from several buffer threshold formulas based on the polynomial and logarithmic shape of the function have yielded the best fit. A new buffer threshold improves stability of GM-MAC.

This paper is structured as follows: Section II describes the related works. Section III gives the description of original GM-MAC and its problem. Section IV proposes the new buffer threshold. Section V gives the experiments analysis. Finally, the conclusion and future work are described in section VI.

II. RELATED WORKS

A. Grid-Based Energy-Efficient Routing

A space is divided into several virtual sections in Grid-Based Energy-Efficient Routing. All sensor nodes have same energy capacity. Sensor node sends header announcement-packet (HA-packet) to other sensor nodes in same virtual section. A sensor node that has data to send makes data announcement-packet (DA-packet). A DA-packet is sent to header node of its section. A header node of each section sends data according to announcement quorum.[6]

B. Two-Tier Data Dissemination

Two-Tier Data Dissemination (TTDD) is expandable. A source node has its position information. A space is divided based on dissemination node (DN). A sink sends its position information only to DN through the grid structure. A sink sends query when it wants to send data. The DN that receives query from sink is assigned immediate dissemination node (IDN). The collected data is sent to sink through road that query used. A grid lifetime technology and information duplication technology are used in TTDD to maintenance grid structure.[7]

III. Group-Management MAC (GM-MAC)[8]

A. Initial Group Number Setting

Sensor nodes have its own group number based on distance from sink. All sensor node sends data only to upper sensor node. Upper sensor node means the sensor node that has a small group number.

Initial group number setting starts GM-MAC. It is done according to the following procedure.

1) sink: Sink sets its own group number by 0. Group number of sink is always 0. It makes advertisement packet that has group number information. It sends the advertisement packet to other sensor nodes in the communication range. The communication range depends on the performance of the sensor.

2) sensor node

a) sensor node without group number: If a sensor node without group number gets advertisement packet, it sets its group number by adding 1. After that, it produces and sends its own advertisement packet to other sensor nodes.

b) sensor node with group number: If a sensor node that already has group number receives advertisement packet, it compares its own group number and the information of advertisement packet. If the information of advertisement packet is smaller than its own group number, it updates group number. After that, it sends its own advertisement packet to other sensor nodes. On the contrary, it does not do anything.

3) Until all sensor nodes get group number, step 2-a) and step 2-b) are repeated.

Fig. 1. shows the example. It is the network that the initial group number setting is completed. A red circle with an 'S' in the middle of figure represents the sink. A white-circles with number are sensor nodes. The number in the circle is group number of sensor node. The black arrow indicates the direction in which data is transmitted. All data is ultimately collected by the sink.

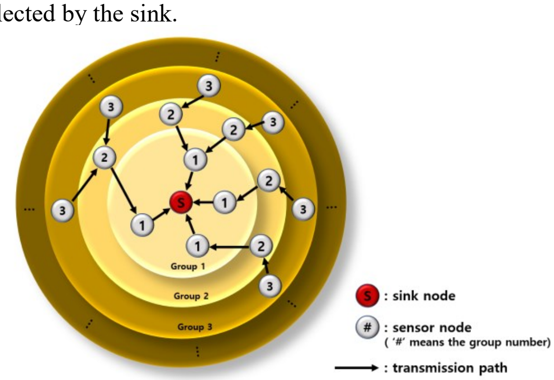

Fig. 1. Example of sensor nodes in GM-MAC

B. Group Number Resetting

If sensor node moves a lot, it can not use its group number information anymore. This is because the sensor node can transmit data only to a sensor node that is one less than its group number.

Sensor node that wants to get a new group number sends hello packet to neighboring sensor nodes. The neighboring sensor node that gets hello packet answer using reply packet. Reply packet has group number information. A new group number is assigned by using this information.

C. Buffer Threshold

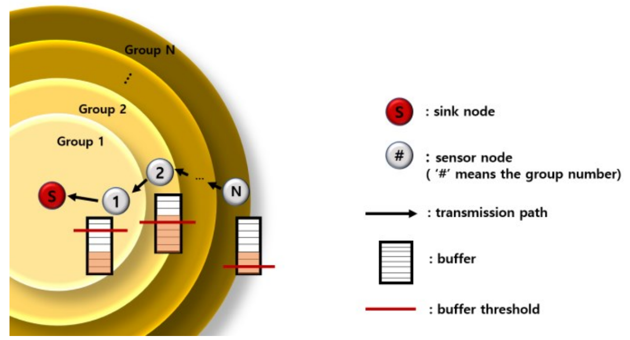

Fig. 2. Buffer Threshold

A buffer threshold is set by group number. A sensor node that located far away from sink has smaller buffer threshold than a sensor node that located near by sink. As a result, the smaller the group number, the smaller number of data transfers.

$$B_i = \beta \times \frac{B_t}{3 \times (i-1) \times i + 1} \tag{1}$$

A buffer threshold is assigned by equation (1). A symbol 'i' is group number.

IV. A New Buffer Threshold

An original buffer threshold has some problems. It has data loss. Data integrity cannot be guaranteed. Also, there is bottleneck phenomenon. This is because the buffer threshold becomes extremely small as the group number increases. Fig. 3. shows bottleneck phenomenon. A sensor node with group number 1 cannot reasonably accommodate data because of an inappropriate buffer threshold. Buffer overflow is reason for data loss.

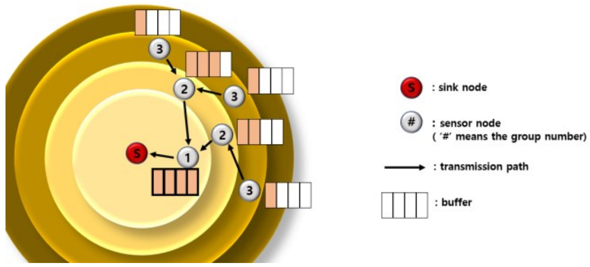

Fig. 3. Disadvantage of original buffer threshold

To get a new buffer threshold, numerous experiments have been carried out.

Equation (2) is polynomial shape of the function and equation (3) is logarithmic shape of the function. To find buffer threshold that ensure energy efficiency while eliminating any data loss, numerous experiments are conducted by putting numbers in 'a', 'b' and 'c'.

$$B_X = \beta \times \frac{B_t}{aX^2 + bX + c} \tag{2}$$

$$B_X = \beta \times \frac{B_t}{(a * log_b(X+1)) + 1} \tag{3}$$

- B_X: buffer threshold of sensor node with group number X
- β: buffer use rate (expectation value), $0 \le \beta \le 1$
- B_t: total buffer size of the sensor node
- X: group number of the sensor node

Fig.4. is experiment topology. The total space is 800 meters wide and 800 meters long. There is sink at the center. Sensor nodes are arranged in a uniform arrangement based on a constant interval. The number in each circle means group number.

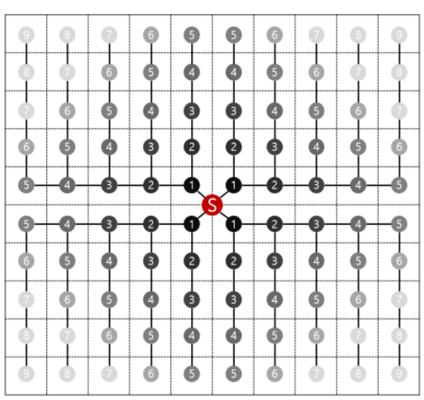

Fig. 4. Topology to Find a New Buffer Threshold

Table 1 is experiment environment. A buffer Utilization is 0.6 and each result is obtained by doing 100 random tests on a variable. To conduct experiments with other elements purified, all sensor nodes have no mobility.

TABLE 1. EXPERIMENT ENVORINMENT

Components	**Descriptions**
physical space	800 m * 800 m
Number of sensor devices	1 sink, 100 sensor nodes
Type of sensor devices used in simulation	CC2420
Battery capacity	3000mW
Tx energy consumption	0.0145mW
Rx energy consumption	0.0156mW
Buffer size	8192 Byte
Maximum Communication distance	about 90 m
Data generation	average 1 time/1 minute
Number of experiments	100

Fig. 5. and fig. 6. are results from polynomial function and 'a' is 0. It uses equation (2). In fig. 5, the best result is 2796 days when 'a' and 'c' is 0 and 'b' is 1. However, this value is cannot be used. Because there is data loss when 'a' and 'c' is 0 and 'b' is 1 in fig. 6.

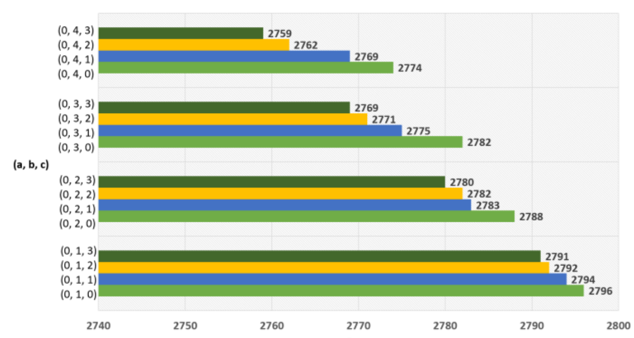

Fig. 5. The first sensor node exhausts all energy when using a polynomial function and 'a' is 0

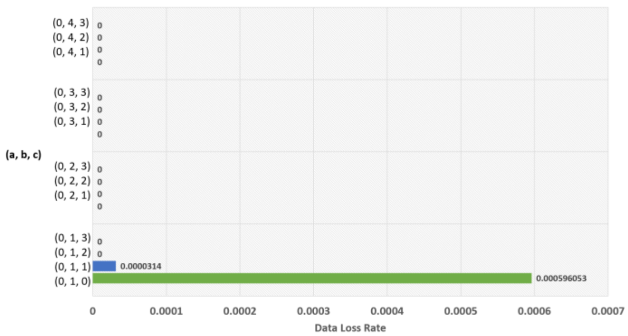

Fig. 6. Data loss rate when using a polynomial function and 'a' is 0

Fig. 7. and fig. 8. are results from polynomial function and 'a' is 1. It uses equation (2). In fig. 7, the best result is 2780 days when 'a' and 'b' is 1 and 'c' is 0. Also, there is no data loss.

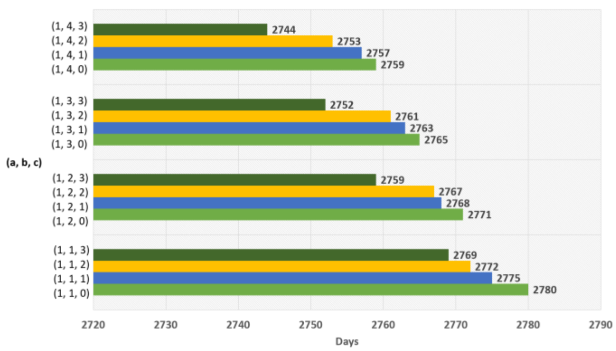

Fig. 7. The first sensor node exhausts all energy when using a polynomial function and 'a' is 1

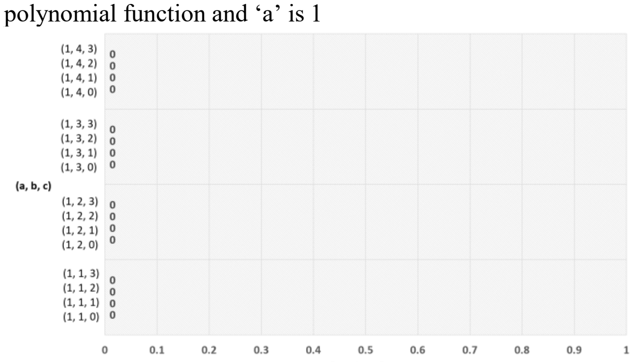

Fig. 8. Data loss rate when using a polynomial function and 'a' is 1

Fig. 9. and fig. 10. are results from logarithmic function. It uses equation (3). In fig. 9, the best result is 3001 days when 'a' is 1 and 'b' is 9. However, there is data loss in fig. 10. The best result in fig. 9. is 2790 days when 'a' is 3 and 'b' is 2. There is no data loss when 'a' is 3 and 'b' is 2.

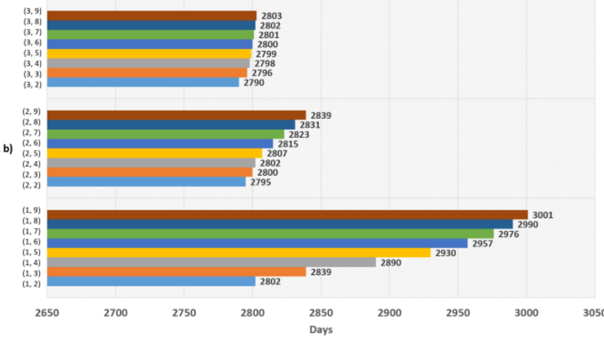

Fig. 9. The first sensor node exhausts all energy when using a logarithmic function

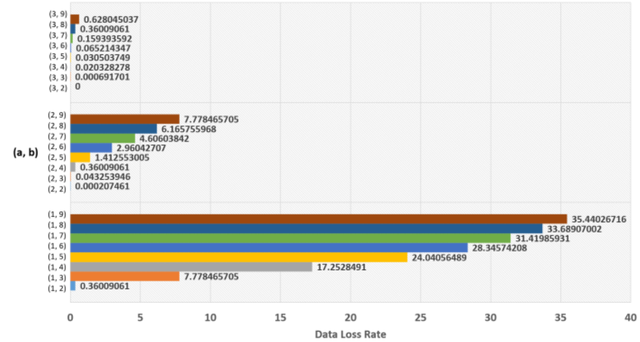

Fig. 10. Data loss rate when using a logarithmic function

Considering all the results of the polynomial and logarithmic function experiments together, the most appropriate buffer threshold is the logarithmic function when 'a' is 3 and 'b' is 2. It saves energy. Also, there is no data loss. An equation (4) is new buffer threshold equation.

$$B_X = 0.6 \times \frac{B_t}{(3 * log_2(X+1)) + 1} \tag{4}$$

- B_X: buffer threshold of sensor node with group number X
- B_t: total buffer size of the sensor node
- X: group number of the sensor node

V. Simulation and Consideration

A. Compare with Original Buffer Threshold

To consider new buffer threshold equation, simulation is conducted. Environment of simulation is same with table 1.

The time when the first sensor node exhausts all energy is 2789days on original buffer threshold. That of proposed buffer threshold is 2790days. In terms of energy efficiency, the two buffer threshold have no different.

In the original buffer threshold, the data loss rate records high. It is about 9.4143%. On the other hand, the newly proposed buffer threshold has no data loss. Also, in terms of data collection rate, it is only about 90.5851% in original buffer threshold. On the contrary, proposed buffer threshold collects almost all data with a data collection rate of about 99.9991%. The reason for not reaching 100% is because there is data in the middle of the way to the sink. The strength of buffer threshold proposed in this paper appears in data loss rate and data collection rate.

TABLE 2. A COMPARATIVE EXPERIMENT RESULT FOR THE BUFFER THRESHOLD VALUE.

	buffer threshold of original GM-MAC	buffer threshold of proposed in this paper
time when the first sensor node that exhaust all energy is generated [days]	2789	2790
data loss rate [%]	9.4143	0
data collection rate [%]	90.5851	99.9991

B. Mathematical Theory

A mathematical theory is method to eliminate data loss while maximizing energy efficiency based on mathematical calculations. When 'n' is amount of collected data by each sensor node, a sensor node sets its buffer threshold to value that added 'n' to buffer threshold of the child node. A buffer size is value added buffer threshold of sensor node with group number 1 to maximum buffer threshold of child node.

Fig. 11. is example of applying mathematical theory to uniform arrangement. Sensor nodes that do not have child sensor node set its buffer threshold to 'n'. Sensor nodes that have child sensor node set its buffer threshold to value that added 'n' to the buffer threshold of child sensor nodes. For example, sensor node with group number 1 in fig. 11. sets its buffer threshold to '25n'. The '25n' is result of adding '20n', '4n' and 'n'. A buffer size is '45n'. The '45n' is result of adding '25n' and '20n'. The '25n' is buffer threshold of sensor node with group number 1 and the '20n' is the biggest buffer threshold among child sensor nodes of sensor node with group number 1.

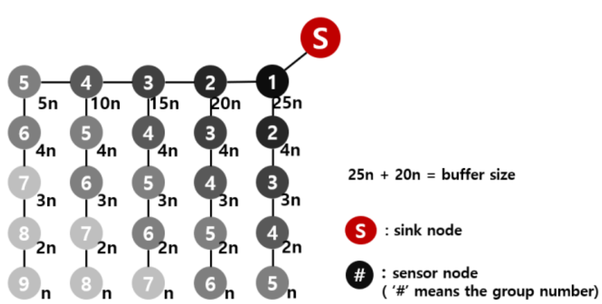

Fig. 11. Mathematical theory on uniform arrangement

C. Results of Comparing New Buffer Threshold Equation with Mathematical Theory

To prove superiority of a new buffer threshold proposed in this paper, it is simulated with mathematical theory for two types of topologies.

Fig. 12. is uniform arrangement. Circles are sensor nodes. A number inside the circle is group number. A value written below each sensor node is buffer threshold. A left side of fig. 12. is topology of an equation (4). A right side of fig. 12. is topology of mathematical theory.

1) Uniform Arrangement

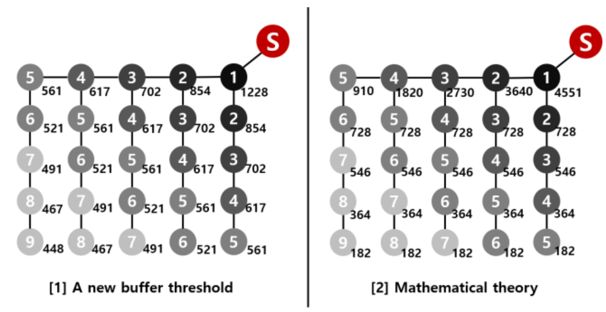

Fig. 12. Uniform arrangement

Table 3 is experiment results of uniform arrangement. The time when the first sensor node consumes all energy is 16017 minutes in equation (4) and 28500 minutes in mathematical theory. Energy efficiency is better when mathematical theory is used in uniform arrangement. In both methods, there is no data loss at all. The amount of data that does not be transmitted to the sink at the time when the first sensor node that consumed all energy is 5350bytes in equation (4). There is no data that does not be sent in mathematical theory.

TABLE 3. RESULTS OF UNIFORM ARRANGEMENT

	Equation (4)	Mathematical Theory
The time when the first sensor node consumes all energy [mins]	16017	28500
Data loss rate [%]	0	0
The amount of data that does not be transmitted to the sink [bytes]	5350	0

2) Tree Arrangement with 2 Child Sensor nodes

Fig. 13. is tree arrangement with 2 child sensor nodes. A left side of fig. 13. is topology of an equation (4). A right side of fig. 13. is topology of mathematical theory.

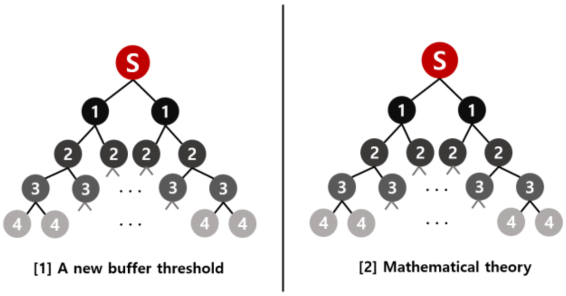

Fig. 13. Tree Arrangement with 2 Child Sensor nodes

Table 4 is experiment results of tree arrangement with 2 child sensor nodes. The time when the first sensor node consumes all energy is 46501 minutes in equation (4) and 28501 minutes in mathematical theory. Energy efficiency is better when equation (4) is used in tree arrangement with 2 child sensor nodes. There is no data loss at all in equation (4). On the other hand, these is data loss about 0.0178% in mathematical theory. The amount of data that does not be transmitted to the sink at the time when the first sensor node that consumed all energy is 28520bytes in equation (4) and 11320bytes in mathematical theory.

TABLE 4. RESULTS OF TREE ATTANGEMENT WITH 2 CHILD SENSOR NODES

	Equation (4)	Mathematical Theory
The time when the first sensor node consumes all energy [mins]	46501	28501
Data loss rate [%]	0	0.0178
The amount of data that could not be transmitted to the sink [bytes]	18520	11320

3) *Superority of a New Buffer Threshold*

The results of the two experiments show that a new buffer threshold proposed in this paper has superiority to mathematical theory. A new buffer threshold has no data loss at all. However, mathematical theory has data loss except for uniform arrangement.

Also, a mathematical theory can be applied only to situation that all sensor nodes are fixed and the amount of data collected by each sensor node is all the same. To apply mathematical theory, sensor node must know whole information of child sensor nodes. It is impossible to apply mathematical theory to GM-MAC with mobility.

A new buffer threshold proposed in this paper can be applied to GM-MAC with mobility. In new buffer threshold, sensor nodes do not need to know any information about child sensor nodes.

VI. CONCLUSION

In this paper, a new buffer threshold for GM-MAC is proposed. There is stability problem in original buffer threshold in GM-MAC. Because there is severe data loss and bottleneck phenomenon. To solve these problems, a new buffer threshold is suggested through numerous experiments with polynomial and logarithmic shape of the function. Equation (4) is derived as a new buffer threshold.

A new buffer threshold in this paper has superiority to mathematical theory. A mathematical theory is only applicable in certain situations. On the other hand, a new buffer threshold has flexibility. It can be used to any situations. It improves stability of GM-MAC. Also, it does not have data loss at all.

Additional experiments and consideration are needed to apply buffer threshold to GM-MAC with 3-Dimensional environment. It is future work to do.

ACKNOWLEDGMENT

This research was supported by Korea Electric Power Corporation. (Grant number: R18XA02)

REFERENCES

[1] IXem Labs, Alina Plesca, Riccardo Stefanelli and Daniele Trinchero "Dynamic wireless sensor networks for real time safeguard of workers exposed to physical agents in construction sites", IEEE Topical Conference on Wireless Sensors and Sensor Networks (WiSNet), Austin, TX, USA, March, 2013, pp. 55-57,.

[2] YoungSang Yun, Ye Xia, Behnam Behdani and J. Cole Smith, "Distributed Algorithm for Lifetime Maximization in a Delay-Tolerant Wireless Sensor Networks with a Mobile Sink," IEEE Transactions on Mobile Computing, vol. 12, no. 10, October, 2013. pp.1920-1930.

[3] Hyunchul Kim and Jungsuk Kim, "Energy-Efficient Resource Management in Wireless Sensor Network," IEEE Topical Conference on Wireless Sensors and Sensor Networks, Phoenix, AZ, USA, January, 2011, pp. 69-72.

[4] Jangsu Park and Byoungchul Ahn, "Mobile Sink Data Gathering through Clustering," Journal of the Institute of Electronics Engineers of Korea – Computer and Information, vol. 46, no. 5, September, 2009, pp.79-85.

[5] Sanglae Kim, Junho Park, Dong-ook Seong and Jaesoo Yoo, "An Energy-Efficient Data Gathering Method Based on Mobile Sinks in Wireless Sensor Networks," Journal of Korea Information Science Society: Information Networking, vol. 40, no. 1, February, 2013, pp.36-43.

[6] Kisuk Kweon, Hojin Ghim, Jaeyoung Hong and Hyunsoo Yoon, "Grid-Based Energy-Efficient Routing from Multiple Sources to Multiple Mobile Sinks in Wireless Sensor Networks," 4th International Symposium on Wireless Pervasive Computing, Melbourne, VIC, Australia, February, 2009 .

[7] Haiyun Luo, Fan Ye, Jerry Cheng, Songwu Lu and Lixia Zhang, "TTDD: Two-Tier Data Dissemination in Large-Scale Wireless Sensor Networks," Wireless Networks, vol.11, Issue1-2, January, 2005, pp.161-175

[8] Intae Ryoo, Kyunghee Sun, Jaesun Lee, Seokhoon Kim· "A 3-dimensional group management MAC scheme for mobile IoT devices in wireless sensor networks." Journal of Ambient Intelligence and Humanized Computing, Aug. 2017, pp.1-12.