Performance Evaluation of Wireless Communications using Orbital Angular Momentum Multiplexing

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***Abstract* – This paper investigates the performance of wireless communications using orbital angular momentum multiplexing in terms of modulation/demodulation, multiplexing/demultiplexing, and power control. This work enabled us to clarify the effect of mode-dependent power attenuation and provides insight regarding the potential and limitations of OAM-based wireless communications.**

***Index Terms* — Orbital angular momentum multiplexing, OAM, uniform circular array**

1. Introduction

Recently, wireless communication using OAM (Orbital Angular Momentum) has drawn much attention as an emerging candidate of 5G/Beyond 5G technology. OAM is a physical property of electro-magnetic waves that are characterized by a helical phase front in the propagation direction. Since the characteristic can be used to create multiple orthogonal channels, wireless communication using OAM can increase radio spectrum efficiency and expand the capacity of the scarce radio spectrum [1, 2].

To explore these possibilities, in the work reported in this paper we investigated the performance of modulation/demodulation algorithms of the technology. This work enabled us to clarify the effect of mode-dependent power attenuation and consider a simple method for pre-compensating transmission power. In doing so we generated OAM signals by using a UCA (uniform circular array) that comprises multiple omnidirectional antenna elements.

2. Modulation and Demodulation

Modulation and demodulation using OAM can be mainly categorized into two schemes. We detail these schemes as follows.

1) OAM Shift Keying (OAMSK) [3]: This scheme simply puts binary data into an OAM mode. For example, bit “0” is mapped as OAM mode 1, while bit “1” is mapped as mode -1. OAMSK modulated signals can be demodulated by using the phase gradient method, an FFT-based method, or ML (maximum likelihood) detection. The gradient method uses the phase difference between two receive antennas to determine the OAM mode. The FFT-based method conducts the FFT process using reception (Rx) UCA and chooses the maximum coefficients. ML detection selects the OAM mode with the closest distance to the received signal.

2) OAM Division Multiplexing (OAMDM) [4]: This scheme uses OAM modes to carry multiple streams of data simultaneously. An OAM mode can carry one stream, similarly to the way that one OFDM subcarrier can. This scheme potentially improves the spectrum efficiency. With it, OAMDM modulated signals are demodulated similarly to the way they are with MIMO equalization techniques such as zero forcing or minimum mean square error equalization, assuming the channel information is available. This assumption is feasible because OAM-based wireless communication is the most commonly used communication method in a LOS environment.

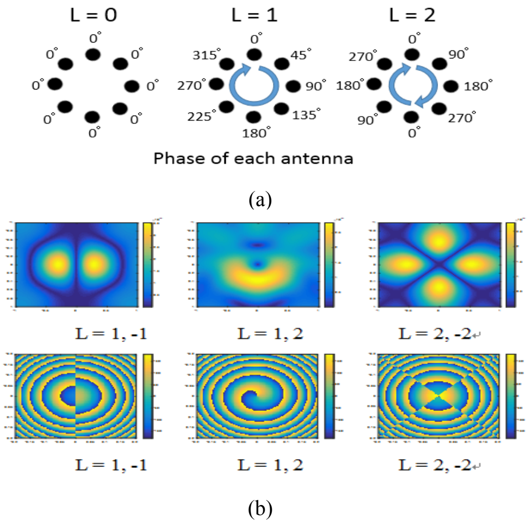

Fig. 1 (a) Generation of OAM modes with a UCA, (b) Intensity distribution (above) and phase front (below) of combined OAM modes (L is the number of modes).

3. Mode-dependent Power Distribution

In the work we report here, we also considered two key issues regarding the mode-dependent power distribution among different OAM modes. These issues are as follows.

1) Peak Rx Power Degradation. As the number of OAM modes increases, the radiation becomes wider, the angle from the beam axis at the peak Rx power becomes wider, and the SNR at its peak Rx power becomes smaller. Accordingly, the performance is degraded as the number of OAM modes increases.

2) Non-identical Peak Rx Power Locations: The peak Rx power locations of each OAM mode are not identical because their radiation patterns are distinct. Therefore, the mode-dependent performance degradation becomes more severe when a single Rx UCA is used because some OAM

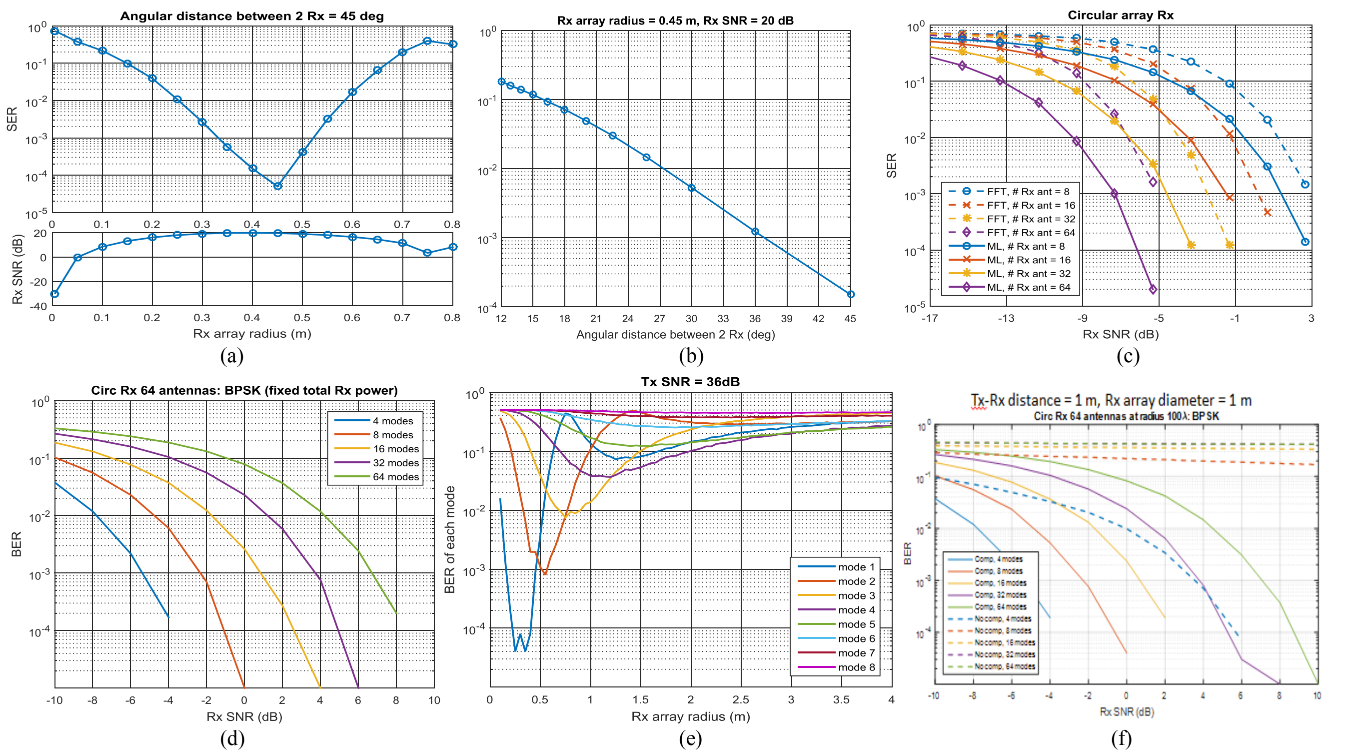

Fig. 2 Performance evaluations of (a) OAMSK (phased gradient method with varying Rx array radius), (b) OAMSK (phased gradient method with varying angular distance), (c) OAMSK (FFT-based and ML methods), (d) OAMDM with fixed Rx power, (e) OAMDM with varying Rx array radius, (f) OAMDM with pre-compensation.

modes might not have the peak Rx power at a certain location. To prevent such mode-dependent performance degradation it is necessary to pre-compensate the transmission power for each mode.

4. Evaluation

We implemented a simulation testbed of OAM based wireless communication at 60 GHz. Figure 1(a) shows an illustration of the generation of OAM signals using UCA. Note that concurrent transmission of multiple OAM modes can be achieved by superposing multiple OAM signals as in Fig. 1(b).

Figures 2(a) and 2(b) show the OAMSK performance obtained by the phase gradient method with varying Rx array radius and angular distance between two Rx antenna elements. Although the performance is poorer than those of FFT-based and ML methods, only two antenna elements are necessary rather than all the antennal elements of the Rx UCA. This is favorable for higher OAM mode transmission. Figure 2(c) shows the OAMSK performance obtained by using the FFT-based method and ML detection while varying the number of antenna components in the Rx UCA. We found that in both cases the ML detection yields generally better results and additional performance gain is achieved as the number of antenna components in the Rx UCA increases. Figure 2(d) shows the OAMDM performance with fixed total Rx power among OAM modes. Note that Rx signals in this curve are obtained at the location of the peak Rx power of each mode. In this case we observed performance degradation of 3 dB as the number of OAM modes increased. Figure 2(e) shows the effect of the non-identical location of the peak Rx power by varying the Rx array radius. As the OAM mode number increases, the Rx array radius for the best BER performance also increases. Correspondingly, if the Rx array radius is customized for a certain OAM mode, the performance of other OAM modes' signals might be deteriorated severely. Figure 2(f) shows the results we obtained for the unlimited pre-compensation of transmission power by using the water filling method. The performance enhancement was confirmed because the transmission power was adjusted so as to be equal for Rx signals of different OAM modes. However, 60 and 200 dB of pre-compensation were respectively needed for 8 and 16 OAM modes, which can cause a practical limitation. Therefore, a practical solution would seem to be using OAM modes up to the 3rd mode, for which necessary power for pre-compensation is around 10 dB.

5. Conclusion

We studied the potential and limitation of OAM-based wireless communication in terms of mode-dependent power attenuation through the use of modulation/demodulation algorithms. We confirmed that the spectral efficiency can be increased by applying proper power compensation to a certain degree. Further study is necessary to fully rectify the undesirable effects of the mode-dependent power attenuation.

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