Wavelet Transform based Pulse Shaping for MIMO-SEFDM to Reduce Compression-Induced Interference

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Abstract

Multiple Input Multiple Output (MIMO) and spectral efficient frequency division multiplexing (SEFDM) are the two mainstream techniques to improve the capacity of Internet of Things (IoT) networks. Due to the non-orthogonality of SEFDM, the induced interference degrades the performance of MIMO-SEFDM network. To recover signals affected by inter carrier interference (ICI), efficient pulse shaping method can play an important role to reduce the effect of induced ICI and higher side lobes energy. In this study, a wavelet-based pulse shaping method is suggested for MIMO-SEFDM as it improves the symbol error rate (SER) of the system and can provide significant gain over traditionally utilized Fast Fourier Transform (FFT) based pulse shaping.

Ⅰ. Introduction

Fifth-generation (5G) wireless communication is already explored enough, and expats all over the world are working on sixth-generation (6G) cellular networks. MIMO (Multiple Input Multiple Output) appears to address the KPIs of future 6G networks by accommodating multiple users and high data requirements of future 6G wireless communication. MIMO is a wireless technology that uses multiple antennas at both the transmitter and receiver to increase the capacity and performance of wireless communication systems. The basic idea behind MIMO is to use multiple antennas at both the transmitter and receiver to create multiple independent channels, which can be used to transmit multiple data streams simultaneously. This results in an increase in the data rate and a reduction in the error rate, leading to a more efficient communication system

Similarly, spectral efficient frequency division multiplexing (SEFDM) is a method of transmitting multiple signals simultaneously over a shared frequency band. It uses a technique called frequency division to separate the signals into different frequency bands, allowing them to be transmitted on the same channel with compression factor that enhances spectral efficiency. This method increases the amount of data that can be transmitted in a given frequency band, making it more spectral efficient than other methods on the cost of induced interference.

In order to benefit with the gains of both MIMO and SEFDM technology, authors in this article present an analysis of MIMO-SEFDM technique that uses multiple antennas at the transmitter and multiple users at the receiving end to increase the spectral efficiency of wireless communication systems. By transmitting and receiving multiple signals simultaneously over different spatial paths, MIMO SEFDM can effectively increase the capacity of wireless communication systems. MIMO SEFDM technology can be used in wireless standards such as Wi-Fi, 4G, and 5G. This technology is based on the idea that multiple antennas at the transmitter or receiver can be used to create multiple independent channels, which can be used to transmit multiple data streams simultaneously. This results in an increase in the data rate and a reduction in the error rate, leading to a more efficient communication system.

II. System Model

Consider a system with N subcarriers, each of which is non-orthogonal at a normalized subcarrier spacing represented by $\alpha \in (0,1)$, where α calculates bandwidth compression and saves bandwidth by a factor of (1-α) * 100%. The transmitted SEFDM expression x is as follows:

$$x(k) = {}^{1}\!/\!_{\sqrt{N}} \sum_{n=1}^{N} \sum_{i=1}^{M} v_n \, s_n^i(k) e^{j2\pi n \alpha_k / N}$$

where s is the QPSK modulated signal on n^{th} subcarrier and i^{th} antenna, α is the compression factor of the n^{th} subcarrier. N is the total number of subcarriers; M is the number of antennas at the BS and v is the precoding vector of the intended user. This equation is just a representation of a possible signal that can be used in MIMO-SEFDM, the signal and modulation scheme may vary depending on the specific implementation.

Each SEFDM symbol has 128 subcarriers. These subcarriers are then compressed in the frequency domain, and the packet is ready for transmission through the communication channel after being converted to the time domain. A multipath Rayleigh fading channel is used. The signal-to-noise ratio ranged between 0 and 30 decibels. Traditionally, Fast Fourier transform (FFT) based filters are utilized for pulse shaping at the transmitter and inverse FFT (IFFT) is used at the receiver. The drawbacks of traditional pulse shaping are the increased out of band radiation and higher peak to average power ratio (PAPR). Since, SEFDM is already compressed which induces inter carrier interference (ICI) and after propagating through the channel, transmitted signal further attenuates and this reduces the overall system's symbol error rate (SER).

The authors used wavelet filter-based pulse shaping for MIMO-SEFDM to suppress out-of-band (OOB) radiation and compensate for SER. Wavelet produces variable sidelobe attenuation values that are substantially lower than standard FFT based SEFDM depending on the wavelet filter type used. Even when there are carrier frequency offsets, this reduces the ICI. The application of FFT and Wavelet is a linear transformation process of a signal. By applying either FFT or Wavelet transformation on the received signal Y is given as:

$$y(t) = FFT[x(t) + N(t)]$$
$$y(t) = X(t) + N_{FFT}(t)$$

Whereas the output of the wavelet filter bank is given as:

$$y(t) = DWT[x(t) + N(t)]$$
$$y(t) = X(t) + N_w(t)$$

In comparison to FFT-OFDM, the power density of wavelet filter banks is extremely restricted. OFDM systems suffer from significant OOB energy radiation due to large side lobes, resulting in high ICI. Alternatives to reducing OOB energy radiation have been presented in research, however these strategies, such as weighted carrier cancellation, may produce an increase in SER or PAPR while also being spectrally inefficient. Wavelet provides time-limited wave forms with very strong attenuation side lobes, eliminating the requirement for cyclic prefix to overcome inter-symbol-interference (ISI), as is done in OFDM-based conventional SEFDM.

III. Performance Evaluation

In this section, the results are discussed to justify the suggested wavelet-based MIMO-SEDFM which performs better than conventional FFT-based MIMO-SEFDM. Fig. 1. presents the SER of traditional OFDM and the suggested wavelet based SEFDM. As mentioned in Section II, compression factor of 0.7, 0.8 and 0.9 yield 10%, 20% and 30% bandwidth savings, respectively. In this study, a maximum of 30% compression is attempted since at 40% compression, the BER worsens and the signal is beyond recovery.

It can be seen in Fig. 2. that wavelet possesses lower side lobe energy compared to FFT filter-banks. Detecting and recovering data is already difficult in SEFDM, since the SER degrades owing to compression. Wavelets, on the other hand, improves SEFDM signal detection and data recovery significantly. At $20dB$, for conventional MIMO-SEFDM, 30%, 20% and 10% compression provide $1.4x10-1$, $0.4x10-2$ and $0.1x10-2$ SER, whereas at the same value of SNR the suggested wavelet based SEFDM provides $0.7x10-2$, $0.3x10-2$ and $0.4x10-3$ SER, respectively. It is important to mention here that if the SER performance degrades, the overall system's performance and throughput also deteriorate. Therefore, wavelet-SEFDM performs better than FFT-SEFDM due to its high-quality filter banks.

V. Conclusion

In this paper, the authors have presented the impact of wavelet filter banks for better signal and data recovery of MIMO-SEFDM compared to the conventionally utilized FFT based pulse shaping method. In Future work, the deep learning model can be applied to reduce interferences and the performance of SEFDM up to 40% compression rate can be enhanced utilizing deep neural networks.

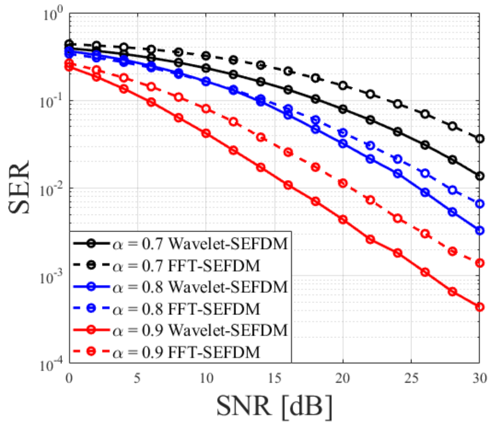

Fig. 1. SER of FFT and Wavelet based MIMO-SEFDM

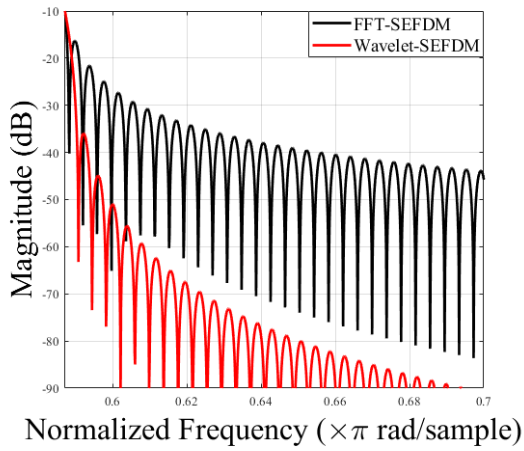

Fig. 2. Power Spectra of FFT and Wavelet based SEFDM

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