Smart Metering based on Wireless Networks for Improved Water Management

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***Abstract*— In the field of water resources management, the application of Smart Water Grids (hereafter SWG) has rapidly gained traction as a popular method for achieving stable water supplies and minimizing the wasting of water. However, unlike the smart grids that have been applied to electricity and gas sectors, Smart Water Grids are more complicated due to the fact that water meters are typically installed under the ground making power supply and data transmission more difficult. This study takes full advantage of analog meters by using L(inductor)/C(Capacitor) sensors in the water meter counters for the purpose of developing various wireless communication methods in order to find an optimal transmission method. Wireless communication systems were examined according to their specific frequency environmental conditions to optimize the pipeline network operation and management.**

Keywords - Smart Meter; Smart Water Grid; Wireless Communication.

I. INTRODUCTION

Smart grid technologies are being studied actively for the efficient production and supply of energy against climate change and large-scale power shutdown [1-2]. In the field of water resource management, the popularity of smart metering systems is increasing based on their abilities to obtain water usage data in real time which are needed to ensure a stable water supply, reduce water treatment costs, and meet unexpected water demand increases.

The price of tap water is very low compared to the cost of electricity and gas in Korea, and the cost of installing mechanical water meters is relatively cheap. On the other hand, the use of mechanical type meters presents many challenges in terms of implementing real-time data transmission for smart metering. In addition, smart metering systems do not work well due to the additional constraints of difficult installation conditions which are much different from the electricity and gas sector [3-4].

In Korea, pipeline networks are mostly installed with the meters but they are very slowly developed. There is still work to be done so these networks become efficient and to the point where they can ensure the safety of water quality and the consistency of water pressure and structural integrity. Technical approaches, such as monitoring and sensor technologies and optimization techniques, are needed in order to overcome the weak points [5].

The concepts and technologies applied to achieve intelligent water distribution systems have sparked a global movement to maximize the efficiency and to optimize the operation of water distribution networks. Various systems are being developed by combining a variety of technologies like water quality and quantity sensors and pipeline network software. To achieve a sophisticated and intelligent operation and management distribution network, the most important priorities are real-time leak detection and water quality monitoring in cases of emergencies. Thus, the development of new types of meters, sensors and integrated operation systems should be developed using cutting edge information and communication technologies.

II. DEVELOPMENT OF SMART METERS

A device used in each home's water meter diameter 50mm or less can be classified into direct and indirect measurement. The indirect method depends on the rotation speed of the actual flow and the direct method measures the constant volume of water, which is used primarily for testing.

Half-electronic meters have the mechanical type of sensing and transmission to convert electrical signals, but do not have any internal microprocessors. There are two kinds of mechanical types of water meters. One of them is the pulse counting method which uses a lead switch and the other is the camera method which takes and sends photos, which through image processing, can be analyzed. A digital device should be equipped with a microprocessor in order to transmit real-time data.

An electronic water meter consists of sensors and additional indicators for flow measurement. The meter has a microprocessor which allows for internal data processing and storage by detecting electronic signals and displaying them in numerical values. A variety of electronic meters have been developed using lead switches, hall sensors, and magnetic sensors worldwide [6].

Electronic meters, in general, still have some limitations. For example, they are relatively expensive, frequently damaged, and their use might not be extended nationwide. Therefore, a half-electronic meter is considered as an alternative, which can use the robustness and cheap cost of the mechanical meter by adding a sensing unit. In addition, while preserving the advantages of an analog meter, it could transfer the data from three kinds of wireless transmitters, which are as follows: 424MHz Single, 424MHz Multi, and 2.4GHz ZigBee transmitter.

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A. Development and Performance Test of Flow Meters

Performance analyses for water meters were carried out empirically, and their impellers, upper plates and lower plates, nozzles and adjustment screws were the decisive factors for determining performance [7]. In case of calculating hourly flow from the meters to check their accuracy, the following equation should be applied to multiple their diameter and velocity.

$$Q = A \cdot V = \frac{\pi \cdot D^2}{4} \cdot V \tag{1}$$

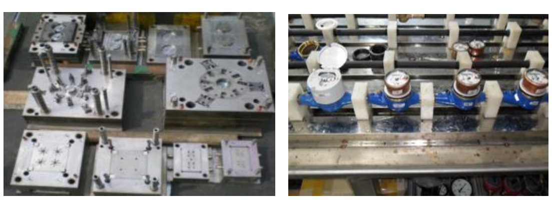
where, Q : flow(m^3 / h), A : pipe unit area(m^2)
V: Velocity(m / s), D: pipe diameter(m)

In case of the mechanical water meter, hourly flow was not used, but the integral flow was used instead in order to check the rotation of the impeller. Its equation is as shown in (2).

$$Q = \frac{1}{k} \cdot N \tag{2}$$

where, Q : integral flow(m^3),
k : criteria constant(rpm / m^3)
N: rotation speed of impeller

In this study, the final mold of the water meter was determined through 12 experiments to investigate the effects of measurement accuracy by each factor or combination of factors with each other. Finally, the mold for the water meter was completed like in Fig. 1.



(a) Final Mold (b) Water Meter

Figure 1. Overview of the Water Meter

The developed meter should transfer its data to a main receiving center through wireless communication. Fig. 2 shows that a sensing and communication module can be added to the water meter for transmission. The module can be used only as a mechanical meter as shown in the left figure, but if necessary, the special module can be added to transmit the sensed data by wireless communication as shown in the right of Fig. 2.

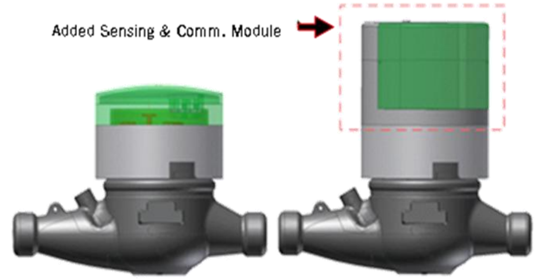


Figure 2. Configuration of Smart Meter

The sensing part of the meter adopts a L/C sensor in order to receive the data from the mechanical water meter on the bottom. Fig. 3 shows the configuration of the sensing coil and rotating plate. The L/C sensor is divided into two parts, which are metallic and non-metallic, to sense the variation of waves being rotated by the mechanical meter. Variations can finally be easily digitized and sent to remote sites.

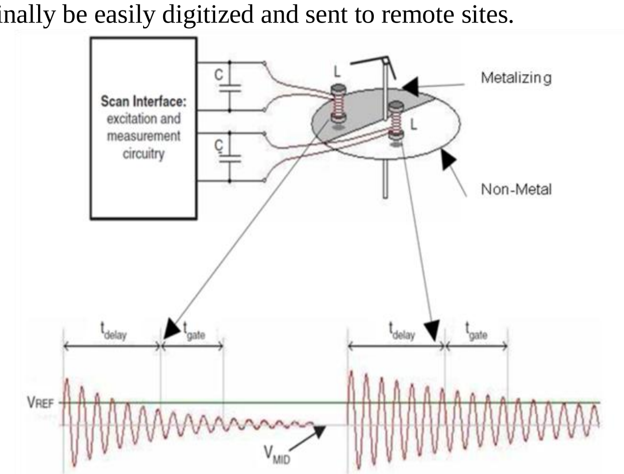


Figure 3. Configuration of Sensing Coil and Rotation Plate

The L/C sensor signal gives two data, as shown in Fig. 4. In case that the sensed level is lower than V_{ref}(Reference Voltage), it emits a signal value of zero which means it is going through a reflection panel. In case of a higher level than the reference voltage, it emits a signal value of one which means it is going through a non-reflector. Signal 1 has more voltage compared to the others owing to not having a reflection plate. Even though signals 2 and 3 have the same conditions as having a reflection plate, they have different attenuations which can be caused by their distance, size and material. Thus, signal 2 in the middle of the figure shows it senses one even in a reflection plate. To prevent this situation, the reference voltage has been designed to automatically change in order to compensate the error by the distance between the L/C sensor and reflection plate.

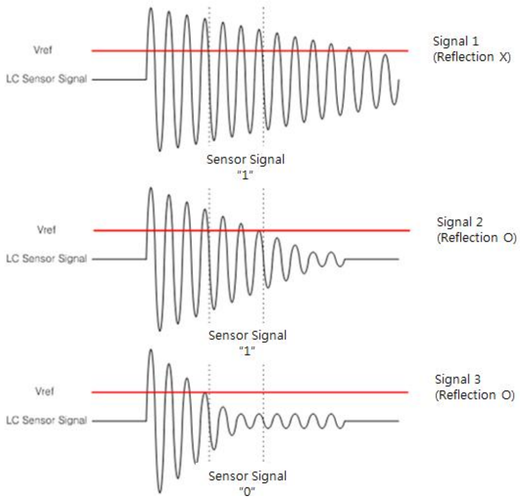


Figure 4. Sensor Signal from L/C sensor

B. *Development and Performance Test of the Transmitter*

In this study, three kinds of wireless communication methods, 400 MHz single-band, 400 MHz multi-Band, 2.4 GHz ZigBee were selected to find the optimal communication method by analyzing the communication characteristics of difficult water meter installation sites.

400 MHz Single-band adopts the module with a central frequency of 424.750 MHz and 2 level FSK modulation as shown in Table 1. In addition, 400 MHz Multi-Band applies the frequency range of 424.700 MHz ~ 424.950 MHz and channel spacing is 8.5 KHz, resulting in a module which has 20 channels. 2.4 GHz band ZigBee adopts the IEEE 802.12.3 standard module with O-QPSK modulation scheme and data rate of 250 KBPS, as shown in Table I [8].

At first, these three kinds of wireless modules, two 400 MHz band and one 2.4GHz band, are designed and manufactured through laboratory tests in order to guarantee stable transmission. Personal Data Assistant (PDA) was also developed with a specific inside module to receive transmitted data from the three modules for field testing. The PDA also has a special software program for monitoring data and analyzing communication environment from water meters, which makes it possible to conduct field tests with mobility and convenience.

The software, based on Win CE, has been designed to allow for selective input data such as weather, distance, location and cover type. Inputted and measured data are saved in the database to transfer to an analytic computer program, by which we can know the best results among the three modules. In Fig. 5, an image of the PDA screen shows the test program to input measuring conditions and calculate its transmission results. The image on the left side in Fig. 5 shows the parameter setting screen such as weather, position, distance, casing, and test number to do performance test. The image on the right side shows the results of a ping test. These tested data were accumulated in the database in order to analyze them.

TABLE I. CHARACTERISTICS OF WIRELESS COMMUNICATION

Type	Item		Specification
400 MHz Single -band	Front-End	Central Freq.	424.750 MHz
		Freq. Deviation	2.5 KHz
		Modulation	2 Level FSK
		Output	Less than 10 mW
		Sensitivity	-115 dBm
		ANT. Gain	Less than 2.3 dBi
	Comm. Method	Front-End	PWM
		Ext. I/F	UART 9600 BPS
400 MHz Multi -band	Front-End	Freq. Range	424.700 MHz ~ 424.950 MHz
		Freq. Deviation	2.5 KHz
		Modulation	2 Level FSK
		CH. Interval	8.5 KHz
		CH. Number	20 Ch
		Output	Less than 10 mW
		Sensitivity	-115 dBm
		ANT. Gain	Less than 2.3 dBi
	Comm. Method	Front-End	Manchester
		Ext. I/F	UART 9600 BPS
2.4 GHz ZigBee	Front-End	Freq. Range	2.4 GHz ~ 2.483 GHz
		Modulation	O-QPSK
		Data Rate	250 KBps
		Channel Num.	11 Ch ~ 26 Ch
		Output	Less than 10 mW
		Sensitivity	-85 dBm
	Comm. Method	Front-End	SPI
		Ext. I/F	UAT 115 KBPS

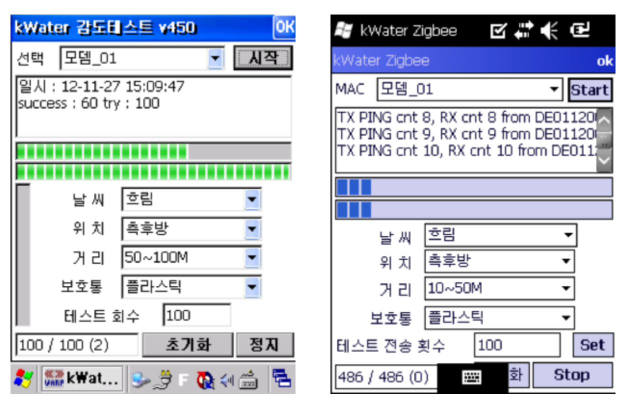


Figure 5. Operation Display of the PDA Program

Because the industrial PDA was designed for a low powered wireless communications (424MHz, 2.4GHz) module to receive data from smart meters, it was very easy to test the three kinds of developed modules by changing real distances, lab and open space environments, and then, field tests were carried out after each RF module was set to have the same performance. Table II shows each module's electric field strength and communication length using a spectrum analyzer.

TABLE II. ELECTRIC FIELD STRENGTH AND LINE OF SIGHT

RF Module	Electric Field Strength	Distance	Remark
2.4 GHz Zigbee	-21.94 dBm	640 m	Height : 2 m
424 MHz Single	-22.10 dBm	630 m	
424 MHz Multi	-22.06 dBm	630 m	

Most of the water meter covers are made of polyethylene, galvanic, or iron casing, as shown in Fig. 6. Each case has its own propagation characteristics. They were examined by conducting field tests.

(a) PE Case (b) Galvanic Case (c) Iron Case

Figure 6. Cover Types for Water Meters

Fig. 7 shows the four installation sites in Gwang-Ju City, Kyeung-gi Province, South Korea. Each section has its own unique characteristics such as congestion, located in quite areas, or being nearby to main roads. Performance testing was done after installation of the three kinds of RF modules at 40 points and selecting the possible direction among the front, side and rear position.

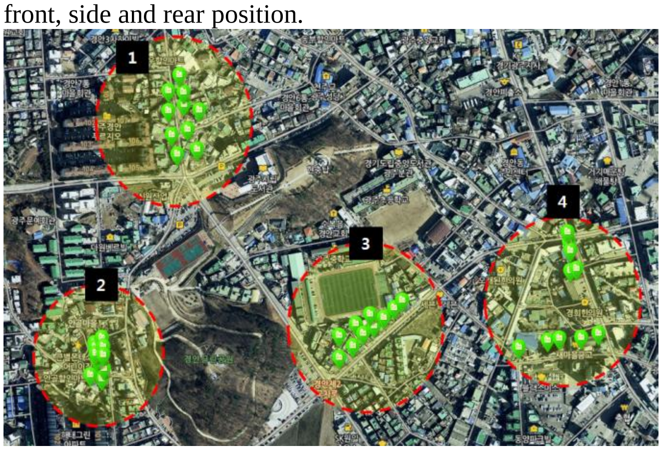


Figure 7. Testbed for Performace Test

Data and field work photos was collected into the database server to analyze the performance, as shown in Fig. 8. The database was constructed using a web program for the purpose of making accessibility easy for authorized persons when onsite.

(a) Analysis of Distance (b) Characteristics

Figure 8. Analyzing Program for the Smart Meter

Performance results by distance and direction are shown in Fig. 9. The figure on the left side had no differences in terms of distance and direction. But the images in the middle and on the right side had the worse success rates in rear areas. This was because the water meters were installed in blind spots owing to building structures and relatively poor propagation environments.

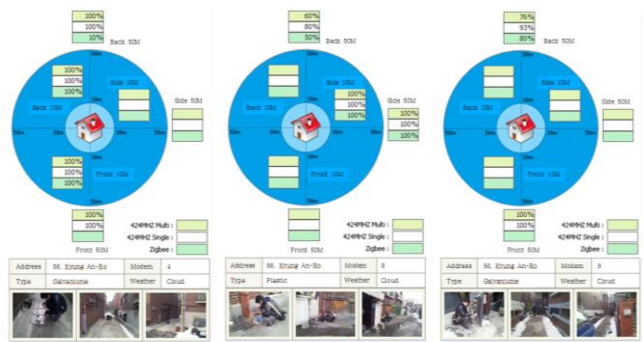


Figure 9. Result of Performace Test by distance and direction

A transmission distance comparison is shown in Fig 10, in which the success rate decreased as the distance became farther. But the success rate suddenly increased at 90m, which was caused by as small portion of data, 10 among 700 data. Most of the data at 90m were measured from the side of the water meter, whereas only one was collected from the rear and it is believed to have the worst success rate. Each of the success rates of communication modules are as follow: 424Mhz Multi module was 78%, 424Mhz Single module was 88%, and the Zigbee module was the lowest at 77%.

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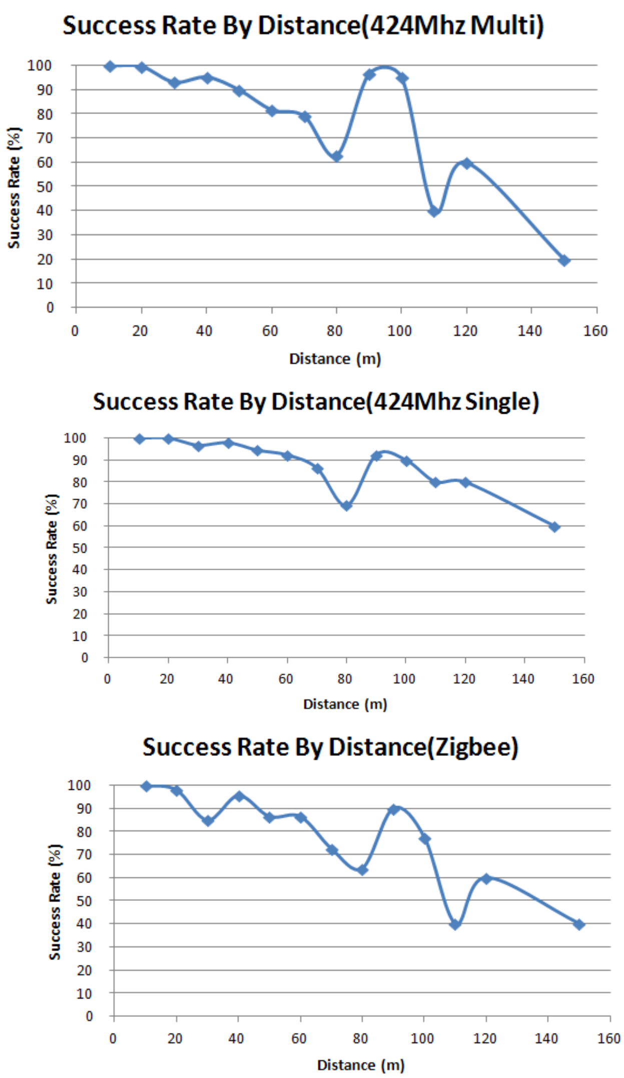

Figure 10. Success Rate by Distance

The transmission distance was almost similar in the 424 MHz Multi and 2.4 GHz Zigbee modules. However, it was analyzed that the 424 MHz Single module was 10 percent more efficient than the other modules in regards to the transmission distance. Besides, the casing for the water meter was analyzed depending on the type of casing, plastic or galvanic. The results show that the plastic casing had a 93% success rate and the galvanic casing had a success rate of 90%. Both of the casings have limited influence on data transmission.

III. CONCLUSION

As the application of smart technologies is expanding in urban infrastructure systems, the developed smart meters for distribution networks can be used to operate and manage water supply efficiently and economically. A newly developed half-electronic water meter combines the standard mechanical water meter with an electrical signal transmission. Thus, it can remove some of the weak points of existing electronic water meters such as the risk of data loss, which is believed to be a major impediment of smart metering.

Also, three kinds of wireless modules were tested in various communication environment conditions to determine which modules were best suited for specific terrain characteristics. Thus, it is expected that customized transmission services can be provided. Finally, this research will be applied to large demonstration sites in the near future.

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