Performance Evaluation of Uplink Multiuser MIMO-OFDM System With Single RF Chain Receiver

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ABSTRACT In response to the recent increase in wireless-traffic demand in various wireless communication networks, the number of spatial multiplexings, represented by multiple input multiple output (MIMO) systems, has been increasing. Assuming a realistic hardware configuration achieving an increase in the number of spatial multiplexings depends on increasing the amount of hardware, such as analog/digital (A/D) and D/A converters, and radio frequency (RF) chains. Simplifying the hardware configuration while maintaining large channel capacity was the challenging issue to further improve the channel capacity in Beyond-5G and 6G. This paper proposes a novel system configuration based on an uplink multiuser MIMO - orthogonal frequency division multiplexing (OFDM) system with a single RF chain receiver. By oversampling OFDM signals with a single RF chain receiver, our approach provides an additional spatial multiplexing by switching the antenna directivity pattern in synchronization with the received sampling frequency. Oversampled OFDM signals are typically used for noise reduction, in the proposed configuration, they are used for adding spatial multiplexings. We clarify the potential of the proposed configuration for improving the channel capacity by applying it to the uplink multiuser MIMO-OFDM system. To demonstrate its feasibility, we developed a testbed and analyzed its effectiveness in experiment in an actual indoor office environment.

INDEX TERMS Uplink, multiuser MIMO, OFDM, oversampling, RF chain, channel capacity, hardware simplification.

I. INTRODUCTION
The amount of mobile wireless traffic continues to increase, as indicated by global traffic trends [1], [2]. To stably accommodate such huge traffic in wireless communication systems, academic and industry researchers are shifting focus towards the sixth generation (6G) of mobile communication networks. Many articles outlining visions and technologies for 6G have been published [3], [4], [5], [6], [7], [8], [9], [10], [11]. Among the various key performance indicators (KPIs), such as capacity, latency, coverage, reliability, energy/cost, and connectivity in 6G, the capacity represents the biggest challenge; to increase it, innovative technologies will need to be developed that integrate frequency and spatial domains, centered on expansion of the bandwidth from sub-6 GHz to terahertz bands [12], [13], [14], [15] and multiple input multiple output (MIMO) systems [16], [17], [18], [19], [20]. In regard to the use of sub-6 GHz bands, the number of spatial multiplexings on MIMO systems will have to be increased due to the limited frequency resources. In this regard, research institutions have studied massive MIMO systems that use antenna arrays with a large number of elements at the base station (BS) to provide signal amplification by beamforming and high spatial resolution to multiplex many simultaneous users [21], [22], [23]. Toward implementation, experimental measurements on massive MIMO systems have also been carried out with the aim of enhancing the fifth generation (5G) mobile communication systems [24], [25], [26], [27].
Theoretically, the channel capacity of massive MIMO systems can be increased in proportion to the number of antennas and related devices [28], [29]. However, such a general approach results in greater complexity and higher hardware costs for the actual equipment in wireless communication systems. Also, the hardware complexity and cost rise with the number of transmitter and receiver antennas. Therefore, practical technologies are needed that can simplify hardware without degrading MIMO system performance. The current approaches include antenna miniaturization, reduction in the number of radio frequency (RF) front-end modules and RF chains including analog/digital (A/D) and D/A converters, and so on. A way to reduce the number of RF-front end modules is to use hybrid beamforming wherein the antenna arrays at the transmitter and receiver consist of multiple sub-arrays, each of which connects to multiple RF chains, and each RF chain connects to all the antennas corresponding to the sub-array [30], [31], [32]. By using such configurations, it is possible to obtain a beam gain by sub-array analog beamforming with fewer RF front-end modules. At present, and various demonstration experiments aimed at practical implementation of this idea are underway [27], [33], [34].

Another approach that we are paying attention to, and which, several studies have been devoted to, is to perform MIMO using only a single RF chain [35], [36], [37], [38], [39]. As reported in [35], various structures (antenna selection, time division multiplexing (TDM), code division multiplexing (CDM), and parasitic antenna) have been evaluated, and simulations and hardware implementations have been performed. They suggest that implementing the hardware with a single RF chain, would be a significant simplification compared with the hybrid configuration. Many previous papers have reported theoretical or simulation studies; however very few papers have evaluated actual implementations in actual environments. For instance, one paper aimed at practical use [35] introduced a hardware configuration and evaluated the effect of diversity in a single input multiple input (SIMO) system. For practical applications, it will be necessary to clarify its effectiveness on spatial multiplexing in MIMO systems and MHz-class OFDM signals, which were not evaluated in [35].

For simplification of the hardware of a massive MIMO system in the era beyond 5G, this paper presents experimental results on an uplink multiuser MIMO - orthogonal frequency division multiplexing (OFDM) system with a single RF chain receiver. In our system configuration, the BS at the receiver side has a single RF chain with an antenna unit including parasitic antennas and a digital signal processing (DSP) unit. In the antenna unit, the antenna directivity pattern creates an additional spatial multiplexing gain by switching the antenna directivity pattern in synchronization with the received sampling frequency. In the DSP unit, oversampled OFDM signals are split into signals in different spaces by periodic down sampling. In addition, this paper indicates the potential for improving the channel capacity by applying the proposed configuration to an uplink multiuser MIMO-OFDM system.

Moreover, it describes the hardware configuration at the BS and experimental results on the proposed configuration to clarify its effectiveness and feasibility.

The rest of this paper is organized as follows. Section II describes the related work on simplifying the hardware of massive MIMO-OFDM system and our contributions. Section III outlines the system configuration of the uplink multiuser MIMO-OFDM system with a single RF chain receiver; and Section IV and V report the results of a simulation and experiment. Conclusions are drawn in Section VI.

II. RELATED WORK AND CONTRIBUTIONS

As described in the Introduction of Section I, one of the challenges facing practical massive MIMO systems is simplification of the hardware of both transmitter and receiver. There are various ways to meet this challenge, including antenna miniaturization, analog and digital hybrid beamforming for reducing the RF front-end, and use of low-cost devices. This study is aimed at simplifying the hardware through the use of a single RF chain, which means one receiver or one receiver. This approaches has been studied by various research institutions [35], [36], [37], [38], [39]. In particular, Mohammadi et al. [35] devised and antenna selection structure, TDM, CDM, and a parasitic antenna for realizing a MIMO system with a single RF chain, and clarified its effectiveness through theoretical simulations and an operational verification on their testbed. Kalis et al. [36] investigated a technology using parasitic antenna elements called “beamspace MIMO” and evaluated it under the assumption of specific antenna directivity. Other approaches under investigation are promising for realization of future wireless networks [37], [38], [39].

The number of RF chains can be reduced at the transmitter side, receiver side, or both. But when the above techniques are applied only to the transmitting side, bandwidth expansion over the air will occur due to the multiplexing of the independent transmitted signals. Thus, attempting an RF chain reduction at the transmitting side has a trade-off between bandwidth expansion and hardware simplification. Because of this problem, we decided to focus on a reduction at receiver side without bandwidth expansion over the air. In particular, we supposed an uplink multiuser MIMO-OFDM system in order to maximize the benefits of the RF chain transmitter.

| TABLE 1. Qualitative characteristics of each unit. |
|---|---|---|
| **Antenna Unit** | **Switching speed** | **Spatial DoF** | **Complexity** |
| Selection [35] | Good | Poor | Good |
| Combination Parasitic [35][36] | Good | Average | Average |
| TDM [35] | Poor | Good | Poor |
| RF chain unit | Oversampling [37] | Average | Good |

VOLUME 10, 2022
side on this system, \( N_t \) mobile terminals (MTs) simultaneously transmit independent MIMO-OFDM signals to the BS over the same frequency band. At the receiver side, the BS consists of an antenna unit and an RF chain, and it performs MIMO-OFDM reception using single RF chain. The elements in the antenna unit include those for antenna switching, antenna combination, and parasitic antennas.

The qualitative characteristics of the antenna and RF chain units are listed in Table 1. Here, assuming the use of OFDM signals, the antenna characteristics must be switched extremely quickly, within the same symbol. This requires the switching operation to be proportional to the number of antennas required within an OFDM symbol, and even higher speeds for broadband transmissions with short sampling intervals. Although antenna switching/combination using RF switches is relatively fast, the parasitic antenna used by electronically steerable passive array radiator (ESPAR) \([40],[41]\) contains varactor diodes, so high switching speed cannot be expected. Turning to the spatial degrees of freedom (DoF) which represent the potential of spatial multiplexing one finds that the number of spatial multiplexings depends on the number of antennas, since the spatial DoF of the antenna switching/combination depend on the installed antennas, which become a bottleneck. On the other hand, the antenna directivity of a parasitic antenna can be increased by changing the characteristics of each element. This process allows us to vary the signal for each angle, which improves the spatial DoF. In regard to the hardware complexity, as the required circuit size and device increases, the complexity and cost increase.

The RF chain unit of the uplink multiuser MIMO-OFDM systems can use, the TDM approach as described in \([35]\) and the oversampling approach described in this paper. As shown in Figure 1, the TDM approach is characterized by synchronized antenna switching and splitting up of the processing to the A/D converters. The signal acquired by antenna switching is passed through a low pass filter (LPF) to remove of the imaging signal and is converted into baseband signals by each converter. The DSP unit for MIMO-OFDM reception is used to separate the OFDM signals from each MT. Note that the sampling frequency of the TDM approach must be similar to that of conventional MIMO-OFDM reception. The oversampling approach is characterized by the use of a single A/D converter whose speed depends on the number of required spatial multiplexings instead of signal splitting by RF switches as in the TDM approach. This approach allows a reduction in the number of hardware components, although the required for sampling speed is higher than in the TDM approach. The specific configuration is described in the next section.

As shown above, MIMO systems with a single RF chain have been studied from a theoretical point of view. On the other hand, there are very few papers that evaluate actual implementations or their effectiveness in actual environments. On such example is reference \([35]\), which described a hardware configuration and the effect of diversity gain in a SIMO system using a testbed. However, for practical applications, it is necessary to clarify the effectiveness of spatial multiplexing in general MIMO systems and MHz-class OFDM signals. In this paper, we report our experimental evaluation aimed at accelerating the practical application of uplink multiuser MIMO-OFDM systems with a single RF chain. The following are the contributions of this research.

- We propose a novel hardware configuration of the uplink multiuser MIMO-OFDM system with a single RF chain receiver and indicate its potential for increasing the channel capacity.
- We experimentally demonstrate the effectiveness of the proposed configuration in an uplink multiuser system.
information on the different directivities can be obtained created is pre-set to reduce antenna correlation and maximize the effect patterns with different beam directions and beam widths are is limited. Therefore, in the proposed configuration, antenna is placed around the antenna element shown in Figure 1. controlling the reflector characteristics of the parasitic anten nas placed around the antenna element shown in Figure 1. The number of antenna patterns that can be set for an antenna is limited. Therefore, in the proposed configuration, antenna patterns with different beam directions and beam widths are pre-set to reduce antenna correlation and maximize the effect of spatial multiplexing. Note that the number of antennas created is \( N_t \). By using this antenna unit, it is expected that information on the different directivities can be obtained by receiving with different antenna characteristics for each sampling.

Let \( x = [x_1, x_2, \ldots, x_N]^{\top} \) denote a vector comprised of the MIMO-OFDM symbols simultaneously transmitted by all users in one use of the channel. Here \([ ]^{\top}\) is the transpose of a vector. It is assumed that the transmit powers of each MT are the same. Let \( H \in \mathbb{C}^{N_r \times N_t} \), where \( H = [h_1, h_2, \ldots, h_{N_t}]^{\top} \) is the channel response matrix. \( h = [h_{1k}, h_{2k}, \ldots, h_{N_tk}]^{\top} \) is the channel response vector from MT \( k (k = 1, 2, \ldots, N_t) \) to the BS, and \( h_{jk} \) denotes the channel gain from the \( k \)th MT to the \( j \)th antenna pattern at the BS. The received symbol vector at the BS in a channel use, which is denoted by \( y \in \mathbb{C}^{N_r} \), can be written as

\[
y = Hx + n.
\]

where \( n \) is a noise vector whose entries are modeled as independent and identically distributed (i.i.d.) \( \mathcal{CN}(0, \sigma^2) \).

With a linear MIMO-OFDM demodulation, the decision vector for the received symbol is

\[
\hat{x} = wy = wHx + wn.
\]

Using singular value decomposition (SVD), we have

\[
H = U \begin{bmatrix} \Lambda & 0 \\ 0 & 0 \end{bmatrix} V^H = [U_s \hspace{1em} U_n] \begin{bmatrix} \Lambda & 0 \\ 0 & 0 \end{bmatrix} V^H = U_s \Lambda V^H,
\]

where \( U \) and \( V \) are \( N_r \times N_t \) and \( N_r \times N_r \) unitary matrices and \([ ]^H \) is the Hermitian transpose. \( U_s \) and \( U_n \) are the signal and null spaces. \( \Lambda \) is a vector of the eigenvalues,

\[
\Lambda = \text{diag} \left\{ \lambda_1, \lambda_2, \ldots, \lambda_{N_t} \right\},
\]

where \( \lambda_{N_t} \geq 0 \). There are many ways of designing the linear receiver weight \( w \). Since receiver design is not the focus of this paper, we will assume a zero-forcing (ZF) receiver, i.e.,

\[
w = \left( U_s^H U_s \right)^{-1} U_s^H,
\]

for simplicity. Note that the restriction \( N_t \leq N_r \) is needed for a ZF receiver to be used. The decision vector is

\[
\hat{x} = \Lambda x + \hat{n},
\]

where \( \hat{n} = \left( U_s^H U_s \right)^{-1} U_s^H n \), which is Gaussian distributed with zero mean and covariance matrix,

\[
E \left[ \hat{n} \hat{n}^H \right] = \sigma^2 \left( \left( U_s^H U_s \right)^{-1} \right)^H,
\]

with all elements on the diagonal being \( \sigma^2 \).

IV. ANALYSIS VIA COMPUTER SIMULATIONS

This section presents the potential of the proposed configuration in improving for the channel capacity. We calculated the channel response from computer simulations with the ray-tracing approach and computed the channel capacity on the uplink multiuser MIMO-OFDM system, \( C \),

\[
C = \sum_{i=1}^{N_t} \log_2 (1 + \lambda_i).
\]

Figure 2 shows the relationship between the channel capacities of the proposed and conventional configurations and the number of oversamplings on the receiver side. In detail we
indicate the relative merits of the gains of the signal to noise power ratio (SNR) improvement and spatial multiplexing based on the proposed configurations when the number of oversampling frequencies is fixed. The conventional configuration includes a single input single output (SISO) system where the MT with a single antenna transmits OFDM signals to a BS with a single antenna. We assume SNR of averagely 30 dB and an i.i.d. channel response between the MT and BS. In general, oversampling can be expected to improve the SNR by suppressing the noise power within the received signals, so it can be regarded that the channel capacity increases as the oversampling increases. On the other hand, in the proposed configuration, it is possible to receive MIMO-OFDM signals with a different antenna directivity pattern through the effect of high-speed antenna switching synchronized with the sampling frequency and oversampling signals. It is expected that spatial multiplexing can be realized by regarding it as a signal from multiple antennas and this will substantially enlarge the channel. Note that the deterioration caused by antenna directivity switching is ignored. Moreover, the evaluation is in a high-SNR (30 dB) environment, we think that a large gain in channel capacity can be obtained. When SNR is low, it is expected that oversampling will have a large noise power reduction effect and the noise tolerance will be small. Therefore, the proposed configuration is considered to be effective in a high-SNR environment. It can be seen from the figure that the proposed configuration has the potential to raise the maximum channel capacity. However, in more realistic environments, it will be necessary to analyze the characteristics based on the noise power, status of multipath fading, the antenna correlation for each antenna directivity pattern, and the amount of deterioration due to antenna directivity pattern switching.

Next, we examined the impact of the proposed configuration by the antenna directivity pattern and MT positions by computer simulations. Figure 3(a) and 3(b) show the simulation scenarios with and without walls to vary the multipath condition. The area was 100 m (W) × 100 m (D) × 3 m (H). Table 2 lists the ray-tracing parameters.

The frequency was 4.85 GHz, as in sub-6 GHz based 5G networks. The Rx of BS was placed in the center of the area, two Tx of MTs were placed at 30 to 180 degrees around the Rx. The distance between Rx and each Tx was adjusted so that the SNR was 30 dB. The number of reflections was three and diffraction was taken into account. Each Tx antenna was a horizontally omnidirectional dipole antenna. On the other hand, the Rx antenna had an active element in the center and eight equally spaced parasitic elements around it, as described in Figure 3. The spacing between the active and parasitic elements was from 0.1 to 1 wavelength. Additionally, the antenna directivity pattern was controlled by varying the phase of the varactor diode connected to the parasitic element (0 or 180 degrees). In other words, since there were eight parasitic elements, a total of 256 patterning directives could

| TABLE 2. Ray-trace simulation parameters. |
|------------------------------------------|
| **Frequency** | 4.85 GHz |
| **Area (W×D×H)** | 100 m×100 m×3 m |

| Basic parameter | Value |
|-----------------|-------|
| Reflection number | 3 |
| Diffraction | Active |
| Distance between Tx and Rx | 30 dB |

| Tx antenna | Value |
|-------------|-------|
| Interval of Tx positions | 2 |
| Antenna type | Dipole |
| Number of Rxs | 1 |
| (Active element) |
| Number of reflection elements | 8 |

| Rx antenna | Value |
|------------|-------|
| Distance of active and reflection elements | 0.1 − 1 wavelength |
| Antenna pattern candidate | 256 (2^8) |

[FIGURE 3. Simulation scenarios.](image)

[FIGURE 4. Example of antenna directivity patterns.](image)
be created. Figure 4 shows one of the antenna directivity patterns corresponding to reflective element conditions. The channel responses for each Tx antenna position were calculated and merged to generate the channel matrix \( H \). The channel capacity calculation was then performed using Eq. (8). Furthermore, in the proposed configuration, the channel capacity is calculated for all combinations of antenna directivity patterns and the highest-capacity pattern was selected.

Figure 5(a) and 5(b) plot the channel capacity versus the distance between the active and refractive elements when the multipath environment was varied according to the presence or absence of a wall. The results for Tx positions are plotted in these figures. A comparison of the figures shows that the results differ somewhat depending on the presence or absence of the wall, but the trend is the same. Specifically, it can be seen that the highest channel capacity is achieved when the element spacing is about 0.3 wavelength. Since a similar spacing was set in the ESPAR study [40], [41], we consider that this simulation gave a reasonable result.

Next, looking at the data around 0.3 wavelength, we find that the channel capacity varies with the angle between the Tx antennas. As the distance between the Tx antennas increases, the channel capacity also increases. This can be attributed to the fact that antenna correlation is less likely to decrease when antenna directivity is changed at shorter terminal distances. The above shows that there are scenarios that can be improved with the proposed configuration.

V. FEASIBILITY ANALYSIS VIA EXPERIMENTAL MEASUREMENTS

A. EXPERIMENTAL SETUP AND ENVIRONMENT

The objective of this paper is to clarify the effectiveness of the proposed configuration in an office environment where wireless devices are used frequently and in a multipath fading environment. Figure 6 shows our measurement environment and the Tx/Rx antennas positions. Table 3 lists the experimental conditions. We conducted the measurements in our office room, which covers an area of 20 m (W) × 10 m (D) × 3 m (H), as shown in Figure 7(a). This room is enclosed by three concrete walls and a window. The Rx (BS) was placed in the center of the room and four Tx (MTs) were placed around it. Each Tx consists of four dipole antennas as shown in Figure 7(a). In addition, we measured the data by shifting the locations of the Tx/Rx to avoid testing in only a specific environment. MIMO-OFDM signals of 4.85-GHz center frequency and 1-MHz bandwidth were transmitted through an RF front-end and each antenna. The modulation scheme was OFDM with quadrature phase shift keying (QPSK). For the evaluation of the proposed configuration, we assumed that synchronizations within the testbed of the phase, frequency, and timing were perfect.

Figure 7(b) shows a photograph of the Rx antenna, which has an active element in the center and eight equally spaced parasitic elements around it. In the conventional ESPAR configuration, varactor diodes are used to vary the characteristics of the reflective element, but the response time is over a millisecond, which is not fast enough for the sampling frequency. In our testbed, reflective elements of different lengths are connected to each other by an RF switch, and the phase change of the reflective elements is controlled by the switch. The RF switch we used can be switched on the order of 100 ns, allowing the switching to match the sampling frequency. The sampling frequency of the testbed was set at 20 times the bandwidth (1 MHz), and 20 antenna directivity patterns were randomly set among the patterns that achieve relatively different directions. Figure 8(a) and 8(b) show examples of antenna directivity patterns we generated with the testbed. Figure 8(a) shows the antenna directivity when all reflective elements are turned off. As can be seen, the directivity characteristics are similar to those of an omnidirectional antenna as they do not act as reflective elements. The characteristics when three elements are turned on and work as reflective elements are shown in Figure 8(b). These results show the antenna directivity when all reflective elements are turned off. As can be seen, the directivity characteristics are similar to those of an omnidirectional antenna as they do not act as reflective elements. The characteristics when three elements are turned on and work as reflective elements are shown in Figure 8(b). These results show the antenna directivity can be changed by turning the elements on and off. The 12-quantization-bit A/D converter in the signal processing unit acquired 20 oversamplings of the signals received signals through the Rx antenna and RF front-end unit. The oversampled signals were split into.
signals with each antenna directivity pattern. Thereafter, the general MIMO-OFDM demodulation unit evaluated the segmented signals by applying a zero-forcing algorithm to the MIMO-OFDM signal as shown in Figure 2. We evaluated the MIMO-OFDM channel capacity from the channel response matrix between the Tx antennas and time-shifted Rx antennas and calculated the throughput from the uncoded bit error rate (BER).

### B. EXPERIMENTAL RESULTS

Figure 9 presents the channel capacity results of the uplink multiuser MIMO-OFDM systems calculated from measured channel response matrix based on Eq. (8). In the proposed configuration, MIMO-OFDM signals were randomly extracted from 20 oversampled signals to create segmented signals with 4 to 20 different antenna directivity patterns. These results were obtained from the antenna directivity pattern set with the largest channel capacity. To compare the conventional and proposed configurations, we measured the MIMO-OFDM channel matrix between four Tx antennas and four Rx antennas composed of half wavelength dipole antennas in the proposed configuration. The SNR in this environment was approximately 22 dB for both configurations. The figure shows that the channel capacity of the proposed configuration grows significantly with the number of time-shifted signals. This result indicates that antenna directivity pattern switching based on the proposed configuration is effective. Compared with the conventional configuration, there is no significant degradation. Figure 10 shows a box-and-whisker diagram of the channel capacity, including some antenna directivity pattern sets for each condition. As can be seen, when the number of time-shifted signals is small, some of the antenna correlations are close to each other and are thus not stable, while the results for the $4 \times 20$ configuration show a higher spatial DoF and more stable channel capacity. Moreover, Figure 11 plots the relationship between antenna correlation and channel capacity including some antenna directivity pattern sets for each condition. Note that antenna correlation means the average of the correlation values between antennas. As shown in this figure, lowering the antenna correlation is expected to improve the channel capacity. Therefore, the proposed configuration requires the antenna directivity pattern to be optimized.

To further clarify the feasibility of the proposed configuration, we examined the demodulated QPSK constellations of four Txs without and with the antenna directivity switching. Figure 12(a) shows the result without antenna directivity switching, and Figure 12(b) shows the result with it. Without antenna directivity switching, MIMO-OFDM reception is not possible because the correlation between the antenna
directivity patterns are identical. On the other hand, the proposed configuration results in a constellation of QPSK signals. This is because it performed antenna pattern switching and MIMO-OFDM demodulation of the order on 100 ns. This result shows that the proposed configuration enables MIMO-OFDM reception in a single RF chain. In addition, we compared the throughputs when actual data were transmitted in terms of the normalized throughput with the throughput of the conventional configuration set to 1. The throughput was calculated from the BER obtained by our testbed. Figure 13 shows the normalized throughput of the conventional and proposed configurations when the antenna directivity pattern with the lowest BER was used. It shows that the throughput improves with increasing number of RX antennas, similar to the trend of the channel capacity in Figure 9. The throughput of the $4 \times 20$ configuration was close to that of the conventional configuration. Thus, the proposed configuration...
Directivity patterns. With these improvements, more spatial multiplexes can be achieved. The second is the application to the downlink system, which can be mounted on MTs by miniaturizing the proposed configuration. This is expected to expand the channel capacity of the uplink and downlink systems.

VI. CONCLUSION

In order to simplify the hardware while maintaining high channel capacity of the uplink massive MIMO-OFDM systems, this paper proposed a novel spatial division multiplexing configuration that has a single oversampled receiver with an antenna unit for creating additional spatial diversity by switching the antenna directivity in synchronization with the received sampling frequency. The proposed configuration enables spatial multiplexing with only one RF chain even through the BS configuration is simplified. To clarify the effectiveness of the proposed configuration, we evaluated it by simulation and experiment was conducted in an actual indoor office environment to show the feasibility of the configuration in a situation with multipath fading and deterioration due to antenna directivity switching. By increasing the number of spatial multiplexings, the throughput of the proposed configuration can be obtained in the same manner as a conventional transmission having multiple RF chains. Thus, we confirmed that the proposed configuration could be applied to future wireless communication systems. Although this paper targets an indoor office environment, we expect that our method would give similar results in a multi-path propagation environment, such as an urban area. However, we think that its effectiveness in an outdoor environment still needs to be evaluated in order to expand the application area.

We have two major issues for further channel capacity improvement. The first is the need for faster antenna directivity switching and lower spatial correlation between antenna directivity patterns.
T. Murakami et al.: Performance Evaluation of Uplink Multiuser MIMO-OFDM System With Single RF Chain Receiver

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