Network Technology Supporting an Intelligent Society: WisReed

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Fujitsu intends to help achieve an intelligent society by providing cloud-based solutions to social issues, such as energy-saving measures to counter global warming and safety-improvement measures to guard against disasters. To that end, it is necessary to densely and widely deploy different types of sensors to collect data on such things as energy usage, river levels, and structural deterioration in an accurate and timely manner and then aggregate that data in a cloud. One problem with this is the cost of constructing and operating an infrastructure for the required enormous number of sensors, and this has hindered the implementation of a sensor network. Accordingly, Fujitsu has developed "WisReed" technology for autonomously forming a network to facilitate the collection of sensor data. This paper describes the background of WisReed's development and its technological features, presents a case example of its adoption for smart metering, and discusses potential applications, which are expected to expand.

1. Introduction

Fujitsu has a long-term vision of an intelligent society in which cloud services are extended beyond the key systems used for conventional information and communications technology (ICT) applications to systems at the societal level, thereby bringing to everyone a more comfortable life through a higher sense of security.

Example activities in an intelligent society are the collection of energy use data and the storage of that data in a cloud to serve as the basis of a highly detailed understanding of energy usage, thus making it possible to better identify waste and formulate countermeasures. Other example activities are the collecting and storing of data on the water levels in rivers for use in predicting flooding and of data on soil moisture levels for use in predicting landslides. Such activities will contribute to a sense of safety and security in our lives. In ways such as these, we can expect the intelligent society to solve various problems that we face in modern society.

Implementing these activities, however, requires reliable and timely collection of on-site data, and sensor networks are gaining attention as a means of satisfying that requirement. Such networks would comprise various types of sensors placed in many locations to collect data on physical phenomena.

Using a sensor network to collect the detailed data needed requires a dense placement of different types of sensors and communication devices over a wide area and the extension of an existing communication network to cover that area. However, constructing such a system using conventional technologies (optical fiber, cellular, etc.) alone is impractical because of the enormous costs of construction and maintenance. There is therefore a need for a technology that can be used to easily and inexpensively construct networks that bridge the 'last one mile' between an existing network and the various types of sensors and communication devices that are in place. In response to this need, Fujitsu has developed “WisReed,” a network technology for commercial applications.

In this paper, we first describe the requirements of Fujitsu’s target sensor network and then explain how WisReed can be used to help implement it. We also describe an example application of WisReed to a smart meter network and other potential applications, which are expected to expand.

2. Ad hoc networks

Conventional centrally managed networks are too expensive and time consuming for the efficient networking of the large number of sensors needed to implement a sensor network. Therefore, ad hoc network technology is currently an important research area. “Ad hoc” is a Latin term meaning “for this purpose.” We use “ad hoc network” to mean a network in which multiple communication devices interconnect without making connections via base stations or access points. Ad hoc networks are attractive because they can be used to construct an autonomous and distributed network without the need for detailed network design.

One ad hoc network communication specification is called “ZigBee.” It is currently being introduced to the market, mainly in the area of home electronics. As listed below, there are several problems in constructing practical sensor networks for supporting social systems that ZigBee cannot handle. Fujitsu is thus addressing these problems as part of its effort to implement sensor networks that support social systems.

1) Construction of large-scale networks

With current ad hoc network technologies, construction of large-scale networks is difficult. Although ZigBee can be applied to mobile terminals, the network becomes unstable if the number of terminals connected exceeds about 50. This is because the huge number of control packets generated when the communication route is determined limits network expansibility. Such networks are therefore not suited to the development of social systems and other such large-scale systems. Technology that can be applied to large-scale networks is thus needed.

2) Achievement of high network reliability

When applied to diverse scenarios of sensor network use, wireless networks are affected by electromagnetic interference, weather conditions, and other such factors that greatly change the communication environment. In conventional ad hoc networks, communication paths are repeatedly re-established when the communication environment changes, and communication quality becomes unstable. Application of ad hoc networks to social systems requires measures to avoid such changes in the communication environment.

3) Reduction of operation burden

Large-scale sensor networks applied to social infrastructure must connect sensors and communication devices regardless of the manufacturer. Moreover, devices are frequently added and removed in accordance with need, so the operation of complex, large-scale sensor networks is burdensome. Therefore, ways to reduce the burden of system operation are required.

3. Fujitsu sensor network technology

To solve the problems associated with using sensor networks in social infrastructure, it is first necessary to guarantee reliability and extensibility in ad hoc communication. There is also a need to provide operation technology for identifying network problems and flexible task applications for responding to customer requests. However, existing routing protocols for forming ad hoc networks do not satisfy these requirements.[1),2)]

To address those requirements, Fujitsu has developed original technology for autonomous and distributed ad hoc communication in which networks that are capable of self-repair and adaptation to changes in the network environment can be constructed automatically, without the need for setup.[3] To enable its application to social systems, we also developed sensor middleware that enables seamless cooperation between nodes and gateways and between data center servers. "WisReed" is the name given to the line of solutions based on this technology for autonomous and distributed ad hoc communication and sensor middleware. ("WisReed" is a coined term meaning 'wise reed.') In this section, we describe the ad hoc communication features of WisReed and the functions of the middleware.

3.1 Ad hoc communication

The WisReed protocol has an ad hoc routing function for creating ad hoc networks. It mainly manages connections between communication terminals and performs routing (management of the data communication path) for the sending and receiving of data. Parts of the second layer (data link layer) and third layer (network layer) of the OSI reference model are relevant, and the protocol is also suited for application to wireless communication. Since it is highly independent of the lower layers, application to wired communication is also possible.[4]

The WisReed routing protocol is compared to that of an existing routing protocol in **Figure 1**. In the existing protocol, the path is determined before data is transmitted. A path search message is broadcast to the entire network, and the path to the destination terminal is determined using a width-first search. In unstable networks such as wireless networks, the number of path search messages increases with network size and causes congestion. In the WisReed ad hoc protocol, on the other hand, the search is depth-first. Each terminal is informed of adjacent terminal information using a Hello message, and the link between the final address and the adjacent terminal is managed by a routing table. A terminal processes the received data if the data is addressed to it; if the data is addressed to another terminal, the receiving terminal checks the routing table and selects an adjacent terminal as the first candidate for forwarding the data. The path is thus determined as the data is being transmitted. Accordingly, no unnecessary path search messages are generated, making it possible to construct a large-scale wireless ad hoc network that connects over 1000 terminals.

Furthermore, the routing table maintains information on multiple redundant paths, so if the first-candidate adjacent terminal is affected by device failure or a network problem, a redundant path is selected and data transmission continues. There is also a function for detecting, in advance, terminals that may

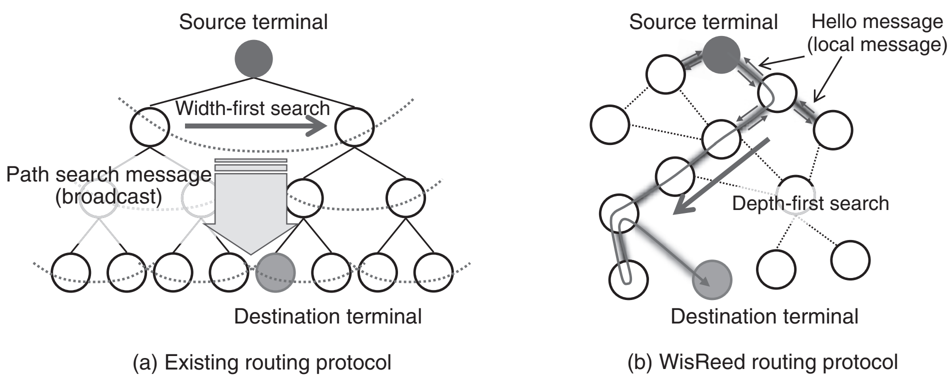

Figure 1
Comparison of routing protocols.

have communication disabled due to a network problem. It works by monitoring the redundant paths of each terminal.

As the scale of the sensor network increases, the number of failures also increases. WisReed monitors indications of possible network problems so that communication is maintained even if there is a device failure or other problem. As a result, a highly reliable sensor network can be provided in any environment.

3.2 Sensor middleware

Sensor middleware is a platform for seamless data communication without awareness of physical location, device, or communication protocol.

Many different protocols are used in existing sensor networks, so interconnection of different networks is not easy. Sensor middleware introduces a protocol conversion driver that operates only at the edge between sensor networks to facilitate construction of a seamless network environment. This enables existing sensor networks to be used without modification (**Figure 2**).

The sensor middleware provides three functions.

1) Protocol abstraction: a function for abstracting different protocols, such as ZigBee and transmission control protocol (TCP)
2) Network abstraction: a function for transmitting and receiving data for which an arbitrary transmission destination identification number (ID) is specified
3) Sensor middleware API: a function for creating a universal network by using an application programming interface (API)

The relationships among these functions are illustrated in **Figure 3**.

In the protocol abstraction layer, multiple protocol drivers can be loaded in a plug-in format, and the correspondence between network and protocol driver is maintained in a protocol conversion table. This sensor middleware environment with protocol drivers makes it easy

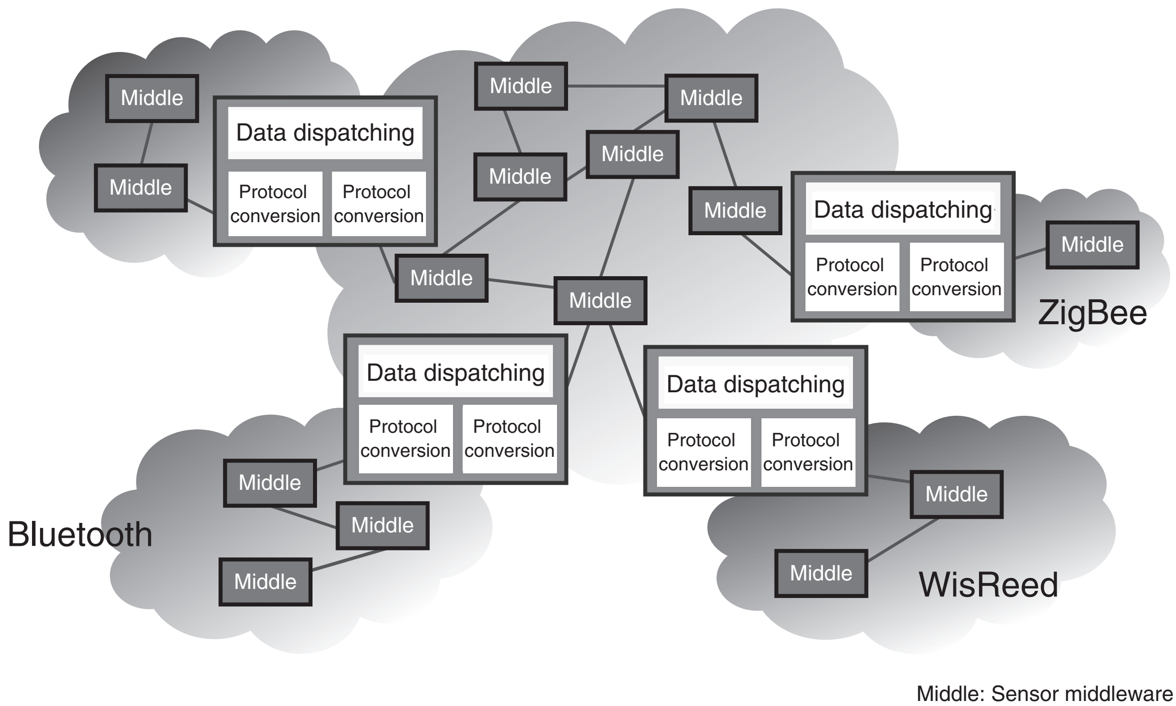

Figure 2
Model of connections between different sensor networks.

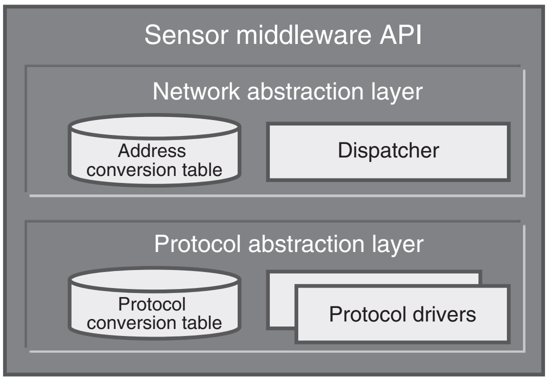

Figure 3
Relationships among functional components of sensor middleware.

to construct a cloud network.

The network abstraction layer makes it possible to transmit data to any destination with protocol transparency by specifying the destination ID. The ID can be determined by address conversion table look-up. Because any ID can be specified for the destination, data can be sent to or received from any node or application in a cloud network.

4. Application to smart meters

The field of smart energy grids continues to grow rapidly due to ongoing energy problems. Here, we describe a demonstration application of WisReed to the networking of smart meters, for which there is an urgent demand.

4.1 Problems and system requirements of KCEC Corporation

We use as an example the Kit Carson Electric Cooperative (KCEC) in New Mexico, a power distribution company in the United States that has been supplying electrical power, gas, and regional communication infrastructures (telephone and later the Internet) to about 30 000 households since being established in 1944. KCEC investigated the introduction of a smart grid with the idea of developing a regional broadband service in addition to increasing the efficiency of reading meters and supplying electricity in sparsely populated areas.

The automatic meter reading by power line communication (PLC), which KCEC previously used, had become unsatisfactory. Comparison of the correct meter-reading ratio (probability that the amount of electricity used by a household was correctly read from the server side) with the cost of operating the system showed that it was not a cost-effective approach. However, since there was a need to provide automatic meter reading networks in sparsely populated areas, KCEC first provided networks in those areas and later implemented Internet connections using networks. KCEC identified two requirements for addressing these problems.

1) Achieve an automatic correct meter reading ratio of at least 99%
2) Provide Internet service to all areas with a minimum connection speed of 256 kb/s

4.2 Overview of verification system

Fujitsu proposed that KCEC install a smart meter system to meet these requirements (**Figure 4**). Prior to performing a small-scale testing, we configured small-scale system of 100 smart meters for verification purposes. The other main components were a server for collecting the meter reading data, a router to connect the server to the optical fiber network, a router to connect to the Internet, a gateway, a dynamic host configuration protocol (DHCP) server, repeaters, and personal computers. We installed the smart meters in homes specified by KCEC. The communication path from each meter up to the gateway was established autonomously by WisReed, and the meter reading data was transmitted to the gateway periodically via the wireless network for delivery to the meter-reading server. Each personal computer connected to the Internet by connecting wirelessly to the smart meter in the home, which was equipped with an access point function. Because the communication quality of the radio signal deteriorates beyond a certain distance

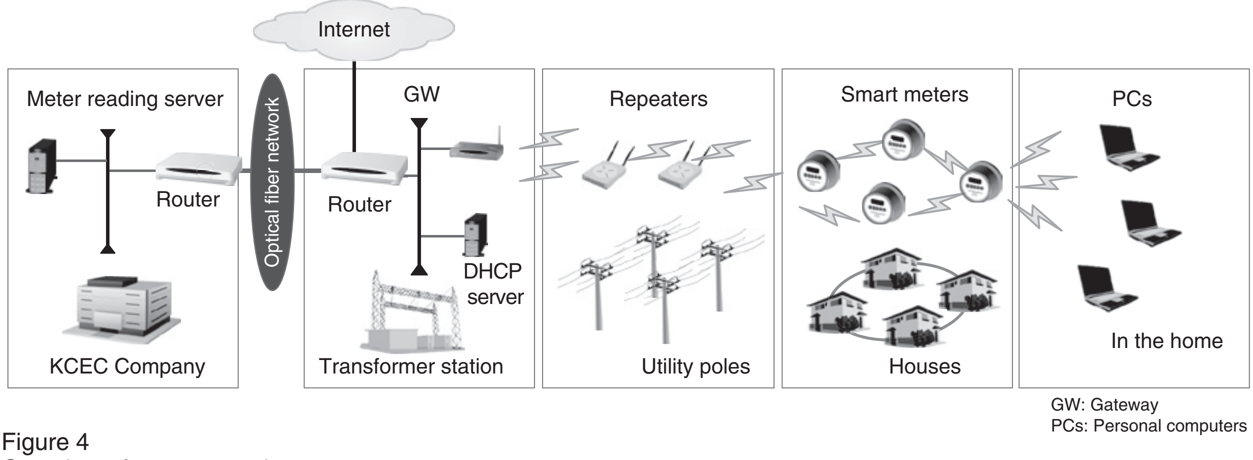

Figure 4
Overview of smart metering system.

between meters, the network was designed with repeaters for the wireless signal.

4.3 Results of field test

In 2010, we conducted small-scale testing using 176 smart meters at the KCEC test site. The site was 2000 m above sea level and was subject to a severe environment with temperatures below minus 30°C in winter. The results were positive.

1) Automatic meter reading

Sending meter data from the 176 smart meters to the gateway every 15 minutes was initially problematic due to radio signal fluctuations and weather effects. By implementing a mechanism for retransmission when automatic reading failed (“recovery meter reading”), we were able to achieve an automatic meter reading ratio of 100% within the test period.

2) Internet speed

Multi-hop communication (a data transfer method that uses other terminals as relay points) such as used in WisReed is characterized by a decrease in end-to-end throughput with each hop. Even for a maximum of ten hops between the gateway and a personal computer, however, an Internet speed of at least 300 kb/s was achieved.

3) Feasibility of automatic meter reading for time of use charging

KCEC purchases electrical power from power generating companies and delivers it to end users. At the time of purchase, a hierarchical time of use charging system is set, and whether or not high-use time (peak charge) periods have been purchased affects business performance. For that reason, a time-of-use (TOU) charging system had been introduced to some households to achieve power leveling, but meters with a TOU function are expensive. The field test showed that using the automatic meter reading system offered by Fujitsu overcomes this problem. This system performs the TOU charge calculation on the server side rather than at the meter. This means that expensive meters with a TOU function can be replaced with less expensive meters without a TOU function, which enables cost reduction.

4) Remote on/off operation

Another problem is the cost of sending personnel to a customer’s home to turn the meter on or off as required because of non-payment or household moving. WisReed provides for two-way communication, so meters can be turned on and off from the server side. The field test confirmed that remote operation of the meter from the server side is possible.

4.4 Results analysis (feedback)

All of the KCEC system requirements were satisfied in the small-scale test. One of the test items, Internet monitor feedback, showed high customer satisfaction due to high throughput and short response time. KCEC was highly satisfied with the results. Large-scale testing currently in progress and premised on commercialization is demonstrating normal operation even during severe winter conditions.

5. Feasibility of introduction to social systems

Fujitsu plans to expand globally the application of WisReed to smart meter networking, which continues to exhibit rapid growth. By also expanding into other fields where social needs for safety and security are high, such as the environment, and by looking to the future, Fujitsu intends to position WisReed as a communication infrastructure technology well suited for implementing social systems that support an intelligent society (**Figure 5**).

In this section, we describe an example application of WisReed within Fujitsu, potential applications to social systems, and our activities regarding standardization.

5.1 Application of WisReed to data center environment monitoring

The increasing density of servers in data centers has created a need for environment monitoring of the temperature and airflow in the vicinity of server racks as a measure against overheating. In Fujitsu's environmentally aware data centers, we have used WisReed to construct wired sensor networks for environment monitoring. A single cable is used for both communication and power supply, so environment-monitoring sensors can simply be plugged into the system with no need for a separate power supply. WisReed is thus an optimum solution with respect to installation and maintenance for data centers, where equipment may frequently be added or removed as the customer's rack space increases or decreases.

Introducing such an environment monitoring sensor network enables both sensor networks on the scale of tens of thousands of sensors and high-density environment sensing,

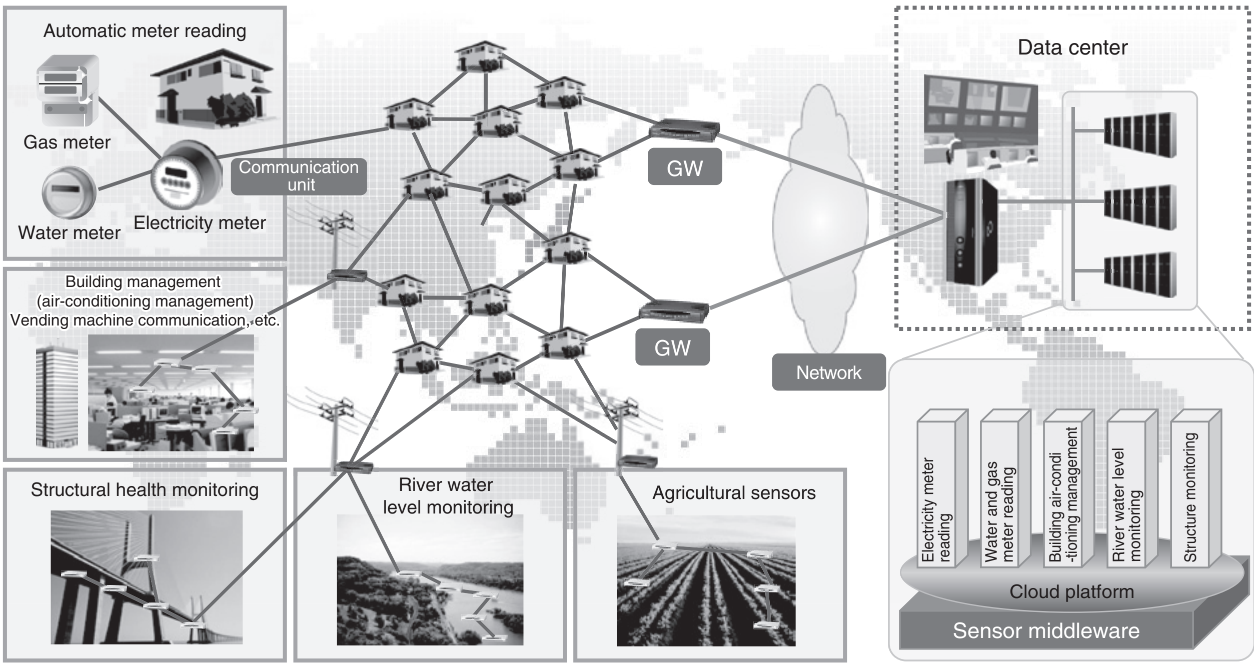

Figure 5
Image of social infrastructure technology using WisReed.

resulting in efficient air-conditioning control.[5)]

5.2 Potential applications

WisReed's features are well suited to the deployment of sensor networks on a large scale. Example applications include

1) Health monitoring for structures such as bridges
2) Building and factory management and control
3) River monitoring
4) Landslide early warning

Because WisReed is a communication platform technology, there are no limits to its application, so the range of potential applications will continue to widen.

5.3 Standardization

With the objective of expanding the use of WisReed to all of society, we are actively making proposals to international standardization organizations. We will continue to deepen cooperation with such organizations with the aim of having WisReed adopted as an international standard technology.

6. Conclusion

We have described the problems of applying sensor network technology to social systems and have explained the features of WisReed, the technology we have developed to solve those problems. We also described an example application to a smart meter network.

By adding WisReed to the diverse network services Fujitsu has been providing, we expect to be able to respond fully to the increasing diversity and complexity of network requirements.

Although WisReed is already on the market, we will continue its development to better satisfy customer needs and endeavor to expand the number of potential applications.

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