Performance Comparison of MIMO-OCDM and MIMO-OFDM in Next-Generation Wireless Communication Systems

Muneeb Ahmad, Salman Ahmad, Soo Young Shin*
Department of IT Convergence Engineering,
Kumoh National Institute of Technology, Gumi, South Korea
muneeb.ahmad@kumoh.ac.kr, salman@kumoh.ac.kr, *wdragon@kumoh.ac.kr

Abstract

This paper presents a comprehensive performance comparison between Multiple-Input Multiple-Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Chirp Division Multiplexing (OCDM) for future wireless communication systems. The evaluation focuses on Bit Error Rate (BER) performance across different modulation schemes (4-QAM, 16-QAM, 64-QAM) and equalization techniques (Zero Forcing (ZF) and Minimum Mean Square Error (MMSE)). The results demonstrate that MIMO-OCDM consistently outperforms MIMO-OFDM in terms of BER, especially in environments characterized by frequency-selective fading and multipath interference.

Ⅰ. Introduction

It is anticipated that sixth-generation (6G) mobile networks will support a wide range of devices and use cases, each with specific needs [1]. 6G encompasses various categories of network evaluation factors such as massive machine-type communication (mMTC), ultra-reliable low-latency communication (URLLC), improved mobile broadband (eMBB), Artificial Intelligence (AI) based network and many more [2]. Every category has distinct needs and relates to a distinct use case. For instance, URLLC must be dependable with latencies of less than 1 ms, eMBB must provide mobile devices with high data-rate uplink and downlink connections, and mMTC must cover many devices that use less power and have longer network lifetimes [2].

The standardization process for eMBB has already implemented OFDM as multiple access scheme, owing to its minimal complexity equalization and orthogonality of subcarriers. On the other hand, OFDM's error performance may be severely compromised by burst errors brought on by channel nulls or interference [3]. Because of these issues, it may be unable to ensure the dependability limits inherent in URLLC. Furthermore, interference is inevitable in mMTC networks because of their operation in unlicensed bands. As a result, other strategies must be researched, and spreading systems such as OCDM offer great potential for addressing these issues. This paper discusses the comparison between MIMO-OCDM and MIMO-OFDM for next-generation wireless communication. The authors compare the BER for various equalization approaches and modulation algorithms.

Ⅱ. System Model

OFDM and OCDM allows for the transmission of data in parallel by dividing the frequency spectrum into orthogonal subcarriers and chirps, respectively. Multiple antennas are used to transmit and receive OFDM and OCDM signals in MIMO setup, which improve data speeds and reliability by increasing spatial diversity and multiplexing. The MIMO-OFDM and MIMO-OCDM signal representation is given below, respectively:

$$x[n] = \sum_{k=0}^{N-1} X[k] e^{j\frac{2\pi kn}{N}}, \quad x[n] = \sum_{k=0}^{N-1} C_k e^{-j\frac{\pi(n-k)^2}{N}} \qquad (1)$$

Data is modulated using a digital modulation scheme such as QAM. The modulated data symbols are converted from serial to parallel and mapped onto orthogonal subcarriers and chirps using an IFFT and Inverse Discrete Fresnel Transform (IDFnT), respectively [1]. A CP is then added to each symbol to mitigate inter-symbol interference (ISI) due to multipath propagation. The signal propagates through a MIMO channel, modeled as:

$$Y = Hx_t + n \qquad (2)$$

At the receiver, the cyclic prefix is removed, and the received signal is transformed back to the frequency domain using an FFT and DFnT. Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) equalization is applied to detect the transmitted symbols. The detected symbols are finally demodulated to retrieve the transmitted data.

III. Performance comparison of OCDM with OFDM under MIMO setup

By using chirp signals, OCDM provides resilience to frequency-selective fading and multipath interference, ensuring lower BER and improved performance in challenging wireless environments. A chirp signal is one in which the frequency increases or decreases over time. For OCDM, the frequency of each chirp varies linearly with time. Chirp signals inherently spread their energy across a wide frequency band. This contrasts with OFDM, where each subcarrier occupies a narrow frequency band.

Due to the large frequency range occupied by a chirp signal, only a tiny fraction of its energy is affected by narrowband interference or deep fade. This reduces the likelihood of frequency-selective fading affecting the signal. Frequency diversity is introduced when information is dispersed over a large frequency spectrum. This implies that even if certain sections of the signal spectrum are severely faded, others may still be received properly, hence boosting total signal resilience.

IV. Multipath Interference and Time-frequency Localization

Chirp signals are inherently resistant to multipath effects, which cause inter-symbol interference (ISI). Multipath interference arises when transmitted signals reflect off many objects, sending multiple delayed copies of the original signal to the receiver at different times. Because chirp signals fluctuate in frequency, multipath components are spread over various frequency bands. This spreading helps the receiver distinguish multipath components. Due to its positive autocorrelation, chirp signals may be distinguished from delayed ones. The receiver can reduce signal interference by distinguishing direct and reflected paths. Chirp signals' unique properties keep multipath components orthogonal, reducing destructive interference. This orthogonality ensures that multipath components do not significantly interfere with the main signal, minimizing ISI and enhancing BER, as shown in Fig. 1.

In the presence of time-frequency dispersive channels, which produce time delay and Doppler shifts, orthogonality requires chirp signal time-frequency localization. Chirp signals are well-localized in both time and frequency due to their linear frequency change. Dual localization distributes signal energy in a controlled way that the receiver may use. The varying frequency of chirp signals makes them less vulnerable to Doppler changes. Since the signal's frequency is variable, a Doppler shift affects various regions of the chirp differently, enabling the receiver to extract information. Chirp signals' time-frequency structure helps differentiate sub-chirps and multipath components. This structure helps the receiver to decode the signal properly even with high time-frequency dispersion and can be seen in Fig. 2.

V. Conclusion

MIMO-OCDM has greater performance in multipath situations and in the presence of inter-numerology interference, as compared to MIMO-OFDM. This advantage is especially notable since MIMO-OCDM does not need the use of guard bands. Nevertheless, MIMO-OFDM could still be used in less complicated situations or where maintaining compatibility with current systems is crucial. The selection of modulation order allows for precise adjustment of the balance between data rate and bit error rate (BER) according to the application and channel circumstances.

In the future, the authors want to expand the work using additional multiple access approaches and the incorporation of deep learning into the network to improve signal detection.

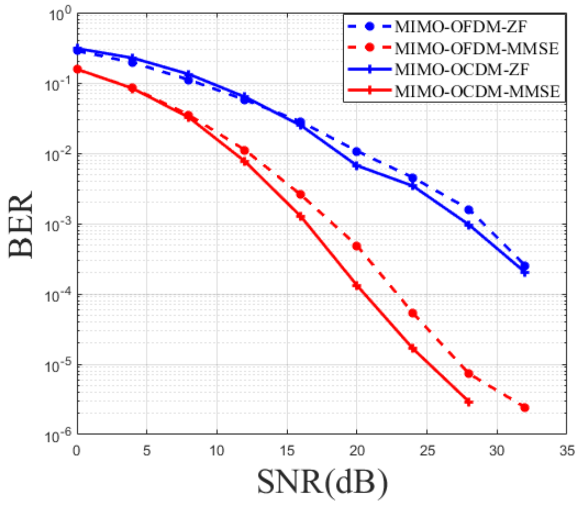

Fig. 1 BER comparison of OFDM and OCDM under MIMO setup for ZF and MMSE equalization

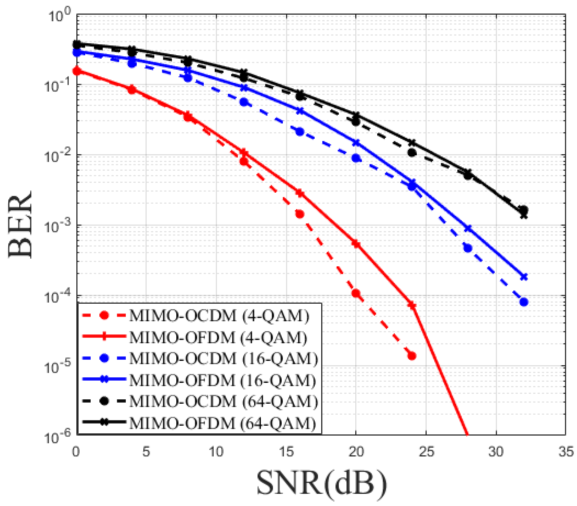

Fig. 2 BER comparison of MIMO-OFDM and MIMO-OCDM for 4, 16 and 64-QAM under high time-frequency dispersion

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