Design of Power Domain Non-Orthogonal Demodulation Based on OFDM System

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ABSTRACT

In mobile ad-hoc networks, OFDM technology is widely used, and in order to improve system capacity and reduce the problem of multiple retransmissions caused by collisions, non-orthogonal multiple access technology is usually used, which leads to non-orthogonal aliasing at the receiver of the OFDM system. In order to solve the aliasing signal separation problem of OFDM system, SIC(successful interference cancellation) technology, a non-orthogonal demodulation method based on OFDM system is proposed in this paper, according to the channel error vector magnitude (EVM), selecting sub-carrier blocks with better channel conditions for transmission, focusing on the use of subcarrier block SIC solution when there is non-orthogonal aliasing in the power domain at the receiver under strict synchronization. The simulation results show that, in this case, the aliasing signal separation technology for OFDM system adopted in this paper can not only improve the system capacity and improve the bit error performance, but also easy to implement in engineering.

Keywords: Subcarrier block SIC, OFDM, Non-orthogonal aliasing in power domain, EVM

1. INTRODUCTION

OFDM technology, as a modulation technology, has always played an important role in various communication fields, especially in mobile ad-hoc networks. However, in multi-node mobile communication, due to channel conditions and other factors, users inevitably perform multiple collisions and retransmissions, which will greatly affect communication efficiency and lead to waste of resources. As one of the important research technologies of 5G, the non-orthogonal multiple access technology allows multiple users to occupy the same resources for data transmission at the same time, which can significantly improve the system capacity. Therefore, the non-orthogonal multiple access technology based on the OFDM system is an important research direction.

How to recover the effective data of each user from the aliased signal at the receiving end of the OFDM system is the premise of realizing non-orthogonality. SIC technology is an important method of baseband non-orthogonal multiple access reception which was originally proposed by P. Patel et al. These results have important guiding value for improving the reliability of non-orthogonal demodulation. Japanese scientist Y. Saito et al have elaborated the concept and principle of non-orthogonal multiple access technology [1][2], and pointed out that compared with orthogonal multiple access system, non-orthogonal multiple access system can improve system capacity and spectral efficiency under frequent retransmissions circumstance. Power domain non-orthogonal demodulation means that OFDM technology is used to filter out the orthogonal useless signals firstly at the receiver, and then the multiple access interference of other users is eliminated by SIC, thus the demodulation is performed correctly [3][4].

At present, the existing literatures are mainly devoted to the channel estimation algorithm in the case of strict synchronization of received signal in the power domain non-orthogonal SIC demodulation [5-7]. The main contribution of this paper is based on OFDM system, combining with the intra-slot SIC demodulation technology to achieve non-orthogonal reception in the power domain. At the same time, this paper is different from the existing research in [8][9], using subcarrier block SIC technology, and the subcarrier blocks with better channel conditions are selected by EVM for transmission[10], while the ones with poor channel conditions are not transmitted. Although part of system capacity is sacrificed, it is of great significance in improving the bit error performance. At the same time, this method is also easy to implement in engineering.

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2. SYSTEM MODULATION AND ALGORITHM DESIGN

2.1 Traditional OFDM system

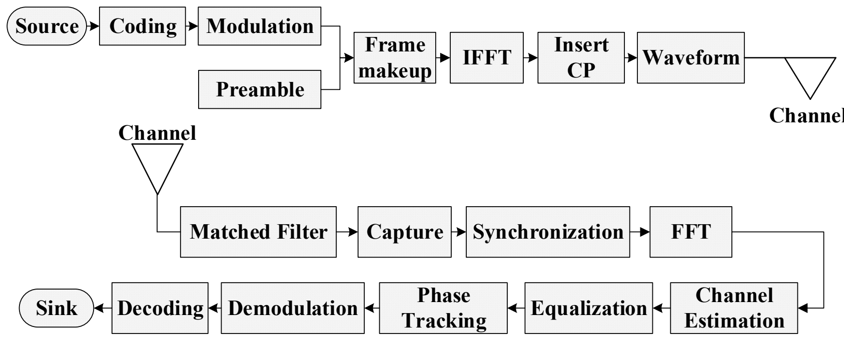

Fig. 1. Baseband processing structure of traditional OFDM system

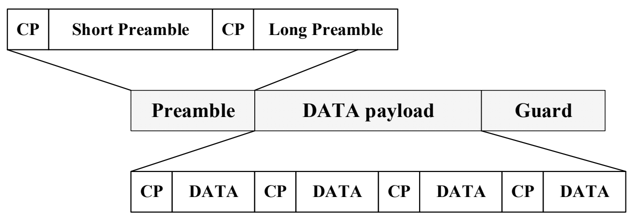

Fig. 2. Traditional frame format in OFDM system

Fig. 1 shows the baseband processing flow of traditional OFDM system. The transmitter undergoes operations such as coding, modulation, framing, FFT, etc., and then transmits signal through radio frequency. The receiver performs corresponding inverse operations on the signal to achieve successful demodulation. Fig. 2 shows the traditional physical layer frame format, CP is used before both preamble and data to reduce inter-symbol interference. Short preamble is used for capture and synchronization, long preamble is used for channel estimation and equalization. When the received signal is non-orthogonal aliased, if the traditional frame structure is used, long preamble used for channel estimation will also be aliased, which greatly reduces the success probability of SIC demodulation. Thus, designing a new frame format is especially important for non-orthogonal demodulation performance.

2.2 Intra-Slot SIC based on OFDM description

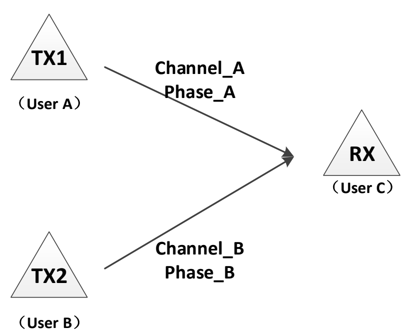

Fig. 3. Three-user communication scenario

The only way to distinguish different user signals depends on the difference in power. Assuming that two transmitters and one receiver are set, the RX will receive aliased signals. In order to ensure normal demodulation, SIC is required. The specific process of SIC detection at receiver is:

1. The receiver uses conventional single-packet reception techniques to resolve the signal with highest power from the aliased signal.

2. The receiver reconstructs that signal and then subtracts the reconstructed signal from the received aliased signal, so for the data of other users, it is equivalent to eliminate the strong interference signal, which can demodulate low-power signals.

In OFDM system, it is assumed that the data of user 1 is modulated to form a high-power signal $s(t)$, and the data of user 2 is modulated to form a low-power signal $c(t)$, which are signals with different powers but the same frequency at the same time, expressed as follows:

$$s(t)=\frac{1}{N}\sum_{k=-\infty}^{\infty}\sum_{n=0}^{N-1}\sqrt{P_s}\cdot s_{n,k}\cdot\exp\left[j2\pi(f_c+n\Delta f)(t-kT_s)+\phi_0\right]\cdot g(t-kT_s) \tag{1}$$

$$c(t)=\frac{1}{N}\sum_{k=-\infty}^{\infty}\sum_{n=0}^{N-1}\sqrt{P_c}\cdot c_{n,k}\cdot\exp\left[j2\pi(f_c+n\Delta f)(t-kT_s)+\phi_0\right]\cdot g(t-kT_s) \tag{2}$$

In the above formula, N is the number of subcarriers, while k is the number of OFDM symbols, P_c and P_s are the powers of two signals, f_c is the carrier frequency and Δf and T_s are subcarrier spacing and OFDM symbol period respectively. $T_s = T_u + T_{cp}$, $T_u = 1/\Delta f$.

As shown in Fig. 3, assuming that the channel between two communicating nodes is an Additive White Gaussian Noise channel, the signal received by user C is expressed as

$$r(t)=s(t)+c(t)+n(t) \tag{3}$$

where $n(t)$ is white Gaussian noise. The receiver firstly demodulates and decodes high-power signal $s(t)$, then subtracts it from the aliased signal, so as to obtain the data of another user as

$$r'(t)=c(t)+n(t) \tag{4}$$

2.3 Model and Scheme Design of SIC based on OFDM

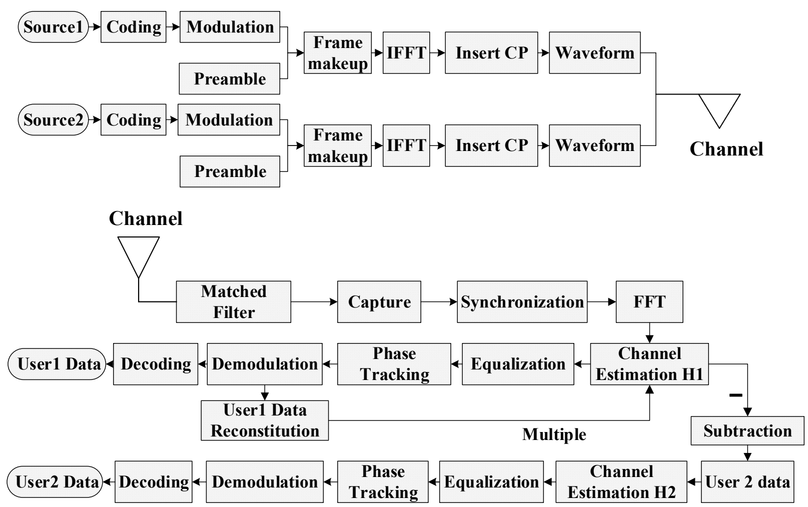

Fig. 4. Baseband processing structure of OFDM using intra-slot SIC

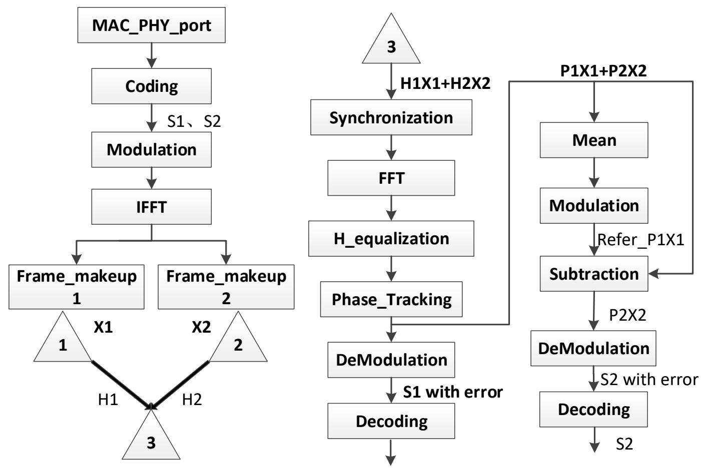

Fig. 5. Transceiver processing flowchart of OFDM using intra-slot SIC

Short Preamble1	Long Preamble1	0	DATA 1

Short Preamble2	0	Long Preamble2	DATA 2

Fig. 6. Improved frame format in OFDM system

Assuming that the unit power signals sent by two transmitters are respectively expressed as X_1 and X_2 , The transmit power $P_1 > P_2$, Therefore, when channel noise N exists, the aliased signal received by the receiver is:

$$r^{(1)}(t) = r_1(t) + r_2(t) + N = H_1 P_1 X_1 + H_2 P_2 X_2 + N \tag{5}$$

In order to correctly solve the aliased signal at the receiver, the following conditions need to be met:

$$SINR_1 = \frac{P_1 X_1}{P_2 X_2 + N} > \gamma \tag{6}$$

$$SINR_2 = \frac{P_2 X_2}{\left(P_1 X_1 - P_1^{'} X_1^{'}\right) + N} > \gamma \tag{7}$$

Therefore, the receiver needs to decode the first user's data, then subtract the first user's signal from the aliased signal.

$$X_1^{'} = \frac{r^{(1)}(t)}{H_1^{'}} \approx P_1 X_1 + \frac{H_2 P_2 X_2 + N}{H_1^{'}} \tag{8}$$

$$\begin{aligned} r^{(2)}(t) &= r^{(1)}(t) - r_1^{'}(t) \\ &= H_1 P_1 X_1 + H_2 P_2 X_2 + N - H_1^{'} P_1^{'} X_1^{'} \\ &\approx H_2 P_2 X_2 + N \end{aligned} \tag{9}$$

After that, the second user's data is decoded according to the normal receiving steps.

$$X_2^{'} = \frac{r(t)^{(2)}}{H_2^{'}} = \frac{H_1 \Delta X_1 + H_2 P_2 X_2 + N}{H_2^{'}} = P_2 X_2 + \frac{H_1 \Delta X_1 + N}{H_2^{'}} \tag{10}$$

2.4 Model and Scheme Design of Intra-slot chunked SIC based on OFDM

Unlike full-band SIC, chunked SIC-OFDM system divides the total frequency band into blocks, selecting the respective available frequency bands according to the frequency patterns of two users, then the receiver solves the data respectively according to their own patterns. The schematic diagram is as follows:

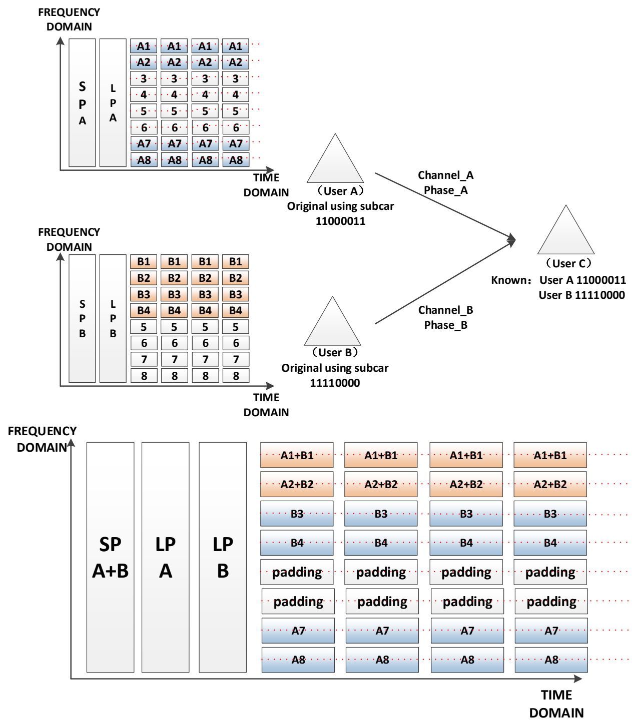

Figure 7. Chunked SIC-OFDM patterns of three nodes

As shown in Fig. 7, after the OFDM data subcarriers are divided into blocks, the subcarriers are divided into 8 independent blocks according to the frequency in the figure. Each transmission selects the carrier block with better channel conditions according to the EVM for data transmission. When the channel conditions of the entire communication band cannot support the full-band SIC, OFDMA combined with chunked SIC is used to expand the communication capacity, and compared with the full-band SIC, although part of the system capacity is sacrificed, the bit error performance will be improved.

Which subcarrier blocks the sender selects in this transmission is determined by subcar in the demodulation module of receiver after previous transmission, and this variable is determined by the deviation of data received in the previous transmission and the standard modulation point，which is called EVM. Taking QPSK as an example, assuming the data after modulation is set as $z=a+b\mathrm{i}$. The vector coordinates of standard QPSK constellation points are (1, 1), (1, -1), (-1, 1), (-1, -1), then the EVM is calculated as follows:

$$\mathrm{EVM} = \frac{\sqrt{(c\pm1)^2+(d\pm1)^2}}{\overline{P_M}} \tag{11}$$

c and d are the real part and imaginary part corresponding to z, $\overline{P_M}$ is the average power of modulated signal at the transmitter. The smaller the EVM value, the better the channel quality. So in the next transmission, these blocks can be used to transmit data. If the EVM value of sub-carrier block is large, it means that the data on the sub-carrier block is far from the standard modulation point, and the channel quality is poor, so data will not be sent on this block in the next transmission. At this time, blocks are not used will be filled by other data. At the receiver, blocks with good channel conditions need to be demodulated by SIC, and the ones with poor channel conditions can be demodulated normally (without using SIC), so except for the data modulation and demodulation module, the rest of the processing flow is the same as that of SIC-OFDM.

3. SIMULATION AND RESULTS ANALYSIS

The system simulation parameters are shown in Table I. Fig. 8 shows the bit error performance of the block SIC with different signal power ratios (PR).

Table 1. Simulation parameter settings.

Coding Type	RS+CC	Number of Long Preambles	128*2
Modulate Type	QPSK	Number of blocks	8
Number of Symbols	4	Channel Type	AWGN
Number of Subcarriers	256	Channel Estimation Method	LS

As Figure 8 shows, when PR is less than or equal to 2, the large signal has bit errors, and the small signal bit error rate decreases sequentially. When PR is 4, 8, 16, and 32, there is no bit error for large signal, and the BER for small signal is not improved much. Therefore, for the correct demodulation of high-power signals, the power of low-power signals needs to be small enough. For the correct demodulation of the low-power signal, the power of low-power signal needs to be large enough.

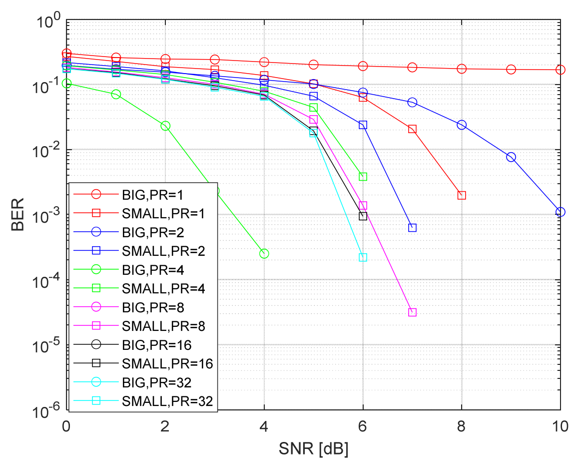

Fig. 8. BER of Chunked SIC-OFDM of different PR

What's more, we compared the subcarrier chunked SIC with normal SIC (full-band SIC), and the simulation results are shown in Fig.9 and 10:

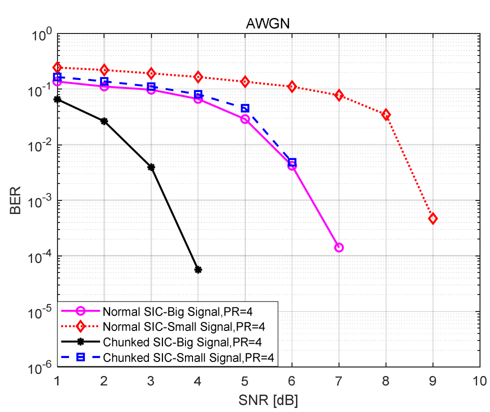

Fig. 9 BER between SIC and chunked SIC-OFDM

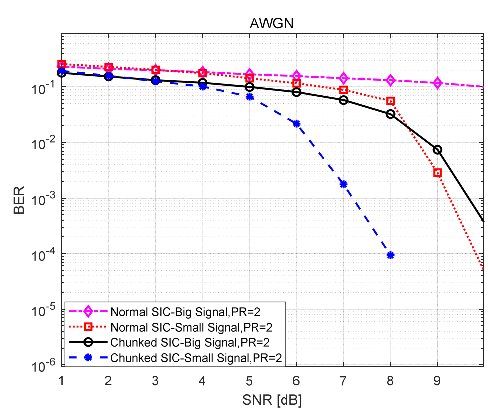

Fig. 10 BER between SIC and chunked SIC-OFDM

Taking PR=4 as an example, in normal SIC, BER of large signal drops to 10^{-4} when SNR=7dB, and BER of small signal drops to about 10^{-3} when SNR=9dB. While in chunked SIC, the bit error rate can be reduced to 10^{-4} when the large signal is only SNR=4dB, and when the small signal is SNR=6, the bit error rate can be reduced to 10^{-3} already. All in all, we compared both BER of same channel of different power ratios, and BER of different channels with a fixed power ratio, the results show that the subcarrier chunked SIC performance is generally better than normal SIC demodulation.

4. CONCLUSION

This paper focuses on the improvement of the system capacity of non-orthogonal multiple access technology in 5G. Based on OFDM system, chunked SIC demodulation in power domain is implemented. Different transmitters select subcarrier blocks with better channel conditions according to the EVM instead of using all subcarriers. The simulation results show that non-orthogonal chunked SIC can not only improve the system capacity, but also improve the demodulation performance compared with normal SIC reception. Future work can analyze the optimization of the bit error performance of each user in the case of asynchronous intra-slot chunked SIC reception.

REFERENCES

[1] Benjebbour A, Saito Y, Kishiyama Y, et al. Concept and practical considerations of non-orthogonal multiple access (NOMA) for future radio access[C]//Intelligent Signal Processing and Communications Systems (ISPACS), 2013 International Symposium on. Okinawa: IEEE Press, 2013: 770-774.

[2] Saito Y, Kishiyama Y, Benjebbour A, et al. Non-orthogonal multiple access (NOMA) for cellular future radio access[C]//Vehicular Technology Conference (VTC Spring), 2013 IEEE 77th. Dresden: IEEE Press, 2013: 1-5.

[3] Patel P, Holtzman J. Analysis of a simple successive interference cancellation scheme in a DS/CDMA system[J]. IEEE journal on selected areas in communications, 1994, 12(5): 796-807.

[4] Saito K, Benjebbour A, Kishiyama Y, et al. Performance and design of SIC receiver for downlink NOMA with open-loop SU-MIMO[C]//Communication Workshop (ICCW), 2015 IEEE International Conference on. London: IEEE Press, 2015: 1161-1165.

[5] Spencer QH, Swindlehurst AL, Haardt M. Zero-forcing methods for downlink spatial multiplexing in multiuser MIMO channels [J]. IEEE Transactions on Signal Processing, 2004, 52(2): 461-471.

[6] Madkour MF, Gupta SC, Wang YP E. Successive interference cancellation algorithms for downlink W-CDMA communications[J]. IEEE Transactions on Wireless Communications, 2002, 1(1): 169-177.

[7] Park JH, Whang Y, Kim K S. Low complexity MMSE-SIC equalizer employing time-domain recursion for OFDM systems[J]. IEEE Signal Processing Letters, 2008, 15: 633-636.

[8] J. Hou, J. Smee, HD Pfister, and S. Tomasin. Implementing Interference Cancellation to Increase the EV-DO Rev A Reverse Link Capacity. IEEE Communication Magazine,v44, n2, p96-102,February 2006.

[9] S. Verdu. M8ultiuser Detection. Cambridge University Press, 1998.

[10] VOELKER K.Apply Error Vector Measurements in Communications Design[J].Microwave &RF, 1995(12):30-33.