Evaluating the impact of Guard Period on the performance of MIMO-OFDM system

Mitalee Agrawal*, Yudhishthir Raut**

*(Department of Electronics & Communication Engineering, RGTU, Bhopal)
** (Department of Electronics & Communication Engineering, RGTU, Bhopal)

ABSTRACT

The Orthogonal frequency-division multiplexing (OFDM) is a technique of choice in the modern digital communication system, which divides a channel with a higher relative data rate into several orthogonal sub-channels with a lower data rate. This very special & unique feature of the technique attracts the new generation of communication, which is widely called as "fourth generation technology". The paper has been divided into two parts dealing with one of the most important aspect/ performance parameter of OFDM. The 1st part will talk about the significance of Guard Period presence in MIMO-OFDM system in sagging Inter-Symbol Interference (ISI). On the other hand the 2nd part will demonstrate how the different modulation technique & guard period insertion impact the performance of MIMO-OFDM system in different ways with the help of MATLAB simulation result

Keywords **- Cyclic Prefix, Cyclic Suffix, Guard Period, ISI, MIMO-OFDM, Zero Padding**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is becoming widely applied in wireless communications system due to its high rate transmissions capability with high bandwidth efficiency and its robustness with regard to multipath and delay.[1] It has been used in digital audio broadcasting systems (DAB), digital video broadcasting (DVB) systems, digital subscriber line (DSL) standards, and wireless LAN standards such as the American IEEE std. 802.11(WiFi) and WiMAX (stands for Worldwide Interoperability for Microwave Access), are one of the standards of IEEE which utilizes the idea of OFDM, and is aimed to provide high throughput broadband connections over long distances. The basic idea of OFDM is to divide available bandwidth into N narrow sub- channel at equidistant frequencies. The sub-channel spectra overlap each other but the subcarrier signals are still orthogonal. The single high-rate data stream is subdivided into many low-rate data streams for the sub-channels. Each sub-channel is modulated individually using 64-bit QAM Technique and will be transmitted simultaneously in a superimposed and parallel form. But like other technology OFDM also has its own advantages & disadvantages, like High peak to average power ratio (PAPR), Inter-channel/ Symbol interference (ISI/ICI), Sensitive to Doppler Shift & Sensitiveness to frequency synchronization problem. In-spite of these disadvantages, the popularity of OFDM is still far above the other techniques due to its Praiseworthy advantages. This gave rise to find the solution for overcoming or reducing to the extent possible these lacunas in OFDM to design a cost effective high performance system. There has been many studies has been in this direction to deal with the different aspect of improving OFDM system performance. One of the principal advantages of OFDM is its utility for transmission at very nearly optimum performance in un-equalized channels and in multipath channels. Inter-symbol interference (ISI) and inter-carrier interference (ICI) can be entirely eliminated by the simple expedient of inserting between symbols a small time period known as guard period. In this paper, based on some simulation result, we will demonstrate how the introduction of guard period is playing a key role is optimizing the Inter-Symbol Interference, which will be abbreviated as ISI in the paper for ease of usage. There are several questions about the how much benefit can be avail by implementing this optimizing technique? Also how efficiently, the OFDM can be used with other technique to come-up with less complex & value-adding system?

The paper has been divided into two parts. In the first part we have put forward the importance of adding guard period in MIMO-OFDM system. In the second part, a brief analysis of simulation result to demonstrate the impact of different modulation technique in conjunction with guard period insertion on MIMO-OFDM.

II. ISI REDUCTION ON GUARD PERIOD INSERTION

To optimize the performance of an OFDM link, time and frequency synchronization between the transmitter and receiver is of absolute importance. This can be achieved by using known pilot tones embedded in the OFDM signal or attach fine frequency timing tracking algorithms within the OFDM signal's cyclic extension (guard Period/ Period). To prevent ISI, the individual blocks are separated by guard periods wherein the blocks are periodically extended. In addition, once the incoming signal is split into the respective transmission sub-carriers, a guard period is added between each symbol. Each symbol consists of useful symbol duration, T_s and a guard period, Δt, in which, part of the time, and a signal of T_s is cyclically repeated. This is shown in Fig. 1.

As long as the multi path propagation delays do not exceed the duration of the period, no inter-symbol interference occurs and no channel equalization is required.
For a delay spread that is longer than the effective guard period/ Period, the BER (Bit Error Rate) rises rapidly due to the inter-symbol interference. The maximum BER that will occur is when the delay spread is very long (greater than the symbol time) as this will result in strong inter-symbol interference. In a practical system the length of the guard period can be chosen depending on the required multipath delay spread immunity required.

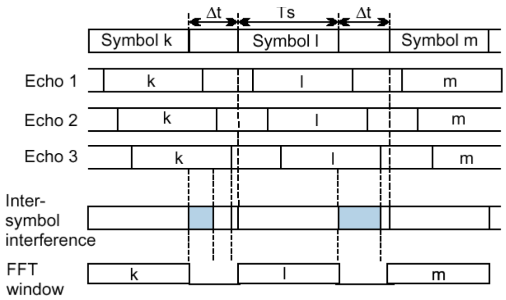

Fig.1. Combating ISI using a guard period **[2]**

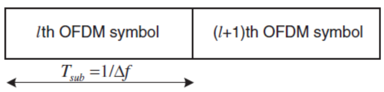

Fig. 2(a) OFDM symbol without guard period **[3]**

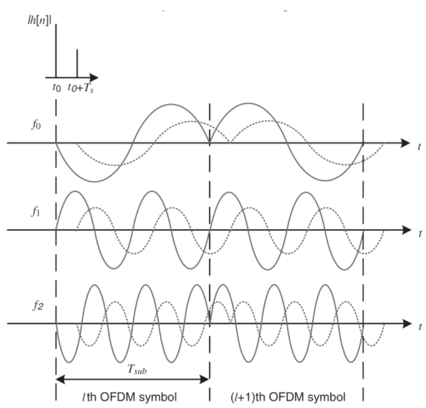

Fig. 2(b) ISI Effect of a multipath channel for each sub-carrier **[4]**

Figure 2 illustrates an ISI effect of the multipath channel over two consecutive OFDM symbols. Let T_{sub} denote the duration of the effective OFDM symbol without guard interval. Since $W = 1/T_s$ and thus, $\Delta f = W/N = 1/(NT_s)$ and $T_{sub} = NT_s = 1/\Delta f$. By extending the symbol duration by N times (i.e., $T_{sub}= NT_s$), the effect of the multipath fading channel is greatly reduced on the OFDM symbol. However, its effect still remains as a harmful factor that may break the orthogonality among the subcarriers in the OFDM scheme. As shown in Figure 2(b), the first received symbol (plotted in a solid line) is mixed up with the second received symbol (plotted in a dotted line), which incurs the ISI. It is obvious that all subcarriers are no longer orthogonal over the duration of each OFDM symbol. To warrant a performance of OFDM, there must be some means of dealing with the ISI effect over the multipath channel. As discussed in the sequel, a guard interval between two consecutive OFDM symbols will be essential.

The Guard Period in OFDM System can be inserted in two different ways. One way is the zero padding (ZP) i.e. pads the guard period with zeros. The other way is the cyclic extension of the OFDM symbol (for some continuity) by insertion of CP (cyclic prefix) or CS (cyclic suffix). CP is to extend the OFDM symbol by copying the last samples of the OFDM symbol into its front.

1. Cyclic Prefix

Let T_G denote the length of CP in terms of samples. Then, the extended OFDM symbols now have the duration of $T_{sym}=T_{sub}+T_G$. Figure 3(a) shows two consecutive OFDM symbols, each of which has the CP of length TG, while illustrating the OFDM symbol of length $T_{sym}=T_{sub}+T_G$. Meanwhile, Figure 3(b) illustrates them jointly in the time and frequency domains. Figure 3(b) shows the ISI effects of a multipath channel on some subcarriers of the OFDM symbol. It can be seen from this figure that if the length of the guard interval (CP) is set longer than or equal to the maximum delay of a multipath channel, the ISI effect of an OFDM symbol (plotted in a dotted line) on the next symbol is confined within the guard interval so that it may not affect the FFT of the next OFDM symbol, taken for the duration of T_{sub}. This implies that the guard interval longer than the maximum delay of the multipath channel allows for maintaining the orthogonality among the subcarriers. As the continuity of each delayed subcarrier has been warranted by the CP, its orthogonality with all other subcarriers is maintained over T_{sub}, such that:

$$\frac{1}{T_{sub}}\int_0^{T_{sub}} e^{j2\pi f_k(t-t_0)} e^{j2\pi f_i(t-t_0)} dt = 0, k \neq i \qquad (1)$$

for the first OFDM signal that arrives with a delay of t_0, and

$$\frac{1}{T_{sub}}\int_0^{T_{sub}} e^{j2\pi f_k(t-t_0)} e^{j2\pi f_i(t-t_0-T_s)} dt = 0, k \neq i \qquad (2)$$

for the second OFDM signal that arrives with a delay of $t_0 + T_s$.

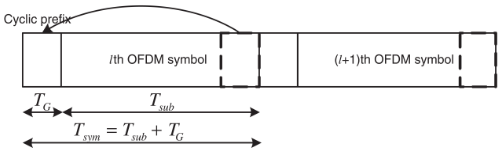

Fig.3 (a) OFDM symbol with CP [3]

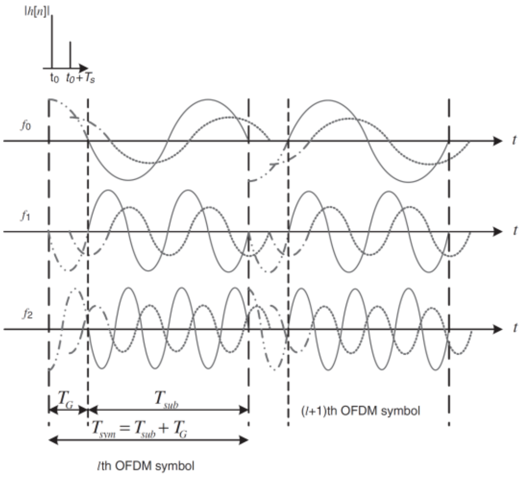

Fig. 3(b) ISI Effect of a multipath channel for each sub-carrier [4]

2. Cyclic Suffix (CS)

Cyclic suffix (CS) is also a cyclic extension of the OFDM system. It is different from CP only in that CS is the copy of the head part of an effective OFDM symbol, and it is inserted at the end of the symbol. CS is used to prevent the interference between upstream and downstream, and is also used as the guard interval for frequency hopping or RF convergence, and so on. Both CP and CS are used in Zipper-based VDSL systems in which the Zipper duplexing technique is a form of FDD (Frequency-Division Duplexing) that allocates different frequency bands (subcarriers) to downstream or upstream transmission in an OFDM symbol, allowing for bidirectional signal flow at the same time. Here, the purpose of CP and CS is to suppress the ISI effect of the multipath channel, while ensuring the orthogonality between the upstream and Therefore, the length of CP is set to cover the time dispersion of the channel, while the length of CS is set according to the difference between the upstream transmit time and downstream receive time. Figure 4 shows the structure of the OFDM symbol used in Zipper-based VDSL systems, where the length of the guard interval is the sum of CP length T_{CP} and CS length T_{CS}.

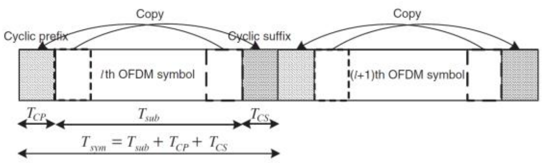

Fig.4. OFDM Symbol with CP & CS [6]

3. Zero Padding (ZP)

We may insert zero into the guard interval. This particular approach is adopted by multiband- OFDM (MB-OFDM) in an Ultra Wide-band (UWB) system. Figures 5 (a) and (b) show OFDM symbols with ZP and the ISI effect of a multipath channel on OFDM symbols for each subcarrier, respectively. Even with the length of ZP longer than the maximum delay of the multipath channel, a small STO causes the OFDM symbol of an effective duration to have a discontinuity within the FFT window and therefore, the guard interval part of the next OFDM symbol is copied and added into the head part of the current symbol to prevent ICI as described in Figure 6.

Since the ZP is filled with zeros, the actual length of an OFDM symbol containing ZP is shorter than that of an OFDM symbol containing CP or CS and accordingly, the length of a rectangular window for transmission is also shorter, so that the corresponding sine-type spectrum may be wider. This implies that compared with an OFDM symbol containing CP or CS, an OFDM symbol containing ZP has PSD (Power Spectral Density) with the smaller in-band ripple and the larger out-of-band power, allowing more power to be used for transmission with the peak transmission power fixed.

Note that the data rate of the OFDM symbol is reduced by $T_{sub}/T_{sym}=T_{sub}/(T_{sub}+T_G)$ times due to the guard interval.

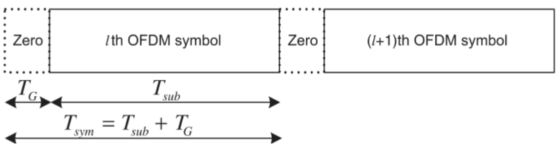

Fig. 5(a) OFDM Symbol with ZP [3]

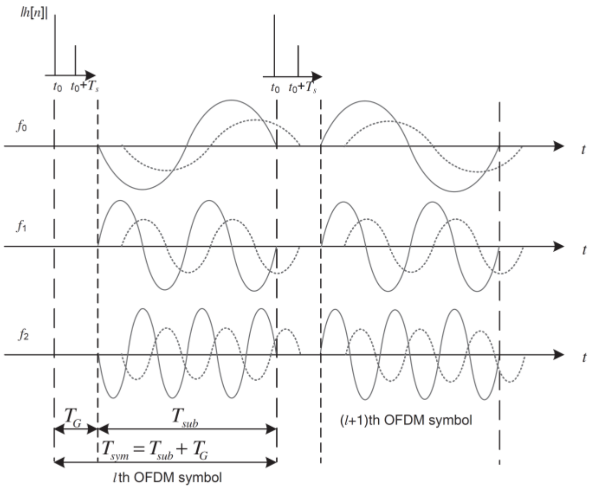

Fig. 5(b) ISI Effect of a multipath channel on OFDM symbols with ZP [4]

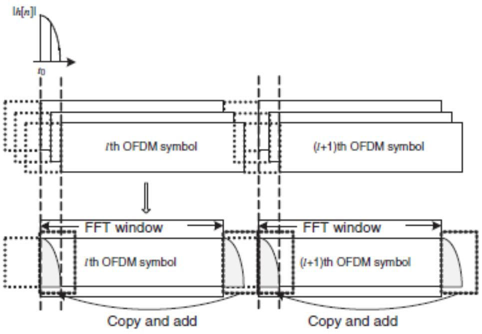

***Fig.6. Copying and adding the guard interval of the next symbol into the head part of the current symbol to prevent ICI.* [5]**

III. BER ANALYSIS OF OFDM SYSTEM

The analytical BER expressions for M-ary QAM signaling in AWGN and Rayleigh channels are respectively given by equation (3) & equation (4) [6] as:

$$P_e = \frac{2(M-1)}{M\log_2 M} Q\left(\sqrt{\frac{6E_b}{N_0}\cdot\frac{\log_2 M}{M^2-1}}\right) \tag{3}$$

$$P_e = \frac{(M-1)}{M\log_2 M}\left(1-\sqrt{\frac{3\gamma\log_2 M/\left(M^2-1\right)}{3\gamma\log_2 M/\left(M^2-1\right)+1}}\right) \tag{4}$$

Where, γ and M denote E_b/N_0 and the modulation order, respectively, while Q(x) [7] is the standard Q-function defined as:

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2/2}dt. \tag{5}$$

Note that if N_{used} subcarriers out of total N (FFT size) subcarriers (except $N_{vc}=N/N_{used}$ virtual subcarriers) are used for carrying data, the time-domain SNR, SNR_t [8], differs from the frequency-domain SNR, SNR_f , as follows:

$$SNR_t = SNR_f + 10\log\frac{N_{used}}{N}[dB] \tag{6}$$

IV. RESULTS

The BER Performance of MIMO OFDM system has been analyzed for two scenarios, one is with Guard period inclusion and the other one without Guard period inclusion. Also the effect of the different modulation techniques over the performance of MIMO-OFDM system is illustrated thru the simulation results. After comparing the simulation result obtained by plotting Bit Error Rate (BER) against the Signal to Noise Ratio (SNR), there are two facts which are quite obvious and lead to conclusion. First, the presence of Guard Period in the MIMO OFDM System improves BER performance to the significant extent. Secondly, the different modulation techniques also affect the BER performance of the system.

The simulation set-up is divided into three sub-parts. In the first part, one of the three Guard period insertion techniques is chosen for the experiment purpose. As per results, since cyclic prefix gives better result at the selected guard period value, it has been selected for the present experimental set-up.

In the second part, alternatively different Modulation techniques has been taken to analyze, which techniques is most suited to MIMO OFDM system. The different techniques used for analyses in present set-up are QPSK, 16-QAM & 64-QAM.

In the third part the value of Guard period is taken. After successive testing, the two values which has been taken in present experimental set-up are GP=32 & GP=0 for with guard period & without guard period case respectively.

From Figure 7(a), 7(b) & 7(c), it is clear that the BER performance with CP of length of 32 samples shows some inconsistence with improvement as we move for 64-QAM to QPSK for modulation technique with that of the analytic result in the Rayleigh fading channel. This implies that the OFDM system is just subject to a flat fading channel as long as GP is large enough. It is also clear that the BER performance in an AWGN channel is almost consistent with the simulation channel. This is true regardless of how long GP is, because there is no multipath delay in the AWGN channel. As illustrated in Figure 7(d) & compared to Figure 7(a), 7(b) & 7(c), however, the effect of ISI on the BER performance becomes significant in the multipath Rayleigh fading channel as the length of GP decreases, which eventually leads to an error floor.

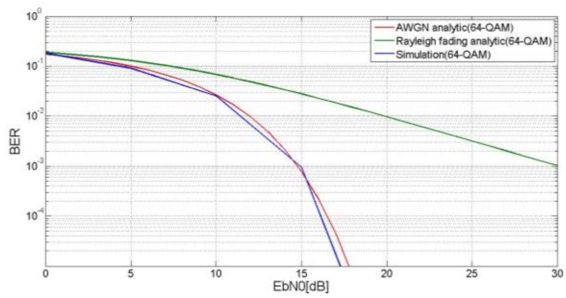

Fig. 7(a) GP length: Ng = N/2 = 32 with 64-QAM

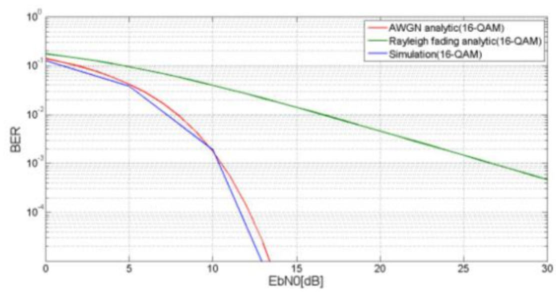

Fig. 7(b) GP length: Ng = N/2 = 32 with 16-QAM

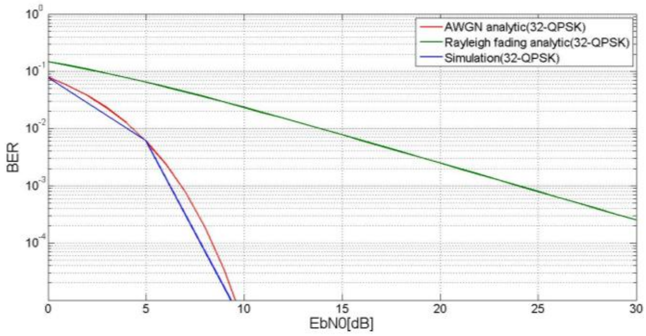

Fig. 7(c) GP length: Ng = N/2 = 32 with QPSK

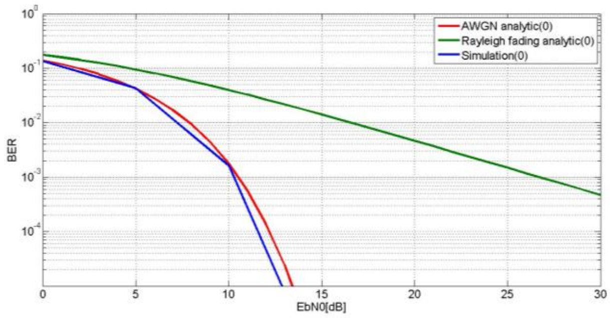

Fig. 7(d) GP length: Ng = 0 (i.e. no GP) with QPSK

Fig.7. BER Performance for OFDM system with QPSK, 16-QAM & 64-QAM.

V. Conclusion

Results simulated shows that the insertion of Guard Period plays a significant role in improving the performance of the MIMO-OFDM system. Also it is quite visible from the result that if the value of Guard Period is chosen appropriately in conjunction with right modulation technique the performance can be enhanced to a significant extent. As the results depict the fact that the QPSK gives best result for MIMO OFDM system while 16-QAM modulation technique cause negligible improvement in the BER performance of the system. However, there is still further possibility of improving the performance of the OFDM system, which can be achieved by using OFDM in conjunction to other multiple access technique such as FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access) & CDMA (Code Division Multiple Access).

REFERENCES

[1] Mitalee Agrawal, Yudhishthir Raut, "Effect of Guard Period Insertion in MIMO OFDM System", (IJCTEE)International Journal of Computer Technology & Electronics Engineering, Texas, US, Vol. 1 No. 2, 2011.
[2] http://users.cecs.anu.edu.au/~jian/Course_mc_files/MC_note1.pdf
[3] Hermann Rohling, OFDM Concept & Future, Springer Heidelberg Dordrecht London New York, 2011.
[4] Yong Soo Cho, Jaekwon Kim, Won Young Yang, Chung G. Kang, MIMO-OFDM Wireless Communications with MATLAB, John Wiley & Sons (Asia) Pte Ltd., 2010.
[5] Srabani Mohapatra, Susmita Das, "A study on OFDM System and its Performance Analysis," Proceedings of Emerging Trends in Computing and Communication (ETCC-08), pp.81-84, Dec 30-31, 2008, Computer Science Dept, NIT Hamirpur, H.P.
[6] M. P. Chitra, Dr. S. k. Srivastsa, "Impact of Guard Interval in Porposed MIMO-OFDM system for Wireless communication", (IJCSIS) International Journal of computer Science and Information Security, Vol. 8 No.9, 2010.
[7] http://en.wikipedia.org/wiki/File:OFDMA_subcarriers.png
[8] Ravitej Amasa, "Inter Carrier Interference Cancellation in OFDM System", Dept. of Electronics & Communication Engineering, NIT, Rourkela, session 2009.
[9] Govingd Singh Parihar, "Synchronization Techniques for OFDM" Bachelor Project Report, Dept. of Electronics & Communication Engineering, NIT, Rourkela, Session 2008-2009.
[10] Samaneh Shooshtary, "Development of a MATLAB simulation environment for vehicle-to-vehicle and infrastructure communication based on IEEE 802.11" Master dissertation, Dept. of Telecommunication, University of Galve, Vienna, December 2008.
[11] Dominik Bischoff, " Noise Variation Estimaton for MIMO-OFDM Testbed" Master dissertation, Dept. of Information Technology & Electrical Engineering, Swiss Federal Institute of Technology, Zurich, December 2008.
[12] Dominik Bischoff, "Noise Variance Estimation for MIMO-OFDM Testbed", Department of Information and Electrical Engineering, ETH, Zurich Winter Session, 2008
[13] J. G. Proakis, Digital Communications, McGraw-Hill, 2008.
[14] M. Jiang and L. Hanzo, "Multiuser MIMO-OFDM for next generation wireless systems," Proceedings of IEEE, vol.95, pp.1430-1469, July 2007.
[15] Cisco Systems GMBH, "Überblick über die Wireless-Technologie 802.11n," www.cisco.com, 2007.
[16] Sarod Yatawatta and Athina P. Petropulu, "Blind Channel Estimation in MIMO OFDM Systems with Multiuser Interference" IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 54, NO. 3, MARCH 2006.
[17] Luis Litwin and Michael Pugel, "The Principles of OFDM" RF signal processing, January 2001.
[18] J. Armstrong, "Analysis of new and existing methods of reducing inter carrier Interference due to carrier frequency offset in OFDM", IEEE Transaction on

Communication, Vol. 47, No. 3, pp. 365–369, Mar. 1999.

[19] Michael Speth, Stefan A. Fechtel, Gunnar Fock, and Heinrich Meyr, "Optimum Receiver Design for Wireless Broad-Band Systems Using OFDM", IEEE Transaction on Communications, Letters, VOL. 47, NO. 11, November 1999.

[20] Yinman Lee, Yun-Jung Hsieh, and Hong-Wei Shieh, "Multi-objective Optimization for Pre-DFT Combining in Coded SIMO-OFDM Systems" IEEE Communications, Letters, VOL. 14, NO. 4, pp. 303-305, APRIL 2010.