Power Amplifier Switching/Selection (PAS) for Energy Efficient MIMO Systems

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Abstract

We propose a power amplifier (PA) switching/selection (PAS) method to improve energy efficiency (EE) of a multiple-input multiple-output (MIMO) system. By using multiple dissimilar, auxiliary, low peak envelope power (PEP) PAs in addition to multiple identical high-PEP PAs, we can switch on the most efficient PA among all eligible low-PEP PAs that can support a target rate, hence avoid efficiency degradation arising from using the high-PEP PA for low-power transmission. Since the activated PA operates with its own maximum output power and maximum efficiency, the average EE of the MIMO system can be improved on low-power transmission regime for a low target rate. Numerical results verify the efficacy of the proposed PAS with respect to the dynamic EE purpose of MIMO systems.

Index Terms

Energy efficiency (EE), power amplifier switching/selection (PAS), multiple-input multiple output (MIMO).

I. INTRODUCTION

Recently, green wireless communications have been vigorously studied with consideration of a practical power amplifier (PA) model (e.g., see the references in [1]). Since the PA is a major power consumer in wireless communications, a high-efficiency PA is preferably used to save energy consumption. In [1], device-, system-, and network-level approaches to improve EE have been introduced, namely, i) transmitter architecture with PA packages, ii) signal processing such as input backoff (IBO), peak-to-average power ratio (PAPR) reduction, and linearization using feedback/forward distortion, and iii) network protocols such as discontinuous transmission [2], sleeping, coordinated multipoint transmission [3], and coordinated napping [4]. Based on the device-level approach, how to switch on and off the PA, specifically, a switch bias control circuit, has been studied for a PA switching/selection (PAS) method, in which either a low or high peak envelope power (PEP) PA is selected based on the desired output power [5]. Energy efficiency (EE) with a PAS between a traditional PA and an envelope tracking PA has been evaluated [6]. On the other hand, the PAS method has been studied based on system-level approach, for a single-antenna system with full channel state information at the transmitter (CSIT) [7], [8] and for a transmit antenna selection (TAS) and maximum ratio combining (MRC) system with partial CSIT [9]. In the PAS systems, the most efficient PA is switched on for transmission while satisfying the required spectral efficiency (SE); as a result, the EE of the network can be improved.

In a conventional multiple-input multiple-output (MIMO) system, multiple information streams can be transmitted through multiple identical high-PEP PAs. As an example, Fig. 1 illustrates a two-transmit and two-receive (2-by-2) antenna system that transfers two data streams, $x_1$ and $x_2$, through two identical PAs, denoted by $PA_3$. The conventional MIMO transmitter may reduce the transmission power to save power consumption if it can support the given target rate, i.e., power control. To do this, the receiver feeds back the power control information. In the example, 2 bits are fed back from the receiver to inform one of five-power levels including an off mode as summarized in Table I. However, the reduction of the transmission power from the allowable peak envelope power (PEP) decreases the PA efficiency $\eta$, e.g., a power-added efficiency (PAE), significantly [13], as shown in Fig. 2. The PAE is defined as

$$\eta = \frac{P_{out} - P_{in}}{P_{PA}} \approx \frac{P_{out}}{P_{PA}}, \quad (1)$$
where $P_{\text{out}}$, $P_{\text{in}}$, and $P_{\text{PA}}$ are PA’s output power, input power, and power consumption, respectively. The approximation of PAE to a drain efficiency in (1) is valid, because $P_{\text{in}}$ is relatively small compared to $P_{\text{out}}$ and $P_{\text{PA}}$ in generic wireless communications. The efficiency degradation is severe as shown in our previous survey over various PAs in Fig. 2. The PAEs of PA$_3$ for particular transmit power levels are summarized in Table I. The PAE degradation causes significant overhead power consumption at the PA, resulting in network EE degradation.

In this paper, to circumvent the network EE degradation, we apply a PAS method to a MIMO system. To this end, dissimilar, auxiliary, low-PEP PAs are employed at the transmitter as illustrated in Fig. 3. Each of the auxiliary PAs is designed to achieve the maximum efficiency at the low-power level. In this study, we focus on a system-level approach, namely when to switch and which PA switch to. The answer to choose an eligible PA is to find which PA can support a target rate with the low overhead power consumption. For the example MIMO system that performs a five-level transmit power control with PA$_3$ in Fig. 1, we can employ PA$_1$ and PA$_2$ additionally to cover the same power levels. Refer to Fig. 2 and note that the power levels and the corresponding efficiencies shown in Table II. Since PA$_1$ and PA$_2$ can achieve higher PAE at the power level $P_1$ and $P_2$, respectively, than PA$_3$, the system EE

Fig. 1. Example of conventional 2-by-2 MIMO system.

TABLE I
EXAMPLE OF PA OUTPUT POWER ($P_{\text{out}}$ W) CORRESPONDING 2-BIT POWER CONTROL, AND THE PA EFFICIENCY ($\eta$%) FOR CONVENTIONAL MIMO SYSTEM.

<table>
<thead>
<tr>
<th>Level</th>
<th>PA</th>
<th>$[P_{\text{out}}$ W]</th>
<th>$\eta$%</th>
<th>feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>two PA$_1$’s</td>
<td>$2 \times 0.315$ W (25 dBm)</td>
<td>5%</td>
<td>00</td>
</tr>
<tr>
<td>$P_2$</td>
<td>two PA$_1$’s</td>
<td>$2 \times 1.25$ W (31 dBm)</td>
<td>15.5%</td>
<td>01</td>
</tr>
<tr>
<td>$P_3$</td>
<td>two PA$_1$’s</td>
<td>$2 \times 5$ W (37 dBm)</td>
<td>42%</td>
<td>10</td>
</tr>
<tr>
<td>$P_4$</td>
<td>two PA$_1$’s</td>
<td>$2 \times 10$ W (40 dBm)</td>
<td>60%</td>
<td>11</td>
</tr>
<tr>
<td>$P_5$</td>
<td>off</td>
<td>0</td>
<td>0</td>
<td>null</td>
</tr>
</tbody>
</table>

Fig. 2. Power added efficiency (PAE) versus output power $P_{\text{out}}$ of the power amplifiers [9].
Fig. 3. 2-by-2 MIMO system model with two main PAs and \( M \) auxiliary PAs for the proposed power amplifier switching (PAS) method.

### Table II

**Example of PAS and Efficiency (\( \eta \%) \) for Five Power Levels.**

<table>
<thead>
<tr>
<th>Level</th>
<th>PA</th>
<th>( P_{\text{out}} ) [W]</th>
<th>( \eta )%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_1 )</td>
<td>( PA_1 )</td>
<td>0.63 W (28 dBm)</td>
<td>55%</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>( PA_2 )</td>
<td>2.5 W (34 dBm)</td>
<td>43%</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>( PA_1 )</td>
<td>10 W (40 dBm)</td>
<td>60%</td>
</tr>
<tr>
<td>( P_4 )</td>
<td>two ( PA_1 )'s</td>
<td>2 × 10 W (40 dBm)</td>
<td>60%</td>
</tr>
<tr>
<td>( P_5 )</td>
<td>off</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

can be improved if we use the additional PAs properly. To find the proper PA, we define three communication modes of the PAS MIMO system: a PAS-MRC mode (single-input multiple-output: SIMO), a MIMO mode with CSI at the receiver (CSIR), and an off mode.

In PAS-MRC mode, the transmitter switches on the lowest output power PA among PAs that can support the target rate using one single antenna. The TAS is not considered in the paper, yet it is readily employed to the PAS-MRC mode as [9]. If no single PA can support the target rate, the MIMO mode is activated using two main high-PEP PAs, which is newly considered in the paper. However, if the target rate is too high for even the MIMO mode to support it, the transmitter stays at the off mode by switching off all PAs. Since the transmitter selects the most efficient PA/PAs that operate at the PEP and satisfy the target rate with the least power consumption, the system EE is improved compared to the conventional MIMO system employing the identical main PAs. Our main contribution of this work is summarized as follows:

- PAS method is proposed for MIMO systems.
- PAS criteria based on a target rate is derived.
- Numerical results are provided to
  - verify the PAS technique in terms of EE.
  - provide observation on an EE optimal target rate.

The rest of the paper is organized as follows. In Section II, the proposed PAS MIMO system is introduced. Section III presents a communication mode selection criterion. In Sections IV, the EE of the proposed PAS MIMO is analyzed. Section V is devoted to verify the proposed PAS through computer simulation. After discussing future work and remaining issues for energy efficient wireless communications, we conclude this paper in Section VI.
REFERENCES


