

Adaptive Tone-Reservation PAPR Technique with Optimal Subcarriers Allocation Awareness for Multi-User OFDMA Systems

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Abstract— In this paper, an adaptive tone reservation technique with optimal subcarrier allocation awareness for multi-user OFDMA systems is investigated. In general, a variety of approaches have been proposed to cope with the PAPR problem in OFDM systems. A tone reservation (TR) is an effective technique for reducing PAPR, in which it does not need to transmit any side information and there is no distortion on the data-transmitting carriers. However, there is no rule to reserve the tone in the TR technique. In this paper, we propose to use a non-selected tone resulted from the optimal subcarrier allocation algorithm, based on the subcarrier's channel gain approach, as a reserved tone. This proposed technique could enhance the throughput while reducing PAPR of the OFDMA systems. Simulation results show that the proposed TR method with optimal subcarrier allocation in OFDMA systems achieves better PAPR reduction and throughput performance than the conventional TR without subcarrier allocation systems.

Keywords— OFDMA, PAPR, TR, optimal subcarrier allocation, throughput performance

I. INTRODUCTION

As an attractive technology for wireless communications, orthogonal frequency division multiplexing (OFDM) offers a considerable high spectral efficiency, multipath delay spread tolerance, immunity to the frequency selective fading channels and power efficiency [1]. As a result, OFDM has been chosen for high data rate communications such as Digital Video Broadcasting (DVB) and mobile worldwide interoperability for microwave access (mobile WiMAX). However, one of the main problems in OFDM systems is the high peak-to-average power ratio (PAPR) of transmitting signals due to the superposition of many subcarriers which leads to significant in-band distortion and spectral spreading when passed through a nonlinear device such as power amplifier (PA). A low PAPR allows the transmit power amplifier to operate efficiently. When the PAPR is high, a high dynamic range is required for both digital-to-analogue converter (DAC) and power amplifier to avoid amplitude clipping. Such high dynamic range increases complexity while reducing efficiency of the system. On the other hand, if the dynamic range is too low, there would be a substantial amount of signal distortion, which

increases a bit error rate (BER). Furthermore, the distortion would cause an out-of-band radiation.

A number of approaches have been proposed to cope with the PAPR problem [2]: an amplitude clipping method [3], a block coding method [4], a selected map

ping method (SLM) [5], a partial transmit sequence method (PTS) [6] and a tone reservation method [7],[8]. Basically, these methods were designed for OFDM systems to reduce the PAPR value. For OFDMA systems, the PAPR reduction problem could be more complicated than in OFDM systems. There are some existing PAPR reduction techniques which can easily be applied to OFDMA systems such as PTS, SLM and TR. Among these techniques, the tone reservation is the most effective method when the number of subcarrier is large. In this technique, a portion of subcarriers (tone), not being used for data transmission, are reserved to create a dummy data in time domain which can minimize the PAPR of the overall signal. Note that since the dummy data on the reserved tone is separated (in frequency domain) from the data-transmitting carriers, the data is not distorted and, hence, the BER performance will not be degraded [7], [8]. Furthermore, TR does not require any side information to be sent to the receiver. Thus the dummy data can be easily discarded at the receiver after the FFT processing. Theoretically, the dummy data in TR technique can be found by minimizing of PAPR value via standard direct optimization technique which may cause high computationally complexity. Therefore, many suboptimal approximation techniques were proposed such as iterative clipping and filtering (ICF) [3] with the tone reservation constraints.

Referring to the existing TR, there is no a rule to define the number and position of reserved tones, especially when applying to OFDMA systems. This fact motivates us to investigate and propose the PAPR reduction technique based on the TR method with optimal subcarrier allocation awareness for OFDMA systems. In this paper, we propose an adaptive tone reservation technique by using a non-selected tone resulted from the optimal subcarriers allocation algorithm for OFDMA downlink systems.

The rest of this paper is organized as follow. Section II introduces the system model including PAPR and TR methods

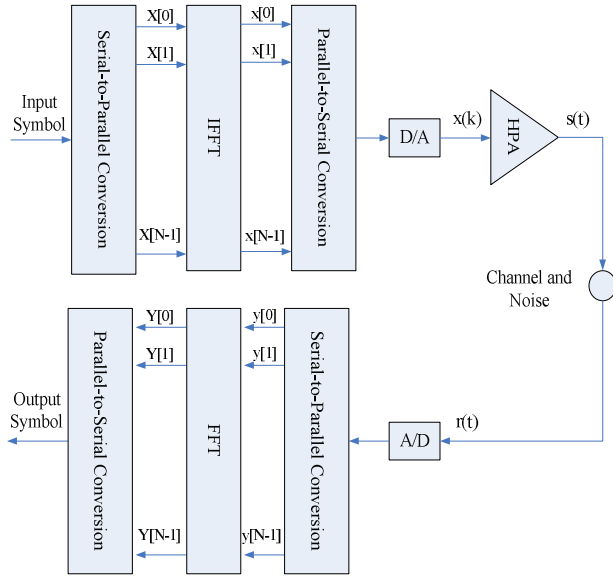


Figure 1. The OFDM system block diagram with IFFT/FFT implementation

in OFDM systems and subcarriers allocation scheme for OFDMA systems. The propose method is described in Section III. In Section IV, we present the simulation results of the proposed method. Finally, the conclusion is given in Section V.

II. SYSTEM MODEL

In this section, we first briefly review the basic of the OFDM signals and the PAPR definition. Moreover, the tone reservation method and the optimal subcarriers allocation scheme for OFDMA systems are also exposed.

A. Orthogonal Frequency Division Multiplexing and Peak-to-Average Power Ratio

The OFDM signal is the sum of many orthogonally overlapped subchannels of equal bandwidth. In order to realize these spectrally overlapping subchannels, the Inverse Fast Fourier Transform (IFFT) is employed at the OFDM transmitter. The IFFT yields the OFDM discrete signals consisting of the sequence $x_k = x_0, \dots, x_{N-1}$ of length N . Figure 1 shows an OFDM system block diagram with IFFT/FFT implementation.

The baseband sample for OFDM signals, with N subcarriers, at the output of IFFT is given by [1]:

$$x_k = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X_i e^{j2\pi i k / N} \quad (1)$$

where $0 \leq k \leq N-1$ and X_i denotes the data symbol at the i^{th} subcarrier.

The PAPR of the signal is defined as:

$$PAPR(dB) = 10 \log_{10} \left(\frac{\max_{0 \leq k \leq N-1} [x_k^2]}{E[x_k^2]} \right) \quad (2)$$

where $E[\cdot]$ is the expectation operator, representing the average power of the signal.

B. Tone Reservation

The TR method can reduce the PAPR value in the OFDM signals by utilizing the reserved subcarriers which are not used for data transmission. In this technique, the baseband signal in (1) could be modified as

$$x_k = \frac{1}{\sqrt{N}} \left(\sum_{m \in S} X_m e^{j2\pi k m / N} + \sum_{n \in R} C_n e^{j2\pi k n / N} \right) \quad (3)$$

We assume that there are two mutually exclusive subsets of subcarriers: S is the set of subcarriers used for the data transmission and R is the set of remaining subcarriers used as the reserved tones.

With the TR method, the PAPR of the signal is defined as

$$PAPR(x_k) = \frac{\max |x_k|^2}{E[|x_k|^2]} \quad (4)$$

Basically, we can adjust the value of C_n to reduce the peak value of x_k without disturbing the actual data contained in X_m . Thus, C_n must be investigated to minimize the maximum norm of the time domain signal x_k , expressed as

$$C^{(opt)} = \arg \min_c \max_k |x_k| \quad (5)$$

The optimization of (5) leads to high computational complexity. However, the dummy data sequence can be determined from a predefined set of a sequence such as all '0', '1' or complementary sequence [7]. Another technique, which is one of the simple suboptimal techniques for tone reservation, is the iterative clipping and filtering (ICF). In each iteration, the baseband signal from IFFT is clipped by a hard-limiter to the predefined threshold A in time domain[3], that is

$$x_{clipped} = \begin{cases} x_k, & |x_k| \leq A \\ A e^{j\phi_k}, & |x_k| > A \end{cases} \quad (6)$$

Then the clipped signal $x_{clipped}$ is filtered to remove a portion of out-of-band components (ϕ_k is the phase of x_k). Note that, the clipping noise exists only on the reserved tone.

C. Optimal Subcarriers Allocation in OFDMA Systems

In OFDMA systems, one challenge issue of wireless communications is adaptive resource allocation: power and subcarrier allocation. As a result of frequency-selective fading in OFDMA systems, the channel gains are distinct for each different subcarrier. This benefit is exploited to adaptively

allocate the subcarriers to users so that each user satisfies a high channel gain. In the optimal subcarriers allocation, a user measures the channel and sends back to its own base station. The base station utilizes these channel state information to assign subcarriers to each user. After that, the subcarriers assignment information is sent to the user via a separate control channel; therefore, each user needs only to demodulate the bits on its respective assigned subcarriers. In this paper, we assume that there are U users and K subcarriers in the system. The wireless channel is modelled as frequency selective Raleigh fading channel. Additive white Gaussian noise (AWGN) is presented with single-sided noise power spectral density (PSD) level of N_0 for all subcarriers of all users. The data rate R_u in bits/s for the u^{th} user in a zero margin system is given by[10]

$$R_u = \frac{B}{K} \sum_{k=1}^K c_{u,k} \log_2 \left(1 + \frac{p_{u,k} |H_{u,k}|^2}{N_0 (B/K)} \right) \quad (7)$$

where B is the total bandwidth of the system, $c_{u,k}$ is a scalar in which it is equal to one when the k^{th} subcarrier is assigned to u^{th} user, and zero otherwise. The channel gain and the power of the k^{th} subcarrier for the u^{th} user can be denoted as $H_{u,k}$ and $p_{u,k}$ respectively. The maximum change in the achieved data rate of the u^{th} user can be defined as[9]

$$V_{u,max} = \frac{B}{K} \log_2 \left(\frac{1 + p_{u,k} (H_{u,mean} + s_u)^2}{1 + p_{u,k} (H_{u,mean} - s_u)^2} \right) \quad (8)$$

where $H_{u,mean}$ is the average channel gain for all subcarriers of user u and s_u is the u^{th} user's channel gain standard deviation from the mean.

III. THE PROPOSED ADAPTIVE TONE RESERVATION WITH SUBCARRIERS ALLOCATION AWARENESS

An OFDMA system is a very efficient technique for broadband data transmission. It is used in almost all new wireless technologies nowadays. Since the OFDMA system is based on OFDM, the PAPR problem also arises. Nevertheless, there are various kinds of techniques that can cope with this issue such as the TR technique. It is known that the existing TR method can reduce the PAPR efficiently, however, there is no rule to reserve the tone. Therefore, we adopt a suboptimal algorithm for subcarriers allocation [9] to define the position of the reserved tones. When this technique is combined with TR method, not only the subchannels is adaptively assigned to different users based on a subcarrier's channel gain approach, but also the PAPR value is reduced effectively. The advantage of the combined technique is that it offers maximum in both throughput and PAPR reduction performances simultaneously. Figure 2 shows a block diagram of downlink OFDMA systems with the proposed method.

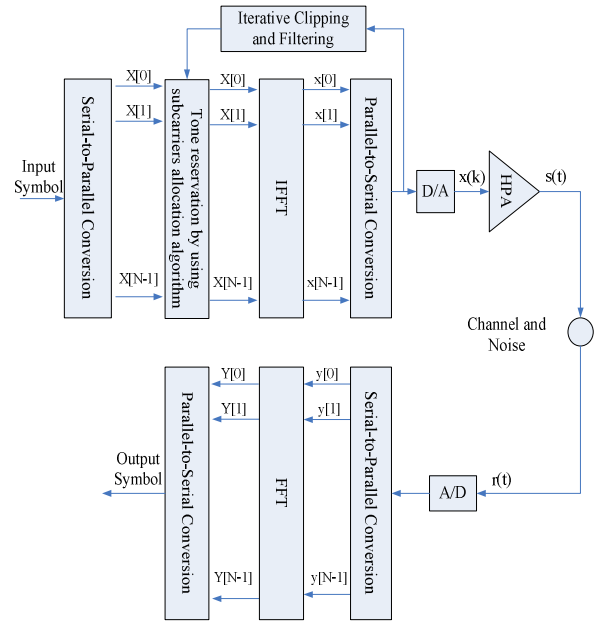


Figure 2. A block diagram of downlink OFDMA systems with the proposed method

- (i) Initialization

$$c_{u,k} = 0, \forall u, k$$

$$R_u = 0, \forall u$$

$$R = \{1, 2, \dots, K\},$$

$$S = \emptyset,$$

$$U = \{1, \dots, U\},$$

(ii) Subcarriers Allocation

$$u = \arg \max V_{u,max},$$

$$k = \arg \max_{k \in R} H_{u,k},$$

$$c_{u,k} = 1,$$

$$R = R - \{k\} \text{ and } S = S \cup \{k\},$$

Repeat until $k=K-r$, r =number of reserved tone

(iii) Tone Reservation for PAPR reduction

Feedback x to ICF (See Fig.2) $\rightarrow X = FFT\{x\}$

Let R being a set of reserved tone

Replace the reserved tone by

$$C_n = X \quad \text{where } n \in R$$

end

Figure 3. The proposed algorithm

The proposed adaptive tone reservation method with subcarriers allocation awareness, as shown in Figure 3, is described below.

1) The optimal subcarriers allocation is firstly processed by generating subcarrier's channel for each user by using six independent Rayleigh fading multipaths used for typical urban area with exponential power delay profile. The Jake's model [1] is used to characterize each flat fading multipath channel, and the average SNR ranges from 1–40 dB.

2) The maximum change in the achieved data rate of each user is measured by using (8) and equal power distribution is assumed across all subchannels.

3) The user, which has a highest difference of data rate for all subcarriers, is prioritized to choose the satisfied available subcarriers. It implies that the sensitive user have a smallest immunity to the frequency selective fading channels because the variance of subchannel gain is strong. Thus, we prioritize the weakest user to occupy the best available subcarrier to obtain the optimal subcarrier allocation.

4) The TR algorithm is processed. According to subcarriers allocation in the first step, there are unused subcarriers which can be dedicated to the reserve tone assignment to decrease the PAPR value.

5) To obtain more PAPR reduction gain, we then apply the ICF technique in the proposed TR method.

In our experiments we investigate three kinds of method to observe PAPR reduction and throughput performance. In the proposed method, called as Method 1, we insert the reserved tone at the unused subcarrier resulted from the subcarrier allocation algorithm. Method 2 is a conventional TR without using subcarrier allocation algorithm. For Method 3, we use the last portion of subcarriers for the reserved tones with the conventional TR and the rest of subcarriers, which belong to transmitting data, are arranged through the subcarrier allocation algorithm. All of these methods are presented in Figure 4–6 respectively. In the simulation, the subcarriers allocation algorithm is processed by using the same subchannel gains for all methods.

IFFT Input						
Subcarriers assignment for data and reserved tones						
X1,0	X2,0	C0	X2,1	C1	X1,1	

Figure 4. Data block based on Method 1

IFFT Input								
User1			User2			Reserved tones		
X1,0	X1,1		X2,0	X2,1		C0	C1	

Figure 5. Data block based on Method 2

IFFT Input								
Subcarriers assignment for data						Reserved tones		
X1,0	X2,0	X2,1	X1,1			C0	C1	

Figure 6. Data block based on Method 3

TABLE 1. SIMULATION PARAMETERS

Parameters	Value
Modulation Method	BPSK
OFDMA bandwidth	1 MHz
number of subcarriers	64
number of users	2
number of reserved tone	16
channel model	AWGN
Rayleigh fading multipaths	COST 231(6 paths)

IV. SIMULATION RESULTS

This section presents computer simulation results to verify the performance of proposed method in terms of PAPR reduction and throughput performances. Table 1 shows the list of simulation parameters.

In our simulation, a total of 5000 different channel realizations were used and the results were averaged. Moreover, the probability distribution of the PAPR values from each method is characterized by the complementary cumulative distribution function (CCDF). In the simulation, the channel state information of all user in the systems is assumed to be known at the base station.

From the CCDF results in Figure 7, we clearly seen that the PAPR value obtained from all methods can be reduced compared with that of original signals without PAPR reduction.

Moreover, the PAPR reduction of Method 1 is slightly lower than that of Method 2 and 3. From our experiments, however, we found that it is possible for Method 2 and 3 to offer the highest PAPR reduction. Thus, in order to make more obvious results, we apply ICF technique to all methods and the results is shown in Figure 8.

Figure 8 presents the PAPR reduction comparison for all methods applied with ICF technique through i times iterations ($i = 5$) to improve the PAPR reduction performance. It is observed that the PAPR reduction methods using ICF technique gain about 0.5 dB for Method 1 in comparison to Method 2 and 3.

Clearly, the proposed TR method with subcarrier allocation, referred as Method 1, offers the lowest PAPR reduction compared with the other methods.

The simulation results to investigate the throughput performance for Method1, 2 and 3 can be shown in Figure 9. It can be seen that the proposed algorithm has achieved higher total throughput than the other method. This advantage is due to the subcarriers allocation technique which is adopted firstly for assigning the subcarriers based on the highest variance of channel gains. As a result, this method maximizes the total throughput.

Method 3 offers a slightly lower throughput because subcarriers allocation algorithm is applied to deal with the rest of subcarrier after we reserve tone already. Since subcarriers allocation algorithm is not considered in Method 2, the throughput is the lowest.

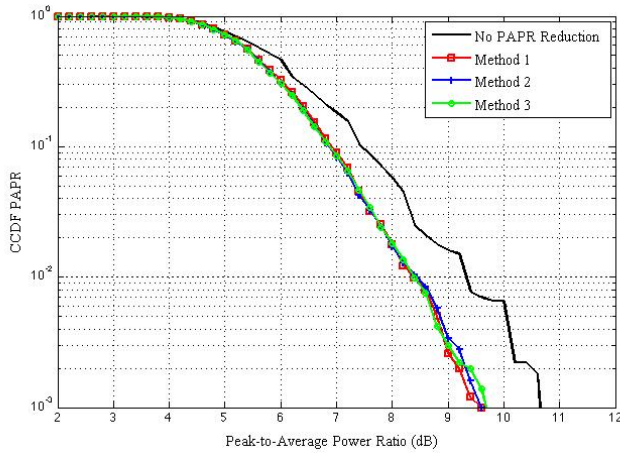


Figure 7. PAPR reduction comparison of the different methods without ICF technique

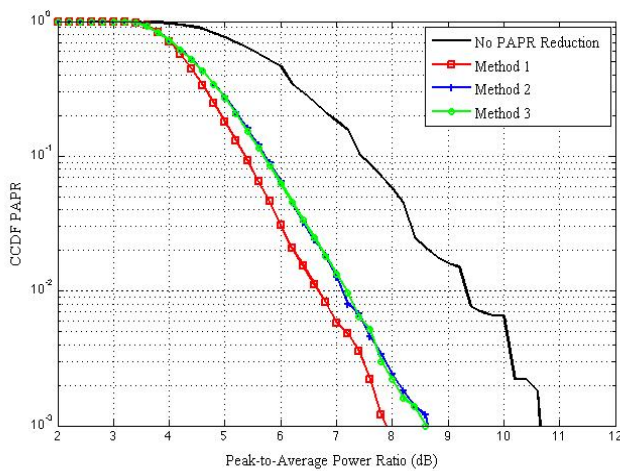


Figure 8. PAPR reduction comparison of the different methods by using ICF technique (five iterations)

V. CONCLUSIONS

In this paper, a combined method of subcarrier allocation algorithm and PAPR reduction for OFDMA downlink systems is proposed. All methods with using ICF technique yield a better PAPR performance than the case of without using ICF technique by 2 dB for Method 1, and 1.5 dB for Method 2 and 3 at CCDF of 10^{-1} . In addition, Method 1 achieves the maximum total throughput resulted from using the subcarrier allocation algorithm. Thus, the proposed technique is better than the ordinary scheme such that it improves both throughput and PAPR reduction performances. In the future

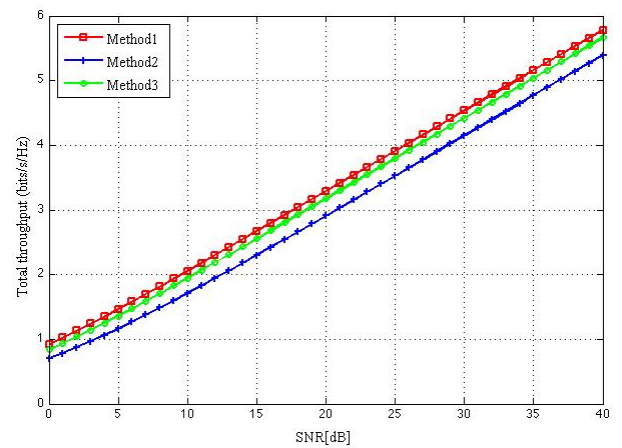


Figure 9. The total throughput vs. SNR

work, not only the channel state information is taken into account for designing the subcarriers allocation, but also PAPR, transmit power limit and data rate requirement for different services will be considered to optimize the subcarriers allocation performance.

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