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Power Efficient OFDM Signals with Reduced Symbol's Aperiodic Autocorrelation

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***Abstract*—**Three new algorithms based on minimization of autocorrelation of transmitted symbols and the SLM approach which are computationally less demanding have been proposed. In the first algorithm, autocorrelation of complex data sequence is minimized to a value of 1 that results in reduction of PAPR. Second algorithm generates multiple random sequences from the sequence generated in the first algorithm with same value of autocorrelation i.e. 1. Out of these, the sequence with minimum PAPR is transmitted. Third algorithm is an extension of the second algorithm and requires minimum side information to be transmitted. Multiple sequences are generated by modifying a fixed number of complex numbers in an OFDM data sequence using only one factor. The multiple sequences represent the same data sequence and the one giving minimum PAPR is transmitted. Simulation results for a 256 subcarrier OFDM system show that significant reduction in PAPR is achieved using the proposed algorithms.

***Keywords*—**aperiodic autocorrelation; OFDM; PAPR; SLM; wireless communication.

I. Introduction

ORTHOGONAL frequency division multiplexing (OFDM) is a technique used for high data rate wireless transmission. It is also a good technique to mitigate the effects of multipath delay spread over a wireless channel. Therefore, it has been implemented in several wireless LAN standards such as IEEE 802.11. A major drawback of OFDM is the high peak-to-average power ratio (PAPR) of the transmitted signal. OFDM signal consists of a number of independently modulated subcarriers. When N modulated subcarriers are added with the same phase, the peak power is N times the average power of OFDM signal. The high PAPR occurs due to certain data sequences such as all zeros and all ones. The high PAPR makes OFDM sensitive to nonlinear distortion caused by the transmitter's power amplifier (PA). Without sufficient power backoff, the system suffers from inter-modulation distortion and consequently, performance degradation. High level of backoff which is equivalent to increasing the operating range of PA reduces the efficiency of the PA. Various methods have been proposed to reduce PAPR of OFDM signals.

In [1], a technique based on signal set expansion has been proposed in which the original signal set is expanded to a larger signal set. Each point in the original set is associated with multiple points in the expanded set and the signal point with lowest PAPR is transmitted. One major drawback of this method is the need of extra redundant bits to represent the expanded signal set [1]. Recently different constellation and shaping methods have been used to reduce PAPR [2] e.g. trellis shaping method using a metric based on the Viterbi algorithm [3]. Another technique for reducing PAPR is partial transmit sequences (PTS) in which a set of sub-optimum factors are used to generate multiple symbols and the one with lowest PAPR is transmitted [4-8]. Although, significant reduction in PAPR is achieved but the number of trials for computing PAPR which corresponds to the number of times IFFT is being computed and the complexity increases with the number of factors being used and the grouping level. Selected mapping (SLM) technique is another efficient and a simple method to reduce PAPR [9-14]. Both PTS and SLM require side information to be transmitted to recover the original data sequence. New PTS and SLM techniques have also being designed such that minimal or even no side information are needed to be transmitted. SLM method combined with Hadamard constellation is an example of SLM technique that requires no side information and achieves considerable reduction in PAPR [14]. In [15], PAPR reduction is achieved using selective scrambling of the transmitted sequence that generates a number of statistically independent alternative transmit sequences. A selective function (SF) is computed for every sequence and the sequence with lowest SF corresponding to lowest PAPR is transmitted. SF depends on a parameter called Aperiodic Autocorrelation coefficients (AAC). Many authors show that low values of AAC correspond to low PAPR values [16-18]. In this paper, we have proposed three different novel algorithms by combining SLM technique and AAC. Results show considerable reduction in PAPR values 3.5 dB.

Rest of the paper is organized as follows: in Section 2, a brief introduction of OFDM system and the PAPR problem is given. In Section 3, the first algorithm called Selective Autocorrelation (AC) is proposed. The main idea behind this algorithm is to reduce the first AAC term for a sequence and then applying SLM technique. The second algorithm called Random Sequence with Fixed Autocorrelation (RSFA) is proposed in Section 4 in which random copy sequences are produced with low values of AAC and the one with lowest PAPR is transmitted. To overcome the randomness issue in RSFA, Selected Sequences with Variable Autocorrelation (SSVA) is proposed in Section 5 which follows the same methodology of RSFA but now the sequences are generated according to a rule and not randomly. The autocorrelation of

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the sequences in this case is changed. Simulation results are discussed in Section 6. In addition, in this section we show that the SF parameter which is based upon Hamming weight of a sequence gives misleading result and cannot be used for PAPR reduction. Finally conclusion is given in Section 7.

II. OFDM AND PAPR

A Block diagram of an OFDM transmitter is shown in Figure 1 and works as follows: Bit stream are encoded using an encoder for a robust transmission. The encoded data are passed through a modulation block (mapper) and maps the input bits into parallel complex signals. The parallel signals are called the subcarriers of the OFDM system. Modern OFDM systems consist of more than 1024 subcarriers. The output of the mapper is complex numbers represented by d_k where subscript k indicates the subcarrier index. For a Quadrature Phase Shift Keying (QPSK) mapper, $d_k \in (\pm 1, \pm j)$. An OFDM sequence or symbol D is basically a set of N different d_k complex numbers that can be written in a vector form as $D = [d_0, d_1, \ldots, d_{N-1}]$. These complex numbers are further modulated with orthogonal frequencies using the Inverse Fast Fourier Transform (IFFT) block for better bandwidth utilization. Furthermore, a guard interval is inserted to mitigate the affect of multipath fading and inter symbol interference (ISI). The resultant parallel signal at the output of the IFFT block is transformed into a serial composite signal after which it is converted into an analog signal. The analog signal is modulated using an RF modulator and transmitted through a wireless channel.

The problem of high peaks appears at the output of the IFFT block and hence the guard interval has no affect on the occurrence of these peaks. The baseband discrete OFDM signal at the output of the IFFT without the guard interval is given as

$$s(q) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} d_k e^{j2\pi kq/N}; \quad k,q = 0,1,\ldots,N-1 \tag{1}$$

where q is the discrete time index, N is the number of subcarriers and s is the base band discrete time OFDM signal. The complex sinusoids of all subcarriers are added together constructively. Due to this addition, at some points of the composite signal, high peaks occur. The highest peak in a signal occurs due to some specific data sequences such as all zeros or all ones. Since the high peaks exhibit high power, they limit the transmission of such signals and requires high cut off range for the power amplifier. These situations results in an inefficient utilization of power especially for portable wireless devices which are operated by battery. Hence power of such peaks are reduced before the transmission of signals.

The most widely and well established method for measuring the peaks is the PAPR. It is defined as the ratio of peak power and average power of the transmitted signal which is given as

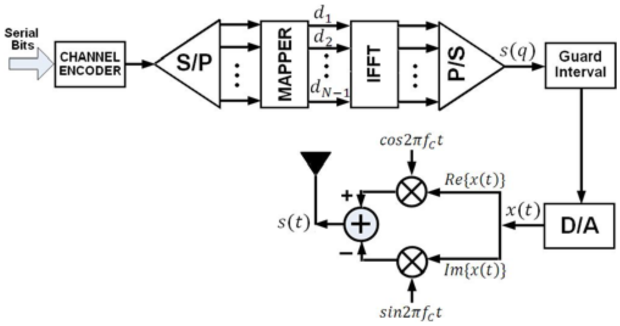

Fig. 1 Block diagram of an OFDM transmitter

$$PAPR = \frac{\max\limits_{0 \le q \le N-1} |s(q)|^2}{\frac{1}{N}\sum_{q=0}^{N-1} |s(q)|^2} \tag{2}$$

Oversampling (1) by a factor of J where ($J > 1$) gives a better PAPR estimation. It has been shown in [19] that $J = 4$ is sufficient to capture the peaks of the transmitted OFDM sequence.

III. SELECTIVE AUTOCORRELATION (SA)

Let $D = \{d_0, d_1, \ldots, d_{N-1}\}$ represent the original complex sequence to be transmitted. The aperiodic autocorrelation of any two complex symbols d_i and d_j from this sequence is given by $d_i d_j^*$ where '*' denotes complex conjugate. Further, the aperiodic autocorrelation of the complex sequence at the output of the modulation block is computed as follows [15]

$$R_i = \sum_{k=0}^{N-1-i} d_k d_{k+i}^*; \quad 0 \le i \le N-1 \tag{3}$$

For $i = 1$, (3) can be written as

$$R_1 = \frac{d_0}{d_1} + \frac{d_1}{d_2} + \ldots + \frac{d_{N-2}}{d_{N-1}} \tag{4}$$

It can be observed that for a QPSK modulation having $d_k \in (\pm 1 \pm j)$, the terms in (4) can have a value belonging to $\in (1, -1, j, -j)$. As shown in [15], the selection function (SF) for an OFDM symbol is defined as

$$SF = \frac{|W_H - N|^2 + |R_1|^2}{2N^2} \tag{5}$$

where W_H denotes the Hamming weight of the sequence to be transmitted and R_1 denotes the first coefficient of the aperiodic autocorrelation of that sequence. A lower SF results in lower PAPR. Theoretically, the smallest value of SF can be zero when $|R_1| = 0$ and $W_H = N$ simultaneously. However, it is extremely difficult to find such a data sequence having $|R_1| = 0$ and $W_H = N$. Infact, it is not possible to optimize $|R_1|$ and W_H at the same time. Hence we choose to minimize $|R_1|$ in order to reduce SF and hence PAPR. One way to reduce the value of $|R_1|$ is by manipulating the complex numbers d_k's such that the sum of every two adjacent terms in (4) becomes zero. Let $(d_{2m-2} / d_{2m-1}) + (d_{2m-1} / d_{2m})$ be a pair of any two adjacent terms in (4). To make their sum zero, the first term is multiplied by a factor g_m whose value is given by

$$g_m = -\frac{(d_{2m-1})^2}{(\bar{d}_{2m-2} d_{2m})}; \qquad 1 \le m \le \left\lfloor \frac{N-1}{2} \right\rfloor \tag{6}$$

where $\bar{d}_{2m-2} = g^*_{m-1} d_{2m-2}$. This is equivalent to multiplying the denominator of the first term by g^*_m. Multiplying the denominator of the first term with g^*_m instead of multiplying its numerator with g_m results in forward modification i.e. numerator of the second term in such pair, whereas multiplying the numerator of the first term of such pair by g_m will result in backward modification which is more difficult to manipulate than forward modification. Further, the denominator of the second term in such pair is also multiplied by g^*_m to make the sum of this pair equal to 0. This modifies the numerator of the first term in the next adjacent pair shown as $\bar{d}_{2m-2}$ in (6). As a result, every term in the complex sequence D is modified except the first and the last complex numbers and its $|R_1|$ becomes 1. We call this modified sequence D_1 sequence where $D_1 = \{d_0, \bar{d}_1, \bar{d}_2, ..., \bar{d}_{N-2}, d_{N-1}\}$. It can be noted that there are $\left\lfloor \frac{N-1}{2} \right\rfloor$ pairs in R_1 (see Eqn. (4)) whose denominators will be multiplied by the factor g^*_m. Hence, the last term will not be paired with any of the terms in (4) and will remain unchanged. These factors are sent as side information and used to recover the original data sequence D from the transmitted sequence D_1. Each g_m is used to recover two complex numbers in D as follows

$$d_{2m-1} = \frac{\bar{d}_{2m-1}}{g^*_m} \quad \text{and} \quad d_{2m} = \frac{\bar{d}_{2m}}{g^*_m} \tag{7}$$

PAPRs of D and D_1 are compared and the one with lower PAPR is transmitted. It can be noted that (6) is valid for all the adjacent pairs in (4) except the first pair for which g_m is given by

$$g_1 = \frac{-d_1^2}{d_0 d_2}; \qquad \text{for} \quad m = 1 \tag{8}$$

IV. Random Sequences with Fixed Autocorrelation (RSFA)

The number of possible combinations of binary data sequences in an OFDM system is $q = 2^{LN}$. Let p be the number of possible data sequences having $|R_1| = 1$ then, $p = 2^S$ where $S < LN$ and $p \subset q$. Every two D sequences i.e. one with $|R_1| \neq 1$ and the other with $|R_1| = 1$ or D_1 itself map into a single D_1 sequence. As a result, the total number of sequences having $|R_1| = 1$ is $p = 2^{LN/2}$. This can be shown as follows: In case of QPSK modulation and assuming that the complex numbers d_k are independent of each other and the values of these complex numbers $\in (\pm 1 \pm j)$ are equally probable, and since the values of the side information $g_m \in (\pm 1 \pm j)$ are equally probable as well, then the total number of bits required to send the side information is (N-2) bits for even values of N. Since the side information is unique, the total number of sequences having $|R_1| = 1$ is ($2^{N-2} \times 2^2$) because the last term in D i.e. d_{N-1} can represent one of the four symbols $\in (00,01,10,11)$. This result is the same as $p = 2^N$ when $L = 2$. This is valid for all M – ary mappers in an OFDM system. Some of these sequences with $|R_1| = 1$ have high PAPR values and others have low PAPR value. To find the optimum sequence with $|R_1| = 1$ and lowest value of PAPR requires an exhaustive search. One way to generate such sequences having $|R_1| = 1$ called $\bar{D}_1^v$ is to multiply every second term in D_1 by one of the factors $\in (1, -1)$. It is obvious that multiplying the even terms in D_1 by –1 will not affect $|R_1|$ i.e. $|R_1|$ would remain 1. The number of possible uniquely generated $\bar{D}_1^v$ sequences including D_1 for a particular D sequence is $2^{N/2}$ i.e. $1 \le v \le 2^{N/2}$ and v is an integer value with $\bar{D}_1^1 = D_1$ when every second term is multiplied by 1. For QPSK, the number of D sequences is 2^N. Hence, the total number of $\bar{D}_1^v$ for all D sequences is $2^{5N/2}$. But since the total number of sequences with $|R_1| = 1$ is only 2^N, then ($2^{5N/2} - 2^N$) are common $\bar{D}_1^v$ sequences that are equally distributed amongst all the 2^{2N} D sequences. Finding a sub-optimum sequence with lowest PAPR amongst all $2^{N/2}$ $\bar{D}_1^v$ sequences that represent the same D sequence still requires an exhaustive search and becomes more complex and impractical for large value of N. As a result, T number of sequences belonging to $\bar{D}_1^v$ are randomly selected. The PAPRs of D, D_1 and T random sequences are compared and the sequence with lowest PAPR value is transmitted.

V. Selected Sequences with Variable Autocorrelation (SSVA)

A major drawback of RSFA algorithm is the additional side information required to indicate the T sequence being transmitted because such sequence is selected randomly. In this algorithm, which is an extension of the second algorithm, a number of different sequences are generated from the modified sequence D_1 by multiplying selective complex numbers in D_1 with a factor of –1 rather than multiplying them randomly. For example, if z represents the location of such complex numbers i.e. z is an integer, where $z \in (m:n)$, $(m:n) = (m, m+1, m+2, ..., n-1, n)$, then every z^{th} complex number will be multiplied by –1 resulting in $(n - m + 1)$ new complex sequences. For example, if $z \in (3:5)$, then each and every third complex number of D_1 will be multiplied by -1 resulting in a new complex sequence say D_3. Similarly, every fourth and fifth complex number will be multiplied by -1 resulting in two more new sequences say D_4 and D_5. PAPRs of D (original sequence), D_1 (modified sequence with $|R_1| = 1$) and D_m to D_n are compared and the one with lowest PAPR is transmitted. Minimal side information is needed to indicate the sequence being transmitted. It is noted that $|R_1|$ is modified only for odd values of z except when $z = 1$.

VI. Simulation Results

Figure 2 shows complementary cumulative distribution function (CCDF) of a 256-subcarrier OFDM-QPSK system when the proposed algorithms are used. The simulations were run for 50,000 OFDM blocks and the transmitted signal was oversampled by a factor of four which is sufficient to capture the peaks. With reference to the first algorithm (i.e. AC) where the autocorrelation of complex sequence has been made 1, it can be seen that a reduction of almost 1.3 dB in PAPR is achieved for a CCDF of 0.001. With SSVA algorithm, the improvement begins from 2 dB when $z \in (3{:}4)$ and goes to 3.5 dB when $z \in (3{:}128)$. It is noted that while going from $z \in (3{:}4)$ to $z \in (3{:}8)$, improvement in PAPR is 0.7 dB. However, for $z \in (3{:}16)$ and $z \in (3{:}128)$, only marginal improvement in PAPR is observed. Hence, the values of $z \in (9{:}128)$ have minimal contribution towards the reduction of PAPR and $z \in (3{:}8)$ can be regarded as the best possible range of indices that achieves acceptable PAPR reduction for all practical purposes. Indices 1 and 2 have not been considered as these do not contribute towards PAPR reduction. Results for $z \in (3{:}8)$ and $z \in (3{:}16)$ are not shown in Figure 2.

In RSFA algorithm, improvement starts from 2.6 dB to 3.0 dB for a CCDF of 0.001 as T goes from 10 to 100. It is noted that both SSVA with $z \in (3{:}8)$ and RSFA with $T = 10$ give same improvement of almost 2.6 dB. The number of SLM sequences generated in SSVA with $z \in (3{:}8)$ is less than that generated by RSFA with $T = 10$. Further, the side information needed in SSVA is minimal compared to side information in RSFA. Note that $|R_1| = 1$ for all the SLM sequences generated in RSFA algorithm whereas $|R_1| = 1$ only when z is even in SSVA algorithm.

Figure 3 shows PAPR values for all proposed algorithms with different subcarriers for a fixed CCDF of 0.001. The improvement is almost fixed for all subcarriers indicating a constant gain maintained by all proposed algorithms.

According to [15], when QPSK modulation is applied, a sequence having equal number of 1's and 0's i.e. Hamming weight equals to N generally exhibits low PAPR value. Further, when (5) is applied on number of generated sequences that represent the same data sequence, the sequence with lowest value of SF will have lowest PAPR value. It means that this SLM approach used in [15] is based on the value of the factor SF which reflects the value of PAPR instead of computing PAPR of the sequences. According to simulation results, this is not true for those sequences having $|R_1| = 1$. Figure 4 shows that with RSFA and $T = 10$, when the decision of selecting the sequence with the lowest PAPR is based upon (5) instead of evaluating the PAPRs of the sequences, there is no improvement in PAPR. Infact, when $T = 100$, the performance is slightly degraded. Figure 5 confirms this point by investigating 3,000 randomly generated OFDM symbols. It is obvious that majority of OFDM symbols when the decision is based on SF factor have their PAPRs on the higher side (represented by cross) compared to normal decision based on the PAPR of the OFDM symbols (represented by dots). Note that in both RSFA based on (5) and RSFA based on traditional PAPR comparison, we have excluded D i.e. only D_1 and the T sequences are used for SLM comparison. This is because we only want to see the validity of (5) for those sequences having $|R_1| = 1$ since D may or may not have its autocorrelation value equals to one. In this way, by fixing the value of $|R_1|$ to 1, we can observe the PAPR values of the sequences based on their Hamming weights. Note that RSFA for $T = 100$ with and without D sequence gives same result.

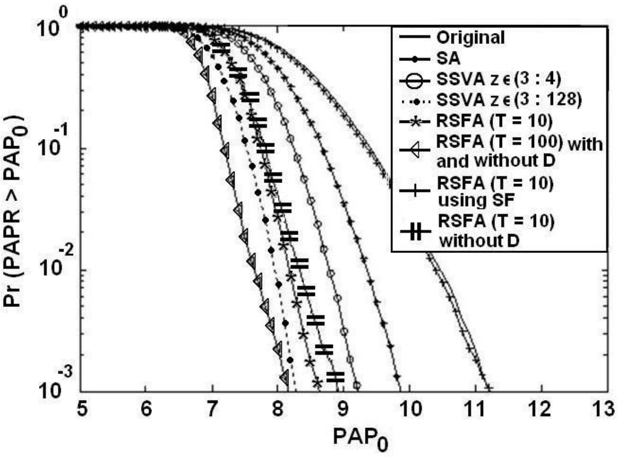

Fig. 2 CCDF curves for 256-subcarrier OFDM-QPSK system using the proposed algorithms

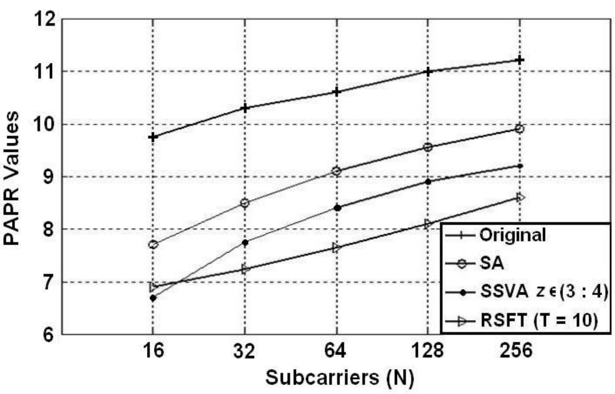

Fig. 3 PAPR values of various subcarriers for OFDM-QPSK system at CCDF of 0.001 using the proposed algorithms

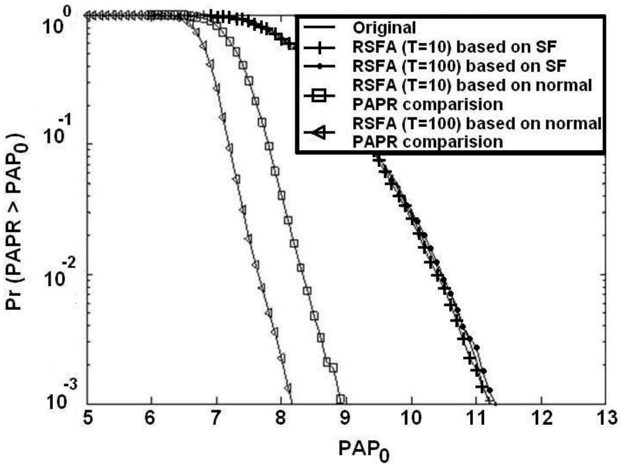

Fig.4 CCDF curves for 256-subcarrier OFDM-QPSK system when RSFA-SLM is used with the selection decision based upon Selective Function (SF) see (eqn. (5)) and normal PAPR

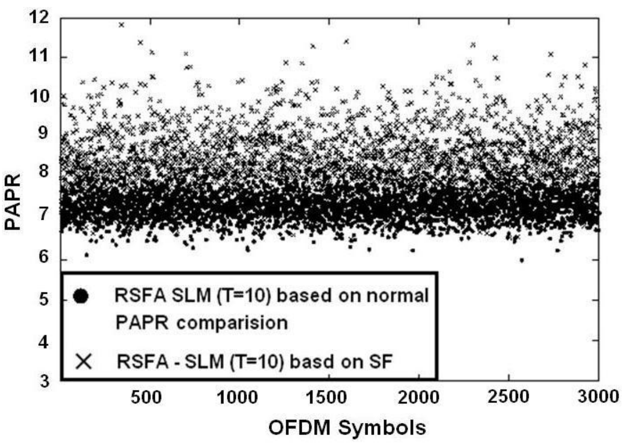

Fig.5 PAPR comparison for 3,000 randomly generated OFDM symbols for 256-subcarriers OFDM-QPSK system when RSFA (T = 10) is used based upon Selective Function (SF) and normal PAPR

VII. Conclusions

We have proposed three novel algorithms for PAPR reduction in OFDM system. With the proposed algorithms, it is possible to achieve improvement in PAPR by more than 3 dB. The complexity of these algorithms is minimal. The algorithms are equally applicable for arbitrary number of subcarriers and signal constellations. It has been shown also that PAPR decision based on SF equation is not valid for all sequences especially for those sequences having $|R_1|$ equals to 1. One disadvantage of these algorithms is the amount of side information needed especially when minimizing the autocorrelation value. This could be handled by proper manipulation of the complex numbers and could be further investigated.

References

[1] Seung Hee Han and Jae Hong Lee, "Peak-to-average power ratio reduction of an OFDM signal by signal set expansion," *in Proc. IEEE International Conference on Communications 2004 (ICC 2004)*, Paris, France, June 2004, vol.2, pp. 867– 871.

[2] Al-Shaikhi, A.A. and How, J., “Erasure Based PAPR Reduction Using Minimally Expanded Constellations in OFDM Systems”, *in proc. IEEE Global Telecommunications Conference 2007* (*GLOBECOM '07*), Washington DC, USA, Nov. 2007, pp. 2904–2909.

[3] Hideki Ochiai, "A novel trellis-shaping design with both peak and average power reduction for OFDM systems", *IEEE Transactions on Communications*, vol. 52, no. 11, pp. 1916–1926, Nov 2004.

[4] S. H. Muller and J. B. Hüber, “OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences,” *IEE Electron. Lett.*, vol. 33, no. 5, pp. 368–369, Feb. 1997.

[5] Cimini, L.J., Jr. and Sollenberger, N.R., "Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences," *IEEE Communications Letters,* vol.4, no.3, pp.86–88, March 2000.

[6] Christian Siegl and Robert 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, Article ID 325829, 11 pages. January, 2008.

[7] Theodoros Giannopoulos and Vassilis Paliouras, “A Low-Complexity PTS-based PAPR Reduction Technique for OFDM Signals without Transmission of Side Information”, *Journal of Signal Processing Systems*, vol. 56, no. 2–3, pp. 141–153, September 2009.

[8] Xinchun Wu, Zhigang Mao, Jinxiang Wang, Bin Zhou, "A Novel PTS Technique with Combinative Optimization in Real Part and Imaginary Part for PAPR Reduction in OFDM Systems,", *in proc. Third International Conference on Next Generation Mobile Applications, Services and Technologies 2009*, Cardiff, Wales, pp.215–218, September 2009.

[9] Chin-Liang Wang and Yuan Ouyang, "Low-complexity selected mapping schemes for peak-to-average power ratio reduction in OFDM systems," *IEEE Transactions on Signal Processing,* vol.53, no.12, pp. 4652–4660, Dec. 2005.

[10] Suckchel Yang, and Yoan Shin, “An Adaptive SLM Scheme Based on Peak Observation for PAPR Reduction of OFDM Signals”, *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*, vol. E91, no. 1, pp. 422–425 January 2008.

[11] Jayalath A.D.S and Tellambura C., "SLM and PTS peak-power reduction of OFDM signals without side information," *IEEE Transactions on Wireless Communications,* vol.4, no.5, pp. 2006–2013, Sept. 2005.

[12] Breiling, H.; Muller-Weinfurtner, S.H.; Huber, J.B., "SLM peak-power reduction without explicit side information", *IEEE Communications Letters,* vol.5, no.6, pp. 239–241, Jun 2001.

[13] Jyh-Horng Wen, Shu-Hong Lee and Chu-Hsuan Cheng, "SLM-based PAPR reduction method using partial data circulation and side information insertion in OFDM systems", *International Journal of Communication Systems*, vol. 22, no. 1, pp. 87–100, January 2009.

[14] Mobasher, A. and Khandani, A.K., "Integer-based constellation-shaping method for PAPR reduction in OFDM systems," *IEEE Transactions on Communications*, vol.54, no.1, pp. 119–127, Jan. 2006.

[15] P. Van Eetvelt, G. Wade and M. Tomlinson, “Peak to Average Power Reduction for OFDM Schemes by Selective Scrambling,” *IEE Electronics Letters*, vol. 32, no. 21, pp. 1963–1964, October 1996.

[16] H. Nikookar and R. Prasad, “Weighted multicarrier modulation for peak-to average power reduction,” *IEICE Trans. on Commun.*, vol. E83–B(8), pp. 1864–1872, Aug. 2000.

[17] Homayoun Nikookar and Knut Sverre Lidsheim, “Random phase updating algorithm for OFDM transmission with low PAPR”, *IEEE Transactions on Broadcasting*, vol. 48, no. 2, pp. 123–128, June 2002.

[18] Abolfazl Ghassemi and T. Aaron Gulliver, “Low Autocorrelation Fractional PTS Subblocking for PAPR Reduction in OFDM Systems”, in proc. *Conference Communication Networks and Services Research 2008 (CNSR 2008)*, Halifax, NS, May 2008, pp. 41–45.

[19] C. Tellambura, “Computation of the continuous-time PAR of an OFDM signal with BPSK subcarriers,” *IEEE Commun. Lett.*, vol. 5, no. 5, pp. 185–187, May 2001.

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