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ICI/ISI Cognizant-Beam Forming Technique for Outdoor WLAN 802.11n

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ABSTRACT: An orthogonal frequency division multiplexing (OFDM) system suffers poor performance degradation as the channel impulse response is greater than the length of the cyclic prefix (CP) . The main reason for this performance degradation is the Inter-Carrier Interference (ICI) and Inter-Symbol Interference (ISI). The conventional Aware Beamforming technique mitigates the ICI/ISI caused due to multipath delay. However, the suppression is very limited. We propose an alternative technique, ICI/ISI Cognizant-Beamforming (ICBF) algorithm in which aware Beamforming is implemented along with Maximum Likelihood Sequence Equalizer (MLSE) which increases the ICI/ISI mitigation compared to conventional system. Proposed system reduces the Block Error Rate (BLER) and hence provides good performance of the channel. Optimal steering vectors are derived to maximize the Signal-to-Interference-plus-Noise (SINR). The simulations are performed in an outdoor WLAN 802.11n (Wi-Fi) using OPNET.

KEYWORDS: OFDM, ISI/ICI, SINR, CBF

I.INTRODUCTION

The growth of wireless communication in recent years has created the demand for the reliable, high speed and spectrally effective communication over the wireless channel. This requirement can be satisfied by the Orthogonal Frequency Division Multiplexing(OFDM). OFDM concept is based on the multicarrier transmission. This technique divides the channel into N narrowband sub-channels, each with a bandwidth much smaller than the coherence bandwidth of the channel. OFDM is initially designed to overcome the impairments caused by the transmission. The major advantage of the OFDM system is that it converts the frequency selective fading into flat fading. To implement successfully, we require that the channel impulse response must be smaller than the Cyclic Prefix(CP) to cope with the channel impulse response. When the length of the CP is smaller than the channel impulse response, the received data is corrupted by the Inter-Symbol Interference (ISI) and the Inter-Carrier Interference (ICI). For this issue, a simple one-tap equalizer is not enough and we need a complex equalization algorithm to achieve a better performance. To increase the efficiency of wireless communication link with multiple transmitting antennas and multiple receiving antennas, also known as Multiple-Input Multiple-Output (MIMO) like OFDM system. In many mobile communication systems, adaptive equalization is required to mitigate the effect of multipath dispersion and non-stationary channel. Maximum Likelihood Sequence Estimator (MLSE) are used to develop an adaptive equalizer .MLSE receivers operate in non-stationary channel an often required channel tracking and prediction. Given the increasing popularity of wireless LANs (WLANs), there is interest in deploying IEEE 802.11n is effective for outdoor environment applications. However, these standards were initially designed only for the indoor applications. There is need for operating these techniques in outdoor environment without changing the CP length. But when the length of the channel impulse response exceeds the CP length, the received data is corrupted by both inter channel interference (ICI) and inter-symbol interference (ISI).

In this scenario, a simple one-tap equalizer is not sufficient and complex equalization is necessary for good performance. In literature, ICI/ISI equalization of OFDM for Digital Subscriber Lines (DSL) has been extensively studied, resulting in algorithms for time-domain equalization [1] [2] and frequency domain equalization [3]; algorithms have also been proposed for MIMO-OFDM systems, [4]–[7]; and ICI caused by frequency-offset errors or Doppler spread has been addressed in [8]–[13]. Because ICI/ISI is related to a channel's spatial properties, it is natural to expect Beamforming techniques, which are often deployed in MIMO systems, to help combat interference problem in MIMO-OFDM. This algorithm exploits the spatial properties of the interference through the formation of optimal steering vectors at the transmitter and/or receiver. It is a per-tone processing approach that has only moderate computational complexity and is compatible with existing MIMO Beamforming systems. From the literature, we come to know that the link performance is high sensitive to the presence of ICI and ISI. In this paper, we propose a scheme that mitigates the ICI and ISI. The prerequisite for our scheme is an

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estimate of the multipath channel between the transmitter and receiver. In Wireless Local Area Networks (WLANs) that use Time Division Duplex (TDD) channels, channel reciprocity allows the estimates to be made directly by the transmitter. However, links of WLANs based on Frequency Division Duplex require feedback from the receiver. The feedback overhead required in this case depends on the number of subcarriers, the required precision of the estimates, and the variation rate of the multipath channel.

The paper is organized as follows. We introduce the ICI/ISI system model for MIMO-OFDM in Section II. The complex optimization problem for MIMO links is solved, using a simplified approximation strategy, In Section III. ICI/ISI-COGNIZANT BEAMFORMING is proposed. Section IV simulation and results, discussed in Section V, concludes our work and indicates the possible enhancements.

II. ICI/ISI SYSTEM MODEL

Initially we explain the ICI/ISI system model with a single-antenna OFDM system and then we extend the OFDM system model to multiple antenna configurations. Consider an N-subcarrier OFDM signal, and p(k) an dis transmitted at time k over a multipath channel. The multipath channel is represented by the vector $m=[m_0, m_1,\ldots\ldots\ldots, m_{L-1}]^T$, where L is the length of the channel response. The input symbols are assumed to be independent, i.e. $E[x(k)\,x(k)^H] = I$, where I is an N x N identity matrix. We consider two cases, $L \leq N$ and $L > N$. The received signal vector is represented as

$$q(k) = HW_N\, p(k) - UW_N\, p(k) + VW_N\, p(k-1) + n(k) \qquad (1)$$

where, H is a circular matrix of size NXN which represents the multipath channel; W_N is the unitary Inverse Discrete Fourier Transform (IDFT) matrix; U and V, represent ICI and ISI components of the channel respectively and n (k) is the noise received at the receiving section, The elements of the H, circular matrix is defined as $[h]_{i,j}=h_{(i-j)N}$owhere i and j are the row and column of the circular matrix. By assuming perfect synchronization, the rectangular pulse shape matrices U and V are derived in the time domain and are represented as follows

$$U=\begin{bmatrix} 0 & \cdots & h_{L-1} & \cdots & \cdots & h_{v+1} & 0 & \cdots & 0 \\ 0 & \cdots & 0 & h_{L-1} & \cdots & h_{v+2} & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & 0 & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & 0 & h_{L-1} & 0 & \cdots & 0 \\ 0 & \cdots & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 \end{bmatrix} \qquad (2)$$

$$V=\begin{bmatrix} 0 & \cdots & 0 & h_{L-1} & \cdots & \cdots & h_{v+1} \\ 0 & \cdots & 0 & 0 & h_{L-1} & \cdots & h_{v+2} \\ \vdots & \ddots & \vdots & \ddots & 0 & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & 0 & 0 & h_{L-1} \\ 0 & \cdots & 0 & \cdots & \cdots & 0 & 0 \\ \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \cdots & 0 & 0 \end{bmatrix} \qquad (3)$$

Where *v* is the Cyclic prefix which are measured in samples. Due to excessive multipath channel delay, ISI is caused when one OFDM symbol is overlapped with the other (previous) OFDM symbol; V describes this overlapping. ICI results when the symbols lose the orthogonality because of truncation and –U represents the part being truncated. When $v \geq L-1$, both U and V are zero and the system is interference-free.

At the receiving section, a unitary DFT matrix W_N^{-1} transforms the time-domain vector q(k) into the frequency-domain vector $q_f(k)$.

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Denoting $H' = W_N^{-1}\ HW_N$, $U' = W_N^{-1}\ UW_N$, $V' = W_N^{-1}\ VW_N$, C= H - U, and $n'(k) = W_N^{-1}\ n(k)$,

We have,
$q_f(k)=H'p(k) - U'p(k) + V'p(k-1) + n'(k)$
$q_f(k)= Cp(k) + V'p(k-1) + n'(k)$ (4)

Here, H' is a diagonal matrix which represents the interference-free component of the channel, whose main diagonal is DFT of the channel impulse response h and the property is called straightforward because H is a circular matrix which represents the circular convolution. The relationship between the ICI and ISI can be described as

$$V' = U'diag(1, W_N^{-v}, W_N^{-2v}, ..., W_N^{-(N-1)v}) \qquad (5)$$

Consider any subcarrier j, the ISI and the ICI from any of the subcarriers other than j are significantly the same and the only difference is the phase of the interference. An perceptive explanation for the property is that V' is the *v*-column right-shift version of U' in the time domain; so that in the frequency domain, each column of V' is rotation of corresponding column of U', thus the property can be used to calculate V' from U', and thus the computational complexity reduces..

For MIMO-OFDM system with n_t transmits antennas and n_r receive antennas, at the receiving section the output is the stacked version in frequency domain.

The received signal vector at the receiving section in the frequency domain is expressed as

$$q(k) = H\,p(k) + Vp(k-1) + N, \qquad (6)$$

$$H \triangleq \begin{bmatrix} \sum_{i=0}^{n_t-1} C(0,i)Q(i) \\ \sum_{i=0}^{n_t-1} C(1,i)Q(i) \\ \vdots \\ \sum_{i=0}^{n_t-1} C(n_r-1,i)Q(i) \end{bmatrix} \qquad (7)$$

$$v \triangleq \begin{bmatrix} \sum_{i=0}^{n_t-1} V'(0,i)Q(i) \\ \sum_{i=0}^{n_t-1} V'(1,i)Q(i) \\ \vdots \\ \sum_{i=0}^{n_t-1} V'(n_r-1,i)Q(i) \end{bmatrix} \qquad (8)$$

$$N \triangleq \begin{bmatrix} \sum_{i=0}^{n_t-1} n'(0,k) \\ \sum_{i=0}^{n_t-1} n'(1,k) \\ \vdots \\ \sum_{i=0}^{n_t-1} n'(n_r-1,k) \end{bmatrix} \qquad (9)$$

Where Q(*i*) is the Beamforming matrix for the *i*th transmit antenna, and C (*j*,*i*) and V'(*j*,*i*) the ICI matrix and ISI matrix, which is corresponding to the single-input single-output(SISO) multipath channel between the ith transmit antenna and the *j*th receive antenna. Combining matrix R is employed at the receiving section to get back the transmitted signal which is represented as $\hat{p}(k)$

$$\hat{p}(k) = \sum_{j=0}^{n_r-1}\sum_{i=0}^{n_t-1} R(j)^H C(j,i)Q(i)p(k) + \sum_{j=0}^{n_r-1}\sum_{i=0}^{n_t-1} R(j)^H C(j,i)Q(i)p(k-1) + \sum_{j=0}^{n_r-1} R(j)^H n'(j,k) \qquad (10)$$

Where, $R=[R(0)^T, R(1)^T, \ldots\ldots, R(n_r-1)^T]^T$

III.ICI/ISI-COGNIZANT BEAMFORMING

From (10) we can observe that the Matrices C and V' contribute to the ICI and ISI, so to mitigate ICI completely, matrices R and Q must satisfy the following condition

$$R^H CQ = \Lambda, \qquad (11)$$

where Λ is a diagonal matrix.

In order to remove, the Inter-Symbol Interference by making

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$$R^H V' Q = 0, \qquad (12)$$

or we can mitigate the ISI by using a decision feedback equalizer(DFE) ,but when considering for the large DFT size, the this approach(DFE) is computationally complex and not used for the real-time applications of a system with a large number of antennas and subcarriers. To overcome these issues, we propose a similar method which is significantly less complex. So, in particularly we can make use of one-tap per-tone (PTEQ). Even though per-tone processing with a small number of antennas cannot remove the interference completely, it can reduce the ICI/ISI power significantly, and it is simple to analyze and implement in a MIMO-OFDM Beamforming system.
For simplifying our analysis, we illustrate with the Single-Input Multiple-Output (SIMO) case, and then extending it to the Multiple-Input Single-Output (MISO) and then MIMO cases.

A.SIMO
In the case of Single Input Multiple Output(SIMO), only one transmitting antenna is used, so there is no steering vector Q. then we can represent (10) as

$$\begin{aligned}\hat{p}(k) = &\sum_{j=0}^{n_r-1}\sum_{i=0}^{n_t-1} R(j)^H C(j,i)p(k) + \\ &\sum_{j=0}^{n_r-1}\sum_{i=0}^{n_t-1} R(j)^H C(j,i)p(k-1) + \\ &\sum_{j=0}^{n_r-1} R(j)^H n'(j,k)\end{aligned} \qquad (13)$$

Here we are assuming per-tone processing, **R** can be expressed as

$$G = \begin{pmatrix} diag(r(0)) \\ diag(r(1)) \\ \vdots \\ diag(r(n_r-1)) \end{pmatrix} \qquad (14)$$

Where, $r(i) = [r_i^0, r_i^1 \cdots .., r_i^{n-1}]^H$ is the combining vector for i[th] receiving antenna.

$$\begin{aligned}\hat{p}_n(k) = &r_n^H h_n p_n(k) + \\ &r_n^H C_{\bar{n}} p_{\bar{n}}(k) + \\ &r_n^H h_n p_n(k-1) + r_n^H n_n\end{aligned} \qquad (15)$$

Where ,

$h_n \triangleq [[C(0,0)]_{n,n}, [C(1,0)]_{n,n}, \ldots\ldots, [C(n_r-1,0)]_{n,n}]^T$,

$r_n \triangleq [r_n(0), r_n(1), \ldots\ldots\ldots, r_n(n_r-1)]^H$,

$p_n(k) \triangleq [p_0(k), p_1(k), \ldots\ldots, p_{N-1}(k)]^T$,

$V_n \triangleq [[V'(0,0)]^T_{n,0:N-1}, [V'(1,0)]^T_{n,0:N-1}, [V'(N_r-1,0)]^T_{n,0:N-1}]^T$

B.MISO

In the case of MISO, **R** (0) = **I** at the receiver. That is, in receiving section there is no combing vector. So, the estimated output at the receiver $\hat{p}(k)$ becomes as

$$\begin{aligned}\hat{p}(k) = &\sum_{j=0}^{n_r-1}\sum_{i=0}^{n_t-1} C(j,i)Q(i)p(k) + \\ &\sum_{j=0}^{n_r-1}\sum_{i=0}^{n_t-1} C(j,i)Q(i)p(k-1) + n'(j,k)\end{aligned} \qquad (16)$$

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Similar to the SIMO we apply the per-tone processing, **Q** can be represented as

$$Q=\begin{pmatrix} diag(q(0)) \\ diag(q(1)) \\ \vdots \\ diag(q(n_r-1)) \end{pmatrix} \tag{17}$$

Where, $q(i)=[q_i^0, q_i^1 \cdots .., q_i^{n-1}]^H$ is the steering vector for i[th] receiving antenna.

Looking at eq(), we can observe that , we cannot get a maximum SINR as in the case of SIMO, here in MISO any receive estimate of the transmitted signal of subcarrier n is not only correlated with the steering component $q_n(i)$ of subcarrier n, but it also correlated to all other subcarriers, which makes the optimization very difficult and impractical to solve, so we propose an effective alternative approach, which is the suboptimal solution to attain the objective.

Total ICI/ISI power leakage is from the subcarrier n to all other subcarriers are completely determined by the steering vector components $q_n(i)$ .If we can reduce this power leakage, then we can reduce the overall ICI/ISI crosstalk among the subcarriers and improve SINR of the all subcarriers.

We define P_n^{ICI} and P_n^{ISI} as the total average ICI and ISI power leakage from the n[th] subcarrier to all other subcarriers in the next symbol, P_n^{ICI} and P_n^{ISI} can be expressed as

$$P_n^{ICI} = E\{q_n^H C_{\bar{n}}^H p_n(k)^H p_n(k) C_{\bar{n}} q_n\} \tag{18}$$

$$P_n^{ISI} = E\{q_n^H V_n^H p_n(k-1)^H p_n(k-1) V_n q_n\} \tag{19}$$

C. MIMO

In the case of MIMO, both the steering vector **Q** at the transmitter and the combining vector **R** at the receiver should be optimized jointly, because of the optimization difficulties in the MISO case, and we again consider a suboptimal approach. By considering the optimization at the receiver and the transmitter separately, we can achieve our objective, a MIMO system can be implemented in such a way, that consists of as a MISO at the transmitter and the SIMO at the receiver. So, we can apply the optimization technique in MISO and SIMO separately at the transmitter and the receiver to get a suboptimal steering vector q_n^* and combining vector r_n^* .

IV. SIMULATION AND RESULTS

Therefore we have analysed and simulated the performance of BLER for MISO and SIMO based on the existing system , is shown in fig 1. For simulation purposes, we assume that an OFDM system which uses 64-point DFT and 16-QAM, with the sampling rate as 20MHz, corresponding sampling interval is 50ns. The length of the OFDM symbol is 3.2µs and the length of 0.4 µ.

Assuming Rayleigh fading channel with delay spreads 0.4 µs, 0.8 µs, 1.2 µs, 1.6 µs.

We simulated a simple Wi-Fi network in OPNET Modeler version 14.5-PL3.

The network consists of a BS with six nodes for the outdoor WLAN 802.11n environment structure is shown in fig 2. And Base station configured successfully for the Wi-Fi network is shown in fig.3.

We conducted a simulation study based on the analysis of the ICI/ISI cognizant beamforming scheme and evaluated performance for different antenna configurations for the outdoor WLAN 802.11n environment and the comparisons are performed using MLSE equalizer..

Comparison of BLER for ICBF with MLSE and without MLSE using 16 QAM and 64 QAM is shown in fig 4 and fig 4 and its corresponding simulation parameters are tabulated in Table 1 and Table 2.

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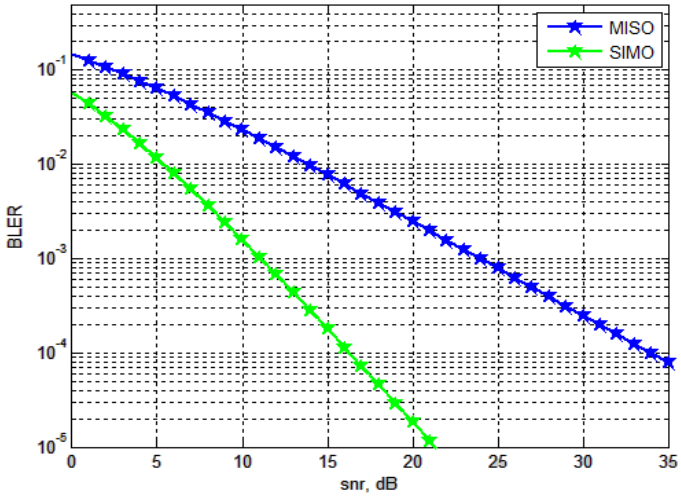

Fig 1.. ICI/ISI Cognizant beamforming for a 4x1 antenna Vs 1x4configuration using 16-QAM

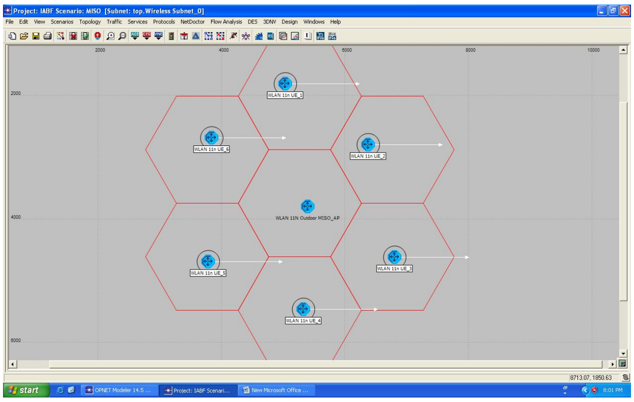

Fig 2. OPNET simulation of a small Wi-Fi network includes one BS, and six nodes.

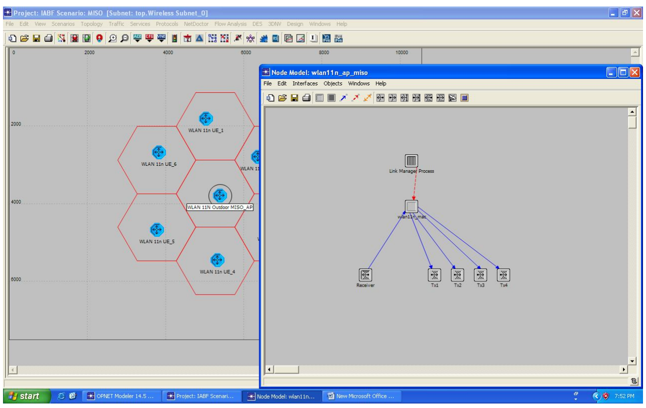

Fig 3. Base station configuration

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Table 1 Simulation Parameters

Bandwidth	**20MHz**
OFDM symbol rate	50ns
Length of OFDM	3.2µs
Length of Cyclic Prefix	0.4µs
Modulation	16 QAM

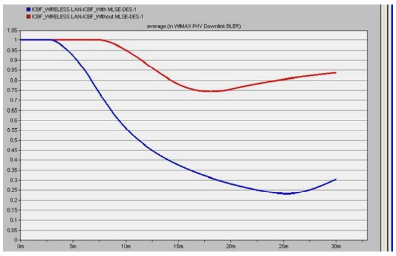

Fig 4. Comparison of BLER for ICBF with MLSE and without MLSE using 16 QAM.

Table 2 Simulation Parameters

Bandwidth	**20MHz**
OFDM symbol rate	50ns
Length of OFDM	3.2µs
Length of Cyclic Prefix	0.4µs
Modulation	64 QAM

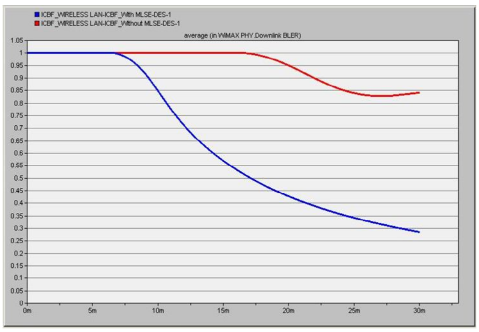

Fig 5. Comparison of BLER for ICBF with MLSE and without MLSE using 64 QAM.

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V.CONCLUSION AND FUTURE WORK

In this paper we proposed an ICI/ISI Cognizant Beamforming (CBF) algorithm which is compared with per-tone equalizer and Maximum Likelihood Sequential Equalizer. The performances are compared in terms of BLER and SNR.
A possible extension of this work would be using a decision Feedback Equalizer (DFE) to improve the performance or can use MLSE algorithm along with DFE to reduce the implementation complexity.
We can achieve better performance in terms of BLER and SNR with perfect channel state information.

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