International Gas Union Research Conference 2014

The development of wireless communication technology for smart gas meters in Japan

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ABSTRACT

Wireless communication technology for smart gas meters has been developed by Japanese gas utility companies. The technology is composed of three main components: a wide area network (WAN) device, a U-Bus Air system, and ultrasonic gas meters. Two important technologies used for the system are described in this paper. One technology is a WAN device to construct a wide area network called “Pu-NCU,” and the other is a combination of multi-hop and ad-hoc mesh networks called “U-Bus Air.”

The meter reading system based on PSTN has been used in Japan since 1987 and is quite reliable. However, as use of the Internet and cell phones spreads, the number of conventional telephone line users has decreased significantly. This makes it difficult for Japanese gas utilities to continue to provide the automatic meter reading (AMR) service. To solve these problems, the three major Japanese city gas utilities have developed a new gas metering system in cooperation with the representative institute of the liquefied petroleum (LP) gas industry (KHK), wireless communication equipment manufacturers, gas meter manufacturers, and telecommunications carriers.

The system is based on a low-power-consumption communication system, and it can operate for 10 years on batteries. A combination of WAN device (Pu-NCU) and U-Bus Air achieved cost reductions and can cover a wider area than existing systems.

Pu-NCU, using the PHS network (the cellular standard in Japan), was employed as the WAN device, which was developed with Ymobile Corporation as a wide-area access network that links each consumer to the center. More than 30,000 devices have been installed since 2013.

U-Bus Air was employed as a neighborhood area network (NAN), which is used for multi-hop relaying of metering data from gas meters outside the WAN service area to the WAN device. U-Bus Air can save power, and it can be used to construct a highly reliable metering network. The PHY layer of U-Bus Air utilizes IEEE 802.15.4 g/e, the 920-MHz band, and a 10-mW output. U-Bus Air has also been installed since FY 2013.

We have been working on standardization and international interoperability of this new wireless communication system, which will lead to a stable supply and cost reduction of the system. We applied to the Standardization Task Force of Japan Utility Telemetering Association (JUTA), and U-Bus and U-Bus Air were adopted as the industry standard. We proposed PHY and part of the MAC layer of U-Bus Air to IEEE 802.15.4 g/e, which adopted them as the standard at the end of 2011. In addition, an interoperability test of U-Bus Air is being conducted by Wi-SUN Alliance and JUTA.

1 Introduction

The Gas Smart Metering System, developed by Japanese gas utilities, is composed of a smart meter and a wireless communication system.

The two important technologies used in the wireless communication system are described in this paper. One technology is a wide area network (WAN) device called “Pu-NCU,” which is used to construct the wide area network. The other is a multi-hop and ad-hoc mesh network called “U-Bus Air.”

2 Characteristics of Advanced Metering Infrastructure(AMI)

Domestic gas meters in Japan are equipped with three functions: a measurement function, a safety function, and a communication function. AMI provides not only automatic meter reading (AMR) but also security monitoring services and remote shutoff operations that utilize the safety functions of the meters (“Micom” meters) and their communication functions.

3 Existing AMI

3.1 Basic System

Figure 1 shows the basic structure of the existing AMI. The gas meters are connected to the metering center via the fixed telephone lines of our customers, through a communication modem called a network control device (NCU). Telephone lines are wirelessly connected to gas meters via specified low-power devices (429 MHz).

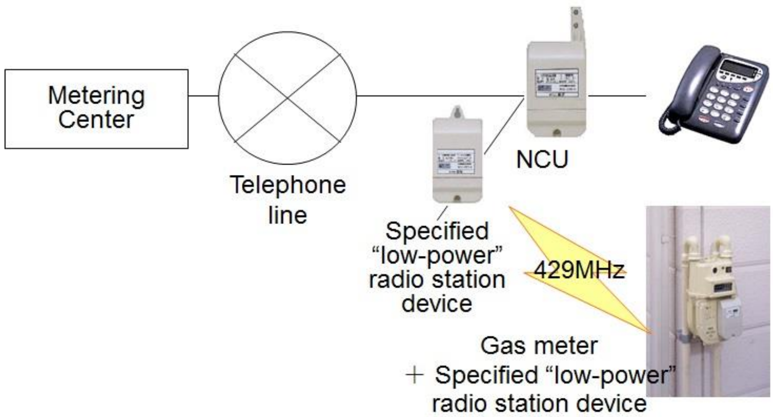

Figure 1 Structure of Existing AMI

3.2 Problems of Existing AMI

There are two major problems in the existing AMI.

a) Reduction of fixed telephone lines

Communication lines have been rapidly changed and diversified, making it difficult to provide existing metering services to our customers via their fixed telephone lines.

b) Limitation of providing new value-added services

The specified low-power radio station devices currently used are not suitable for multi-hop wireless devices because the speed of the devices is limited to 2.4 kbps. However, with the growing number of high-rise condominiums and expanding needs for new value-added services for energy efficiency and safety, a higher-performance communication infrastructure is needed.

4 Gas Smart Metering System

To solve these problems related to existing gas metering systems, three city gas utilities—Tokyo Gas, Osaka Gas, and Toho Gas—have been considering specifications for a Gas Smart Metering System in cooperation with the liquefied petroleum (LP) gas industry, manufacturers, and a telecommunications carrier.

The Gas Smart Metering System consists of a gas meter with a new communication interface, and a wireless communication system that connects this meter to the information systems of the gas utility, as shown in Figure 2.

The wireless communication system is composed of two main components. One is a WAN device to construct a wide area network called “Pu-NCU,” and the other is a multi-hop and ad-hoc mesh network called “U-Bus Air.” A combination of WAN device (Pu-NCU) and U-Bus Air achieved cost reductions and could cover a wider area.

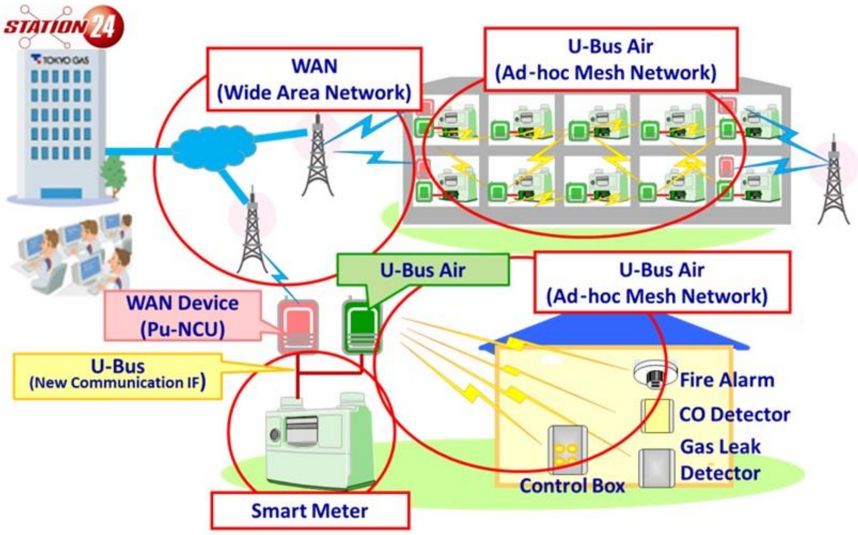

Figure 2 Configuration Diagram of the Gas Smart Metering System

5 Technologies

5.1 Pu-NCU

“Pu-NCU” was employed as the WAN device. Using highly sophisticated intermittent reception and an ultra-low energy chipset, Pu-NCU can operate for more than 10 years with three lithium batteries. The power consumption of the chipset provided by Ymobile Corporation, in December 2011 is almost one-fourth less than the usual chipset. Following are the characteristics of the device:

Table 1 Specifications of Pu-NCU

Item		Specifications
Wireless Interface	Standards	ARIB STD-28
	Protocol	PIAFS
	Modulation Scheme	π/4　QPSK
	Output Power	Average: 10 mW（Peak: 80 mW）
	Frequency Band	1.895–1.918 GHz
	Bit Rate	32 kbps
Wired Interface		U-Bus
Power supply		3 lithium batteries

(1) Installability

Because it uses the PHS line of cellular standards, Pu-NCU can be installed by simply attaching it to the gas meter. The system does not require a customer‘s fixed telephone line.

The device is equipped with a simple field strength measurement function. The electric field strength from the base station can be displayed as one of five levels. This is straightforward and easy to operate for installers.

(2) Extensibility

The device is equipped with up to six lithium batteries, and can be used for applications that communicate frequently.

Because it can be used in combination with the U-Bus Air, Pu-NCU is also applicable to additional services and can accommodate multiple meters.

(3) Use Case of Pu-NCU

In order to support the safety of the home, Tokyo Gas is providing almost 400,000 customers with "My Tsuho" service, which is a paid remote monitoring service for remote shutoff and automatic warning.

This service had utilized the legacy system as its communication infrastructure, but recently Pu-NCU has been adopted. Pu-NCU was employed as the WAN device, and more than 30,000 devices have been installed since 2013.

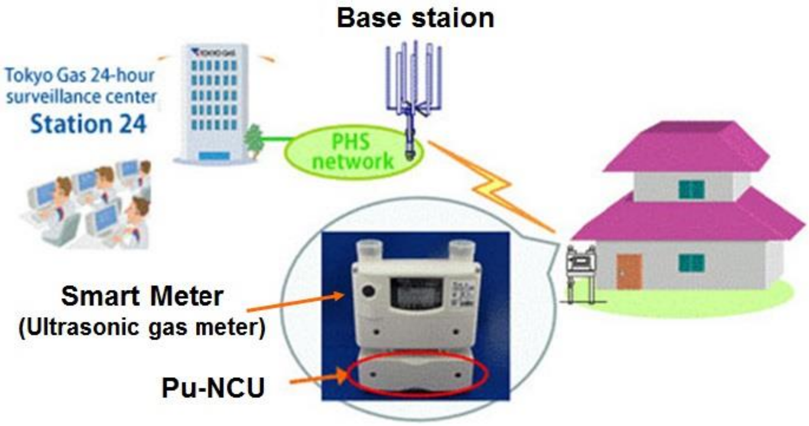

Figure 3 Network Composition for Remote Monitoring Service

5.2 U-Bus

“U-Bus” is a new communication interface installed on a meter. This interface speeds up the standard communication interface specifications of conventional city gas meters. U-Bus uses a packet communication system, which is the current primary communication technology. U-Bus improves compatibility with wide-area wireless units and U-Bus Air devices, and also with various types of communication networks such as WAN and HAN (home area network). Thus, U-Bus offers more versatile communication specifications.

Table2 shows the outline specifications of U-Bus Air:

Table 2 Specifications of U-Bus (Wired Communication)

Layer	Specification	Description
Physical layer	Bus connection	Allows shared use of various devices.
	High transmission speed (9600 bps)	Wider application and higher service level as a result of high-speed transmission (approx. 30 times faster than the legacy device)
Data link layer	Packet communication	- Improved bidirectional communication between devices with different transmission speeds - More efficient use of communication links - Improved resistance against faults
	Fixed packet length (104 characters per packet)	- Improved efficiency of data processing by devices - Faster response (0.12 s with each packet)
Security	Encryption as a standard	- Improved access control and security protection

5.3 U-Bus Air (Ad-hoc and Mesh Network Devices)

U-Bus Air is a low-power-consumption wireless communication device for short distances. U-Bus Air is used in conjunction with wide-area wireless devices or a handheld computer's wireless devices. These devices are equipped with (1) a function to automatically construct a mesh network, and (2) a function to automatically select a suitable communication route. These functions provide potential benefits, including diversification of services (simplification of extensions), reduction of maintenance due to improvement of communication reliability, and easier installation. The following characteristics of the multi-hop wireless devices achieve these functions.

(1) Outline of Communication Specifications

Table 3 summarizes the communication specifications of the U-Bus Air. These devices enable a mesh network to be constructed with up to 50 devices per network. The network can operate for 10 years and is powered by batteries.

Table 3 Outline Specifications of U-Bus Air

Device	Frequency band	920 MHz (Japan) or other Sub-GHz (other countries)
	Standards	ARIB STD-T108 * IEEE802.15.4g
	Output power	20 mW / 10 mW / 1 mW
	Data rate	100 kbps
	Life span	10 years
	Power supply	Lithium battery
Network	Network topology	Mesh structure
	Communication direction	Two-way
	Number of relays	Max. 15 hops
	Number of nodes	Max. 50
	Number of meters	Max. 50 (1/node)

(2) Intermittent Operation (Receiver-Driven Method)

U-Bus Air devices use an intermittent operation approach to reduce power consumption (Figure 4). Because the devices are all battery-driven, they are in operation for only a short time compared to their time in sleep mode (Figure 4 ①). During operation, each wireless device transmits a signal called a beacon (Figure 4 ②). When transferring data, the wireless device enters into a continuous reception mode (Figure 4 ③), receives beacons from surrounding wireless devices, and finds a transmittable counterpart. Then the device transfers data by specifying the destination. This method ensures reliable data transmission (Figure 4 ④).

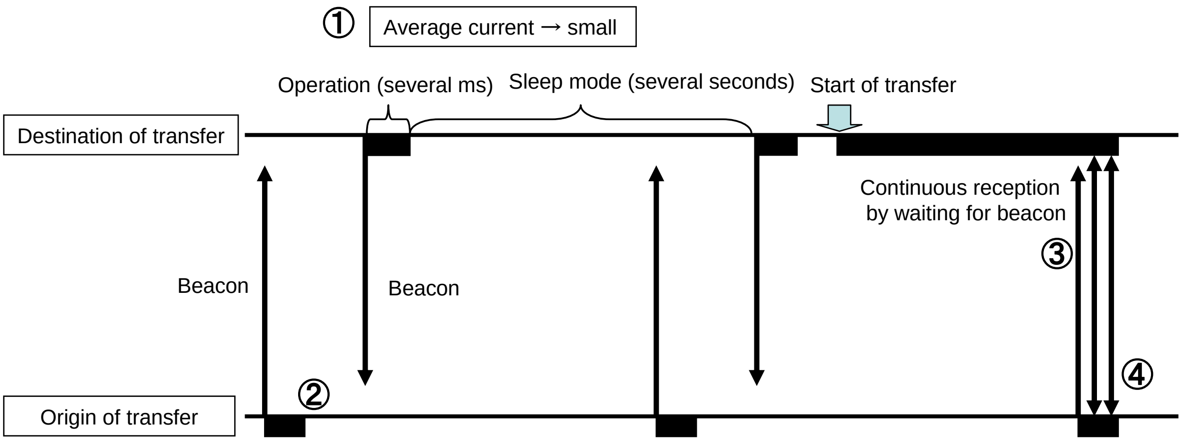

Figure 4 Intermittent Operation Method

(3) Routing Protocol (Distance Vector Type)

Because this method is based on the multi-hop transfer, each wireless device performs transit processing of packets. The proposed system is called a distance vector routing protocol. All of the wireless devices keep the routing table for a set of relay nodes, in which a method used in the “full mesh network” and the above-mentioned intermittent operation method are combined. This method is often used in wired systems in which the number of devices is limited.

In this method, each wireless device prepares a relay node table by exchanging the table with adjacent wireless devices (Figure 5 ①). Then, each device compares its own relay node table with that of the adjacent device, and prepares a routing table (Figure 5 ②). When sending a packet, the device refers to its own routing table, and transfers the packet to the forward adjacent device, thus performing a packet transmission (Figure 5 ③).

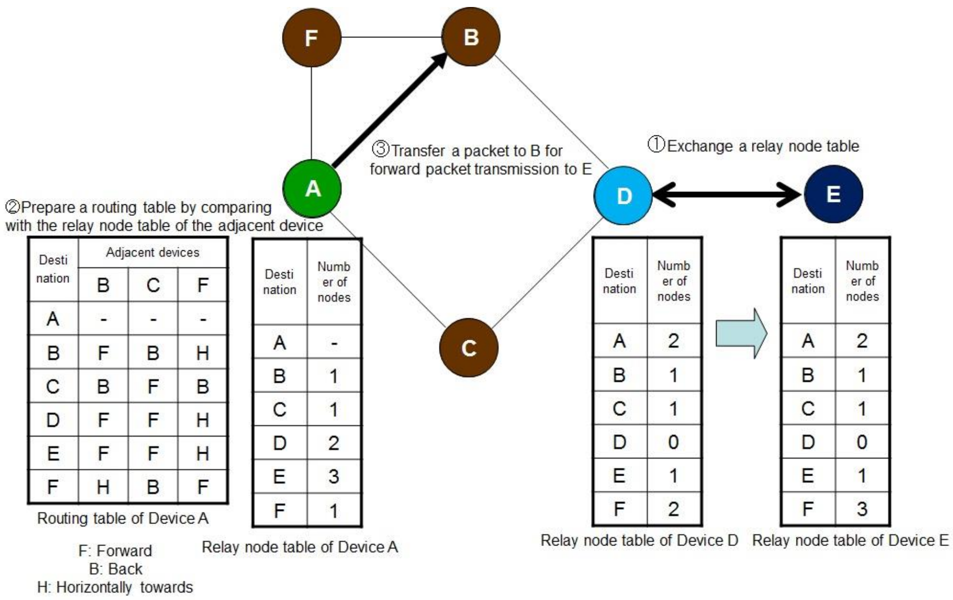

Figure 5 Routing Protocol

In this process, reliability is enhanced by using a routing protocol that can flexibly select a detour route other than the minimum hop route. When Device A transmits data to Device E in Figure 6, Devices B and C are the forward adjacent devices. However, if Device A temporarily cannot transfer a packet of data to Devices B and C (for example, due to radio wave conditions), it instead transfers the packet to Device F, whose beacon it can confirm by detouring. Thus, Device A can transfer the packet to Device E, which is the destination of the packet transmission (Figure 6 ①).

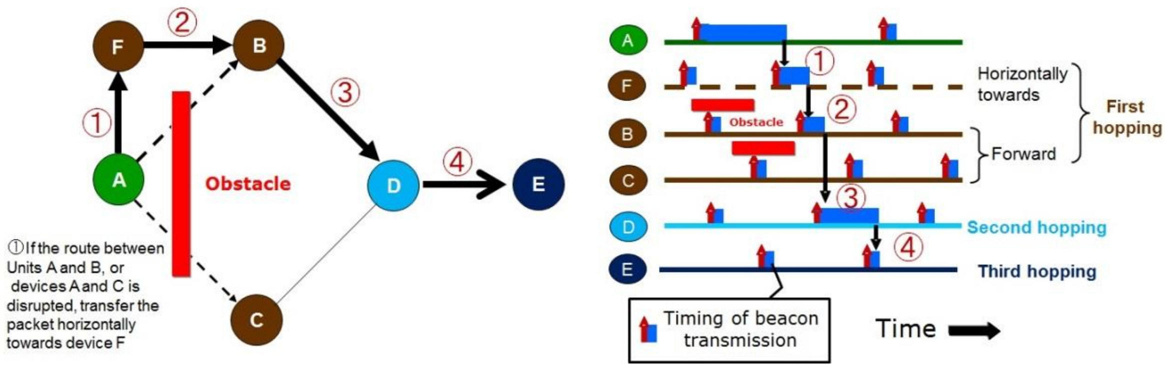

Figure 6 Routing Protocol with Obstacle

(4) Use Case of U-Bus Air

U-Bus Air system is a good solution for metering condominiums with electronically locked entrances that are difficult to enter. There are two approaches to reading meters: by using a handheld computer or by using a WAN device. Depending on the operation, either approach can be selected.

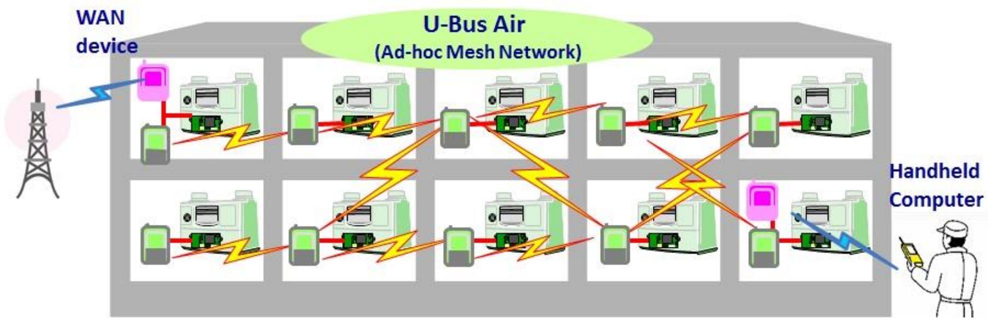

Figure 7　Metering Condominium Service

6 Field Test

6.1 Environment of Field Test

To evaluate the communication performance of the U-Bus Air described in the preceding section, a field test was carried out by installing devices in condominiums. The devices were installed in pipe shaft (PS) in the proprietary areas of the condominiums.

●building facade　●pipe shaft(PS)　●U-Bus Air (with Smart Meter in PS)　●floor plan

Figure 8　Test Environment

6.2 Automatic Network Construction Function

The results of evaluating automatic networking by installing U-Bus Air in the PS of the condominiums listed in Figure 9 were as follows:

In this case, 50 wireless devices were installed in the PS of a 10-story condominium. It was confirmed that a mesh network was automatically constructed by four nodes of communication from the gateway (GW). We carried out communication tests with each device 1000 times. The overall average success was 99% (Figure 10). Similar results were also obtained by other manufacturers.

	Room 6	Room 5	Room 4	Room 3	Room 2	Room 1
10F	2	3	4			4
9F	2	2	3	3	3	4
8F	2	2	3	3	3	4
7F	1	2	3	3	3	4
6F	1	2	3	3	3	4
5F	1	2	2	3	3	4
4F	1	2	2	2	3	3
3F	1	1	2	2	2	3
2F	GW	1	1			

Figure 10 Number of Hops from Gateway

	Room 6	Room 5	Room 4	Room 3	Room 2	Room 1
10F	100.0%	99.9%	100.0%			100.0%
9F	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%
8F	100.0%	100.0%	99.9%	100.0%	100.0%	99.9%
7F	100.0%	100.0%	100.0%	99.9%	100.0%	99.9%
6F	100.0%	100.0%	100.0%	99.9%	100.0%	99.7%
5F	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
4F	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3F	100.0%	100.0%	99.8%	99.8%	100.0%	100.0%
2F	Start	100.0%	100.0%			

Figure 9 Success Rate from Gateway

In response to the positive results of the field tests, Tokyo Gas started to install U-Bus Air via handheld computer in March 2014.

7 Procedure of Standardization Activity

Because the new system not only helps to unify the communication specifications for city gas and LP gas industries, but may also be useful for various other industries, we have proposed the system to the Standardization Task Force of the NPO Japan Utility Telemetering Association (JUTA). As a result, U-Bus and U-Bus Air were recognized as the industry standards.

For industries abroad, a technical standard proposal regarding the standardization of technologies of the PHY and part of the MAC layer of U-Bus Air was adopted by the Institute of Electrical and Electronics Engineers (IEEE), which provides international standards.

In addition, in order to ensure the interoperability of U-Bus Air, we have been promoting standardization in the Wi-SUN Alliance, which provides a certification service for wireless products with low power consumption.

8 Conclusion

This paper presented the characteristics of a wireless communication system, which is one of the components of the Gas Smart Metering System. In addition, this paper presented the results of field tests carried out in condominiums.

This system succeeds in reducing power consumption and improving reliability, and it is a good solution for new value-added services for energy efficiency and safety.