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Re:	IEEE 802.16m-09/00028 "Call for Comments and Contributions on Project 802.16m Amendment Content"
Abstract	This contribution addresses the high PAPR issue related to MIMO precoding and IFFT. 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 precoding and IFFT can be reduced, is also provided in this contribution as an example of such general remedies.
Purpose	For discussion by IEEE 802.16m TG
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Power Balancing for MIMO Precoder

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1. Introduction

In the most recently issued AWD (IEEE 802.16m-09/010r2) [1], the multiple input multiple output (MIMO) architecture of the system is based on concatenation of a MIMO encoder and a precoder which maps streams to antennas. Since precoding related methods usually result in increase of the peak-to-average power ratio (PAPR), the system performance will be degraded when the power amplifier (PA) nonlinearity is present. In addition, the precoded will be mixed by OFDM which results in even higher PAPR.

In this contribution, the PAPRs of the precoding codebooks specified in the AWD and the singular value decomposition (SVD) based precoding are simulated. The results show that the codebooks in the AWD and the SVD based precoding both have high PAPR. In addition, IFFT also highly increases PAPR. Since high PAPR affects the performance, especially in the uplink scenario, it is thus suggested that PAPR be included as a criterion for the precoding codebook design. An alternative is to employ a general remedy to the PAPR problem for the existing precoding codebooks without introducing signal distortion (performance degradation) and additional control signaling. As an example of such general remedies, this contribution provides the simulation results using a method based on constellation shaping that can balance the transmission signal power.

2. The PAPR Issue

In [2], it was shown that the SVD based precoding together with IFFT can cause high PAPR. To further investigate the PAPR issue of precoding, we consider in this contribution a 4-stream, 4-antenna, 1024-subcarrier OFDM system with the precoding codebooks given in the AWD. Figure 1 compares the PAPR of the codebooks in the AWD and the SVD based precoding. To demonstrate the PAPR caused by the precoder, this figure considers one-carrier only. The PAPR of the codebooks in the AWD was obtained by randomly switching the system between codewords. The PAPR of the SVD based precoder was obtained by using the SVD precoding matrix at the transmitter according to the channel condition. It is shown in Figure 1 that the codebooks in the AWD results in slightly higher PAPR than SVD based precoder. Thus the codebooks in the AWD also cause high PAPR.

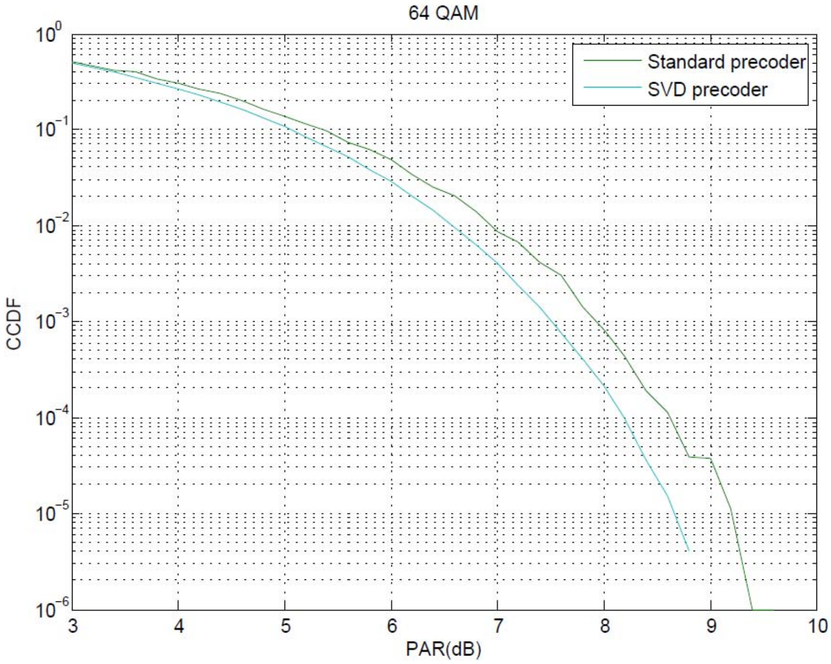

Figure 1: Power CCDF of AWD and SVD precoders.

3. Power Balancing

In [2], a general solution to the PAPR issue of MIMO OFDM systems with precoding which does not change the signal structure or introduce distortion was proposed. 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, this method can simply become an add-on component to existing systems. The basic idea of this method is based on constellation shaping, and is summarized in [2]. The detailed derivation and algorithms can be found in [3]. One example of the corresponding decoder of this method can also be found in [2]. The decoding algorithm resembles a sphere decoding algorithm. Thus concatenation of this decoder and the channel decoder is similar to concatenation of a sphere inner decoder and an outer channel decoder.

4. Simulation Results

In all of the following simulations, the system is MIMO OFDM with 4 transmit antennas, 4 streams, and the precoding codewords in the AWD. The modulation is 64QAM. The fading is Rayleigh and independent on the sub-carriers and antennas.

Figures 2 and 3 compare the PAPR with and without using the power balancing method, when the user uses 64 and 1024 carriers, respectively. In both cases, the PAPR is reduced about 2 dB with the power balancing method.

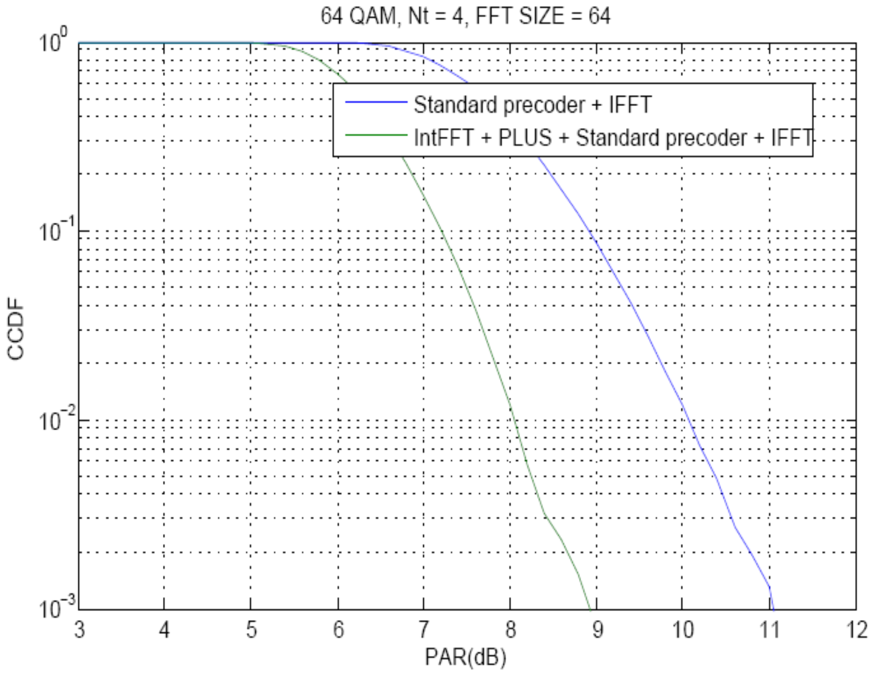

Figure 2: Power CCDF of the precoded OFDM systems with and without power balancing. The user uses 64 carriers.

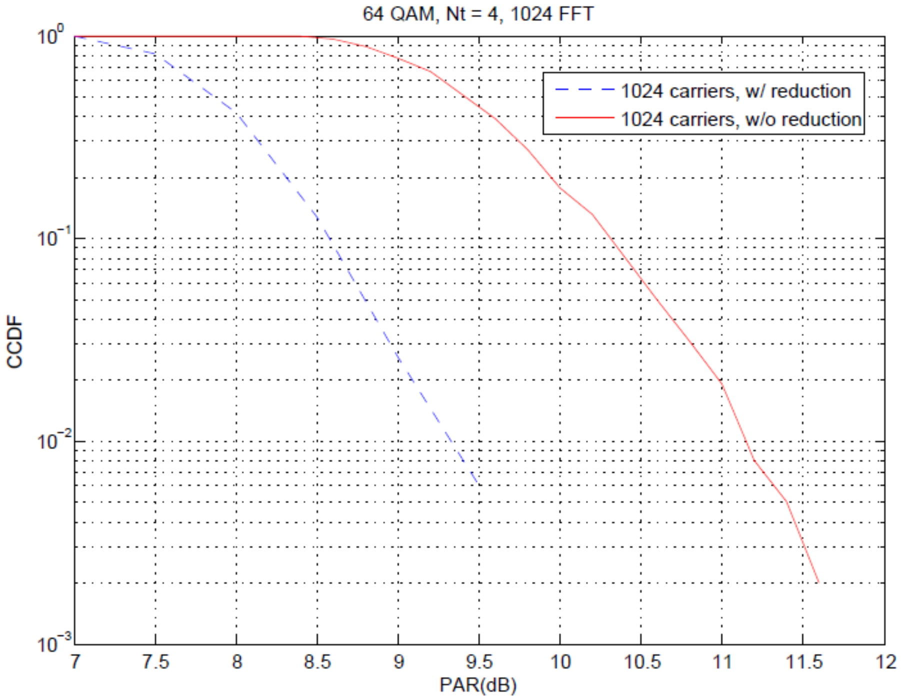

Figure 3: Power CCDF of the precoded OFDM systems with and without power balancing. The user uses 1024 carriers.

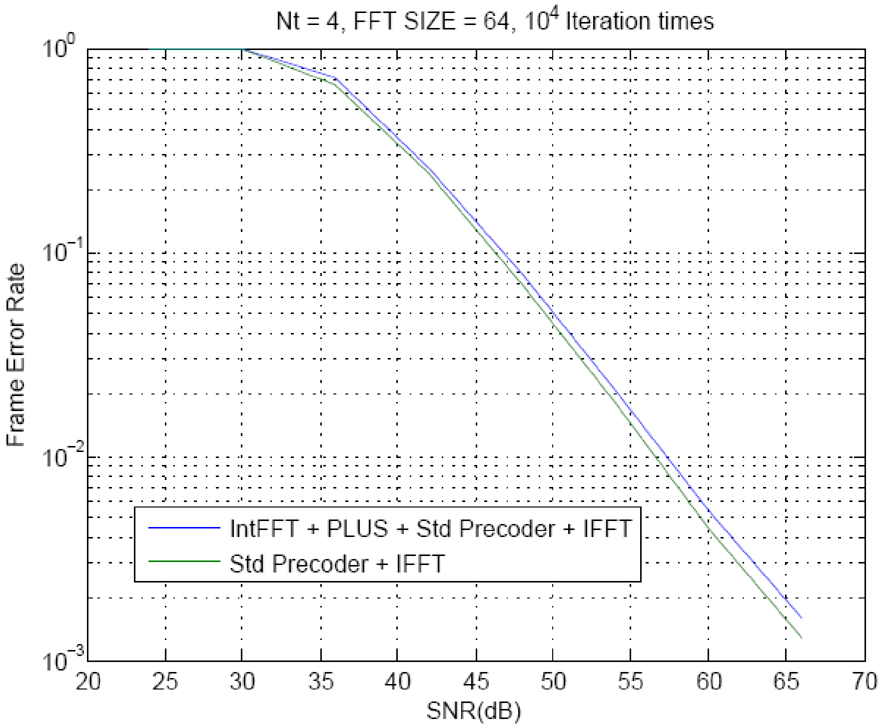

Figure 4: Frame error rates of systems using the AWD precoder with and without power balancing. The user uses 64 carriers.

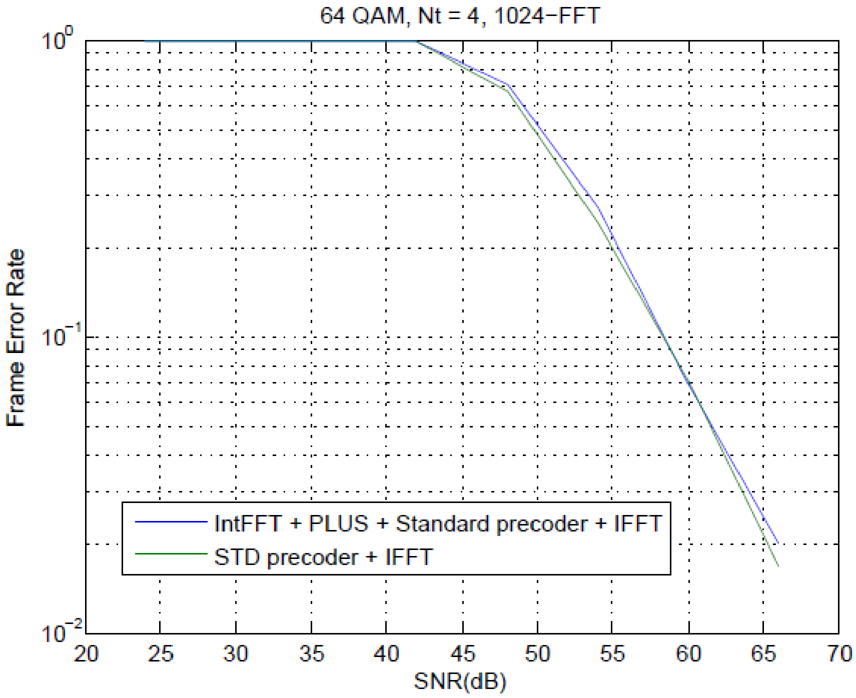

Figure 5: Frame error rates of systems using the AWD precoder with and without power balancing. The user uses 1024 carriers.

Figures 4 and 5 give the frame error rate (FER) of MIMO OFDM with and without power balancing, when the user uses 64 and 1024 carriers, respectively. A frame contains (number of bits per QAM)*(number of streams)*(number of carriers) bits, and channel coding is not considered. The decoding method for the system with power balancing is described in [2]. The figures show that the power balancing method only degrades the performance a little with the simple decoding method which can be improved.

5. Conclusions

In this contribution, we addressed the PAPR problem related to the 4-stream, 4-antenna scheme with the precoding codebooks in the AWD. A method based on constellation shaping to balance the transmission power was shown to be able to alleviate the PAPR problem of precoding and IFFT with very little FER performance degradation and no additional control signaling. It is thus proposed that the 802.16m systems should include the PAPR reduction functionality for MIMO precoding and IFFT. The following proposed text is suggested to be included in the AWD, where the matrix decomposition of reversible integer mapping is obtained using the method in [4].

Proposed Text:

15.3.10.1 UL MIMO architecture and data processing

Modify Figure 514 as follows.

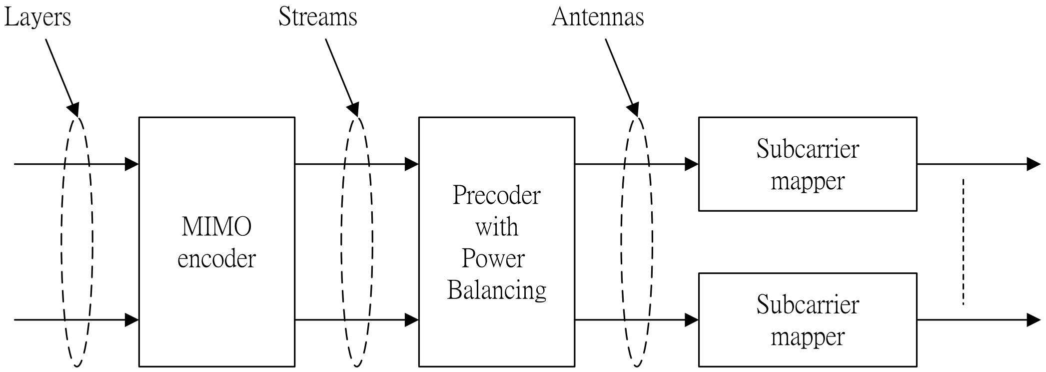

Figure 514 -- UL MIMO architecture

Add the following section on power balancing for the precoder and IFFT.

15.3.10.1.2.3 Power Balancing

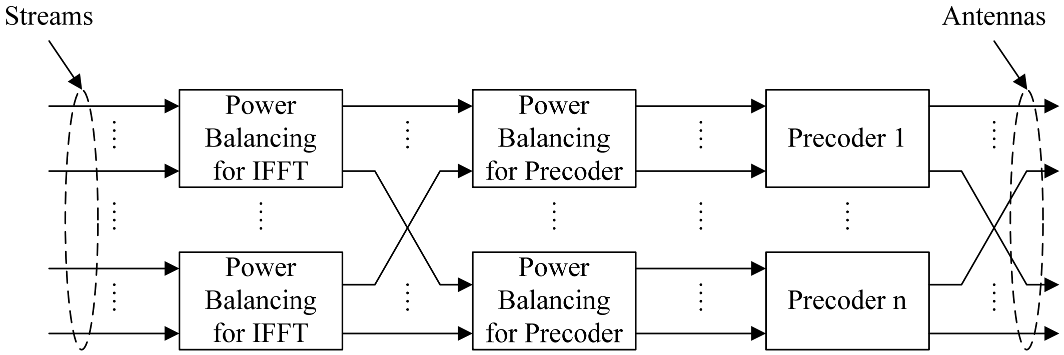

Figure XXX – Precoder with Power Balancing

Power balancing can be performed to alleviate the high peak power problem caused by the precoder and IFFT. The precoder block with power balancing is shown in Figure XXX. The power balancing operations are in the order of power balancing for IFFT first, then power balancing for precoding. Power balancing for precoding is an integer-to-integer mapping which is an approximation of the inverse of the precoding matrix, where integer means Gaussian integer defined on the grid of the signal constellation. For any precoding matrix, the integer-to-integer mapping of the power balancing operation is factorized into a series of Integer Reversible Matrix Mapping (IRMM)

$$\mathbf{s}' = P\Big[L\Big[U\big[S\mathbf{s}\big]\Big]\Big]$$

where $\mathbf{s}$ is the input vector of Gaussian integers to the power balancing block, and $\mathbf{s}'$ is the output vector of Gaussian integers. S is a single-row elementary reversible matrix (SERM) in which the diagonal elements $j_m = \pm 1$, and all but the last row of the off-diagonal elements are all zeros. The integer-to-integer mapping of the SERM, denoted $\mathbf{y} = [S\mathbf{s}]$, is as follows:

$$\begin{aligned} y_N &= j_N s_N + \left[\sum_{n=1}^{N-1} a_{Nn} s_n\right] \\ y_m &= j_m s_m, \quad \text{for } m \neq N \end{aligned}$$

where N is the dimension of S and a_{Nn} denotes the elements on the last row of S. The mapping $\mathbf{y} = [S\mathbf{s}]$ is invertible, and the inverse integer-to-integer mapping is

$$\begin{aligned} s_m &= y_m / j_m, \quad \text{for } m \neq N \\ s_N &= \left(y_N - \left[\sum_{n=1}^{N-1} a_{Nn} s_n\right]\right) / j_N \end{aligned}.$$

U is a unit upper triangular elementary reversible matrix (TERM) with diagonal elements $j_m = \pm 1$ and off-diagonal elements $\{a_{mn}\}$. The integer-to-integer mapping of the upper TERM, denoted $\mathbf{y} = [U\mathbf{s}]$, is as follows:

$$\begin{aligned} y_m &= j_m s_m + \left[\sum_{n=m+1}^{N} a_{mn} s_n\right], \quad m = 1, \ldots, N-1 \\ y_N &= j_N s_N \end{aligned}$$

and its inverse integer-to-integer mapping is

$$\begin{aligned} s_N &= y_N / j_N \\ s_m &= (1/j_m)\left(y_m - \left[\sum_{n=m+1}^{N} a_{mn} s_n\right]\right), \quad m = N-1, \ldots, 1 \end{aligned}.$$

L is a unit lower TERM with diagonal elements $j_m = \pm 1$. Its integer-to-integer mapping and inverse mapping are similarly defined. P is a permutation matrix.

The *PLUS* decomposition of the rank-4 codebook C(4,4,3) in Table 698 is as follows:

For C(4,4,3,0):

$$P=\begin{bmatrix}1&0&0&0\\0&0&0&1\\0&0&1&0\\0&1&0&0\end{bmatrix},L=\begin{bmatrix}1&0&0&0\\1&1&0&0\\0&-0.5&1&0\\0&0.5&-1&1\end{bmatrix},U=\begin{bmatrix}1&0.5&-0.5&-0.5\\0&-1&1&0\\0&0&1&0.5\\0&0&0&1\end{bmatrix},S=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\1&0&0&1\end{bmatrix}$$

For C(4,4,3,1):

$$P=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix},L=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&-1+i&1&0\\-i&-i&-i&1\end{bmatrix},U=\begin{bmatrix}1&i&-1&-0.5\\0&-1&0&-0.5i\\0&0&1&-0.5i\\0&0&0&1\end{bmatrix},S=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\1&-1+2i&-1&1\end{bmatrix}$$

For C(4,4,3,2):

$$P=\begin{bmatrix}1&0&0&0\\0&0&1&0\\0&1&0&0\\0&0&0&1\end{bmatrix},L=\begin{bmatrix}1&0&0&0\\0&1&0&0\\-0.5-0.5i&0.5+0.5i&1&0\\0.5-0.5i&-0.5+0.5i&-1&1\end{bmatrix},U=\begin{bmatrix}1&0&0&-0.5\\0&1&0&0.5\\0&0&-1&-0.5i\\0&0&0&-i\end{bmatrix},S=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\1&-1&1&1\end{bmatrix}$$

For C(4,4,3,3):

$$P=\begin{bmatrix}1&0&0&0\\0&0&1&0\\0&1&0&0\\0&0&0&1\end{bmatrix},L=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0.5+0.5i&-0.5-0.5i&1&0\\0.5-0.5i&-0.5+0.5i&1-2i&1\end{bmatrix},U=\begin{bmatrix}1&0&-1+i&-0.5\\0&1&1-i&0.5\\0&0&1&0.5\\0&0&0&-i\end{bmatrix},S=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\1&-1&-1+2i&1\end{bmatrix}$$

For C(4,4,3,4):

$$P=\begin{bmatrix}0&0&1&0\\0&0&0&1\\0&1&0&0\\1&0&0&0\end{bmatrix},L=\begin{bmatrix}1&0&0&0\\-0.5+0.5i&1&0&0\\-0.5-0.5i&-1&1&0\\0&0&-1&1\end{bmatrix},U=\begin{bmatrix}-1&0&0&0.5i\\0&-1&0.5-0.5i&-0.25+0.25i\\0&0&1&0.5i\\0&0&0&i\end{bmatrix},S=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\-i&-1&-i&1\end{bmatrix}$$

For C(4,4,3,5):

$$P=\begin{bmatrix}0&1&0&0\\0&0&1&0\\0&0&0&1\\1&0&0&0\end{bmatrix},L=\begin{bmatrix}1&0&0&0\\-1.207-0.207i&1&0&0\\-0.707-0.293i&0&1&0\\0.207-0.207i&i&0.707+1.293i&1\end{bmatrix},U=\begin{bmatrix}1&-i&0.293-0.707i&-0.354+0.354i\\0&1&0.293&0.354i\\0&0&-1&0.5i\\0&0&0&1\end{bmatrix},S=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\-1.414-0.414i&-1&1.414-1.586i&1\end{bmatrix}$$

The power balancing for the IFFT is an integer-to-integer mapping which is an approximation of FFT. Its structure is the same as an FFT, with the butterfly matrix

$\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{W_N^k}{\sqrt{2}} & -\frac{W_N^k}{\sqrt{2}} \end{bmatrix}$, where $W_N^k = \exp\left(-i\frac{2\pi k}{N}\right)$. The *PLUS* decomposition of the butterfly matrix is

$$P = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, L = \begin{bmatrix} 1 & 0 \\ \left(\sqrt{2}-1\right)W_N^k & 1 \end{bmatrix}, U = \begin{bmatrix} 1 & \frac{1}{\sqrt{2}} \\ 0 & -W_N^k \end{bmatrix}, S = \begin{bmatrix} 1 & 0 \\ 1-\sqrt{2} & 1 \end{bmatrix}.$$

These power balancing operations are all invertible with the inverse mappings of *L*, *U*, and *S* specified above. The receiver can perform inverses of the power balancing operations to recover the streams.

References

[1] IEEE 802.16m-09/010r2, "Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems".

[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-09/0784r1, "Power Balancing 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.

[4] P. Hao and Q. Shi, "Matrix factorizations for reversible integer mapping," *IEEE Trans. Signal Processing*, vol. 49, pp. 2314–2324, Oct 2001.