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# DEVELOPMENT OF UBIQUITOUS METERING SYSTEM

# (NEW WIRELESS COMMUNICATION DEVICE

# FOR SMART METERING)

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# 1.ABSTRACT

Tokyo Gas Co., Ltd., Osaka Gas Co., Ltd. and Toho Gas Co., Ltd with the strength of computerized gas meter technology launched a joint-development project for a highly reliable, cost efficient, next-generation smart gas metering system called Ubiquitous Metering System, in collaboration with Japan's 3 leading meter manufacturers (Yazaki Corporation, Aichtokeidenki Co., Ltd. and Toyogasmeter Co., Ltd.), top 3 electronics makers (Panasonic Corporation, Toshiba Toko Meter Systems Co., Ltd. and Fuji Electric Holdings Co., Ltd), and the Japanese largest carrier, NTT. Our novel AMI is composed of 3 main components, which are 1) WAN Device for receiving wide area ubiquitous network, 2) Ad-hoc Mesh Networks (U-Bus Air), and 3) Ultrasonic Gas Meters Interfaced with a Next-Generation Communication Line (U-Bus). This paper will describe features of ad-hoc mesh networks (U-Bus Air) and some results of field tests.

## CONTENTS

# 2. BODY OF PAPER

## 2.1 INTRODUCTION

For more than 20 years, city gas and LP gas utilities in Japan have widely promoted automatic telemetering services that use customers' telephone lines. In the days ahead, demand is expected to grow for smart meters that allow sensor networking and higher security in residential houses and that help create energy-efficient household electrical appliances for reducing $CO_2$ emissions. This paper presents an overview of Adhoc Mesh Networks (U-Bus Air) units, which are one of the important components of the next-generation gas metering system now under examination for future smart meters, and our work on standardizing these units.

## 2.2 CHARACTERISTICS OF ADVANCED METERING INFRASTRUCTURE (AMI) IN JAPAN

AMI in Japan provide not only automatic meter reading (AMR) but also security monitoring services and remote shutoff operations utilizing the safety functions of the meters ("Micom" meters). Therefore, gas utilities offer emergency monitoring services (for a fee) for safer gas utilization at the request of our customers, not just for solving the difficulties of metering.

Typical examples of monitoring services (services vary among utilities)

- Abnormal decrease of supply pressure
- Occurrence of abnormally large flow of gas (breaks, improper use)
- Earthquake, etc.

The function to detect an abnormal decrease of supply pressure enables gas utilities to promptly detect the location of an abnormality through calling from the Micom meter, thus increasing the stability of supply.

## 2.3 EXISTING AMI

### 2.3.1 Basic System

Figure 1 shows the basic structure of the present 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 unit (NCU). As the Internet along with fiber optic cables and ADSL has spread, telephone line connectors have become installed in the modular connectors inside the house instead of the telephone line lightning protectors outside the house. Therefore, telephone lines are now usually connected to gas meters wirelessly via specified low power units.

The communication protocols (communication procedures) among gas meters, NCUs and specified low power radio station units are standardized by the Japan Gas Association (JGA) for the city gas industry, and by the High Pressure Gas Safety Institute of Japan (KHK) for the LP gas industry.

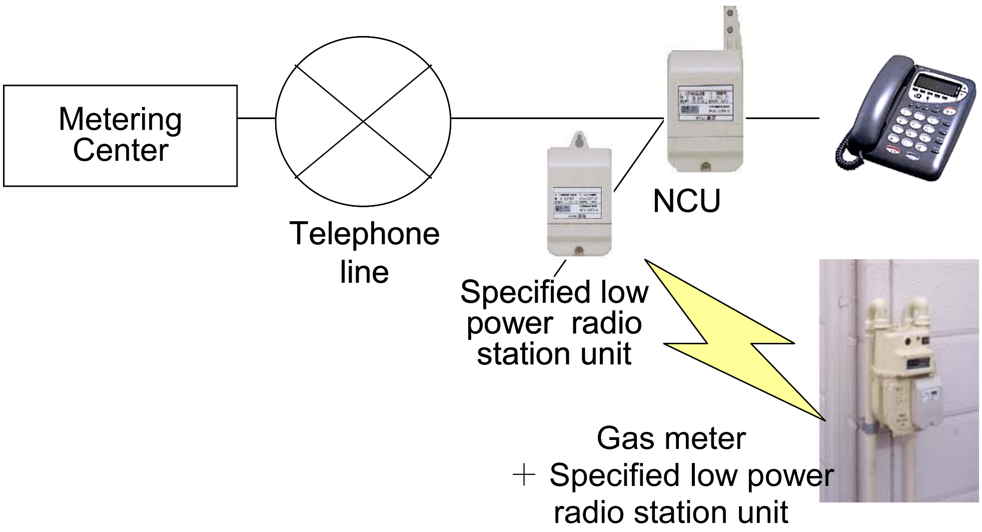



Figure 1 Structure of Existing AMI

### 2.3.2 Problems of Existing AMI

There are two major problems in the existing system:

**a) Difficulty in sharing customers' telephone lines with AMI**

Communication lines have rapidly changed and diversified, from fixed telephone lines to the Internet and wireless broadband services, making it difficult to stably deliver metering services to our customers via their telephone lines. In addition, although a public wireless network such as FOMA could be used exclusively for gas metering instead, this would involve a number of problems:

- Communication technology evolves extremely quickly, and the communication infrastructure is diversifying and short-lived;
- As the monthly charges accrue, it would cost more than using fixed telephone lines.
- It is difficult to operate a unit by battery for 10 years.

**b) Limitation of a single hop wireless system**

The specified low power radio station units currently used are not suitable for multi-hop wireless units as their speed is limited to 2.4 kbps; the current units are intended for a single hop network structure. However, with the increase in medium-to-high rise condominiums with an electronically locked entrance and expanding needs for new value-added services for energy efficiency and safety, a new multi-hop wireless system with networking flexibility that can be easily coordinated with various types of sensors is needed.

## 2.4 NEXT-GENERATION AMI

To solve these problems related to existing gas metering systems, the three city gas utilities of Tokyo Gas, Osaka Gas, and Toho Gas have been considering the specifications of the next-generation gas metering system, the "Ubiquitous Metering System", in cooperation with KHK, a representative institute of the LP gas industry, manufacturers of communication equipment (Panasonic Corporation , Toshiba Toko Meter Systems Co., Ltd. and Fuji Electric Co.,Ltd.), manufacturers of meters (Yazaki Corporation, Aichi Tokei Denki Co., Ltd and Toyo Gas Meter Co., Ltd.), and a telecommunications carrier (Nippon Telegraph and Telephone Corporation). The

Ubiquitous Metering System consists of a meter with a next-generation communication interface, wide-area wireless system and U-Bus Air units, as shown in Figure 2. The following are the characteristics of each terminal.

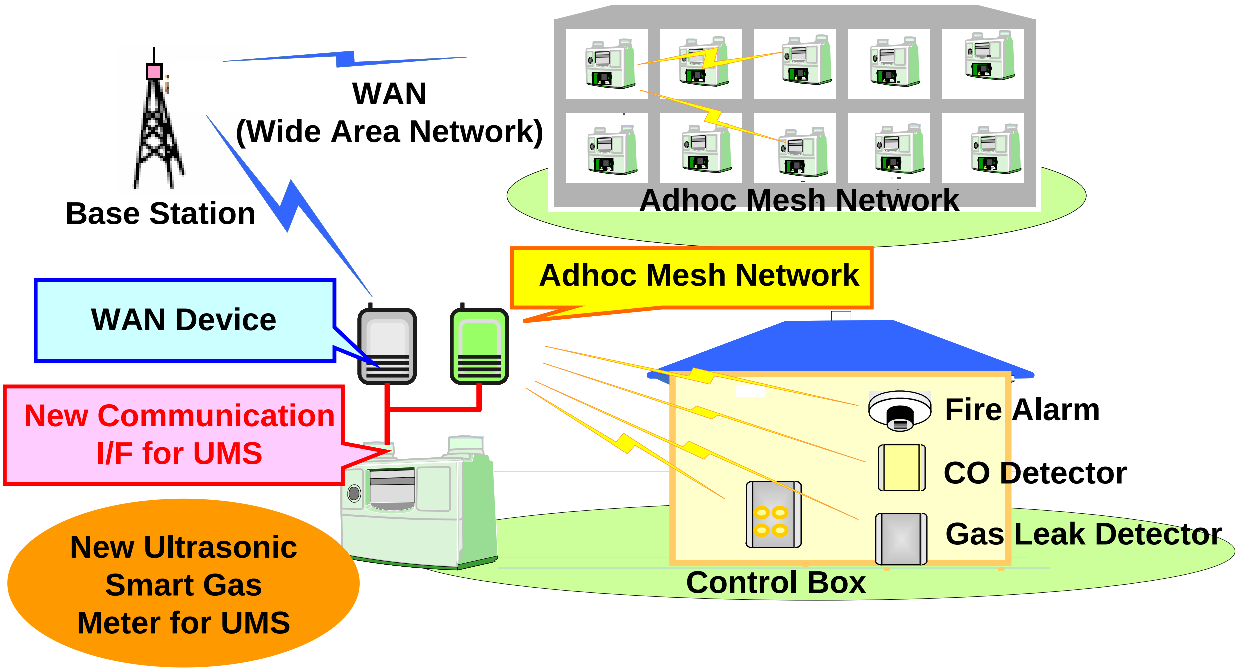



Figure 2 Configuration Diagram of the Ubiquitous Metering System

**2.4.1 Next-Generation Communication Interface (U-Bus)**

"U-Bus" is a new communication interface installed on a meter. U-Bus speeds up the standard communication interface specifications of conventional city gas meters and uses a packet communication system, which is the main communication technology today. U-Bus improves the compatibility with wide-area wireless units and U-Bus Air units and also with various types of communication networks such as WAN (Wide Area Network) and HAN (Home Area Network), and thus offers more versatile communication specifications.

**2.4.2 Wide-Area Wireless Units**

We have been examining the possibility of using the terminals using a wide-area ubiquitous network (wide-area wireless units) as a promising candidate for a wide-area access network linking the center and each consumer. This technology has been investigated and demonstrated by NTT Network Service Systems Laboratories and NTT Access Network Service Systems Laboratories. We consider the wide-area ubiquitous network, with the following advantages, is suitable for the next-generation gas metering system:

・Wireless communication network with a wide coverage (radius of several km);
・Low-power consumption communication system that allows long-term battery-powered operation;
・Low-fare communication service exclusively for carrying small amounts of information (approximately several hundred bytes/month)

### 2.4.3 U-Bus Air units (Adhoc Mesh Network units)

U-Bus Air units are wireless communication units for short distances, and are used in conjunction with wide-area wireless units. These units are also based on a low-power consumption communication system and can operate for a long time powered by batteries. Furthermore, U-Bus Air can be built by these units unlike the previously-mentioned single-hop low-power base units used in the existing gas metering system in response to the increase in medium-to-high rise condominiums with an electronically locked entrance and for providing new value-added services. U-Bus Air units are equipped with (1) a function to automatically construct a network and (2) a function to automatically select a suitable communication route. These functions provide potential benefits including diversification of services (simplification of extension), reduction of maintenance due to improvement of communication reliability and easier installation. The following characteristics of the multi-hop wireless units achieve these functions.

## 2.5 OVERVIEW OF THE U-BUS AIR UNITS

### 2.5.1 Outline of Communication Specifications

Table 1 summarizes the communication specifications of the U-Bus Air units. These units enable a mesh network to be constructed with up to 50 units per network, and also to operate for 10 years powered by batteries.

Table 1　Communication Specifications ofthe U-Bus Air Units

| | |
|---|---|
| Frequency | 950-MHz band (conforming to ARIB STD-T96) |
| Output | 10 mW, 1 mW (selectable) |
| Communication speed | 100 kbps (maximum) |
| Network structure | Mesh type |
| Number of hops | 15 hops (maximum) |
| Number of component units | 50 units/network |
| Power source | Lithium primary battery (lasts for 10 years) |
| Major functions | Automatic registration and deletion at the terminals, automatic routing |

### 2.5.2 Frequency Band

U-Bus Air units use the 950-MHz band (Note 1), which has a good balance of radio wave footprint and transmission rate as shown in Table 2 compared with other frequency bands used in smart meters. Thus, it is suitable for U-Bus Air units, considering the operability of multi-hop communication and low power consumption.[1]

Note 1: Transition to 920-MHz band has been decided for restructuring the frequencies in view of increased use of wireless broadband.

Table 2 Comparison with Other Methods in Other Frequency Bands

| | | **Wireless LAN 2.4 GHz** | **PHS 1.9 GHz** | **U-Bus Air 950 MHz** | **Conventional method 429 MHz** |
|---|---|---|---|---|---|
| Radio property | Footprint | △ | ○ | ◎ | ◎ |
| | Diffraction property | △ | △ | ◎ | ◎ |
| System property | Radio wave interference | △ | ◎ | ○ | △ |
| | Throughput | ◎ | △ | △ | × |
| | Multi-hop | ○ | △ | ○ | △ |
| | Low power consumption | × | × | ◎ | ◎ |
| | Transmission delay | ◎ | △ | ○ | △ |
| Operability | Communication cost | ○ | × | ○ | ○ |
| | Compatibility with IP system | ◎ | ○ | △ | △ |
| Comprehensive judgment | | △ | △ | ◎ | ○ |

### 2.5.3 Characteristics of the Recently Developed System

The system we have recently developed offers high reliability supported by a full mesh network and while enabling operation for 10 years by batteries, thus saving electric power. Especially, the receiver-driven intermittent drive method (beacon method), combined with a distance vector routing protocol, delivers unconventional power saving and a highly reliable metering network.[2]

#### a) Intermittent Operation (Receiver-driven Method)

It is crucial to reduce power consumption for battery-operated U-Bus Air units; we chose an intermittent operation approach (refer to Figure 3). As the units are all battery-driven, the units are in operation for only a short time compared to the time in sleep mode, and so the average power consumption is extremely small (Figure 3 ①). Each wireless unit transmits a signal called a beacon, which contains a code identifying a particular wireless unit, during operation (Figure 3 ②). When transferring data, the wireless unit enters into a continuous reception mode (Figure 3 ③), receives beacons from surrounding wireless units, and finds a transmittable counterpart, then transfers data by specifying the destination. This method ensures reliable data transmission (Figure 3 ④).

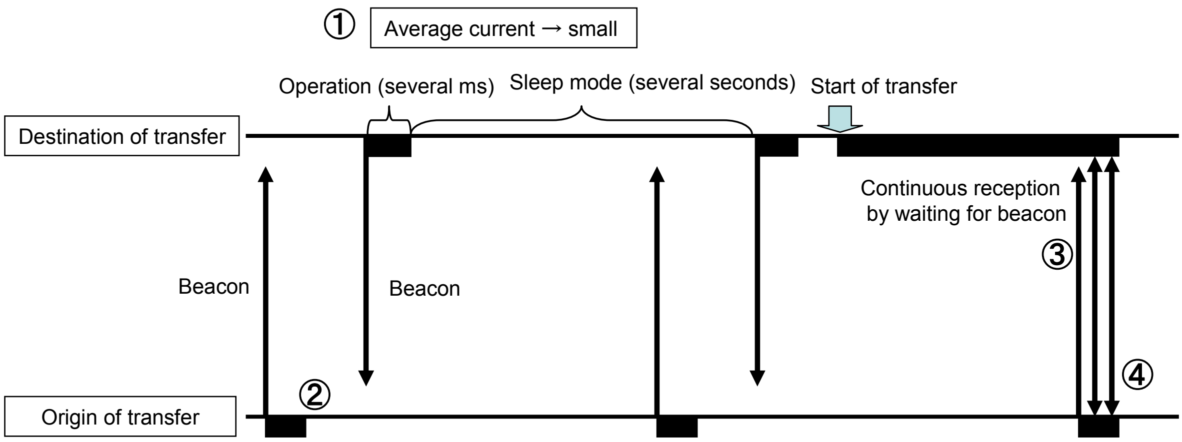


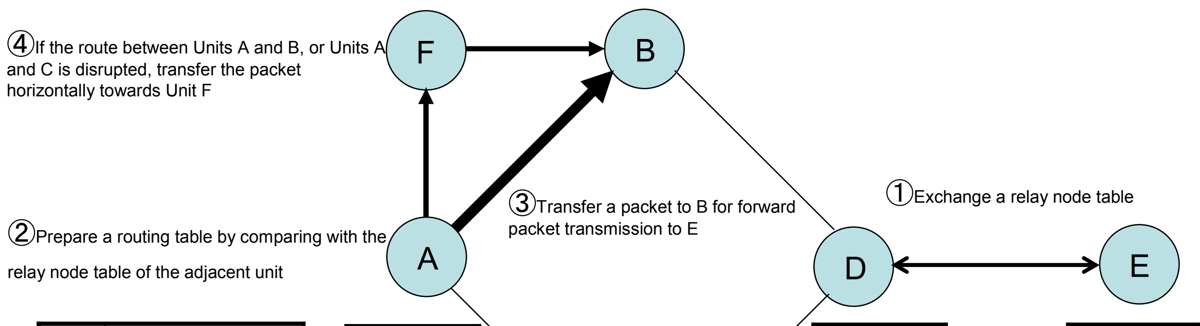

Figure 3 Intermittent Operation Method

**b) Routing Protocol (Distance Vector Type)**

As this method is based on the multi-hop transfer, each wireless unit performs transit processing of packets. The proposed system is called a distance vector routing protocol by which all the wireless units 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 terminals is limited. However, the present system is effectively applied to a wireless network by comparing the number per network with the operating environment and setting the number appropriately (up to 50 units per network).

In this method, each wireless unit prepares a relay node table by exchanging the table with adjacent wireless units (Figure 4 ①). Then, each unit compares its own relay node table with that of the adjacent unit and prepares a routing table (Figure 4 ②). When sending a packet, the unit refers to its own routing table, and transfers the packet to the forward adjacent unit and thus performs packet transmission (Figure 4 ③).

In this process, reliability is enhanced by using a routing protocol which can flexibly select a detour route other than the minimum hop route. When Unit A transmits data to Unit E in Figure 4, Units B and C are the forward adjacent units. However, if Unit A temporarily cannot transfer a packet of data to Units B and C such as due to the radio wave conditions, Unit A gives up transferring a packet of data to Units B and C whose beacon it cannot confirm, and instead transfers the packet to Unit F whose beacon it can confirm by detouring, and thus Unit A can transfer the packet to Unit E, which is the destination of the packet transmission (Figure 4 ④).




| Destination | Adjacent units | | |
|---|---|---|---|
| | B | C | F |
| A | - | - | - |
| B | F | B | H |
| C | B | F | B |
| D | F | F | H |
| E | F | F | H |
| F | H | B | F |

Routing table of Unit A

| Destination | Number of nodes |
|---|---|
| A | - |
| B | 1 |
| C | 1 |
| D | 2 |
| E | 3 |
| F | 1 |

Relay node table of Unit A

| Destination | Number of nodes |
|---|---|
| A | 2 |
| B | 1 |
| C | 1 |
| D | - |
| E | 1 |
| F | 2 |

Relay node table of Unit D

| Destination | Number of nodes |
|---|---|
| A | 3 |
| B | 2 |
| C | 2 |
| D | 1 |
| E | - |
| F | 3 |

F:Forward
B:Backs
H:horizontally towards

Figure 4 Routing Protocol

## 2.6 Field Test

### 2.6.1 Environment of Field Test

A field test was carried out by installing terminals in condominiums in order to evaluate the communication performance of the U-Bus Air units described in the preceding section. The terminals were installed in pipe shaft (hereafter “PS”) in the proprietary areas of the condominiums. PS configurations were diverse, ranging from semi-open corridors and inner corridors to staircases, etc. because the prescribed communication performance must be ensured regardless of the PS configuration. Therefore, the field test was performed at four types of condominiums with different PS configurations.

Table 3 Outline of the Condominiums

| Building | Number of stories | Number of apartments | PS configurations |
|---|---|---|---|
| A-1 | 10-story | 100 apartments | Semi-open corridors |
| A-2 | 5-story | 43 apartments | |
| B-1 | 4-story | 24 apartments | Inner staircases (shared PS) |
| B-2 | 9-story | 45 apartments | Inner staircases (individual PS) |

●Building A-1

●Building A-2

●Building B-1

●Building B-2

●Building A-1　PS

●Building B-1　PS

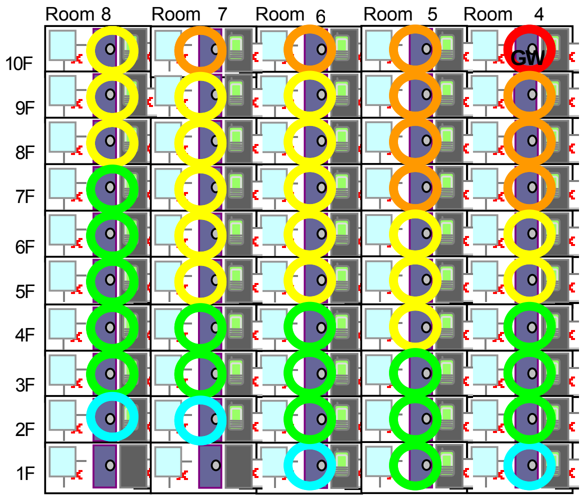
Figure 5 Views of Condominiums and Installation Conditions of Pipe Shaft

### 2.6.2 Automatic Network Construction Function

The results of evaluating automatic networking by installing U-Bus Air units in the PS of the condominiums listed in Table 2 were as follows.

The characteristics of each function are shown as the evaluation results for the units installed in the condominiums. In the case of building A-1 where 48 wireless units were installed in the PS of a 10-story condominium, it was confirmed that a mesh network was automatically constructed by 4 nodes of communication and that 48 meters were appropriately covered (Figure 6). Also in other cases, it was confirmed that mesh networks were automatically constructed. Circled numbers stand for the number of nodes from the gateway (GW).

●Building A-1




●Building B-1

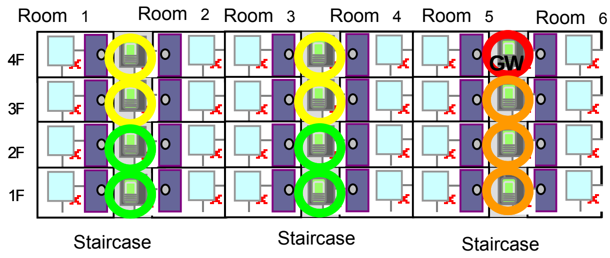



Figure 6 Example of number of hops of networks

### 2.6.3 Function of Automatic Selection of Communication Route

A confirmation test of communication routes during communication among the U-Bus Air units was carried out in the condominiums listed in Table 3. Detailed data analysis revealed some cases where a different route was selected in the outward and homeward routes. This shows that the units search for a suitable route on a case-by-case basis and that they can flexibly respond to the ever-changing environment of wireless communications (Figure 7). As these results suggest, it was confirmed that a mesh network was automatically constructed, and thus a highly reliable and stable metering network was built by autonomous routing.

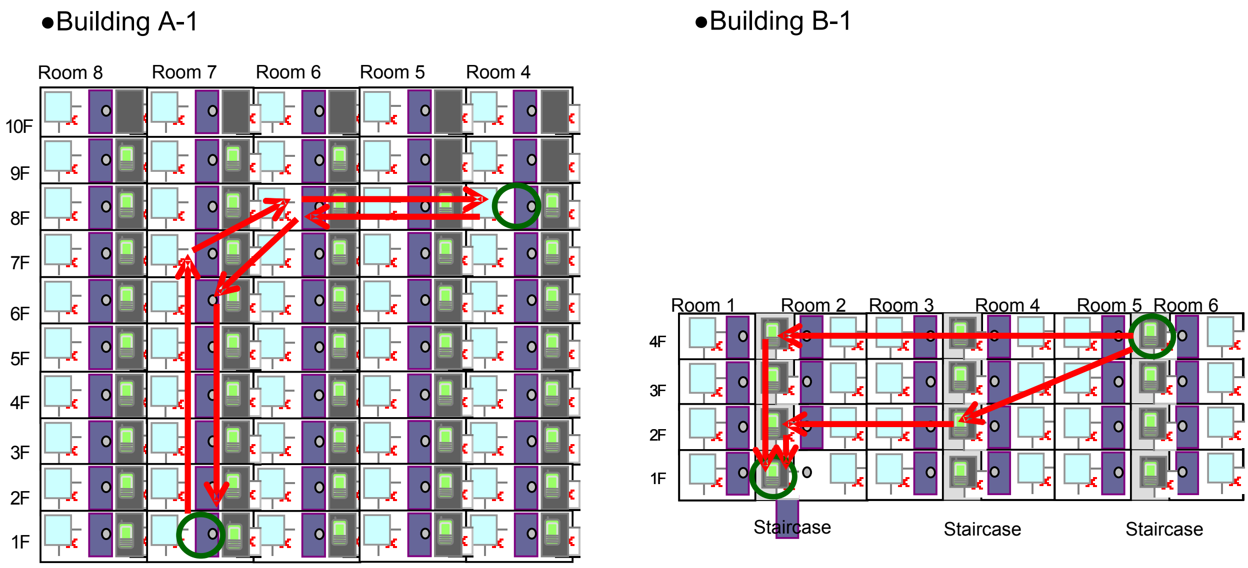



Figure 7 Analysis Results of Communication Routes

## 2.7. Standardization

Figure 8 shows our efforts for standardizing the technologies related to the Ubiquitous Metering System. As the new system not only helps to unify the communication specifications in the 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 an NPO Japan Utility Telemetering Association (of approximately 70 companies and organizations). As a result, U-Bus and U-Bus Air were decided to be the standards. This result of standardization was reported to the Ministry of Internal Affairs and Communications by JUTA. Also, a proposal was submitted to the Institute of Electrical and Electronics Engineers (IEEE) which provides international standards regarding the standardization of technologies of the physical layer of U-Bus Air and a part of the MAC layer, and thus we have been actively involved in the global effort to standardize smart meters.

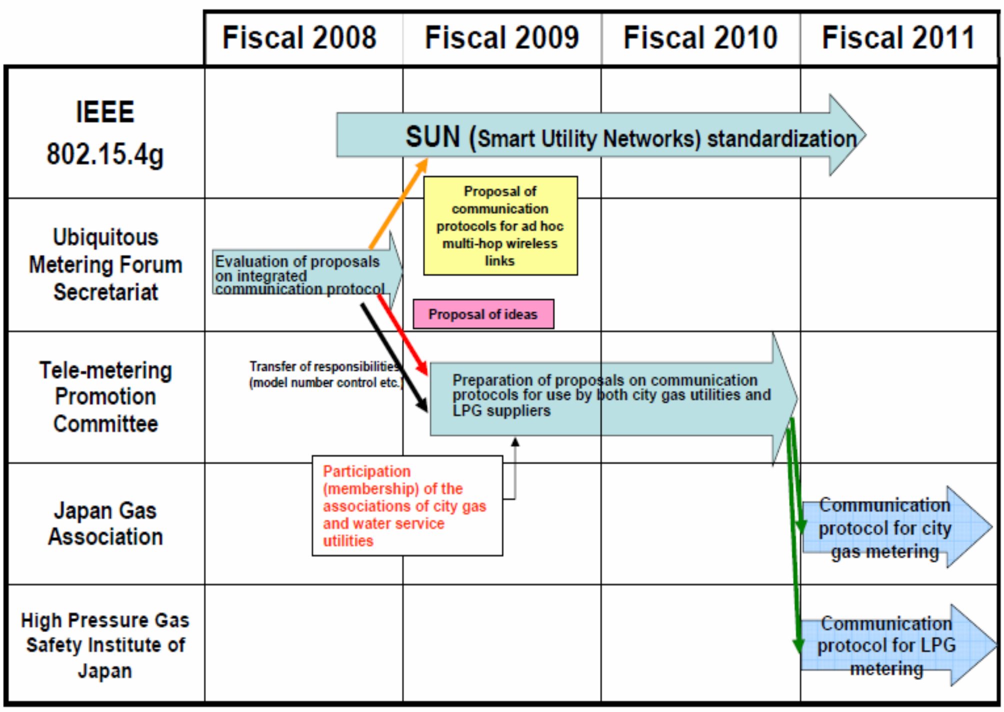



Figure8　Direction of Standardization of Technologies

## 2.8. Conclusion

This paper presented the characteristics of U-Bus Air units, which are one of the components of the next-generation gas metering system, and the results of field tests carried out in condominiums.

U-Bus Air succeeds in reducing power consumption while improving reliability by adopting intermittent operation (Receiver-driven Method) and Distance Vector routing protocol. The results of the field test carried out in the condominiums confirmed that the functions to automatically construct a network and to automatically select communication routes work effectively.

## 3. References

[1]”Smart Meter System”,Triceps Co.,Ltd.
[2] HATAUCHI Takaaki, FUKUYAMA Yoshikazu, ISHII Misato, SHIKURA Tatuyuki,” A Power Efficient Access Method by Polling for Wireless Mesh Networks”, The transactions of the Institute of Electrical Engineers of Japan. C, A publication of Electronics, Information and System Society 128(12), 1761-1766, 2008-12-01

## 4. List Tables



## 5. List of Figures