# 2-4 Research and Development on the Low-Energy Wireless Grid Technologies for Agricultural and Aquacultural Sensings

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This article reports on the R&D on the low-energy operation that is defined as one of capabilities for the wireless-grid systems where several radio devices are connected in the grid-like topology. This R&D activity includes a study on low-energy multi-hop transmission technology that realizes relay transmissions among devices by holding a low-energy MAC scheme with effective sleep-periods. In the assumed wireless Personal Area Network (PAN) employs the low-energy superframe structure that is defined in the IEEE 802.15.4e global standard and deploys intermittent active periods on every radio devices with time synchronization, thereby achieves power consumption reduction entire the PAN and establishes a suitable tree-shaped multi-hop communication topology. It is confirmed that the assumed low-energy operation theoretically enables more than 20 years operation with only three AA batteries. We have successfully developed low-energy radio devices with the proposed low-energy multi-hop communication capability and confirmed its suitable performances via several proof tests. As an example of effective utilities of such radio devices, we have successfully applied the radio device equipped sensor-buoys to the periodical sensing of water-temperature and salinity conditions in the Mozuku seaweed farm. Besides such an aquacultural application, we have further studied on the radio device application to the agricultural water management application and confirmed that the developed radio devices have effectively worked for both low-energy sensing operations such as rice farm water level monitoring and low-latency control operations such as water pump control.

## 1 Introduction

The National Institute of Information and Communications Technology (NICT) carries out research and development regarding the efficient use and social development of a wireless grid structure composed of a spidery (grid) connection topology by multiple wireless terminals that are expected to have an effect on the IoT field in which demand has recently increased. One of the typical examples of the application of the wireless grid structure is the Smart Utility Network (SUN) which is formed by a smart meter equipped with a radio device, and which implements automatic meter reading, control, etc. [1][2]. Figure 1 shows an overview of SUN. The main technical problems for SUN are considered to be the two below.

(1) Low-energy technology which assumes battery operation

(2) Multi-hop technology which extends the service area

For item (1), the technology becomes of particular importance when, for gas and water meters, the power supply from outside the meter by wire, etc. is not easy, and assuming the operation of the meter and SUN radio by a built-in battery. It goes without saying that the battery changing cost due to the increase of the battery changing frequency due to battery drain is a problem that may reverse the premise of the SUN system. From the standpoint of meter operation, in general, continual operation for 10 years or more without changing the battery is regarded as a goal.

Next, for item (2), as shown in Fig. 1, when the meter is placed far from a collection station or the meter is placed in a cutoff environment, such as in a housing complex, damping of the signal due to the distance and cutoff and occurs, and direct communications alone cannot be implemented in the required service area, so the technology collects all meter reading data by executing a multistep relay. For the damping due to distance, multistep relay by introducing multi-hop technology can increase the reachable radio distance in a linear manner, and for the damping

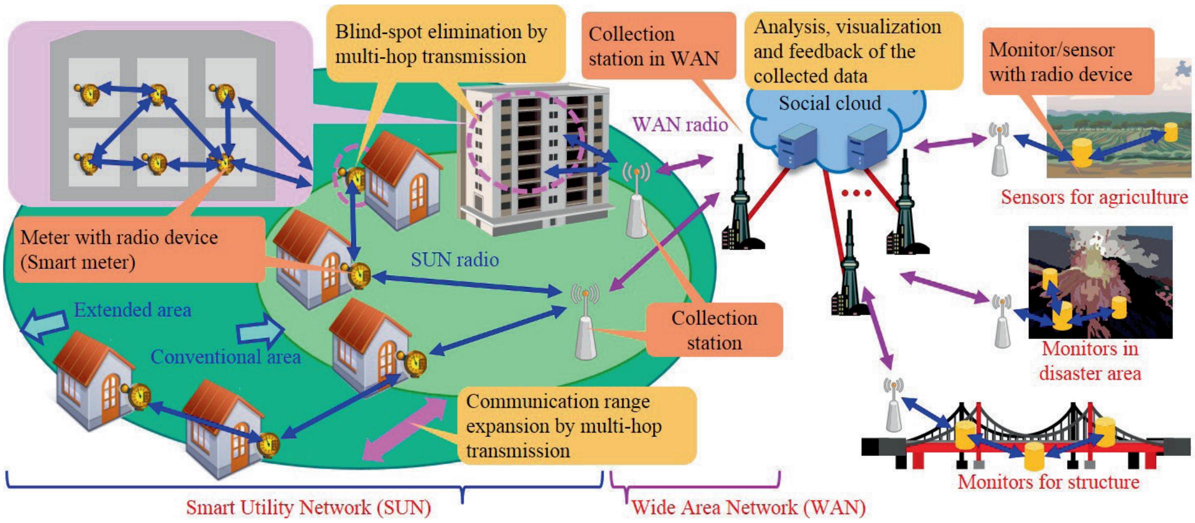



**Fig. 1** Overview of smart utility network

due to cutoff, the establishment of a low-damping alternative path using multistep relay can resolve the radio blind spot. Consequently, the multi-hop technology can extend the service area.

NICT works in research and development regarding the establishment of low-energy multi-hop communication technology with the goal of the effective implementation of SUN. As shown in Fig. 1, SUN is expected to be effective for wide uses for not only smart meter systems but also for sensor networks, etc. Here we describe the research and development regarding the low-energy multi-hop communication technology and an application demonstration to fishery and agriculture.

## 2 Overview of the low-energy multi-hop communication technology

### 2.1 Overview of the low-energy MAC method

Figure 2 shows an operating example of the low-energy MAC method [3]–[7] applied in this research and development. This method was proposed by NICT, and uses the low-energy superframe structure defined in IEEE 802.15.4e [8][9]. The superframe is a time period forming the basis of the Time Division Multiple Access (TDMA) control, and is specified by a cyclic beacon signal. The beacon interval (BI), a basic time unit, is divided into the active period (AP) — sending and receiving, or standby — and the sleep period (SP) which turns off the power and does not execute the sending and receiving, and the active period is operated as the real communication period. On the other hand, the sleep period allows each device to go into sleep. For the low-energy action, the beacon signal is not sent to

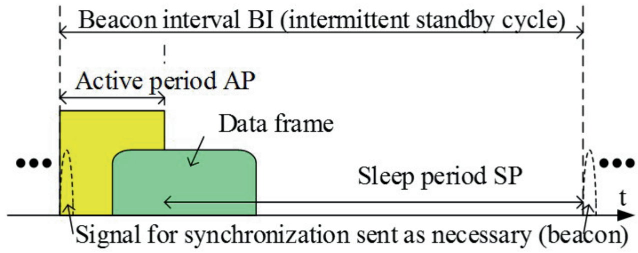



**Fig. 2** Operating example of low-energy MAC method

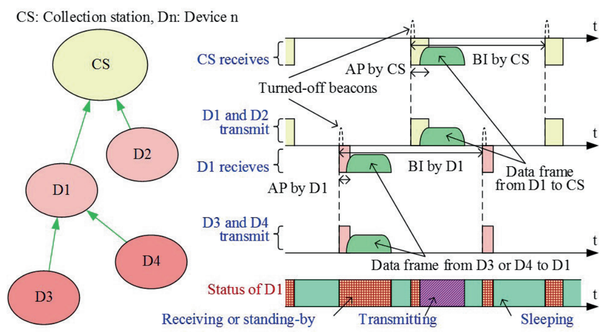



**Fig. 3** Operating example of multihop communications

every superframe, and essentially, is sent only if temporal synchronization is required. In addition, as shown in the figure, as the active period is sometimes shorter than the data frame, the end of the data frame shall not be limited within the active period and should be before the starting point of the next superframe. As a result, reduction of the active period becomes possible, regardless of the data frame length. In other words, because the reception status for the start of the standby and the sending and receiving of the data frame at each terminal is executed only in the active period and the terminals other than the terminals involved in the sending and receiving of the data frame continuing from the active period can go into sleep during the sleep period, reduction of power consumption can be realized.

## 2.2 Multi-hop communications on PAN topology

Figure 3 shows an operating example which implements the multi-hop communications by using the low-energy MAC method described in the previous section on the topology of the personal area network (PAN) which is the premise for SUN. PAN is the radio device network specified in the IEEE 802.15.4 standard [10], and is composed of a radio device called a PAN coordinator, which is first activated to declare PAN establishment, and a radio device which executes association, a subscribing procedure to PAN. Paying attention to the relationship between the radio device which executes association and the radio device which receives association, we can find the tree-structured PAN topology whose root is the PAN coordinator. We propose a multi-hop communication configuration which collects data from other devices using this tree structure to the PAN coordinator as a collection station (CS). In Figure 3, it can be confirmed that when the D3 or D4 sends the data frames to D1, the sending conforms to the superframe specified in D1, and when D1 sends them to CS, the sending conforms to the superframe specified in CS.

Figure 4 shows the estimated result of battery life when assuming the low-energy multihop communications as referred to above. The assumed battery capacity is three AA batteries. The calculated result shows that if the beacon interval is 80 seconds, data length is 100 octets, and the data generation interval is one minute or so, the battery life can be expected to be 10 years or more.

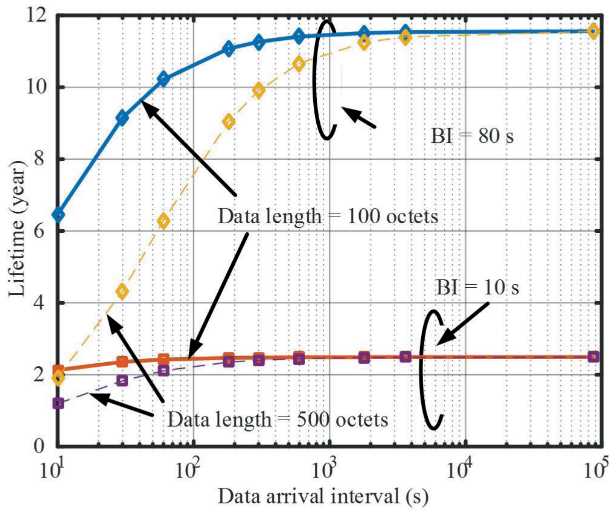
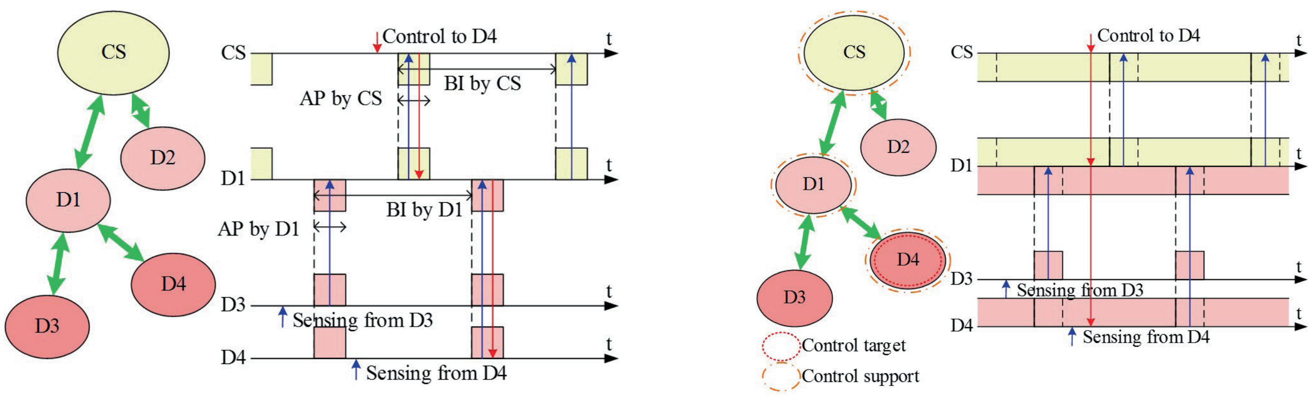



**Fig. 4** Estimated battery life

## 2.3 Study of low-latency communications for control, etc.

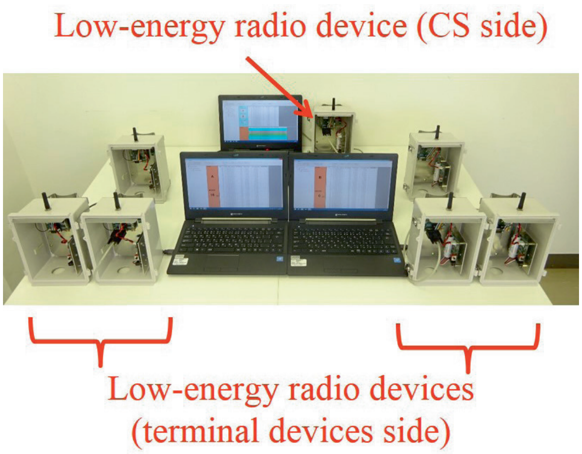
As mentioned in the previous subsection, the basic principle of low-energy action is the intermittent standby by the introduction of a sleep period. On the other hand, it is believed that the operation modes for the wireless grid can include the control action which executes the data transmission from the collection station to each device by assuming an actuator, etc. as the device, in addition to the sensing action which mainly executes data transmission from each device to a collection station by assuming a sensor, etc. as the device. It is expected that in such control action, delay inevitably occasioned by the introduction of the sleep period sometimes becomes serious. For this reason, this research and development has studied the pattern to implement low-latency control action in parallel with low-energy sensing action.

Figure 5 shows the concept of low-latency communications. For PAN, this study defines the device connecting to the actuator, etc. above as a control target device, and the

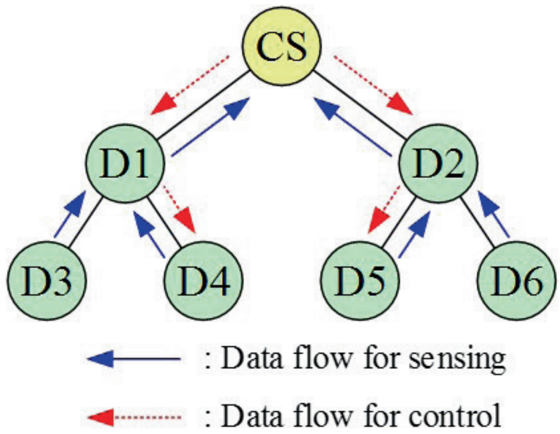



(a) Conventional action (b) Low-latency action

**Fig. 5** Concept of low-latency communications




(a) Configuration




(b) Overview of topology and data transmission

**Fig. 6** Overview of evaluation test for low-latency communications

**Table 1** Evaluation results of low-latency communications

| Control signal destination | Average latency | Variance of latency |
|---|---|---|
| D5 (with low-latency action) | 0.0 s | 0.0 $s^2$ |
| D4 (without low-latency action) | 15.15 s | 16.87 $s^2$ |

**Table 2** Specifications of low-energy radio module

| | |
|---|---|
| Size | 20 mm × 40 mm × 3 mm |
| Weight | 4 g |
| Frequency band | 920.6-928.0 MHz |
| Transmission power | 20 mW |
| Modulation scheme | 2 GFSK |
| Data rate | 50, 100, 200 kb/s |
| Consumption current | Active state: 50 mA<br>Sleep state: 30 $\mu$A |
| I/O interface | Serial |

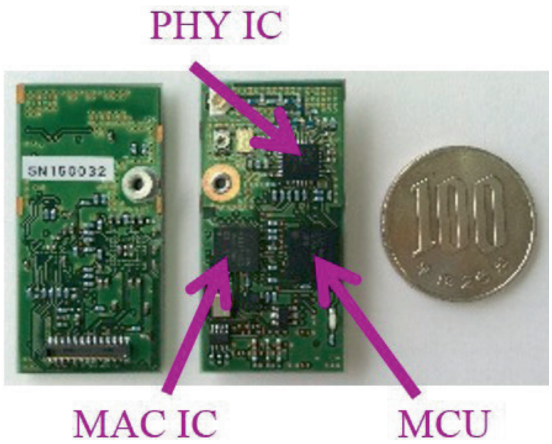



**Fig. 7** Appearance of low-energy radio module

devices in the multi-hop communication pathway as control support devices. As the control target devices and the control support terminals handle the data transmission for the control action, the devices adjust the sleep period above and operate so that the delay time falls within an acceptable range. Figure 5 shows clear operating examples where both the control target device and the control support devices do not apply the sleep period.

For the evaluation test to confirm the action of the proposed low-latency communications, Fig. 6 shows an overview and Table 1 presents the results, respectively. Table 1 consolidates the characteristics related to the delay time on the data transmission from CS for D4 and D5 in Fig. 6 (b). In Figure 6 (b). Although each device uses the multi-hop communication topology where the beacon interval is 10 seconds, it is assumed that D5 and D2 are set to the control target device and the control support device, respectively, and that they operate without introducing the sleep period. As a result, as per Table 1, if not implementing low-latency action, the delay occurs due to the beacon interval, but it has been found that low-latency action eliminates the effect.

## 3 Development and implementation of low-energy radio

### 3.1 Overview of low-energy radio module

Figure 7 shows the developed low-energy radio module. In addition, Table 2 shows the specifications for this module. This module is successfully implemented in the minimum composition on the circuit board (4 cm × 2 cm) of the integrated circuit for the physical layer, MAC layer and MCU (Micro Controller Unit: embedded microprocessor) for control, including additional functions such as FEC (Forward Error Correction) after assuming various utility forms. This module is expected to be developed in a great variety of usage environments such as housing into a smart meter, installation into an outdoor monitoring post which takes wind and rain effects into account, a small plug-in radio equipped with a USB terminal, devices connected to sensors, etc.

### 3.2 Application demonstration to fisheries field

In the following, we report the demonstration of the low-energy wireless grid by the application of a low-energy radio with an embedded low-energy radio module. This subsection describes an example of remote sensing on the Mozuku fishery as the application demonstration to the fisheries field. This demonstration laid, on the sea surface, multiple buoys which are equipped with a low-energy radio at the top and which connect to sensors that measure the sea temperature and salt concentration around the Mozuku seaweed farm on the ocean floor 8 m deep in an area 2 km from the coast, and was successful in the collection of the above periodic sensing data into a coast building through the low-energy multi-hop communications. Figure 8 is the appearance of the sensor buoy in this demonstration and Fig. 9 is the installation appearance of the sensor buoy, respectively.

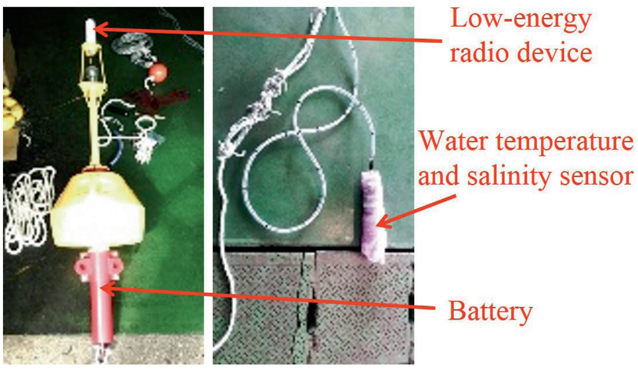



**Fig. 8** Appearance of sensor buoy

**Fig. 9** Installation appearance of sensor buoy

### 3.3 Application demonstration to agricultural field

This subsection describes the remote sensing and control using the low-energy radio in field water management as an application demonstration to the agricultural field. This demonstration combined low-energy sensing and low-latency control, and successfully operated the pattern to properly implement low-energy action in the whole PAN through radio communications by connecting to a water level sensor which assumes the water level sensing for the field, to a pump and valves subject to control, and to a PCL (Programmable Logic Controller) which is sometimes used for control equipment in the agricultural business. Figure 10 shows this demonstration which was implemented in a test field in an experiment building. Furthermore, we are planning an expanded outdoor demonstration in an actual field for the future.

## 4 Conclusions

This paper described the research and development regarding low-energy action as one operation mode of a wireless grid structure. As a result of studying the implementation of a low-energy multi-hop communication configuration, the battery capacity of three AA batteries or so was found to be theoretically operable over 10 years.

Furthermore, developing a low-energy radio, we implemented periodic sensing for water temperature and salt concentration on a Mozuku seaweed farm as an application case. Consecutively, in the agricultural field, we studied and demonstrated the setting of the low-energy radio to combine low-energy sensing for information on the field water level, etc. and low-latency control for agricultural equipment such as a pump. A future agenda item is further function expansion assuming a variety of application fields which require low-energy action.

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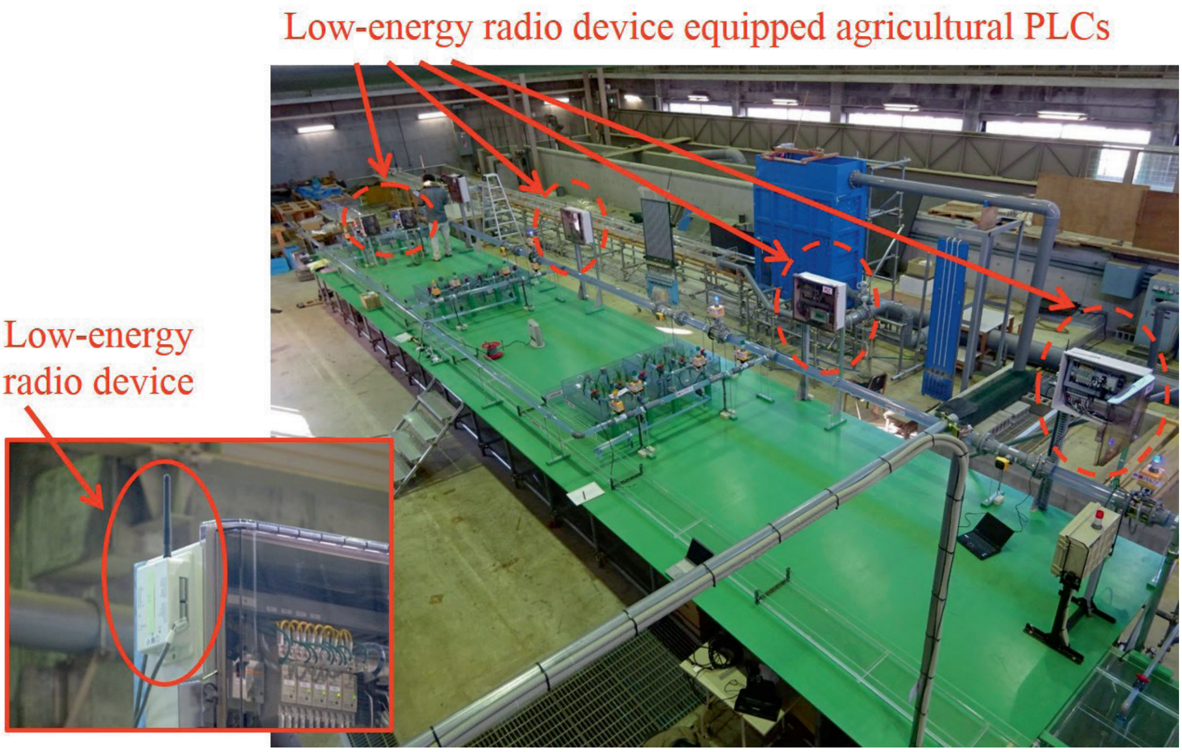


**Fig. 10** Application demonstration of low-energy radio to agricultural equipment

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