PAPR Reduction for Very High Throughput WLAN with Backward Compatibility to IEEE802.11 a/n

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Abstract - **We propose a simple technique to reduce PAPR for a Very High Throughput Wireless LAN with backward compatibility with IEEE 802.11a/n system. By applying proposed phase rotation in partial transmit sequence technique we got PAPR reduction up to 3.01dB lower than conventional one, yields in comparable PAPR with IEEE802.11n preamble.**

Keywords - **Gigabit, Wireless LAN, backward compatibility, IEEE802.11a/n WLAN System, PAPR reduction.**

I. INTRODUCTION

The very high throughput (VHT) wireless LAN (WLAN) system which is under discussion by IEEE802.11TGac, offers throughput more than 1Gbps in MAClayer\[1]. This system is assigned to use 80 MHz bandwidth and work in the 5 GHz band, same band as IEEE802.11a/n WLAN system [2], [3], therefore ensuring the backward compatibility with both systems is included in the functional requirements [4]. Those systems above take advantage of using OFDM toget high data rate and employ MIMO to boost the throughput. However same as other OFDM-based system, they also suffer from peak-to-average-powerratio (PAPR) problem. Between them, theIEEE802.11ac shall face the highest PAPR problem due to using the largest number of subcarriers.

Many PAPR reduction techniques, such as amplitude clipping [5], clipping and filtering [6], coding [7], tone reservation and tone injection[8], active constellation extension [9], and multiple signal representation techniques such as partial transmit sequence (PTS) [10], selected mapping [11], and interleaving [12], we re discussed and compared in [13]. Those techniques achieve PAPR reduction at the expense of transmit signal power increase, biterror rate(BER) increase, data rate loss, computational complexity increase, and soon.the discussion was closed with conclusion there is no special technique as the best solution for all OFDM systems. Rather, the PAPR reduction technique should be carefully chosen according to various system requirements. In the other hand, the IEEE802.11n system uses special form of PTS to reduce the PAPR.

In this paper, we report our work in developing a Gigabit WLAN system based on IEEE802.11TGac's functional requirements. Since it uses large number of subcarriers we need to mitigate the PAPR problem. However, the above PAPR reduction techniques were restricted by considering backward compatibility with IEEE802.11a/n WLAN system. Here we propose a simple technique to reduce PAPR by applying proper phase rotation in PTS method. This technique give slow PAPR signal while maintaining low complexity and backward compatibility with IEEE802.11a/n system. The resulted time domain signal has comparable PAPR with IEEE802.11n's signal.

This paper is organized as follows. The PTS method is briefly explained in section II. The proposed phase rotations for PAPR reduction using PTS for Gigabit WLAN system with backward compatibility to IEEE802.11a/n are analyzed in section III. Finally, we draw some conclusions insection IV.

II. PARTIAL TRANSMIT SEQUENCE SCHEME

The complex baseband OFDM signal with N subcarriers can be written as

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_k . e^{j2\pi k \Delta_F t} \quad 0 \le t \le NT \qquad (1)$$

where $S\ k$ is the symbol transmitted in subcarrier k, ΔF is the frequency spacing, which is chosen to be $1/NT$, and T is the symbol duration of the original input signal. When $s(t)$ is sampled at the symbol rate $1/T$, (1) gives a standard N-point IDFT. However, in most applications, the OFDM signal must be oversampled, and thus an oversized IDFT is normally used. The instantaneous power of $s(t)$ is given by

$$P(t) = |s(t)|^2 \qquad (2)$$

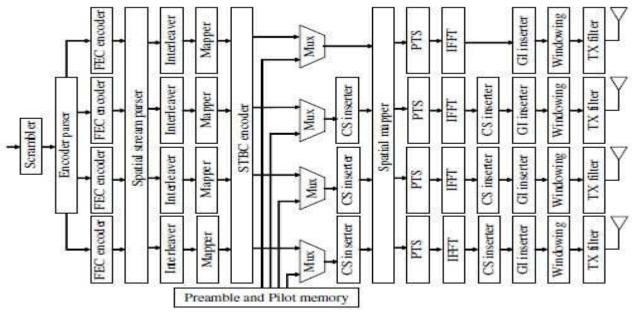

Fig. 1. Proposed Transmitter of Gigabit WLAN system with PTS for PAPR reduction

The PAPR of the OFDM signal is defined as

$$\mathrm{PAPR} = \frac{max(|s(t)^2)}{E\{|s(t)|^2\}} = \frac{max\{P(t)\}}{P_{av}} \qquad (3)$$

where $Pav = E\{|s(t)|2\}$ represents the average power of thesampled OFDM signal.

Let $\mathbf{S} = [S\ 0, \cdots, S\ N-1]$ be the input data vector for the IDFT block. In the PTS method, is split into M subvectors, each subvector being appropriately padded with zeros to form an N- dimensional vector. Then, **S** can be rewritten as

$$\mathbf{S} = \sum_{m=1}^{M} \mathbf{S}_m \qquad (4)$$

where any two of the Sms (m = 1, 2, ..., M) are othogonal,i.e., they disjointly contain the elements of S. By multiplying each vector Sm by a rotation factor bm = $e^{j\theta m}$, we obtain the combination of the rotated vectors as given by

$$\tilde{\mathbf{S}} = \sum_{m=1}^{M} b_m\ \mathbf{S}_m \qquad (5)$$

The objective of the PTS method is to determine the M coefficients, b_m (m = 1, 2, · · · , M), such that the IDFT of ˜S,

$$\bar{s} = IDFT\{\tilde{S}\} = \sum_{m=1}^{M} b_m\ IDFT\{\tilde{S_m}\} = \sum_{m=1}^{M} b_m\ s_m \qquad (6)$$

has the minimum PAPR. Because an oversampled OFDM signal is usually needed for the generation of the continuoustime signal for transmission, the IDFT size in obtaining (6) is $N\times L$, where L is the oversampling rate. The oversized IDFT of ˜**S** can be obtained by inserting $L-1$ zeros in each **Sm**. Usually, the *bm*s are chosen as complex values with unit amplitude, i.e., $bm = e^{j\theta m}$, θm Є [0, 2π]. Thus, (6) can be rewritten as has the minimum PAPR. Because an oversampled OFDM signal is usually needed for the generation of the continuoustime signal for transmission, the IDFT size in obtaining (6) is $N\times L$, where L is the oversampling rate. The oversized IDFT of ˜**S** can be obtained by inserting $L-1$ zeros in each **Sm**.

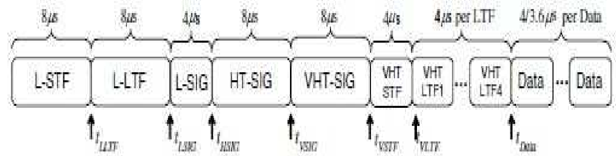

Fig. 2. The proposed mixed format preamble for Gigabit system which has backward compatibility with IEEE802.11a/n.

Usually, the *bm*s are chosen as complex values with unit amplitude, i.e., *bm* = *ej*θ*m*, θ*m* □ [0, 2π]. Thus, (6) can be rewritten as

$$\bar{s} = \begin{bmatrix} s_{1,1} & s_{1,2} & \cdots & s_{1,M} \\ s_{2,1} & s_{2,2} & \cdots & s_{2,M} \\ \vdots & \vdots & \ddots & \vdots \\ s_{NL,1} & s_{NL,2} & \cdots & s_{NL,M} \end{bmatrix} \begin{bmatrix} e^{j\theta_1} \\ e^{j\theta_2} \\ \vdots \\ e^{j\theta_M} \end{bmatrix} \qquad (7)$$

The PTS method is to find an optimum phase vector $\Theta = [\theta_1, \theta_2, \cdots, \theta_M]^T$ such that the PAPR is minimized. Therefore one should perform an exhaustic search for $(M-1)$ phase factors, and θ^{M-1} sets of phase factors are searched to find the optimum one. The search complexity increases exponentially with the number of subblocks M. Further, the number of required side information bits to be sent to receiver is $\lfloor \log_2\theta^{M-1} \rfloor$, where $\lfloor X \rfloor$ denotes the smallest integer that does not exceed X, decreases the data rate. Next, to mitigate these complexity and side information problem, we first search the optimum θ for each field and propose single value of θ for all field then set the receiver with the same θ.

III. PAPR REDUCTION IN THE PROPOSED GIGABIT SYSTEM

Block diagram of transmitter of the proposed Gigabit system is shown in Fig. 1. There are four streams and PTS is done before the IFFT to reduce the PAPR in each stream. The proposed mixed format (MF) preamble for this system which considers backward compatibility with IEEE802.11a/n is shown in Fig. 2. It consists of three main parts, short training fields (STF), long training fields (LTF) and SIGNAL fields (SIG) of legacy (L), high throughput (HT) and very high throughput (VHT) parts. The time domain representation of those fields on transmit chain *iTX*, *i* = 1, 2, 3,4 are: determined by equations (8) until (14), where *NTX* = 1, . . . , 4 is number of transmit antenna, 1 √*NTX*.48 , 1 √*NTX*.208 , and 1 √*NTX*.228 are the scale factors to ensure that the total power of the time domain signal of STFs, LTFs, and SIGs and Data field, respectively, as summed over all transmit chains is either 1 or lower than

$$s_{LSTF}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.48}} w_{T_{LSTF}}(t) \sum_{k=-122}^{122} \Upsilon_k S_k . e^{j2\pi k \Delta_F (t - T_{CS}^{iTX})} \quad (8)$$

$$s_{LLTF}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.208}} w_{T_{LLTF}}(t) \sum_{k=-122}^{122} \Upsilon_k L_k e^{j2\pi k \Delta_F (t - 2T_{GI} - T_{CS}^{iTX})} \quad (9)$$

$$s_{LSIG}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.208}} w_{T_{LSIG}}(t) \sum_{k=-26}^{26} (D_k + P_k) \\ (e^{j2\pi(k-96)\Delta_F(t - T_{GI} - T_{CS}^{iTX})} + je^{j2\pi(k-32)\Delta_F(t - T_{GI} - T_{CS}^{iTX})} \\ + e^{j\theta}(e^{j2\pi(k+32)\Delta_F(t - T_{GI} - T_{CS}^{iTX})} + je^{j2\pi(k+96)\Delta_F(t - T_{GI} - T_{CS}^{iTX})})) \quad (10)$$

$$s_{HSIG}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.208}} \sum_{n=0}^{1} w_{T_{HSIG}}(t) \sum_{k=-26}^{26} (jD_{k,n} + p_{n+1} P_k) \\ (e^{j2\pi(k-96)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})} + je^{j2\pi(k-32)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})} \\ + e^{j\theta}(e^{j2\pi(k+32)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})} + je^{j2\pi(k+96)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})})) \quad (11)$$

$$s_{VSIG}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.208}} \sum_{n=0}^{1} w_{T_{VSIG}}(t) \sum_{k=-26}^{26} (jD_{k,n} + p_{n+2} P_k) \\ (e^{j2\pi(k-96)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})} + je^{j2\pi(k-32)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})} \\ + e^{j\theta}(e^{j2\pi(k+32)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})} + je^{j2\pi(k+96)\Delta_F(t - nT_{SYM} - T_{GI} - T_{CS}^{iTX})})) \quad (12)$$

$$s_{VSTF}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.48}} w_{T_{VSTF}}(t) \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX}, i_{STS}} \Upsilon_k S_k \\ e^{j2\pi k \Delta_F (t - T_{CS}^{i_{STS}})} \quad (13)$$

$$s_{VLTF}^{(n, i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.228}} w_{T_{VLTF}}(t) \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} [\mathbf{Q}_k]_{i_{TX}, i_{STS}} [\mathbf{P}]_{i_{STS}, n} \\ \Upsilon_k H_k e^{j2\pi k \Delta_F (t - T_{GI} - T_{CS}^{i_{STS}})} \quad (14)$$

$$s_{Data}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{TX}.228}} \sum_{n=0}^{N_{SYM}-1} w_{T_{SYM}}(t - nT_{SYM}) \sum_{k=-122}^{122} \sum_{i_{STS}=1}^{4} \\ [\mathbf{Q}_k]_{i_{TX}, i_{STS}} (D_k + p_{n+2} P_{i_{STS}, n}^{k}) \Upsilon_k . e^{j2\pi k \Delta_F (t - nT_{SYM} - T_{GI} - T_{CS}^{i_{STS}})} \quad (15)$$

1.wT f ield (t) is the time windowing function to meet the spectral mask's requirement which is defined as a rectangular pulse wT (t) of duration T.

$$w_T(t) = \begin{cases} \sin^2(\frac{\pi}{2}(0.5 + \frac{t}{T_{TR}})) & \text{for } (\frac{-T_{TR}}{2} < t < \frac{T_{TR}}{2}) \\ 1 & \text{for } (\frac{T_{TR}}{2} \le t < \frac{T - T_{TR}}{2}) \\ \sin^2(\frac{\pi}{2}(0.5 - \frac{(t-T)}{T_{TR}})) & \text{for } (\frac{T - T_{TR}}{2} \le t < \frac{T + T_{TR}}{2}) \end{cases} \quad (16)$$

with T_{TR} is the transition time between two consecutive fields. S_k are the four times duplication of IEEE802.11a STF symbols, L_k are the four times duplication of IEEE802.11a LTF symbols, H_k are the two times duplication of IEEE802.11n HT-LTF symbols. TiTX CS and TiSTS CS represents the cyclic shift diversity to prevent unintentionally beamforming for legacy and non-legacy part, respectively. D_k and P_k are the data SIG fields and pilot, respectively which allocated on k-th subcarrier. p_n is pilot polarity controller sequence which can be generated by IEEE802.11a's scrambler with the "all ones" initial state and by replacing all "1's" with -1 and all "0's" with 1. Q_k is a spatial mapping matrix which maps the each space time stream (STS) symbols onto transmit chain symbols s(iTX) k . P is 4 × 4 orthogonal mapping matrix defined as:

$$\mathbf{P} = \begin{bmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{bmatrix} \quad (17)$$

The constants to calculate the timing used in this system are listed in Table I. Υ*k* represents the proposed rotation of the subcarriers in 80MHz channel to get low PAPR signal while considering the backward compatibility with IEEE802.11a/n system, as:

$$\Upsilon_k = \begin{cases} 1 & \text{for } k \le -64 \\ j & \text{for } -64 < k \le 0 \\ e^{j\theta} & \text{for } 0 < k \le 64 \\ j.e^{j\theta} & \text{for } k > 64 \end{cases} \quad (18)$$

The 80 MHz channel for the Gigabit system is divided into two 40 Mhz channel lower and upper, each consists of 20 MHz lower and upper. With 256 subcarriers, as k is the subcarrier index, the negative subcarriers ($k \le 0$) are for lower 40 MHz channel which consists of $k \le -64$ as the lower 20 MHz and $-64 < k \le 0$ as the upper 20 MHz channel, while the positive subcarriers ($k > 0$) are for 40 MHz channel upper which consists of $0 < k \le 64$ as the lower 20 MHz and $k > 64$ as the upper 20 MHz channel, as illustrated in Fig. 3. The IEEE802.11n 40 MHz rotates the subcarriers in 20 MHz upper by 90 [deg] relative to the subcarriers in 20 MHz lower to reduce the PAPR.

TABLE I
THE CONSTANTS FOR CALCULATION THE TIMING OF GIGABIT WLAN SYSTEM

Parameter	Value	Parameter	Value
Δ_F	312.5kHz (80MHz/256)	T_{LSTF}	8 (μs)
T_{DFT}	3.2 μs ($1/\Delta_F$)	T_{LLTF}	8 (μs)
T_{GI}	0.8 ; 0.4 (μs)	T_{LSIG}	4 (μs)
T_{SYM}	4 ; 3.6 (μs)	T_{HSIG}	8 (μs)
T_{TR}	0.1 (μs)	T_{VSIG}	8 (μs)
$T_{CS}^{iTX}, i=1,2,3,4$	0,-0.05, -0.1, -0.15 (μs)	T_{VSTF}	4 (μs)
$T_{CS}^{iSTS}, i=1,2,3,4$	0, -0.4, -0.2, -0.6 (μs)	T_{VLTF}	4 (μs)

TABLE II
PHASE ROTATION TRADE-OFF FOR PAPR REDUCTION BETWEEN STFS AND LTFS

θ	PAPR [dB]			
	$L, VHT-STF$	$L-LTF$	$VHT-LTF$	Average
69	**3.42**	4.49	4.73	4.34
70	3.43	4.44	4.68	4.31
71	3.53	4.38	**4.65**	**4.30**
72	3.64	4.33	4.75	4.36
73	3.74	**4.29**	4.85	4.43
74	3.84	4.39	4.96	4.53

A. First Proposal for PAPR Reduction

Since the PAPR reduction using PTS technique for the proposed Gigabit 80MHz was restricted by consideration of backward compatibility with IEEE802.11a/n, we should keep the 90 [deg] phase difference between 20 MHz lower and upper for each 40 MHz channel. Therefore only the phase rotation between 40 MHz lower and upper can be adjusted to reduce the PAPR. The division of the 80 MHz channel with proposed phase rotation is illustrated in Fig. 4, which also describes the phase rotation in Eq. 18.

We first searched the $\theta \in [0, \pi]$ to obtain the lowest PAPR signal for L-STF then continue for other fields, i.e. VHTSTF, L-LTF and VHT-LTF. However the phase rotations for lowest PAPR of those fields are not the same, therefore we take an average of them wich has lowest PAPR to be used in all field. This is done to accomodate single phase rotation for all field so that low complexity system can be achieved. This also eliminates the need of sending side information when the receiver is set with the same phase. The phase rotation searching from 40 [deg] to 100 [deg] versus PAPR reduction for STFs and LTFs is displayed in Fig. 6. The tradeoff between them are listed in Table II where the bold-printed are the values of θ for the lowest PAPR of each field. As it gives the lowest average PAPR, the value of θ is choosen to be 71 [deg] for all field. By applying this phase rotation we get PAPR reduction up to 1.786 dB lower than the conventional one.

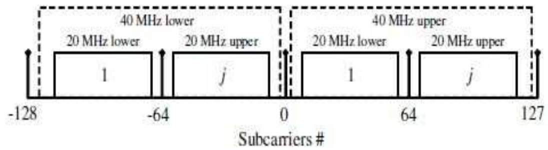

Fig. 3. Contruction of the conventional Gigabit 80 MHz channel

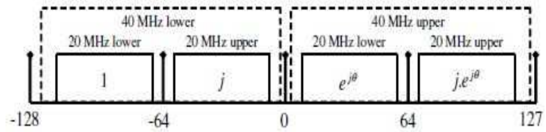

Fig. 4. Contruction of the fisrt proposal to reduce the PAPR of the Gigabit system

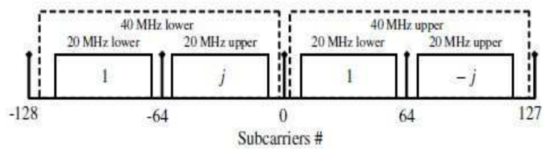

Fig. 5. Contruction of the second proposal to reduce the PAPR of the Gigabit system.

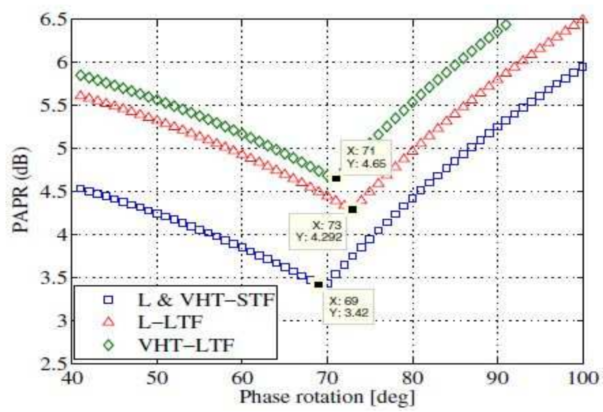

Fig. 6. Phase rotation searching for PAPR reduction of STFs and LTFs.

B. Second Pproposal for PAPR Reduction

Here we propose another phase rotation with the same PTS technique. The subcarriers in the 20MHz upper of the 40 MHz upper is phase rotated 90[deg] c.c.w. relative to the subcarriers in the lower one, as illustrated in Fig. 5. This configuration might decrease the support of backward compatibility with IEEE802.11n in the 40 MHz upper, however since it is applied in all fields, the channel information which is taken from the LTFs preamble is valid to be used for decoding the SIGs and the Data field. The phase rotation for second proposal is represented as

$$\Upsilon_k = \begin{cases} 1 & \text{for} \quad k \le -64, \quad 0 < k \le 64 \\ j & \text{for} \quad -64 < k \le 0 \\ -j & \text{for} \quad k > 64 \end{cases} \qquad (19)$$

By applying this configuration we re-calculate the PAPR of all fields and obtain up to 3.01 dB lower PAPR than the conventional one, yields in comparable PAPR with IEEE802.11n system.

TABLE III
PAPR OF THE PROPOSED GIGABIT MF PREAMBLES AND IEEE802.11N MF PREAMBLE

Field	Conventional (dB)	Proposed-1 (dB)	Proposed-2 (dB)	IEEE802.11n (dB)
L-STF	5.099	3.539	2.239	2.089
L-LTF	6.176	4.389	3.166	3.168
L-SIG	9.759	7.973	6.749	5.769
HT-SIG1	9.825	8.039	6.815	6.815
HT-SIG2	12.043	10.532	9.233	9.032
VHT-SIG1	11.083	9.297	8.073	-
VHT-SIG2	8.799	7.013	5.789	-
HT-STF	-	-	-	2.089
HT-LTF	-	-	-	3.406
VHT-STF	5.099	3.539	2.239	-
VHT-LTF	6.417	4.650	4.032	-
Data	7.925	7.844	7.856	7.287

Table III displays the obtained PAPR of the Gigabit system MF preamble using conventional, first and second proposed phase rotation compared to IEEE802.11n MF pramble. The PAPR of STFs and LTFs are constant since they have definite symbols in frequency domain. The PAPR of SIGs and data fields might change depend on the contained information. We calculate the PAPR with setting parameters as: L-part: Length=100, Data rate=6. HT-part: MCS=31, Length=64K, STBC=0, LDPC coding=0, Short GI=0. VHT-part: MCS=31, Length=128K, STBC=0, LDPC coding=0, Short GI=0, constellation= 64 QAM, coding rate=5/6.

IV. CONCLUSION

We have been developing a Gigabit MIMO WLAN system which consider backward compatibility with IEEE802.11a/n.

The proposed phase rotations with partial transmit sequence technique reduces the PAPR from the conventional one up to 3.01 dB, yields in comparable PAPR with the IEEE802.11n MF preambule

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