An Experimental Evaluation of $2 \times 2$ MIMO System Using Closely-Spaced Leaky Coaxial Cables

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Abstract—This paper introduces a two by two multiple-input multiple-output (MIMO) system using two closely-spaced leaky coaxial cables (LCXs). In this LCX-MIMO system, two different types of LCXs are placed in parallel with a narrow spacing, and different RF signals are fed to each of the LCXs from the same side. We show with our experimental results that the proposed LCX-MIMO set up works as well as MIMO transmission specified by the IEEE802.11n standard in the 2.4 GHz ISM band.

I. INTRODUCTION

Wireless local area network (WLAN) systems are widely used for the Internet connection in office, home, vehicle, public space, and everywhere. Many application softwares require the connection at any time to get data from servers and to execute a software properly. Internet users download a great amount of data to see a picture, news, movie and so on. For a countermeasure of increased traffic, multiple-input multiple-output (MIMO) capability becomes indispensable for modern wireless systems such as the IEEE 802.11n WLAN standard.

Meanwhile, a leaky coaxial cable (LCX) is utilized as an antenna for short range radio communications, because an LCX has advantage in coverage of a linear service area and stability of connection for mobile terminals. For example, an LCX is employed for public safety radio systems in underground shopping malls and the access lines of WLAN service in the Tokaido Shinkansen trains which run up to 270 kilometers par hour in Japan. Nowadays an LCX for WLAN system has also been developed [1], [2]. Although, when MIMO technique is applied to WLAN system with LCX, it requires to lay more than two LCXs with a wide separation [3]. Since a cabling cost for LCX is quite high, a novel method is desired to support MIMO with a single cable.

Thereupon, we had proposed a novel method that achieves $2 \times 2$ MIMO with a single LCX [4], and conducted experiments to confirm the feasibility of the method. In our previous work [5], an evaluation of the LCX system was conducted at 2.447GHz that was nearly center frequency of the 2.4GHz ISM band. It shows that the proposed method satisfactory achieves $2 \times 2$ MIMO transmission at this frequency band. And, frequency characteristics of the MIMO channel were also presented for confirmation of OFDM system application [6].

When we expand these fundamental studies for $4 \times 4$ MIMO, further techniques are needed to establish a MIMO channel using a single cable. If the LCXs of the same characteristic are combined into one multi-linear cable, MIMO channel can not be made stable because the channels between antenna and the LCXs are highly correlated with each other. Hence, we are proposing another method by combining LCXs which have a different radiation characteristic.

As an initial feasible study, we had conducted an experiment for $2 \times 2$ MIMO using LCXs placed in parallel with 30 millimeters spacing. It was confirmed that the $2 \times 2$ MIMO can be realized by the proposed method.

In this paper, we introduce the $2 \times 2$ MIMO system using two closely-spaced LCXs. We also show from our experimental results that the proposed method works as well as MIMO transmission specified by the IEEE802.11n standard in the 2.4GHz ISM band.

The paper is organized as follows, section II shows a characteristic of LCX. The proposed method is introduced in section III. The experiment setup and results are explained in section IV, followed by the conclusion in section V.
II. STRUCTURE OF LCX AND ITS RADIATION PATTERN

An LCX has two characteristic aspects, one is as a feeder and the other is as an antenna. Fig. 1 shows an example structure of a single-mode LCX which radiates a vertical polarized wave. Radio waves are radiated and received from slots which are periodically located along the outer conductor in LCX. The signal strength of radio waves at the far field region from LCX is related to the sum of the radiated radio waves from the slots. Strength and polarization of the waves can be controlled by the pattern of the slots. Radiation angles with peak directivity for a vertical polarized wave type cable are,

$$\theta_m = \sin^{-1}\left(\sqrt{\epsilon_r + \frac{m\lambda_{RF}}{P}}\right), (m = -1, -2, \ldots), \quad (1)$$

where $m$ is an order of harmonic, $\epsilon_r$ is relative permittivity of insulator in LCX, $\lambda_{RF}$ is wavelength of input radio frequency (RF) signal, and $P$ is the period of slots[7]. $\theta_m$ is an angle relative to the direction of the RF signal propagation in the LCX. Equation (1) suggests that the direction of radiation waves can be controlled by setting the $P$ of LCX to an appropriate value. To avoid radiation of harmonics, LCX is typically designed as taking value $m = -1$, that is single-mode cable. When a LCX designed with the value $m \leq -2$, it becomes a multi-mode cable and radiates not only vertical polarized wave but also a horizontal one.

III. PROPOSED MIMO METHOD

At the right side in Fig. 2, the configuration of $2 \times 2$ MIMO with a single LCX by previous work is shown as a reference. We think that when these two methods are combined, it will realize $4 \times 4$ MIMO using two LCXs with close spacing.

As explained in section II, LCX has directional radio wave radiation. The proposed method exploits this property to realize $2 \times 2$ MIMO, as shown at the left side in Fig. 2. By feeding different RF signals from the same side of LCXs with different radiation patterns, different propagation paths can be made in spite of narrow spacing between the parallel LCXs. It is shown by the arrows with different color and direction in the figure.
If propagation channel values which are made from the propagation paths maintain a low correlation condition over the linear cell area, stable MIMO can be achieved even if a terminal has mobility.

Fig. 3 and 4 show a measured radiation patterns of the single-mode LCX for vertical polarized wave (Type 1) and multi-mode LCX for dual polarized wave (Type 2) respectively. Specifications of these LCXs are listed on Table I. A 50 Ω terminator is attached at the other end of the LCX through the measurement.

Dominant radiation of vertical polarized wave is observed on –25 degree in type 1 and on +20 degree in type 2. In type 2, horizontal polarized wave is also observed on –25 degree. As the 10 meters length LCX under the experiments was too long to place on a turntable to measure the radiation pattern, another 3 meters length LCX from the same manufacturing lot was used for the measurement. Though the length is short, an angle of the dominant radiation will be the same because the radiated wave at far field region is the sum of approximately 40 waves which radiated from each slot. We employed these two types’ of LCX for the experiment.

IV. EXPERIMENTAL EVALUATIONS

The configuration of the setup is shown in Fig. 5. In this evaluation, we measured throughput performance between the PCs instead of the wireless section throughput between the AP and the STA. We used Iperf [10] that is a TCP and UDP bandwidth performance measurement software tool. Each of the datagram size is set to 1470 bytes, and UDP mode is selected. Measurement period is set to 1 second to clear the stacked data on queues and to avoid mischief from the previous period. The server and client PCs are connected by wire to the AP and the STA, respectively. A local area network (LAN) connection from the PC to the AP has capability of the 100 Mbps Ethernet. The STA is connected to the PC by the Universal serial bus (USB). Then, the effect of the wire connection part to the result will be negligible.

The model names of AP and STA are ‘WAPM-APG300N’ [8] and ‘WLI-UC-AG300N’ [9] respectively. Both devices support IEEE802.11n standard and manufactured by Buffalo inc.. Unfortunately STA can use only built-in antennas, and the specifications of the antennas e.g. gain, polarization and directional pattern are not clear. Since the AP has connectors for external antennas, we can use them for LCXs.

The experiments were carried out in an electromagnetic anechoic chamber to evaluate under the worst conditions for MIMO. Fig. 6 shows a geographical setup of measurement points. An X axis is a direction along the LCX. A Y axis is a direction from the LCX to the STA with built-in antennas that are perpendicular from the LCX. An origin point is a center of the LCX. Since there is no reflection path and channel propagation is static in the anechoic chamber, a shape of a cell formed by the LCX can be assumed to be symmetric against X axis and Y axis. Given this assumption, the measurement point was reduced to a quarter from the entire cell area. We
decided Y = 0.5 meters at the experiment because a shorter distance will make higher correlation of the channel and we do not consider a signal-to-noise ratio (SNR) of the channel. The SNR can be changed easily by transmission power control and cable parameter decision. Communications will be made at high SNR condition in linear cell. The configuration of the experiment is shown in Fig. 7. The LCX is laid in the foaming polystyrene which is placed on foaming polystyrene cube piled on the a radio wave absorber. It is approximately 0.9 meters above a floor.

The STA is placed on a slider and moved linearly on the rail by stepping motor with fixed speed. The speed is less than 0.1 meter per second this time. This mechanism realized a continuous throughput measurement along the LCX.

The measurement results are shown in Fig. 8. The trace of type 1 is the result using only one single-mode LCX, and it is approximate 35 mega bits per second. The result provides that it cannot achieve MIMO because AP uses only one antenna. The trace of type 2 is the result using only one multi-mode LCX. It is almost the same as the trace of type one. The trace of the type 1 and 2 is the result using two LCXs that are single and multi modes. It achieves more than 60 mega bits per second because 2×2 MIMO can be realized. One of the advantage by the proposed method is stability of the MIMO transmission. At almost all positions in the measured area, the throughput exceeds the maximum throughput of the non MIMO condition in spite of line-of-sight and no reflection environment.

V. CONCLUSIONS

We have proposed an efficient MIMO method for wireless system such as IEEE802.11n by using parallel-placed LCXs with narrow spacing. To confirm the performance of the proposed 2×2 MIMO system, we have measured a throughput using software tool ‘Iperf’ and WLAN devices on the market. The measurement results show that the proposed method has an ability in achieving a 2×2 MIMO using two LCXs with 30 millimeters spacing at most of the positions on the 0.5 meters distance along the LCX. The throughput of the proposed system exceeded the maximum value of IEEE802.11g system on average and realized double the throughput compared to the single LCX system.

REFERENCES


