Energy-efficient Information Dissemination Based on Received Signal Strength in Wireless Sensor Networks

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***Abstract*—Power-saving is one of the important issues in wireless sensor networks and many studies on power-saving in wireless sensor networks have been done. However, most of these studies have focused on saving power in gathering the information. In this paper, we tackle the issue of the energy-efficient information dissemination in wireless sensor networks. We propose method of disseminating information while optimizing electric power consumption in wireless sensor networks. Our new dissemination method employs flooding and uses the receiver signal strength to determine the broadcast timing. In our method, the node farthest from the sending node will rebroadcast the message first and a broadcast is canceled when a node scheduled to broadcast receives a duplicate of the scheduled message from other nodes. We evaluate our proposed method by simulation. As a result, it is found that the electric power consumption of the proposal method in the entire network is one-third that of the flooding method at the maximum. Furthermore, we show that the farther the transmitting distance of the wireless radio wave becomes, the more efficiently our method can disseminate information to the network.**

***Keywords*—sensor network, energy efficiency, information dissemination**

I. INTRODUCTION

In recent years, the miniaturization of wireless devices has advanced as progress has been made on semiconductor technology, and wireless sensor networks are receiving increasing attention. Wireless sensor networks have already been applied in many fields [1]. Disaster detection systems, environmental monitoring systems, and environmental management systems are representative examples of wireless sensor networks. In disaster detection systems, sensor nodes are deployed in places too dangerous for people to enter. Environmental monitoring systems can monitor conditions such as gas discharge from factories and the atmosphere in a town by using nodes that detect a toxic gas. Environmental management systems in buildings can detect the number of people in a building and then manage the air-conditioning and lighting appropriately.

Although wireless sensor networks have been used in various fields, as mentioned above, the network environment differ according the area where the network is used. For instance, in the case of an environmental management system for a building, it is assumed that nodes can have receive periodic maintenance, and so it is not necessary to take into account either failure of nodes or electric power demands. In contrast, these factors should be taken into account for a disaster detection system.

For a source node to send a message to a destination node, one difficulty is how to determine a path, in advance, from the source node to the destination node as the network status changes because of node movements or failures. In such networks, disseminating information to the entire network is a method for guaranteeing that the message is sent to a specific destination node [2].

This approach to information dissemination has already been applied in previous research on sensor networks. As examples, in [3] the method of disseminating the sensor information on each node to all nodes in a network so as to efficiently gather information from nodes is proposed. Further, in [4], a management system for mitigating the effects of node failures in a sensor network is proposed. In order to guarantee that a destination node will receive the information, the system disseminates the information to the entire network. Moreover, in [5] a method for installing a program to nodes that are already in operation is proposed. In order to send a program to a destination node with certainty, the authors adopted an approach that disseminates information to the entire network.

Thus, dissemination of information to the entire network may be necessary in many cases when operating applications in sensor networks. Because it is expected that sensor networks will be used in many fields and that the applications operating on these networks will increase in number and complexity, we believe that information dissemination methods will become much more important in wireless sensor networks.

One of the problems with the method of disseminating information to the entire network is that this increases electric power consumption. In wireless sensor networks, the amount of electric power consumed by transmission and reception of messages by wireless communications accounts for a large percentage of the electric power consumed by the sensor nodes [6]. To utilize limited electric power resources effectively, as well as to extend the lifetime of networks, it becomes important to reduce the power consumed by wireless communications.

Some research in information dissemination has already been done. However, prior research has focused on reducing the number of messages in a network with the aim of avoiding congestion; most proposed methods do not account for electric power consumption. Additionally, many studies on power-saving in wireless sensor networks have been done, but most of these studies have focused on saving power during the information-gathering stage.

In this paper, we propose an information dissemination method for that takes into account the electric power consumption of wireless sensor networks. Our method disseminates information through a flooding method [7]. In flooding methods, when a node receives new information it broadcasts that information to all adjacent nodes. Nodes that have previously received this information do not rebroadcast it.

The proposed method controls the broadcast timing of messages using the strength of the received wireless signal at the time of reception by the node. In our dissemination method, the node farthest from the sending node will rebroadcast the message first. Moreover, if the same message is received from other nodes before the node broadcasts the message, the node cancels broadcasting the message. The proposed method can disseminate information to the entire network with only a small number of broadcasts in the network, which reduces the electric power consumption. In this paper, we deploy our dissemination method in the wireless sensor network where IEEE 802.11 is used. Note that this does not mean that our method depend on IEEE 802.11; with a small change, our method can work in the network where IEEE 802.15.4 is used.

In this paper, we run simulations in a network where sensor nodes are arranged in square lattices. As a result, we show that the farther the transmitting distance of the wireless radio wave becomes, the more efficiently our method can disseminate information to the network. Furthermore, we perform simulation in a network where sensor nodes are randomly located and show that the proposed method can efficiently perform information dissemination, with results similar to the case where nodes are located in square lattices.

The structure of this paper is as follows. In Section II we describe the related work on information dissemination in wireless networks. In Section III, we propose a new information dissemination method that uses received signal strength. In Section IV, we present numerical simulations and show that our method can disseminate information to the network efficiently. Finally, in Section V, we conclude this paper and discuss future works.

II. Related work

There have been previous studies on analyzing the information dissemination in wireless networks [8-11]. For example, in [8, 9], the authors analyzed the throughput and the delay for the information dissemination in wireless ad hoc networks. They showed the trade-off relationship between the throughput and the delay. In [10], the authors presented a diffusion model based on the spread of infection, applying this to a complex wireless network consisting of a sensor network, a vehicular network, a wireless local-area network, and more. Using their models, they showed the relation between the information delivery ratio and the time for the dissemination. In [11], the authors analyzed an epidemic model process in wireless mobile networks and derived the time for diffusing the message to the entire network. However, in [8-11], they focused on the process of data diffusion and they did not address energy efficiency.

On the other hand, there have been some studies done on the energy efficiency in the information dissemination in wireless networks [12-14]. In [12], the energy efficient broadcast protocol based on OLSR, which is a routing protocol, for mobile ad hoc networks was proposed. They ran simulations for the network where their protocol was implemented on IEEE 802.11. As a result, their protocol showed longer network lifetime than flooding method. However, their protocol depends on the proactive routing protocol and their protocol cannot be used the network where a routing protocol other than proactive routing protocols operate.

In [13], an adaptive information dissemination algorithm for ad-hoc mobile networks was proposed. This algorithm determines whether to rebroadcast or discard a message that is received by examining the packet inter-arrival time. The authors showed that their algorithm reduces the number of broadcasts and achieves a high information delivery ratio and good energy efficiency. In [14], the authors proposed an information dissemination method for wireless sensor networks. The method controls message broadcasting by treating messages from adjacent nodes as acknowledgments. They ran simulations where their method was worked over IEEE 802.11 and showed that their method achieves a high information delivery ratio even when the probability of frame loss is high. However, their methods [13, 14] are focused on the network where the frame loss is likely, and so their methods are not energy efficient in a network where frame loss is infrequent.

We already have literatures for sensor networks focused on the received signal strength, on which we focus in this paper [15, 16]. In [15], the energy efficient localization scheme using the received signal strength for wireless sensor networks was proposed. By simulation, the authors showed the proposed scheme achieved both energy efficiency and localization accuracy. However, their scheme is for detecting the sensor localization and their research object is different from us.

In [16], the authors investigated received signal strength with respect to distance, sending power level, direction and alignment of the sensor node from base station. Through experiments using sensor units, energy consumption of sensor nodes can be reduced by setting the proper power level and the proper alignment. However, they assumed that they can arrange all of sensor units properly and the network status does not change. Their results cannot apply to the large part of the region of sensor networks.

III. Proposed method

Our proposed method, a flooding-type method, disseminates information efficiently. In this paper, we implement our information dissemination method on CSMA/CA of IEEE 802.11. Note that it is straightforward to implement our method on CSMA/CA of IEEE 802.15.4.

In a flooding method, a node having a new message to disseminate broadcasts a message to all adjacent nodes. The node that received the message broadcasts a message if the received message was new. When a duplicate received message is received, the node does not rebroadcast the message. In this way, nodes controlled by a flooding method rebroadcast to adjacent nodes and the message is thereby disseminated to the entire network.

The proposed method controls the broadcast timing of a message by using the strength of the received signal when a node receives a message wirelessly. Generally, received signal strength decreases due to propagation loss in radio waves when communicating over long distances. In our method, the lower the signal strength is when a node receives a message, the sooner the node will rebroadcast the message. That is, the node farthest from the sending node will rebroadcast the message first. Moreover, if the message is received multiple times before the node broadcasts the message, then the node cancels that broadcast.

Figure 1 shows the process of disseminating a message by (a) the flooding method and (b) the proposed method. In these figures, circles with a solid border indicate nodes and dotted lines show the range of the wireless communication. A message is created in the node with the thick border and the message is disseminated. The number written in each node shows the number of times that the node received the message. Dotted circles indicate a broadcast, and so the number of such circles is the number of broadcasts in the network. Figure 1 shows that the proposed method can reduce the number of transmissions and receipts of the message in the entire network. Moreover, we can expect that the proposed method will disseminate information to the network in a more energy-efficient way by increasing the transmitted electric power and increasing the range of wireless communication.

When a node receive a radio message from a node over a distance d, the received signal strength $P_r(d)$ is given by [17]

$$P_r(d) = P_{tx} + G_t - L_p(d) + G_r, \tag{1}$$

where P_{tx} is the transmission power, G_t is the antenna gain of the sending node, $L_p(d)$ is the propagation loss, and G_r is the antenna gain of the receiving node. We assume that the network consists of identical nodes and that their configurations are the same. Using the transmission power P_{tx} and the antenna gains of the sending and the receiving node, G_t and G_r, respectively, the maximum received signal strength P_r^{max} is derived as

$$P_r^{max} = P_{tx} + G_t + G_r. \tag{2}$$

This is the case where the sending node is very close to the receiver node and the propagation loss is zero.

In the flooding method, a node that receives a new message broadcasts the message after a time T, which is given by [18]

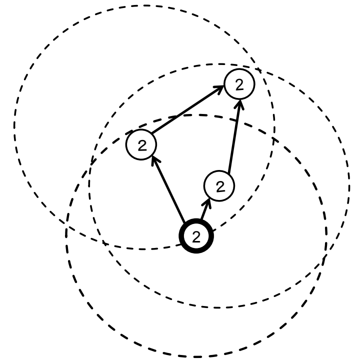
$$T = DIFS + CW \times slot\_time, \tag{3}$$

where $DIFS$, CW, and $slot\_time$ are CSMA/CA (carrier sense multiple access with collision avoidance) parameters of IEEE 802.11.

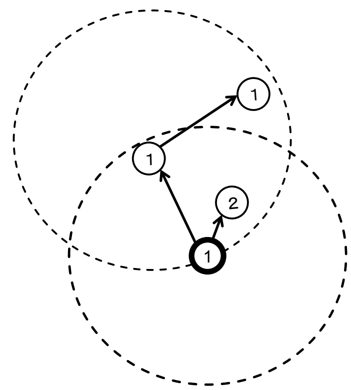
From Eqs. (2) and (3), the proposed method determines the time to broadcast the message after a node has received a new message, using the received signal strength P_r to calculate this. We determine the time T to broadcast the message as

$$T = DIFS + \left(CW + \left\lfloor CW \times \frac{P_r}{P_r^{max}} \right\rfloor \right) \times slot\_time.$$

The node that has the lowest received signal strength broadcasts the message soonest after receipt. We summarize the notation used in the proposed method in Tab. I.



(a) Flooding method



(b) Proposed method

Fig. 1: Process of a message dissemination

TABLE I: Notation

P_r	Received signal strength
P_r^{max}	System-wide maximum of received signal strength
P_{tx}	Transmission power
G_t	Antenna gain of sending node
G_r	Antenna gain of receiving node
CW	Parameter of CSMA/CA in IEEE 802.11
$DIFS$	Parameter of CSMA/CA in IEEE 802.11
$slot\_time$	Parameter of CSMA/CA in IEEE 802.11

IV. Performance evaluation

In this section, we evaluate our proposed method by simulation. For comparison purposes, we also evaluate the flooding method.

A. Simulation environment

The nodes used in simulations are assumed to be commercial wireless sensor units with the characteristics of Crossbow

TABLE II: Simulation parameters

Frequency band	2.45 [GHz]
Transmit data rate	250 [Kbit/s]
Send & receive antenna gain	0 [dBm]
Receive sensitivity	-90 [dBm]
Current when receiving data	19.7 [mA]
Current: radio range is 100 [m]	85.19 [mA]
Current: radio range is 150 [m]	178.81 [mA]
Current: radio range is 200 [m]	309.87 [mA]
Voltage	3.0 [V]
Frame size	127 [bytes]
Communication success probability	90%

MICAz motes [19]. In the node model, the frequency band is 2.45 [Ghz], the transmit data rate is 250 [Kbit/s], the frame size is constant at 127 [bytes], and the entire message can always be stored in one frame. The voltage is 3.0 [V] and the current is 19.70 [mA] when the node receives the message. Both the send and receive antennas have gain 0 [dBm], and the receive sensitivity is -90 [dBm]. The communication success probability between nodes is 90%.

We assume that there are no obstructions and no reflection to communication between nodes, that is, the attenuation of the radio waves follows the free-space loss model. In free-space loss model, the propagation loss $L_p(d)$ over a distance d between a sending node and a receiving node is given by [17] as

$$L_p(d) = (4\pi d/\lambda)^2 , \tag{4}$$

where λ is the radio wavelength.

We simulate radio ranges of 100, 150 and 200 [m]. We determine the transmission power so that the received signal strength of the receive node is -80 [dBm] when the distance between the sender and receiver is 100, 150, and 200 [m] depending on the range. From Eqs. (1) and (4), the transmission power with radio range of 100, 150, and 200 [m] is 10.22, 13.74, and 16.24 [dBm], and the current is 85.19, 178.81, and 309.87 [mA], respectively. Note that although we use the free-space loss model as the propagation loss model for radio waves in this paper, it is straightforward to change the propagation loss model and evaluate the proposed model in other network environments. We calculate the electrical energy, J, when the node sends or receives a message by the following equation.

$$J = I \times V \times \frac{L}{r}$$

Here, I is the current when the node sends or receives a message, V is the voltage, L is the frame size, and r is the data transmission rate.

In this environment, we run 100 simulations and measure the information delivery ratio and total electric power consumed for message delivery to the network. Table II summarizes the parameters used in the simulations.

B. Square lattices model

Figure 2 shows the network model used for the simulations. We use a network model comprising a 100 $\times$ 100 square lattice, with each edge distance set at 100 [m].

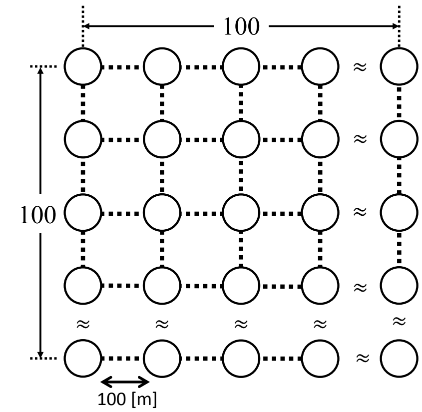


Fig. 2: Simulation model

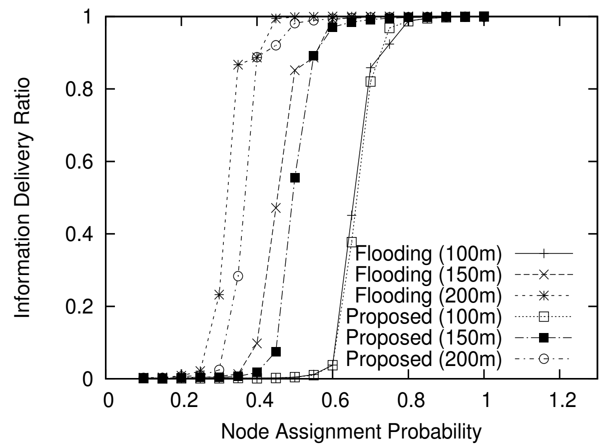


Fig. 3: Information delivery ratio with nodes arranged in square lattices

Figure 3 shows the information delivery ratio in the flooding and proposed method for different node assignment probabilities in square lattices. From this figure, it can be seen that both methods have a threshold value for the node assignment probability above which the information delivery ratio rises rapidly. Moreover, the longer the radio range becomes, the smaller the threshold value for the node assignment probability; that is, the larger the region where the information delivery ratio is high. This can be explained as follows. The number of nodes that can receive a message from one broadcast of the message increases as the radio range increase. Consequently, the information delivery ratio also increases, even when the node assignment probability is small.

Furthermore, in the case where the radio wave range is 100 [m], it turns out that the information delivery ratio of the flooding method and the proposed method are mostly the same. This is because the two methods perform almost the same operation when the edge distance in the square lattice is 100 [m]. In contrast, when the radio wave range is 150 or 200 [m], the flooding method has a slightly smaller threshold values for node assignment probability than the proposed method has. This is because the number of broadcasts in the flooding method is larger than that in the proposed method.

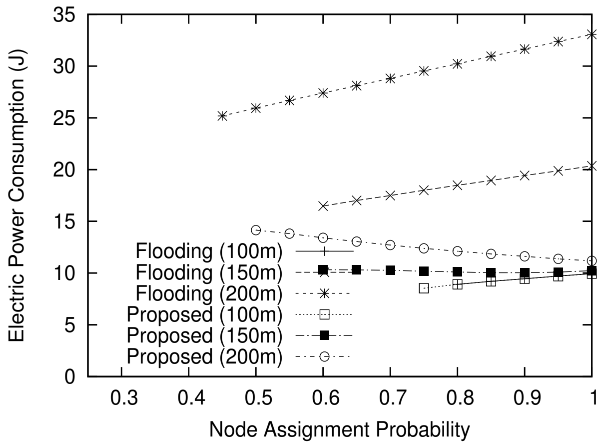


Fig. 4: Total electric power consumption with nodes arranged in square lattices

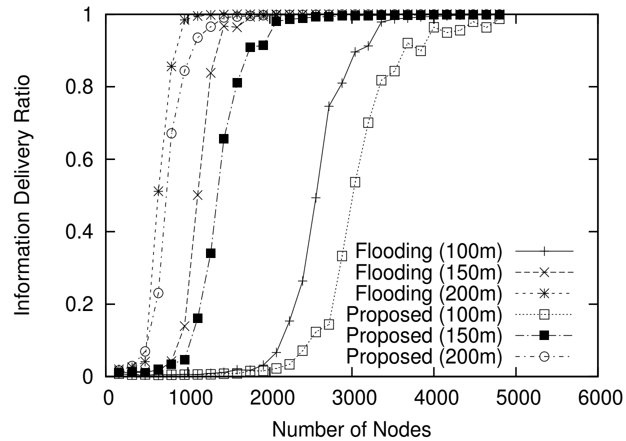


Fig. 5: Information delivery ratio with randomly located nodes

Consequently, the flooding method has a larger region than the proposed method when the information delivery ratio is high and the node assignment probability is small.

Next, we focus on the region where the information delivery ratio is at least 95%. Figure 4 shows the total electric power consumption in the network for the flooding and proposed method. It is found that the electric power consumption in the flooding and proposed method is almost equal when the radio wave range is 100 [m]. This is for the same reason mentioned above for the almost equal information delivery ratios of both methods.

In contrast, when the range of radio waves is 150 or 200 [m], it turns out that the electric power consumption increases as the assignment probability increases in the flooding method. This is because the number of nodes in the network increases as the assignment probability increases. In the flooding method, each node broadcasts the message when a new message is received, regardless of the receiving status of the message of other nodes. Therefore, the number of broadcasts and the number of the receipts of the message in each node will also increase greatly when the number of nodes increases. Consequently, the total electric power consumption in the network increases in the flooding method.

Moreover, from Fig. 4, it can be seen that the total electric power consumption in the flooding method increases quite a lot as the radio range grows. This is because increasing the radio range requires increasing the transmitting power. In addition, the number of nodes that receive a single broadcast message increases along with the radio range, and so, simultaneously, then the number of broadcasts increases.

For the proposed method, in contrast, Fig. 4 shows that the electric power consumption decreases as the node assignment probability increases for radio ranges of 150 and 200 [m]. Furthermore, the decrease in electric power consumption with a higher node assignment probability and a radio range of 200 [m] is larger than for the same probability with a radio range of 150 [m]. This means that the proposed method allows more efficient dissemination of the message as the node assignment probability increases and as the radio range becomes large.

To summarize the above: both the flooding method and the proposed method can enlarge the region of high information delivery ratio by increasing the radio range. However, the flooding method consumes substantially more total electric power in such cases, whereas the proposed method disseminates the message more efficiently, in terms of energy, as the radio range increases.

C. *Random located model*

In the previously discussed network model, nodes are arranged in square lattices. We now perform simulation using a network model that is closer to a real network than the previous one. In this simulation, we randomly locate nodes in a square region with sides of length 4,000 [m]. The configuration of the nodes is the same as that in Tab. II, and propagation loss of the radio waves follows Eq. (4) as before.

Figure 5 shows the information delivery ratio for different numbers of nodes in the network. From Fig. 5, it is seen that the information delivery ratio rapidly increases after a threshold value, similar to the behavior in Fig. 3.

Figure 6 shows the total energy power consumption of the entire network when the information delivery ratio is at least 95%. Similar to the situation in Fig. 4, the total electric power consumption of the flooding method increases when numbers of nodes in the network becomes large. In contrast, the proposed method reduces the total electric power consumption when the numbers of nodes in the network becomes large. From the above, it is shown that the proposed method can disseminate information energy efficient way.

V. Conclusion and Future Work

In this paper, we proposed an information dissemination method for use in wireless sensor networks that considers electric power consumption. The proposed method is based on the flooding method and controls broadcast times according to strengths of received signals. Furthermore, a broadcast is canceled when a node scheduled to broadcast receives a duplicate of the scheduled message from other nodes.

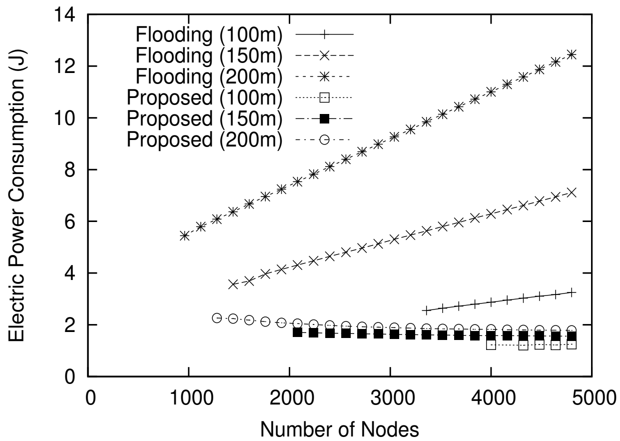


Fig. 6: Total energy power consumption with randomly located nodes

We ran simulations of a network where nodes are arranged in square lattices. As a result, we showed that the proposed method achieve a high information delivery ratio by increasing the transmitting power. It was also shown that the proposed method can disseminate information to the network in an energy efficient manner when the transmitting power becomes large. Furthermore, we ran simulations in a network with randomly located nodes and showed that the proposed method had the same characteristics as when nodes were arranged in square lattices.

As future work, it will be important to evaluate the proposed method with other propagation loss models, such as a two-ray ground model. It is also important to evaluate the proposed method in an experimental network that uses sensor units such as Crossbow MICAz motes. It would be interesting to analyze the proposed method by applying percolation theory from statistical physics. Furthermore, we are now considering extending the proposed method to delay tolerant networks.

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