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Title	**Power Balancing of Beamforming/Precoding Schemes**
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Re:	IEEE 802.16m-09/0021 “Call for Comments and Contributions on Project 802.16m System Description Document (SDD)” for SDD Section 11.12.1 “UL MIMO Architecture and Data Processing”
Abstract	This contribution addresses the high PAPR issue related to MIMO beamforming/precoding and OFDM. It is suggested that a general remedy to the PAPR issue without introducing signal distortion or side information feeding forward should be considered in 802.16m. A method based on constellation shaping to balance the signal power, such that the high PAPR caused by beamforming/precoding and OFDM can be reduced, is also provided in this contribution as an example of such general remedies.
Purpose	For discussion by IEEE 802.16m TG
Notice	
Release	
Patent Policy	

Power Balancing of Beamforming/Precoding Schemes

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1. Introduction

In the most recently issued SDD (IEEE 802.16m-08/003r8) [1], the multiple input multiple output (MIMO) architecture of the system adopted the methods which are based on beamforming/precoding as its closed-loop MIMO solution. However, beamforming/precoding related methods usually result in increase of the peak-to-average power ratio (PAPR). As a result, the system performance is degraded when the power amplifier (PA) nonlinearity is present.

In this contribution, we use a MIMO OFDM system with singular value decomposition (SVD) based precoding as an example to demonstrate the PAPR issue. It is suggested that PAPR be included as a criterion when beamforming/precoding schemes are proposed to 802.16m. In addition, a general remedy to the PAPR issue without introducing signal distortion or side information feeding forward should be considered in 802.16m. A method based on constellation shaping to balance the transmission signal power is provided in this contribution as an example of such general remedies.

2. The PAPR Issue

In [2], we have already shown that in a single carrier system, the SVD based precoding can cause high PAPR. To further investigate the PAPR issue, we consider in this contribution a 4-antenna, 1024-subcarrier OFDM system with and without using the SVD precoding scheme. The simulation results are shown in Figure.1. In Figure 1, the green solid line sketches the complementary cumulative distribution function (CCDF) of the PAPR value of the system with SVD precoding, while the blue solid line represents the CCDF of the system without SVD precoding. Comparing the results with the single-carrier PAPR in [2], it is quite clear that OFDM also causes high PAPR. Surprisingly, the figure also shows that the PAPR values with and without SVD precoding are almost the same. In other words, the unitary property of the SVD precoding does not further increase the PAPR already raised by the IFFT at the transmitter.

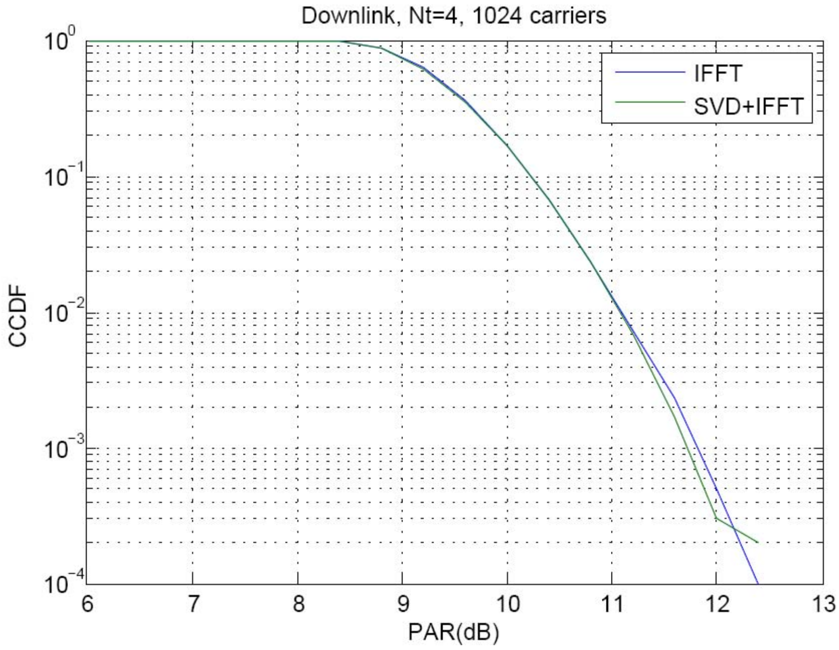

Figure 1: CCDF of systems with and without SVD precoding.

3. Power Balancing

When beamforming/precoding across antennas is performed, PAPR on each transmit antenna will increase due to random combining of the information streams. For example, for MIMO systems with SVD based precoding at the transmitter, each information stream is transmitted on an eigen mode which distributes the information stream over all transmit antennas according to a certain set of weights obtained via SVD. The weighted information streams are then combined and transmitted on the antennas. In the worst case, these weighted information streams will add constructively and result in high peak power. The PAPR in general increases with the number of transmit antennas.

In this contribution, we propose a general solution to the PAPR issue of OFDM systems with beamforming/precoding which does not change the signal structure and introduce distortion. Moreover, unlike some PAPR reduction methods which require certain parameters to be fed forward periodically from the transmitter to the receiver, this solution does not need such side information and additional forward channel bandwidth. With these advantages, the proposed method can simply become an add-on component to existing systems. The basic idea of the proposed method is summarized as follows. The detailed derivation and algorithms can be found in [3].

Considering that for a regular single-antenna system using square QAM constellations, the PAPR approaches 3 when the constellation is large, if the boundaries of the constellations on each transmit antenna of a precoded MIMO system can also be made square (i.e., in a cubic shape), PAPR as low as 3 can be expected. To do so, and assuming that QAM constellations are used for the information streams before precoding, the QAM constellation of each information stream can be tessellated over the plane to form cosets with the original constellation points as the coset leaders. With precoding, a point from the coset corresponding to each stream's data is selected such that after the weighted combining on each transmit antenna due to precoding, the constellation boundary of the combined sing is approximately cubic. This is equivalent to changing the QAM boundary of each information stream to a different shape. In order not to destroy the structure and properties of the precoded signals, a reversible integer-to-integer mapping derived from the precoding matrix has to be used. In [3], several such methods were proposed. This kind of methods can effectively reduce PAPR by balancing the power of transmission signal. The concept of "cubic shaping" is shown in the following figure where the constellation on the left-hand side is the original constellation of each information stream. After precoding, the boundary of the constellation on each antenna will change. The method proposed in [3] changes the original constellation of the information streams, and results in a cubic boundary of the transmitted constellation which has an asymptotic PAPR of 3.

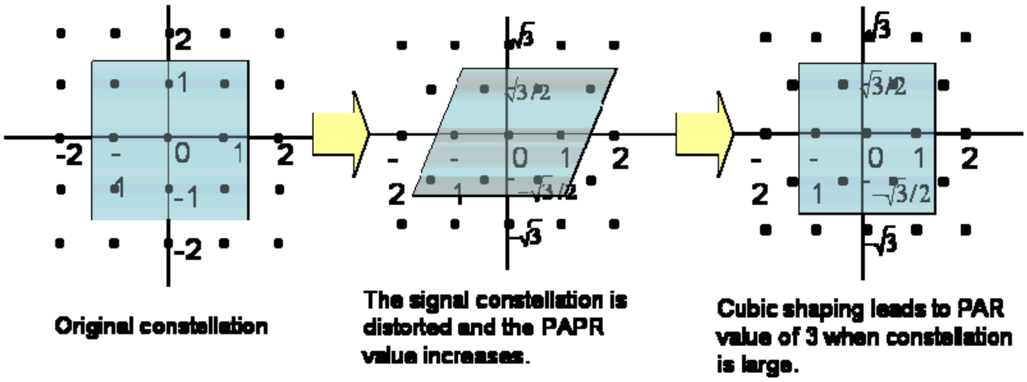

Figure 2: Concept of cubic shaping.

In practice, there are a limited number of possible precoding matrices due to limited channel condition feedback. In this case, the integer-to-integer mapping can be computed offline and stored in a lookup table to reduce the real-time computational complexity.

Since the transmitter IFFT in OFDM can be considered a precoder, the above method can also be applied to reduce the high PAPR caused by IFFT. In the following simulation results, we will show that, even though SVD precoding does not further increase the already high PAPR caused by the IFFT, if we only apply the above method to counter the effect of IFFT but not the SVD precoding, the PAPR will remain high due to the SVD precoding. Similarly, if we only counter the effect of SVD precoding, the PAPR will remain high due to IFFT. Thus, it is suggested that the effects of IFFT and precoding should be considered together in power balancing.

4. Decoding Algorithm

To decode the received signal vector $\mathbf{x}$, the receiver processes the signals with a proper receive filter and then rounded to nearest integer points within constellation boundary. With the proposed shaping algorithm, however, the nearest integer vector $[\hat{\mathbf{x}}]$ obtained by rounding $\hat{\mathbf{x}}$ may not belong to the range of the shaping function $f(\cdot)$ due to disturbance of noise. Therefore, we need to search the nearest integer vector $\mathbf{z}$ around $\hat{\mathbf{x}}$ such that $\mathbf{z}$ belongs to the range of $f(\cdot)$. Here we proposed a heuristic algorithm to search this vector.

Define A and B as the domain and the range of $f(\cdot)$, respectively. For example, if 64-QAM is adopted for modulation, A is the set of all possible integer vectors where each element belongs to the 64-QAM constellation. Since $f(\cdot)$ is one-to-one,

$$\mathbf{z} \in \mathrm{B} \text{ iff } f^{-1}(\mathbf{z}) \in \mathrm{A},$$

where $f^{-1}(\cdot)$ denotes the inverse function of $f(\cdot)$. Let $\{d_k\}$ be the diagonal elements in $\mathbf{D}$, the singular value matrix of channel $\mathbf{H}$. Without loss of generality, $\{d_k\}$ is in increasing order, that is, $d_i \le d_j$ for $i \le j$.

Define z_k^0 as the closest integer near $\hat{x}_k$, the k th element of $\hat{\mathbf{x}}$, and z_k^1 the second closest, *i.e.*,

$$z_k^0 = [\hat{x}_k]$$
$$z_k^1 = z_k^0 + sign(\hat{x}_k - z_k^0),$$

where $sign(\cdot)$ is defined as

$$sign(x) = \begin{cases} 1, & x \geq 0 \\ -1, & x < 0 \end{cases}$$

The proposed algorithm is to check whether $\mathbf{z} = [z_1^{b_1}, ..., z_{N_r}^{b_{N_r}}]^T \in \mathrm{B}$ given $\mathbf{b} = [b_1, ..., b_{N_r}]$, where $b_k \in \{0,1\}$, by checking whether $f^{-1}(\mathbf{z}) \in \mathrm{A}$. The choice of $\mathbf{b}$ is decided by the binary representation of integer $j = b_{N_r} ... b_2 b_1$, in the order that $j = 0$ to $j = 2^{N_r} - 1$. Since the noise component in $\hat{x}_k$ is relatively large for small channel gain d_k, searching from elements with smaller channel gain is more probable to succeed. Compared with exhaustive search, the list decoding keeps good performance with moderate complexity. The algorithm is summarized in Table 1.

Table 1 List Decoding Algorithm

```
function list_decoding
    for j = 0 : 2^{N_r} - 1
        b = [b_{N_r} ... b_2 b_1] = binary(j)
        z = [z_1^{b_1}, ..., z_{N_r}^{b_{N_r}}]^T
        if f^{-1}(z) ∈ A then
            break
    next j
    return z
```

5. Simulation Results

In all of the following simulations, the systems are all 1024-subcarrier OFDM, equipped with 4 antennas and SVD precoding. The fading is independent on the sub-carriers and antennas.

First, we simulated two systems with and without using the power balancing method to counter the SVD precoding. The simulation results in Figure 3 show that PAPR values with and without power balancing are almost the same. This is because the power balancing method makes the constellation after SVD precoding cubic which is similar to the constellation boundary without SVD precoding. In Figure 1 it is already shown that the PAPR values with and without precoding are almost the same. Thus countering only the SVD precoding does not make a difference.

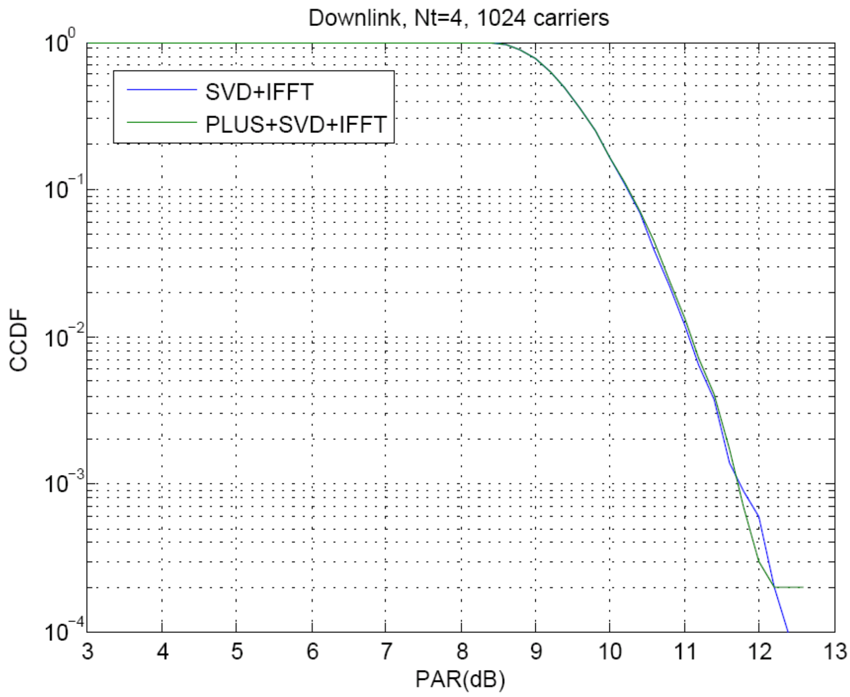

Figure 3: CCDF of systems with and without power balancing against SVD precoding.

We also considered two systems with and without power balancing against the effect of IFFT. The simulation results in Figure 4 again show that the PAPR is not reduced.

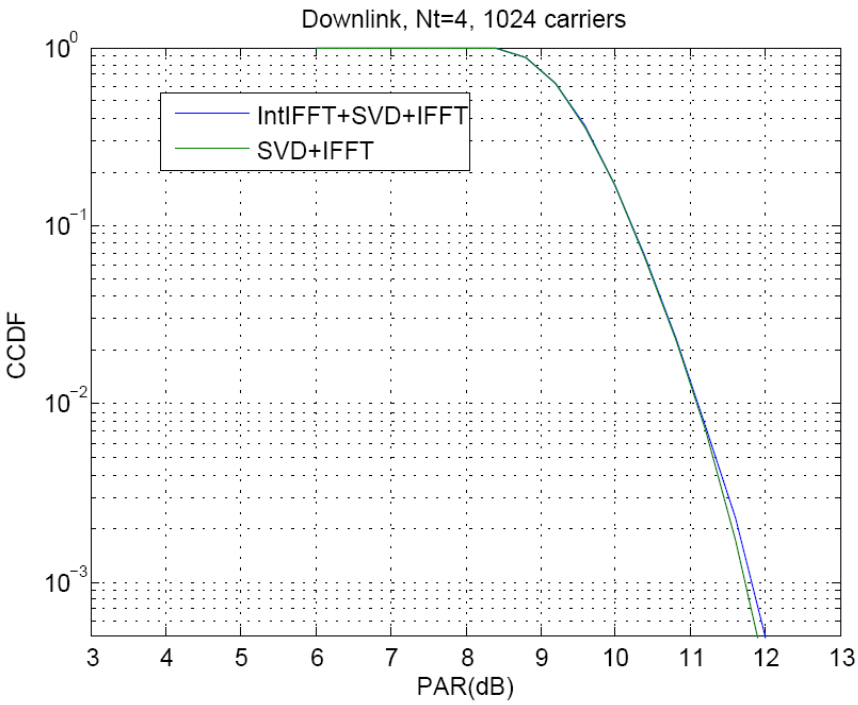

Figure 4: CCDF of systems with and without power balancing against IFFT.

Finally, we considered applying power balancing against both SVD precoding and IFFT. The results in Figure 5 show that the PAPR can be reduced about 2 dB at 10^{-2} CCDF.

A similar simulation was done for a downlink OFDMA system with 2 users each allocated 512 subcarriers. The power balancing was done separately and independently for the 2 users. Figure 6 shows that, in this situation, power balancing still provides PAPR reduction of about 0.8 dB at 10^{-2} CCDF.

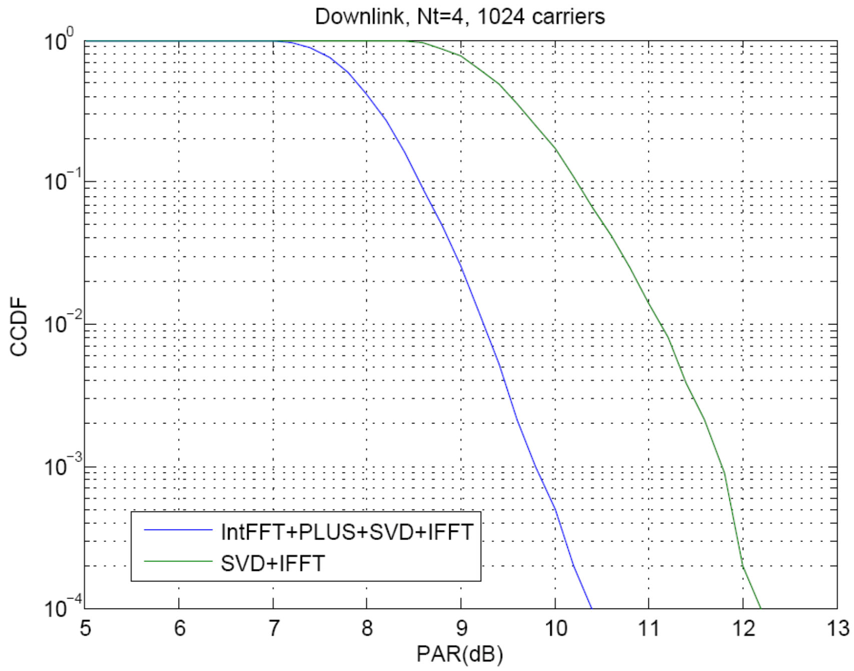

Figure 5: CCDF of systems with and without power balancing against both SVD precoding and IFFT.

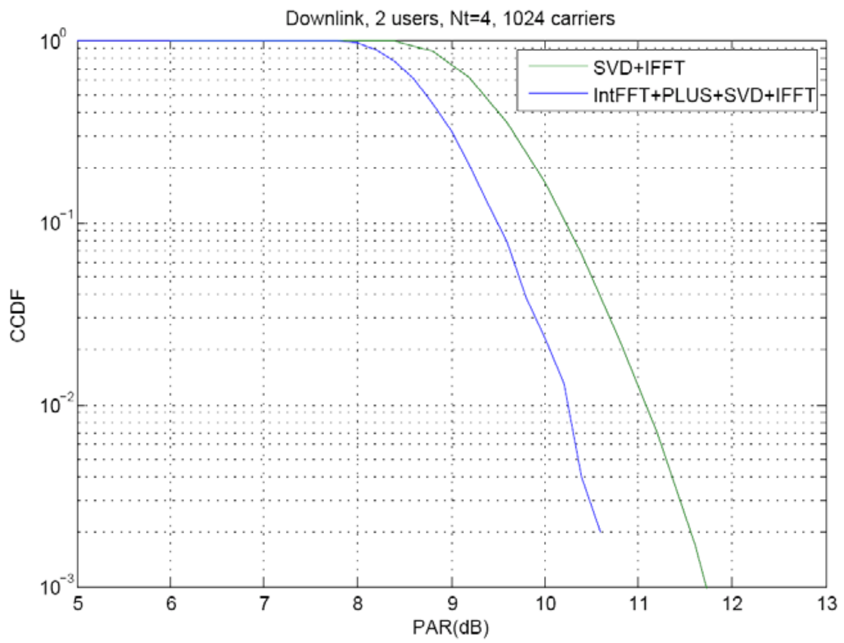

Figure 6: CCDF of a downlink OFDMA system with individual power balancing for two 512-subcarrier users.

For uplink OFDMA, a user only uses a fraction of the subcarriers. The power balancing results for a user using 1024 and 512 subcarriers are shown in Figures 7. These results again show the PAPR reduction of the power balancing method. For 1024-subcarrier system, there is a 2 dB PAPR reduction. For 512-subcarrier system, the PAPR reduction decreases to about 1 dB.

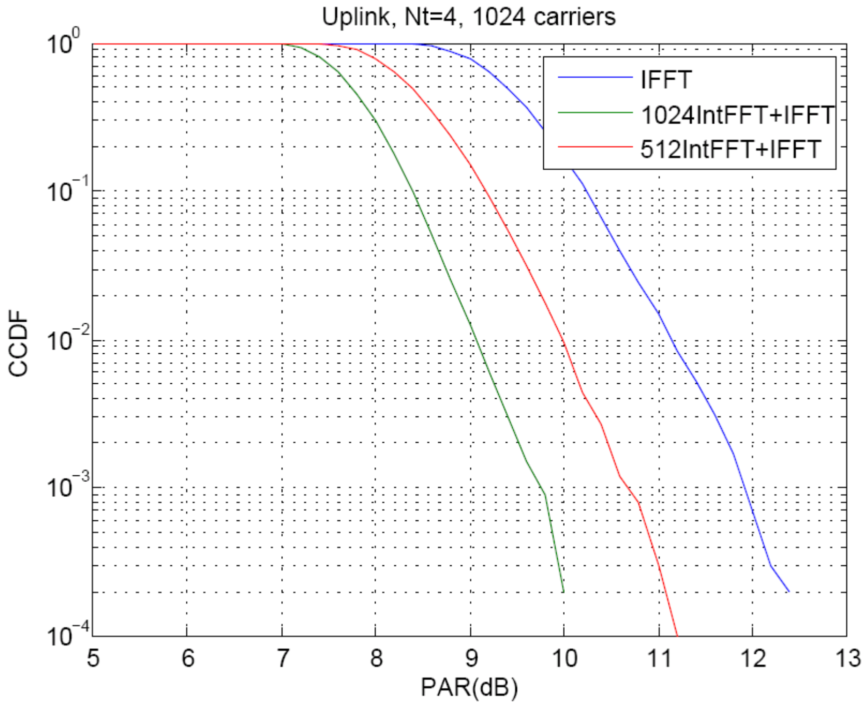

Figure 7: CCDF of 1024-subcarrier and 512-subcarrier uplink OFDMA system.

To show that the power balancing method does not degrade the performance, we consider a simple example where the number of subcarrier is 64, the numbers of transmit and receive antennas are both 4, and the modulation used is 64-QAM.

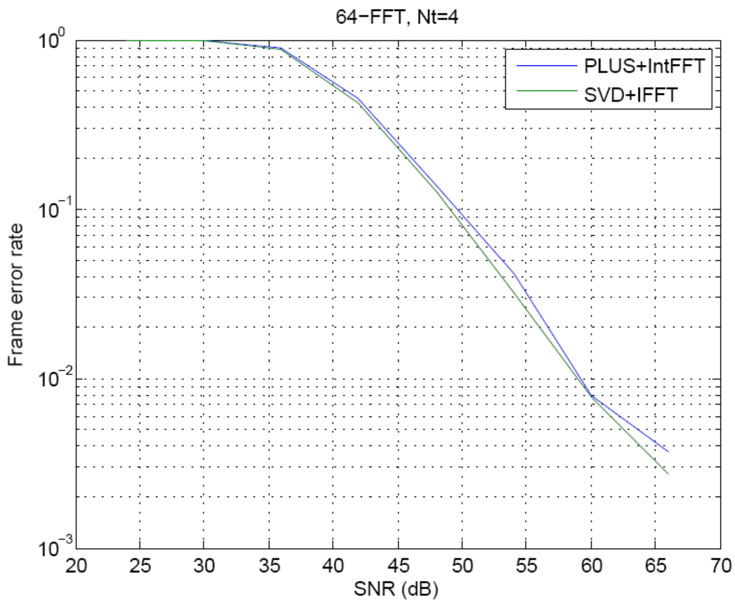

Figure 8: Frame error rate of MIMO OFDM with and without shaping.

Figure 8 shows the frame error rate of MIMO OFDM with and without shaping, which applies to both SVD precoder and IFFT. The FER performance degradation of shaping is about 1 dB.

6. Conclusions

In this contribution, we have addressed the high PAPR issue related to MIMO beamforming/precoding and OFDM. It is suggested that a general remedy to the PAPR issue without introducing signal distortion or side information feeding forward should be considered in 802.16m. A method based on constellation shaping to balance the signal power, such that the high PAPR caused by beamforming/precoding and OFDM can be reduced, is also provided in this contribution as an example of such general remedies.

It is proposed that the 802.16m systems should include the PAPR reduction functionality via power balancing for the MIMO beamforming/precoding and IFFT, and the SDD should adopt the proposed texts listed as follows.

Proposed Text:

11.12.1 UL MIMO Architecture and Data Processing

Modify Figure 55 as follows.

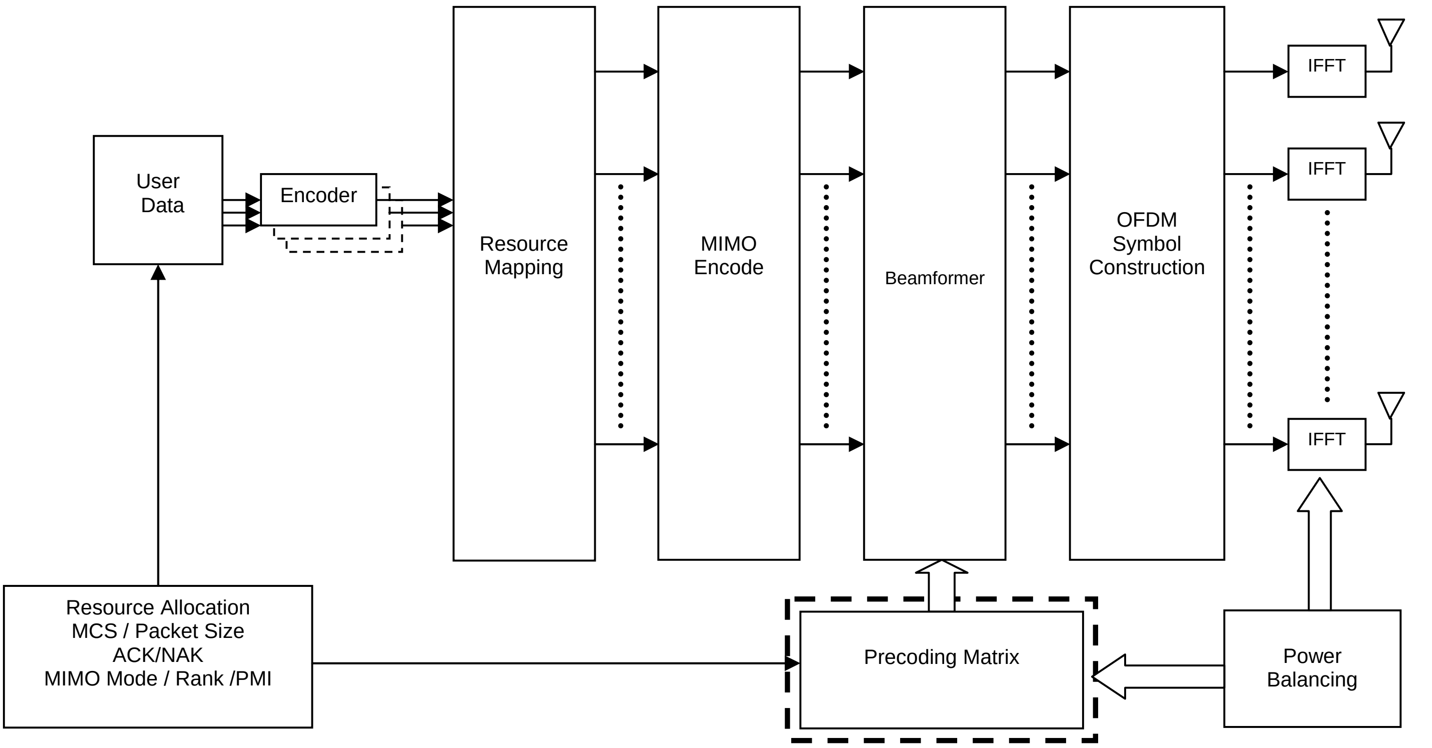

Figure 55 MIMO Architecture

Add the following text to line 7 on page 116.

Power balancing functionality in the beamformer/pre-coder and IFFT block is optional.

The power balancing functionality should be implemented as the functional blocks shown in Figure XXX

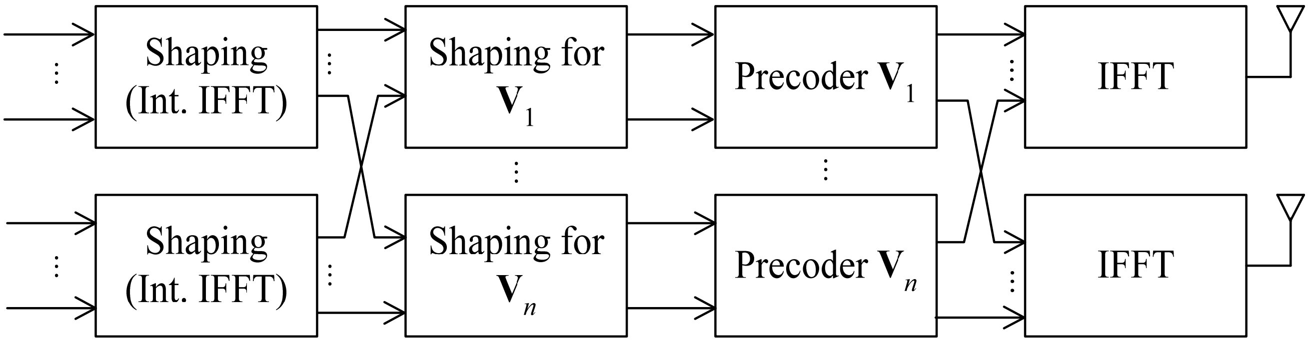

Figure XXX MIMO Architecture

In Figure XXX, the Shaping (Int. IFFT) blocks are designed to transform the IFFT coefficients to integer values for balancing the effects caused by IFFT blocks. The blocks named “Shaping for V_i” deal with the effects caused by Precoder V_i to balance the power of the transmitted signal constellation.

References

[1] IEEE 802.16m-08/003r8, “802.16m System Description Document”.

[2] H.-J. Su, C.-P. Lee, C.-Y. Chen, W.-S. Liao, R.-J. Chen, C.-L. Ho, C.-L. Tsai, Y.-X. Zheng, IEEE C802.16m-08/1302r3, “Peak-to-Average Power Ratio Issue of Beamforming/Precoding Schemes”.

[3] C.–P. Lee, H.–J. Su, “Peak to Average Power Ratio Reduction of Space-Time Codes That Achieve Diversity-Multiplexing Gain Tradeoff,” *IEEE International Symposium on Personal, Indoor and Mobile Communications*, September 2008.