Peak-to-Average Power Ratio (PAPR) Reduction Techniques of OFDM Signals

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***Abstract*—It is well-known that one of the most serious problems of Orthogonal Frequency Divison Multiplexing (OFDM) is its high Peak-to-Average Power Ratio (PAPR) which seriously limits the power efficiency of High Power Amplifier (HPA). This paper introduces various methodologies to cope with this problem.**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has several desirable attributes, such as high immunity to inter-symbol interference, robustness with respect to multi-path fading, and ability for high data rates, all of which are making OFDM to be incorporated in various wireless standards.

OFDM also has some of disadvantages comparing with single carrier systems. Among them, high Peak-to-Average Power Ratio (PAPR) of the OFDM signal is regarded as the most serious problem which significantly reduces power efficiency of High Power Amplifier (HPA). The high PAPR of OFDM signals makes the signals operating beyond linear range of HPA and consequently causes nonlinear distortion. There are various ways to cope with this problem.

In this paper, we show two different approaches to mitigate the high PAPR problem. The first approach is digital Pre-Distortion (PD) approach which is using a Pre-Distorter (PD). The PD is a kind of nonlinear device which is located before the HPA and increases linear range up to the saturation region. The second approach is using PAPR reduction techniques. Rather than increase the linear range of HPA, these techniques propose reducing PAPR of OFDM signals, consequently reducing nonlinear distortion of HPA. And in this approach, we briefly introduce Single Carrier Frequency Division Multiple Access (SC-FDMA). The SC-FDMA has been considered as a 3GPP LTE uplink transmission technique due to its low PAPR.

The rest of the paper is organized as follows. In Section II, we describe OFDM and PAPR. In Section III, digital PD techniques are briefly described. In Section IV, various PAPR reduction techniques which include SC-FDMA are introduced. The conclusions are given in Section V.

II. OFDM AND PEAK-TO-AVERAGE POWER RATIO

An OFDM signal on N subcarriers can be represented as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{j2\pi f_k t},\ 0 \leq t \leq T_s \quad (1)$$

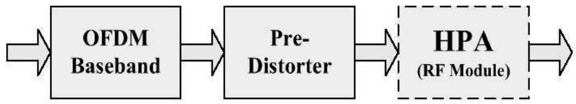

Fig. 1. A simple block diagram of PD-equipped OFDM HPA system

where T_S is duration of the OFDM signal and $f_k = \frac{k}{T_s}$.

The high PAPR of OFDM signal arises from the summation in the above IDFT expression. The PAPR of OFDM signal in analog domain can be represented as

$$PAPR_c = \frac{\max_{0 \leq t \leq T_s} |x(t)|^2}{E(|x(t)|^2)} \quad (2)$$

III. DIGITAL PRE-DISTORTION APPROACH

In this section, we introduce PD techniques to cope with high PAPR of OFDM signals. Mitigation of the nonlinear distortion caused by the high PAPR of the OFDM signals is based on passing it through a Pre-Distorter prior to its entry into the HPA [1], as depicted in Fig. 1.

Various PD techniques are summarized as follows, (1) Using the exact inversion of a HPA model as a PD [2]; (2) using a Look-Up Table (LUT) and updating the table via Least Mean Square (LMS) error estimation [3] [4]; (3) two-stage estimation, using Wiener-type system modeling for the HPA, and Hammerstein system modeling for the pre-distorter [5]; (4) simplified Volterra-based modeling for compensation of the HPA nonlinearity. [6] [7]; and (5) polynomial approximation of this nonlinearity [8].

IV. PAPR REDUCTION APPROACH

Even though the Digital Pre-Distortion Technique may significantly reduce nonlinear distortion in an OFDM system and thus allow a signal with high PAPR to go through the HPA, it only works in a limited peak power range, that is, up to the saturation region of the HPA. However, in practical situations, the OFDM signal has a peak power exceeding this range. Thus, even using the digital pre-distortion technique, a high Input Back-Off (IBO) is needed to avoid the significant in-band distortion and out-of-band radiation that would otherwise occur at the output of the HPA. This high IBO, in turn, reduces transmission power efficiency. For this reason, as a complementary approach to pushing the OFDM signal with a given

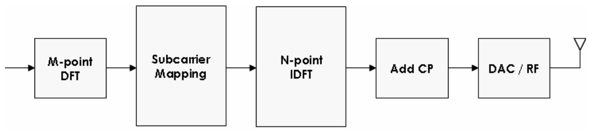

Fig. 2. A block diagram of SC-FDMA Transmitter

PAPR through the HPA using digital pre-distortion, several techniques have been and are being developed to appropriately manipulate the OFDM signal so that the transmitted signal has lower PAPR than the original one. These techniques may be partitioned into the following nine categories: (1) Clipping and Filtering technique [9] [10], (2) Block Coding technique [11] [12], (3) Partial Transmit Sequence (PTS) technique [13], (4) Selected Mapping (SLM) technique [14], (5) Interleaving technique [15], (6) Tone Reservation/Injection technique [16], (7) Active Constellation Extension technique [17], (8) Companding technique [18], and (9) Other techniques including SC-FDMA.

The SC-FDMA is a modified version of OFDM(A) proposed for 3GPP LTE uplink transmission [19] [20]. The structure of SC-FDMA is quite similar with OFDM as shown in Fig. 2. The SC-FDMA just locates DFT block before the normal OFDM transmitter to reduce the PAPR of OFDM signal in time domain. Instead, the frequency domain signal of SC-FDMA has high PAPR. Even SC-FDMA can get better power efficiency by low PAPR, there are several disadvantages comparing with OFDM(A). The link level performance of SC-FDMA is usually worse than OFDM(A) in frequency selective fading channel due to Inter-Symbol Interference (ISI). Moreover complexity of SC-FDMA is usually higher than OFDM(A). Especially in MIMO (Multi-Input Multi-Output) system, ML (Maximum Likelihood) detection of SC-FDMA is much more complex than OFDM(A), thus not feasible to use in practical system.

Therefore, it is a little bit difficult to say that SC-FDMA is better than OFDM(A). In some cases, OFDM(A) with a PAPR reduction technique can show better performance. However, SC-FDMA shows better PAPR characteristic inducing high power efficiency which is good for Mobile Station. This is the reason that SC-FDMA has been considered for uplink transmission.

V. Conclusion

Two different approaches to cope with PAPR of OFDM signals are introduced. By locating a digital PD before the HPA, we can increase the linear range of HPA, thus get high power efficiency. But, this PD approach only works in the limited range. As a second and complementary approach, we introduce various PAPR reduction techniques. Among them, SC-FDMA is considered as one of promising OFDM(A) modification technique for uplink transmission.

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