Peak-to-average power ratio minimization and complexity reduction in MIMO-OFDM systems using spatial circular shifting and temporal interleaving method

Dubala Ramadevi, Polipalli Trinatha Rao
Department of Electronics and Communication Engineering, GITAM School of Technology, GITAM University, Hyderabad, India

Article Info

Article history:

Received Aug 23, 2022
Revised Mar 6, 2024
Accepted Mar 9, 2024

Keywords:

Inverse fast Fourier transform
Low complexity
Modified enhancement asymmetric arithmetic coding scheme
Orthogonal frequency division multiplexing
Spatial circular shifting and temporal interleaving

ABSTRACT

Multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) technological support for the simultaneous and frequent access by a large number of users to radio resources. For 5G cellular systems, this exhaust is not enough to provide physical layer services. An appropriate Peak-to-average power ratio (PAPR) minimization principle, which maximizes data capacity and channel utility, has been used to address this issue. In this paper, mainly focus on minimize the high PAPR of the candidate sequence of the OFDM sub-block using modified enhancement asymmetric arithmetic coding scheme (M-EAAC). According to this, circular shifting of the candidate sequence is established in the spatial circular shifting and temporal interleaving (SCS-TI) form to generated different set of conjugated phases which is multiplied with candidate sequence. Then, the transmitting antenna is identified the best lowest PAPR of the candidate sequence is chosen for entire OFDM data transmission. The simulation results conveys that the proposed SCS-TI method provide acceptable improvement in the PAPR reduction as compared with conventional selective mapping (SLM) and pseudo-random SLM (PR-SLM). Moreover, the complexity evaluation which ensure the proposed method provides better improvement at three important stages includes inverse fast Fourier transform (IFFT) operation, optimization process, and PAPR calculation at each candidate sequence.

Corresponding Author:

Dubala Ramadevi
Department of Electronics and Communication Engineering, GITAM School of Technology, GITAM University
Hyderabad, Telangana, India
Email: dubalarama@gmail.com

1. INTRODUCTION

Widespread interest in orthogonal frequency division multiplexing (OFDM) based wireless communications has grown in recent years [1]. It provides high immunity booster against such as multipath fading, co-channel interference, and high spectral efficiency [2], [3]. It is possible only if the wideband frequency slow down into narrowband frequency which can be operated simultaneously in the respective subchannels. Most of the standard wireless networks includes IEEE 802.11 and IEEE 802.16 are preferred modulation scheme as OFDM. Using cognitive radio technology in regional area networks has been studied by IEEE 802.22 and the next generation of mobile communication [4]. Wireless system of the future could benefit from the use of combined form of OFDM and multi-input-multi-output (MIMO) technology [5]. By this combination, may results in high signal quality, reduce bit error rate (BER), and enhance system capacity. Consequently, many wireless systems and standards have shown interest in MIMO-OFDM [6]. An orthogonal combination of waveforms is generated in the time domain which transmits MIMO-OFDM signal. However, it demonstrates that large peaks always exceed the average magnitude of the signal are achievable. As a result, high peak-to-average power ratio (PAPR) at the transmitter side plagues MIMO-OFDM systems [7]. Non-linear complication may emerge as a result of this in the digital-to-analog conversion (DAC), mixer, and high-power amplifiers (HPAs). Hence, nonlinear distortion has an effect on spectrum spreading, signal structure, and modulation. To solve this problem, expensive power amplifiers are required, but fails power efficiency during the amplification process. PAPR reduction techniques based on signal modification have also been proposed as a solution to the PAPR problem. In general, two types of approaches are used to reduce the high PAPR: i) distortion and ii) distortion-less.

In the case of distortion approaches, which include clipping [8], filtering [9], and nonlinear companding transform [10], the BER performance suffers due to unstained signal amplitude. The clipping method [11] reduces PAPR by setting a threshold value. As a result, whenever an input signal is fed into a digital multicarrier system, a threshold value is checked to see if it is higher than the threshold. It also causes significant bit error rate (BER). Thus, encoding method is PAPR reduction [12]. It effectively reduces PAPR but loses data transfer capabilities. In multiple signal representation (MSR) approaches, a distinct phase sequence is created based on the input signal, and the candidate signal for transmission is picked from the least PAPR [13]. Similarly, distortion-free approaches such as partial transmit sequence (PTS) [14], selective mapping (SLM) [15], tone injection [16], and active constellation extension [17] reduce PAPR at the expense of increasing transmit power, decreasing data rate, and increasing computational complexity. This occurred as a result of a rise in the number of inverse fast Fourier transform (IFFT) operations, which makes it computationally complex and required the transmission of side information. PAPR reduction for MIMO-OFDM space frequency block coding has recently been addressed [18]–[20]. The initial PAPR reduction statistics can be induced using ordinary-PTS [21] and alternate-PTS [22] techniques. However, these solutions are computationally demanding and do not take use of MIMO transmission potential.

In this paper, mainly focus on minimize the high PAPR of the candidate sequence of the OFDM sub-block using modified enhancement asymmetric arithmetic coding scheme (M-EAAC). According to this, circular shifting of the candidate sequence is established in the spatial and temporal form to generate different set of conjugated phases which is multiplied with candidate sequence. Then, the transmitting antenna is identified the best lowest PAPR of the candidate sequence is chosen for entire OFDM data transmission. The following sections make up the remainder of the paper: section 2 deals system model andordinary decomposed SLM. Section 3 describes the proposed spatial circular shifting and temporal interleaving in terms of complexity and PAPR reduction. The proposed model's experimental results are summarized in section 4. Section 5 concludes with a look toward the future.

2. METHOD

2.1. System model

Figure 1 demonstrates the system model and Figure 1(a) shows the MIMO-OFDM block diagram. Consider, the input data stream consists of ‘N’ symbols (i.e., S_{input} = (S_1, S_2… S_N)), which are spread evenly and independently. It is ensured that each input data set has an independent and identically distributed sequence of ‘N’ symbols. It is used for modulation with quadrature amplitude modulation (QAM). In order to construct an N-carrierdiscrete-time OFDM signal, use expression (1):

$$(n) = IFFT\{S(k)\} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} (k).\, e^{j2\pi nk/} ; n = 0,1,2, \ldots . N-1 \quad (1)$$

Because of the repeated multiplication of the same phase factors in an OFDM signal when transmitted symbols are very large, a high PAPR is unavoidable. So, the central limit theoremPAPR trade off analysis requires only a Gaussian distribution channel. For the most part, PAPR is defined as the maximum-to-average power ratio of a signal being transmitted, and its mathematical equivalent is provided in (2).

$$PAP\{s(n)\} = \frac{||s(n)||^2}{\{||s(n)||^2\}} ; 0 \le n \le (N-1) \quad (2)$$

where, {.} be the expected values and oversampling factors (L) in (2). The PAPR reduction is required for both discrete and continuous time OFDM signals (i.e., $PAP\{s(n)\} \cong PAP\{s(t)\}$) provider if the ‘$L$’ value is greater than four [23]. To determine whether PAPR reductions are having the desired effect, the complementary cumulative distribution function (CCDF) can be utilized for MIMO-OFDM system, as shown in (3).

$$CCDF\{PAPR_{MIMO}\{s(n)\}\} = Pr(\,PAPR_{MIMO}\{s(n)\} > PAPR_{AD_{THD}}) \quad (3)$$

where, $PAPR_{AD_{THD}}$ is an adaptive threshold value that is based on the event's chance of probability occurrence $P(v)$. Hence, equation (3) demonstrates that as the number of transmit antennas increases, the PAPR problem gets more problematic. It is clear that an effective PAPR reductionapproach is needed in the MIMO instance

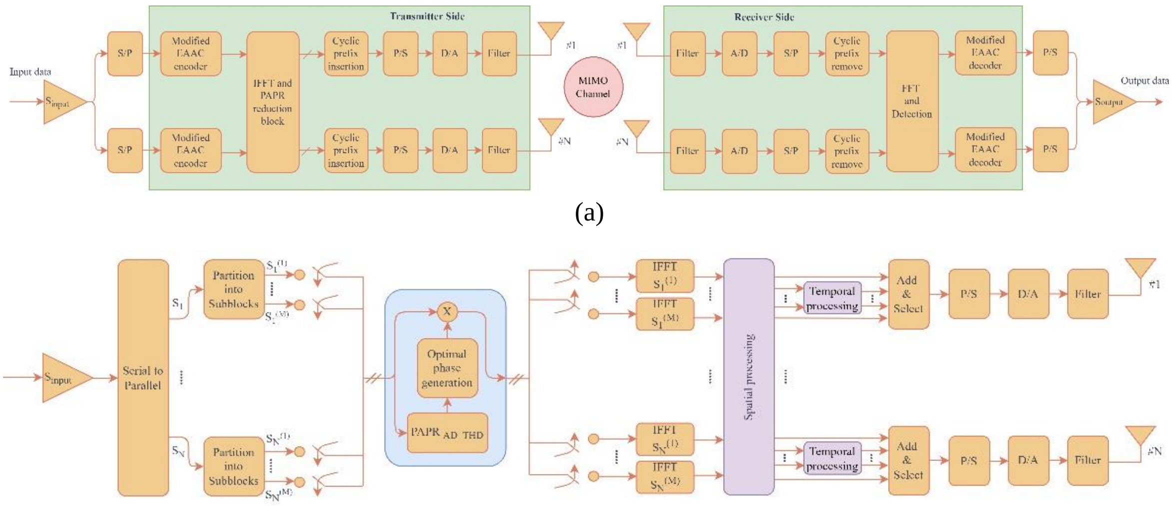
2.2. Ordinary decomposed SLM

A decomposed SLM (Dcomp-SLM) technique is depicted in study [24], where the sequence of each input datum is multiplied by randomly generated phase sequences (W). Thus, phase scrambling$(s{*}B^i)$ is done in order to reduce high PAPR values to a minimum which implies $B^i = e^{i\varphi}$; $\varphi_s \in (0,2\pi)$. Where, $B^i = \{B^1, B^2, \dots, B^W\}$; $i = 1,2, \dots, N-1)$. Once W sequences are transformed into t candidate signals using the IFFT, the Dcomp-SLM technique is shown in (4). The Dcomp-SLM technique is used to select the signal with the lowest PAPR (available candidate signals) as the transmission signal for the OFDM system is shown in (5).

$$(n) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}(k). B^i \,. e_t^{j2\pi nk/}; i = 1,2,\dots.,W \quad (4)$$

$$S_{selecte}(n) = arg(\,min(\,PAPR\{S^i\,(n)\})) \quad (5)$$

It is necessary to know which signal is used to transmit the data in order to restore the original input data sequence at the receiving end. Thus, determines number of bits are required for additional information retrieval at receiver side. The phase-generation mechanism of the Dcomp-SLM approach still has certain limitations, despite its excellent performance in lowering PAPR: Due to the random production of phase sequences, the phase-generating technique lacks a logical framework. The technique does not provide a mechanism for selecting a phase sequence that gives the best PAPR candidate signal. Figure 1(b) shows the proposed decomposed SLM with space-time-block coding (STBC) scheme at transmitter side.



(a)

(b)

Figure 1. System model (a) MIMO-OFDM block diagram, and (b) proposed decomposed SLM with STBC scheme at transmitter side

3. PROPOSED METHOD

In this section discusses two ways to reduce PAPR in MIMO-OFDM systems. From Figure 1(b) the frequency domain subblocks are partitioned into different blocks after being translated to the time domain by the IFFT procedure. The time domain subblocks are subsequently processed spatially and temporally on all transmit antennas. Finally, a candidate sequence with the best PAPR statistics is chosen for each transmit antenna. The M-EAAC includes spatial shifting as well as temporal shifting over subblocks of the randomly generated at the transmitting antenna. The detailed operations of both are clearly explained as follows.

3.1. Spatial circular shifting and temporal interleaving (SCS-TI)

Using spatial circular shifting, separate subblocks are first generated at each transmit antenna in this manner. Different candidate sequences are generated by applying temporal circular shifting to the subblocks of each transmit antenna. For each transmit antenna, a search of all candidate sequences yields the sequence with the lowest PAPR. Then, this technique is referred as spatial and temporal shifting (STS). For better understanding of this process, consider four subblocks (i.e., M=4) and four transmitting antenna (i.e., N=4). Where, each transmitting antenna assigned with discrete subblocks. For better understanding, it is denoted as vectors such as (5).

$$r_1^{(1)}\varsigma_1^{(2)}\varsigma_1^{(3)}\varsigma_1^{(4)} \qquad \varsigma_4^{(1)}\varsigma_4^{(2)}\varsigma_4^{(3)}\varsigma_4^{(4)} \tag{5}$$

Initially, odd vectors are involved for the spatial shifting, that implies, circular shift of two is followed which produced another a new vector sequence from that a new odd subblocks are obtained and then assigned to each transmitting antenna. As a result, interleaving function is included in the spatial shifting process which is mathematically expressed as (6) [25].

$$(i) = mod(M*(i+(N-1)*[\frac{M*i}{D}])-(D-1),D); i = 0,1,\ldots(D-1) \tag{6}$$

In the temporal shifting, odd subblocks are kept fixed and now, even subblock is shifting initiated which produced large number of candidate sequence and select the lowest PAPR for signal transmission available at the transmitting antennas. The number of spatial and temporal shift allowable to odd subblocks are computed using (7) and (8) respectively.

$$S_{spatial} = N*(M/2) \tag{7}$$

$$S_{temporel} = [N*(M/2)][N.C^{M/2}] \tag{8}$$

where, C be the set of subblocks are selected from the transmission. As a result, the PAPR reduction performance will be greatly enhanced if circular shifting is applied to the even subblocks as well in temporal shift processing. According to SCS-TI, generates $[(M/2)]^2[N.^{(M/2)}]$ number of candidate sequence with $2[log_2(N)+log_2(M/2)+N[log_2(C^{M/2})]]$ number of side information bits are required. The detailed spatial circular shifting of the vectors are shown in Figure 2. Spatial interleaving should be applied to all transmit antenna subblocks. Afterwards, each transmit antenna's even subblock elements are generated using a temporal interleaving procedure. The sequence with the lowest PAPR for each transmits antenna was finally determined after an extensive search.

3.2. Complexity evaluation

It is very much indeed to estimate the complexity evaluation which ensure the proposed method provides better improvement at three important stages: i) IFFT operation, ii) (C'_{IFFT}) optimization process $(C"_{optimal})$, and iii) PAPR calculation at each candidate sequence$(C"_{PAPR})$. Therefore, total complexity per transmitting antenna as

$$C_{total} = M.C'_{IFFT} + Vc.(c"_{optimal} + C"'_{PAPR}) \tag{9}$$

where, V_c be the total number of candidate sequence generated at each transmitting antenna and L is the length of the candidate sequence. The complexity of the IFFT operation takes $(NL/2)og_2(NL)$ multiplications and $(NL)log_2(NL)$ additions. In that, IFFT operation concerned with four multiplication and two additions. But, the proposed SCS-TI method does not involved multiplication only addition is required. Similarly, optimization process also need addition alone.

Therefore, both C_{IFFT} and $C_{optimal}$ is almost reduced. In case of PAPR calculation, only takes power of the high peaks utilizes $2NL$ and NL real multiplication and addition required respectively. The computational complexity reduction ratio (CCRR) of the proposed SCS-TI method with respect to conventional SLM as mentioned in Table 1 [26].

$$CCRR = (1 - \frac{Complexity\ of\ SCS-TI}{Complexity\ of\ Conv-SLM}) \times 100\% \tag{10}$$

The comparative analysis is carried at two different scenarios where the proposed SCS-TI method is validated such as: i) N=2 and M=8, 16, and 32; and ii) N=4 and M=8, 16, and 32. The complexity is significantly reduced as compared to conventional SLM and PR-SLM. For an instant, case-I the proposed SCS-TI reached reasonable improvement in the multiplication (53.12% to 92.56%) and addition (68.45% to 95.61%) respectively. Similarly, for case-II, results in multiplication (46.73% to 95.73%) and addition (64.26% to 97.28%) respectively. The achievable rate always go raises as number of subblocks increases simultaneously.

Figure 2. SCS-TI approach in the decomposed SLM technique

Table 1. The percentage of CCRRs of the proposed SCS-TI over conventional SLM for V_c=4

Method	% of CCRR Multiplication at N=2			% of CCRR Multiplication at N=4		
	M=8	M=16	M=32	M=8	M=16	M=32
Proposed SCS-TI	74.72	81.57	92.19	78.56	93.63	98.46
Conv-SLM [24]	45.34	63.85	88.21	53.17	79.13	83.47
	% of CCRR Addition at N=2			% of CCRR Addition at N=4		
Proposed SCS-TI	84.56	93.18	97.35	91.23	95.47	97.53
Conv-SLM [24]	61.02	84.06	87.89	83.53	93.76	95.24

4. RESULTS AND DISCUSSION

In this section, describes the evaluation of the proposed SCS-TI technique under different transmitting antennas say N=2 and N=4 in which separate M-ary encoding schemes are used such as 16-QAM and 32-QAM respectively. In simulation purpose, 256 subcarriers are considered for evaluation with oversampling factor of L=2 [27], [28]. The OFDM block is randomly generated in the order of 10^4 which is allocated to transmitting antenna. This block is further divided into subblocks of M=8, 16, and 32. Therefore, a new phase sequence generation is included in the proposed SCS-TI technique in order to enhance the phase generation procedure. In favor to this, a seed matrix is employed with size of 3×3 which ensure recursive production of pseudo-random phase sequence of the length of N_L. In this matrix, each individual elements are denoted by which has different phase sequence sets such as $P\in\{\pm1, \pm2, \pm3, \pm j, \pm 2j, \pm 3j\}$. The decomposed SLM method is sufficient for optimistic phase generation which is fully depends on predefined adaptive threshold value. The proposed SCS-TI technique follows minimum number of temporal shift ($i.\ e.$, $c \leq 8$) and interleaving matrix of $S_{spatial} = 4$.

In case of simulation, the CCDF graph is generated for the following existing methods such as original MIMO-OFDM (without PAPR reduction), Conv-SLM, PR-SLM, and O-decomp-SLM respectively. In Figure 3 shows the CCDF of PAPR reduction using proposed SCS-TI technique. It is observed that the SCS-TI reached better PAPR reduction as compared to existing techniques such as Conv-SLM, PR-SLMand O-decomp-SLM respectively. In case of 0.1% of CCDF, the performance of PAPR reduction is increased using proposed SCS-TI technique under *N*=2 over Conv-SLM, PR-SLM and O-decomp-SLM are 1.93, 1.26, and 0.75 dB, respectively. Similarly, if *N*=4 in such case, the performance of PAPR reduction is reached as 2.56, 2.13, and 1.03. It is clearly depicted in Figure 4. The CCDF curve of the different PAPR reduction techniques included for two different QAM constellation (Q=16 and 32) as shown in Figure 5.

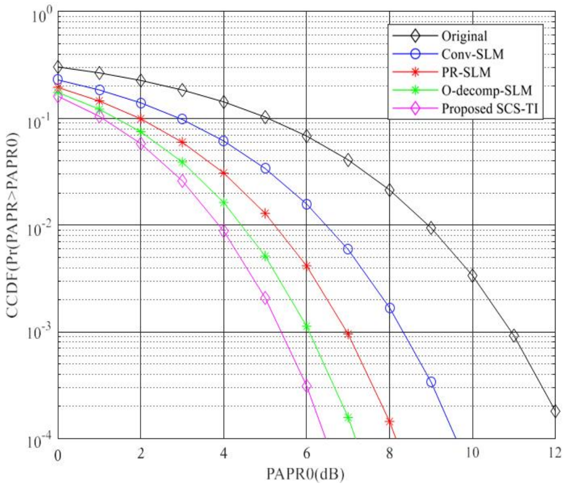


Figure 3. The comparative CCDF curve of the PAPR reduction under *N*=2, *M*=8, 16, and 32 using proposed SCS-TI technique

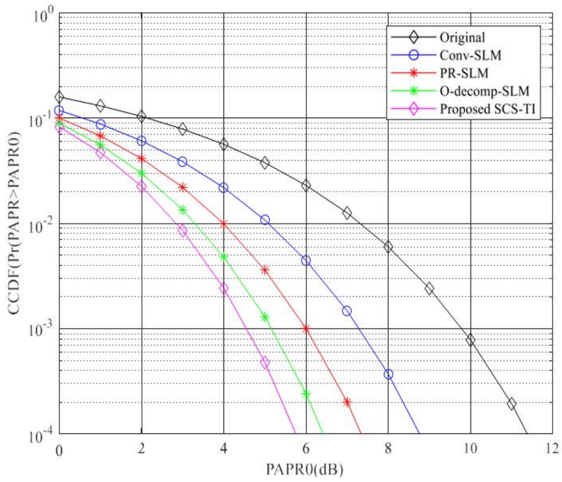


Figure 4. The comparative CCDF curve of the PAPR reduction under *N*=4, *M*=8, 16, and 32 using proposed SCS-TI technique

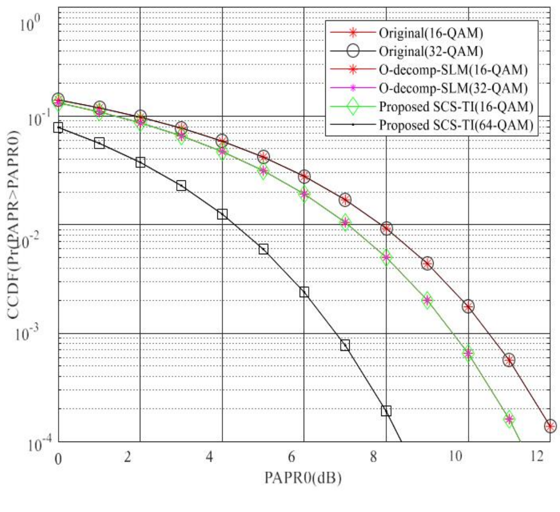


Figure 5. CCDF curve of different PAPR reduction techniques under 16 and 32 QAM constellation

On comparing, Figures 3 and 4 conveys that the constellation size increases then interrupts PAPR reduction profile slightly. Therefore, if the number of subcarriers is considered sufficiently large, the output signal becomes Gaussian following the central limit theorem and the PAPR is no longer dependent on mapped data [29], [30]. The precision of the SCS-TI method depends heavily on synchronization between the transmitted signal and the receiver. Misalignments can lead to inter-symbol interference (ISI) and reduce the efficacy of PAPR reduction. Conveying side information necessary for the receiver to understand the spatial and temporal shifts can add to the overhead, reducing the effective data throughput. This algorithm might face performance degradation under rapidly changing channel conditions, such as high mobility scenarios where the channel characteristics vary quickly over time.

5. CONCLUSION

To reduce the high PAPR of the OFDM sub-block candidate sequence, a M-EAAC method is introduced in this paper. The candidate sequence is SCS-TI to generate a separate conjugated phase set that is multiplied with the candidate sequence, according to this method. When the antenna is recognized, the optimal low-PAPR sequence is selected for the full OFDM data transmission. The simulation results show that the suggested SCS-TI approach improves PAPR reduction over standard SLM. IFFT operation, optimization process, and PAPR calculation for each candidate sequence are all part of the complexity evaluation that ensures the proposed SCS-TI method improves at three critical phases. For the purposes of comparison, two distinct validation scenarios for the proposed SCS-TI approach will be considered: I N=2 with M=8,16, and 32; (ii) N=4 with M=8,16, and 32. As compared to traditional SLM, and PR-SLM the complexity is much decreased. To put things into perspective for a moment, in scenario I SCS-TI achieved a reasonable improvement in multiplication (53.12% to 92.56%) and addition (68% to 95.61%). Similar findings may be obtained for cases (ii) in terms of multiplication (46.73% to 95.173%) and addition (64.26% to 97.283%). It is always possible to get a higher throughput when more subblocks are added simultaneously. Furthermore, implementing adaptive algorithms that adjust the number and type of shifts according to current channel conditions can help maintain performance without excessively increasing complexity. Moreover, improving timing and frequency synchronization can mitigate the impact of Inter-Symbol Interference (ISI) and preserve the integrity of spatial and temporal shifts. Employing more efficient search methods to select the candidate sequence with the lowest PAPR can also reduce computational burden and power consumption.

REFERENCES

[1] S. B. Weinstein and P. M. Ebert, "Data transmission by frequency-division multiplexing using the discrete Fourier transform," *IEEE Transactions on Communication Technology*, vol. 19, no. 5, pp. 628–634, Oct. 1971, doi: 10.1109/TCOM.1971.1090705.

[2] Y. Wu and W. Y. Zou, "Orthogonal frequency division multiplexing: A multi-carrier modulation scheme," *IEEE Transactions on Consumer Electronics*, vol. 41, no. 3, pp. 392–399, 1995, doi: 10.1109/30.468055.

[3] R. V. Nee and R. Prasad, *OFDM for wireless multimedia communications*. Artech House, 2000.

[4] K. Fazel and S. Kaiser, *Multi-carrier and spread spectrum systems: From OFDM and MC-CDMA to LTE and WiMAX: Second edition*. Wiley, 2008.

[5] T. Hwang, C. Yang, G. Wu, S. Li, and G. Y. Li, "OFDM and its wireless applications: A survey," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 4, pp. 1673–1694, May 2009, doi: 10.1109/TVT.2008.2004555.

[6] L. Hanzo, Y. J. Akhtman, L. Wang, and M. Jiang, *MIMO-OFDM for LTE, WiFi and WiMAX: Coherent Versus Non-coherent and Cooperative Turbo Transceivers*. Wiley, 2001.

[7] V. Tarokh and H. Jafarkhani, "On the computation and reduction of the peak-to-average power ratio in multicarrier communications," *IEEE Transactions on Communications*, vol. 48, no. 1, pp. 37–44, 2000, doi: 10.1109/26.818871.

[8] R. O'Neill and L. B. Lopes, "Envelope variations and spectral splatter in clipped multicarrier signals," in *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, 1995, vol. 1, pp. 71–75, doi: 10.1109/pimrc.1995.476406.

[9] R. Raman, M. Kaul, R. Meenakshi, S. Jayaprakash, D. Rukmani Devi, and S. Murugan, "IoT applications in sports and fitness: enhancing performance monitoring and training," in *2023 Second International Conference on Smart Technologies for Smart Nation (SmartTechCon)*, Aug. 2023, pp. 137–141, doi: 10.1109/SmartTechCon57526.2023.10391301.

[10] M. J. Omidi, A. Minasian, H. Saeedi-Sourck, K. Kasiri, and I. Hosseini, "PAPR reduction in OFDM systems: Polynomial-based compressing and iterative expanding," *Wireless Personal Communications*, vol. 75, no. 1, pp. 103–118, Aug. 2014, doi: 10.1007/s11277-013-1350-2.

[11] J. Armstrong, "Peak-to-average power reduction for OFDM by repeated clipping and frequency domain filtering," *Electronics Letters*, vol. 38, no. 5, pp. 246–247, 2002, doi: 10.1049/el:20020175.

[12] J. A. Davis and J. Jedwab, "Peak-to-mean power control in OFDM, Golay complementary sequences, and Reed-Muller codes," *IEEE Transactions on Information Theory*, vol. 45, no. 7, pp. 2397–2417, 1999, doi: 10.1109/18.796380.

[13] Z. Liu, Y. Li, and Y. L. Guan, "New constructions of general QAM Golay complementary sequences," *IEEE Transactions on Information Theory*, vol. 59, no. 11, pp. 7684–7692, Nov. 2013, doi: 10.1109/TIT.2013.2278178.

[14] W. S. Ho, A. S. Madhukumar, and F. Chin, "Peak-to-average power reduction using partial transmit sequences: A suboptimal approach based on dual layered phase sequencing," *IEEE Transactions on Broadcasting*, vol. 49, no. 2, pp. 225–231, Jun. 2003, doi: 10.1109/TBC.2003.813440.

[15] S. H. Han and J. H. Lee, "Modified selected mapping technique for PAPR reduction of coded OFDM signal," *IEEE Transactions on Broadcasting*, vol. 50, no. 3, pp. 335–341, Sep. 2004, doi: 10.1109/TBC.2004.834200.

[16] B. R. Karimi, M. Beheshti, and M. J. Omidi, "PAPR Reduction in MIMO-OFDM Systems: Spatial and temporal processing," *Wireless Personal Communications*, vol. 79, no. 3, pp. 1925–1940, Dec. 2014, doi: 10.1007/s11277-014-1965-y.

[17] B. S. Krongold and D. L. Jones, "PAR reduction in OFDM via active constellation extension," *IEEE Transactions on Broadcasting*, vol. 49, no. 3, pp. 258–268, Sep. 2003, doi: 10.1109/TBC.2003.817088.

[18] Z. Latinović and Y. Bar-Ness, "SFBC MIMO-OFDM peak-to-average power ratio reduction by polyphase interleaving and inversion," *IEEE Communications Letters*, vol. 10, no. 4, pp. 266–268, Apr. 2006, doi: 10.1109/LCOMM.2006.1613742.

[19] T. Jiang and C. Li, "Simple alternative multisequences for PAPR reduction without side information in SFBC MIMO-OFDM systems," *IEEE Transactions on Vehicular Technology*, vol. 61, no. 7, pp. 3311–3315, Sep. 2012, doi: 10.1109/TVT.2012.2201970.

[20] H. S. Joo, J. S. No, and D. J. Shin, "A blind SLM PAPR reduction scheme using cyclic shift in STBC MIMO-OFDM system," in *2010 International Conference on Information and Communication Technology Convergence, ICTC 2010*, Nov. 2010, pp. 272–273, doi: 10.1109/ICTC.2010.5674679.

[21] C. Siegl and R. F. H. Fischer, "Partial transmit sequences for peak-to-average power ratio reduction in multiantenna OFDM," *Eurasip Journal on Wireless Communications and Networking*, vol. 2008, no. 1, Oct. 2008, doi: 10.1155/2008/325829.

[22] A. D. S. Jayalath, C. Tellambura, and H. Wu, "Reduced complexity PTS and new phase sequences for SLM to reduce PAP of an OFDM signal," in *IEEE Vehicular Technology Conference*, 2000, vol. 3, pp. 1914–1917, doi: 10.1109/vetecs.2000.851605.

[23] S. Gardner, "The HomePlug standard for powerline home networking." Proceedings of the 5th International Symposium on Power Line Communications and its Applications (ISPLC 2001), Malmo, Sweden, pp. 15–22, 2001.

[24] A. D. S. Jayalath and C. Tellambura, "SLM and PTS peak-power reduction of OFDM signals without side information," *IEEE Transactions on Wireless Communications*, vol. 4, no. 5, pp. 2006–2013, Sep. 2005, doi: 10.1109/TWC.2005.853916.

[25] T. Jiang and Y. Wu, "An overview: Peak-to-average power ratio reduction techniques for OFDM signals," *IEEE Transactions on Broadcasting*, vol. 54, no. 2, pp. 257–268, Jun. 2008, doi: 10.1109/TBC.2008.915770.

[26] S. Hussain, "Peak-to-average power ratio analysis and reduction of cognitive radio signals," Doctoral Thesis, University of Rennes, 2009.

[27] M. Y. I. Afifi, M. S. Elbakry, E. S. S. A. Said, and A. A. Ammar, "An efficient technique for out-of-band power reduction for the eliminated CP-STC-shaped system for 5G requirements," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 5, pp. 5306–5315, Oct. 2020, doi: 10.11591/ijece.v10i5.pp5306-5315.

[28] S. Pyla, K. Padma Raju, and N. B. Subrahmanyam, "Performance analysis of adaptive filter channel estimated MIMO OFDM communication system," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 5, pp. 3829-3836, Oct. 2018, doi: 10.11591/ijece.v8i5.pp3829-3836.

[29] T. Meenakshi, R. Ramani, A. Karthikeyan, N. S. Vanitha, and S. Murugan, "Power quality monitoring of a photovoltaic system through IoT," in *2023 International Conference on Sustainable Communication Networks and Application (ICSCNA)*, Nov. 2023, pp. 413–418, doi: 10.1109/ICSCNA58489.2023.10370494.

[30] R. Raman, S. Muthumarilakshmi, G. Jethava, R. Jagtap, M. Lalitha, and S. Murugan, "Energy monitoring in solar-powered buildings using internet of things," in *2023 2nd International Conference on Smart Technologies for Smart Nation, SmartTechCon 2023*, Aug. 2023, pp. 318–322, doi: 10.1109/SmartTechCon57526.2023.10391826.

BIOGRAPHIES OF AUTHORS

Dubala Ramadevi is a Ph.D. scholar in the Department of Electronics and Communication Engineering, GITAM University, Hyderabad, India. She has completed her master's in engineering with majors in VLSI and embedded systems from Vasavi College of Engineering, Osmania University, India. She completed her bachelor of technology in electronics and communication engineering from Bhoj Reddy Engineering College for women, Hyderabad, India. She can be contacted at dubalarama@gmail.com.

Polipalli Trinatha Rao is a professor in the Department of Electronics and Communication Engineering, GITAM University, Hyderabad, India. He did his Ph.D. in communication networks from College of Engineering, Andhra University, Visakhapatnam, India. He has completed his masters in engineering with majors in optical communication, College of Engineering, Guindy, Chennai, India. He completed his bachelor of engineering in electronics and communication engineering from College of Engineering, GITAM, Visakhapatnam, India. He has more than 20 years of Teaching and Research Experience. Eight (8) Ph.D degrees have been awarded under his guidance. He is presently guiding 14 research scholars in the areas of cognitive radio and software defined networks. He has published more than 85 research papers in International Journals and Conferences. He is presently the Professor In charge for the innovation center, GITAM University, Hyderabad. He is the Editorial Board member for different Journals. He was a key note speaker in many University and Government Organizations. He was also chair for the different Conferences and Seminars. He has reviewed books in the area of optical fiber communications. One of the research paper titled, "Routing protocols in wireless sensor networks: a survey" has been awarded as best research paper by a renowned Journals. He was honored with Best Researcher Award-2017, received from honorable vice-president of India, Sri Venkaiah Naidu, Sri T. Harish Rao, Minister for Irrigation, Marketing and Legislative Affairs (Government of Telangana), November 18, 2017. He can be contacted at email: tpolipal@gitam.edu.