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A Study of Increasing Communication Reliability of Low-cost Field Servers

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Abstract -We develop a rice cultivation management system using field servers (FSs) to reduce the workload of farmers. The system realizes the possibility to manage environmental data for rice fields using sensors. The features of our FSs are reasonable price and mobility. To achieve the reasonable price, the accuracy of time synchronization is sacrificed. The system we have developed may not be able to obtain data due to rare accidents such as a car stopping next to an FS. This paper describes a new algorithm to solve the above problem. The proposed algorithm includes a data retransmission algorithm named simultaneous-transmission-type flooding algorithm. We also report the experimental results. This algorithm is robust for the rice cultivation management systems because it uses a robust resend algorithm. Therefore, it meets farmers' expectation of utilizing reasonable FSs.

Keywords: LoRa, Fail-safe, Multi-hop, Ad hoc transmission algorithm, Time synchronization

1 INTRODUCTION

The agricultural working population has decreased by approximately 925,000 from 2010 to 2019 in Japan [1]. The situation in the field of agriculture has been dire. Hence, development of Internet of things (IoT) to support rice farming is desired. In recent years, field servers for rice cultivation have been proposed, but they are expensive, and many of them are fixed type that cannot be easily moved, such as holding a large solar panel [2].

We develop a rice cultivation management system using the field servers (FSs) to reduce the workload of farmers [3, 4, 5, 6]. It is a system that can acquire environmental data of rice fields using a sensor, send the data to the master unit system using Low Power Wide Area (LPWA), and check it on the website. It is known that the higher the position of the FS antenna has the better the propagation characteristics. When the time of harvesting rice, the rice grows to a height of about 1.2 m [7]. On the other hand, considering the ease of movement, the FS should be as compact as possible. Therefore, we set the height of FS to about 1 m. The system has a reasonable price that is less than ten thousand yen per one FS; therefore, rice farmers can make a profit even if they introduce one FS for each rice field [3].

[1] This research is supported by 2018 Ishikawa commercialization promotion support project.

Figure 1: Transmission failure and transmission route change.

The proposed system allows time errors to achieve the reasonable price. We set one step period as tens of seconds to allow for time error. We do not perform precise time management. Hence, the star method used in conventional LPWA communication was not practical because it required nearly 1 h to send data for 100 FSs to the master unit system. Therefore, we proposed a data collection algorithm to collect data within a short period of time [4, 5]. Using this algorithm, it is possible to collect all the data in a few minutes, thus achieving a user's request within 5 min. It also runs on batteries for about 6 months, which is the period from rice planting to harvesting.

However, this system needs to be more reliable. Since the height of the FS is approximately 1 m, the developed system may not be able to obtain data owing to an accident such as signal interference due to a car stopping next to a FS. This is a very rare phenomenon, but the system must never make a transmission error. As shown in Figure 1, it is necessary to improve the reliability of retransmission by changing the transmission route.

Dynamic routing in wireless multi-hop networks has been proposed to improve communication reliability [8]. The node corresponding to FS periodically broadcasts a Hello message, exchanges quality information with neighboring nodes, and dynamically determines a route. However, there is a problem that the maintenance cost of the network is high. And it is difficult to use in FS that requires intermittent operation.

Recently, the simultaneous-transmission-type flooding algorithm has been proposed as a method of transmitting data without scheduling [9]. This method can build a stable and efficient sensor network by repeated flooding without the use of routing. No scheduling is required, so there is no need for updating the network status sequentially. However, this method requires high-precision time synchronization and the apparatus becomes expensive. In Japan, a low cost FS is desired. In addition, when this algorithm is used for FS data collection, as with the star method, data collection requires a significant amount of time. Therefore, this method cannot be used to collect data from hundreds of FSs.

To achieve the reasonably priced FSs, the accuracy of time synchronization was sacrificed. For effective application to the rice field, it is necessary to have an algorithm that can tolerate time error, has high reliability of communication, and can collect data in a short period. In this paper, we propose an algorithm that collects data in a short period in an environment that accepts the time error.

The data are collected in a short period using the proposed data collection algorithm. Then, master unit system requests the FS that could not receive the data correctly to resend data using the simultaneous-transmission-type flooding algorithm. The FS that was requested to resend the data retransmits data using the simultaneous-transmission-type flooding algorithm. The simultaneous-transmission-type flooding algorithm is a very time-consuming method, but since the data collection algorithm shows almost no transmission error, this method was adopted because it is a useful method for transmitting data of a few FSs.

2 OVERVIEW OF RICE CULTIVATION MANAGEMENT SYSTEM

The rice cultivation management system monitors the water level in rice fields. The system is composed of the FS system, master unit system, and cloud service. The field server for rice cultivation needs to operate outdoors for about 6 months using only batteries. In order to move out of the way of agricultural machinery, the weight of FS must be below about 2 kg. Farmers hate wild birds that are perched on the field servers, so the height of FS needs to be below about 1m.

Figure 2 shows the overall structure of the rice cultivation management system. The FS system is installed in the rice fields and accumulates sensor data for the water level. Further, the data are sent to the master unit system through the LoRa wireless network. The master unit system integrates the sensor data from the FS system and sends the data to the cloud service through the cellular telephone line or Wi-Fi. The water level can be checked on a mobile terminal via the cloud service. These services provide data to farmers serving as an alert regarding water levels, proposing a suitable work plan, preserving work records etc.

Communication between the FS system and the master unit system using LoRa is possible due to long-distance communication. LoRa has been estimated to have a practical communication distance of 3,000–4,000 m as shown via a basic communication characteristics survey conducted previously [3]. The rice field of Ishikawa prefecture was considered; the linear distance between the master unit system and the FS system was within 3,000 m. Hence, we adopted LoRa, which enables direct communication between the FS system and master unit system.

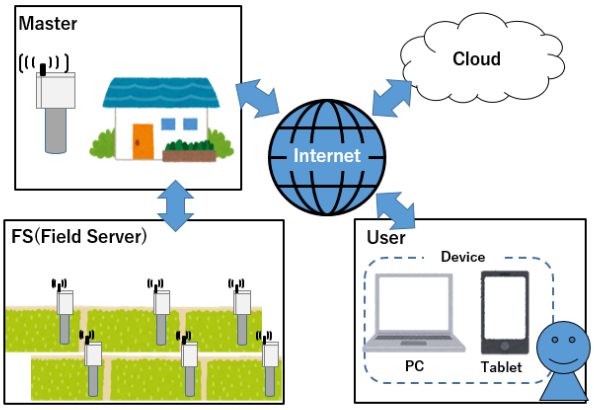

Figure 2: Rice cultivation management system.

In the proposed rice cultivation management system, the FSs are placed in a position where data can be transmitted to the master unit in one hop. Both the master unit and FSs have one LoRa antenna and do not have the function of transmitting and receiving using multiple channels at the same time. In order to realize low cost, FS does not hold expensive parts such as crystals and GPS, and has a time error. The FS must send a water level data to the master unit once an hour. The process which is once an hour of is called one round. It have to be within about 5 minutes to collect all FS data.

In the proposed algorithm, first, the FSs data is collected in the master unit system by using the data collection algorithm. Next, the master unit system confirms the data that has not been received and sends a retransmission request to the FSs. Upon receiving the retransmission request, the FSs send the data to the master unit system using the simultaneous-transmission-type flooding algorithm.

3 DATA COLLECTION ALGORITHM

The data collection algorithm is explained [4, 5]. An FS closest to the master unit system sends data to the master unit system. Other FSs create pairs and send data. The FSs that have sent data turn off the power. This is repeated until all the FSs are turned off. The data collection algorithm is detailed below.

1. Turn on the power of each FS to start the servers.
2. Send a transmission request by broadcasting from the master unit system to the FSs.
3. The FSs measure the sensor data.
4. The FS closest to the master unit system transmits the data to the master unit system. The remaining FSs establish a connection with each other using the shortest distance and transmit the data from the remote FS to the pair FSs.
5. Turn off the power of the FSs that have completed the transmission of data.
6. Repeat step4 and step5 until all FSs transmit data and their power has been switched off.

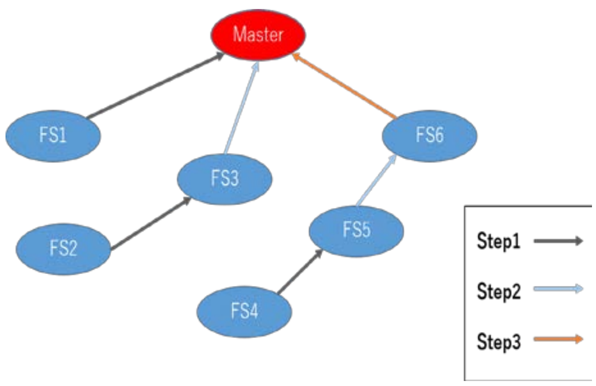

Figure 3: Example of transmission to the master unit system.

Figure 3 shows an example of the six FSs. In step 1, FS 1 transmits the data to the master unit system, FS 2 transmits the data to FS 3, and FS 4 transmits the data to FS 5. In Step 2, FS 3 transmits the data received from FS 2 and the data held by it to the master unit system. FS 5 transmits the data received from the field server 4 and the data held by it to FS 6. In step 3, FS 6 transmits the data to the master unit system. In the case of six FSs, the direct method requires six steps; however, the data collection algorithm consists of three steps and is twice as fast.

Data collection algorithm is made up of two of the processing of the scheduling phase and data collection phase. The detailed scheduling phase is shown below.

```
//Scheduling phase

node={all FSs}

//find(key)=Find a FS that is closest to key from list.
//findf(key)=Find a FS that is farthest to key from list.
//remove_list(key1)= Remove key from list
//remove_node(key1)= Remove key from node
//add(key1,key2)= Add a transmission schedule from
              key1 to key2 to Scheduling table[period].list

   period=0
 while (node != NULL) {
 list = node
 period++
 SFS=find(master unit)
 remove_list(RFS)
 remove_node(RFS)
 add(SFS, master unit)
          While (list != one or less){
              RFS=findf(master unit)
              remove_list(RFS)
              SFS=find(RFS)
              add(RFS, SFS)
              remove_list(SFS)
              remove_node(RFS)
            }
   }
```

The detailed data collection phase is shown below. Data collection is done by scheduled. The processing of the master unit and the processing of each FS are showed. The period number of master unit system is globally managed and updated within the master unit system. Similarly, the period number of the FS is globally managed and updated within the FS.

```
// Data collection phase
//Master unit system

  while (receive data) {
        Save data to database.
        }
```

```
// Data collection phase
//FS

 // Variable
 period number   //The current number of periods
                 // It is calculated from timer.
 Scheduling table[].mode   //Scheduling table
                           //(mode: receive, send, sleep)

data list = sense data  // Sensor data of FS
While(Scheduling table[period number].mod!=NULL){
  if ( Period ! = period number){
       State = Scheduling table[period number].mode
       Period = Period number
         }
   if ( State == receive){ // Receive mode
      Receive data
      Add data to data list
      State = NULL
      }
  else if ( State == send){ // Send mode
     Send data list
     State = NULL
      }
     else if( State == sleep){ //Sleep mode
     Sleep one period
     State=NULL
       }
  }
```

4 SIMULTANEOUS-TRANSMISSION-TYPE FLOODING ALGORITHM

The study of the simultaneous-transmission-type flooding algorithm for the rice cultivation management system is explained in [6]. The first FS or master unit system broadcasts data to its range and powers down. Each FS that receives the data immediately broadcasts it and turns off the power. This is repeated until all the FSs are turned off. Figure 4 shows an example of six FSs. In step 1, the master unit system broadcasts data. FSs 1, 2, and 3 receive the data. In Step 2, FS 1 broadcasts the data. Further, FSs 2 and 3 broadcast the data. FSs 4, 5, and 6 receive the data.

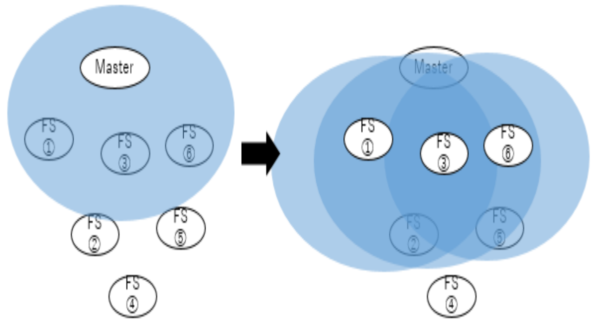

Figure 4: Hierarchy broadcasting from the master unit system.

The detailed simultaneous-transmission-type flooding algorithm from the master unit system to FSs is shown below. The processing of the master unit and the processing of each FS are showed. The master unit system broadcasts the data to all FSs. On the other hand, when each FS receives the data, it broadcasts the data and turns it off. Processing is done asynchronously.

```
// Simultaneous-transmission-type flooding algorithm
//Master unit system

    Broadcast data
```

```
// Simultaneous-transmission-type flooding algorithm
//FS

  while (receive data) {
        Broadcast data.
        Power off.
        }
```

Simultaneous-transmission-type flooding method increases the number of packet transmissions as compared with the routing method; however, as the sequence is repeated until all FSs receive and transmit the data, it is definitely the best way to broadcast data to all FSs. We chose this method because we need to ensure that the transmit request is sent to the untransmitted node and that the data from the untransmitted node is sent to the master unit system. This method is likely to have multiple transmission paths to an FS with a communication failure. In addition, it is a method with a high possibility of receiving data from a node with a communication failure via multiple routes. Therefore, the reliability of communication is high.

5 AD HOC TRANSMISSION ALGORITHM

Roads exist in the rice fields. Since the FS for rice field is approximately 1 m high, the transmission may not be performed correctly if a car is parked in the path of propagation [10, 11]. When the position of the antenna of the FS is half the height of the car, it may interfere with radio waves. As shown in Figure 5, when the FS and the office are close to each other, it is difficult for the radio waves to go around an obstacle; the radio waves may not reach the master unit system under the following conditions. Condition 1 refers to a car parked within 1 m of the FS antenna. Condition 2 refers to a car parked along the straight line connecting the FS and the office. To ensure transmission accuracy, we propose an ad hoc transmission algorithm to solve this problem.

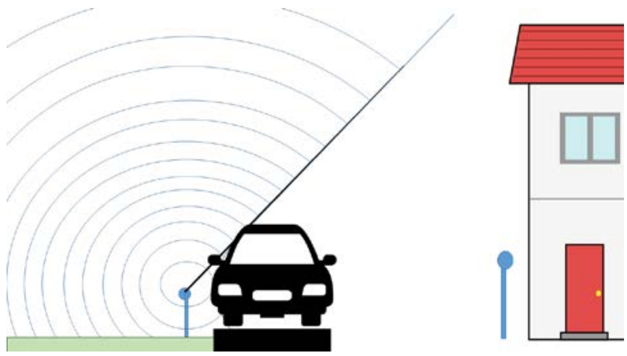

Figure 5: State of radio wave propagation.

The data collection algorithm collects data from all FSs in a short period. However, since the data collection algorithm transmits data through a fixed route, sometimes the data may not be transmitted correctly. In such cases, the data will have to be resent via the simultaneous-transmission-type flooding algorithm. After data collection, the master unit system transmits the retransmission scheduling information indicating whether all the data has been correctly received using the simultaneous-transmission-type flooding algorithm. When the retransmission scheduling information is empty, it indicates that all data have been transmitted correctly. When retransmission scheduling information is present, data are transmitted from the FSs to the master unit system using the simultaneous-transmission-type flooding algorithm according to the scheduling. The detailed ad hoc transmission algorithm is shown below.

```
//Ad hoc transmission algorithm

//Schedule mode
Collect data from all FSs using the data
collection algorithm
//Fail Safe ad hoc mode
While(){
  if (Was the master unit system able to collect data
      from  all FSs?)
     // Broadcast EndMessage
      then{
        Master unit system transmit the retransmission
        scheduling information by using the simultaneous-
        transmission-type flooding algorithm.
```

6: Break;}
// Broadcast NoconnectedList
7: else{
8: Master unit system transmit the retransmission scheduling information by using the simultaneous-transmission-type flooding algorithm.
9: Data are transmitted from the FSs to the master unit system using the simultaneous-transmission-type flooding algorithm according to the scheduling.
}

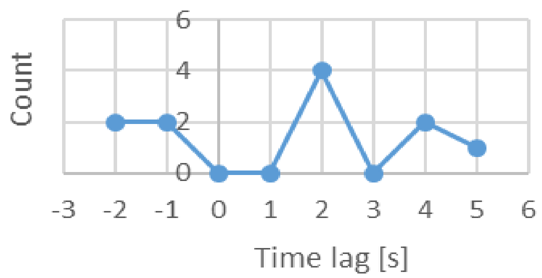

Figure 6: Microcomputer time error.

6 EXPERIMENTAL RESULT

6.1 Experimental Environment

We aim to develop a low-cost FS. Hence, the time error of the microcomputer is accepted and an expensive element such as a special crystal is not used. In the proposed method, the time is corrected once every hour when data are transmitted. Figure 6 shows the results of measuring the time error of the selected microcomputer ATMEGA328P-PU. The average time error is 3 s, the variance is 9, and the maximum error width is 7 s.

The proposed ad hoc transmission algorithm was tested using a low-cost FS with time error. Since this is an operation confirmation experiment, the experiment was conducted indoors. We performed the experiment without an antenna. One master unit system and six FSs were used.

IoT devices such as FSs are used outdoors. As there is no power supply, conventional measuring instruments cannot be used. We need to use a battery-powered measuring instrument. However, as such a measuring instrument is not available, we developed a battery-powered measuring instrument using a current sensor module called INA219 for current and time measurements [12].

The proposed method is a method that allows time errors. Therefore, detailed verification is required to check the operation. Since the FS we created consumes a current of about 50mA when transmitting data, we can verify the system operation by checking the current waveform. In order to measure the current waveform, it is necessary to give an accurate time to the battery-powered measuring instrument for observation. Therefore, one battery-powered measuring instrument was installed in every FS, and the time was given to the battery-powered measuring instrument via LAN. This experiment was conducted indoors. Figure 7 shows the experimental environment. Since the master unit and the battery-powered measuring instrument are connected to the same LAN, the master unit and the battery-powered measuring instrument can be completely synchronized. Therefore, accurate measurement is possible.

An experiment of transmission delay was also conducted depending on the transmission distance. This experiment was conducted outdoors in Nonoichi City, Ishikawa Prefecture.

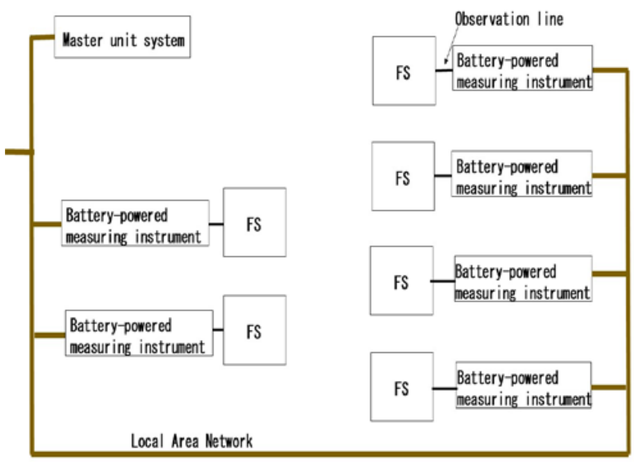

Figure 7: Experimental environment.

6.2 Experimental Results of the Data Collection Algorithm

The experimental results of the data collection algorithm are shown in Figure 8. We explain the results using the example of Figure 3 which has six FSs. Figure 8(a) shows the sequence diagram of the example. In addition, Figure 8(b) shows the current waveform of FSs 4, 5 and 6. Look at the circled area of Figure 8(b). The field server 6 is up for a few seconds, then the field server 5 is up, and a few seconds later, the field server 4 is up. Our device has a time error, so it cannot start at the same time. It can be confirmed that the transmission interval is not constant and is asynchronous. Similarly, the timing to turn off the power is when the data is sent, so you can confirm that the power has not been turned off at the same time.

The current waveform indicates that the transmitted current is approximately 50 mA. Data are transmitted in the following order: FS 4, FS 5, and FS 6. Using this process, the data of FSs 4, 5, and 6 are sent to the master unit system. Next, the time correction signal from the master unit system are sent to FS 6, FS 6 sends the time correction signal to FS 5, and then FS 5 sends the time correction signal to FS 4. Thus, we can confirm that processing is carried out correctly.

Even with the same scheduling, the current waveform will be different each time. This is because the variation of the device is different each time. In order to execute the operation correctly, it is important to determine the step period so that there is no overlap in each step, including variations.

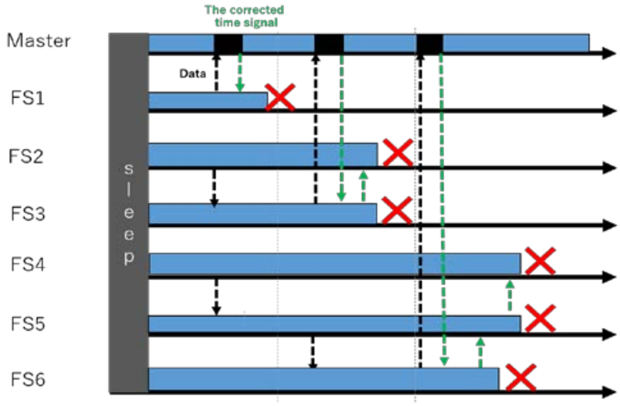

Figure 8(a): Sequence diagram of Figure 3.

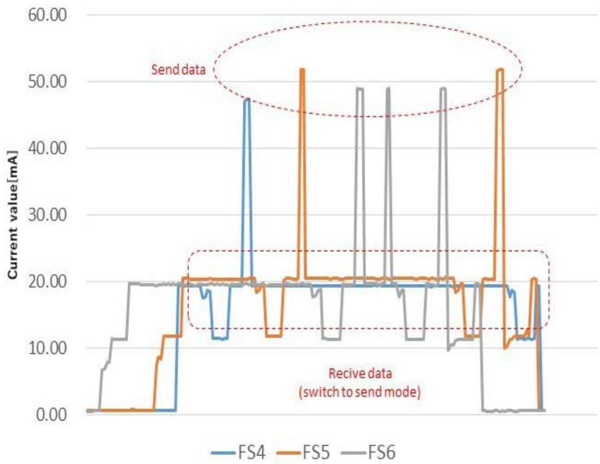

Figure 8(b): Current measurement result of Figure 3.

6.3 Experimental Results of Simultaneous-Transmission-Type Flooding Algorithm

The experimental results of the simultaneous-transmission-type flooding algorithm are shown in Figure 9. Figure 9(a) shows a sequence diagram. First, the master unit system transmits the scheduling information by broadcasting. FSs 1, 2, and 3 receive the data and change the mode from reception mode to transmission mode, which requires about 10 s. Second, since there are individual differences time error between the FSs, in this example, FS 1 transmits data first. Since the transmission cannot be performed at the same time, the other FSs wait for the transmission to end. The data sent by the FS 1 are received by FS 6. FS 6 changes the mode to the reception mode. FS 2 sends data, which are received by FS 5. Similarly, FS 3 sends data, which are received by FS 4. FSs 4, 5, and 6 also transmit data. This process seems unnecessary, but it is necessary because there is no way to check if all FSs have received the data. Whenever an FS receives data, it sends the data to complete the processing and turn off the power. Figure 9(b) shows current waveforms of a six FSs example. It can be confirmed that the transmission interval is not constant and is asynchronous.

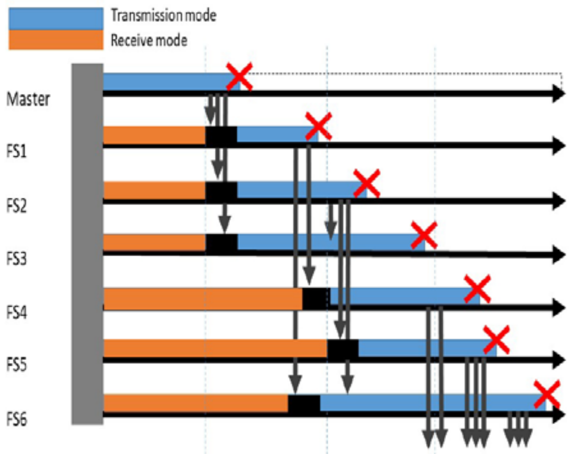

Figure 9(a): Sequence diagram of the simultaneous-transmission-type flooding algorithm.

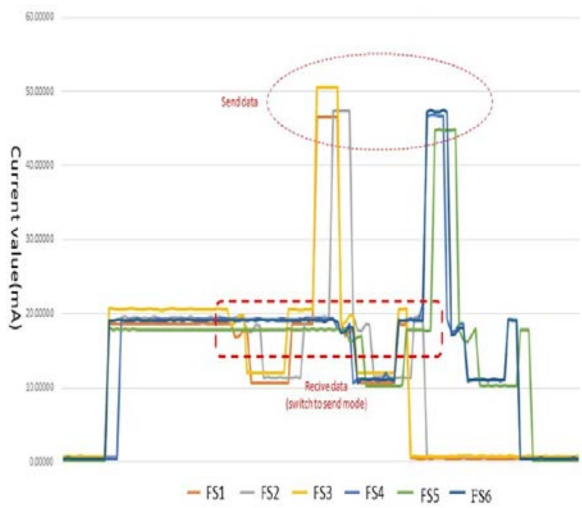

Figure 9(b): Current waveforms of six FSs example.

Figure 10 shows the measurement results of transmission from random points in Nonoichi City to the gateway on the roof of the Kanazawa Institute of Technology Library Center. The horizontal axis represents the RSSI. The vertical axis represents the transmission delay. Nonoichi City is located in the center of Ishikawa Prefecture and is a completely flat land with no mountains or sea. In addition, it is 4.5 kilometers east-west and 6.7 kilometers north-south, which is a size that can cover the city with LPWA. As you can see from the Figure 10, the transmission delay also varies. And there is a delay of a few seconds. If you run the simultaneous-transmission-type flooding algorithm under these conditions, the process may not be completed within the step period if several multi-hops occur. Since the system is configured within the range where it can be directly transmitted to the gateway, it is unlikely that more than one multi-hop will occur. In addition, the step period is determined so that there is sufficient time to spare even if two multi-hops occur, so the process is designed so that it will be completed in time. However, exceptionally, if the processing is not completed within the step period, it gives up and shifts to the phase in which the master unit confirms the unreceived data, which is the next treatment.

The proposed method assumes that all FSs can communicate without multi-hop. Therefore, even if there is some problem and the transmission from the master unit system cannot be received, the transmission from the plurality of FSs that received the transmission from the master unit system can be received. Since there are multiple transmission routes, the probability of not receiving data in two multihops is very low. Our method is a reliable method. Therefore, the step is set to about twice the worst transmission delay. If communication is not possible by this highly reliable proposed method with multiple communication paths, it is considered that there was a failure peculiar to that time, such as the field server being pulled out for work, and it is decided to proceed to the next process.

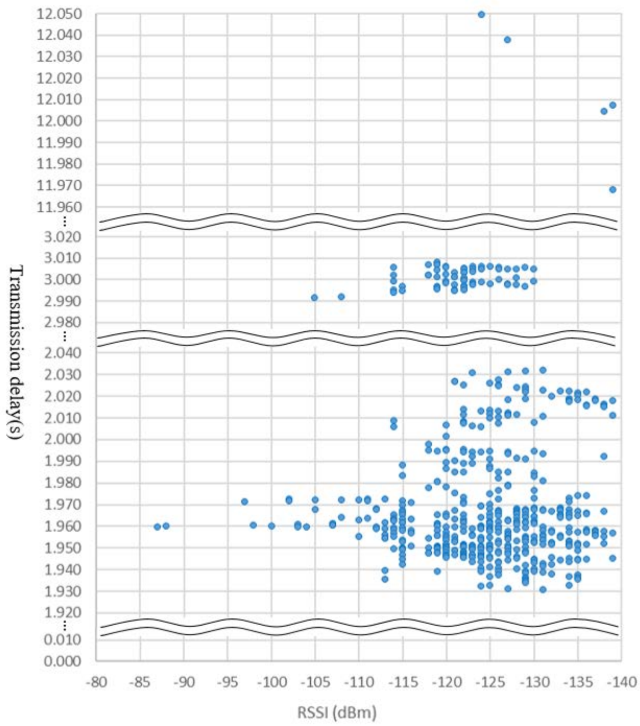

Figure 10: Transmission delay variation.

6.4 Experimental Results of the Ad Hoc Transmission Algorithm

We explain the channel setting for the ad hoc transmission algorithm. The transmission channel is set as shown in Table 1 such that no collision occurs. The simultaneous-transmission-type flooding algorithm used FS channel setting mode 1. The data collection algorithm used FS channel setting mode 2.

An experiment was conducted to confirm the operation of the proposed algorithm that sends the data of all FSs to the master unit system. Since data transmission errors rarely occur, we made an environment where data transmission errors occur intentionally and conducted experiments. Two examples are shown to display the working of the algorithm.

	#Node	Mode1 #Channel	Mode2 #channel
Master Unit	1	2	2
FS1	2	2	2
FS2	3	2	2
FS3	4	2	2
FS4	5	2	2
FS5	6	2	3
FS6	7	2	4

Table 1: FS channel settings

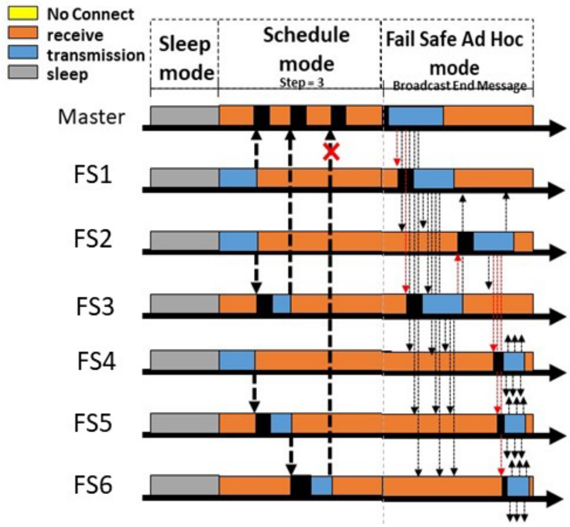

Figure 11(a): Sequence diagram where retransmission processing does not occur.

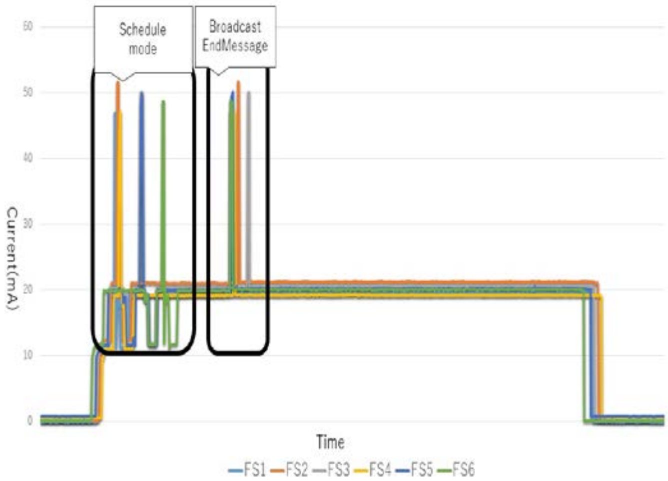

Figure 11(b): Current waveforms of a Figure 11(a).

First, the experimental results of Figure 3 are shown when the operation is normal without retransmission. Figure 11 (b) is a sequence diagram, and Figure 11 (c) is an example of the corresponding current waveform. The data collection algorithm was executed, unreceived data was confirmed in the master unit system, and since there was no unreceived data, the completion information was sent by the simultaneous-transmission-type flooding algorithm.

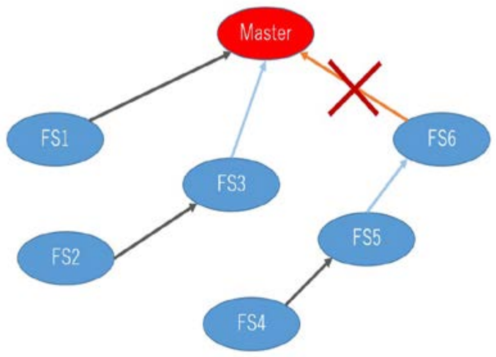

Figure 12(a): Test example 1.

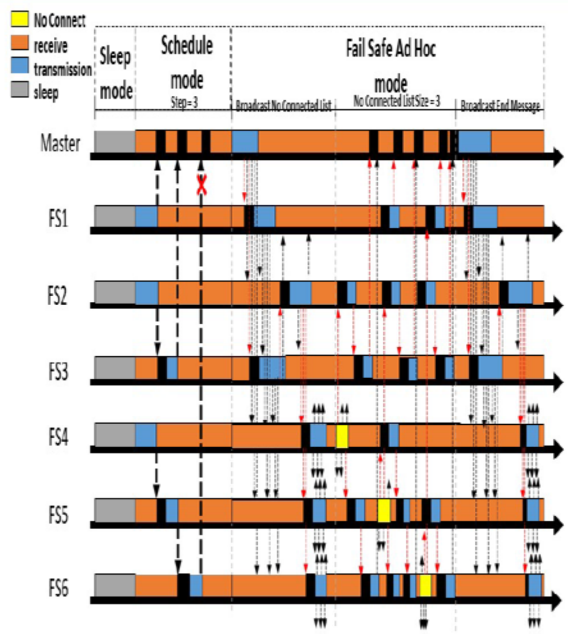

Figure 12(b): Sequence diagram of Figure 12(a).

Next, the experimental results of resending are shown. An experimental result of an example where transmission from FS 6 to the master unit system is disabled is shown in Figure 12. Figure 12(a) shows the operation image of the data collection algorithm. In step 1, FS 1 sends data to the master unit system, FS 2 sends data to FS 3, and FS 4 sends data to FS 5. In step 2, FS 3 sends data to the master unit system and FS 5 sends data to FS 6. In step 3, FS 6 sends data to the master unit system. However, communication is not possible due to the large distance between FS 6 and the master unit system.

The master unit system determines that the communication is not complete, and broadcasts the retransmission scheduling information of FS 6, FS5 and FS4 for which communication is not completed, using the simultaneous-transmission-type flooding algorithm. In the next step, FS 6, FS5 and FS4 retransmits data using the simultaneous-transmission-type flooding algorithm. After that, the master unit system rechecks whether all data have been received. When the master unit system determines that the communication has been completed, it broadcasts the retransmission scheduling information indicating that the communication has been completed. Figure 12(b) shows the sequence diagram of Figure 12(a).

Figure 12(c) shows the measurement results of the current waveform during operation in Figure 12(b). The current at the time of transmission is approximately 50 mA. We compare the position of the transmission on Figure 12(c) to the blue box position showing transmission in Figure 12(b). Thus, we can confirm that the transmission position is the same. It is a mechanism to erase the data after transmission due to the problem of the memory amount of the FS CPU. Therefore, retransmission processing is performed with FS6, FS5, and FS4. In the case of this example, if the problem of memory amount is solved, it is possible to send the data of FS6, FS5, and FS4 only by resending FS6. Memory problems can easily be resolved when we can use an expensive CPU. However, the system we propose cannot use an expensive CPU. Therefore, it is a necessary process to realize a low price FS.

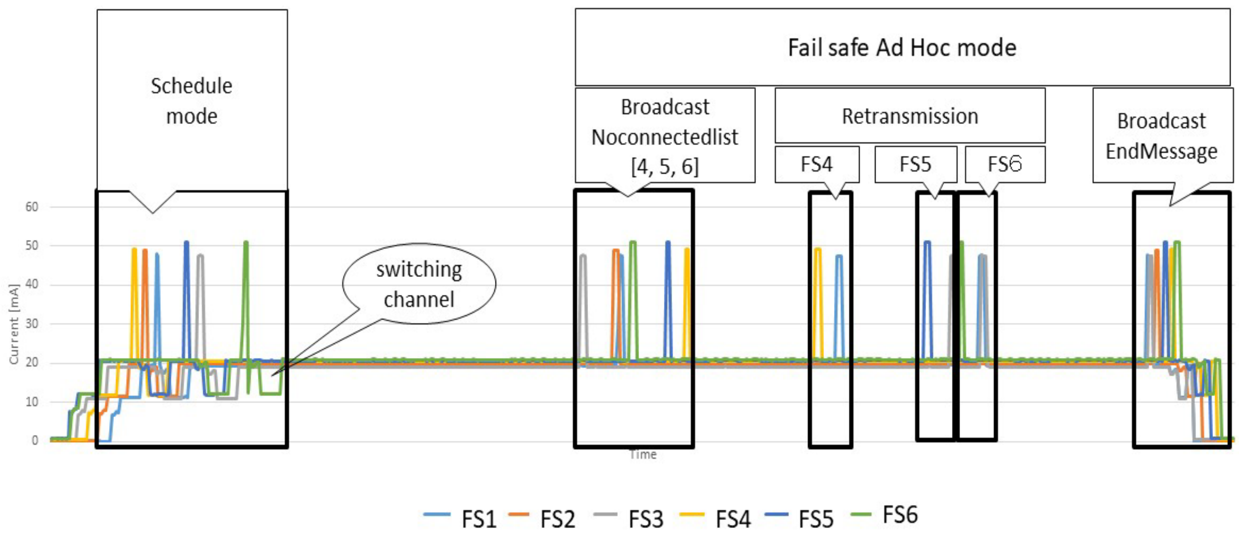

Figure 12(c): Current waveform of Figure12 (a).

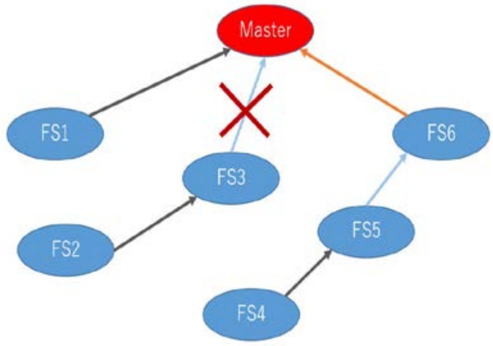

Figure 13(a): Test example 2.

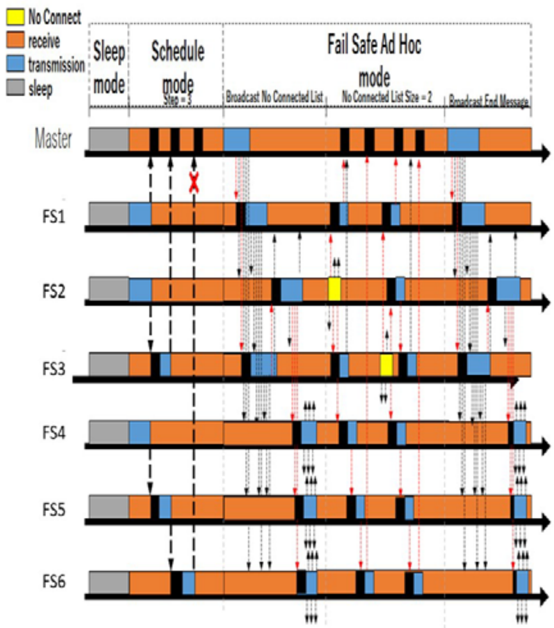

Figure 13(b): Sequence diagram of Figure 13(a).

The process in which all FSs acquire sensor data and collect the data in the master unit system is called one round. One round of processing is performed every hour. The second example is the measurement results for one round, which are shown in Figure 13(a). Figure 13 (b) is a sequence diagram, and Figure 13 (c) is an example of the corresponding current waveform. First, communication is performed according to the scheduling information. In step 1, FS 1 sends data to the master unit system, FS 2 sends data to FS 3, and FS 4 sends data to FS 5. In step 2, FS 5 sends data to FS 6 and FS 3 sends data to the master unit system. However, communication is not possible due to the large distance between FS 3 and the master unit system. In step 3, FS 6 sends data to the master unit system.

After that, the master unit system determines that the communication is not complete, and broadcasts the retransmission scheduling information of the FS for which communication is not completed in hierarchy, and shares the information with all FSs. Each FS compares the node information of the FSs that have not completed the communication with their own node number, and if the codes match, broadcasts data in hierarchy according to scheduling. When the transmission described in the retransmission scheduling information is complete, the master unit system rechecks whether has all data have been received. When the master unit system determines that the communication has been completed, it broadcasts retransmission scheduling information indicating that the communication has been completed.

In this manner, even if the FS cannot receive the data due to some error, it can receive data from other nodes considering the redundant transmission. Therefore, it is a robust algorithm.

The data collection algorithm requires approximately log 2n steps when the number of FSs is n [4]. The master unit system sends the retransmission scheduling information to FSs in one step; each unsent FS sends the data to the master unit system in one step. Therefore, the proposed algorithm is a useful technique in situations where there are few retransmissions.

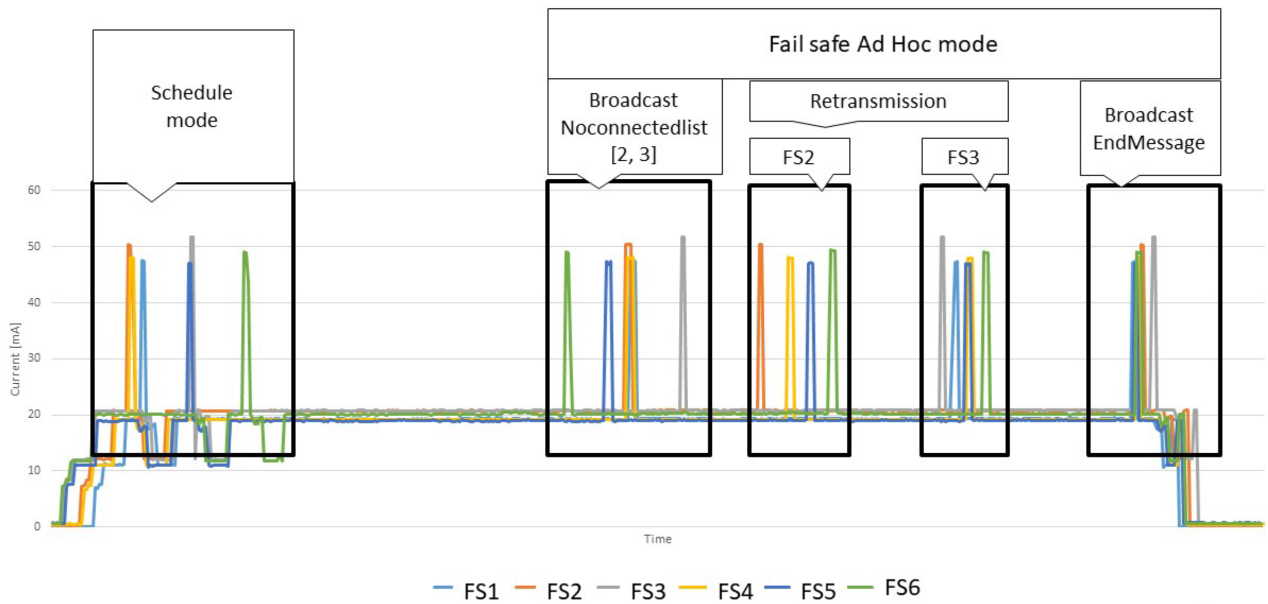

Figure 13(c): Current waveform of Figure 13(a).

To achieve low cost, FS does not hold expensive parts such as crystals and GPS, and has a time error because of device variations. The amount of CPU memory is also minimal. The proposed algorithm allowed device time variations and transmission delay variations. Also, each variation is several seconds. Therefore, it is necessary to set the time for one step so that this variation can be tolerated. In the experiment shown in this paper, one step was set to about 1 minute for the purpose of clearly showing each process. In other words, if their variation is small, the time for one cycle can be shortened and the processing time can be shortened. And many FSs can be connected to one master unit system. Our goal is to make a low-priced FS, which meets the purpose of collecting the data requested by the user in about 5 minutes under the conditions that there are device restrictions to reduce costs. We think that the purpose is satisfied.

7 CONCLUSION

We develop a rice cultivation management system using the field servers (FSs) to reduce the workload of farmers. Price reduction is essential for the introduction of FSs. Low cost FSs have poor time synchronization accuracy. Therefore, an algorithm that allows for a time error was required. We proposed an algorithm that works with low cost FSs and could collect data in a short period. However, this method was vulnerable to data transfer fail due to an accident.

In this paper, we proposed an algorithm to improve the reliability of data transfer. The proposed method is to take advantage of the fact that the data collection algorithm has few untransmitted data, and to adopt the simultaneous-transmission-type flooding algorithm, which is a robust algorithm with an increased number of transmissions. The conventional simultaneous-transmission-type flooding algorithm requires highly accurate time synchronization; however, by avoiding this perfect simultaneous transmission, it was possible to successfully operate with a low cost FS.

As a result of the experiment, we have confirmed that the master unit system was recieved all data of FSs. In addition, the current waveform is shown to show the operation accurately. This protocol is robust for the rice cultivation management systems, because the unreceived node is retransmitted using multiple routes. Therefore, it meets farmers' expectation to utilize a reasonable FS.

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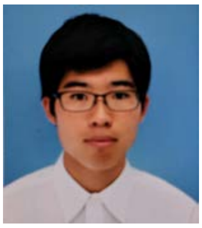

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