Multi-Hop Wireless Network for Industrial IoT

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If wireless communication is utilized to collect data in a production site, manufacturing processes can be modified more flexibly without building a new network. However, it is not easy to achieve stable wireless communication in a factory because signal strength changes frequently due to various factors such as the rearrangement of equipment and the movement of machinery and workers. Therefore, we have developed a wireless repeater and controller that automatically manage communication quality. This development will enable full wireless networks for quick and reliable data collection.

Keywords: industrial IoT, wireless relaying

1. Introduction

Manufacturing sites are facing the major challenge of how to improve productivity in order to cope with working-style reforms, the demographic trends of low birthrate and aging society, and globalization. Sumitomo Electric Industries, Ltd. is working on data collection and utilization at its plants. There are growing needs to make information and communication processing technologies, such as the Internet of Things (IoT) and artificial intelligence (AI), useful for productivity improvement. To collect data, an infrastructural network is required. Such networks are subject to frequent changes in equipment and sensor positions due to production line and floor layout modifications. To install a network, many sites need to stop lines or rearrange processes. Consequently, it appears beneficial to use wireless communications to form a network infrastructure. In this regard, mobile phone and other public circuits incur monthly communication charges, making it uneconomic to use a large number of installed wireless devices. Meanwhile, to construct an in-house network using wireless LAN, it is necessary to install network cables to connect short radio-range access points (APs). Moreover, other challenges include interference issues and band coordination with wireless LANs used for clerical work and equipment control.

To explore a solution, we have continued fundamental research of in-house wireless communication networks (full wireless networks) for industrial IoT, capable of ensuring stable communications without the need for any mobile phone, wireless LAN, or wired networks and not requiring any installation work.[1] This paper reports on a newly developed prototype and a field experiment conducted at a manufacturing site.

2. Overview of Prototype System and Equipment

Figure 1 shows a rendered image of a working full wireless network for industrial IoT. The network collects data acquired with sensors placed at suitable locations in the plant and aggregates the data to a management server via relay nodes and a controller. All communication lines before data aggregation are implemented by wireless means. The controller manages and controls the wireless communication relaying routes. When installed, the controller automatically sets the routes. If, during operation, a forklift truck or other obstacle comes up, it automatically switches the route.

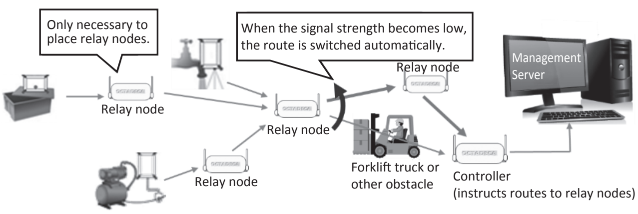


Fig. 1. Rendered image of working network

Figure 2 shows the overall structure of the system. The identifier (ID) of and data from each sensor are aggregated to the host server via relay nodes and a controller. Each relay node relays sensor data and at the same time reports to the controller information relating to the communication, such as signal strength and the amount of data. The controller automatically analyzes the report it receives

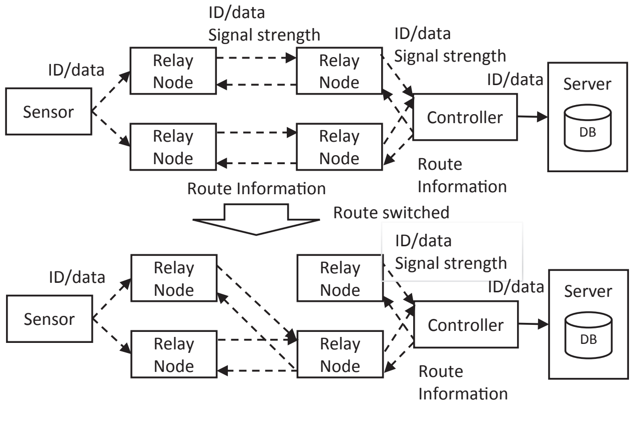


Fig. 2. System configuration

via relay routes, determines the best relay route and instructs this to the relay nodes.

Figure 3 illustrates the internal structure of a relay node. The switch block performs routing for the sensor ID and data signals sent from the wireless module. The information acquisition block receives data from the switch block, calculates link information such as signal strength and loss rate, and sends the link information to the link information notification block. Additionally, upon receipt of route information destined for it, the information acquisition block updates the route table. The route table block retains the route table used for routing by the switch block. The link information notification block sends link information received from the information acquisition block to the switch block. Note that the controller is the ultimate destination of the link information.

Figure 4 shows the internal structure of the controller. The controller and relay nodes have hardware commonality, but have different software in them. The controller runs controller software in addition to the same relay software that relay nodes use. In the controller software, the link information acquisition block acquires link information transmitted from relays in the network. The decision-making block determines the best route based on the link information. The route information notification block informs relay nodes of the route information. The management information notification block informs the server of link information of each relay node.

Photo 1 shows a prototype relay node. Table 1 provides the specifications.

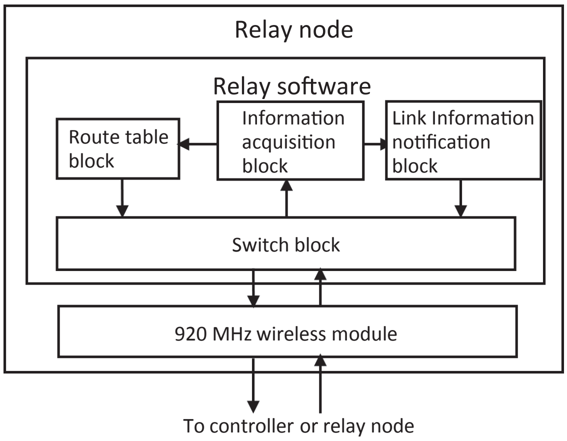


Fig. 3. Relay node block diagram

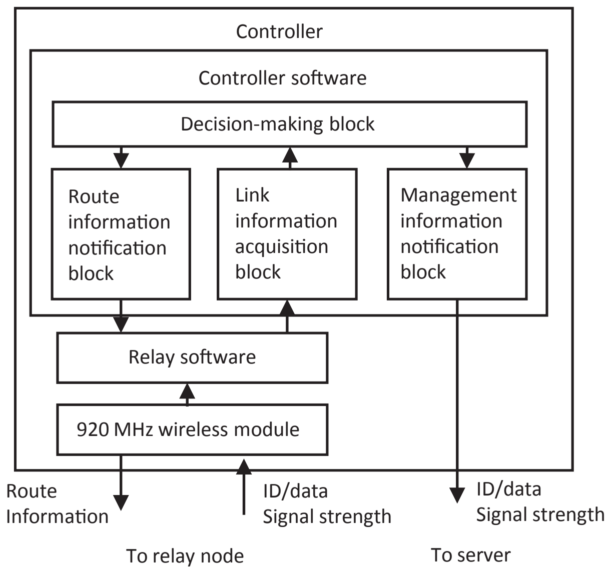


Fig. 4. Controller block diagram

Photo 1. Exterior of relay node

Table 1. Specifications of prototype relay node and controller

Parameter	Specifications
Communication mode	Compiles with ARIB STD-T108, standard for specified low-power radio equipment in 920 MHz band
Communication Topology	Mesh
Topology control mode	Centralized control type
Max. no. of hops	255 (Proven track record: 5)
Max. no. of relay nodes accommodated	255 (Proven track record: 10)
Max. no. of sensors accommodated	Depends on wireless propagation environment (Proven track record: 105)
Frequency band	922.5-927.7 MHz
No. of frequency channels	14
Antenna power	20 mW
Transmission distance	Indoors: approx. 50 m

The most notable feature of the prototype network is that, while in a meshed communication topology, it implements centrally controlled routing. Incorporating decentralized control, conventional technology[(2)] had difficulty in ensuring stable communication in the event of an abrupt change in the wireless propagation path.

The prototype adopted a relatively new standard for specified small power radio equipment in the 920 MHz band to avoid interference with the existing wireless network in the plant. However, the very same hardware configuration as the present prototype can be used to form a relay network using an existing system such as wireless LAN, simply by replacing the wireless block. Lastly, the numbers of hops, relay nodes accommodated, and sensors accommodated depend only on the communication environment. The newly developed network is almost free of any equipment design and specification restrictions.

3. Field Experiment at Sumitomo Electric Plant

3-1 Overview of wireless relaying experiment

This paper presents the results of a field experiment being conducted at a plant of the Sumitomo Electric Group. Figure 5 outlines the experiment-related part of the floor layout of the plant. The network consists of 10 sensors from S1 to S10 (see Table 2 for more details) operating at 1-min transmission intervals, 1 controller C1, and 3 relay nodes from R1 to R3.

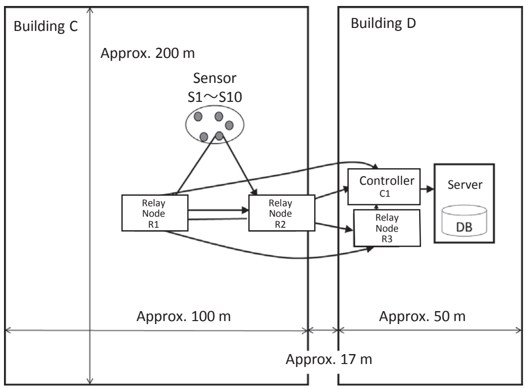


Fig. 5. Floor layout of field experiment in plant

The purpose of the experiment, in which sensors are installed in Building C, is to collect production site information. Since the plant staff station is located in Building D, it is necessary to store and manage data in Building D. The two buildings are separated by a 17-m wide passage. Radio waves from Building C do not directly reach Building D. Furthermore, not only people use the passage, but also logistics/transport vehicles move up and down the passage at random times, creating an unstable radio wave environment. Installation of LAN cables in plants requires a large amount of investment and needs an elaborate plan in advance to eliminate the need to change the installation layout. Meanwhile, at production sites, new challenges emerge on a daily basis. Wireless equipment is not so difficult to introduce to site and becomes available for data collection in a relatively short period. As such, we proceeded with the wireless relaying experiment with the consent of the plant staff.

3-2 Experimental results

Table 2 shows packet loss rates of 10 sensors installed in the plant. The table reveals that packet loss rates decreased within 4 weeks of September 26, the start date. This is attributable to adjustment of relay node placement locations. This implies that wireless coverage can be easily improved by adjusting the relay node placement according to the radio wave environment.

Table 2. Loss of sensor terminal packets

Sensor	Loss Rate [%]			
	Sep. 26	Oct. 3	Oct. 10	Oct. 17
S1	1.67	1.96	0.33	0.13
S2	3.01	1.69	0.28	0.18
S3	2.13	2.22	0.30	0.15
S4	2.71	1.85	0.29	0.13
S5	2.44	1.91	0.29	0.19
S6	1.90	1.86	0.27	0.05
S7	2.81	1.84	0.36	0.39
S8	2.32	1.93	0.46	0.11
S9	1.96	2.32	0.27	0.06
S10	1.90	1.74	0.21	0.14

Figure 6 shows link quality indication (LQI) characteristics between the sensor terminals and relay nodes, as data supporting the results shown in Table 2. Incidentally, LQI is a standard under IEEE 802.15.4[(2)] adopted by the standard ARIB STD-108. Detailed LQI specifications should be established by IC manufacturers in their respective ways, between the minimum and maximum integer values of 0 and 255. Physically, LQI means signal strength or signal power to noise power ratio (SNR). Time is plotted on the x-axis spanning 6 days from October 14 to October 20.

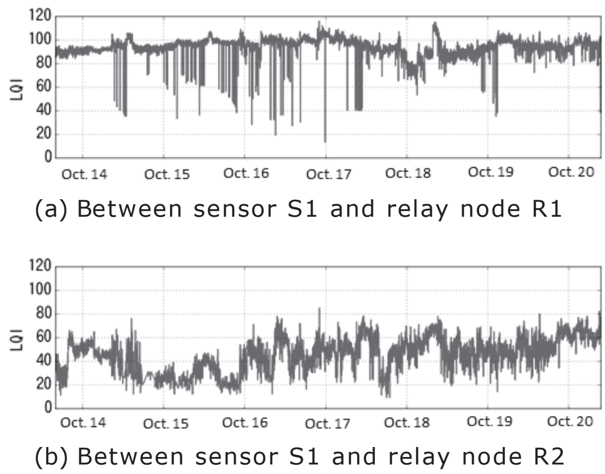
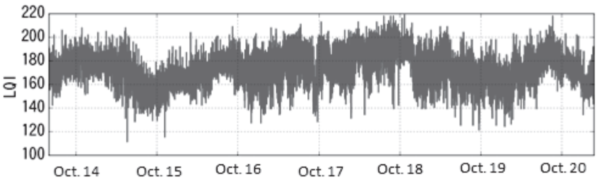


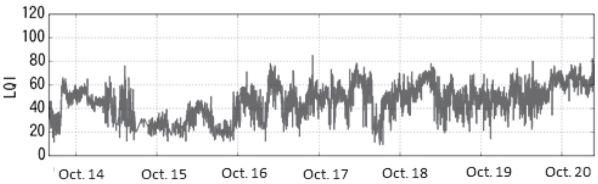
Fig. 6. LQI characteristics between sensor and relay node

On the whole, the wireless propagation environment varies substantially due to radio wave reflections and refractions. The LQI value of (a) between sensor S1 and relay node R1 is large and relatively advantageous as a communication channel. However, when in some time zones its LQI drops momentarily, it is more advantageous for sensor S1 to communicate with relay node R2, as shown in Fig. 6.

Similarly, Fig. 7 shows LQI characteristics between relay nodes.



(a) Between relay node R1 and relay node R2

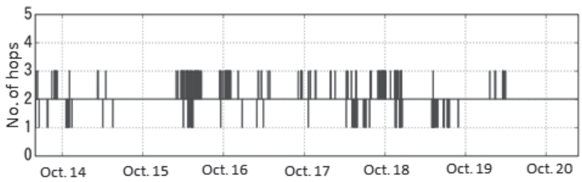


(b) Between relay node R2 and controller C1

Fig. 7. LQI characteristics between relay nodes

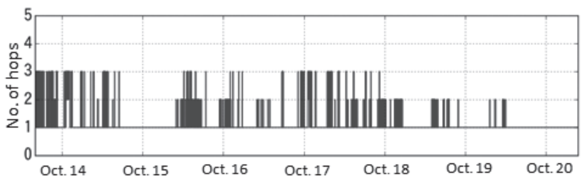
The signal strength between relay node R2 and controller C1 is somewhat low, because a passage exists between them. Consequently, when the signal strength is low in any section of the relaying route S1 → R1 → R2 → C1, it is advantageous, in terms of reduced packet loss rate, to automatically select a route using relay node R3 or directly connecting R1 and C1.

Figure 8 represents time-varying numbers of hops. The figure reveals that the relaying route changed frequently within about 1 week according to changes in the radio wave environment, although the route from relay node R1 → R2 → C1 is dominant.



1 hop : R1⇒C1
2 hops : R1⇒R3⇒C1, R1⇒R2⇒C1
3 hops : R1⇒R2⇒R3⇒C1, R1⇒R2⇒R3⇒C1

(a) Number of hops between relay node R1 and controller C1



1 hop : R2⇒C1
2 hops : R2⇒R1⇒C1, R2⇒R1⇒C1
3 hops : R2⇒R1⇒R3⇒C1, R2⇒R3⇒R1⇒C1

(b) Number of hops between relay node R2 and controller C1

Fig. 8. Time-varying number of hops

4. Conclusion

This paper described prototype relay nodes and controller used to form a full wireless network for plants and the results of a field experiment. The prototype is in use effectively as a simple means of expanding the wireless coverage of plants. As a future task, we intend to work on improving the packet loss rate.

References

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