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AN IMPROVED CARI ALGORITHM BASED ON SLIDING WINDOW IN MIMO-OFDM SYSTEM

Abstract. *MIMO-OFDM is one of the core technologies in mobile communication system. As multicarrier modulation is adopted, the MIMO-OFDM system usually leads to high Peak-To-Average power ratio (PAPR), which can decrease the communication quality. The cross-antenna rotation and inversion (CARI) is an algorithm with better performance to reduce Peak-To-Average power ratio of mimo-ofdm system. However, needing a large number of iterations is a shortage of CARI. The sub-optimal scheme of CARI – successive suboptimal CARI (SS-CARI) can reduce the number of iterations, but the PAPR reducing performance of it is lost largely. In view of this problem, a sub-optimal CARI method using sliding window to search for rotation and reverse combination is proposed in this paper. By using sliding window to search for the local optimal rotation and reverse combination, not only the overall traversal search can be avoided and the computational complexity of CARI algorithm can be reduced greatly, but also the PAPR reduction performance of SS-CARI can be improved. Simulation results show that a good trade-off between complexity of system and the PAPR reduction performance can be achieved by applying the proposed scheme.*

Keywords: ***peak to average power ratio (PAPR); MIMO-OFDM systems; cross-antenna rotation and inversion (CARI); sliding window***

Problem statement

In recent years, MIMO-OFDM with the advantages of large capacity, high frequency availability and antimultipath fading ability has been selected as the core technology of data transmission and greatly enhances the users' communication experience. However, due to adopting multi-carrier modulation, the mimo-ofdm system exhibits the high peak-to-average power ratio (PAPR) inevitably.

So far, PAPR reduction algorithms based on MIMO-OFDM system have been proposed in many references [1 – 10]. In [1] and [2], SLM algorithm proposed for OFDM was introduced into MIMO-OFDM. It was improved appropriately, but a large number of complex multiplication operations could not be avoided.In [3] the CARI algorithm was presented.Compared with SLM and PTS, CARI has better PAPR reduction performance and can avoid complex multiplication in each iteration to reduce computational complexity. While this method still has a large amount of computation for many iterations.In order to reduce the number of iterations of CARI, reference [3] also raised the Successive Suboptimal Cross-Antenna Rotation and Inversion (SS-CARI) algorithm, but the loss of PAPR reduction performance is relatively large. So a sub-optimal CARI method using sliding window to search for rotation and reverse combination is proposed in this paper to achieve a better trade-off between complexity of system and PAPR reduction performance. By using sliding window to search for the local optimal rotation and reverse combination, not only the overall traversal search can be avoided and the computational complexity of CARI algorithm can be reduced greatly, but also the PAPR reduction performance of SS-CARI can be improved.

BASIC MATERIAL

System Model And PAPR Definitions

Suppose that there are N_t transmit antennas in MIMO-OFDM system and N_c subcarriers in the OFDM. If $N_t \times N_c$ samples sent during the period of the nth OFDM symbol are recorded as N_tN_c dimensional column vector $\boldsymbol{x}(n)$, then there is

$$x(n)=\left(x_1^{\mathrm{T}}[n],x_2^{\mathrm{T}}[n],\cdots,x_{N_t}^{\mathrm{T}}[n]\right)^{\mathrm{T}} \qquad (1)$$

where

$$x_i[n]=\left(x_i[n,0],x_i[n,1],\cdots,x_i[n,N_c-1]\right)^{\mathrm{T}}$$
$$i=1,2,\cdots,N_t \qquad (2)$$

and $(\ )^{\mathrm{T}}$ denotes transpose.

The PAPR in MIMO-OFDM can be given by

$$PAPR=\frac{\max\limits_{0\le k<N_c}\left|x_{i.k}(n)\right|^2}{E[\left|x_{i.k}(n)\right|^2]}, \qquad (3)$$

where $E[\bullet]$ denotes the expected value and k is the index of subcarriers. I denotes the index of transmit antennas, $i\in(1,N_t)$. And $x_{i.k}(n)$ is signal of the ith subcarrier in the kth transmit antenna.

According to the central limit theorem, when the number of subcarriers N is large enough, the sampled signal in time domain $x_{i.k}(n)$ approximately obeys complex Gaussian distribution with mean 0. Given the threshold value PAPR0, the probability that the PAPR exceeds the threshold value is the complementary cumulative distribution function (CCDF)

$$CCDF=\mathrm{P}\{PAPR>PAPR_0\}=1-(1-e^{-PAPR_0})^{\alpha N_c} \qquad (4)$$

where α is the oversampling; $\alpha=4$, it can show the continuous signal well; $\alpha=1$, it is the Nyquist sampling rate.

The cross-antenna rotation and inversion (CARI) algorithm and the sub-optimal scheme

The cross-antenna rotation and inversion (CARI) algorithm

For simplicity, Let us assume a STBC-OFDM 2 transmit antennas. The block diagram of the CARI algorithm is shown in Fig. 1.

Suppose that the subcarriers number of OFDM system is N$_c$ and the data flow on each antenna is divided into M equal blocks, which are numbered sequentially.Therefore the sent data can be expressed as:

$$X_i=\left[X_{i,1},X_{i,2},\cdots,X_{i,M}\right], \qquad (5)$$

where i denotes the Sequence Number of transmit antenna, $i=1,2$.

Then, according to the rules in [1], subblocks with the same number on different antennas are operated rotation and inversion permutations in turn, by which 4^M groups new data stream with the same informations obtained. Finally based on the minimum maximum (mini-max) criterion,{ $\tilde{X}_1$, $\tilde{X}_2$ }with the best PAPR performance are chosen for transmission. In order to find the optimal sequence,the number of iterations we should do is 4^M. Then the computation is very big for a system with a large M.

Successive Suboptimal CARI (SS-CARI) Algorithm

In the SS-CARI algorithm, the CARI transformation is first operated for the first subblock X_{11}, X_{12},whereas all other subblocks remain unchanged and the other subblocks are unchanged. Then the remaining subblocks are transformed in turn, meanwhile the other M-1 subblocks keep unchanged. Finally, { $\tilde{X}_1$, $\tilde{X}_2$ } with the best PAPR performance are chosen for transmission. The block diagram of the SS-CARI algorithm is shown in Fig. 2.

This algorithm can reduce the number of iterations to 4M, and the computation is greatly reduced. However, this method is essentially a search process for a quadtree (each subblock has four combinations of invariant, inverse, rotation, rotation and inverse). Because the selection of each branch in the search path simultaneously excludes the optimal rotation and reverse combination information of all other branches at the same level and their subordinate branches, the performance of CARI algorithm is lost highly.

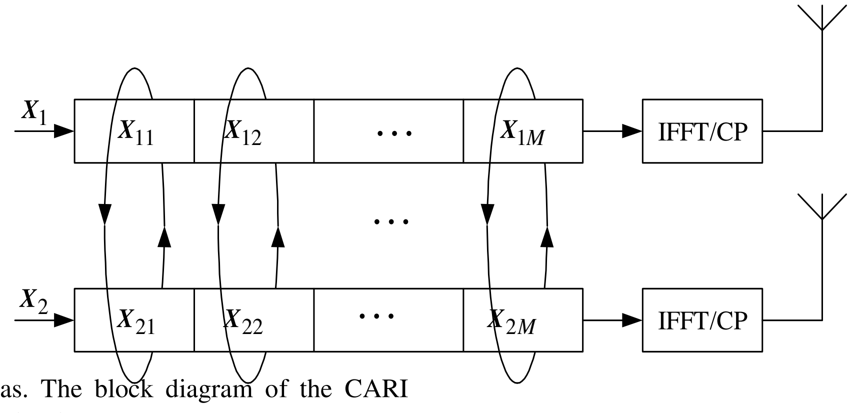

Figure 1 – Block diagram of the CARI algorithm

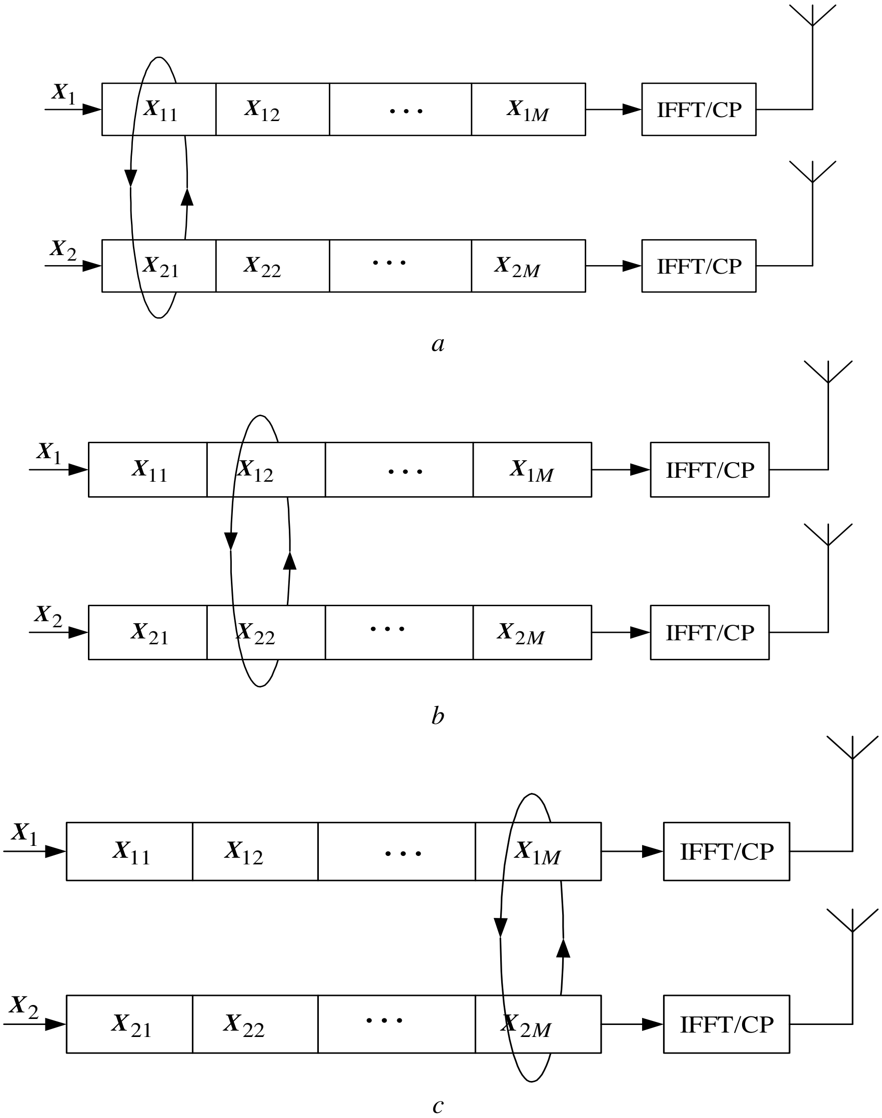

Figure 2 – Block diagram of the SS-CARI algorithm: a –the first subblock transformed; b – the second subblock transformed; c – the Mth subblock transformed

An improved CARI algorithm based on sliding window

The main idea of the sliding window searching CARI algorithm is as follows: Firstly, window is added to the adjacent N subblocks, and all possible rotation and reverse combinations are searched in the window, then the optimal path is selected to obtain the local optimal rotation reverse combination. After completing the search in the window, the system saves the optimal rotation and reverse combination information obtained,and slides the window forward with step K. At this point, the information going out of the window is the suboptimal rotation and reverse combination information obtained by the search.After sliding, the system repeats the above operation to the subblocks in the window until the $M-N+1$ subblock (M is the number of subblocks of OFDM signal on each antenna). The schematic diagram of sliding window searching CARI algorithm is shown in fig. 3.

In this algorithm, when the search sliding window length N=M and the sliding step length K=1, the algorithm is equivalent to the optimal CARI algorithm.When the search sliding window length N=1 and the sliding step length K=1, the algorithm is also equivalent to successive suboptimal CARI (SS-CARI) algorithm. It can be seen that both the optimal CARI algorithm and the SS-CAR algorithm are special examples of sliding window searching CARI algorithm, which indicates that the algorithm proposed in this paper has great flexibility.

Based on analysis and computation, the calculation amount of this algorithm is $4^N \times [(M-N+1)/K]$. From the formula can be seen, even when M is fixed, the calculation can be controlled by limiting the size of N as required. In addition, the calculation amount can be controlled by selecting the sliding step length K appropriately.

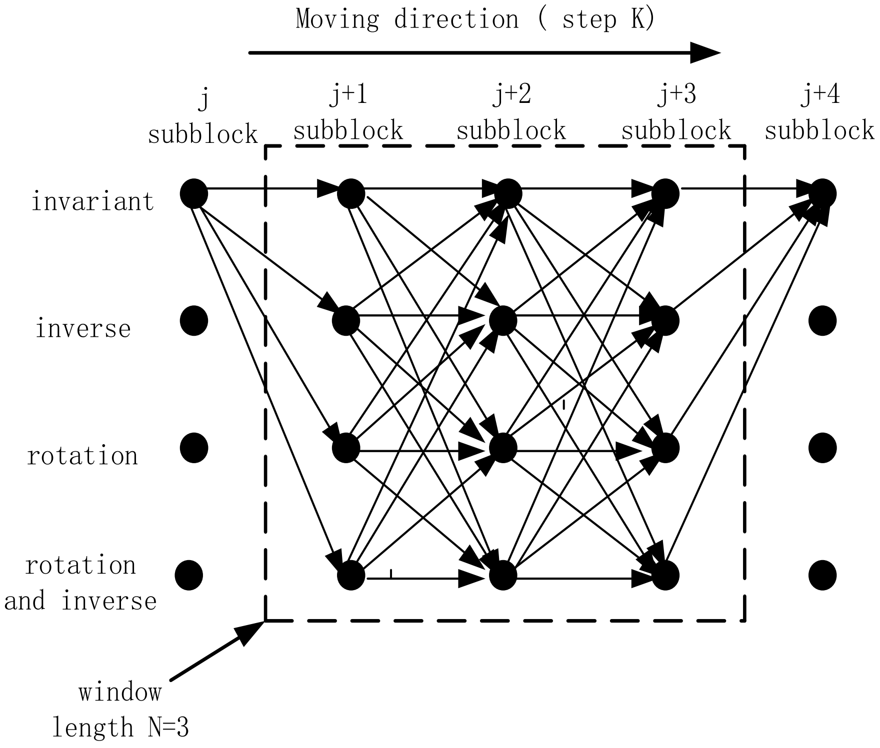

Figure 3 – Schematic diagram of sliding window searching CARI algorithm

As long as N and K are selected reasonably, the calculation amount of proposed algorithm can be much smaller than that of the optimal CARI, so as to solve the large calculation amount problem of the optimal CARI. Meanwhile by adding sliding window, rotation and reverse combinations in the window are traversed, and the combination selected by each subblock is closer to the optimal combination, so that the large loss of PAPR reduction performance of SS-CARI can also be overcome.

Simulation and analysis

Take the STBC-OFDM system with two transmit antennas as an example (N_t=2), and the simulation parameters are set as follows: use the OFDM with 128 subcarriers and QPSK modulated, do 10^5 Monte Carlo simulations, and set the sampling factor to be 1.

For $M=4$, the PAPR comparisons among SS-CARI, sliding window searching CARI (proposed algorithm) and optimal CARI are shown in Fig. 4. From the figure, we can observe that the PAPR reduction gain of SS-CARI is lost nearly 1dB at $CCDF=10^{-4}$, compared with the optimal CARI.Then the proposed sliding window searching CARI algorithm (proposed algorithm) is closer to optimal CARI performance. When $N=2$, $K=2$, the proposed algorithm is about 0.5dB better than SS-CARI, and less tha 0.5 dB worse than optimal CARI. When $N=2$, $K=1$, the proposed algorithm is about $0.6\sim0.8$ dB better than SS-CARI, and $0.2\sim0.4$ dB worse than optimal CARI. For the case of M=4, the calculation amount of the optimal CARI searching for the optimal rotation and reverse combination is $4^4=256$, then the calculation amount of the proposed sliding window searching algorithm is $4^2\times2=32$ when $N=2$, $K=2$, and the calculation amount of it is $4^2\times3=48$ when $N=2$, $K=1$. It can be seen that the proposed algorithm achieves a large reduction in the optimal CARI calculation only with a small performance loss.

For $M=8$, the PAPR comparisons among SS-CARI and proposed algorithm under four values of N and K are shown in Fig. 4. As shown in Fig. 4, the performance of the proposed algorithm is much higher than that of SS-CARI, which is closer to the performance of the optimal CARI. Additionally, it also be seen that the performance of proposed algorithm when $N=3$ is significantly better than the performance when $N=2$. When N is the same, the performance of K=1 is significantly better than that of K=2. Thus the performance of proposed algorithm is closely related to sliding window length N and sliding step K. The larger N is, the better proposed sliding window searching algorithm is. And the smaller K is, the better performance is.

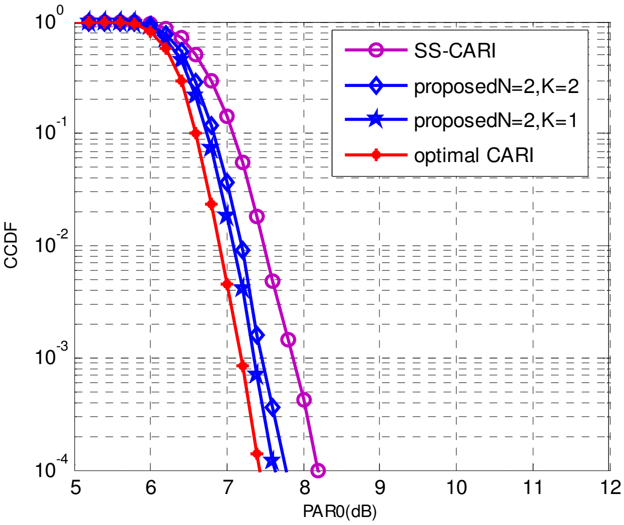

Figure 4 – PAPR comparisons of SS-CARI, proposed CARI and optimal CARI (M=4)

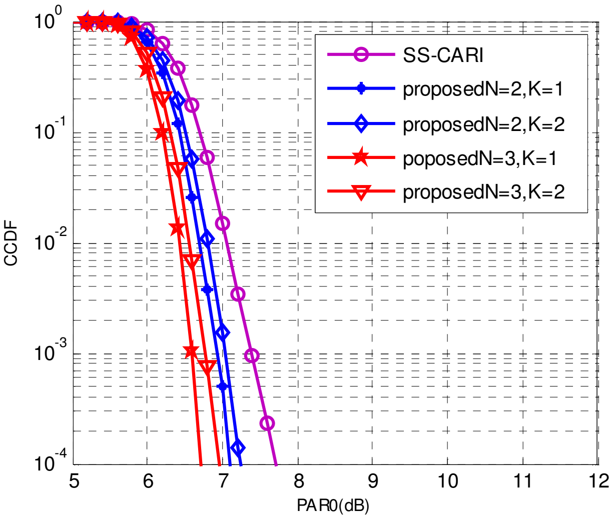

Figure 5 – PAPR comparisons of SS-CARI, proposed CARI (M=8)

Conclusions

In this paper, one better suboptimal algorithm sliding window searching CARI is proposed, which not only can overcome too large calculation amount problem of optimal CARI, but also can solve the problem that the PAPR reduction performance of SS-CARI is lost too much. Additionally, this algorithm also has great flexibility, as it can improve PAPR reduction performance of system through changing the length N and sliding step K of sliding window, according to the requirement of system. The bigger N is, the better performance of sliding window searching CARI is, while the smaller K is, the better performance is. Meanwhile, it's worth noting that the length N has a great influence on the calculation.When N is too big, also system calculation is too big. Therefore, the size of N needs to be controlled as much as possible in actual application.

References

1. Yung-Lyul, Lee, Young-Hwan, You, Won-Gi, Jeon, Jong-Ho, Paik, Hyoung-Kyu, Song. (2003). Peak-to -Average Power Ratio in MIMO-OFDM Systems Using Selective Mapping. IEEE Communications Letters, 12, 575-577.

2. Ben Jmâa, Ahmed Bassem, Jarboui, Slaheddine, Bouallegue, Ammar. (2007). A PAPR Reduction Method for ST BC MIMO-OFDM Systems Using SLM in combination with Subband Permutation[C]. The Third International Conference on Wireless and Mobile Communications. Guadeloupe, French Caribbean, 3, 88.

3. Mizhou, Tan, Latinovi´c, Zoran, Yeheskel, Bar-Ness. (2005). STBC MIMO-OFDM Peak-to-Average Power Ratio Reduction by Cross-Antenna Rotation and Inversion. IEEE COMMUNICATIONSLETTERS, 7, 592-594.

4. HU, Wu-jun, YANG, Lin. (2015). Modified SLM algorithm based on cyclic shift and signal combination in MIMO-OFDM system.Journal on Communications, 4, 174-181.

5. Amhaimar, Lahcen, Ahyoud, Saida, Asselman, Adel. (2017). Low Computational Complexity PTS Scheme for PAPR Reduction of MIMO-OFDM Systems. Procedia Engineering, 2, 876-883.

6. LI, Wei, LIU, Yun-yun, YANG, Lin. (2016). A Low Complexity SLM Algorithm for Reducing PAPR of MIMO-OFDM System.Study on Optical Communications, 4, 56-59.

7. Mouna, Sghaier, Fatma, Abdelkefi, Mohamed, Siala. (2015). PAPR reduction scheme with efficient embedded signaling in MIMO-OFDM systems. EURASIP Journal on Wireless Communications and Networking, 11, 1-16.

8. Hu, Wujun, Yang, Lin. (2015). Modified SLM algorithm based on cyclic shift and signal combination in MIMO-OFDM system, Journal on Communications, 4, 174-181.

9. Khushboo, Pachori, Amit, Mishra. (2016). An efficient combinational approach for PAPR reduction in MIMO–OFDM system. Wireless Networks, 5, 417-425.

10. Namitha, A.S., Sameer, S.M. (2017). A bandwidth efficient selective mapping technique for the PAPR Reduction in spatial multiplexing MIMO-OFDM wireless communication system. Physical Communication, 9, 128-138.

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ПОЛІПШЕНИЙ АЛГОРИТМ CARI НА ОСНОВІ РОЗСУВНОГО ВІКНА В СИСТЕМІ MIMO-OFDM

***Анотація**. MIMO-OFDM є однією з основних технологій у системі мобільного зв'язку. Оскільки мультиваріантна модуляція приймається, система MIMO-OFDM зазвичай веде до високого співвідношення потужності (PAPR), що може знизити якість зв'язку. Обертання та інверсія крос-антени (CARI) – це алгоритм з кращою продуктивністю для зменшення відношення потужності системи mimo-ofdm до максимального середнього значення. Проте, потреба у великій кількості ітерацій – недолік CARI. Недооптимальна схема CARI – послідовна субоптимальна CARI (SS-CARI) може зменшити кількість ітерацій, але продуктивність PAPR переважно втрачається. З огляду на цю проблему запропоновано недооптимальний метод CARI з використанням ковзного вікна для пошуку обертання та зворотної комбінації. Використовуючи розсувне вікно для пошуку локальної оптимальної обертання та зворотної комбінації, можна не лише уникнути загального пошуку по пересуванню і значно зменшити обчислювану складність алгоритму CARI, але також може покращити ефективність зниження PAPR SS-CARI. Результати моделювання показують, що шляхом застосування запропонованої схеми можна досягти гарного компромісу між складністю системи та продуктивністю зниження PAPR.*

Ключові слова: коефіцієнт максимальної до середньої потужності (PAPR); Системи MIMO-OFDM; перехресна антена обертання та інверсії (CARI); розсувне вікно

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