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A visiting scheme of mobile sink system in distributed sensor networks

Sang-Joon Park*, Jong-Chan Lee*

*Professor, Dept. of Computer Information Engineering, Kunsan National University, Gunsan, Korea
*Professor, Dept. of Computer Information Engineering, Kunsan National University, Gunsan, Korea

[Abstract]

The sensor networks should be appropriately designed by applied network purpose, so that they can support proper application functions. Based on the design of suitable network model, the network lifetime can be maximized than using other general strategies which have not the consideration of specific network environments. In this paper, we propose a non-deterministic agent scheme to the mobile sink in distributed wireless sensor networks. The sensor network area can be divided into several sensor regions. Hence, to these such networks, the specified suitable scheme is requested by the applied network model to implement satisfactory network management. In this paper, we theoretically represent the proposed scheme, and provide the evaluation with the simulation results.

▸ **Key words**: Sensor networks, distributed region, non-deterministic agent, mobile sink, sensor node

[요 약]

센서 네트워크는 네트워크 응용 목적에 따라 적합하게 설계되어야 하며, 이에 따라서 유효한 응용 기능을 지원할 수 있다. 특정 네트워크 환경을 고려하지 않은 일반적인 전략을 사용하는 것보다 적합한 네트워크 모델의 설계를 기반으로 네트워크 수명시간을 극대화 시킬 수 있다. 본 논문에서는 분산 무선 센서 네트워크에서 이동 싱크에 대한 비결정형 에이전트 방식을 제안한다. 센서 네트워크 지역은 여러 분산 구역으로 나누어질 수 있다. 그러므로 이러한 네트워크에 대해 만족스러운 네트워크 관리를 구현하기 위하여 특정 네트워크 모델에 따른 적합한 방식이 요구된다. 본 논문에서는 제안한 방식에 대한 분석과 시뮬레이션 결과의 평가를 제공한다.

▸ **주제어**: 센서 네트워크, 분산 지역, 비결정적 에이전트, 이동 싱크, 센서 노드

• First Author: Sang-Joon Park, Corresponding Author: Jong-Chan Lee
*Sang-Joon Park (lubimia@kunsan.ac.kr), Dept. of Computer Information Engineering, Kunsan National University
*Jong-Chan Lee (chan2000@kunsan.ac.kr), Dept. of Computer Information Engineering, Kunsan National University
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I. Introduction

Wireless network technologies are being continuously extended by the industrial developments and academic researches. Wireless sensor networks (WSN) can be applied into various Information and Communication Technology (ICT) environments with their proper purpose [1][2][7][8][9]. There are many applied areas of WSN such as the healthcare monitoring, the battle field surveillance, inaccessible land and home monitoring system. They are mainly used to monitor the state change of observation environment, or to track the information of target system.

In a geographical area, numerous sensor nodes are employed to gather monitoring data, and they transmit gathered data to the sink system. Deployed sensor nodes have tiny size with limited radio range, so that the multi-hop communication between the sensor node and the sink system is inevitable to send data. And, on the network operations the energy saving of sensor node should be considered because of the constraint battery size. By these system limitations, the operation mode of sensor node and the suitable design of WSN are fundamentally related with the network lifetime. The network lifetime of WSN might be defined as the consumed time from the starting point of WSN operation to the collapse point that substantial data of an area cannot be provided to the sink system. Accordingly, the energy saving considering the network lifetime of WSN is major open issue to provide suitable network service [1][2][6][7].

The sensor node has the operation modes to manage the system implementation for the sensing and transmission/reception of data. The network lifetime can be increased by the management of operation mode. There are some mechanisms to conserve the energy by the arrangement of these operation modes [3]-[5]. Also, the feasible WSN design as well as the operation mode of sensor node should be considered to increase the network lifetime. The WSN design affects the construction of the network architecture which may support the expansion of network lifetime and applications. The relations of sensor node and the sink system may have influence to the design of appropriate WSN. Here, the mobility of sensor node and sink system is an element for the relation between sensor node and sink system. If the sensor node and sink system stay at static location, the sensor node has not much effort to find the connection of sink system whenever it has the transfer data.

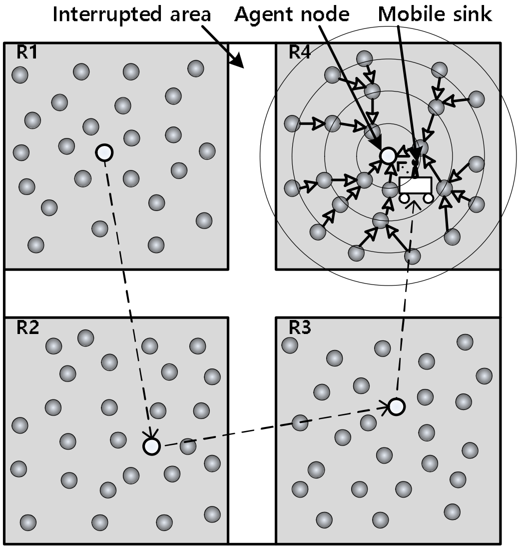


Fig. 1. Base station system state

II. Visiting Scheme of mobile sink

The system In WSN, continuous spread sensor nodes can implement the communication with the mobile sink when they have sending messages. However, the communication interruption may restrict instant sending in distributed sensor network environments. As shown in Fig.1, the intermediate interrupted area between distributed regions has not any sensor node, although sensor nodes within a region are placed continuously. The distributed regional area can be freely configured to suitable applied networks for the large scale WSN. The figure shows that by the visiting scenario the mobile sink visits four distributed regions *(R1, R2, R3 and R4)* which can be clusters to monitor special event. Generally, the visiting scenario might include the visiting sequence of distributed regions, agent node finding, data gathering and the mobility pattern etc. We suppose that in a region sensor nodes are uniformly located with independent randomness. Let N in a region be the total number of sensor node, which follows a Poisson distribution [5].

$$P(N) = \frac{\lambda^{N} e^{-\lambda}}{N!} \tag{1}$$

where λ is the density of sensor node in a region.

When the mobile sink visits firstly a sensor region, it determines the agent node among general sensor nodes. The agent node needs not have special capacity when a general sensor node becomes the agent node. It just changes the node mode from the general node to the agent node. The agent node mainly implements the delivery role of data received from sensor nodes to the mobile sink. In Fig.1, it is assumed that the mobile sink moves inside the region *R4* where sensor nodes are widely distributed with uniform density, and at adequate inside location it sends neighbor sensor nodes a *hello* message which has unique *id* number. If neighbor nodes receive *hello* message, and they have enough energy level to become agent node, they answer the message by sending *hello_ack* message. When those sensor nodes prepare the *hello_ack* message, their energy information is included into the message. Here, the signal of *hello_ack* message is usually transmitted much less than the *hello* signal of mobile sink so that all *hello_ack* signals of neighbor sensor nodes cannot arrive to the mobile sink. However, the mobile sink may hear the signal of near sensor nodes within one hop area. The signal strength is strong enough to reach from neighbor nodes to the mobile sink, although tiny sensor nodes have lower system capacity than the mobile sink to the signal propagation. And those sensor nodes become candidates to the agent node. The mobile sink once receives the *hello_ack* message, among candidate nodes it decides which node is selected as the agent node. The determination criterion of agent node is about the level of remaining energy quantity. If a candidate node has the needed energy level to become agent node, it may get the agent authorization. If plural candidate nodes have same energy level to the target energy level, the mobile sink requests the friendship information which is the neighbor node number to the candidate. Here, the minimum value to the friendship information can be defined to determine agent node. Each candidate node reports its neighbor number, and then the mobile sink chooses a candidate node which has maximum neighbor number. But, if the mobile sink has not received expected reply from candidate sensor nodes, it sends the *cancel* message to the *hello* message of its *id* number. And it travels another area of the region *R4* to search agent node. If the mobile sink receive satisfactory *hello_ack* message from candidate nodes, a sensor node become the agent node, and supports the mobile sink. After a sensor node becomes agent node, it broadcasts the *data_request* message to other sensor nodes so that the routing tree for the data gathering is formed from the reverse path (see Fig.1).

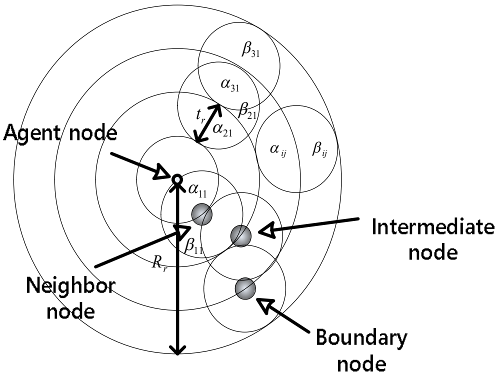


Fig. 2. Transmission range

From the next visiting, the mobile sink easily receives data through the agent node by sending *data_request* message. Also, the mobile sink can alter the agent node if the agent node has low energy to provide its role. Even though the signal propagation has the broadcasting property, the sensor node may implement the direction sending to inside and outside sensor nodes by using hop communication [3][10]. We assume that all sensor nodes have same transmission range, and the transmission of a sensor node is circular with radius t_r as shown Fig. 2. If the transmission range from the agent node to the boundary sensor node is R_r, we simplify the hop count [4]:

$$h_r \approx \frac{R_r}{t_r}. \tag{2}$$

Suppose that the hop count is denoted as integer number, we have

$$N \approx \sum_{k=1}^{h_r} \frac{(N-1)(2k-1)}{{h_r}^2} + 1 \tag{3}$$

where k is the hop number.

In a region, there are three type nodes for the agent node to gather data: neighbor nodes to the agent node, intermediate and boundary nodes. A neighbor node delivers data from next hop nodes, and sends its sensing data to agent node directly. In cases of intermediate and boundary nodes, they only communicate with near sensor nodes. The intermediate nodes send neighbor nodes the data which is sensed themselves or is received from next hop nodes. Also, boundary nodes just transmit their sensing data without data delivery. Hence, in k th hop $(1 \le k \le h_r - 1)$ any sensor node receives data from $k+1$ th hop nodes, and sends data to $k-1$ th hop nodes. And boundary sensor nodes of h_r th hop only send data to $h_r - 1$ th hop nodes. By [8], if all sensor nodes are distributed following to Poisson process with uniform density as (1), and the parameter N_0 is the connectivity number of a sensor node, N_0 can be denoted as $2.195 < N_0 < 10.526.$ Hence, from the node connectivity we can identify the transfer proportion to sensor nodes of k th hop $(1 \le k \le h_r - 1)$. In Fig. 2, the transmission range (Gr) of a sensor node is

$$Gr = \pi {t_r}^2. \tag{4}$$

Suppose that all of nodes have same transmission range such as

$$\begin{aligned} Gr &= \alpha_{11} + \beta_{11} = \alpha_{12} + \beta_{12} = \cdots \\ &= \alpha_{21} + \beta_{21} = \cdots \\ &= \alpha_{31} + \beta_{31} = \cdots \\ &= \alpha_{ij} + \beta_{ij} \end{aligned} \tag{5}$$

where α and β are inside and outside directional area to the transmission of a node, respectively. And i is the hop distance count to the agent, and j is the node number in same hop count.

As an example if a sensor node having number 1 is located at 2 hop distance from the agent, the sensor node transmits its sensing data to neighbor nodes in area α_{21}. Those neighbor nodes are placed in one hop distance from the agent node. If the sensor node receives a message from inside neighbor nodes, it may transfer the message to next hop nodes in area β_{21}. Hence, its overall transmission range is $\alpha_{21} + \beta_{21}$ as shown in the figure. And we can get α_{21} and β_{21} as follows

$$\begin{aligned} \alpha_{21} &= 2\left\{ \int_{\frac{t_r}{4}}^{t_r} \sqrt{{t_r}^2 - x^2}\, dx + \int_{\frac{7}{4}t_r}^{2t_r} \sqrt{4{t_r}^2 - x^2}\, dx \right\} \\ &= 2R^2 \left\{ \int_{\sin -\frac{1}{4}}^{\frac{\pi}{2}} \frac{1+\cos 2\theta}{2}\, d\theta + 2^2 \int_{\sin -\frac{7}{8}}^{\frac{\pi}{2}} \frac{1+\cos 2\theta}{2}\, d\theta \right\} \\ &\approx 1.3946 {t_r}^2 \end{aligned} \tag{6}$$

and

$$\beta_{21} = 2\left\{\int_0^{\frac{t_r}{4}} \sqrt{t_r{}^2 - x^2}\,dx - \int_{\frac{7}{4}t_r}^{2t_r} \sqrt{4t_r{}^2 - x^2}\,dx\right\} + \frac{t_r{}^2}{2}\pi$$
$$= 2R^2\left\{\int_0^{\frac{R}{4}} \frac{1+\cos 2\theta}{2}\,d\theta - 2^2\int_{\sin-\frac{7}{8}}^{\frac{\pi}{2}} \frac{1+\cos 2\theta}{2}\,d\theta\right\} + \frac{t_r{}^2}{2}\pi$$
$$\approx 1.7469 t_r{}^2. \tag{7}$$

Here, although nodes of same hop distance have equivalent α and β area, other hop nodes have different α and β area size such as $\alpha_{11} = \alpha_{12} \neq \alpha_{21} \neq \alpha_{31}$ and $\beta_{11} = \beta_{12} \neq \beta_{21} \neq \beta_{31}$. Assume that $\alpha_s(\alpha_{ij})$ and $\beta_s(\beta_{ij})$ are the transfer proportion parameters of a node to inside and outside direction, respectively. We denote

$$\alpha_s(\alpha_{ij}) = \frac{\alpha_{ij}}{\alpha_{ij} + \beta_{ij}} \tag{8}$$

and

$$\beta_s(\beta_{ij}) = \frac{\beta_{ij}}{\alpha_{ij} + \beta_{ij}} \tag{9}$$

where $i = 1, 2, 3, \cdots, h_r$, and $j = 1, 2, 3, \cdots, n$. Also, $\alpha_s(\alpha_{ij}) + \beta_s(\beta_{ij}) = 1$.

From (6) and (7), $\alpha_s(\alpha_{21})$ and $\beta_s(\beta_{21})$ can be respectively derived as

$$\alpha_s(\alpha_{21}) \approx \frac{\alpha_{21}}{\alpha_{21} + \beta_{21}} = 0.4439$$

and

$$\beta_s(\beta_{21}) \approx \frac{\beta_{21}}{\alpha_{21} + \beta_{21}} = 0.556. \tag{10}$$

Therefore, from (10) we simply have each connectivity value of sensor nodes on 2nd hop distance as

$$0.9743 < N_0(\alpha_{21}) = \cdots = N_0(\alpha_{2j}) < 4.6725 \tag{11}$$

and

$$1.2204 < N_0(\beta_{21}) = \cdots N_0(\beta_{2j}) < 5.8525 \tag{12}$$

where $N_0 = N_0(\alpha_{21}) + N_0(\beta_{21})$.

From (11) and (12), we know the inside and outside connectivity numbers to the intermediate nodes of 2nd hop distance. Accordingly, we can derive the general range of $\alpha_s(\alpha_{ij})$ and $\beta_s(\beta_{ij})$ to a senor node as follows

$$\frac{\alpha_{ij}}{\alpha_{ij} + \beta_{ij}} \le \alpha_s(\alpha_{ij}) < 1 \tag{13}$$

and

$$0 < \beta_s(\beta_{ij}) \le 1 - \alpha_s(\alpha_{ij}) \tag{14}$$

where $i = 1, 2, 3, \cdots, h_r, h_r + 1, \cdots, \infty$, and $j = 1, 2, 3, \ldots, \infty$.

When a sensor node is a neighbor to the agent node by one hop distance, it has the minimum value of α_{ij}, and then the values $\alpha_s(\alpha_{ij})$ and $\beta_s(\beta_{ij})$ are given by $0.391 \le \alpha_s(\alpha_{ij}) < 1$ and $0 < \beta_s(\beta_{ij}) \le 1 - \alpha_s(\alpha_{ij})$, respectively. Hence, the connectivity values to $\alpha_s(\alpha_{ij})$ and $\beta_s(\beta_{ij})$ of all nodes in a distributed region are

$$0.8582 < N_0(\alpha_{ij}) < 10.526 \tag{15}$$

and

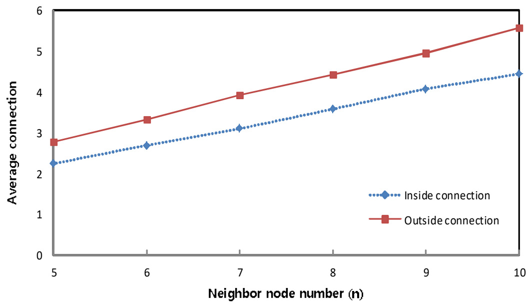
$$0 < N_0(\beta_{ij}) < 6.4103 \tag{16}$$

where $N_0 = N_0(\alpha_{ij}) + N_0(\beta_{ij})$, $i = 1, 2, 3, \cdots, h_r$, and $j = 1, 2, 3, \cdots, n$.

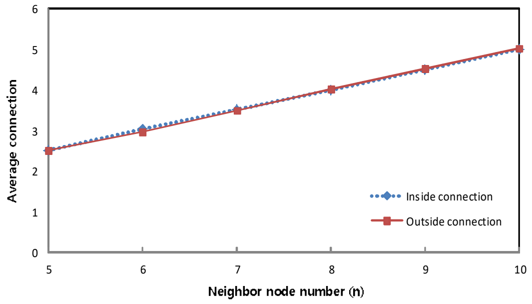
Assume that a distributed region shows very large scale with $h_r \to \infty$, we can see $N_0(\alpha_{ij}) = N_0(\beta_{ij})$ by $\lim_{i\to\infty} \alpha_{ij} = \lim_{i\to\infty} \beta_{ij} = \frac{\pi t_r{}^2}{2}$.

III. Simulation results

In Fig. 3, the simulation results show the average connectivity of sensor node to the transmission direction in a region. Suppose that sensor nodes are uniformly plotted with independent distribution, and the neighbor density to a sensor node has the range from 5 to 10 nodes. Fig. 3(a) illustrates the node connectivity of $N_0(\alpha_{2j})$ and $N_0(\beta_{2j})$ to 2nd tier. It shows almost same results of the inside and outside connections to equations (11) and (12). Fig. 3(b) shows the node connectivity of $N_0(\alpha_{ij})$ and $N_0(\beta_{ij})$ $(i \rightarrow \infty)$. It shows that the inside connectivity shows same connection numbers to the outside connectivity by $\alpha_s(\alpha_{ij}) = \beta_s(\beta_{ij})$ $(i \rightarrow \infty)$.



(a) $N_0(\alpha_{2j})$ and $N_0(\beta_{2j})$



(b) $N_0(\alpha_{ij})$ and $N_0(\beta_{ij})$ in $(i \rightarrow \infty)$

Fig. 3. Node connectivity

Table 1 shows the connectivity values of two node environments. The results have the stable increasement of the node connection to 2nd tier.

Table 1. Connectivity values

Node number	Value	
	Inside	Outside
5	2.23	2.77
6	2.68	3.32
7	3.09	3.91
8	3.58	4.43
9	4.07	4.94

IV. Conclusions

The sensor networks can have various network environments. If the network has distributed regions, it needs the suitable network management mechanism. We provide the visiting scheme of mobile sink in this paper. Especially, we consider the agent node determination in distributed sensor networks. The agent node can provide its role immediately during the visiting of mobile sink system.

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Authors

From December 2000 to May 2002, he was a research engineer in Korea Information Security Agency. From March 2007, he has been a professor at the School of Computer Information Telecommunications, the University of Kunsan National University. His research interests include sensor networks, DEVS formalism, and wireless networks.

He received the M.S. and Ph.D. degrees in computer science and engineering from Soongsil University, Korea, in 1996 and 2000 respectively. Since 2005, he has worked in the Department of Computer Information Engineering, Kunsan National University. His current research interests are in the areas of mobile multimedia networks.