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Performance of an Interference Alignment Based Precoding in MIMO-OFDM System

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ABSTRACT: In this paper, we proposed interference alignment based channel independent precoding in MIMO-OFDM system. We showed that when the number of receive antennas (n_r) is not more than the number of transmit antennas (n_t),our proposed precoding is more bandwidth efficient than the conventional zero-padded or CP added MIMO systems, such as, ZP-only, CP-OFDM and SC-FDE system and When the number of receive antennas is more than the number of transmit antennas, it was shown that the IBI in an MIMO OFDM system can be completely eliminated without any CP or zero-padding or precoding, when the OFDM block size is not too small. In this paper, we consider only CP based block transmission system.

KEYWORDS: MIMO-OFDM, Precoding, Cyclic prefix, IBI

I. INTRODUCTION

The combination of MIMO signal processing with OFDM is considered as one of the most promising techniques for enhancing the data rate of next-generation wireless communication systems. OFDM divides a broadband signal into multiple narrowband subcarriers, where each subcarrier is more robust to multipath. In order to maintain orthogonality among subcarriers, a CP is added at the head of each symbol. In MIMO-OFDM system, insertion of IDFT and CP at the transmitter and removal of CP and DFT at the receiver together it help to convert an inter-symbol interference channel into several ISI free subchannels. The CP length is designed which is not less than the length of the channel impulse response (CIR) in order to eliminate the effects of the interblock interference (IBI) and inter-carrier interference (ICI). A considerably long CP is needed if the multipath delay spread is large, resulting in a substantial loss in both bandwidth and power efficiencies [1] [2].

In a MIMO-OFDM system with insufficient CP, if the IBI from the previous OFDM block can be separated and eliminated, it will be easier to detect the current OFDM block from the desired signal term and the ICI term both of which contain the information of the current OFDM symbol. Interference alignment (IA) [6]–[8] provides a novel concept to deal with interferences. The basic idea of IA is to use well-designed “beamforming” vectors at the transmitter such that the interference vectors are aligned at the receiver in one subspace which is disjoint from the signal subspace. As a result, the interference vectors are separated from the desired signal subspace and are limited in the minimum dimensions and therefore can be eliminated by the zero-forcing operator at the receiver. This basically provides an interference nulling technique [2].

The quality of a wireless link can be described by three basic parameters, namely the transmission rate, the transmission range and the transmission reliability. Conventionally, the transmission rate may be increased by reducing the transmission range and reliability. By contrast, the transmission range may be extended at the cost of a lower transmission rate and reliability, while the transmission reliability may be improved by reducing the transmission rate and range. However, with the advent of MIMO assisted OFDM systems, the above-mentioned three parameters may be simultaneously improved [3].

II. SYSTEM MODEL

A. Block Diagram of MIMO-OFDM System

The following block diagram is of MIMO-OFDM system which consists multiple transmit antenna and multiple receive antenna. In this diagram, the binary source generates digital input data sequence. This binary data is encoded by using digital modulation scheme like BPSK, QPSK and QAM with several different constellations. The serial to parallel block performs data symbols parallelized in N different substreams. Each substream will modulate a separate carrier through the IFFT modulation block. The IFFT block converts parallel sub-streams of frequency domain data symbols into a time domain OFDM symbol. After that we have to insert cyclic prefix to remove inter-block interference and inter-symbol interference. The cyclic prefix means we have to copied last specific length of data bits in start of OFDM symbol. The data are back convert into parallel to serial form. This serially converted data is transmitting from multiple transmit antenna to multiple receive antenna through the channel and AWGN noise is added in received OFDM symbol through the channel.

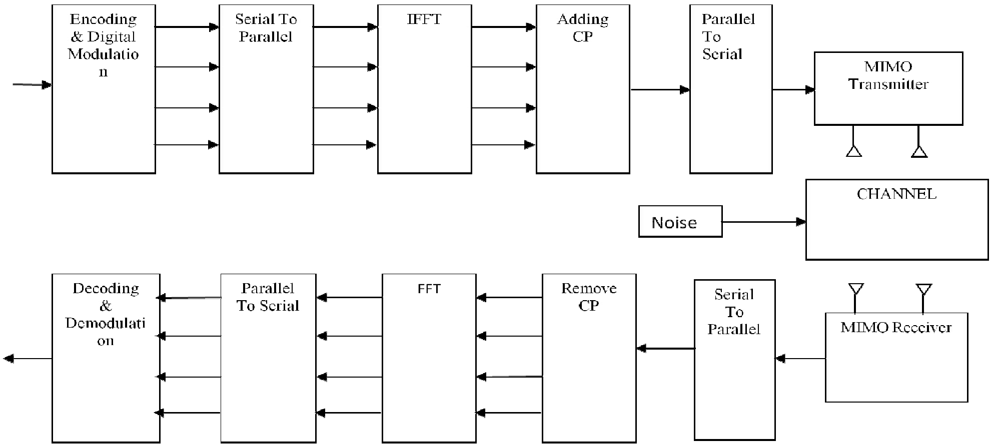

Fig.1 Block diagram MIMO-OFDM System

The received data are first converted in serial to parallel form and also remove cyclic prefix. The FFT block convert this data from time domain symbol in frequency domain and again covert it parallel to serial form. When we have to demodulate and decode the data, we get estimated output. The MIMO-OFDM system has multiple input and multiple output.

B. SISO-OFDM Model

In SISO-OFDM system we consider N subcarriers with frequency selective fading channel and which is represented by a vector $\mathrm{h} = [h(0), h(1), \dots, h(L)]^T$, where L is order of CIR and $L + 1$ is length of channel impulse response and we assume $N \geq L$ in this paper.The input signal vector of kth ofdm block is $\mathrm{r}_k = [r_k^0, r_k^1, \dots, r_k^{N-1}]^T$ Let W_N is the normalized IDFT matrix of size N with entries $[W_N]_{m,n} = (1/\sqrt{N})\exp(j2\pi mn/N)$. The IDFT operation is performed at the transmitter and it converts the input signal from frequency domain to time domain. We add a cyclic prefix v to each time domain vector which is insufficient, $v \leq L$. The transmitted OFDM block is affected by both ICI and IBI components. After the insufficient CP is removed at the receiver, the time domain expression of the kth received OFDM block is given, see, for example [4].

$$y_k = (H - A)W_N r_k + BW_N r_{k-1} + n_k \quad (1)$$

where n_k denotes the time domain received noise vector with the complex Gaussian distribution $\mathcal{CN}(0, \sigma^2 \mathrm{I})$. The channel matrix H is a circulant matrix of size $N \times N$. A and B denote the ICI and IBI components of the channel, respectively [1] [5] [6].

$$\mathrm{A} = \begin{bmatrix} 0_{(L-v)\times(N-L)} & S & 0_{(L-v)\times v} \\ 0_{(N-L+v)\times(N-L)} & 0_{(N-L+v)} & 0_{(N-L+v)\times v} \end{bmatrix} \quad (2)$$

$$\mathrm{B} = \begin{bmatrix} 0_{(L-v)\times(N-L+v)} & \mathrm{S} \\ 0_{(N-L+v)\times(N-L+v)} & 0_{(N- \quad -v)} \end{bmatrix} \quad (3)$$

Where *(L - v)* × *(L - v)* block matrix **S** is:

$$\mathrm{S} = \begin{bmatrix} h(L) & h(L-1) & \cdots & h(v+1) \\ 0 & h(L) & \dots & h(v+2) \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \dots & 0 & \end{bmatrix} \quad (4)$$

In the above equations (2) and (3), matrices A and B are the time domain expressions derived under the assumption of perfect synchronization and a rectangular pulse shape. If CP length v is larger than or equal to the CIR order L, A and B are both the all zero matrices means no ICI or IBI exists in the received signal. For convenience, we denote C = H−A in (1), which is expressed explicitly in the $N \times N$ matrix in [1.] At the receiver, the time domain signal y_k in (1) is coverted into the frequency domain signal z_k by the DFT matrix W_N^{-1} of size N. Which is

$$z_k = W_N^{-1} C W_N r_k + W_N^{-1} B W_N r_{k-1} + \tilde{n}_k \quad (5)$$

Now we have to see precoding, so signal r_k is the precoded output of an $N \times 1$ vector x_k passing through a precoding matrix P of size, $N \times N$ i.e.,

$$r_k = \mathrm{P} x_k \quad (6)$$

The IDFT matrix W_N and precoding P are taken together so it becomes $W_N P$. The time domain precoding matrix is defined as $Q \triangleq W_N P$.After the design of Q, the precoding matrix P can be obtained by multiplying with the inverse W_N^{-1}. So, P and Q are equal and we call both P and Q precoders interchangeably. From (5), (6) and Equation of precoder Q, the received frequency domain signal for the *k*th OFDM block can be equivalently expressed as:

$$z_k = W_N^{-1} C W_N \mathrm{P} x_k + W_N^{-1} B W_N \mathrm{P} x_{k-1} + \tilde{n}_k \quad (7)$$

C. MIMO-OFDM Model

The input to the MIMO-OFDM system is denoted by $\bar{r}_k = [(r_k^0)^T, (r_k^1)^T, \dots, (r_k^{N-1})^T]^T$ where r_k^i denotes the $n_t \times 1$ vector for the n_t transmit antennas at the *i*th subcarrier, $0 \le i \le N-1$, in frequency domain. Next, the input vector $\bar{r}_k$ is transformed into time domain signal by n_t IDFT matrices of size N at n_t transmit antennas. The overall IDFT operation over $\bar{r}_k$ can be represented by $\overline{\mathrm{W}} = \mathrm{W_N} \otimes \mathrm{I}_{\mathrm{n_t}}$. At each transmit antenna, a CP of length v is added to the input signal block and propagates via multipath channel $h_{ij} = [h_{ij}(0), h_{ij}(1), \dots, h_{ij}(L)]^T$ in between the *i*th receive antenna and the *j*th transmit antenna, where we assume that all the entries of h_{ij} are i.i.d. complex Gaussian random variables with 0 mean and the channel length, L+1, is identical for all the channels. We now define $n_r \times n_t$ channel matrices $\mathrm{H}(l)$, $l = 0, 1, \ldots L$, as

$$\mathsf{H}(l) = \begin{bmatrix} h_{11}(l) & \cdots & h_{1n_t}(l) \\ \vdots & \ddots & \vdots \\ h_{1n_r}(l) & \cdots & h_{1n_r n_t}(l) \end{bmatrix} \tag{8}$$

These matrices $\mathsf{H}(l)$, l = 0, 1,......., L, are the multipath channel matrices for the time domain vectors r_k^i serially transmitted at n_t transmit antennas. Due to the randomness of the channel coefficients, all the matrices $\mathsf{H}(l)$ are of full rank almost surely[1].

At the receiver, the CP is removed and the overall time domain received block is given, for example [1] [10].

$$\bar{y}_k = C\bar{W}\bar{r}_k + B\bar{W}\bar{r}_{k-1} + n_k \tag{9}$$

Where n_k is the $Nn_r \times 1$ noise vector with the complex Gaussian distribution $\mathcal{CN}(0, \sigma^2 \mathsf{I})$, C and B of size $Nn_r \times Nn_t$ are the overall channel matrix and IBI matrix, respectively, constructed by stacking sub matrices $\mathsf{H}(l)$

$$\mathsf{B} = \begin{bmatrix} 0 & \ldots & 0 & \mathsf{H}(L) & \cdots & \mathsf{H}(v+1) \\ \vdots & & & \ddots & \ddots & \vdots \\ \vdots & & & & \ddots & \mathsf{H}(L) \\ \vdots & & & & & 0 \\ \vdots & & & & (10) & \\ 0 & \ldots & \ldots & \ldots & \ldots & 0 \end{bmatrix} \tag{10}$$

Before the signal detection, the DFT operation $\mathsf{W}_{\mathrm{N}}^{-1} \otimes \mathsf{I}_{\mathrm{n_r}}$ is applied to $\bar{y}_k$ yielding the received signal $\bar{z}_k$ in frequency domain. For this MIMO-OFDM system, the input vector $\bar{r}_k$ is also the precoded output of information symbol vector $\bar{x}_k = [(x_k^0)^T, (x_k^1)^T, \ldots, (x_k^{N-1})^T]^T$ by an $Nn_t \times Nn_t$ precoding matrix P, where x_k^i is the $n_t \times 1$ information symbol vector associated with r_k^i

$$\bar{r}_k = \mathsf{P}\bar{x}_k \tag{11}$$

$$= \mathsf{P}[(x_k^0)^T, (x_k^1)^T, \ldots, (x_k^{N-1})^T]^T \tag{12}$$

$$\bar{z}_k = [\mathsf{W}_{\mathrm{N}}^{-1} \otimes \mathsf{I}_{\mathrm{n_r}}]CQ\bar{x}_k + [\mathsf{W}_{\mathrm{N}}^{-1} \otimes \mathsf{I}_{\mathrm{n_r}}]BQ\bar{x}_{k-1} + \tilde{n}_k \tag{13}$$

Equation (13) represent the received frequency domain signal in *k*th OFDM block [1].

III. CHANNEL INDEPENDENT PRECODING

A precoding is designed to eliminate the distortion by processing information symbols at the transmitter and it also requires the perfect CSIT.

A. SISO-OFDM Precoding

The equation (1) we have to change like equation (7) using precoding so we obtain following equation

$$y_k = \mathsf{CQ}x_k + \mathsf{BQ}x_{k-1} + n_k \tag{14}$$

For the current *k*th OFDM block, the signal x_k and $\mathsf{BQ}x_{k-1}$ is the IBI and we assume the additive noise n_k is negligible. In order to freely solve for x_k from (14), the space $\mathcal{V}_{signal}$ linearly spanned by the column vectors of CQ and the space $\mathcal{V}_{IBI}$ linearly spanned by the column vectors of BQ need to be disjoint. The determinant of channel matrix C is zero and its rank is full i.e. *N*. we assume rank of precoder Q is *N* – *d* so the rank of IBI matrix BQ becomes *L* – *v* – *d* and rank of CQ is *N* – *d*. The sum of rank of IBI and CQ is not more than the vector size *N*. i.e.

$$N - d + L - v - d \leq N \tag{15}$$

From equation (15),We have to obtain d is and The smdllest value of d is

$$d = \frac{L-v}{2} \tag{16}$$

The above equation shows dimensions of space is spanned by the IBI is *(L - v)/*2. In conventional In the conventional OFDM system (or unprecoded OFDM system), additional $L{-}v$ zeros or redundant symbols are needed to make the IBI disappear. From the above analysis, only half of $L - v$ zeros or redundant symbols are needed to separate the spaces of the signal and the IBI for the signal to be solved freely [1].

We see now a particular example for the above SISO-OFDM precoding idea, let us consider the case when N = 64 subcarriers, CIR length L+1 = 17, i.e., L = 16, and the insufficient CP length v = 8.So rank(CQ) = 60,rank(BQ)= 4.In this example , 60 independent information symbols can be solved freely. With CP length v = 8, in the conventional OFDM of block size N = 64, 8 more zeros or redundant symbols in the OFDM block are needed to completely eliminate the IBI, and thus only 60 independent information symbols are included.

B. MIMO-OFDM Precoding

In MIMO-OFDM system, we have to see the IBI term from previous OFDM block needs to be prevented and current OFDM block should be preserved. The MIMO-OFDM precoding is same as like SISO-OFDM precoding whi ch is explained subsection. In next subsection, we have to consider problem in two different cases for the numbers of transmit and receive antennas[1].

1) Precoding Technique when $n_r \leq n_t$ *(Theorem 1)*

In MIMO-OFDM system, n_t transmit antennas, n_r receive antennas N subcarrier so for each OFDM block there are total $n_r N$ linear equations after the removal of CP. In order to linearly solved for all information symbols, the number independent information symbols passed through n_t transmit antennas should be not more than $n_r N$ The following theorem is solved for number independent information symbols using zero-forcing operator during each OFDM block.

$$\begin{cases} n_t(N - L + v) + \left\lfloor \frac{n_r N - n_t(N-L+v)}{2} \right\rfloor, \\ \quad \text{if } n_t(N - L + v) < n_r N, \\ n_r N, \\ \quad \text{if } n_t(N - L + v) \geq n_r N. \end{cases} \tag{17}$$

The above equation is for insufficient CP MIMO-OFDM system with $n_r \leq n_t$ [1].

2)IBI cancellation when $n_r > n_t$ *(Theorem 2)*

Using following theorem we show that to eliminate IBI there is no precoding or no CP or no zero padding are needed. The total number of independent information symbols can be solved using the zero-forcing operator is $n_t N$ for the insufficient CP MIMO-OFDM system with $n_r > n_t$, where no zero-padding or precoding is needed. See for example [1].

$$N \geq \frac{n_t}{n_r - n_t}(L - v) \tag{18}$$

IV. SIMULATIONS RESULTS

In this section, we shows some simulation results to validate our proposed IA based channel independent precoding. The SNR is accounted in all following figures.

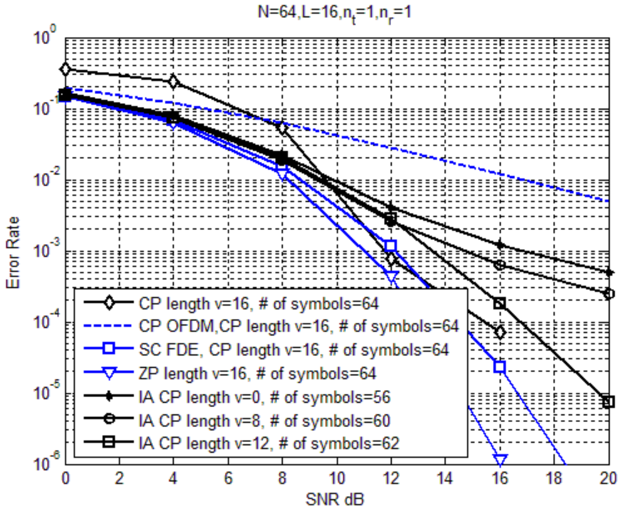

Fig .2 Performance of BER using IA based precoding in CP- OFDM,SC-FDE,ZP-only

The above figure is of performance of BER using IA based precodings in CP-OFDM, SC-FDE, ZP-only with different CP lengths and the number of independent information symbols and we consider SISO case here. This independent information symbols satishfies Theorem 1 means IBI can be completely eliminated.

The the Block length of CP-OFDM, SC-FDE,ZP-only is N = 64 i.e. 64 independent information symbols are sent and CP or ZP length is 16. In IA based precoding ,the block length is N = 64,CP lengths are v = 16,0,8,12 when the independent information symbols are 64,56,60,62 respectively using Theorem 1[11]-[16].This results validate with ref.[1].

The Fig.3 is of the performance of BER using IA based precoding for different CP lengths and different number of information symbols in SISO case. The Theorem 1 do not satisfy when CP lengths are v = 8 and v = 12 and the numbers of transmitted independent information symbols in one block are 62 and 64, respectively and its BER performances for these two cases are dashed curves in Fig.3, where one can see that error floors occur when SNR becomes high because the IBI cannot be completely eliminated and this results validate with ref.[1].

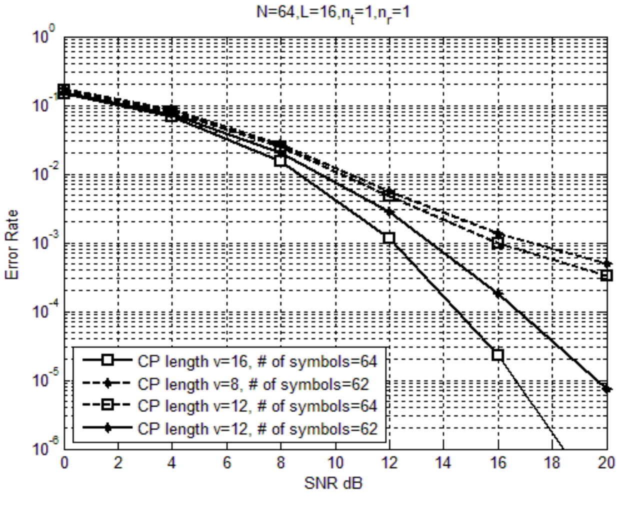

Fig.3. Performance of BER using IA based precoding for different CP lengths and different number of information symbols in SISO Case.

The Fig.4. shows performance of BER using IA based precoding for different CP lengths and different number of information symbols in MISO Case where n_t = 2 and n_r = 1. Here we consider both cases of satisfying (solid curves in Fig.4) and not-satisfying (dashed curves in Fig.4) for Theorem1.Here we take the block size N = 32 and the CIR order

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L = 19. In each case, two different CP lengths are considered. We show example of the v = 2 cases to specify the transmission block:

$$\begin{bmatrix} 0 & 0 & x_k(0) & x_k(2) \cdots x_k(28) & x_k(30) & 0 \cdots 0 \\ 0 & 0 & x_k(1) & x_k(3) \cdots x_k(29) & 0 & 0 \cdots 0 \end{bmatrix}$$

Where there are 16 consecutive zeros are present at the end of each row and each row represents the transmission block at one transmit antenna, and the first two zeros are the CP of length v = 2 in each row.

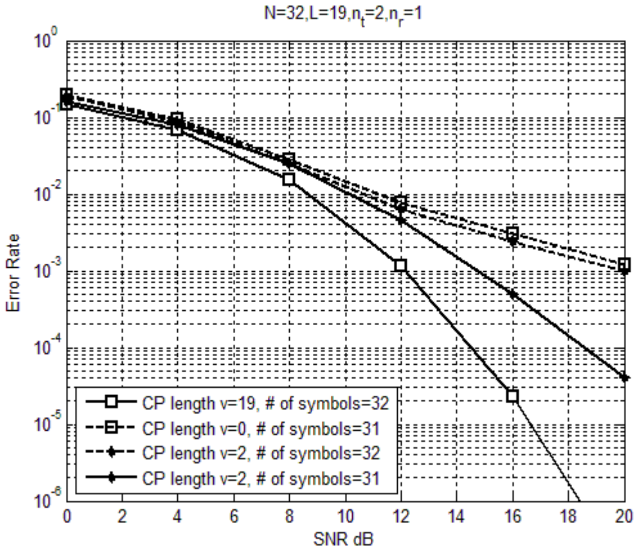

Fig.4. Performance of BER using IA based precoding for different CP lengths and different number of information symbols in MISO Case.

Fig.5 is of performance of BER using IA based precoding for different CP lengths and different number of information symbols in MIMO Case where $n_t = 4, n_r = 4$.

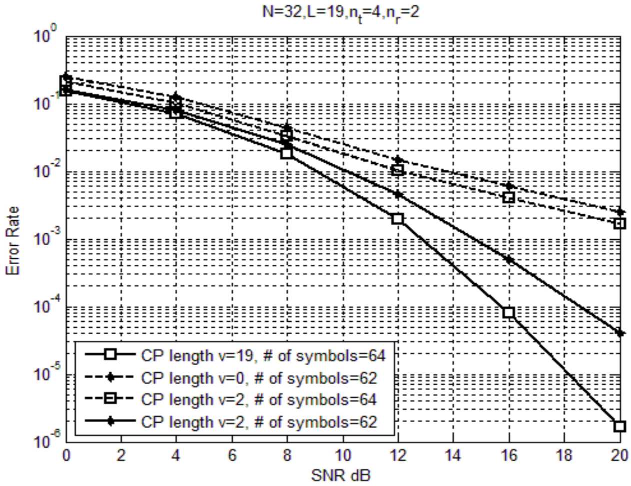

Fig.5.Performance of BER using IA based precoding for different CP lengths and different number of information symbols in MIMO Case.

Here we also consider both cases of satisfying (solid curves in Fig.5) and not-satisfying (dashed curves in Fig.5) for Theorem 1. Here we comparing the results of Fig.4 and Fig.5 for the cases of two transmit and one receive antennas and four transmit and two receive antennas, respectively. we see that the channels are the same (i.e., the CIR orders L, the CP lengths v, the data block sizes N, and the ratios between the numbers of transmit and receive antennas are the same) but the number of independent information symbols can be solved for the MIMO case almost doubles that of the MISO case. Although the bandwidth efficiency gets better for more antennas for our precodings but we can see from these two figures the BER performance degrades, which may be improved by, for example, employing forward error correction coding and this result validate with ref.[1].

V. CONCLUSION

In this paper, we proposed that the interference alignment based channel independent precoding in MIMO-OFDM system with insufficient CP and we conclude also when number of receive antennas are more than number of transmit antennas, we can eliminate total IBI using precoding technique (using Theorem 1).We also explained the total SISO-OFDM model and MIMO-OFDM model and their precodings in detail. Our proposed precoding's bandwidth efficiency is more than the conventional zero-padded or CP added MIMO systems, such as, ZP-only, CP-OFDM and SC-FDE system when $n_r \leq n_t$.

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