

Wireless Harness Inside ICT Equipments

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Abstract— We have been investigating point-to-multipoint wireless communication suitable for the use inside ICT (Information and Communication Technology) equipments to accommodate demands for weight saving, environmental lifecycle CO₂ reduction and improvement of assembly/maintenance efficiency by means of replacing communication wire harnesses with wireless technology, i.e., wireless harness. Through the radio propagation measurements inside four equipments of automatic teller machine (ATM), ticket vendor, vending machine, and printer, a consistent specification applicable to them has been determined. Based on this specification, a test wireless system has been developed. It showed good performance even inside the ATM, that has the most lossy environment among the four equipments we tested.

Keywords— wireless harness, ICT equipment, weight saving, 2.4 GHz ISM band, CO₂ emission

I. INTRODUCTION

One of recent trends in wireless technology is machine-to-machine communication (M2M) using short range devices. As an expansive application of M2M, wireless communication inside machines has been recently receiving much attention aiming for the improvement of assembly/maintenance and weight saving. Several works have focused on these benefits of replacing wire harnesses with wireless communication, that is wireless harness, and reported its potential applicability in various vehicles and equipments such as automotive[1,2], aircraft[3], spacecraft[4,5], personal computers[6], and so on, through fundamental radio propagation measurements and feasibility tests.

Such utility of wireless harness also seems effective as a

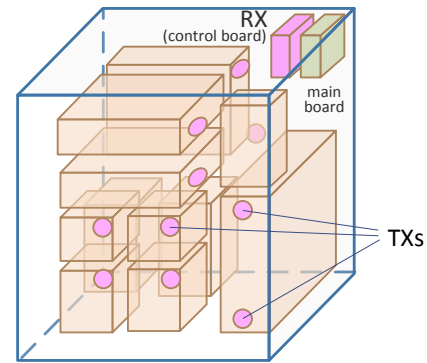


Figure 1. A conceptual picture of wireless harness inside equipments. Replacing the wire harnesses between RX and sensor nodes TXs with wireless communication achieves the reduction of wire harnesses and the abatement of assembly maintenance. The main board receives status data from the control board and controls all the equipment functionalities.

green technology to reduce CO₂ emissions of machines. The reduction of CO₂ emission is a big issue regarding with the global warming and has been challenged at all the sectors and various scenes in Japan. In accordance with these movements we have been studying the application of wireless harness to ICT (Information and Communication Technology) equipments that have considerable amount of wire harnesses inside them. In addition, our study also covers the clarification of how effective the wireless harness of ICT equipments is on the CO₂ emission reduction. As a method to estimate the CO₂ emission, we here employ lifecycle assessment methodology that converts both the consumption of resources and energy into the amount of CO₂ emissions during the whole lifecycle

TABLE 1. EQUIPMENTS TESTED AND INTERNAL RADIO PROPAGATION

Equipment	Size(W x D x H)	Chassis	Propagation loss at distance ≤ 1 m	Propagation Delay	Path loss distribution model at far positions
ATM	57 x 104 x 120 cm	metal	20 – 70 dB	≤ 50 ns	Rayleigh
Ticket vendor	50 x 90 x 150	metal	20 – 50	≤ 50	Nakagami-Rice
Vending machine	70 x 70 x 180	metal	20 – 60	≤ 50	Nakagami-Rice
Printer	48 x 48 x 55	plastics	20 – 60	≤ 30	Nakagami-Rice

of the equipment.

We previously reported a fundamental study on measurements and modelling of radio propagation in four ICT (Information and Communication Technology) equipments; automatic teller machine(ATM), ticket vendor, vending machine, and printer[7]. In this paper, the design and characteristics of our dedicated wireless communication test system for ICT equipments are presented, and its performances inside the equipments are discussed.

II. EQUIPMENTS TESTED

Our specific targets are mechatronics ICT equipments, because they have particularly a lot of sensors and harnesses so as to monitor mechanical states in various positions such as transfer tracks and stockers in real time. A typical example is ATM, which has about 200 sensors for this purpose and the total weight of the harnesses connecting sensors to control boards and a main board goes up to more than a couple of tens kilograms. Since the internal structure of ATM is so complicated and densely packed, the harnesses are swirled along with the frames and modules inside the chassis, resulting much longer than the straight-line distance. This increases technical difficulties in the assembly/maintenance processes. Therefore, the application of the wireless harness into mechatronics equipments is very effective in assembly/maintenance load reduction as well as weight saving. As a whole, these must contribute to the reduction of the lifecycle CO₂ emissions. The situation seems more or less same in other equipments.

The measurement results and modellings of radio propagation inside the four equipments reported in our previous work[7] are summarized in Table 1. The sizes of them are roughly 1 to 2 m, thus we postulate the communication distance is about 1 m or less. Because the inside of each equipment is packed with a lot of modules composed of metals and dielectric materials and surrounded by the chassis, the radio propagation exhibited multi-path propagation. The propagation distribution obeyed the Rayleigh model in ATM and Nakagami-Rice model in other equipments. The worst path loss was observed in ATM among the equipments tested, which must be due to its very densely packed structure. The observed propagation delay was less than about 50 ns in various positions in ATM, ticket vendor, and vending machine. Their chassis are mainly made of metal, however, they have slits and windows so that the radio wave

is easy to dissipate from the inside. This helps the propagation delay be in the same range of that observed in PC chassis[6]. The printer that has a plastic chassis showed shorter propagation delay. Based on these observations we decided to treat ATM as a representative of mechatronics ICT equipments while considering broader applicability to other equipments.

III. SYSTEM DESIGN AND SPECIFICATIONS

Although there were a couple of candidates among commercialized products such as Bluetooth, ZigBee, and ultra wide band (UWB) systems and actually some of them were tested inside our equipments at an early stage of our work, we decided to make a custom system based on a commercialized RF-IC running at 2.4 GHz ISM band. Some of the reasons for this are to satisfy our primary requirements that the system shall simultaneously collect status data from as many as 200 sensor transmitters, each of which runs with 1 kHz sensing frequency and with a system latency of 1 ms. These requirements are mainly derived from a current wired system of ATM as a case reference. The existing technologies such as Bluetooth and ZigBee seemed hardly applicable to meet with these requirements without deep level modification. UWB is a fascinating high-speed technology, however, we have to consider power consumption of sensor transmitters and the radio wave regulation of Japan that limits UWB to indoor use at present. Thus we decided to design a point-to-multipoint custom system. Table 2 summarizes our system specifications.

IV. ANTENNA

Since a lot of metals and dielectric components are closely arranged inside ATM, extra free spaces available for additional placement of wireless modules are not so large. The distances between adjacent components look 2 to 5 cm at best. In some places areal slits are as narrow as less than 1 cm. The situation in other equipments is similar. Therefore antennas of the wireless modules inside equipments have to be inevitably placed close to the components. Figure 2 shows a setup we employed to measure how the antenna performance is affected by adjacent metals. Figure 3 shows the measurement results of a commercially available 2.4 GHz common chip antenna[8].

TABLE 2. SYSTEM SPECIFICATIONS

Num. of sensor modules (transmitters)	up to 200
Sensor data	0/1 (bit datum)
Sensing frequency at each sensor	1 kHz
Radio communication frequency	2.4 GHz ISM band
Modulation	GFSK
Access protocol	FTDMA
Communication speed	1 Mbps (op. 250 kbps, 2 Mbps)

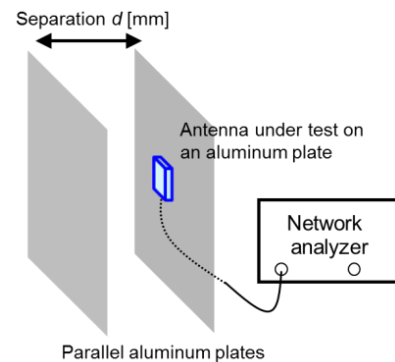


Figure 2. Test measurement setup of antenna characteristics at close positions to metals. An object antenna was placed on the surface of one aluminum plate and the other aluminum plate was brought to closer to the antenna. It was measured with a network analyzer.

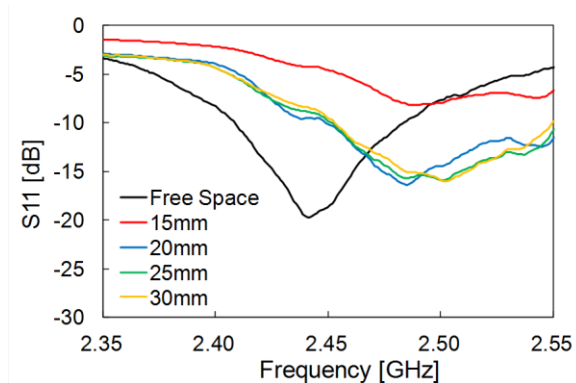


Figure 3. Measurement results of a commercially available 2.4 GHz common chip antenna with using the setup illustrated in Fig.2.

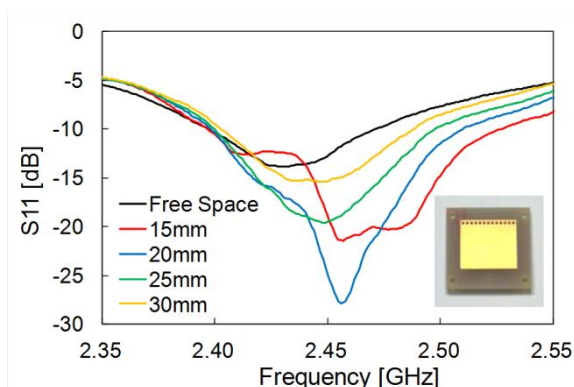


Figure 4. Newly developed antenna and its performance. See Fig. 2 for the measurement setup.

Its reflection characteristic easily varies when a metal plate was closely placed. The wavelength is about 12.5 cm and thus the distance we tested is about in a range of so-called near field. Compared to the free space condition, the S11 at 2.45 GHz got worse to -10 dB at 20 - 30 mm and -5 dB at 15 mm.

In order to obtain stable performance inside equipments, we designed a dedicated antenna to have better performance when a metal plate exists at around 20 mm and to be insensitive to the environmental change. Figure 4 shows a resulted test antenna and its performance. It exhibited much more stable characteristics than the conventional one shown in Fig. 3. The averaged S11 keeps better than -11 dB from the free space to the distance of 15 mm in the range of 2.4 - 2.5 GHz. It is still expected to have good performance at closer arrangement.

V. WIRELESS SYSTEM

A. Wireless Modules

To match the specifications listed in Table 1, we made a custom wireless module based on a commercially-available RF-IC produced by Nordic Semiconductor. Figure 5 shows a terminal module coupled with an antenna developed. It has two connector ports to sensors and a board size of 25 x 30 mm. In this module custom protocols described next are embedded. The combined wireless module shown in Fig. 5 is a kind of

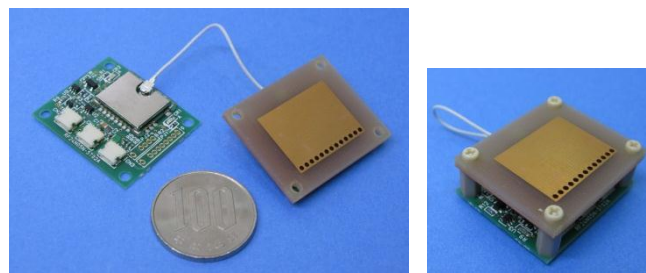


Figure 5. A pair of a wireless module and an antenna. The right picture shows an assembled state. Module dimensions: 25 mm x 30 mm.

functional test version and a smaller and improved version is under investigation.

B. Protocols

Figure 6 shows frequency and time division multiple access (FTDMA) which is implemented on the RF-IC as an access protocol inside ICT equipments. The system is designed to utilize 73 frequency channels in the range of 2400 - 2480 MHz and each channel has four time slots. A guard time is set for compensating the processing delay of RF-IC and guard frequency band is prepared to avoid the interference from adjacent frequency channels. Therefore, the guard time is allocated to the transmission time of both the adjacent frequency channels in order to use frequency band efficiently. The allocation of frequency to each terminal module is pre-processed at initial setting to avoid severe multi-path interference and functionalize frequency diversity effect. Totally the arrangement of slots looks like a checker pattern as shown in Fig. 6. Currently we utilized a pre-installed packet format for communication, and thus put a couple of sensor data into one payload to transmit. Though the packet has a length of 72 bits, that is too long for datum length of each sensor and even for a couple of sensors, the total data volume of 200 sensors with 1 kHz repetition can be successfully transmitted to the access point (RX) with using FTDMA, running at 1 Mbps in each channel.

C. Performance

Performances of our designed wireless module and antenna were measured in ATM. An access point was placed near the backside of the front panel, and the terminal module was placed close to the rear panel. The straight-line distance of

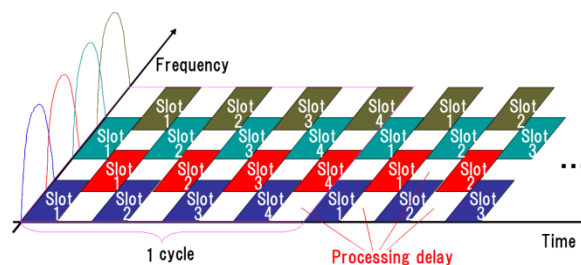


Figure 6. FTDMA protocol sequence using four slots at each frequency with checkerboard packet configuration.

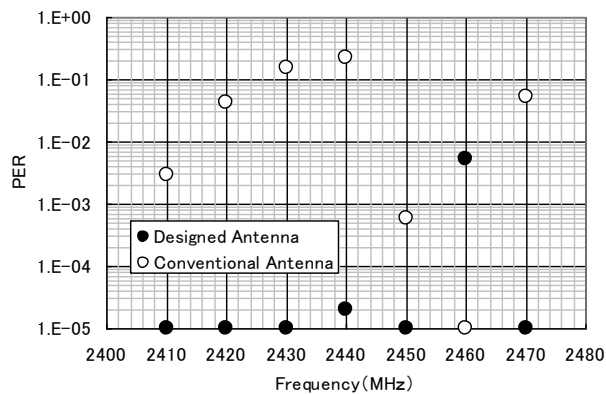


Figure 7. Comparison of packet error rates between our designed antenna and the conventional antenna that the RF-IC supplier recommended.

them was more than 50 cm. The arrangement was where the propagation obeys Rayleigh distribution and the path loss was about 60 dB. Figure 7 shows the measurement results. Figure 7 shows packet error rate (PER) against 7 frequency channels from 2400 to 2480 MHz. In this figure, white and black dots mean performances of conventional and designed antennas. In the wide range of channels PER achieved 10^{-5} level. The degradation of PER at 2460 MHz seems to be due to the severe multi-path interference and a steep increase of path loss, which is sensitive to the position and configuration of the module and antenna. Here we compared our antenna with a conventional meander-line antenna that the RF-IC supplier recommended. Average to say, our designed antenna showed better performance in ICT equipment.

In our early measurement of bit error rates (BER) at various positions inside ATM, about 10 % of the positions exhibited very lossy conditions probably due to the environmental reason and multi-path interference and suggested difficulty to achieve BER being 10^{-5} level or better. However we are now sure to achieve good reliability by adopting our designed antenna and FTDMA based channel allocation.

VI. GREEN EFFECT

The benefit of the wireless harness in terms of lifecycle CO_2 reduction has been estimated[9]. The difficulties in such estimation at an early stage of test development phase include the collection of appropriate primary units of elemental parts and the framework of evaluation.

Table 3 summarizes the trial estimation of CO_2 emissions

TABLE 3. CALCULATED CO_2 EMISSION
(a) Wire harness, (b) Wireless harness, [kg- CO_2 /unit]

Lifecycle process	(a)	(b)
Manufacture of cables and connectors	29	0
Manufacture of wireless modules	0	10
Assembly of connecting wire harness	4	0
Power consumption by wireless modules	0	0.1
Maintenance	1	0
Total	34	10

related to wire and wireless harness in the case of ATM. In the case of wire harness, the major process of the CO_2 emission is found to be the manufacture of cables and connectors. It occupies 84 % in the total CO_2 emission. In the case of wireless harness, it is found to be the manufacture of wireless modules and occupies 99% in the CO_2 emission. This result indicates that the manufacture of cables and connectors and wireless modules are much more important than other factors. The assembly and maintenance processes have been addressed as distinct loads and speculated to have considerable CO_2 emissions, however they occupies no more than 15 % of the total.

These estimated values seem to have considerable errors at current stage and needs to be studied more in details, however, the estimated amount of 24 kg CO_2 per a unit by replacing the harness with wireless harness is not negligible. This indicates the wireless harness almost certainly has a very good effect to the reduction of CO_2 emissions when it is applied to equipments that have a lot of sensors and thus a lot of wire harnesses in them.

VII. CONCLUSIONS

Based on the measurement results of radio propagation inside ICT equipments, we settled down a consistent specification to fit for use of sensor data acquisition, and built up a test system of point-to-multipoint wireless communication. The system runs with 73 channels using 2.4 GHz ISM band. It enables to connect 200 sensor-transmitter modules and retrieve sensor data with dedicated packet protocols. The test system exhibited good performance even inside ATM, the inside of which is the most severe environment for radio propagation among the equipments we tested. The application of wireless harness to ICT equipments seems to offer wider variety of merits such as weight saving, slim-design, abatement of assembly/maintenance, and reduction of lifecycle CO_2 emission as a result.

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