DEVELOPING ADVANCED METERING
(THE UBIQUITOUS METERING SYSTEM)

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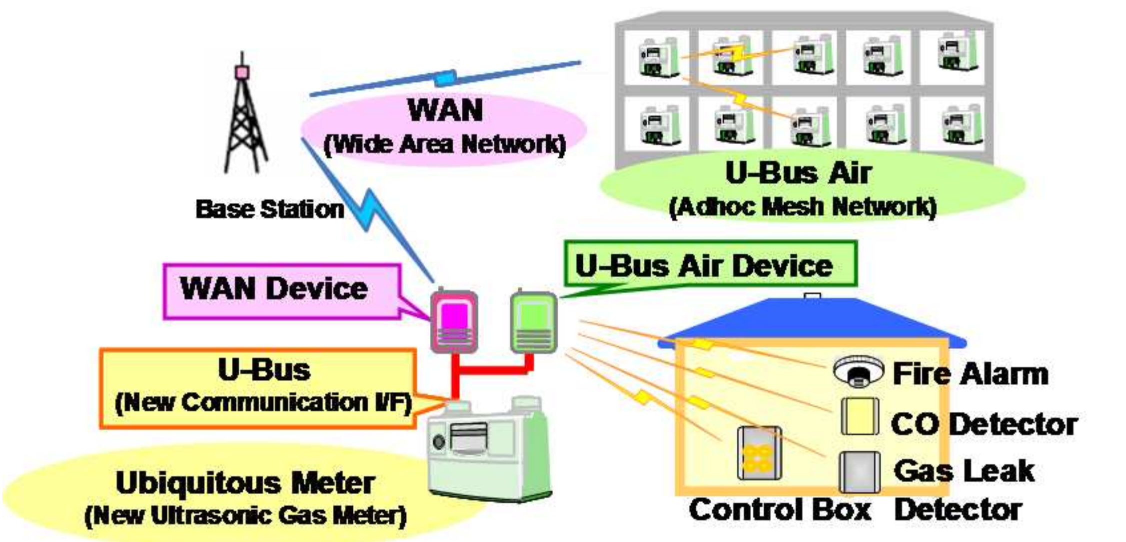
Summary

Smart meters and advanced metering infrastructure (AMI) are one of the hottest trends in the energy sector today, with many of the world's utilities considering installing this novel metering system. Smart metering offers practical benefits, such as demand side energy management, visualization of customers' energy usage, reduction of meter reading costs, and reduction of carbon dioxide emissions. Although smart meters have outstanding development potential, the main requirements remain the same: low operating and device costs, rugged measurement, and stable continuity of meter reading. In Japan, meter reading systems are typically based on public switched telephone networks and therefore are very reliable. However, as the Internet infrastructure and cell-phones continue to spread, the number of telephone line users has fallen dramatically, making it difficult for Japan's gas utilities to continue to provide the automatic meter reading (AMR) service for the market.

To overcome this obstacle, Tokyo Gas, Osaka Gas and Toho Gas, which have strengths in computerized gas meter technology, launched a joint project to develop a highly reliable, cost efficient, next-generation smart gas metering system called Ubiquitous Metering System, in collaboration with Japan's three leading meter manufacturers (Aichi Tokei Denki, Toyo Gas Meter and Yazaki Corporation), top three electronics makers (Panasonic Corporation, Toshiba Corporation and Fuji Electric Holdings), and Japan's largest carrier, NTT. Our novel AMI is composed of three main components: 1) a WAN device for connection to wide area networks, 2) ad-hoc mesh networks (U-Bus Air), and 3) ultrasonic smart gas meters with a next-generation communication port (U-Bus).



Ubiquitous Metering System

Ultrasonic smart gas meters
(Left: Aichi Tokei Denki, Center: Toyo Gas Meter, Right: Yazaki Corporation)

The technical specifications of the Ubiquitous Metering System including the smart gas meter, U-Bus Air, and WAN devices, have already been established, and corresponding devices are now being developed, field tested, or at the pilot installation stage prior to mass production. We believe that the Ubiquitous Metering System will soon provide an excellent next-generation AMI capable of meeting various demands in the utility sector.

1. INTRODUCTION

In order to reduce the risk of gas-related accidents, Japan's gas utilities started deploying microcomputer-controlled gas meters called "Micom Meters" for residential customers in 1983. In addition to a measurement function, the Micom Meter has various safety functions such as a shutoff function, which is activated in the event of a major earthquake or abnormal gas flow. In view of these capabilities, the installation of safety functions for residential customers was made compulsory by law in 1997, and now almost 100% of residential gas meters are Micom Meters. More recently, Japanese gas utilities have started to offer value-added services and automatic meter reading (AMR) using Micom Meters with a communication function. These Micom Meters have a 10-year lifespan, as Japanese regulations require that the measurement accuracy of residential gas meters be certified every decade.

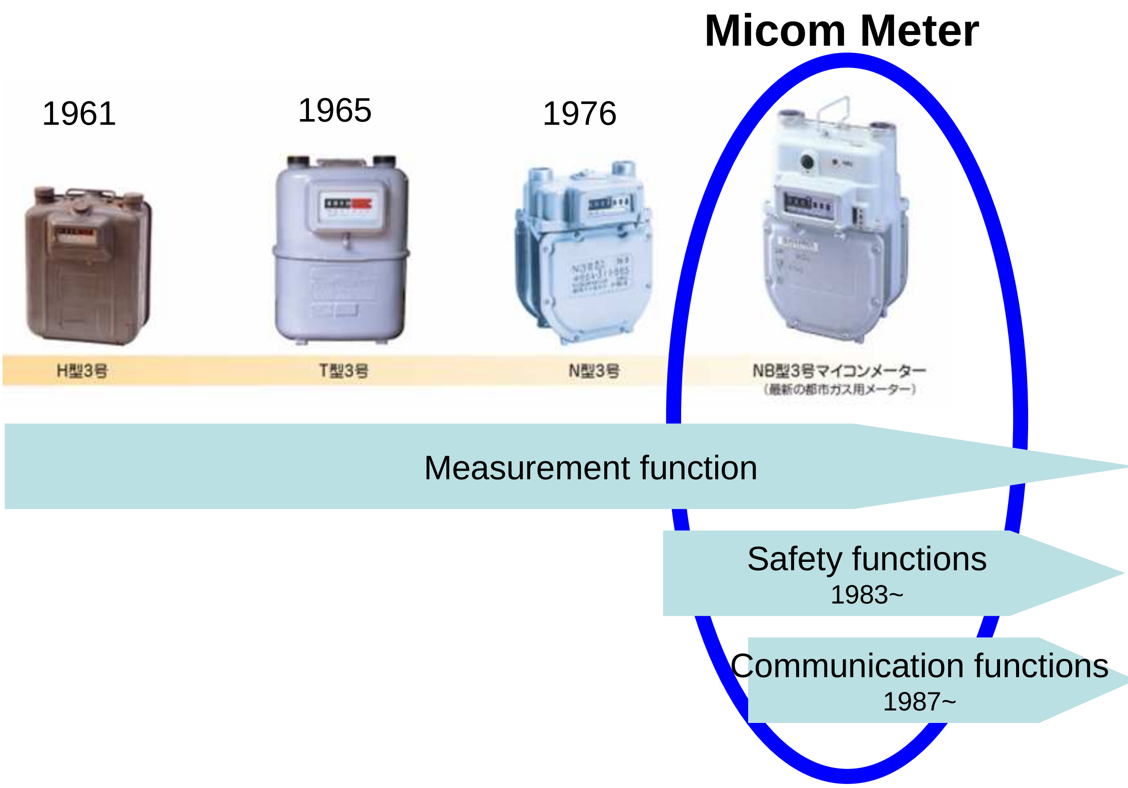


Figure 1: History of domestic gas meters in Japan

To raise the competitiveness compared to other energy providers, facilitate business development and address the needs of an increasingly environment-conscious public, there is a growing need for high-performance smart gas meters that are also economical, offer more advanced services, and are compatible with the network society. Since these objectives are difficult to meet with the conventional existing diaphragm meters, we have been developing intelligent residential ultrasonic gas meters with multiple functions.

The ultrasonic gas meter is characterized by a simple structure with no mechanical moving parts, and compared with the diaphragm type microcomputer-controlled gas meter currently dominant in Japan, is expected to offer the advantages of being more compact, lighter, and cheaper. In addition, by using the meter's wide measurement range and ability to measure instantaneous flow rate, we can provide an environment that allows customers to use gas more safely, by improving the various unique safety functions built into the microcomputer-controlled meters.

Tokyo Gas started installing the first-generation ultrasonic gas meter for commercial use in July 2005 as an early pilot program. Five years of pilot testing more than 40,000 ultrasonic gas meters have shown that the meter is not only highly reliable but can also compete on cost with the conventional diaphragm type micom meter with a communication function.

During the pilot program, we developed the second-generation ultrasonic smart gas meter, which has many features such as U-Bus, a next-generation communication port, and upgraded safety functions. In October 2010, we started installing more than 25,000 meters for pilot testing, and plan to check the reliability of the second-generation meters by 2012.

2. MICOM METER

In order to reduce gas accidents, Japanese gas utilities developed Micom Meter, the meter controlled by micro computer.

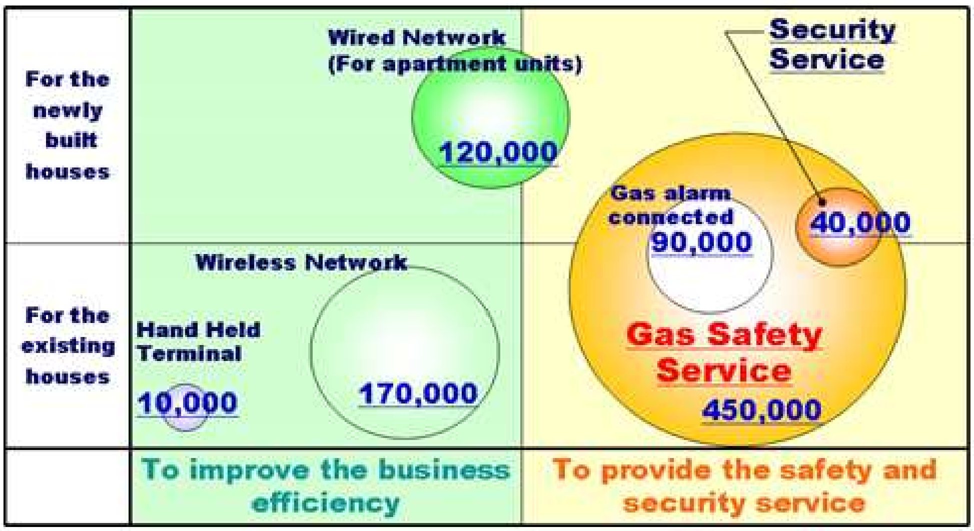
- Year 1983: equipped with safety function, shutdown functions using internal shut-off valve
  - ✓ Seismic
  - ✓ Unusual gas flow
    - ✧ Huge gas flow
    - ✧ Constant flow continuing for a long time
  - ✓ Low pressure
  - ✓ Warning function; gas leak detection more than 3 L/h continuing for a month
- Year 1990: equipped with communication function, low power consumption(300bps)
- Year 1998: equipped with bi-directional valve, remotely Open / Shut-off enabled

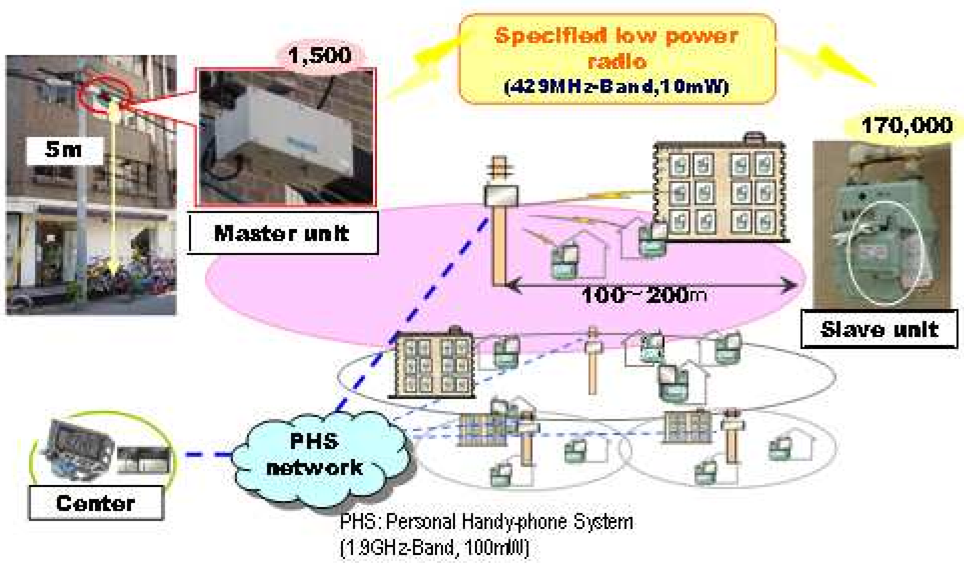
Figure 2: Structure of diaphgram type micom meter

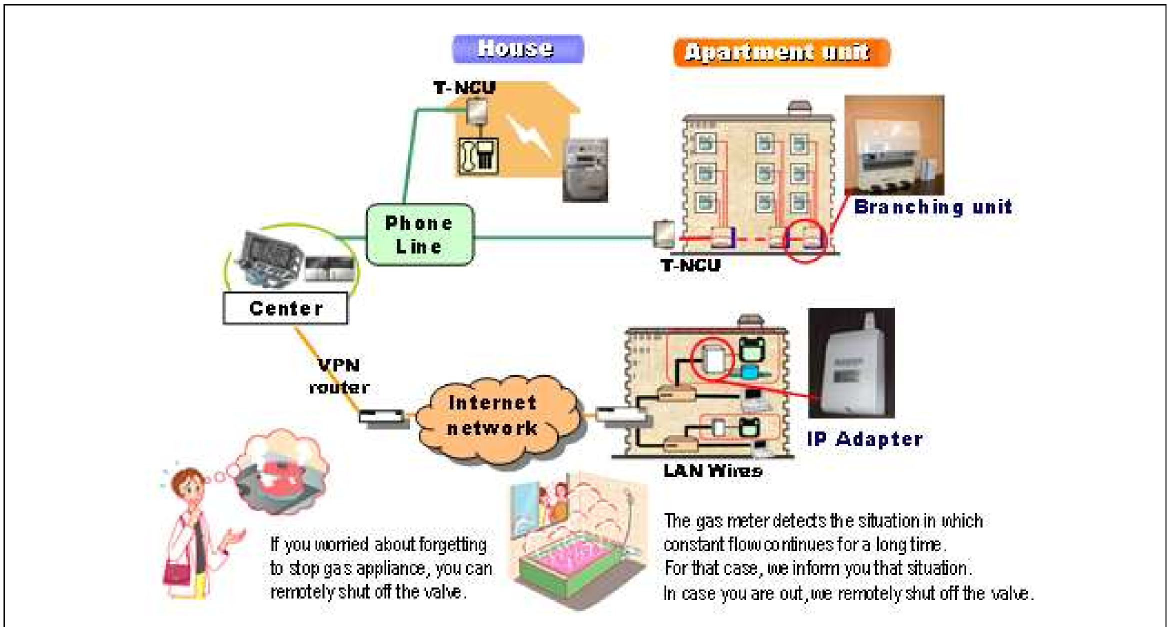
3. CURRENT AMR SYSTEM IN JAPAN

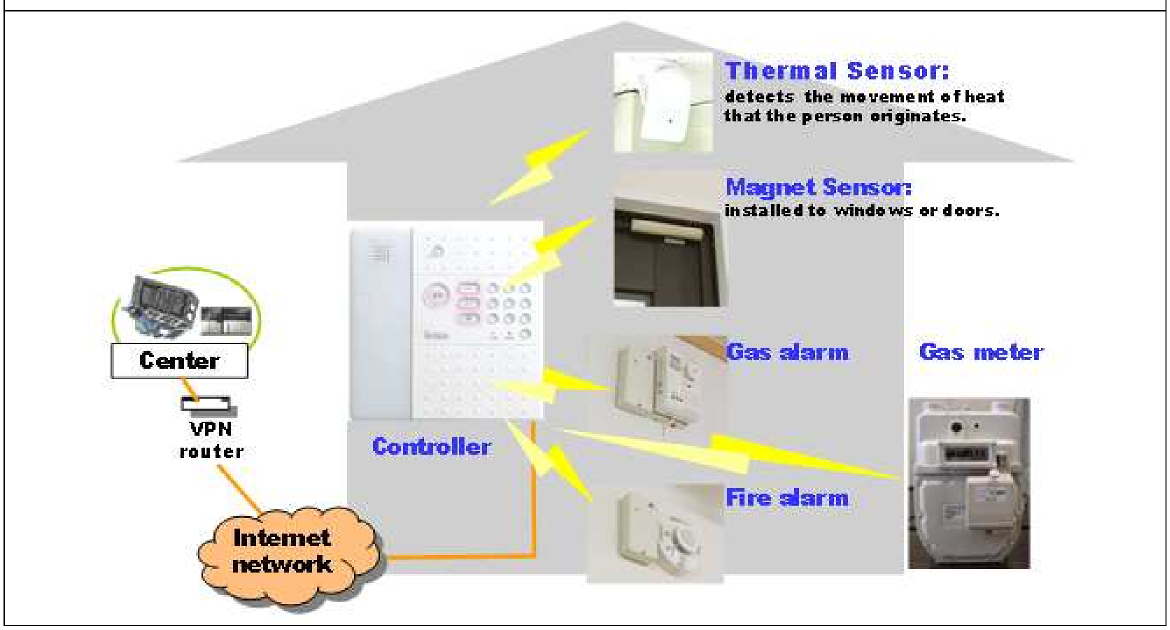
Japanese gas utilities started an automatic Meter-Reading in 1990, which is widespread to more than 1,2 million now. There are 2 objectives to install AMR.

- To improve the business efficiency: in some areas a lot of meters are set up inside the house and their index are hard to be read. In other areas many customers tend to delay due date for payment. To improve the business efficiency, area-wide AMR(Automatic Meter Reading) network is applied for these areas.
- To provide the safety and security service;
  - Gas Safety Service: we connect our computer server with the gas meter through the phone line or Internet network, and are providing service that remotely stops the gas supply according to customer needs for a fee; and
  - Gas Safety and Security Service: for 40,000customers, we connect our computer server with not only the gas meter but also thermal sensor, magnet sensor, gas alarm etc., through the Internet network, and are providing the home security service.









4. PROBLEMS WITH THE EXISTING AMR

The existing AMR has two major problems. Firstly, with the growing variety of fixed telephone lines, the sharp increase in the number of internet users and the expanding popularity of wireless broadband connections, it will become increasingly difficult to ensure stable metering services that rely on shared use with customers' telephone lines. Even though mobile phone networks such as 3G and PHS could be used as an alternative, these commercial wireless communication services have the following drawbacks:

- Rapid evolution of communication technologies leads to a wider variety and shorter life of communication infrastructure;
- They are more expensive than fixed telephone services; and
- With wireless communication methods, it is difficult to achieve a battery life of 10 years.

Secondly, a single-hop network configuration is used since the specified low-power radio station equipment used with the existing AMR is too slow in data transmission (2400 bps) for a multi-hop network configuration. However, there is an urgent need for the greater flexibility of a multihop wireless network and the capability of such a network to interact with various sensors. This is due to the growing number of mid-rise and high-rise condominiums with automatic entrance locks and of reinforced concrete buildings whose walls tend to block radio waves. There is also a growing demand for energy conservation support services and remote monitoring services for safety and security, which need to be supported by better technologies.

5. CONCEPT OF THE UBIQUITOUS METERING SYSTEM

To address problems with the existing AMR, the major city gas utilities of Japan, communication service providers, wireless equipment manufacturers and meter manufacturers have discussed the specifications of the next-generation AMI, which is referred to as the Ubiquitous Metering System (UMS).

Figure 3 illustrates the UMS concept. It comprises: (1) Wide Area Network (WAN) devices; (2)ad hoc mesh networks; and (3) ultrasonic gas meters interfaced with a next-generation communication line (called U-Bus).

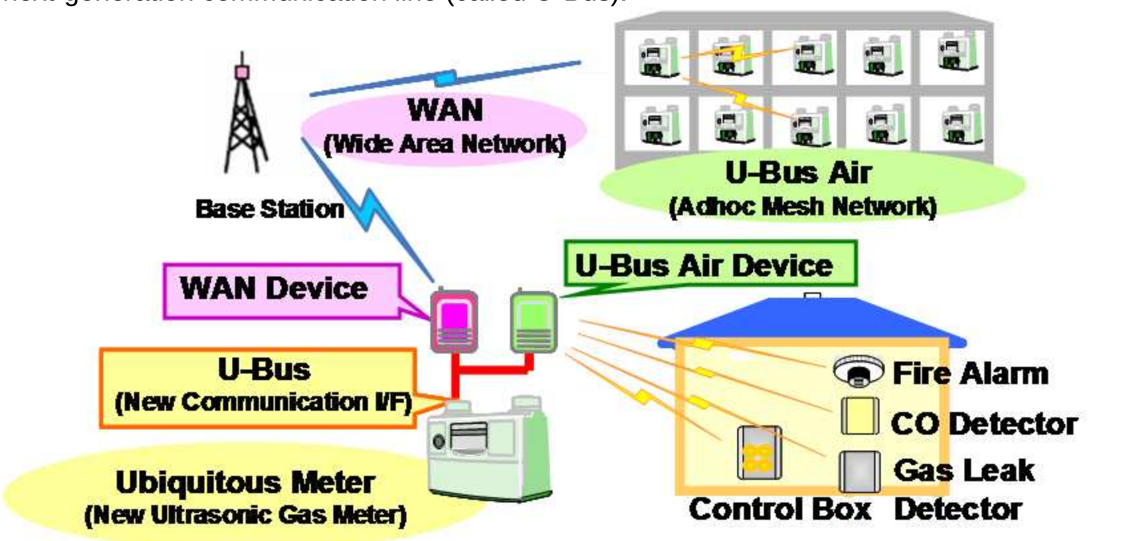


Figure 3: Concept of the Ubiquitous Metering System

6. AD HOC MESH NETWORKS (U-Bus Air)

Ad hoc mesh networks are short-distance wireless networks used for multi-hop relaying of metering data from gas meters outside the WAN service area to a WAN device.

They allow highly flexible multi-hop wireless communication with devices that consume little power. Data transfer by these networks is very reliable because the data are automatically rerouted if a wireless device fails or in the event of adverse conditions for the transmission of radio waves. Automated network configuration simplifies device installation. Table 1 lists the specifications and features of ad hoc mesh networks.

Table 1: Specifications and Features of Ad hoc Mesh Networks

Device	Frequency band	920 MHz (Japan) or other
	Standards	ARIB STD-T108 IEEE802.15.4g PHY (after standardized)
	Output power	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	Average: 5 hops, Max.: 15 hops
	Number of nodes	Max. 50
	Number of meters	Max. 50 (1/node)
Others	Routing features	Automatic routing, route diversity
	Network construction	Easy association with magnetic reed switch

Ad hoc mesh networks are now being fieldtested, with some of the results as follows.

Figures 4 and 5 illustrate the results of field tests in which data communication was attempted after installing 48 ad hoc mesh network devices in the piping shaft compartments of different rooms in a 10-storey multi-household residential building.

Figure 4 shows the number of hops required to access each room at the time of communication from the terminal marked by the red circle to the terminals of each household. The graph on the left shows communication that required a maximum of four hops while that on the right shows communication that required a maximum of three hops.

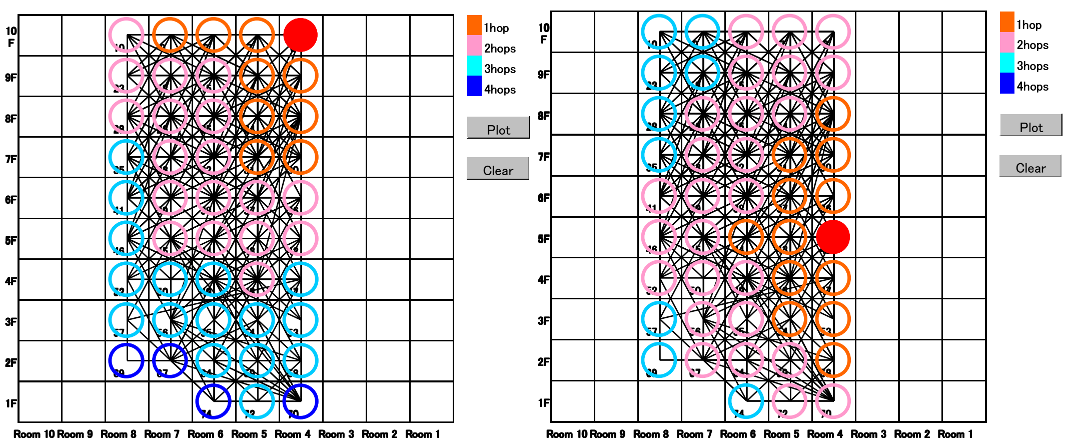


Figure 4: Field tests of ad hoc mesh networks – Number of hops required

Figure 5 shows the routes for incoming data in red and outgoing data in blue. The route for outgoing data may differ from that for incoming data. The route for outgoing data shown on the right indicates a retry operation, where data returned to the original terminal and then were transmitted to another terminal. These test reports demonstrate the terminals' automatic rerouteing capability. This results in high reliability of data transmission because data are automatically rerouted if a wireless device fails or if there are adverse conditions for the transmission of radio waves.

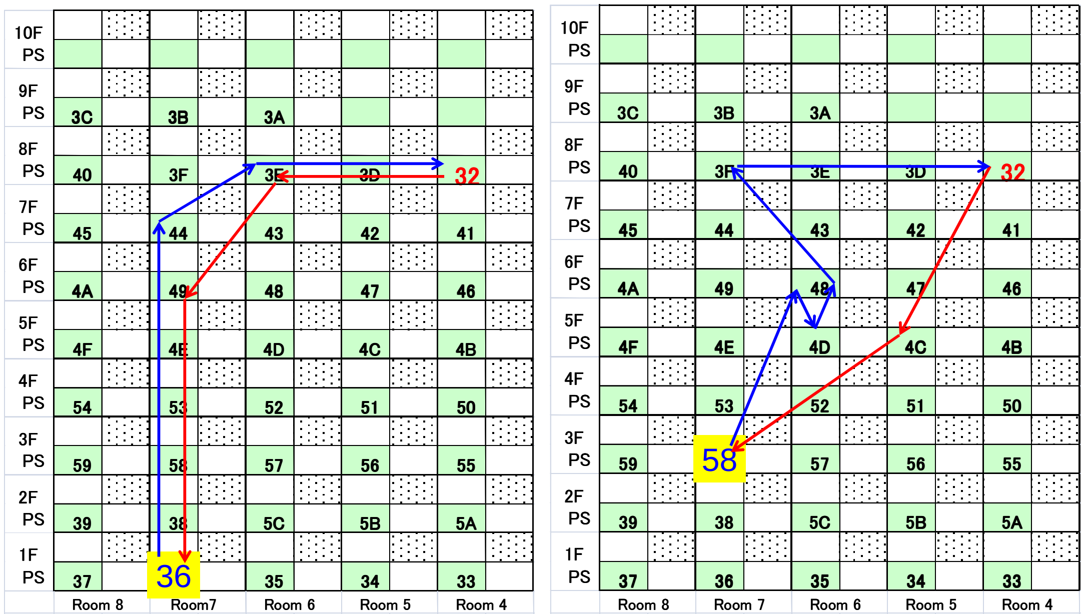


Figure 5: Field tests of ad hoc mesh networks – Data routes

7. Ultrasonic meters interfaced with a nextgeneration communication line

Ultrasonic gas meters are electronic meters that measure flow using the propagation time difference method. Compared with conventional diaphragm meters, the size is about one-third and the weight is almost half, making these meters more compact and better looking. Moreover, with greater communication compatibility and a more powerful CPU, they are capable of supporting new services and business-oriented uses.

Tokyo Gas , Osaka Gas and Toho Gas collaborated with meter and electronics manufacturers to develop these ultrasonic gas meters, and started installing them in fiscal 2005.

Ultrasonic gas meters for the next-generation communication line (U-Bus) are now being developed. Major components include a pair of ultrasonic sensors, battery, controller, shutoff valve, pressure sensor and seismic sensor.

7.1 DEVELOPMENT CONCEPT

The new ultrasonic smart gas meter provides further functional improvements and cost reductions, as well as superior metering and safety functions compared to the existing diaphragm type Micom Meters. The development objectives for the new ultrasonic meters were as follows:

- New Services and New Businesses
  The meter should allow the provision of new services using communications technology in view of future business possibilities.
- Improved Safety Functions
  For the customer's convenience, there should be a function for quickly and correctly assessing safety, based on measuring the instantaneous flow rate, to increase the safety compared with diaphragm meters.
- Reduced Size and Weight
  The space required for meter storage and installation should be reduced, which would enhance business competitiveness. Customers and housing suppliers also want better-looking gas meters.
- Wide Range of Capabilities
  In Japan, gas meters must be able to detect even tiny gas leaks as well as an

abnormal huge gas flow, which are very rare events. Although the legally required measuring range is 80 L/h to 6,000 L/h, a range of 3 L/h to 12,000 L/h needs to be assured in order to provide the same high level of safety as conventional diaphragm gas meters.

- Shared with Propane Gas Metering
  The basic measurement parts should be the same as those of propane gas meters, of which there are nearly 25 million units in Japan, thus offering a broader market for our ultrasonic meters and reducing associated costs.

7.2 MEASUREMENT PRINCIPLE

To design the ultrasonic gas meter, we employed the established ultrasonic meter principle, "Repetitive Inverse Transit Time Difference Method". Two ultrasonic sensors face each other across the gas flow passage as shown in Figure 2.

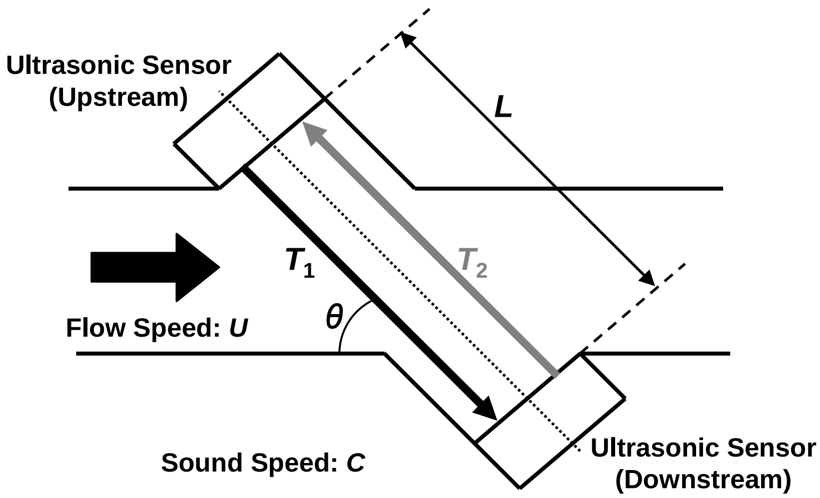


Figure 6: Measurement principle

Ultrasonic waves are initially sent from the upstream sensor to the downstream sensor, and the time taken to arrive (T_1) is then measured. Next, ultrasonic waves are sent in the opposite direction, from downstream to upstream, and the time taken to arrive (T_2) is measured. If there is no flow, there should be no time difference. With a flow speed of *U,* however, these two times will differ: T_1 will be smaller and T_2 will be larger than those without flow.

The speed of the gas flow (*U*) can then be calculated from the difference between the two times taken for the ultrasonic waves to arrive, using the three principal equations:

$$T_1 \approx \frac{L}{C + U\cos\theta} \qquad (1)$$

$$T_2 \approx \frac{L}{C - U\cos\theta} \qquad (2)$$

$$\therefore U \approx \frac{L}{2\cos\theta}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \qquad (3)$$

7.3 SPECIFICATIONS

The specifications of the ultrasonic gas meter are shown in Table 1. Along with several safety functions which were already installed in the conventional diaphragm meters, our ultrasonic smart gas meter has been designed with self-diagnostics functions which are a unique characteristic of smart gas meters. These self-diagnostics functions can detect ultrasonic sensor errors so that the meter can be replaced while its safety is still of a sufficient level.

Table 2: Specifications

<table>
<tr><td>Maximum flow rate</td><td colspan="2">6 m^3/h</td></tr>
<tr><td>Minimum flow rate</td><td colspan="2">80L/h</td></tr>
<tr><td>Detectable minimum leak</td><td colspan="2">3L/h</td></tr>
<tr><td>Operating temperature</td><td colspan="2">-25 – 60ºC</td></tr>
<tr><td>Operating pressure</td><td colspan="2">0 – 3.5kPa</td></tr>
<tr><td>Size</td><td colspan="2">170mm (Width) x 100mm (Depth) x 140mm (Height)</td></tr>
<tr><td>Weight</td><td colspan="2">Approx. 2kg</td></tr>
<tr><td>Pressure loss (air)</td><td colspan="2">< 190Pa at 6m^3/h</td></tr>
<tr><td>Power supply</td><td colspan="2">Lithium batteries</td></tr>
<tr><td>Battery life</td><td colspan="2">10 years or more</td></tr>
<tr><td>Stepping motor valve</td><td colspan="2">Open/close 2-way valve</td></tr>
<tr><td rowspan="3">Communication port</td><td>U-Bus (9,600bps)</td><td>U-Bus Air device, WAN device, etc. are connected</td></tr>
<tr><td>300bps port</td><td>Devices for current AMR system are connected</td></tr>
<tr><td>Contact input port</td><td>Alert system is connected</td></tr>
<tr><td>Liquid crystal display</td><td colspan="2">

• Cumulative flow: 4 digits for m^3, 3 digits for liter
• Valve status: Open/Close
• Alert Indication: 5x5 dot matrix</td></tr>
<tr><td>Calendar & clock</td><td colspan="2">YYMMDD hh:mm:ss</td></tr>
<tr><td>Self-diagnostics functions</td><td colspan="2">• Low battery
• Ultrasonic sensor error
• Valve leakage</td></tr>
<tr><td>Safety functions</td><td colspan="2">• Seismic shutoff & self-reopen after automatic safety verification
• High/low pressure shutoff
• Abnormal huge flow shutoff
• Low leakage alert
• Abnormal long gas usage alert & shutoff</td></tr>
<tr><td>Daily profile</td><td colspan="2">Hourly gas consumption or gas pressure profile</td></tr>
<tr><td>Time based multilevel tariff</td><td colspan="2">Up to 3 time zones per day</td></tr>
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7.4 STRUCTURE

Figure 7 illustrates the configuration of the ultrasonic meter.

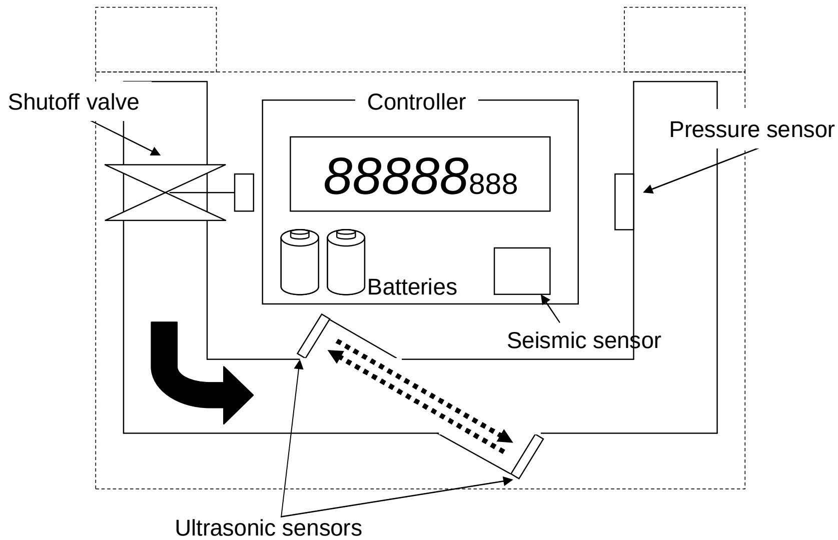

Figure 7: Structure

Major components, including the ultrasonic sensors, pressure sensor, shutoff valve and metering circuit, are shared between city gas and LP gas to reduce the cost through scale merits. The ultrasonic sensors, which are optimized for gas metering, are highly sensitive and are designed to run on a low voltage level. The long battery life of 10 years is achieved by combining these sensors with a low-power controller (microcomputer and metering circuit).

The motor-operated shutoff valve allows remote operation (opening and closing). Unlike solenoid valves, motor-operated valves are unlikely to fail due to external impact, thus minimizing the risk of unintended shutoff.

7.5 SMART FUNCTIONS

Communication functions

Our smart meter is equipped with U-Bus, a next-generation communication port. The specifications and advantages of U-Bus are listed in Table 2. It supports packet communication and 30 times faster transmission of data than the standard communication interface specifications of conventional city gas metering devices in Japan. This means that the new meter uses less energy for communication and so lasts several years longer. These are versatile specifications that support diverse configurations of WANs and PANs with wireless WAN devices, ad-hoc mesh network devices, etc. Since devices with the same communication interface can communicate over the bus, U-Bus will enable new services to be developed such as the control of appliances.

Table 3: Specifications and advantages of U-Bus

Layer	Specification	Description
Physical layer	Bus connection	• Allows shared use of various devices.
	High transmission speed (9600bps)	• Wider application and higher service level as a result of high-speed transmission • Approx. 30 times faster than the current port
Data link layer	Packet communication	• Improved bi-directional communication between terminals with different transmission speeds • More efficient use of communication links • Improved fault resistance
	Fixed packet length (104 characters per packet)	• Improved efficiency of data processing by terminals • Faster response (0.12 sec with each packet)
Network layer	Gateway function added to the meter	• Supports addressing in wide area networks and relayed wireless networks
	Simplified addressing	• Simplified terminal installation
Security	Encryption as a standard	• Improved access control and security protection

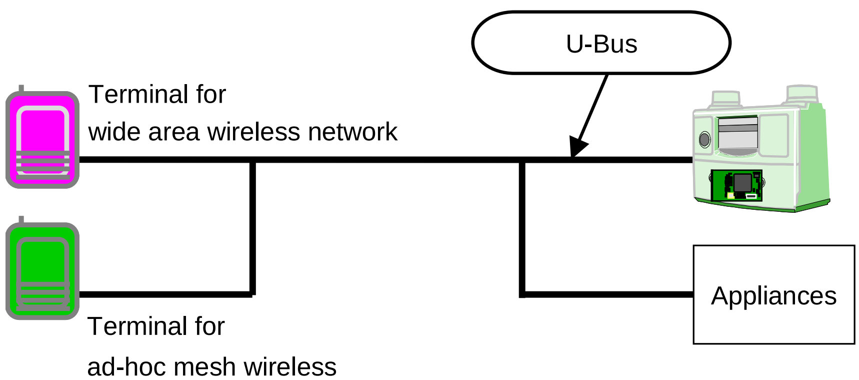

Figure 8: Connecting terminals using U Bus (example)

Safety functions

The ultrasonic gas meter comes with many unique safety functions developed in Japan. It can detect various situations such as leaks of more than 3L/h, unexpectedly large flows, continuous use for a long period, major earthquakes, and pressure drops in the gas supply. In accordance with the detected situation, the shutoff valve in the meter closes to cut off the flow of gas and an alarm is activated. To provide these safety functions, the meter has a shutoff valve, pressure sensor, and seismic sensor as shown in Figure 9.

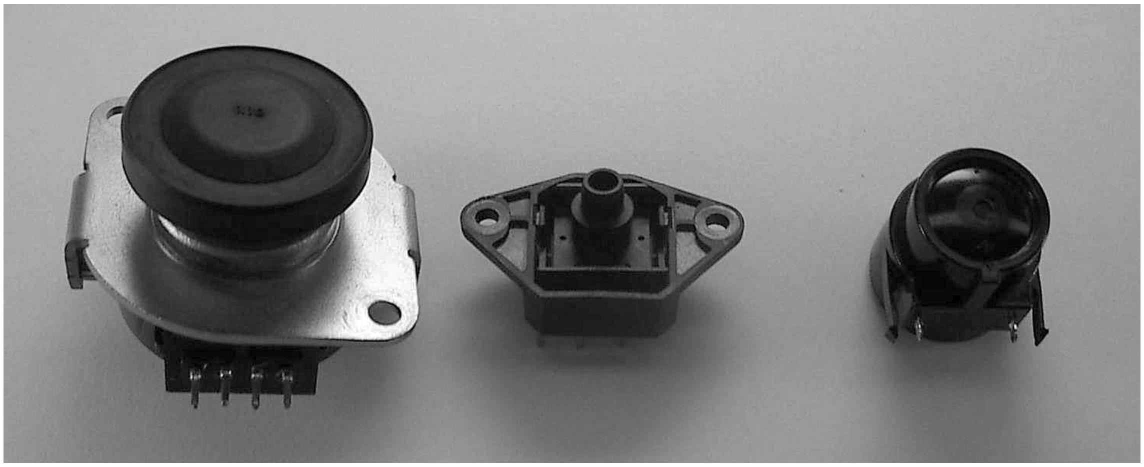

Figure 9: Safety components (from left: shutoff valve, pressure sensor and seismic sensor)

Each part has the following features.

- **Shutoff Valve**
  Shutoff valves are installed in the inlets of internal meters, and can open and close electrically. When the safety features of a meter detect an abnormal condition, the microcomputer on the controller generates a signal to close the shutoff valve. The shutoff valve can be opened by triggering it manually, or by remote control using telecommunications. Conventional microcomputer-controlled gas meters generally use a valve with an electromagnet, however for ultrasonic gas meters, shutoff valves using a stepping motor have been adopted. Hence, while in a conventional microcomputer-controlled gas meter, the shutoff valve can close by mistake if the meter is subjected to a powerful physical shock, this phenomenon is prevented in an ultrasonic gas meter.
- **Pressure Sensor**
  The pressure sensor monitors the pressure in the measuring passage, and responds to a rise or fall in pressure if the gas supply is obstructed. The measuring range is 0–5kPa, and the resolution is approximately 10 Pa. Since the shutoff valve has been installed in the inlet of the internal meter, when the shutoff valve is closed, the area downstream of the meter becomes a closed space. For this reason, when the closed shutoff valve is opened, we can confirm whether a gas leak has occurred by monitoring the pressure with the pressure sensor.
  The beauty of this sensor is that utilities like gas companies can open gas meters remotely without having to dispatch a maintenance engineer to the customer's site. Closing the valve remotely is no problem, but when opening the gas valve, normally it is necessary to check that there is no leak within the house, which means sending a maintenance engineer to the house. But with these sensors, after supplying gas to the house briefly by opening the valve and then closing it, this pressure sensor can detect the pressure drop in the pipe to see if there was any leakage before opening the valve, and also can control the shuttle valve when the pressure is higher or lower than it should be.
- **Seismic Sensor**
  When an earthquake of seismic intensity 5 or more is detected, a signal is sent to the microcomputer on the controller. Upon receiving this signal, the microcomputer sends a signal to the shutoff valve to close the valve.

8. FUTURE PLAN

The technical specifications of the Ubiquitous Metering System including the smart gas meter, U-Bus Air, and WAN devices, have been established. The corresponding devices are now being developed, field tested, or in the pilot installation stage prior to mass production. We believe that the Ubiquitous Metering System will soon provide an excellent next-generation AMI capable of meeting various demands in the utility sector.