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Autonomous control method for wireless sensor networks using pattern formation

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Abstract– In sensor networks, it is necessary to collect information from sensors using less electric power. Therefore, it is proposed that representative sensors called head collect information from neighbors and send them to a base station. The problem is how to decide heads autonomously. In a regular network it is known that a method using pattern formation by a reaction-diffusion (RD) system is useful. However, power efficiency is not so good, because locations of heads are fixed. In this paper we propose a method for deciding heads using pattern formation of the cellular automaton (CA). By computer simulation, we show that our method is less power consumption than the method using the RD system.

1. Introduction

Wireless sensor network is one of the most promising and key technologies for safe, secure and comfortable society. By distributing a large number of sensor nodes and organizing a network through wired/wireless communication, one can obtain detailed information about surroundings, remote region, entities and objects. In addition, due to difficulty in managing a large number of nodes in a centralized fashion, mechanisms must be fully distributed and self-organizing. Since sensor nodes operate on batteries, energy-efficient mechanisms for data gathering are indispensable to prolong the lifetime of a sensor network as long as possible. Therefore, it is proposed that representative sensors called “head” collect information from neighbors and send them to a base station. The problem is how to decide heads autonomously. In a regular network it is known that the method using pattern formation by the reaction-diffusion (RD) system is useful [1]. However, power efficiency is not so good, because locations of heads are fixed.

In this paper, we propose a method for deciding heads using pattern formation of the cellular automaton (CA). By computer simulation, we show that our method is less power consumption than the method using the RD system. In addition, we further evaluate the influence of data loss on pattern formation for considering a practical scenario. Furthermore, our method is compared with Low-Energy Adaptive Clustering Hierarchy (LEACH) [2] which is the most energy-efficient protocol for deciding heads. We show our method can gather data longer than LEACH.

2. Target sensor networks

2.1. Location of the sensors

In this paper, nodes are arranged in an $n \times n$ grid network. Nodes can communicate with four direct neighbors. Nodes at four corners have two neighbors and nodes at the edges have three neighbors. We assume that adding, moving, deleting a node do not occur. Locations of the sensor are presented as (i, j) in Fig. 1. Here the node at (i, j) has a control signal denoted by $s_t(i, j)\ (= 1\ or\ 0)$ where t is a discrete time (integer) increased by one at each data transmission. Here, $s_t(i, j) = 1$ means that the node (i, j) is a head collecting the data from neighbors and send them to the base station. We assume that all nodes are synchronized. The power consumption of sensors is set as shown in Tab.1.

(1,n)						(n,n)
·						
·						
·			(i,j)			
·						
(1,2)						
(1,1)	(2,1)	·	·	·	·	(n,1)

Figure 1: Locations of the sensor.

Table 1: Power consumption of sensor.

transmitter	reciever	power consumption
node	node	0.10mW
node	base station	10mW

2.2. Data lack

Data lack means that nodes can not receive the control signal of neighboring nodes and it is caused by congestion, buffer overflow and so on. We define "loss rate" as "*lacked control signal*" divided by "*all control signal*".

3. CA based autonomous control

3.1. Pattern formation by CA

We propose the method of deciding heads using pattern formation by CA. Nodes are arranged in an $n \times n$ grid network. Table 2 is the initial value of the control signal.

Table 2: Initial value of control signal.

Node	Control Signal
(1,1)	1
otherwise	0

The value of the control signal s_{t+1} is given by the following formula.

$$\begin{cases} i=1, j>1 \\ \quad s_{t+1}(i,j) = s_t(i,j-1) \\ i>1, j=1 \\ \quad s_{t+1}(i,j) = s_t(i-1,j) \\ i=1, j=1 \\ \quad s_{t+1}(1,1) = \bar{s}_t(2,1) \wedge \bar{s}_t(1,2) \wedge \bar{s}_t(1,1) \\ others \\ \quad s_{t+1}(i,j) = s_t(i-1,j) \vee s_t(i,j-1) \end{cases} \quad (1)$$

$\wedge : AND \quad \vee : OR \quad \bar{s}_t : NOT\, s_t$

We repeat the formula (1) until $t = 2(n-1)$.

Next, we correct the control signal by the following formula between t and $t+1$.

$$\begin{cases} s_t'(1,1) = \bar{s}_t(1,2) \wedge \bar{s}_t(2,1) \wedge \bar{s}_t(1,1) \\ s_t'(n,n) = \bar{s}_t(n,n-1) \wedge \bar{s}_t(n-1,n) \wedge \bar{s}_t(n,n) \\ s_t(1,1) = s_t'(1,1) \\ s_t(n,n) = s_t'(n,n) \end{cases} \quad (2)$$

Figure 2 shows the pattern formed by this method. The pattern formed of the RD equation [1] is shown in Fig.3 for comparison. From these figures, we can see that the pattern of Fig.3 is fixed, however our patterns are changed three times. Black cell (head) is located within distance one from any white cell. Black and white indicate $s_t(i,j) = 1$ and 0, respectively.

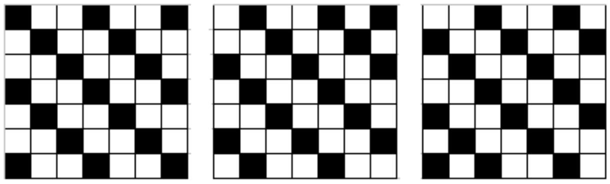

Figure 2: Pattern generated by proposed CA.

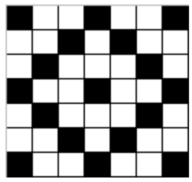

Figure 3: Pattern generated by RD.

3.2. Data lack correction method

We propose a correction method against data lack. We show the correction rule in Table 3. Using this method we can obtain the true control signal from the last three signals.

Table 3: Correction rule.

$s_{t-3}(i,j)$	$s_{t-2}(i,j)$	$s_{t-1}(i,j)$	$s_t(i,j)$
1	0	0	1
0	1	0	0
0	0	1	0
1	0	1	1
1	1	0	1
0	1	1	0
others			0

4. Results

4.1. Comparison of RD and CA

We show the comparison of RD and CA. In sensor networks, it is necessary to collect information from sensors using less electric power. Faster pattern generation is preferred in wireless sensor networks, because the process of pattern formation consumes energy. We calculate the number of communication of the node $(1,n)$ until accomplishment of pattern formation. This result is shown in Figure 4. Note that the RD equation is method (a) in [1].

Furthermore, in sensor networks, it is desirable to collect information from sensors for a long time. We calculate the power consumption of the most consumed node after 3000 communications to the base station. This result is shown in Figure 5.

The CA can effectively reduce the number of communication, however the robustness against data lack is also important. Figure 6 shows the success rate of pattern formation as a function of the data loss rate.

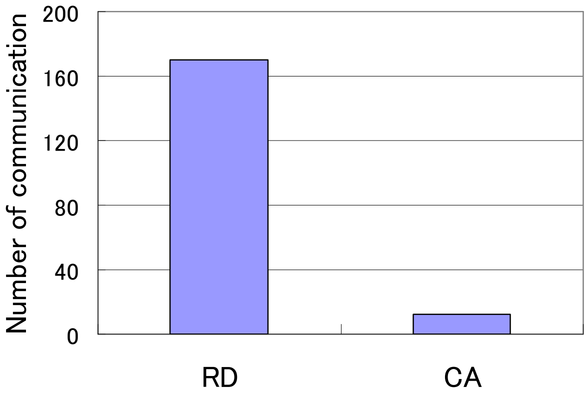

Figure 4: Number of communication for $(1,n)$ node until obtaining pattern Fig.2 or Fig.3.

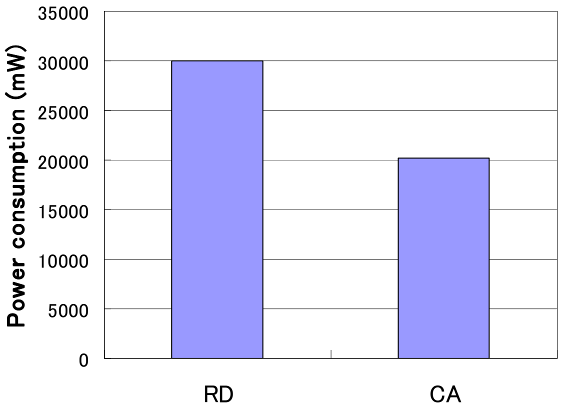

Figure 5: Power consumption of the most consumed node after 3000 communications to a base station.

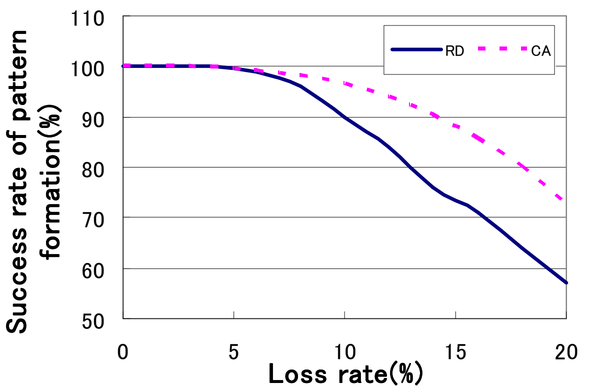

Figure 6: Success rate of pattern formation in data loss environment.

4.2. Comparison of LEACH and CA

We show the comparison of LEACH and CA. LEACH is the most energy-efficient protocol for deciding heads. We calculate the maximum power consumption in all nodes after 20 communications to the base station. This result is shown in Figure 7. Note that the base station is located at $(20,20)$. The power consumption concerning communication is changed by its distance.

Generally, the sensor node works by a battery. In sensor networks, it is necessary to collect information from sensors for a long time. We calculate the lifetime of the sensor network: until one of sensor batteries becomes empty. In this simulation, we suppose a sensor battery and a sensor voltage as Tab.4. This result is presented in Figure 8.

Table 4: Condition of sensor.

Battery	size AA batteries(1000mAh)×2
Voltage	3.0V

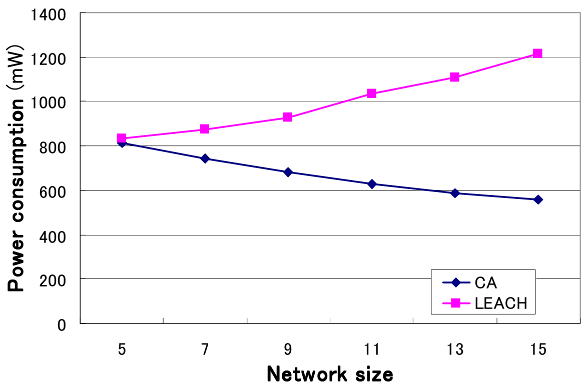

Figure 7: Sensor maximum power consumption until it sends information to a base station 20 times.

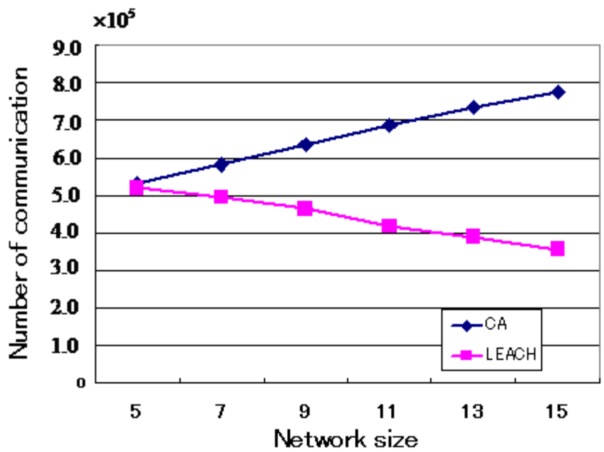

Figure 8: Lifetime of sensor network.

5. Discussion

5.1. Comparison of RD and CA

Our method reduces greatly the number of communication until the accomplishment of pattern formation and power consumption as shown in Fig.4 and Fig. 5.

The reasons are as follows:

(1) The RD system is described by difference equations and the pattern corresponds to a stable fixed point. Thus, a long transient time (many communications) is needed to obtain such an attractor.

(2) The number of patterns is different (RD:1, CA:3), however, in CA, the nodes $(1,1)$ and (n,n) become a head twice in three times. Thus, the power consumption of most consumed node in CA becomes 2/3 of that in RD.

5.2. Comparison of LEACH and CA

Our method reduces greatly the number of communication concerning pattern formation and power consumption. From Fig. 7, we can see that our method (CA) is lower power consumption than LEACH, so the lifetime of the most power consumed sensor is long for CA. The reason is that LEACH is made to have equal probability to be a head for all nodes, however, to decide a head each node sends a message to all other nodes. Our method does not need such broadcasting.

6. Conclusion

In this paper, we proposed a novel method for deciding heads in wireless sensor networks. We verified usefulness of our CA-based method by comparing it with the RD (Reaction-Diffusion) –based method and LEACH. In both comparisons, our method is the lowest power consumption and the lifetime of the sensor networks is longest.

As future works, we need to realize wireless sensor networks using this proposed method and to compare it with other useful methods [3-5].

7. Acknowledgment

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