LETTER

A Routing Method for Fish Farm Monitoring Under Short Transmission Range Condition*

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SUMMARY We have proposed a fish farm monitoring system for achieving efficient fish farming. In our system, sensor nodes are attached at fish to monitor its health status. In this letter, we propose a method for gathering sensor data from sensor nodes to sink nodes when the transmission range of sensor node is shorter than the size of fish cage. In our proposed method, a part of sensor nodes become leader nodes and they forward gathered sensor data to the sink nodes. Through simulation evaluations, we show that the data gathering performance of our proposed method is higher than that of traditional methods.

key words: *fish farm monitoring, data gathering, routing, DTN, sensor networks*

1. Introduction

One of the promising sensor network application is for the primary industry and we have proposed a novel fish farm monitoring system for achieving efficient fish farming [2], [3]. In our system, we assume that a sensor node is attached at a farmed fish and one or multiple sink nodes are placed at the bottom of a fish cage (Fig. 1). Since each sensor node is powered by a battery in our system, energy efficient control of sensor node is highly important for achieving lifetime of a couple of years until shipping. In [2], [3], we proposed distributed methods for gathering sensor data from sensor nodes to the sink node. In these studies, we assume that the transmission range of sensor node is sufficiently large compared to the size of fish cage and a sensor node can communicate with the sink node in a single hop manner.

However, in some cases, the size of transmission range is shorter than the size of fish cage (e.g. diameter of 30 m). For example, strong sound or light may affect health of sensitive fish such as tuna. Therefore, when we consider to use acoustic or visible light as communication media in the fish farm monitoring system of sensitive fish, intensity of light or acoustic waves cannot be increased over a certain level. As a result, the transmission range is shortened. On the other hand, radio wave is major communication media in terrestrial environment and off-the-shelf radio communication equipments are small, low-cost and energy-efficient. Although radio wave also can be used as communication media in underwater environment, it significantly decays and the transmission range is shortened (e.g. 1 m) [4] in underwater environment. When the transmission range is much shorter than the size of fish cage, the network connectivity from sensor nodes to sink nodes is not always kept. Therefore, a store-carry-forward approach in DTN (Delay/Disruption Tolerant Networking) technologies [5] should be used to gather sensor data from sensor nodes to sink nodes.

In this letter, we propose a data gathering method for fish farm monitoring system under short transmission range condition. In our proposed method, we utilize the group behavior of fish and moving direction of fish for efficient control of data gathering. In our method, a part of sensor nodes become leader nodes at first and they collect sensor data locally. Then, leader nodes forward sensor data to the sink nodes by taking into account moving direction of fish. In this letter, we evaluate our proposed method through simulation experiments by comparing the results of the epidemic routing method [6] and the spray and wait method [7] which are major routing methods in DTN.

2. Model

In this section, we explain the fish farm model and the communication model intended in this letter. The overview of our fish farm monitoring system is illustrated in Fig. 1. A side of fish cage is around several tens of meters for tuna farming. In our monitoring system, there are N fish each of

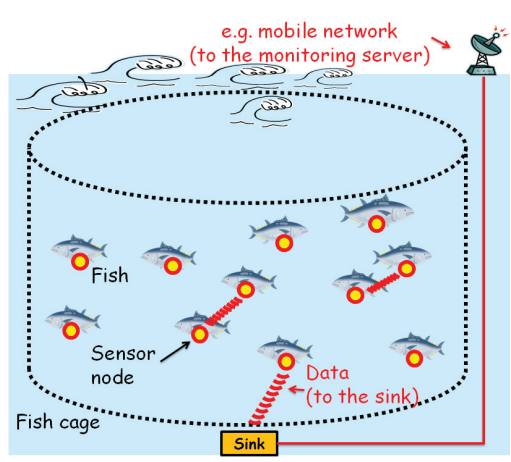

Fig. 1 Fish farm monitoring system

Manuscript received February 21, 2018.
Manuscript revised May 4, 2018.
Manuscript publicized May 16, 2018.

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*This letter is an extended version of work that was presented originally at APWConCSE 2017 [1].

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DOI: 10.1587/transinf.2018EDL8038

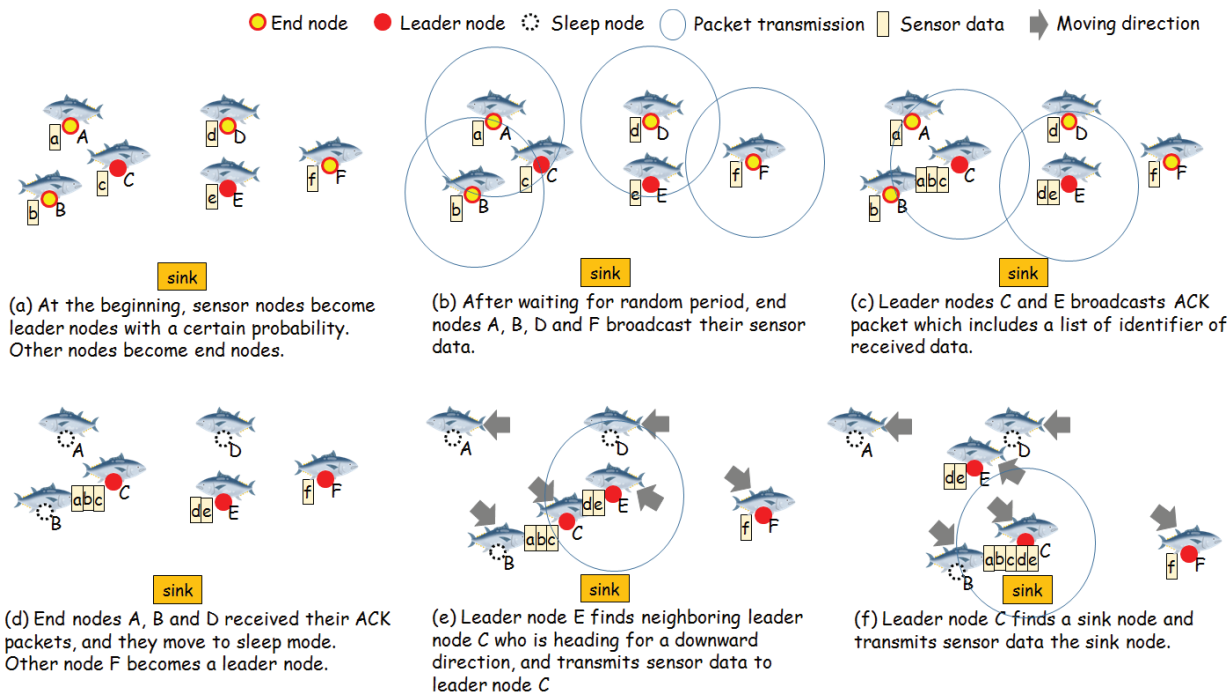


Fig. 2 An example of behavior of our proposed method.

which attaches a sensor node n_i ($0 \leq i \leq N$). We assume a kind of group-based mobility as fish mobility since many fish species move together and form a group. One or multiple sink nodes are installed at the bottom of the fish cage.

A communication module is attached to a sensor node, and a sensor node can communicate with another sensor node or a sink node within the range of d m. For example, the transmission range d is 1 m when we use radio wave in the undersea environment [4]. Here, we assume omni-directional communication model for simplicity in this letter. When the transmission range is much shorter than the size of fish cage, the network connectivity from sensor nodes to sink nodes is not always kept. Therefore, a store-carry-forward approach in DTN technologies [5] should be applied for gathering sensor data in our monitoring system.

Sensor node n_i has a timer t_i. We assume that clock of sensor nodes are synchronized by using traditional time synchronization protocols. In addition, we assume that a sensor node has an acceleration sensor and can obtain the movement direction of itself. Here, acceleration sensors are usual sensors to monitor fish status in the bio-logging research area.

3. Proposed Method

In this section, we explain the behavior of our proposed method.

3.1 Overview

Figure 2 shows an example of behavior of our proposed method. In our proposed method, data gathering is performed periodically with a certain duration of cycle T. Each cycle is divided into two phases: the intra-group data gathering phase and the inter-group data gathering phase. Since fish move together and local network connectivity is available, sensor data is locally gathered to leader nodes at the intra-group data gathering phase. Then, sensor data is gathered from leader nodes to sink nodes in a store-carry-forward manner at the inter-group data gathering phase. In this phase, the moving direction of fish acquired from an acceleration sensor is utilized for efficient control of data forwarding. The details of each data gathering phase in our proposed method are explained in the next sections.

3.2 Intra-Group Data Gathering Phase

We first explain the details of intra-group data gathering phase. The intra-group data gathering phase is divided into two sub-phases: the data transmission sub-phase and the ACK transmission sub-phase, as described in the following sections.

3.2.1 Data Transmission Sub-Phase

At the beginning of the cycle (for simplicity, $t_i = 0$), a sensor node becomes a leader node with the probability P ($0 < P \leq 1$) (Fig. 2(a)). Hereinafter, a sensor node that is not a leader node is called as an end node.

If sensor node n_i is an end node, it randomly sets its random timer value $t_{D,i}$ between zero and T_D. Here, T_D is the duration of data transmission sub-phase. When the timer reaches $t_i = t_{D,i}$, end node n_i broadcasts its sensor data (Fig. 2(b)).

If sensor node n_i is a leader node, it waits for reception of data packets from end nodes while timer satisfies $t_i < T_D$. When a leader node receives the broadcasted sensor data from the end node, it deposits the sensor data to local buffer.

3.2.2 ACK Transmission Sub-Phase

When the timer reaches $t_i = T_D$, sensor nodes move to ACK transmission sub-phase. At first, leader node n_i determines random timer value $t_{A,i}$ between zero and T_A in a similar way to the end nodes in the data transmission sub-phase. Here, T_A is the duration of ACK transmission sub-phase.

When the timer reaches $t_i = T_D + t_{A,i}$, leader node n_i broadcasts an ACK packet which includes a list of identifiers of received sensor data in the data transmission sub-phase (Fig. 2(c)). If its own identifier is included in the received ACK packet at end node n_j, it moves to sleep mode until the end of data gathering cycle (i.e. until $t_j = T$). If its own identifier is not included in received ACK packets until the end of ACK transmission sub-phase (i.e. until $t_j = T_D + T_A$), the end node becomes a leader node (Fig. 2(d)).

We note here that the duration of data transmission sub-phase T_D and the duration of ACK transmission sub-phase T_A affect to the performance of data gathering. Longer values of T_D and T_A result in increase of energy consumption since sensor nodes are active in this duration. In addition, longer values of T_D and T_A result in increase of packet loss and increase of leader nodes since fish move in this duration and local network connectivity may be lost. On the other hand, shorter values of T_D and T_A result in increase of packet loss due to collisions among neighboring nodes. Therefore, these values should be carefully determined. Detailed discussion and evaluation of effect of duration T_D and T_A is one of our future work.

3.3 Inter-Group Data Gathering Phase

In the inter-group data gathering phase, a leader node periodically transmits HELLO packets to detect neighboring leader nodes. A HELLO packet includes the node's moving direction acquired from the acceleration sensor. When a leader node finds a neighboring leader node heading for a downward direction, it transmits the copy of gathered data to the neighboring leader node (Fig. 2(e)). When the leader node receives the ACK packet from the neighboring leader node, it counts the number of data transmissions m. If the number of data transmissions m exceeds threshold M, the leader node stops to transmit the copy of data to the neighboring leader nodes until the end of data gathering cycle. When a leader node finds a sink node, it transmits gathered data to the sink node (Fig. 2(f)). Upon receiving the ACK packet from the sink node, the leader node moves to the sleep mode until the end of cycle.

4. Evaluation

In this section, we evaluate our proposed method through simulation. Due to limitation of space, we explain major points of results.

4.1 Simulation Settings

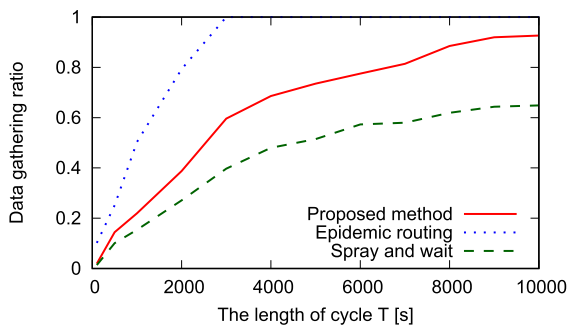
In the simulation, we randomly place $N = 100$ sensor nodes in a fish cage. The shape of fish cage is a cuboid whose width of 30 m, height of 30 m and depth of 10 m. Four sink nodes are placed at regular intervals at the bottom of the fish cage. As the mobility model of fish, we use the boids model [8] which can reproduce group behavior of animals. The transmission range of sensor node is set to $d = 1$ m. As the parameter of proposed method, we use $P = 0.2$. In this letter, in order to evaluate the basic performance of our proposed method, we do not introduce packet loss in the simulation. All results are averaged over 100 simulation runs.

For comparison purpose, we also conduct simulation experiments using comparative methods. Here, our proposed method is designed for a fish farm monitoring application. On the other hand, most existing DTN routing methods assume terrestrial applications and cannot be simply compared. In this letter, to show fundamental results of our proposed method, we use two well-known and simple routing methods, the epidemic routing method [6] and the spray and wait method [7], as comparative methods. Comparative evaluation with other major DTN routing methods, such as that considering moving direction, is one of our future work.

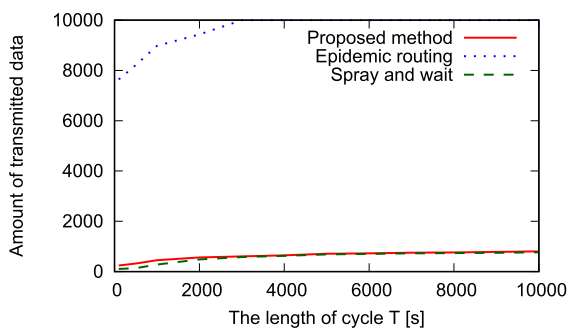
In the epidemic routing method, sensor nodes always try to exchange their sensor data when they are within transmission ranges. Therefore, the data gathering ratio of the epidemic routing method is high although the energy consumption is also high due to high communication cost. In the spray and wait method, a sensor node transmits the copy of sensor data to L neighboring sensor nodes. When a sensor node and a sink node are within their transmission ranges, sensor data is gathered to the sink node. In the spray and wait method, since the number of data transmission is limited, the energy consumption is lower compared to the epidemic routing method.

4.2 Evaluation of Data Gathering Efficiency

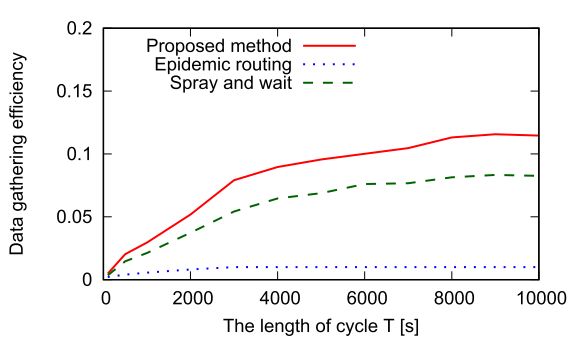
We first evaluate the proposed method by changing the length of cycle T. In this evaluation, we use $M = 3$ for the proposed method. In addition, we use $L = 8$ for the spray and wait method because the amount of transmitted data is similar between the spray and wait method with $L = 8$ and the proposed method with $M = 3$. As the evaluation index, we use the data gathering ratio r and the data gathering efficiency e. The data gathering ratio r is defined as $r = s_{sink}/N$ and the data gathering efficiency e is defined as $e = s_{sink}/s_{total}$. Here, s_{sink} is the amount of sensor data gathered at sink nodes in a cycle and s_{total} is the amount of transmitted sensor data from all sensor nodes in a cycle. Higher amount of transmitted sensor data s_{total} indicates that the to-



(a) Data gathering ratio r



(b) The amount of transmitted data s_{total}



(c) Data gathering efficiency e

Fig. 3 Evaluation results according to the length of cycle.

tal amount of energy consumption is higher. Since energy efficiency is one of the most important index in our monitoring system, the amount of transmitted sensor data s_{total} should be low and the data gathering efficiency e should be high.

Figures 3(a), 3(b) and 3(c) show the data gathering ratio r, the amount of transmitted data s_{total} and the data gathering efficiency e against the length of cycle T. As shown in Fig. 3(a), the data gathering ratio of the epidemic routing method is the highest although the ratio of our proposed method is higher than that of the spray and wait method. We note here that data gathering ratio of our proposed method varies depending on parameters such as M. In the next section, we evaluate performance of our proposed method and comparative methods under same data gathering ratio condition.

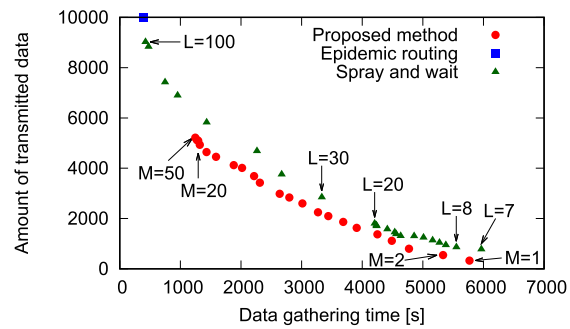


Fig. 4 The relationship between data gathering time and the amount of transmitted data to gather same amount of sensor data to sink nodes.

On the other hand, in the viewpoint of data gathering efficiency, the performance of our proposed method is the highest as shown in Fig. 3(c). In the epidemic routing method, although the amount of sensor data gathered at sink nodes s_{sink} is high as shown in Fig. 3(a), the amount of transmitted sensor data s_{total} is extremely higher than that in other methods as shown in Fig. 3(b). As a result, the data gathering efficiency of epidemic routing method is the lowest. When we compare the results between the proposed method and the spray and wait method, the data gathering efficiency of our proposed method is higher. In our proposed method, sensor data is gathered by taking into account group-based mobility of fish and moving direction of fish. Therefore, the amount of sensor data gathered at sink nodes s_{sink} in our proposed method is higher than that in the spray and wait method even if the amount of transmitted sensor data s_{total} is same.

4.3 Evaluation of Relationship between Data Gathering Time and the Amount of Transmitted Data

We then evaluate the performance of our proposed method according to the parameter M. In this evaluation, we evaluate the time to obtain sensor data from 90% of sensor nodes. Therefore, the data gathering ratio r is fixed to 90% in this evaluation. Hereinafter, we call this time as data gathering time. In addition, we obtain the amount of transmitted data s_{total}.

Figure 4 shows the relationship between data gathering time and the amount of transmitted data by changing parameters of methods. As shown, there is a trade-off between the data gathering time and the amount of transmitted data. In addition, the amount of transmitted data of our proposed method is lower than that of the spray and wait method when the data gathering time is greater than 1240 s. Therefore, we can conclude that our proposed method is effective if a certain delay for gathering sensor data is acceptable.

5. Conclusion

In this letter, we proposed a data gathering method for fish farm monitoring system under short transmission range conditions. Through simulation evaluations by comparing with traditional methods, we showed that the performance of our proposed method is higher than that of other methods.

As future research, we plan to take into account balance of energy consumption among sensor nodes. We also plan to evaluate our method considering packet loss, limitation of buffers, and so on.

Acknowledgments

This work was partly supported by JSPS KAKENHI grant number 16K00146 of Japan. The authors would like to thank the anonymous reviewer for the comments to this work.

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