A Logical Group Formation and Management Mechanism Using RSSI for Wireless Sensor Networks*

Jihyuk Heo, Jin Ho Kim, and Choong Seon Hong**

Department of Computer Engineering, Kyung Hee University,
Sochen-ri, Giheung-eup, Yongin-si, Gyeonggi-do, 446-701, South Korea
jihyuk@khu.ac.kr, jhkim@networking.khu.ac.kr,
cshong@khu.ac.kr

Abstract. Wireless sensor network is a suitable technology for ubiquitous environment. However, in WSN, as the network size grows larger, overheads such as flooding, calculation and memory overhead rapidly increase as well. For reducing the overhead of Micro Controller Unit (MCU) calculation and energy consumption, partitioning of WSN in several groups and hierarchy is suggested. For group formation, these mechanisms typically utilize predesigned network group information or location aware algorithms. However, the existing methods which use network topology information have node distribution and scalability problem in dynamic networks. Also, methods which use location-awareness have energy consumption problems. Therefore, we suggest a logical group formation and management mechanism using sensor association information and received signal strength indication without using any additional devices. With the help of proposed mechanism, WSNs would have stability and long lifetime.

Keywords: Wireless sensor networks, WSN, logical group formation, group management, RSSI.

1 Introduction

Wireless Sensor Networks (WSNs) are organized with a number of tiny sensor nodes. Unlike personal computers, sensor nodes are typically characterized by their limited computing power, limited memory, low power resources and expectedly low cost. Diminutive in size, easy deployment and low cost make sensor nodes a perfect candidate to build a Ubiquitous computing environment.

Because, WSNs are usually deployed to sense certain phenomenon and then forwarding the sensed data to the sink, numbers of small size packets are flowed. However, sensor nodes have limited resources. As a result, large scale WSN has less stability. Similarly, organizing and managing groups are also needed for dynamic network stability.

---

* "This research was supported by the MKE under the ITRC support program supervised by the IITA" (IITA-2008-(C1090-0801-0002))".

** Corresponding author.

Y. Ma, D. Choi, and S. Ata (Eds.): APNOMS 2008, LNCS 5297, pp. 207–216, 2008.

In this paper, we propose a logical group formation and management mechanism for constructing proper number and size of groups using sensor node association information and Received Signal Strength Indicator (RSSI) without additional devices. Through proposed mechanism, WSNs would have stability and long lifetime.

The rest of this paper is organized as follows. In section 2, related work in the field is discussed. In section 3, the proposed logical group formation and management mechanism is defined. In section 4, the performance of the proposed mechanism is analyzed against other group formation scheme and scheme using ad-hoc location aware system. Finally, in section 5, we conclude our work and discuss future work.

2 Related Works

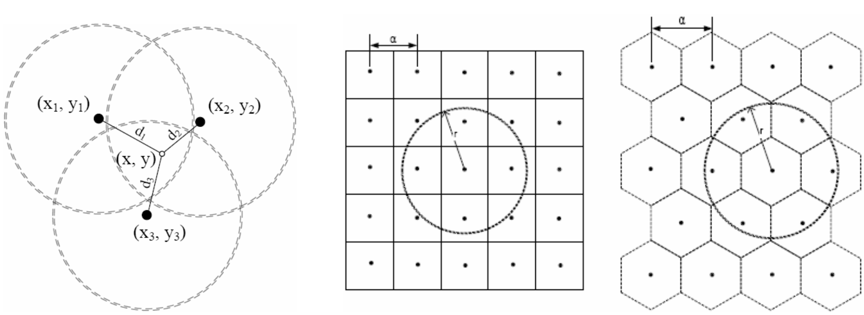
As the WSN size grows bigger and bigger, various overheads increases as follow.

Flooding overhead is first. Because sensor nodes enter or leave the network frequently, the WSNs are very dynamic. So, proactive (on-demand) routing protocol is used for routing algorithms. For example, in ZigBee specification [2], AODV (Ad-hoc On-demand Distance Vector) is used. To discover route to destination, routing control messages are flooded to all network nodes. This flooding is big overhead to sensor node which has limited resources.

Next, decrease of network lifetime. Because of the nature of broadcast, it causes duplicated transmission and broadcast handling cost is very high. It consumes much energy and makes network lifetime shorter consequently.

Finally, as the WSN size increases the ‘key management’ becomes more difficult and the probability of a node of being compromised or key leakage increases as well. Group based network can handle these problems even if size of the network is large. Therefore, group based network management is needed. There are 3 kind way to group formation as follow.

First method uses group topology information. In this method, sensor nodes are deployed on predefined places. Furthermore, nodes are also assigned their group before installation. This method should draw a plan about network size, the number of groups, group deployment position and so on. This method, as it seems, is too strict to adapt dynamic network environment.



(a) Group formation mechanism using ad-hoc location aware system

(b) Group formation mechanism using location awareness

Fig. 1. Group formation mechanism

Second method uses additional device or ad-hoc location aware system for group formation. Firstly additional device like Global Positioning System (GPS) is attached to sensor node for measuring absolute location [3]. Secondly, other sensor nodes calculate relative positions from location aware sensor nodes [4][5]. As you can see in (a) of figure 1, location aware sensor node knows its own location and spread beacon with its own location information. So, sensor nodes can calculate relative position. Through this algorithm, WSN designs rectangle or hexagon shape group like (b) of figure 1. However, the price of GPS chip is much expensive than sensor node [8] and the power of location aware sensor nodes exhaust drastically due to spreading location information which makes this solution less appealing.

Last method makes group logically. WSNs are expanded through node associations. In this association procedure, the new incoming sensor node makes relationship with neighbor node [1][2]. Hence, the nodes which have relationship are located closely. This method uses that association information for group formation [6].

Through one of the above 3 discussed methods, WSN operates in two tiers and operated hierarchically. In the lower level, broadcast spread only within own group. When a sensor node of one group wants to transmit to the sensor node of the other group, data transmission is performed via upper level.

In recent research, location aware algorithm is popularly used for group formation and management. But, regularly used GPS is very expensive than sensor node which has a purpose to reduce the product cost to 2 dollars [8]. Because location awareness is used during initialization phase only, method using location aware algorithm is expensive solution for WSN as most of the time expensive devices are not used. Therefore, mechanism for logical group formation and management without additional device like GPS or ad-hoc location aware system needs to be researched.

3 Proposed Scheme

When a new incoming node joins the network, that node chooses one of the existing node as a parent which has lowest depth (depth means location level of tree structure and it started from root as zero) and highest Link Quality Indicator (LQI; RSSI is a kind of LQI) within neighbor nodes [1][2].

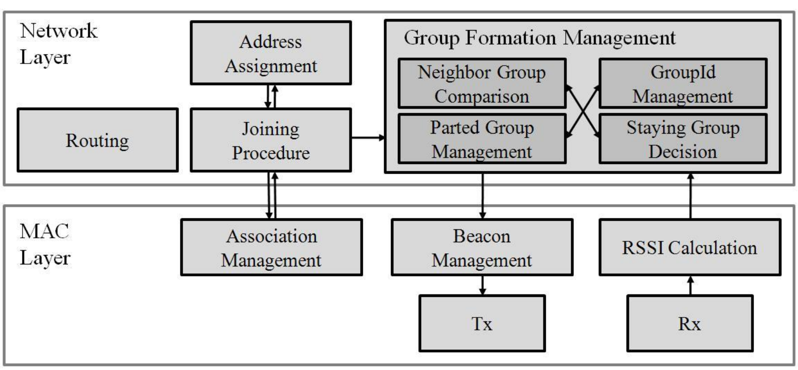


Fig. 2. Group Formation Management Architecture

As you can see in figure 2, our proposed mechanism for logical group formation and management uses association information and calculated RSSI through transmitted and received packets.

3.1 GroupId

Each group has identity which is called GroupId. The GroupId could be described as two ways. Like figure 3, 16/32 bits GroupId is divided into various bits for describing group hierarchy.

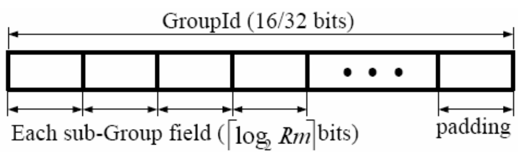
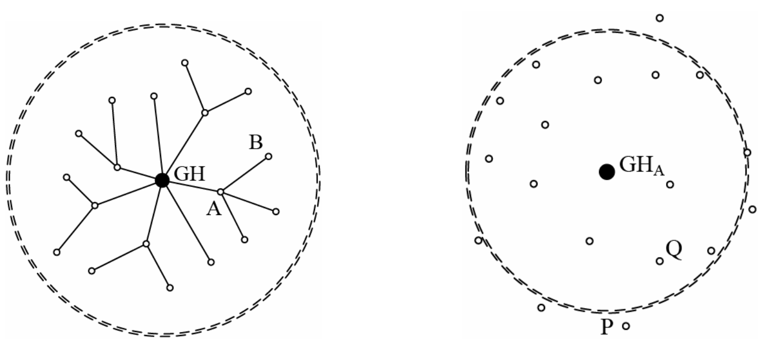


Fig. 3. GroupId for describe group hierarchy

In ZigBee specification, maximum number of router (*Rm*) is defined. The *Rm* is available router number for a sensor node to associate; default value of *Rm* is 0x06. According to figure 3, each sub group has 3 bits ($= \lceil \log_2 6 \rceil$bits) to describe group hierarchy. Through this described method, subneting/superneting algorithm could be applied to group. However, it could not be flexible to describe group hierarchy of too dynamic network because group hierarchy structure too easy to break when sensor nodes frequently enter and leave the network. So, this method is used for relevantly stable network environment.

On the other hand, The GroupId can be described just by 16bits short address of header nodes. Only 16 bits address space is needed to describe GroupId and it has flexibility to describe dynamic network. However, this case is not able to describe group hierarchy. Therefore, this method is used for dynamic network environment.



(a) Group expansion according to sensor nodes association (b) Construction of parted group

Fig. 4. Group construction and expansion

3.2 Expansion of Group

When new incoming sensor node enters the network, it tries to become a part of its parent's group. From this algorithm, group is expanded later on. In this procedure, nodes spread beacon to give their own information to neighbor nodes. Through the information contained in a beacon nodes can recognize neighbor group headers.

Figure 4 (a) shows that wireless sensor network which is organized as tree structure. The connected lines mean parent-child relationship of nodes. The entered sensor node tries to belong to group G as long as RSSI, measured with group header GH, is higher than threshold.

3.3 Parted Group Generation

If sensor node is starting point of network like sink or if RSSIs which are measured with neighbor group headers are below than threshold (it means there is no near group header), sensor node cannot able to belong to the group according to algorithm described in 3.2, Expansion of group. In these cases, sensor node construct parted group.

$$P_r = \left(\frac{K}{4\pi R}\right)^2 \cdot G_t \cdot G_r \cdot P_t$$

$$R = \frac{K}{4\pi}\sqrt{\frac{G_t \cdot G_r \cdot P_t}{P_r}} \Rightarrow R \propto \frac{k}{\sqrt{P_r}}$$

P_r : Receiver side electric power [w] P_t : Sender side electric power [w]
K : Used wavelength (c/f) [m] R : Distance between sender and receiver [m]
G_r : Receiver side antenna electric power gain [dB]
G_t : Sender side antenna electric power gain [dB]

Fig. 5. Received Signal Strength Indicator (RSSI) Fomula

To calculate distance between sensor node and group header node, we can use RSSI. All sensor node can calculates RSSI by formula shown in figure 5 when sensor node transmits or receives packet [1]. The sensor node can guess distance between two nodes according to the formula, because all parameters except R and P_r are fixed in hardware specification. Therefore, new incoming node decides whether belongs to group of parent node or constructs a parted group according to RSSI threshold. For being separate group, parted group should operate merge procedure with nearby groups.

Figure 4 (b) shows the example of parted group construction. Sensor node A and B are belong to group G_A because RSSI of nearest group header GH_A is strong. However, Sensor node P constructs new parted group, because RSSIs of neighbor group header are week or do not exist.

3.4 Merge of Parted Group

In boundary of group, there are many parted groups which do not belong to the ordinary group. Because sensor nodes which are located in group boundary have low signal strength with ordinary group header, that sensor nodes trying to construct parted groups respectively. Therefore, we need merge procedure for a number of parted groups.

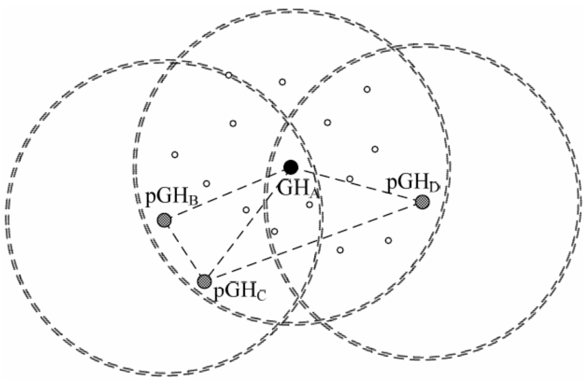


Fig. 6. Merge procedure of parted groups

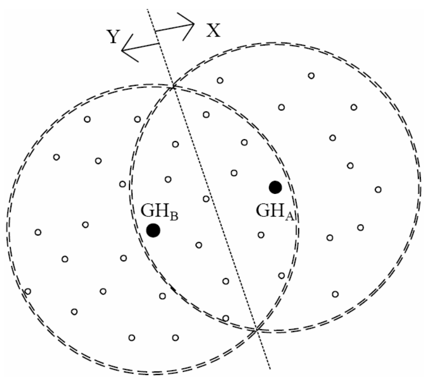


Fig. 7. Decision of normal sensor node to belong to group

Parted group header calculates distances with neighbor group headers or neighbor parted group headers. Then, merge procedure is performed between close distanced group headers. And, group header which has low depth and smaller address going to be a group header of merged group. If parted group header is isolated, it becomes a separated group.

Figure 6 shows that merge procedure of parted groups and group construction of parted group. Node pGH_B, pGH_C and pGH_D are parted group headers, because they have long distance with group header GH_A. Parted group header node pGH_D has no suitable group to merge, so the parted group header pGH_D going to be separate group header. However, parted group header pGH_B and pGH_C are located closely, so they perform merge procedure. Parted group header pGH_B and pGH_C have same depth. Because parted group header pGH_B has lower address, parted group G_C merge to parted group G_B.

3.5 Belonging to Group Decision of Sensor Node

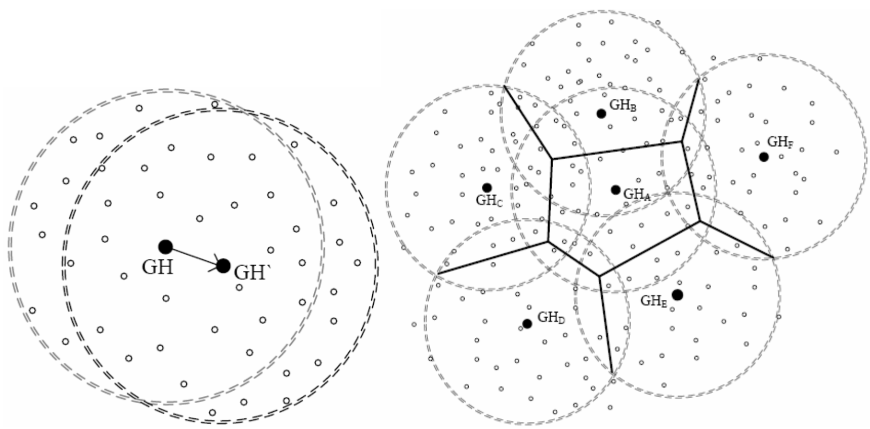
New group formation has an effect on near sensor nodes. Normal sensor nodes belong to group for efficient energy consumption. Normal sensor nodes monitor the distance with group header nodes and try to belong to nearest group.

Figure 7 shows that after node GH_B separates from group G_A, node GH_B construct group G_B. As you see in figure 7, the overlap region is made by two group header nodes GH_A and GH_B. Sensor nodes which are located in this overlap region can decide which group to belong according to comparison of RSSI. Usually, sensor nodes which are located X direction of dotted line belong to group G_A and sensor nodes which are located Y direction of dotted line are belong to group G_B.

3.6 Group Reformation and Management

In the heterogeneous network, sensor node which has routing capability and relevantly more battery power takes a role of group header. Normal sensor nodes transmit packet via group header. So, group header node consumes more energy. As a consequence, group header replacing mechanisms are suggested in heterogeneous network. In this paper, group is formed by radio range of group header node, so group header replacing mechanisms have an effect on sensor nodes group association.

After group header node is changed according to group header election algorithms, normal sensor nodes should be reconfigured. When the group header node is changed, normal sensor nodes which are close or distant from group header node are reconfigured by the algorithm explained in Section 3.5.



(a) Case of group header replace (b) Case of group header power off

Fig. 8. Reconfiguration of group foramtion

Figure 8 (a) shows that sensor node reconfiguration when the group header is changed. Right bottom sensor nodes which are closed to group header node GH` belong to group G` and left top sensor nodes which are far away from group header node GH` belong to other group or construct a new parted group.

Group header node disappearance is another reason of group reconfiguration. When the group header node performs power off or suddenly break down, sensor nodes which are belonged to that group, have to find new group to belong. Some sensor nodes which are located at the boundary belong to nearer groups. Other sensor node which are located the center construct new parted group and perform merge and belong procedure according to the description given in Section 3.4. and 3.5.

Figure 8 (b) shows that example of WSN with 6 groups. In this case, if group header node GH_A of center group is down, sensor nodes which are overlapped with other group G_B, G_C, G_D, G_E, G_F respectively belong to group G_B, G_C, G_D, G_E, G_F. And, sensor nodes which are located at the center of group G_A respectively construct parted group and merge.

Finally, we can form and manage logical group using node association information and RSSI without location aware algorithms or additional chip.

4 Simulation Results

To evaluate the performance of our proposed scheme we have performed simulations using NS-2 on Fedora Core 3. The IEEE 802.15.4 Medium Access Control Protocol is employed as the Data Link Layer. In the simulations, sensor nodes are deployed randomly.

In simulation, we compare our proposed mechanism with a logical group formation scheme using association information [6] and Centroid [5] using location aware algorithm. And we can evaluate efficiency of our proposed mechanism through measurement of group completing time and the number of groups according to RSSI threshold.

Figure 9 shows the group formation completing time with different number of sensor nodes. The Group formation completing time means time required to assign every

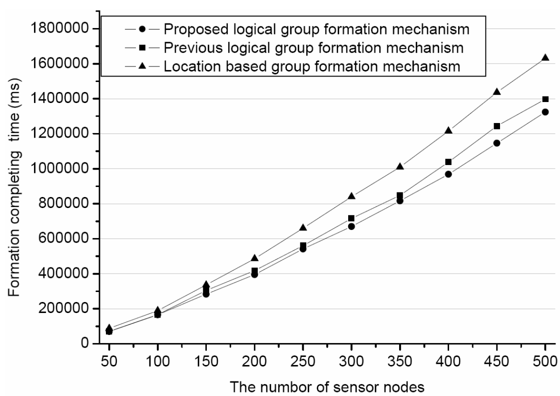


Fig. 9. The group formation completing time

sensor node a group. In each case i.e. proposed mechanism, a logical group formation scheme [6] and Centroid [5], the number of sensor nodes is changed by 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500.

In figure 9, we can see that group formation completing times of logical group formation mechanisms are similar. However, group formation completing times of logical group formation mechanisms are shorter than the location aware group formation mechanism.

The logical group formation mechanisms just calculate and compare without additional RF transmission because nodes decide belonging just according to logical information. However, the mechanisms which use location aware algorithms use transmission of location beacon for confirming its own location. The Additional RF transmission brings time delay and energy consumption.

Figure 10 shows that the number of formed groups according to threshold of RSSI with randomly deployed 100 sensor nodes in 50 square meter.

For convenience, we indicate RSSI by integer value from 0 to 255. Thresholds of RSSI are set 128, 153, 179, 204, 230 and 255.

As figure 10 shows, when the threshold of RSSI is set to 204, the number of formed groups is 23 and the average number of sensor nodes belong to a group is approximately equals to 4. Also, at that point, the energy is consumed less than other.

From above simulations, proposed logical group formation and group management mechanism is more efficient in time and cost of network structure than existing mechanisms that use location aware algorithms [5] or logical group formation scheme [6].

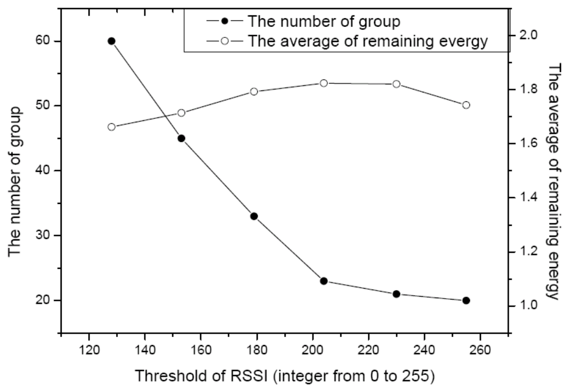


Fig. 10. The number of formed groups

5 Conclusion

In the paper, we suggest a logical group formation and group management mechanism. Using proposed mechanism, WSNs could make and manage proper number and size of groups without additional devices.

Our proposed mechanism uses association information between sensor nodes and RSSI value. Our algorithm operates in following 3 phases for group formation and management. At first, according to RSSI value among group header nodes of own group and neighbor group header nodes, sensor nodes determine whether to make a new group or not. Next, normal sensor nodes decide which group they belong to according to RSSI value of neighbor group header nodes. Finally, group header nodes compare RSSI value of neighbor group header nodes and determine whether to merge group or not.

Effects of sensor node density to logical group formation and management and verification of proposed mechanism through implementation on test-bed are left as the future work.

References

1. IEEE Std. 802.15.4-2006, IEEE Standard for Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements - Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs) (2006)
2. ZigBee Standards, ZigBee Document 053474r15, ZigBee Alliance (Febuary 2007)
3. Luo, H., Ye, F., Cheng, J., Lu, S., Zhang, L.: TTDD: Two-Tier Data Dissemination in Large-Scale Wireless Sensor Networks. Wireless Networks 11(1-2) (Febuary 2005)
4. Chu, H.-C., Jan, R.-H.: A GPS-less, outdoor, self-positioning method for wireless sensor networks. Ad Hoc Network 5(5) (July 2007)
5. Bulusu, N., Heidemann, J., Estrin, D.: GPS-less Low Cost Outdoor Localization for Very Small Devices. IEEE Personal Communications Magazine (October 2000)
6. Lee, J.W., Heo, J., Hong, C.S.: A Logical Group Formation and Key Distribution Scheme in WSN. Journal of Korea Institute of Information Scientists and Engineers 34(4), 296–304 (2007) (in Korean)
7. Miura, H., Sakamoto, J., Matsuda, N., Taki, H., Abe, N., Hori, S.: Adequate RSSI Determination Method by Making Use of SVM for Indoor Localization. In: Gabrys, B., Howlett, R.J., Jain, L.C. (eds.) KES 2006. LNCS, vol. 4252, pp. 628–636. Springer, Heidelberg (2006)
8. Digital Times, http://www.dt.co.kr/contents.html?article_no=2007011702011757730004 (in Korean)