Industrial Paper

Proposal of IoT Communication Method for the Rice Field

Mikiko Sode Tanaka*

*Global Information and Management, International College of Technology, Japan
sode@neptune.kanazawa-it.ac.jp

Abstract -Social application of the internet of things (IoT) and commercialization of the low-power wide-area network (LPWA) by telecommunications carriers are progressing, and efforts to put IoT into practical use using LPWA are ongoing. LPWA is expected to be applied for automatic meter reading of water, gas, etc., and large-scale demonstration experiments have been conducted in Japan. Furthermore, application to fields requiring real-time performance is also being considered. The telecommunications carrier adopts a direct method, but the direct method is not suitable for a usage method in which data are transmitted from IoT nodes at the same time. To solve this problem, a method that gathers data in the shortest time is proposed to attain the capacity of the network fully and provide data at the time desired by the users. In this paper, we provide an example of the field server for rice fields and propose a method for gathering data in a short time. The method is effective with low power consumption. Comparison results with a conventional method using a simulation demonstrate that the proposed method can collect all data in the shortest amount of time. Moreover, the power consumption is lower than that of the conventional method. It was also confirmed that the rate of increase in the time necessary for the parent node to collect data due to an increase in the number of sensor nodes is lower than that of other methods. Therefore, this proposal makes it possible to transmit the situation of a rice field in a timely manner and can be considered to be a useful method for reducing the burden of agricultural work. In addition, it is effective for other applications that require real-time performance.

Keywords: LoRa, Rice field, Data gathering, Multihop routing

1 INTRODUCTION

Social application of the internet of things (IoT) is progressing. Especially, in factory management, IoT has become an indispensable basic tool [1]. In addition, the commercialization of the low-power wide-area network (LPWA) by telecommunications carriers is progressing, and efforts to put IoT into practical use using LPWA are ongoing [2],[3]. Figure 1 shows an illustration of the network provided by telecommunications carriers. With LPWA, it is possible to cover a wide range of areas and also to collect data in both homes and buildings and units of towns and cities.

LPWA is excellent for low-power and long-distance transmission and is expected to be applied for automatic meter reading of water, gas, etc., and large-scale demonstration experiments have been conducted in Japan [2],[3].

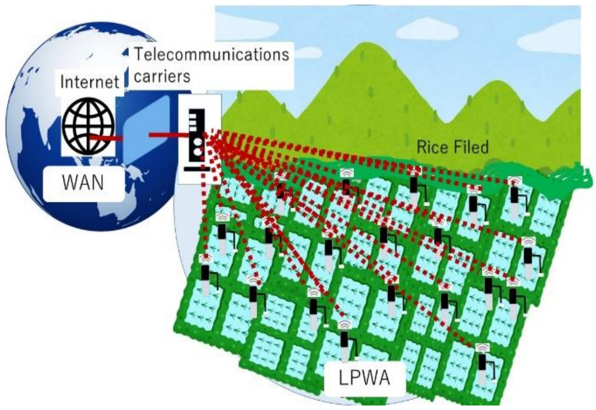

Figure 1: LPWA network for IoT

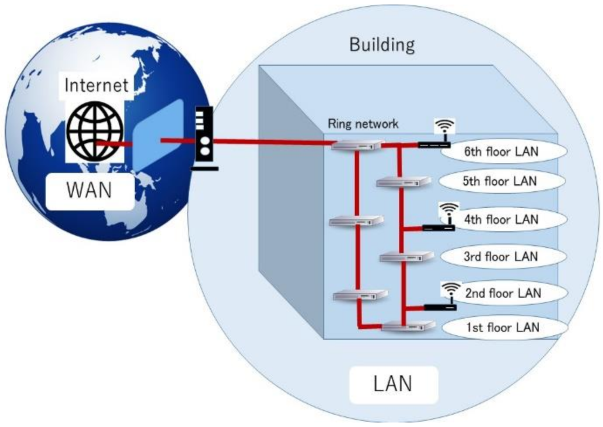

Figure 2: Wired LAN + Wi-Fi network for a building

Automatic meter readings such as those for water and gas are suitable for LPWA because the timing for acquiring and transmitting data is not strictly regulated, and data for a certain period can be sent within an arbitrary period. Furthermore, application to fields that require real-time performance is also being considered [4].

A field server for rice cultivation management system for rice fields is an application that requires real-time performance. The main function of the rice field server is water level management. The water level must be managed in units of several cm in the months immediately after rice planting, and real-time performance is required. However, the telecommunications carrier adopts the direct method. As a result, a conflict may occur and farmers may not be able to see the data in the time they want. Therefore, direct method is not suitable for a usage method in which data are transmitted from IoT nodes at the same time.

When there are many applications that acquire and transmit data at intervals of several minutes, data transmission concentrates at the same time and a conflict occurs. For this reason, to prevent data transmission from occurring at the same time, telecommunications carriers apply an operation method that reduces the probability of competition by providing a difference in usage fees. However, the conflict problem has not been solved.

There are many cases in which companies construct networks with a wired large area network plus wireless fidelity (LAN + Wi-Fi). Figure 2 shows an illustration of the LAN + Wi-Fi network in a building. This method is effective in terms of security and cost. Cost and security are also important items for rice cultivation management system. Thus, when considering a communication system for rice cultivation, there is a high demand for building a wireless network with the same structure as a wired LAN + Wi-Fi network in a company. The most important reason is cost. In addition, to prevent the water level management technique from being stolen, it is desired to manage the water level data locally. However, there is currently no local area wireless network system for rice fields that can realize this objective.

In this paper, we assume an application that acquires and transmits data at an interval of tens of minutes, particularly the system for rice cultivation. In addition, a wireless network that connects all rice fields locally is assumed. The wireless network is of the same type as a wired LAN + Wi-Fi network in a company. We propose a communication protocol to realize real-time performance with this wireless network.

Comparison results with a conventional method obtained using a simulation demonstrated that the proposed method can collect all of the data in the shortest amount of time. Moreover, it was confirmed that the power consumption is also lower than that of the conventional method. Furthermore, it was confirmed that the rate of increase in the time necessary for the parent node to collect data, due to the increase in the number of sensor nodes, is lower than that of other methods.

2 REQUIREMENTS FOR FIELD SERVERS SUITABLE FOR JAPANESE RICE FIELD

In Japan, rice produces a lower income than other crops. Table 1 shows the profit structure of rice production revenue. The unit of 1 pyo is equal to 60 kg, and 1 tan is 0.1 ha. The standard yield per tan is 9 pyo, and this amount of rice can be sold in the market for about 13,000 yen. If the cost is deducted, a profit of about 50,000 yen can be obtained per pyo [5]. In other words, in Japan, farmers can only make a profit of 50,000 yen per year from 1 tan (Table 1). On the other hand, field servers rent for 8,280 yen per month [6]. Thus, the rent for 6 months costs 50,000 yen. This calculation indicates very little profit. Therefore, the introduction of field servers has not progressed among rice farmers. From these facts, in order to introduce the field server practically, the selling price must be less than 10,000 yen. The manufacturing price can be assumed to be around 3,000 yen. Therefore, we assume a field server that can realize this price.

Field servers should not interfere with the farmer's work. Because large agricultural machines are used in the rice field, the field server needs to be easy to move. Therefore, its height must be less than 1 m, and it should be as small as a lunch box and compact. Additionally, because rice fields do not have a power source, it is necessary to operate the servers with batteries from rice planting to rice harvesting. Therefore, intermittent operation is necessary.

To realize an affordable field server, we decided to use a long-range (LoRa) network that does not require a communication line usage fee and can transmit a great distance. LoRa can send more data than Sigfox [7] and is considered more effective in an agricultural field having a relatively large amount of sensor data. In addition, the protocol and frame format can be created freely, so it is suitable for special applications that require performance and price. LoRa can build and operate all architectures including base stations by itself, and its specifications are open. For this reason, it is easy to build a system for special purposes.

Furthermore, to build a reasonable price field server for rice cultivation, it is necessary to reduce the number of parts to the minimum limit. For example, crystal elements and GPS, which are expensive and highly accurate clock sources, cannot be used. In addition, there must be a lightweight communication protocol that operates without expensive components. For this reason, the design must accept time errors, which is a fatal problem for communication systems. To solve the problem of time error, it is necessary to take a time slot longer to be able to tolerate time error. The time slot is a time interval for sending data.

Table 1: Profit structure of rice production revenue

	Breakdown		**Total**
Income	1 pyo (60 kg) Rice crop yield (1 tan)	13,000 Yen 9 pyo	117,000 Yen
Spending	Fertilizer (1 tan): Herbicide and pesticide (1 tan) Agricultural machinery fee (1 tan) Personnel costs (1 tan)	15,000 Yen 10,000 Yen 20,000 Yen 15,000 Yen	60,000 Yen

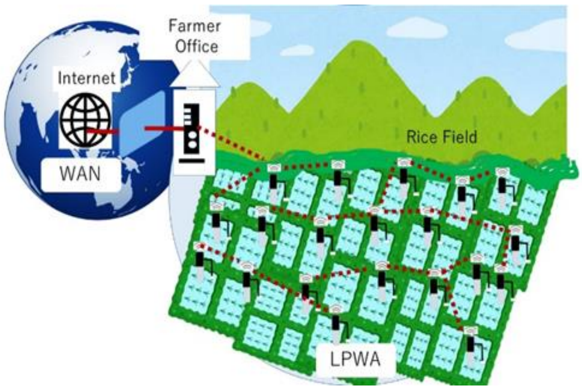

Figure 3: Proposed LPWA network for rice field

A rice cultivation management system using a field server focused on in this paper was developed to manage the field smoothly and flexibly. The configuration is shown in Fig. 3. The system consists of field servers, a parent node, and a cloud service. From the perspectives of cost and security, farmers desire a local wireless network like the wired LAN + Wi-Fi network in a building. Farmers want to check the water level in every hour within 5 minutes after sensor data are acquired.

The field server is installed in the rice field. After acquiring the sensor data, it transmits the data to the parent node via the LoRa wireless network. The parent node aggregates the sensor data from the field servers installed in each rice field and transfers these data to the cloud via a 3G line or Wi-Fi. Cloud services are provided by applications such as smartphones and tablets and web pages. The system provides functions such as water level warnings, work plan proposals, preservation of work records, etc., for the farmers.

The average amount of rice field held by a farmer in Japan in 2010 was 105.1a [8], and the effective transmission distance of LoRa is about 3 km. Therefore, the wireless communication protocol proposed in this paper assumed a rice field area of 3 km × 3 km and a maximum number of field servers to be installed of 100. In the farmer office, the parent node always wake up and have a power supply.

3 BASIC WIRELESS COMMUNICATION PROTOCOL

To operate for 6 months in an environment without a power supply, it is necessary to turn off the power when sensor data acquisition and communication are not being performed. To realize these operations, an intermittent operation communication protocol and time synchronization technology are required. Time synchronization technology has been studied extensively [9]-[12].

For example, a time synchronization method using a radio clock has been proposed [13]. This method requires about 3 minutes to set the time. For this reason, the operation time becomes longer and it is difficult to realize low power consumption. In addition, the received signal (time code) needs to be converted to a format that can be handled in the field server, but a program that performs this processing cannot be written to a low-cost microcomputer, such as a PIC microcomputer, with little memory. Therefore, it is difficult to use it for a rice field server.

A time synchronization method using GPS has also been proposed [10]. To use this method, it is necessary to install a GPS receiver module in each field server, which leads to an increase in the initial cost at the time of introduction. For this reason, it is difficult to use the method for field servers where there is a desire to lower the cost barrier of introduction.

Reference broadcast synchronization (RBS) has been proposed as a time synchronization method for wireless networks [11]. Time synchronization is performed by exchanging time information between field servers that receive a certain broadcast packet. However, RBS has the problem of increasing power consumption because the amount of information exchanged increases in proportion to the increase in the number of receiving field servers. Therefore, it is difficult to apply it to field servers for rice field.

The Timing-sync Protocol for Sensor Networks (TPSN) has been proposed as a method for improving RBS [12]. The TPSN forms a tree structure with the parent node at the top, and the parent node performs time synchronization with the field server. The field server synchronizes time with the field servers below it. In this way, time is synchronized throughout the system. However, because this method requires a long time for time synchronization, it is not suitable for field servers that require low power consumption.

We proposed a wireless communication protocol that achieves low cost [4]. Figure 4 shows a basic communication protocol sequence diagram of the proposed protocol. Communication is performed according to scheduling. In Fig. 4, field server A (FS-A) sends the sensor data to field server B. Then, field server B sends its own sensor data and the sensor data of the field server A to field server C. Field server C constructs a frame with the sensor data of field servers A and B and its own sensor data and sends these data to field server D. The time is transmitted as a signal indicating that data have been received. The time can be synchronized among field servers transmitting and receiving data, but it cannot be synchronized with other field servers. The field server does not include a crystal or other system to measure the exact time, so there is an error of about a dozen seconds between the field servers in the proposed wireless communication

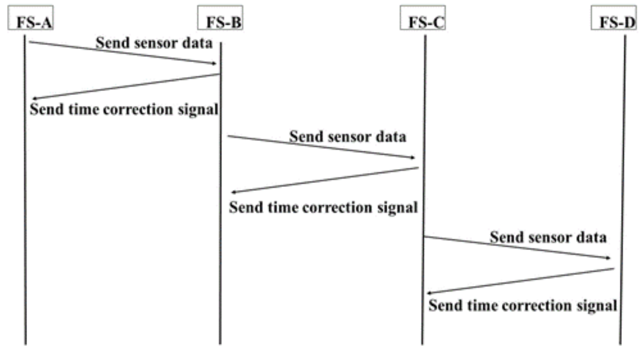

Figure 4: Communication protocol sequence diagram

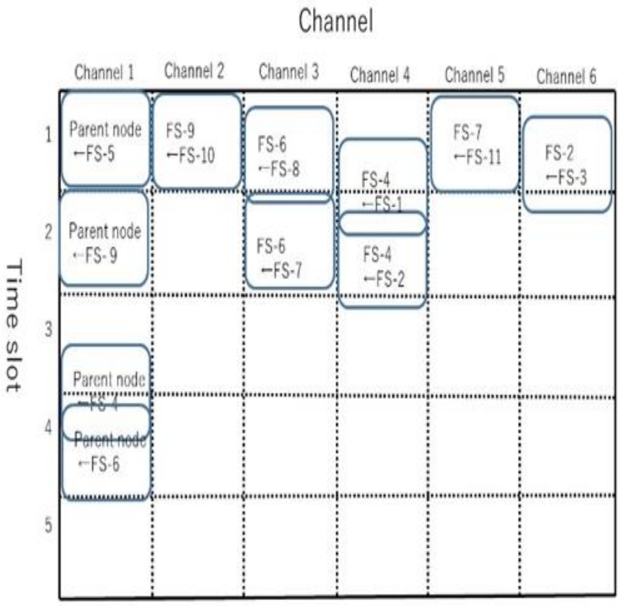

Figure 5: Time slot shift due to time error

protocol. Transmission / reception between field servers takes place within the time slot. The time slot is set to long, when a transmission or a reception fails, a retry is made after a random time.

The operation when a field server is newly introduced follows. The newly added field server first sends a wake-up signal to inform the parent node that it has been added. When the parent node receives the wake-up signal from the field server, the field server number is added to the library and rescheduling is performed. The scheduling result is sent to the field server at the same time. The field server synchronizes the time based on the reception time from the parent node. When a field server is newly introduced, the field server works by direct method at first.

The time at which the field server is installed is arbitrary. Therefore, when another field server is communicating with the parent node, the newly added field server may start communication. However, in this case, collisions may occur. In the event of collision, retransmissions are performed after a random period within a few seconds. This process is repeated until the field server receives the current time information from the parent node.

The proposed method allows time errors. Therefore, as shown in Fig. 5, the original time is deviated and a time slot is generated. It may also occur when time slots overlap. We decided to allow them by setting the time slot to about 7 or 8 times the time for a single transmission. Due to the time error, the transmission times slot executed in each channel are not unified.

4 SYSTEM CONFIGURATION OF RICE CULTIVATION MANAGEMENT SYSTEM

In the LPWA network, the time is often overlapped for the gathering sensor data and for sending them to the parent node that is the gateway. As a result, the user may not be able to confirm the data at a desired time. To solve this problem, a method that the gathering data in the shortest time is needed to fully extract the capacity of the network and the provide data at the time desired by the users [14]-[17].

Table 2: Frame format (Byte length)

Destination	Sender	Payload
1	1	variable

Table 3: Payload for sensor data (Byte length)

FS ID	Sensor data 1	Sensor data 2	Sensor data 3	Sensor data 4	sensor data 5
2	2	2	2	2	2

A rice cultivation management system monitors the air and water temperature of rice fields. This system consists of a field subsystem, a home subsystem, and a management subsystem. The field subsystem is installed in the field, acquires air and water temperature data and transmits the acquired data to the home subsystem via a wireless network. The home subsystem is a system that uploads the data sent from the field subsystem to the management subsystem via the Internet. The management subsystem is a system that analyzes and displays the collected data and allows farmers to check the data accumulated on the cloud via the Internet.

In the field server subsystem, a plurality of field servers are held; each field server acquires data once per hour, and transmits the acquired data to the home subsystem which is a parent node. This single process is called round one. Table 2 shows the frame format used for transmission. The frame is composed of a transmission destination, a transmission source, and a payload. Table 3 shows the sensor data transmission format stored in the payload of Table 2. In addition, the parent node can communicate with at most one field server at the same time, and the field server can communicate with at most one field server or parent node. In a single process, the power is turned off after system startup and after data acquisition, acquisition of a data transmission, and transmission are completed. The time required for this series of processes is defined as one round of operation time. This operation time is the time required to gather data to the parent node. In each field server, the data merging processing is performed as necessary. By this merging process, it is possible to shorten the time required for transmission.

Synchronization between the parent node and field servers is carried out by using the current time transmitted according to the transmission request sent from the parent node [18]. When the field server receives the current time, the time is updated to the current time.

5 LOW DELAY DATA GATHERING METHOD

Currently commercially available LPWA uses the direct method. However, since this method has a long data-gathering-time problem. When the number of field servers is n, and the time step T of direct method which is required can be expressed by the following equation.

$$T = n \tag{1}$$

In the direct method, the time required to transmit the data of all field servers to the parent node increases in proportion to the number of field servers. If one time slot is set to 30 seconds and there are 200 field servers, a time of 30 * 200 = 6000 seconds = 100 minutes is required, and a request of 5 minutes or less cannot be satisfied.

In this paper we propose a method that has a low power consumption and a short data-gathering time. The procedure of the proposed method is shown below.

① After the rice planting, the field servers are installed in the rice field. The field server starts in installation mode.
② Farmer sets the initialization mode to the parent node, and then the field server position confirmation procedure is executed in order to collect position information of the field server.
③ A transmission network graph is created on the parent node based on the field server position information, and the scheduling result is sent to the field servers.
④ Data gathering procedure on the local wireless network is performed based on scheduling result.

The newly added field server first sends a wake-up signal to inform the parent node that it has been added. When the parent node receives the wake-up signal from the field server, the field server number is added to the database and the time for transmitting data to the parent node is sent to the field server. Operation using direct method is started [19].

In this state, when initialization mode is set in the parent node, the field server position confirmation phase starts at the timing when data is sent from the next field server to the parent node.

The field server sends data to the parent node by direct method, then enters the reception mode. Next the field server receives data from other field servers, calculates the radio field strength, and creates a list of field server numbers in order of strength. At the next transmission timing, a list of field server numbers in order of strength is transmitted together with sensor data.

The parent node has a list of field server numbers in order of strength and a list of field server numbers in order of strength sent from each field server. Based on this information, a transmission network graph is created and the scheduling result is transmitted to the field servers by broadcasting. Each field server is turned off when it receives the scheduling result. Thereafter, each field server performs transmission processing with this scheduling result.

6 TRANSMISSION NETWORK GRAPH

We describe the procedure for creating a transfer network graph. A transmission network graph is a graph that describes the order, direction, and transmission timing of data transmission between a field server and a field server, or between a parent node and a field server. Data collection is performed according to this graph. The transfer network is defined by the effective graph G = (V, E). V is a set of the parent node and the field servers. E is a set of edge, and edges e = {i, j} indicate that data is transmitted from node i to node j. E_m is set of edges which data is sent in m steps.

Here, in order to simplify the following discussion, the symbols are defined as follows.

V: {N1, N2} node set
N1: set of parent node
N2: set of field servers
n_i: parent node
n_j: field server j where j=1, 2, 3, ...
l: the number of parent node
m: the number of field server
e={n_j, n_i}:transmission from n_i to node n_j
E_m: set of edges in the step m
E={E_1 , E_2, ⋯ }: set of edges
F: set of transmission completion nodes
E: set of un-transmission completion nodes
Nearest(j, G): The node with the closest distance to node j in node set G for which transmission has not been completed
Farthest(j, G): The node with the farthest distance to node j in node set G for which transmission has not been completed
t: step number
k: tradeoff variable of processing completion time and power consumption

The transfer network graph creation flow is shown below.

```
Procedure Routing(V,  E)
F={n_0};
G=N2;
t=0 ;
k=4;   /* Processing time and power trade-off factor*/
While( There are k or more nodes belonging to G) {

      /* Transmission to the parent node*/
      t=t+1;
      i= Nearest(n_0, G);
     /* Find the nearest field server to the parent.  */
      Create branch {n_0, n_i} and put in set E_t representing processing at t time step
      Delete node i from un-transmit set G.
      Put the node i in the transmission complete set F.

      /* Data transmission between field servers */
      H=G;
      While(There is a node that belongs to H) {
               j=Farthest(n_0,  H);
               Delate j from H.
               i=Nearest(j,  T).
               Delate i from H.
               Generate edges {i, j} and put them in the set E_t representing the processing at t time steps
```

```
                Delete node j from un-transmit set G.
                Put the node j in the transmission complete set F.
      }
}
While(There is a node that belongs to G) {
    /* Transmission to the parent node */
    t=t+1;
    i= Nearest(n_0, G);
  /* Find the closest field server to the parent node. */
    Generate edges {n_i, j} and put them in the set E_t representing the processing at t time steps.
    Delete node j from un-transmit set G.
    Put the node j in the transmission complete set F.
}
```

The movement of the flow is explained using the example of one parent node and 11 field servers shown in Fig. 6. In the first step, the field servers 5 nearest to the parent node is selected, and an edge representing transmission to the parent node is made. Next, the field server 11 which is farthest from the parent node is selected, and an edge from the field server 11 to the field server 7 is made. Similarly, an edge from field server 3 to field server 2, an edge from field server 10 to field server 9, an edge from field server 8 to field server 6, an edge from field server 1 to field server 4 are created, and the first step is complete.

In the second step, as in the first step, an edge from the parent node to the nearest field server 9 to the parent node is created, an edge from the field server 7 to the field server 6, an edge from the field server 2 to the field server 4 is created. In the third step, an edge from the field server 4 to the parent node, and in the fourth step, an edge from the field server 6 to the parent node are created.

7 DATA GATHERING PROCEDURE

The data gathering procedure will be described. Data is gathered to the parent node according to the tree structure of the graph created in the transfer network graph creation flow. Here, the operation is explained using the example in Fig. 6.

In the first step, transmission corresponding to the edges belonging to the branch set E_1 representing the processing in the first step is performed. That is, transmissions from the field server 5 to the parent node, from the field server 11 to the field server 7, from the field server 3 to the field server 2, from the field server 10 to the field server 9, from the field server 8 to the field server 6, and from the field server 1 to the field server 4 are performed. The field server receiving the transmission merges the data held by itself and the transmitted data, creates a frame, and prepares for the next transmission. In the second step, transmission corresponding to the edge belonging to the edge set E_2representing the processing in the second step is performed. That is, transmissions from the field server 9 to the parent node, from the field server 7 to the field server 6, and from the field server 2 to the field server 4 are performed. The field server receiving the transmission merges the data held by itself and the transmitted data, and creates a frame. In the third step, transmission corresponding to the edge belonging to the branch set E_3 that is transmission from the field server 4 to the parent node is performed. In the fourth step, transmission corresponding to the edge belonging to the branch set E_4 that is transmission from the field server 6 to the parent node is performed.

Figure 7 shows a sequence diagram of data exchange between the parent node and field servers. The data of each field servers is merged step by step, and all data is sent to the parent node in the fourth step.

The number of field servers in operation at step T is defined as N (T). The number of steps required to gather data can be expressed by the following equation.

$$N(T+1)=\lceil (N(T)-1)/ 2\rceil$$

Namely, T where N (T + 1) = 0 is a necessary step to transmit all data to the parent node. For example, in the example of Fig. 6,

$$N(0)=11$$
$$N(1)=\lceil (11-1)/2\rceil=5$$
$$N(2)=\lceil (5-1)/2\rceil=2$$
$$N(3)=\lceil (2-1)/2\rceil=1$$
$$N(4)=\lceil (1-1)/2\rceil=0$$

In this example, since the number of field servers is 11, N (0) = 11.Then, all data can be transmit to the parent node in 4 steps.

From the above consideration, the number of steps T required for data gathering can be expressed by the following equation.

$$T = \lceil log_2 n\rceil \quad (2)$$

If one time slot is set to 30 seconds and there are 200 field servers, a time of 30 * $\lceil log_2\ 200\rceil$ = 228 seconds = 3.8 minutes is required, and a request of 5 minutes or less can be satisfied.

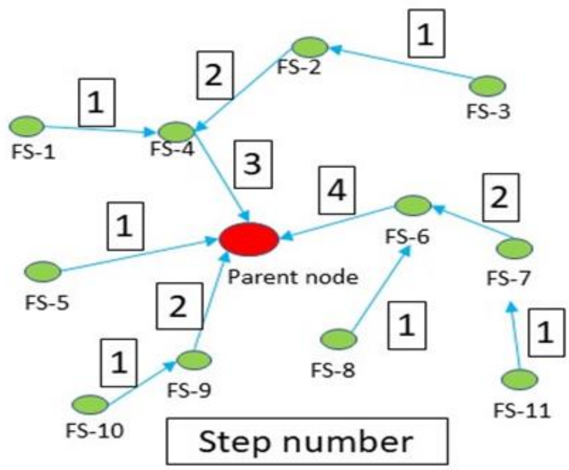

Figure 6: Operation example of one round

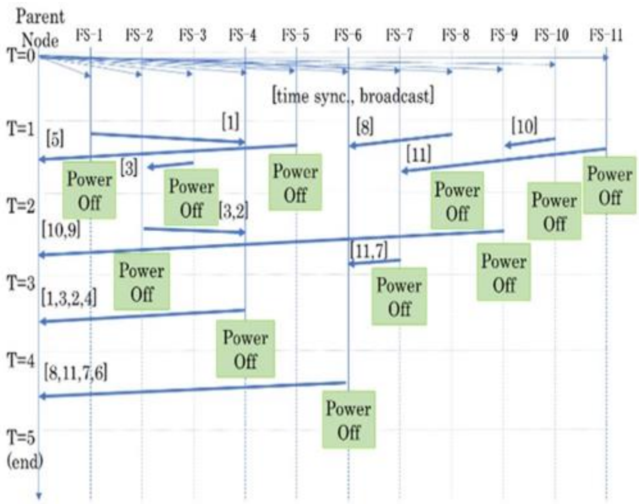

Figure 7: Sequence diagram of operation example

8 PERFORMANCE EVALUATION BY SIMULATION

A comparison was made by simulation to check the data gathering time. Here, we focus on the prompt confirmation of the condition of the rice field required for rice cultivation. Therefore, we verify the data gathering time and the power consumption required to collect all the field server data. Being able to verify the data within an allowable time is an important item even if the number of field servers is increased. The simulator was written in C language. First, the method of calculating the power consumption will be described. Owing to the fact that the parent node is always supplied with power, its power consumption is excluded from the scope of consideration and only field servers are calculated. Each field server has a battery and has a capacity of 75,000 mWh. The field server has six modes (Table 4) according to the operating condition. The current consumption was set from the actual power consumption measurement report [18] using LoRa. The transmission power depends on the distance. Operation voltage is set at 2.5 V. The time of data merge is not considered because it is 1/100 or less of the time required for transmission and reception. Also, since the data transfer network is created only once at first, the influence on the power consumption is not considered because it is small.

Table 4: Six mode of field server

State	State name	Power consumption (mA/s)	Processing time (s)
1	Power OFF	0	-
2	Data transmission mode	53, 62, 69, 78	3.4
3	Data reception mode	13.5	3.4
4	System startup mode	Parent 78 FS 13.5	3.4
5	Sensor data acquisition mode	60.0	60.0
6	Standby mode	2.7	3.4

Table 5: Details of simulation data

	#Parent	#FS	Radius(m)
DATA1	1	99	500
DATA2	1	200	500
DATA3	1	300	3000

The sensor data to be acquired is the data on temperature and humidity. In each round, when each field server reaches the activation time, the system is started and the data is acquired from the sensor. Next, the parent node transmits a data transmission request to all of the field servers. Upon receiving the data transmission request, the field server measures the data from the sensor, and transmits the data to the parent node. Each field server turns off the power source. In this simulation, it is assumed that the time synchronization is perfectly performed. It was assumed that there was no failure of data transmission / reception. In fact, the merging time of the data by the field server was ignored in this simulation. Given that the payload can be transmitted at a data rate of up to 60 bytes, the transmission time can be shortened by the data merging process.

Table 5 shows the three instances of test data created. The field servers have been randomly assigned within the circle of a specified radius, centered on the parent machine.

Comparisons were made between the following methods: direct [20], pegasis [21], epegasis [22], chiron [23] and the proposed method. In addition, the following three items are compared to enable the farmer to confirm the data of the rice field in real time, while reducing the data gathering time and operating with batteries from the time of rice planting to harvesting.

Power Efficient Gathering in Sensor Information Systems (pegasis method) is a chain-based protocol [21]. The field servers are connected only to the closest field server and are chained. Data is sent along the chain to the chain head (the last filed server of the chain) and from the chain head to the parent node. The chain head is randomly selected and has a duty to transmit data to the parent node. The time required to gather data for pegasis method is long.

Epegasis method [22] has been proposed as a method to solve the pegasis method problem. The field servers are broken down into clusters at a distance from the parent node, and a chain is created in each cluster in the same way as pegasis method. Each cluster sends data to the chain head along the chain. When data gathers in the chain head in each cluster, the chain head transfers data to the parent node. Therefore, the time required for data collection can be reduced compared to pegasis method.

Chiron method [23] has been proposed as a method for achieving further improvement. It is characterized by using Beam Star technology [24] to divide into smaller cluster areas than epegasis method. In each cluster, build a chain. Initially, the data for each cluster is collected by the chain head in the same way as pegasis method. Next, a chain between chain heads is created in order from the chain head farthest from the parent node, along which data is sent to the parent node. Chiron method can shorten the time required for data collection in each chain by shortening the chain length, but has the problem that the time required for gathering data in each area to the parent node increases.

i. Time required for data gathering in one round.
ii. Total power consumption of all field servers in one round.
iii. Maximum working days (the number of days during which all the field servers are in operation).

The simulation results of DATA 1 are shown in Table 6. Table 6 shows the operation time, which is the time required for the parent node to gather data, the total value of the power consumed by the field server, and the number of operable days. Figure 8 shows the size of data received by the parent node in the one round. The vertical axis in Fig. 8 represents the data size (byte) received by the parent node, and the horizontal axis represents operating time (seconds). Figure 9 shows the number of field server whose transmission processing has been completed and the power has been turned off within one round. The horizontal axis shows the operating time (seconds), and the vertical axis shows the number of field servers whose power has been turned off. It can be confirmed that the slope of pegasis method is the slowest.

Table 6: Simulation results of data1

	Data collection time / Round (s)	**Total power consumption of field servers /Round (mAS)**	**Number of working days (Day)**
Direct	400.0	74508.5	372
PEGASIS	1902.9	299237.6	58
EPEGASIS	226.6	55253.0	384
CHIRON	158.6	40131.1	448
Proposed	**114.4**	**34177.0**	**566**

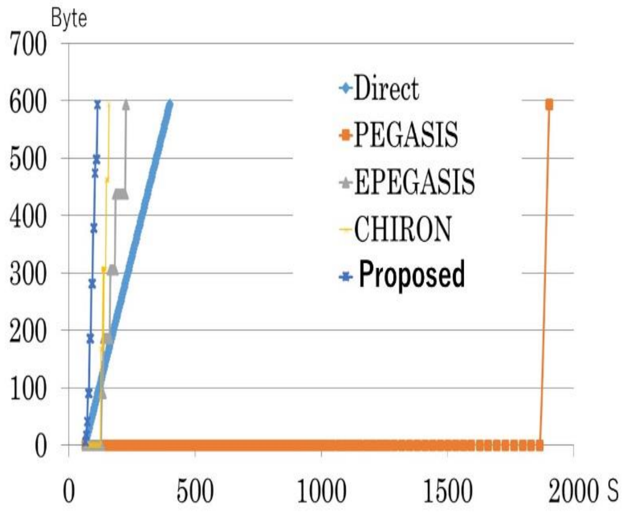

Figure 8: Number of data received by parent node of DATA1.

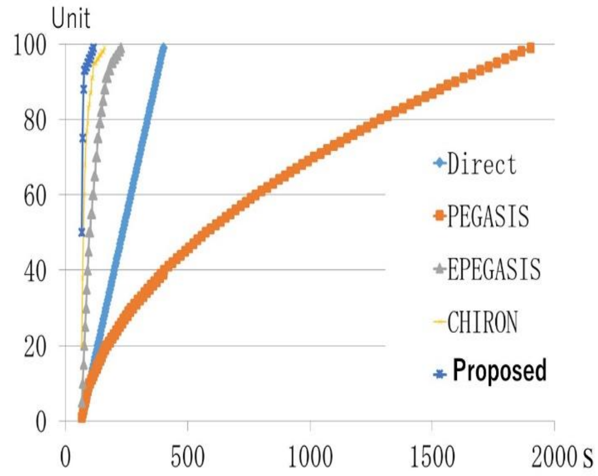

Figure 9: Number of power off field servers of DATA1.

Compared to other methods, the proposed method shows that the time to gather data to the parent node is the shortest. Moreover, the total power consumption is the smallest, based on the simulation, it can be concluded that it can operate for a period that extends from rice planting to harvesting.

The simulation results for DATA 2 are shown in Table 7. Compared to other methods, the proposed method shows that the time for the parent node to collect data is the shortest. In addition, it is understood that the total power consumption is the smallest, and the lifetime is the longest. In the simulation, we can see that it can operate for a period that extends from rice planting to harvesting. In addition, although the proposed method doubles the number of field servers as compared with DATA 1, it can be seen that the increase in time required for data gathering is as short as about 7 s.

The simulation results for DATA 3 are shown in Table 8. Compared to other methods, the proposed method shows that the time to for the parent node to collect data is the shortest. In addition, it is understood that the total power consumption is the smallest, and the lifetime is the longest. Moreover, in terms of the theoretical value, it can be understood that it can operate for a period extending from rice planting to harvesting. In addition, compared to DATA 1, the number of field servers is tripled, but the increase of time increase necessary for collection is short as about 10 s.

Table 7: Simulation results of data2

	Data collection time / Round (s)	**Total power consumption of field servers /Round (mAS)**	**Number of working days (Day)**
Direct	743.4	243604.6	210
PEGASIS	7135.4	1763010.2	18
EPEGASIS	721.0	201747.2	195
CHIRON	248.7	90308.8	209
Proposed	**121.2**	**70925.4**	**231**

Table 8: Simulation results of data3

	Data collection time / Round (s)	**Total power consumption of field servers /Round (mAS)**	**Number of working days (Day)**
Direct	1083.4	519160.0	67
PEGASIS	15771.0	5672543.4	8
EPEGA-SIS	695.8	487720.8	97
CHIRON	322.1	168756.0	151
Proposed	**124.6**	**117871.6**	**185**

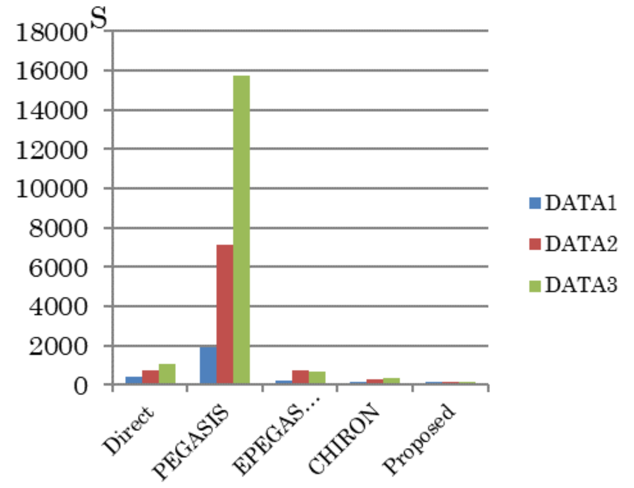

Figure 10: Comparison of time required to gather data in one round.

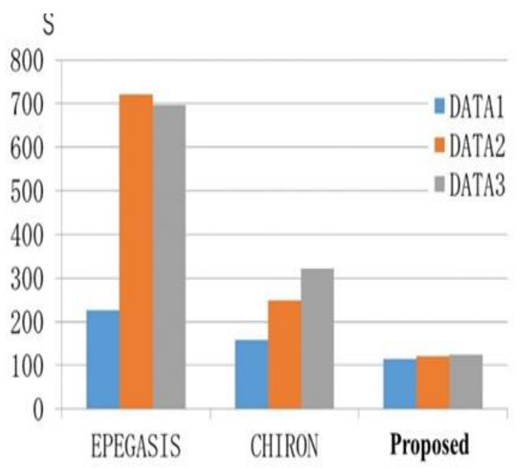

Figure 11: Excerpt from the Fig. 10

Figure 10 displays the time to gather data to the parent node in one round. Figure 11 is excerpt from the Fig. 10. The vertical axis represents the operation time (seconds). For the direct and pegasis methods, as the amount data increases, the time required to gather data to the parent node rapidly increases. For the proposed method, the rate of increase of the time required for data gathering according to an increase in the amount of data is the lowest, and data can be collected in a short time even if the number of field servers increases. In addition, the elongation rate is about a 5% growth with respect to an increase in the number of field servers. This result confirms the validity of Equation (2) and also indicates that the proposed method is superior to other methods in terms of the data gathering time.

The proposed method gather all field server data in a short time. Since all data can be gathered in a short time, the operation time is short and the power consumption can be reduced. In order to gather the data in a short time, three measures were taken to reduce the number of the data transmission to the parent node. The first is compression by the data merging to reduce the number of the transmissions. In order to reduce the number of the transmissions, the upper field server merges the data from multiple lower field servers. The power consumed in the merge process is negligible compared to the transmission. The second is the scheduling method in which the parent node keeps receiving data without idle time. The third is the transfer network graph configuration that minimizes the number of multihops. This has reduced the total amount of data that must be sent.

The proposed method is for IoT, and it is the method for a small data size such as the environmental data of temperature and humidity, or the consumption data of electricity and gas. It is also assumed that the size of the data to be handled is almost the same. Therefore, when the data size is large, the compression effect is reduced and the efficiency may be reduced. And when the data size is significantly different, latency may occur and efficiency may be reduced.

9 CONCLUSION

The telecommunications carrier adopts a direct method, but the direct method is not suitable for a usage method in which data are transmitted from IoT nodes at the same time. To solve this problem, a method that gathers data in the shortest time is proposed to attain the capacity of the network fully and provide data at the time desired by the users.

In this paper, we assume an application that acquires and transmits data at an interval of tens of minutes, particularly a system for rice cultivation. In addition, a wireless network that connects all rice fields locally is assumed. The wireless network is of the same type as a wired LAN + Wi-Fi network in a company. This method is effective in terms of security and cost. We proposed a communication protocol to realize real-time performance with this wireless network.

It is difficult to supply power to rice fields unlike other fields, so low power consumption is an important factor. In addition, the line usage fee required for communication must be reduced as much as possible from the standpoint of the entire cost required for agriculture. Therefore, we investigated interfiled communication using LoRa which is an IoT communication standard, low power consumption using the ISM band and a long transmission distance.

As a result of the comparison with other methods using the simulation, we confirmed that the time required to gather field server data to the parent node is the shortest. Moreover, it was confirmed that the power consumption is smaller than that of conventional systems. Furthermore, we confirmed that the elongation rate of time necessary for gathering data to the parent node due to an increase in the number of field servers is lower than that of the other methods. This result supports the theoretical formula.

Therefore, this proposal makes it possible to transmit the situation of a rice field in a timely manner and can be considered to be a useful method for reducing the burden of agricultural work. In addition, it is effective for other applications that require real-time performance.

REFERENCES

[1] Factory Management Editorial Department, "SMEs begin! Production site IoT," Nikkan Kogyo Shimbun.

[2] "Use LPWA to understand LP gas usage. Large-scale demonstration of participation by thousands of households," https://www.itmedia.co.jp/smartjapan/articles/1805/11/news029.html, (Access 2019/10/21).

[3] "Practical use of automatic meter reading with new technology "LPWA" -Metering solution for water supply using "SIGFOX" -," http://news.kddi.com/kddi/corporate/newsrelease/2017/03/30/2379.html, (Access 2019/10/22).

[4] K.Tanaka, M.Sode, T.Ozaki, M.Nishigaki and T.Mizuno: "A Study on Time Synchronization Method for Field Servers for Rice Cultivation," International Journal of Informatics Society (IJIS 2019), Vol. 11, No. 1, pp.33-pp.44, (2019/6/19).

[5] T. Hagino, "Rice farming in Japan," https://www.fukoku-life.co.jp/economy/report /download/analyst-VOL215.pdf, (Access 2019/10/22).

[6] RiceWatch, https://field-server.jp/ricewatch/rental/index.html, (Access 2018/10/2).

[7] Sigfox, https://www.sigfox.com/en, (Access 2018/10/2).

[8] Cabinet office, "Changes in management scale per farmhouse," https://www.cao.go.jp/sasshin/kisei-seido/meeting/2011/agri/120712/item2-2_2.pdf, (Access 2019/10/22).

[9] T. Watanabe, T. Morito, M. Minami, and H. Morikawa, "Design and Implementation of a Radio Controlled Clock based Battery-less Wireless Sensor Network," IPSJ SIG Mobile Computing and Ubiquitous Communications (SIG-MBL), Vol. 2007, No.44, pp.113-118, (2007).

[10] Position Co., Ltd., "About GPS reception as a time reference," http://www.posit.co.jp/mission/pdf/1998.6.pdf, (Access 2017/5/3) .

[11] J. Elson, L. Girod, and D. Estrin, "Fine-Grained Network Time Synchronization using Reference Broadcasts," Proceedings of the 5th Symposium on Operating Systems Design and Implementation (OSDI' 02), Boston, Massachusetts, (2002).

[12] S. Ganeriwal, R. Kumar, and M. B. Srivastava, "Timing-sync Protocol for Sensor Networks," Proceedings of the 1st ACM Conference on Embedded Network Sensor Systems (SenSys'03), Los Angeles, California (2003).

[13] T. Furuta, H. Nakagawa, T. Kitamura, Y. Kawakami, K. Kurosawa, K. Kogami, and M. S. Tanaka, "Agricultural support system equipped with short-range wireless communication system," 2016 IEEE Technological Innovations in ICT for Agriculture and Rural Development (TIAR) , (2016/07/15-16).

[14] Ministry of Agriculture "Statistics on agricultural labor force", http://www.maff.go.jp/j/tokei/sihyo/DATA/08.html, (2016/11/02 reference).

[15] K. Kurosawa, I. Iizima, Y. Amemiya, S. Yamamichi, M. Toyota, and M. S. Tanaka, "Development of operational control system for rice cultivation," IEICE-CS 2016-12-IE-CS-AVM-BCT, (2016/12/8-9).

[16] Vegetalia, RiceWatch, http://field-server.jp/ricewatch/, (2016/03/02 reference).

[17] PS Solutions, e-kakashi, https://www.e-kakashi.com/, (2016/03/02 reference).

[18] K. Terada, M. Toyota, T. Hirata, Y. Takada, K. Matumoto, and M. S. Tanaka, "Proposal of communication protocol for field management using LoRa," Information Processing Society DICOMO2017 Symposium, pp. 1671-pp. 1678, (2017/6/28-30).

[19] M. S. Tanaka, "Data gathering method of all sensor node in shortest time for LPWA system," International Workshop on Informatics, (2019/9/8-11).

[20] S. Rani, and S. H. Ahmed, "Multi-hop Routing in Wireless Sensor networks," Springer.

[21] S. Lindsey, and C. Raghavendra, "Pegasis: power-efficient gathering in sensor information systems," Proceedings of the IEEE Aerospace conference proceedings 2002, pp.3-1125 –pp.3-1130, vol.3. IEEE. 10.1109/AERO.2002.1035242.

[22] S. Jung, Y. Han, and T. Chung, "The concentric clustering scheme for efficient energy consumption in the pegasis," Proceedings of the 9th international conference on advanced communication technology, pp.260-pp.265, Gangwon-Do: IEEE. 10.1109/ICACT.2007.358351.

[23] K. Chen, J. Huang, and C. Hsiao, "Chiron: an energy-efficient chain-based hierarchical routing protocol in wireless sensor networks," Proceedings of the Wireless Telecommunications Symposium (Wts'2009), pp.183-pp.187, USA: IEEE.

[24] S. Mao, and T. Hou, "Bamstar: an edge-based approach to routing in wireless sensor networks," IEEE Transactions on Mobile Computing, Vol. 6, Issue 11, Nov. 2007, pp.1284-pp.1296.

(Received November 02, 2019)
(Revised March 08, 2020)

Mikiko Sode Tanaka received Dr. Eng. degrees from Waseda University in Fundamental Science and Engineering. She joined NEC Corporation, NEC Electronics Corporation, and Renesas Electronics Corporation. She is Associate Professor of International College of Technology, Kanazawa. Her research interests include wireless communications, AI chip, and personal authentication. She is a member of IPSJ (Information Processing Society of Japan), IEICE (Institute of Electronics, Information and Communication Engineers) and IEEE (Institute of Electrical and Electronics Engineers).