Key Technologies Actualizing Broadband MIMO-OFDM Hardware

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1. Introduction

Due to the recent popularity of mobile phones and broadband wireless LANs, broadband wireless systems employing Orthogonal Frequency Division Multiplexing (OFDM) were introduced to combat the effects of multi-path fading in indoor wireless LAN systems. Moreover, Multiple Input Multiple Output (MIMO) is incorporated into these broadband wireless systems using OFDM to achieve higher transmission speeds without expanding the frequency band [1].

In studies pertaining to MIMO transmission, theoretical analysis and various basic computer simulations are mainly employed [2]. However, in order for a successful broadband MIMO-OFDM transmission in an actual environment, various technologies such as antennas, propagation, and signal processing must be actualized. Moreover, since the channel capacity in MIMO channels largely depends on the antenna configurations, propagation environment, and the decoding algorithm, evaluation using a transceiver that can evaluate broadband MIMO-OFDM transmission is required in an actual environment.

This paper first describes the key technologies to actualize the broadband MIMO-OFDM hardware. Then results of our research on technologies such as an antenna configuration, propagation model, and beamforming method are presented. Finally, a transceiver that can achieve 4×4 MIMO-OFDM transmission in the 100-MHz band and the basic performance characteristics of this transceiver are presented.

2. Technologies Actualizing Broadband MIMO-OFDM

Figure 1 shows a diagram of MIMO-OFDM when assuming an indoor wireless LAN system. Eigenmode transmission, which can obtain the maximum channel capacity in MIMO channels, is depicted in Fig. 1. As shown in the figure, various techniques such as antennas, propagation modeling, and a beamforming method must be established. To actualize the MIMO-OFDM hardware, the following must be clarified.

- Antenna configurations that achieve small terminal stations while reducing the spatial correlation
- A propagation model that can evaluate broadband MIMO-OFDM transmission
- A robust beamforming method for channel state information (CSI) error

To obtain a high channel capacity in MIMO channels, reducing the spatial correlation between antennas is required [2]. To achieve this, the antenna configurations with wider element spacing are effective. However, it is difficult to implement such antenna configurations into small terminal stations as represented by PCMCIA cards in wireless LAN systems. Thus, antenna configurations that actualize small terminal stations while reducing the spatial correlation must be established.

It is well known that the channel capacity in MIMO channels largely depends on the propagation characteristics. Thus, accurate propagation models that consider the actual antenna configuration must be developed to implement the hardware of MIMO-OFDM systems in real systems. Moreover, because bit loading and adaptive modulation should be employed according to the transmission quality of each sub-carrier in Eigenmode transmission, it is very important to investigate the frequency correlation characteristics in broadband MIMO-OFDM systems.

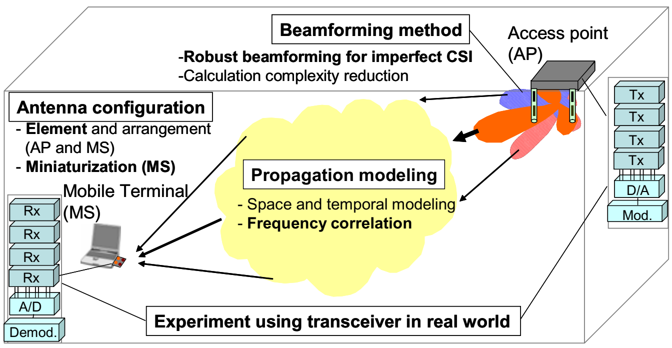

Fig.1 Key technologies actualizing MIMO-OFDM hardware

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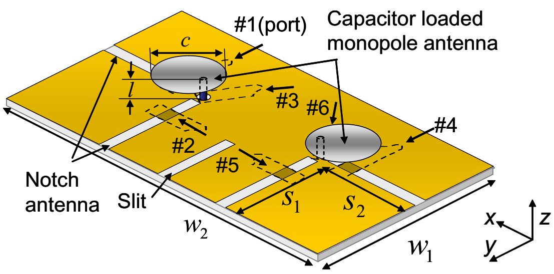
The receiver can obtain a high transmission quality level with simple linear operation such as MRC (Maximum ratio Combining) or ZF (Zero Forcing) by using Eigenmode transmission [2]. Thus, Eigen-mode transmission is very effective for the downlink in which broadband transmissions are required. However, if CSI estimation error arises at the transmitter, the channel capacity deteriorates. Countermeasures for the channel estimation error in terms of abating the channel capacity deterioration are required.
In the following, our research activities for actualizing MIMO-OFDM hardware are described.

3. Antenna Configuration Suitable for MIMO Channels

In MIMO systems, using orthogonal polarization was proposed to reduce the spatial correlation between antennas while downsizing the mobile stations. However, there is still insufficient research concerning specific antenna configurations.
Figure 2 shows the proposed antenna configuration [3]. The proposed configuration can achieve triple polarizations not simply vertical and horizontal polarizations. In the proposed configuration, two notches with grounds are configured around the corner of a rectangular ground plane of a dielectric substrate. The short ends of the two notches must be close to each other in order to reduce the coupling between the two antennas. Also, a top loaded monopole antenna using circular capacitors is configured around the ends of the two notches. These three antennas radiate by using feeding ports formed on the backside of the rectangular dielectric substrate. Furthermore, we fabricated the array antennas with six ports and they can be implemented inside a PCMCIA card at 5.2 GHz by preparing two pairs of these three antennas [3].
Figure 3 shows the measured results of the channel capacity in a 6×6 MIMO indoor propagation channel by employing the proposed triple polarization antennas. The size of the room is 12×16×2.6 m and the terminal antennas are located at (x, y, z) = (3.0, 3.0, 0.7), (3.0, 8.0, 0.7) and (3.0, 14.0, 0.7) m. The antenna at access point is located at (x, y, z) = (2.0, 2.0, 1.0) m. The 6x6 MIMO channel matrix is obtained by using a network analyzer. A triple dipole array with the array spacing of 1.0 and 2.5 wavelengths was used as the transmit antennas. The carrier frequency was 5.2 GHz and the amplitude and phase data on 401 points was aquired at 100 MHz frequencyband. For the conventional antennas, a six dipole array and capacity loaded monopole array were used as the base and terminal stations, respectively.
Figure 3 shows that the proposed triple polarization antennas can obtain a 20 % increase in the channel capacity compared to the conventional vertical polarization antennas when the element spacing is 1.0 wavelength at the base station. Even if the element spacing is 2.5 wavelengths at the base station, the proposed antenna configuration can attain almost the same capacity as the conventional antenna. Therefore, the antenna size can be reduced while improving the channel capacity for the conventional antenna by employing the proposed antenna configuration.



$w_1 = 0.54\lambda_0$, $w_2 = 0.94\lambda_0$, $s_1 = 0.25\lambda_0$, $s_2 = 0.27\lambda_0$, $l = 0.10\lambda_0$, $c = 0.17\lambda_0$
Thickness of substrate = 0.014, $\varepsilon_r = 2.2$

Fig. 2 Antenna configuration that achieves triple polarization

4. Propagation Model Considering Vertical and Horizontal Antenna

Figure 4 shows the proposed propagation model [4]. Since the frequency correlation characteristics are very different between the horizontal and vertical array antennas, a propagation model is required that can consider not only the horizontal, but also the vertical array antenna to estimate the difference in the frequency correlation due to the antenna configuration. The proposed model can consider both the horizontal and vertical array antennas. Below, we describe a method to obtain the propagation channel data using this model.

(1) Determine the size of the room (x, y, z).
(2) Calculate direction d_1 from the access point (AP) to the mobile stations (MSs) and the directions of the reflections at the walls (d_2, d_3) using a geometric optic

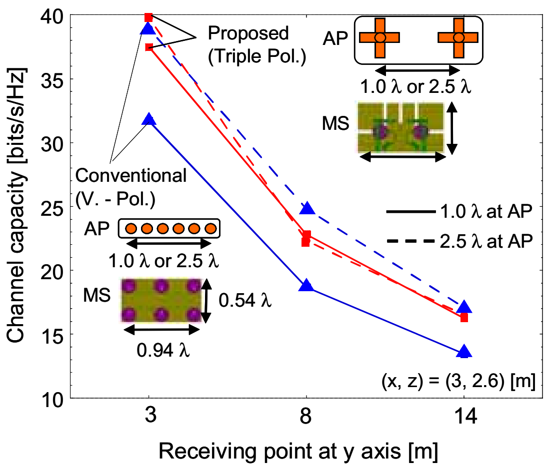


Fig.3 Channel capacity when using triple polarization antenna

method.

(3) Arrange the clusters in the horizontal plane in directions d_1, d_2, and d_3.

(4) Arrange the clusters in the vertical plane according to the clusters in the horizontal plane.

(5) Prepare three delay groups (DG_1, DG_2, and DG_3) for each cluster.

Figure 5 shows the frequency correlation of the 1st eigenvector in a MIMO channel versus the carrier spacing when the proposed model is used. The experimental and simulation results are in good agreement and the frequency correlation of the channel capacity is shown to have dependency on the array antenna arrangement. The new cluster model enables efficient designs of the antenna configuration in a MIMO system.

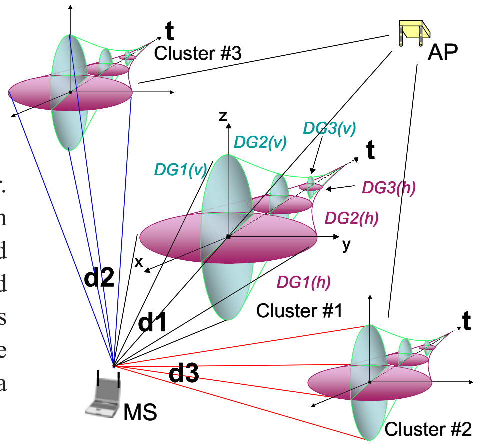


Fig. 4 Proposed propagation model

5. Robust Beamforming Method For CSI Error

Figure 6 shows a block diagram of the proposed beamforming method [5]. Figure 5 shows that a high correlation exists between the channel matrix of adjacent sub-carriers and the proposed method utilizes this feature. The channel matrix, $\hat{H}_k$, for the k-th sub-carrier to obtain the transmit weight in the proposed method is shown as follows.

$$\hat{H}_k = H_k + \frac{1}{2}\sum_{i=1}^{P_i}(H_{k-i} + H_{k+i}) \quad (1)$$

where P_i is considered the number of anteroposterior sub-carriers. Terms P_i is determined from correlation values between H_k and $H_{k-i}+H_{k+i}$. As can be seen in Eqn. (1), to determine the transmission weight of a certain sub-carrier, the proposed method takes advantage of not only the CSI of this sub-carrier, but also that of adjacent sub-carriers and compensates for the channel capacity deterioration due to CSI error.

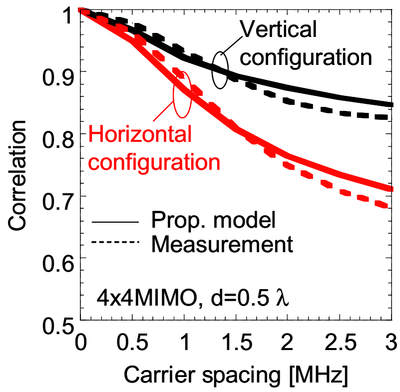


Fig. 5 Frequency correlation characteristics when applying the proposed model

Figure 7 shows the capacity ratio for cases in no CSI errors versus the SNR when the delay spreads are 30, 60 and 90 nsec. The propagation model is based on that in Ref [5]. In the propose method, the parameters P_i is adaptively controled based on the SNR and the correlation values between H_k and $H_{k-i}+H_{k+i}$ [5]. This figure shows that the proposed method can attain a higher channel capacity than the conventional Eigenmode transmission regardless of the SNR and delay spread.

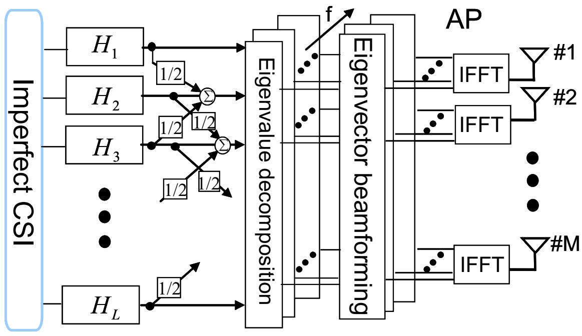


Fig.6 Block diagram of proposed beamforming method (P=1 in Eqn.(1))

6. Experimental Transceiver to Evaluate Broadband MIMO-OFDM Transmission

We implemented the experimental transceiver for broadband MIMO-OFDM transmission in order to verify our proposed techniques [6]. The system configuration and the main parameters are given in Fig. 8 and Table 1, respectively. We can investigate the performance of broadband 4×4 MIMO-OFDM transmission in various actual environments because we can develop software for the signal processing part off-line and various antenna elements can be attached to the equipment [6]. Moreover, not only conventional SDM without beamforming, but also the Eigen-mode SDM scheme can be evaluated using our experimental equipment by using feedback of the channel state information fed through a

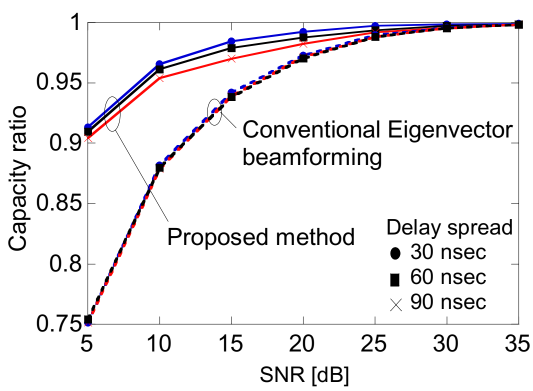


Fig. 7 Effectiveness of proposed beamforming method

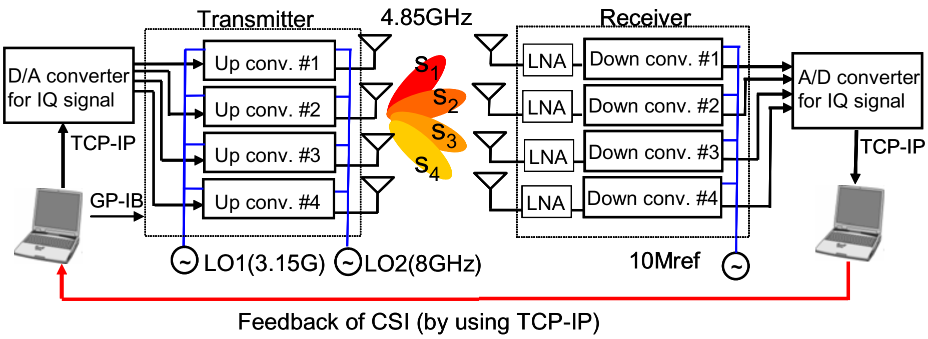


Fig. 8 Experimental equipment for evaluate broadband MIMO transmission

cable [7].

We confirmed the basic transmission characteristics in an indoor environment. Channel estimation was achieved by transmitting half of a long preamble code four times using the IEEE.802.11a standard [6][8]. The constellation of each stream is compared between ZF-SDM and Eigen-mode SDM in Fig. 9. Each stream is assigned the appropriate digital modulation according to the eigenvalue in Eigen-mode SDM transmission.

Figure 9 shows that the constellation of the Eigen-mode SDM on Streams #1 and #2 in which the eigenvalues become high is clearer than that for ZF-SDM. Moreover, 64 QAM can be transmitted in Stream #1 when the Eigen-mode SDM scheme is applied.

7. Conclusion

This paper summarized the techniques required to actualize the MIMO-OFDM hardware. Several techniques for actualizing MIMO-OFDM were also presented. Finally, the experimental transceiver to evaluate MIMO-OFDM transmission in the 100-MHz band was shown and the effectiveness of 4×4 Eigenmode SDM transmission using this transceiver was clarified in an actual indoor environment.

Acknowledgments

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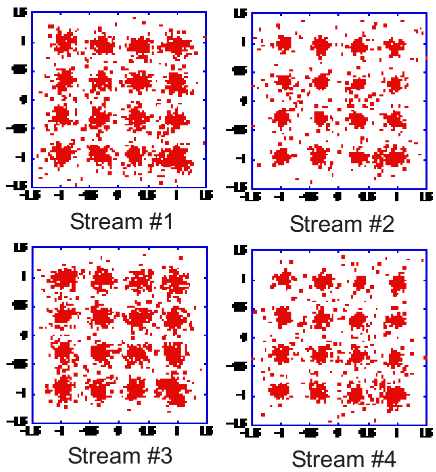
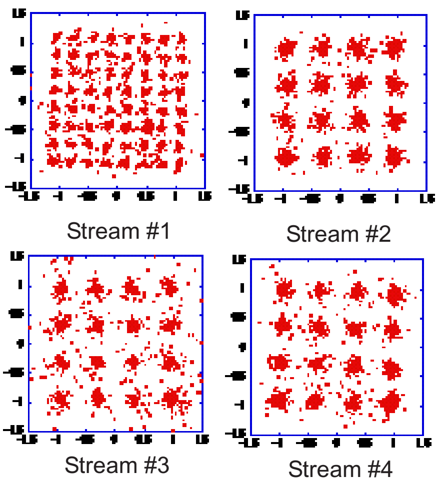
Tabel 1 Main parameter of transceiver

Number of antennas	4(Tx), 4(Rx)
Frequency	4.85 GHz
Bandwidth	100 MHz
Range of AD/DA	14 bits
Transmission power	0 dBm (without HPA)
Sensitivity	-20 to -70 dBm



(a) SDM scheme without beamforming



(b) Eigenmode SDM scheme

Fig. 9 Constellation pattern comparison with 4x4 SDM