Industrial Paper

A Study on Time Synchronization Method for Field Servers for Rice Cultivation

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Abstract - It is important to develop affordably priced field servers for rice farmers for their practical implementation. This restricts the use of expensive GPS or high precision crystals, which have been used for wireless communication so far. To this end, we propose a time synchronization method that does not involve the use of expensive hardware. In the field servers for rice fields that use LPWA technology, which require only batteries for their operation, time synchronization is an important factor in reducing power consumption. Therefore, we describe a method of constructing a wireless network of an economical time-synchronized field server using LoRa for achieving low costs. We also describe the effect of reducing power consumption. From experimental results, we confirmed that the time was synchronized and transmission and reception of data between the master unit and the field server ensued normally. It is theoretically possible to operate the device for 691 consecutive days. In addition, we confirmed that the field server system works correctly from rice planting to rice reaping in the rice field.

Keywords: Agriculture, Field Server, Sensor Network, Low Battery Consumption, Time Synchronization

1 INTRODUCTION

The average age of farmers is rising in Japan [1]. Therefore, reduction of labor burden is an important issue. To reduce labor burden, the introduction of a field server that can reduce the man-hours required for daily field surveillance could be effective. Field servers are available in the market. However, their use is not prevalent owing to the associated high cost. Thus, affordable field servers that rice farmers can purchase are urgently required.

We are developing a field management system that can help reduce labor burden [2]. To introduce the field server to farmers, it is important to reduce the installation and operation costs. Therefore, we adopted LoRa, for its advantages of low power consumption and long communication distance, which make it suitable for communication in the field server for the rice fields [3]. In addition, LoRa does not incur any communication cost.

To reduce installation costs, it is important for the device to be operable using batteries because it is expensive to draw power to rice fields. In addition, it is difficult to install solar panels because solar panels are large and may interfere with farm work. The field server must be able to be battery-operated for at least six months, starting from rice plantation to reaping. Therefore, low power consumption is important for the field servers for rice fields.

To operate for six months with no power supply, the field server needs to turn itself off except when sending or receiving the sensor data or other communication. This requires an intermittent operation communication protocol and a time synchronization method to be implemented.

The time synchronization technique has been extensively studied previously [4, 5]. The method for time synchronization using GPS has also been proposed [4]. To use this method, it is necessary to install a GPS receiving module in every field server, which leads to an increase in the initial cost at the time of installation. The power consumption also increases and, therefore, such a method is not suitable for use in the rice field servers, for which lowering the introduction barrier is desired. Although TPSN [5] has been proposed as the time synchronization method, it requires a long time for time synchronization, which increase the power consumption, and this, this method is not suitable for use in field servers.

To realize low power consumption, intermittent operation is indispensable. Time synchronization is an important technique to ensure that a plurality of field servers operate efficiently by employing intermittent operation. To communicate efficiently, a communication partner must be starting up. In this study, we propose an intermittent operation communication protocol and a time synchronization method to solve the aforementioned problems. In the proposed method, after the field server system transmits the sensor data to the master unit system, the master unit system, on receiving the sensor data, transmits the time correction signal to the field server system, thereby performing time synchronization.

To realize affordable price, it is not possible to use expensive GPS or high precision crystals, which have been used for wireless communication so far. Therefore, we propose a time synchronization method that does not use expensive GPS and high precision crystals. The proposed method has a mechanism to allow time variation of the field server and use it for improving the reliability of the system. In the proposed method, a large frame is taken to allow variations, and retransmission processing can be performed using the margin.

In this paper, section 2 discusses the necessity of affordable price field server, section 3 describes the limitations of the conventional time synchronization systems, section 4 describes the system configuration, section 5 explains the proposed communication protocol and time synchronization method, section 6 presents the operational test and result, and finally, section 7 summarizes the study.

2 NECESSITY OF AFFORDABLE PRICED FIELD SERVER

In Japan, aging of farmers has progressed; the average age of the agricultural working population was 66.8 years in 2014 [1]. In addition, agricultural employment population is decreasing. Currently, agriculture in Japan is in a crisis situation, and it is necessary to increase the number of agricultural workers, for which it is necessary to reduce the burden on the workers. Therefore, acquiring and using the environmental data is considered important. However, field server introduction is not progressing.

In Japan, rice farming generates less revenue compared to other crops. Table 1 presents the profit structure in the rice production revenue. Tan (反) and pyou (俵) are Japanese units of measurement. 1 pyou equals 60 kg, and 1 tan equals 0.1 ha. The standard amount of rice harvested per tan is 9 pyou. One pyou rice can be sold for approximately 13,000 yen. Deducting expenses will result in a profit of approximately 50,000 yen per tan. On the other hand, a field server can be hired at 8,280 yen per month [6]. If the server is rented for 6 months, the cost becomes 50,000 yen, which implies that almost no profit is obtained. Therefore, the introduction of field servers is difficult.

To facilitate practical implementation of the field server, it is necessary for its selling price to be less than 10,000 yen. In other words, it is necessary for the manufacturing price to be approximately 3,000 yen. Therefore, we propose a time synchronization method for field servers, which can help realize cost reduction. We aim to develop protocols for affordable and manufacturable field servers.

The field server should not interfere with farm work. Because large agricultural machines operate in rice fields, the field server needs to be moveable. Therefore, the height of the server should ideally be 1 m or less and it needs to be as compact as a lunch box. Also, because a rice field has no power supply, the device needs to be operable using batteries, from the phases of rice planting to harvesting.

To realize an affordably priced field server, a communication line usage fee is unnecessary, and a LoRa network, which can be transmitted to large distances, is used. LoRa is more effective for IoT in agriculture, as a larger amount of data can be transmitted compared to Sigfox [7], and a relatively large amount of sensor data is involved. Further, it is suitable for special applications in which performance and cost are critical factors, because we can freely create protocols and frame formats. LoRa can be built and operated on its own, including base stations, and its specifications are open.

Table 1 Profit structure in rice production.

60kg(1 俵)	¥13, 000-
Rice crop yield/1 反	9 俵
Revenue/1 反 (Fertilizer ¥15,000- / 1反 Herbicide / pesticide ¥10,000- / 1反 Land improvement expenses for canal improvement and irrigation etc. ¥20,000- / 1反 Labor cost ¥15,000- / 1反)	¥57,000- (Expense ¥60,000-)

To create a field server for use in rice cultivation, it is necessary to reduce the number of high-cost parts. Expensive crystals and GPS cannot be used for time synchronization because of the associated high cost. It is thus necessary to realize time synchronization without these parts.

The operational target is to realize server operation in the rice field of Ishikawa Prefecture's second largest agricultural corporation. The field servers acquire the sensor data once every hour and send it to the cloud.

3 PROBLEMS OF CONVENTIONAL TIME SYNCHRONIZATION SYSTEM

The use of wireless smart utility networks (Wi-SUN) [8] was standardized as the wireless communication method for metering electricity, gas, and water, around the year 2008. Before this, other standardized wireless communication specifications such as ZigBee were proposed to realize a sensor network [9]. The difference between these and Wi - SUN is that Wi-SUN attempts to enable wireless communication in a wide area. Figure 1 shows the MAC protocol architecture of IEEE 802.15.4 / 4e. The MAC protocol of IEEE 802.15.4 / 4e, can roughly be divided into asynchronous and synchronous networks. Synchronous networks have better power efficiency and lower power consumption than asynchronous networks. That is, in IoT, in which low power consumption is essential, the synchronous system is more suitable than the asynchronous system.

The synchronization method can be roughly categorized as the beacon method and channel hopping method. Figure 2 shows an overview of the IEEE 802.15.4 beacon superframe method. This method is basically a better way when all nodes can receive signals during the beacon period. The field server we propose performs intermittent operation to minimize power consumption. When the power supply of the field server is turned on at an arbitrary time on the premise of intermittent operation, it is necessary to prepare a standby time for receiving the beacon separately from the transmission operation of the measured data, and the extra power is consumed. Therefore, it is difficult to use this method for time

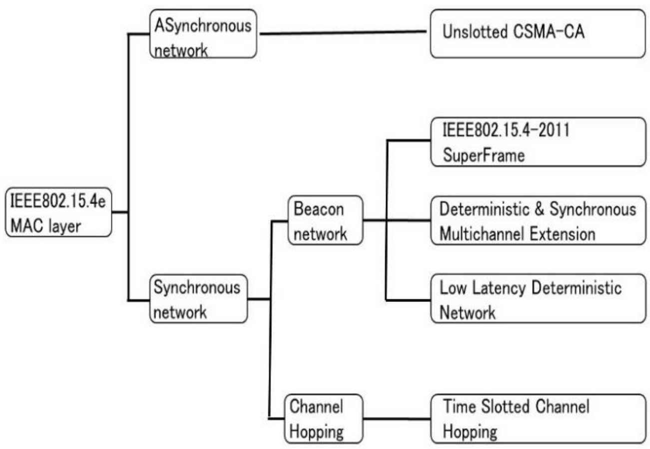

Figure 1: MAC protocol classification of IEEE 802.15.4 / 4e. [8]

synchronization of our system. Figure 3 shows the outline of the IEEE 802.15.4 channel hopping TSCH method. In the beacon superframe method, the beginning of a superframe is determined by a beacon (synchronization control signal), and all the terminals receive it. All terminals then synchronize with each other. On the other hand, in channel hopping, TSCH shares the time with each node with accuracy within tens of microseconds in the whole network. Each node maintains synchronization by exchanging information on the timing error with adjacent nodes. These methods require highly accurate time synchronization, and require GPS and highly accurate crystals, etc., which increase the cost substantially. This standard is therefore unsuitable for use as the communication standard for rice cultivation.

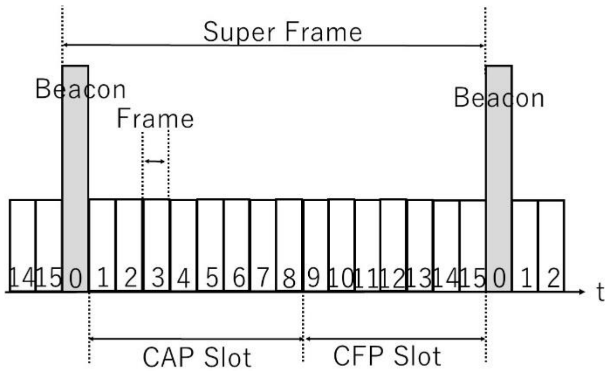

Figure 2: Outline of IEEE 802.15.4 beacon · superframe method.

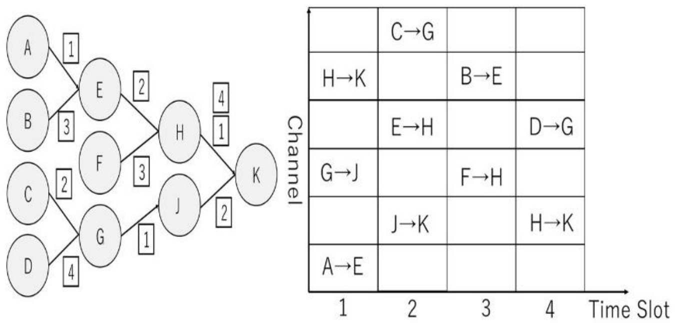

Figure 3: Outline of IEEE 802.15.4 channel hopping · TSCH method.

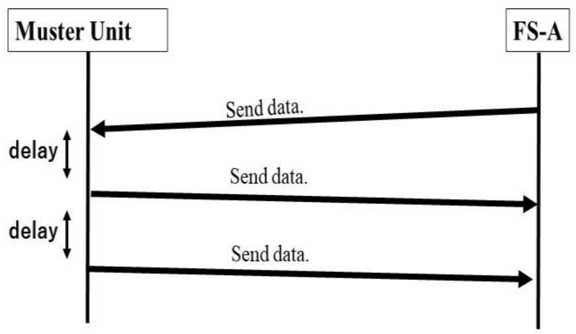

Figure 4: Sequence of LoRaWAN Class A.

The LoRaWAN has three device classes. Class A can transmit data at an arbitrary timing; reception is possible only immediately after transmission, and it is a power saving device that goes to sleep immediately after reception is completed (Figure 4). Since the data is transmitted at an arbitrary time, there is a possibility of collision. In addition to the function of the class A device, the class B device has an arbitrary timing reception mode, and it is a device that can receive the beacon from the master unit; however, the power consumption becomes higher than that of the class A device. Class C is a device that can constantly receive data, and its power consumption is exceedingly high. The time synchronization method of LoRaWAN is basically the same as that of the Wi - SUN. Therefore, even in LoRaWAN, GPS or high accuracy crystals are needed.

4 SYSTEM CONFIGURATION OF FIELD MANAGEMENT SYSTEM

The field management system is composed of the field server system, master unit system, and cloud service. Figure 5 shows the overall structure of the field management system. The field server system is installed in the rice fields and receives the sensor data. Further, the data is sent to the master unit system through the LoRa wireless network. The master unit system integrates the sensor data from the field server system and sends them to the cloud service through the 3G line or Wi-Fi. The cloud services are provided by the smartphone applications, tablet applications, and web pages. These services provide data to farmers to alert them about water levels, propose a suitable work plan, preserve work records etc.

Communication between the field server system and the master unit system using LoRa is capable of long-distance communication. LoRa has been found to have a practical communication distance of 3,000 to 4,000 m as shown by the basic communication characteristics survey [10]. The rice field of Ishikawa prefecture was assumed, and the linear distance between the master unit and the field server was within 3,000 m. For this reason, we adopted LoRa, which enables direct communication between the field server and master unit.

Figure 6 shows the positional relationship between each field and the office of the assumed the agricultural corporation in the Ishikawa prefecture. A, B, C, D, E, F, and G represent the position in each field, where the field servers are installed. P represents the location of the office; the master unit is installed in the office. The linear distances between the field servers A to G and the master unit P are as follows: 397 m between A and P, 923 m between B and P, 943 m between C and P, 684

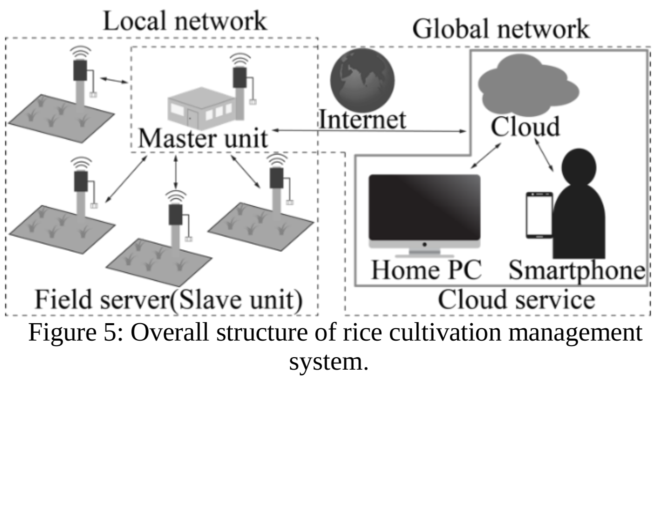

Figure 5: Overall structure of rice cultivation management system.

m between D and P, 1,150 m between E and P, 1,440 m between F and P, and 1,910 m between G and P.

The location and number of field servers installed were examined by the agricultural corporations. The decision method was set as a place to be checked whenever looking around done every day. If it was possible to confirm the water level etc. at the designated place, it was that it was enough for management of the field.

We will further explain the configuration of the field server system installed in the rice field and the master unit system installed in the office. Figure 7 shows the configuration of the field server system. The field server comprises the battery, power ON/OFF circuit, AVR microcomputer, LoRa module, various sensors, and SD card module. The field server is powered by the battery. To realize low power consumption, the power ON/OFF circuit operates only for several tens of seconds in one hour. The wireless modules and the sensors are controlled by the AVR microcomputer. Five types of sensors are mounted to measure the temperature, humidity, water level, soil temperature, and soil moisture content. The sensor data is stored in the SD card together with the time stamp. This is a function for reliably saving the data, considering the case where it cannot be transmitted to the master unit or where the time correction signal cannot be received. The power ON/OFF circuit is composed of the PIC microcomputer and the FET; it controls power supply to the AVR microcomputer. The PIC microcomputer controls the FET by outputting HIGH/LOW at the GPIO pin. The time required for the power supply control is calculated and controlled by using the timer interrupt in the internal clock of the PIC microcomputer.

The configuration of the master unit system is shown in Figure 8. The master unit system is composed of a Raspberry Pi, LoRa module for transmission, LoRa module for reception, and a 3G dongle. When the field server system is turned on for the first time, the time is not held and the time is set after it is transmitted by the master unit system. Therefore, the master unit system always maintains the reception state. It is desirable that the master unit system can respond to communication from the field server system when the field server is installed. Further, the reception and transmission modes exist in the LoRa module, and it takes time to switch the modes. Therefore, by installing two different LoRa modules for receive and transmit, it is possible to reduce the waiting time of transmission and reception and maintain the reception state at all times.

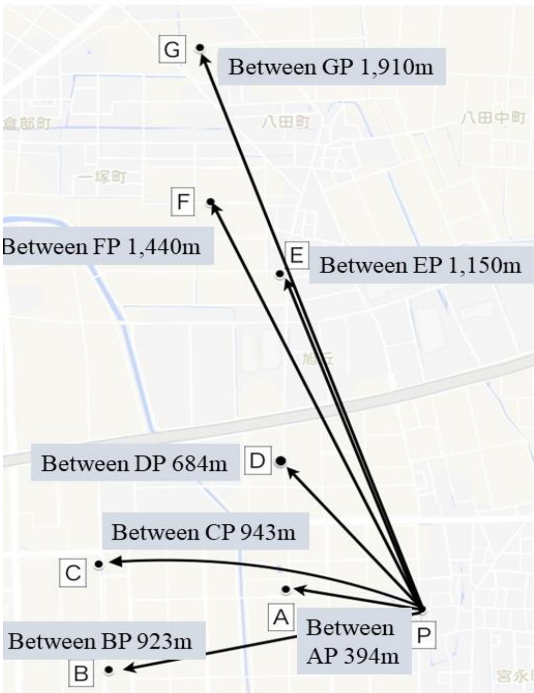

Figure 6: Position of each rice field and the office.

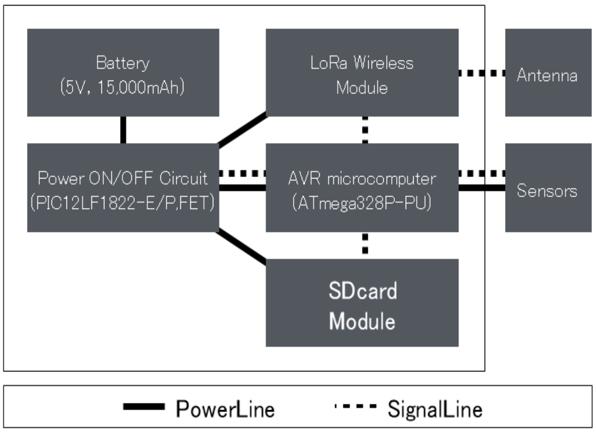

Figure 7: Field server system configuration.

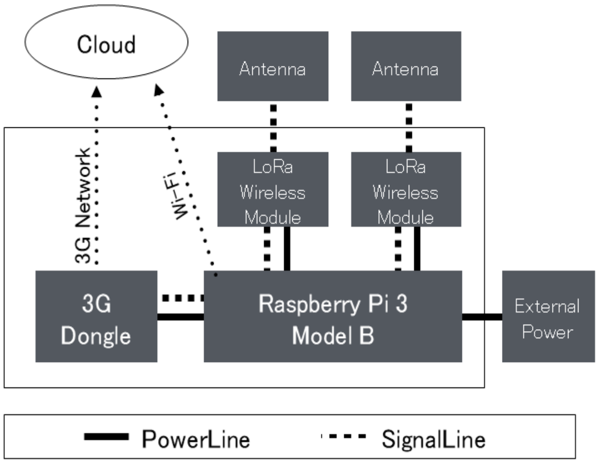

Figure 8: Master unit system configuration.

5 COMMUNICATION PROTOCOL

5.1 Communication Protocol

The frame formats used for the communication are shown in Tables 2, 3, and 4. Table 2 shows the common frame format, consisting of the destination, the source, and the payload. Table 3 shows the format of sensor data transmission. Since there are five types of sensors in use, the sensor data are defined in the format of 1 to 5. The temperature, humidity, water level, soil temperature, and soil moisture content are entered in that order from the sensor data 1 to 5. The acquired five types of data can be stored in 2-byte units. Additionally, when

Table 2: Common frame format.

Destination	Source	Payload
1Byte	1Byte	Variable

Table 3: Format of sending sensor data (Payload).

Sensor Data 1	Sensor Data 2	Sensor Data 3	Sensor Data 4	Sensor Data 5
2 Byte	2 Byte	2 Byte	2 Byte	2 Byte

Table 4: Format of correction time signal (Payload).

Timestamp (UNIX Time)	Correction time
4 Byte	2 Byte

the number of types of sensors increases, 2 bytes are added to the format of sensor data transmission. Table 4 shows the format of the time correction signal. The time stamp and the time correction signal transmitted from the master unit to the field server are stored in the payload. The field server system starts once every hour. It gets the sensor data and transmits it to the master unit system. When transmission is successful, the master unit system sends the correction time to the field server system. The field server system further corrects its own internal clock for the time synchronization. Later, when the field server system receives the corrected time or go on operating time per hour of described later elapses, the power is turned off except for the power control circuit.

Sensor data is acquired at the same time in all filed servers. Therefore, the sending data arbitrarily will conflict with each other. To prevent conflicts, each field server sends the data to the master unit in order. As a result, since the data can be efficiently transmitted to the master unit, power consumption can be reduced. The series of actions shown in figure 9 is basically done within the frame. The frame of each node is made to be large so that it can retransmit several times. The part that controls the transmission order of each node is a big difference from LoRaWAN. Figure 10 shows an example of three field servers in which resending mode does not occur in any of the communications. First, the field server system A (hereinafter, FS-A) is activated. FS-A measures the sensor data and generates the sending packet according to the sensor data. Further, the packet is sent to the master unit system. The field server system has only one LoRa module, therefore it switches from the sending to the reception mode. This switching requires several seconds. After switching to the reception mode, the field server

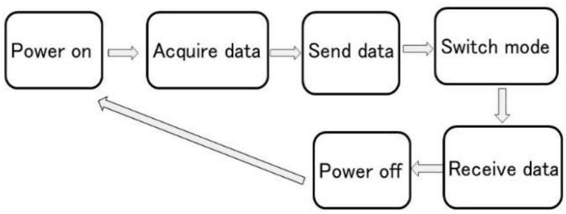

Figure 9: Communication protocol sequence.

system waits until the set timeout period. Further, it receives the corrected time signal from the master unit system. When the master unit system receives sensor data from FS-A, it sends the corrected time signal to FS-A. FS-A corrects its internal time based on the received correction time signal. After the correction, FS-A goes into sleep mode even during the resending possible time. When the field server system fails to receive the corrected time signal or the master unit system fails to send the corrected time signal to the field server system it is necessary to resend it along while the possible resending time. Field server system B (FS-B) and field server system C (FS-C) perform in the same sequence as A.

The operating time per hour can be obtained from equation (1).

$$\begin{aligned}\text{operating time} = {} & \text{sensor data acquisition time} + \\ & \text{sensor data transmission time} + \\ & \text{time correction signal reception time} + \\ & \text{retransmission time}\end{aligned} \tag{1}$$

This operating time is written in advance to the AVR microcomputer and sent to the PIC microcomputer each time the AVR microcomputer is powered on. The PIC microcomputer uses this value to calculate the restart time. Here, the sensor data acquisition time is the time to measure the sensor data. The sensor data transmission time is the time to transmit the sensor data to the master unit. The time correction signal reception time is the time to receive the current time from the master unit. The retransmission time is the time to perform retransmission processing when sensor data cannot be transmitted to the master unit. In the proposed method, time synchronization is performed once every hour. It has been confirmed from the measurement results that there is an error of more than ± 10 seconds at the maximum in an hour [11]. Therefore, the error of acquisition time of sensor data is also about ± 10 seconds. This error is a problem-free range as the sensor acquisition time error for agriculture.

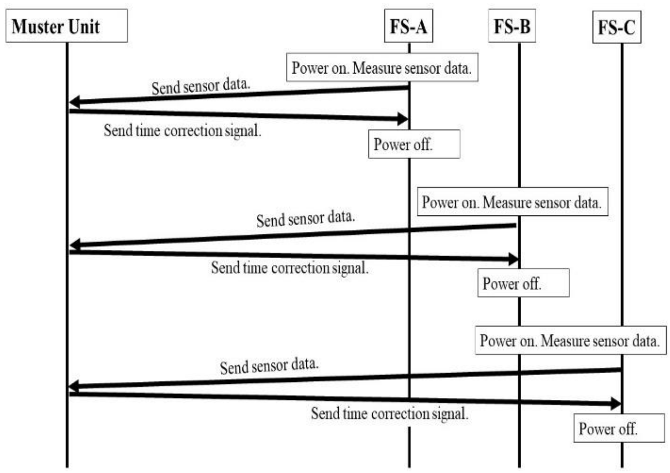

Figure 10: Communication protocol sequence.

5.2 Operation of Resending Mode

When the field server cannot receive the time correction signal and the reception waiting time has elapsed, the field server performs the timeout operation. After the timeout, the field server waits for random seconds from 0.1 to 5.0 s and then retransmits. The following is the cause of the timeout.

1) When the master unit cannot receive the communication from the field server due to the radio wave attenuation
2) When a collision occurs in the transmission data due to overlapping of the transmission times of a plurality of field servers
3) When the field server cannot receive the communication from the master unit due to the radio wave attenuation

The first one and third one are that the cause of the noise is often temporary, so there is a high possibility that the problem will be solved if the transmission process is performed with shifted time. The second one can be prevented by accurate time synchronization.

When the noise or the collision occurs, the master unit does not send the time correction signal to the field server, therefore, the field server's reception standby timeout occurs. The field server that has timed out executes retransmission, but to prevent re-collision with the communication performed by the field server of the initial power-on, a random second standby time is provided. After executing the retransmission, the field server switches from the transmission to the reception mode and waits for reception. This operation is continued until the field server can receive the time correction signal from the master unit. However, to avoid collision of the communication with that of other field servers, the power is turned off forcibly when the other field server's operation is about to start.

The sequence operation in this case is shown in figure 11. In figure 11, the field server C (FS-C) has timed out and is retransmitting. If it is within the possible retransmission time, the processing of the transmission and reception standby is repeated until transmission/reception is completed.

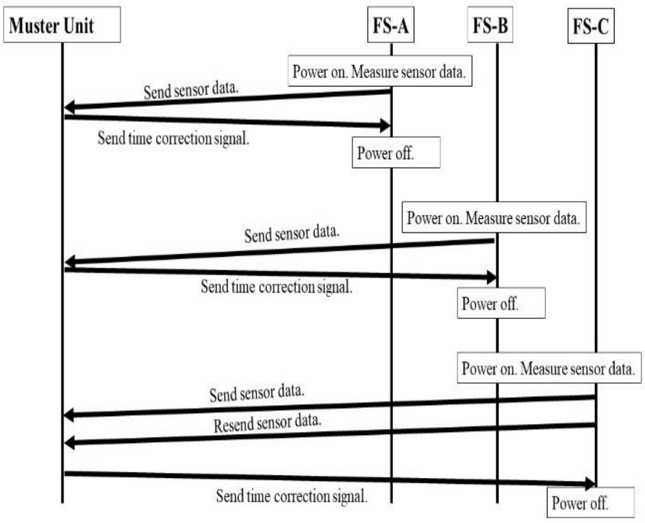

Figure11: Sequence for transmitting sensor data.

5.3 New field server installation mode

This section describes the operation procedure when a new field server is introduced. Figure 12 shows the process of installing a new field server. The newly added field server first sends a wake-up signal to inform the master unit that it has been added. When the master unit gets the wake-up signal from the field server, the field server number is added to the library and the current time, and next activation time is transmitted to the field server. The field server synchronizes the time based on the received time from the master unit.

The time to install the field server is arbitrary. Therefore, when another field server and the master unit are communicating, a newly added field server may start communication. In this case, collision occurs (see Figure 13).

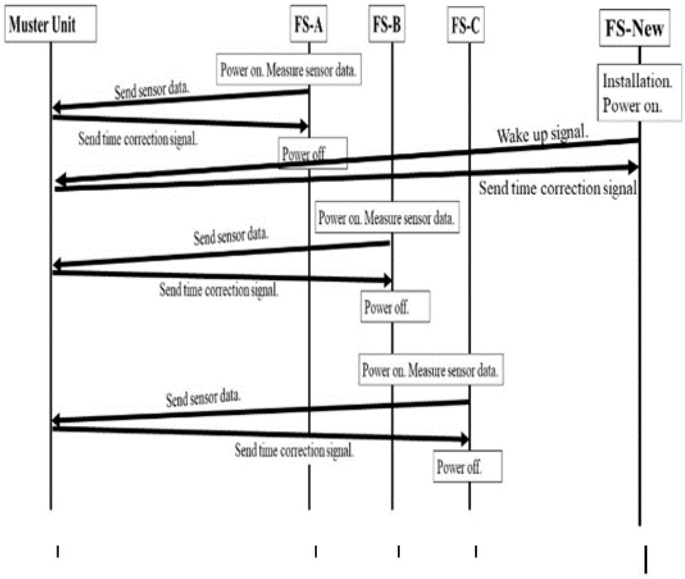

Figure 12: Sequence of new field server installation.

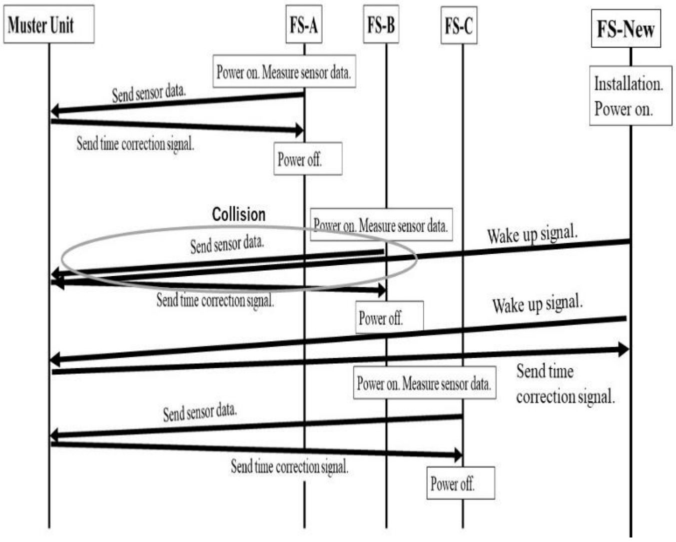

Figure 13: Sequence at collision in new field server installation mode.

When collision occurs, retransmission is performed after a random period within seconds. This process is repeated until the unit is receiving the current time information from the master unit. When the additional field server receives the current time information from the master unit, the time to acquire the sensor data (next time to turn on the power and acquire the sensor data) is calculated, and power is turned off.

5.4 Time Synchronize Signal

The field server can transmit the sensor data at an arbitrary timing because the master unit is always on standby for reception. However, in the case of the rice field management, since sensor data is acquired at the same time in all field servers and data is transmitted to the master unit, transmission from the field server to the master unit occurs at the same time, causing collision and the efficiency decreases. Therefore, in the protocol for the rice cultivation, the master unit performs the scheduling and notifies the time to transmit to the field server, and the field server basically transmits the specified time data. Figure 14 is an example of the scheduling. FS - A, FS - B, FS - C, FS - D are scheduled to send the data to the master unit in order. It is also possible to lengthen the allocation time for places where it is relatively difficult to transmit besides the building or sideways of the expressway and there is a high possibility of retransmitting several times.

The lower section in Figure 14 shows an example in which dispersion occurs with respect to the scheduling result from the above figure. Depending on the field server, the variation can be arbitrary, and there are several ranges and directions of variation. Therefore, although the probability is low, collisions may occur. In this example, FS - B shifted in the direction of lag, and FS - C shifted in the direction to become faster, and thus, overlapping occurred. Therefore, until FS - B processing is finished, FS - C must wait while sending it; however, because each frame has sufficient margin for variation, data can be sent without any problems.

Figure 15 is a diagram showing the state of retransmission when the collision of figure 14 occurs. FS - B is delayed by 12 seconds, FS - C and FS - D are 12 seconds earlier. The transmission periods should not overlap. Therefore, FS - C will retransmit after a random time of 0.1 to 5 seconds. In this example, retransmission occurred after 5 seconds. The transmission processing of FS - B has already been completed, so FS-C can be sent. The transmission of FS-C takes about 12 seconds, but since the transmission of FS-C is completed before FS - D starts transmission, no conflict occurs between FS - C and FS - D. Even if variations occur in such away as to interfere with the transmission and the reception in this case, it is a frame length setting that can be retransmitted sufficiently.

The master unit performs the time synchronization with the NTP server beforehand and acquires accurate time. When the master unit receives sensor data from the field server, the field server calculates the time to transmit next and informs the field server. Simultaneously, a time correction signal is also transmitted. The master unit informs the time to send the next data to the field server, that is, the scheduling result by this processing.

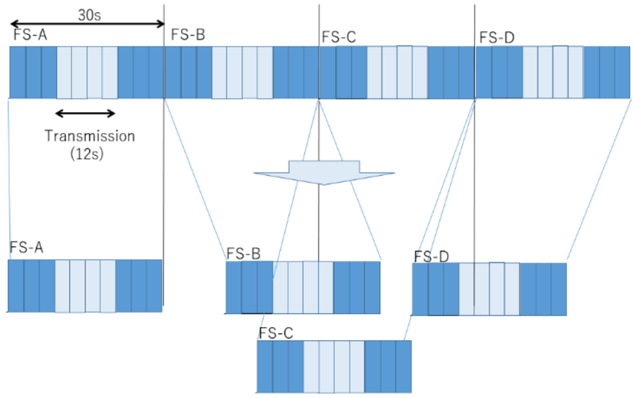

Figure 14: Scheduling and field server time variation.

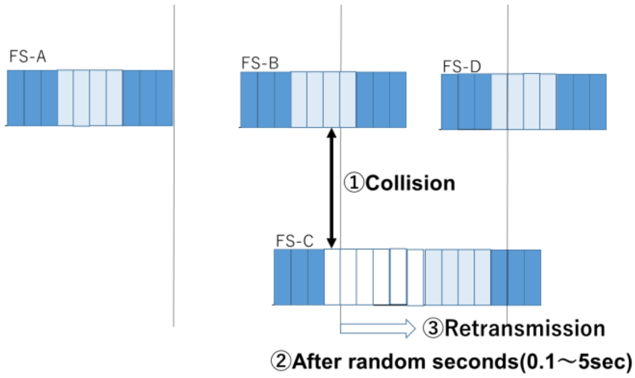

Figure 15: Retransmission processing by collision.

The format of time correction signal is shown in Table 4. The time stamp is entered with 4-byte UNIX time. It is used to write the sensor data to the EEPROM or the SD card of the AVR microcomputer. Since the correction time is used for correcting the time within the PIC microcomputer, the time shifted for each field server from the current time is set as 0 to 3599 s in 2 bytes. CRC etc. is used for detecting and correcting communication errors that are not defined in the format because they are added by the LoRa communication module.

Figure 16 shows the mechanism of the time synchronization between the field server and master unit. The master unit sends the correct time obtained by the NTP server to field server in the corrected time format. Upon receiving the correction time, the field server transfers the correction time via the AVR microcomputer to the PIC microcomputer in the power ON/OFF circuit. To prevent the correction time from starting simultaneously with other field servers, the current time is shifted appropriately according to the scheduling result.

In the example of Figure 15, the frame length is set to 30 seconds. It takes about 12 seconds for the master unit to receive data from the field server, change the communication mode, and send the time data to the field server. The frame length is set to 30 seconds by adding ± 9 seconds, taking into consideration the time variation of the PIC microcomputer.

In the case of the frame length is 30 seconds, a formula for calculating the start time is shown in equation (2). Regarding equation (2), each field server has a uniquely assigned field server identifier (below), and the correction time to transmit

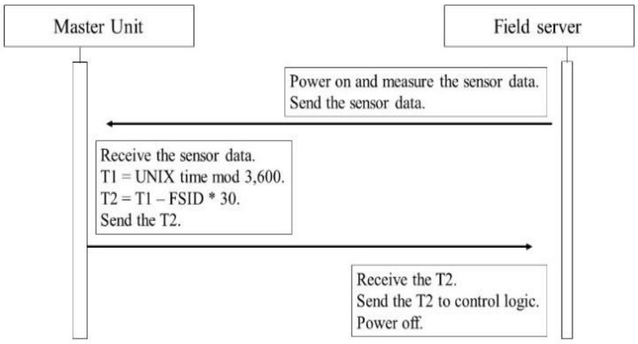

Figure 16: Time synchronization mechanism between master unit and field server.

to the field server is obtained by subtracting from the current time. Depending on the power-on time of the field server, the time becomes a negative value; however, in this case, a value of 3,600 is added.

$$t_2 = t_1 - 30 \cdot \mathrm{FSID} \qquad (2)$$

The FSID can be used in the range of 0x00 to 0x77, and the field servers are started in the ascending order of FSID. By using FSID, simultaneous activation of each field server is prevented, and transmission signals of the field server are prevented from colliding. It became possible to transmit once every 30 seconds and 120 field servers are able to connect one master unit. Based on the results of experiments in the field, 30 seconds was deemed appropriate.

The PIC microcomputer controlling the power ON/OFF circuit always counts 0 to 3,599 s with the internal clock. When the time within the PIC microcomputer reaches 3,600 (0) s, power is supplied to the AVR microcomputer. Upon receiving the time correction signal from the master unit, the field server corrects the time within the PIC microcomputer to the correction time transmitted from the master unit and continues counting. This leads to the time synchronization between the field server and master unit. Even during the second and subsequent runs, when the time within the PIC microcomputer reaches 3,600 (0) s, power is supplied to the AVR microcomputer.

If the master unit fails to normally receive data from the field server due to a communication error etc., the master unit maintains the reception standby state of the sensor data without transmitting the time correction signal.

6 EXPERIMENTAL RESULTS

6.1 Consideration of Communication Protocol

For rice farming, affordable pricing is the most important requirement, and thus, the proposed method is effective. However, the device must also be able to deal with time variations lasting as long as several seconds. In consideration of the variations, we set the length of one frame to approximately two times the required length. By doubling the frame length, we can avoid collisions due to variations and secure time to retransmit. Increasing the frame length reduces the efficiency; however, the reliability of the system is improved.

LoRaWAN is a protocol that can be used for multiple purposes. Applications that collect meter reading values of gas, electricity, and water supply and applications like rice cultivation use the same protocol, although the communication frequency, communication time and intervals are different. In pursuit of price and performance, general-purpose functions are often wasted. For example, in the case of LoRaWAN Class A, the field server can send the data to the master unit at an arbitrary time, but in the case of rice field management, since data is acquired and transmitted at the same time, collision occurs frequently. In addition, although the master unit that receives data from the field server is a specification that transmits data to the field server twice, whether it is necessary to send this data twice depends on the application.

In the proposed protocol, we adopted scheduling to prevent conflicts. This is important for acquiring data at the same time and is an advantage of the proposed protocol.

6.2 Verification of Communication Protocol

We conducted the 7-day operation test to confirm whether the proposed communication protocol works as expected between the master unit and field server. Following are the points for the verification:

1) Confirm whether the master unit can return the time correction signal to the field server within the reception waiting time of the field server.

2) The field server that received the time correction signal confirms whether to shift to the sleep state immediately.

3) Confirm whether each field server properly changes the timing according to the time correction signal and starts at the specified time.

In the verification of the communication protocol, we used seven field servers, which is the same number used in our field. The distance between the field server and the master unit is centered on the master unit and all field servers are installed within a radius of 1 m. The sensor data sent from the field server to the master unit was saved in the verification cloud.

Table 5: Verification results of communication protocol.

Classification	Number of communications
Send sensor data	1,185
Number of resending	9
Completion of time synchronization (resend 1 time)	9

Table 5 shows the verification results of the communication protocol. The number of operational days is seven. The field server gets sensor data at an hourly interval, which is further sent to the master unit. The field server successfully sent the data 1,185 times. Of the 1,185 times, only nine were retransmission. Even when the first communication failed, reception of sensor data was successful from all field servers through retransmission. We confirmed that the protocol works for seven days without problems.

We implemented the designed communication protocols and carried out the operational test for a period of two months in an actual field. Figure 6 shows the measurement result at point C. A master unit was installed at point A. In this experiment, we confirmed that environmental data can be acquired every hour. The field server was equipped with sensors that can measure temperature, humidity, water level, soil temperature, and soil moisture content. The height at which the field server was installed was approximately 1 m from the ground surface to accurately measure the temperature. The height at which the master unit was installed was set to approximately 0.5m. It was confirmed that the measurement can be performed without problems, and data can be transmitted to the master unit. Owing to the fact that there is a communication failure at the rate of approximately 15.8%, the time correction may not be performed. The time synchronization was carried out when the fault was solved and it was confirmed that the protocol was operating properly. We examined the difference between the assumed startup time of the field server and the actual startup time. The results are shown in figure 17. The result displays the representative pattern of eight days from the operational test of two months. From this result, it is understood that when the time correction is performed, the error is suppressed to about in tens of seconds. Moreover, it is understood that the error is suppressed to 0 s in most communication between the master units to field servers.

The time error of the PIC microcomputer is the about 10 s in an hour from actual measurement [11]. This error is accumulated without time synchronization; however, in the field management communication protocol proposed here, this error is within the range in which collision with other field servers does not occur. Therefore, it is confirmed that time synchronization is effective in this communication protocol, and it is possible to reduce the increase in time error, which is proportional to the usage time. As a result, it became possible to transmit once every 30 seconds, and became possible to connect 120 field servers to one master unit.

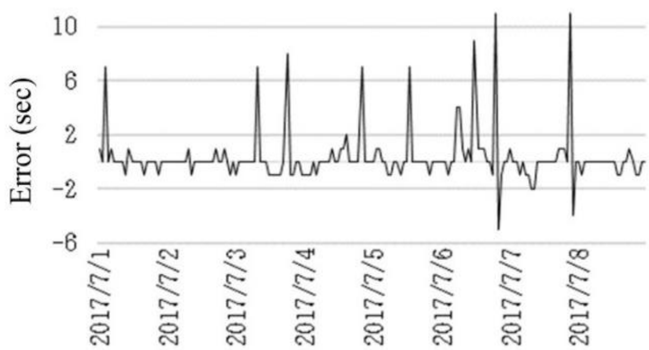

Figure 17: Time error of field server.

6.3 Evaluation of Power Consumption

Apart from the verification of the communication protocol, we conducted an experiment to verify the power consumption. The purpose of the verification is to obtain the power consumption during the operation. First, we measured the voltage, current value, and processing time for each operation mode.

The current measurement method is explained herein. In the case of a communication device, the current value varies depending on the communication state. Therefore, we decided to measure the current value while actually setting it in the field. In the rice field, there was no power supply, and thus, it was difficult to use a commercially available measuring instrument. Therefore, a current measuring device operating with a battery was developed, as shown in figure 18. INA 219 [12] was used for the sensor. In this measurement, the current was measured at intervals of 0.5 s and the change in current was observed. Based on the result, the change time to each mode and the average current in the mode were calculated. Figure 19 shows a field server with an ammeter is actually installed in the field.

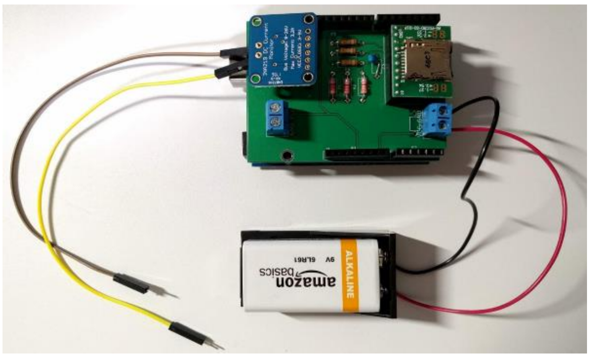

Figure 18: A field server and the sensors with battery.

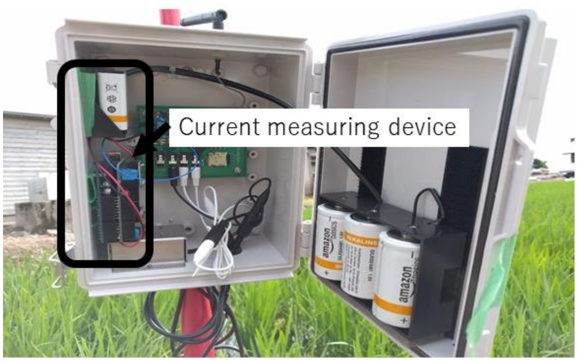

Figure19: A field server and ammeter.

Table 5: Measurement results of power consumption.

	Time(s)	Current(mA)	Voltage(V)
Standby・acquire	6.55	45.8	5
Data send	1.65	86.6	5
Mode switching	3.9	50.1	5
Receiving standby	0.9	86.6	5
Receive	49	39.7	5
Sleep time	3538	0.167	5

Table 5 shows the measured results [13]. The data transmission mode is the most power consuming. It can be confirmed that the sleep time mode has the lowest power consumption among all.

Next, we calculated the power consumption and number of working days. Equation (3) shows the power consumption W [mWh] . Here, V_1 is the rated voltage [V] of the field server system. I_a is the electric current [mA] during the sensor stabilization standby and the sensor acquisition. t_1 is the time[s] during the sensor stabilization standby and the sensor acquisition. I_b is the electric current [mA] during the transmission of sensor data. t_2 is the electric time [s] during the transmission of sensor data. I_c is the electric current [mA] during the mode switching. t_3 is the time [s] during the mode switching. I_d is the electric current [mA] during the standby reception. t_4 is the electric current [mA] during the standby reception. I_e is the electric current [mA] during the data reception. t_5 is the time[s] the during the data reception. I_g is the electric current [mA] during the system sleep state.

$$W = (V_1\{(I_a \cdot t_1) + (I_b \cdot t_2) + (I_c \cdot t_3) + (I_d \cdot t_4) + (I_e \cdot t_5)\} + V_1 \cdot I_g\{3600 - (t_1 + t_2 + t_3 + t_4 + t_5)\}) / 3600 \quad (3)$$

We derived the number of operating days theoretically. In the case of retransmission is not occurred, the power consumption is 4.52 mWh per hour; the consumption being 108.4mWh per day. Therefore, theoretically, the field server can operate for approximately 691 days, assuming the electric quantity of the portable battery charger to be 75000 mWh. From the 7-day operation test described in table 5, 9 times of retransmission occurred by 7 field servers in 7 days, and retransmissions on the second times never occurred. If we assumed that one retransmission would necessarily occur with one transmission, the field server can operate for approximately 659 days.

Although the number of operating days has the theoretical value, it seems that the field server is able to operate for six months, which is the requirement of the agricultural corporation. Because rice field is softer soil, if you install a heavy field server it will fall over with wind etc. Therefore, it is important to reduce the weight of the battery, which is the heaviest component in the field server. From the experimental results in the rice field it has been found that it is necessary to reduce the number of D size battery to 3 or less. Therefore, 75000 mWh or less was set as the criterion.

Figure 20: A field server system in a rice field.

We conducted the operational test in actual rice fields using the 7 field servers of figure 6. The picture of the field server system installed in the rice field is shown in figure 20. We confirmed that the field server system works correctly from rice planting to rice reaping.

In IEEE 802.15.4e [14], two types of time synchronization methods, Beacon and Channel Hopping are defined. In the time synchronization defined in both methods, it is required that all nodes belonging to the network always synchronize the time within an error of ±1 ms, thereby realizing the time division access method. On the other hand, in the proposed method, time synchronization is performed between the master unit and each field server, but time synchronization between the field servers is not performed. Therefore, time synchronization accuracy of about ±10 seconds is sufficient, it is not necessary to hold hardware for special time synchronization and it is easy to put into practical use.

7 CONCLUSION

We proposed a new communication protocol, constructed a local wireless network, and conducted the experiment. In the field servers for the rice field using the LPWA technology, which require only batteries for operation, the proposed time synchronization is an important technology for the purpose of reducing the power consumption. Additionally, the proposed time synchronization is an important technique for increasing the line use efficiency. It was seen from the experimental results that the power consumption of the field server is 108.4mWh per day. Therefore, it was confirmed that the method can continuously work for 691 days based on our calculations. We confirmed that the field server system works correctly from rice planting to rice reaping. The time synchronization is effective and was able to decrease the timing error in direct proportion to the operating time. This protocol is valid for the rice cultivation management systems because the field server is stable and can operate for a long time. Therefore, it meets farmers' expectation to utilize a reasonable field server.

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