

Review and Analysis of Multiuser Detection Techniques for Smart Antenna of SDMA-OFDM

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Abstract – Now days, the antennas which are mostly used at base station are either sectored or omni directional. But using such kind of antennas in the mobile communications is nothing but the wastage of power due to fact that most of the power is radiated in other directions rather than estimated mobile users. Also as the power is radiated in the other directions and this are results into the interference for the mobile users. Hence in this review paper we are discussing the smart antennas system by investigating performances of adaptive smart antenna with different adaptive equalizers. The Space-Division Multiple Access (SDMA) is nothing but the MIMO (multiple inputs and multiple outputs) communication mechanism for wireless networks. SDMA is having the potential of increasing the system performance as well as spectral efficiency. Generally, smart antenna is combining the multiple elements of antenna with the capability of signal processing in order to optimize automatically its radiation pattern in the mobile communications and against the signal environment. In this paper we are presenting the review and analysis of four type's adaptive equalizers for multi-user system communication system for multi user detection using the adaptive smart antenna

Keywords – OFDM, SDMA, Multiuser Detection, Adaptive Equalizers, Spectral Efficiency, ML, MMSE Introduction.

I. INTRODUCTION

The mechanism of using the several antenna elements as well as innovative signal processing in order serve more intelligently the wireless communications is introduced since from long time. In the defense was prevented in commercial applications. The DSPs (Digital Signal Processors) which is low cost and powerful advent as well as innovative software oriented signal processing tools made the intelligent antenna systems for the real time deployment in wireless communication systems. Now days, as the solutions which are spectrally efficient are enhancing the business imperative, such systems are supporting for the wider coverage area, interference rejection highly, as well as substantial capacity improvements. Thus, the solutions of smart antenna required as the interference, number of users, and the propagation complexity growing out [2] [3].

The wireless communication system's exponential growths as well as the limited availability of bandwidth for those systems are creating several problems for the big organizations working. Recently the advances in central processing unit as well as digital signal processor resulted into the more improvements in the algorithms and smart antenna system's experimental validations build the environment where the use of cost effective smart antennas is feasible in different kinds of wireless markets.

Due to the various activities involved in the smart antenna systems that are provided by them space of smart

antenna is quite busy. First thing is that multipath fading effect in the wireless communication systems can be reduced significantly.

After that the second thing is that, battery life for the handsets which is used for transmitting the base station is less as compared to the one required for conventional systems [4]. This is only because of fact that base station antenna array achieving the diversity gain as well as nullifying gain, and hence needed transmit signal is reduced for the handset. The third thing, the QoS (Quality of Service) of communication network is improved by the smart antenna via the range extension, better building presentation and hole filling. Thus, such advantages of QoS resulted into the infrastructure cost reduction for the smart antenna systems. At last, smart antenna systems are used for increasing the capacity of system, which is frequently limited by SIR (Signal to interference) ratio. The SIR ratio of wireless communication systems improved by the smart antenna systems and hence the system capacity is increases significantly [4]. The concept of smart antenna is not actually making the use of various types of antennas. Multiple antenna elements are used by the system over one side of the communications link at least as well as utilizes better the algorithms of signal processing in order achieve its advantages. The ways where the multiple antennas signal are processed most probably at the side of baseband, and hence this makes "smart" system. The smart antenna system is divided into the different levels like the level which require the minimal processing to the level which required extremely advanced systems that needs the antenna arrays at receiver and transmitter. The highest level of such smart antenna based systems is MIMO (multiple inputs/ multiple outputs) in terms of performance and complexity. As we know that MIMO has multiple types of antennas used at transmitter and receiver, which is resulted into the better performance as compare to the other techniques of smart antenna [2] [3].

Research in the development of efficient signal detection algorithms for SDMA-OFDM systems have generated much interest in recent years, and several detection algorithms have been proposed in the literatures [4]. Among the various MUDs, the classical linear ZF and MMSE MUDs exhibit low complexity at the cost of a limited performance. The high-complexity optimum ML MUD provided here has capable of achieving the best performance with an exhaustive search [5] [6] [7]. However, the complexity of nonlinear ML detector generally avoids its use in practical systems especially with many users and large constellations. QR decomposition using tree search is a most promising algorithm, which can be implement with low complexity and also provides near optimal solution [8] [9].

In this paper we are presenting discussion over different equalizers used for multiuser detection of SDMA-OFDM used at smart antenna. We are investigating the two other methods such as Likelihood (ML) as well as Minimum Mean Square Error (MMSE) equalizers. In section II we are discussing the overview of OFDM system with its mathematical representation.

II. REVIEW OF OFDM SYSTEMS

2.1 OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique that divides the available spectrum into subcarriers, with each subcarrier containing a low rate data stream. The subcarriers have proper spacing and pass-band filter shape to satisfy orthogonality as shown in Figure 1. OFDM will play an important role in realizing Cognitive Radio (CR) concept by providing a proven, scalable, adaptive technology for wireless communications [10]. Inter-symbol interference (ISI) is reduced completely by using a guard band in every OFDM symbol. In OFDM, using guard band is cyclically extended in order to avoid inter-carrier interference (ICI). The advantage of OFDM system is robustness to channel fading in wireless communication environment. Frequency selective fading is reduced by increasing the number of subcarriers. By choosing the coherence bandwidth is greater than the subcarrier spacing of the channel, each subcarrier is going to be affected by a flat channel and thus no or simple channel equalizer is needed.

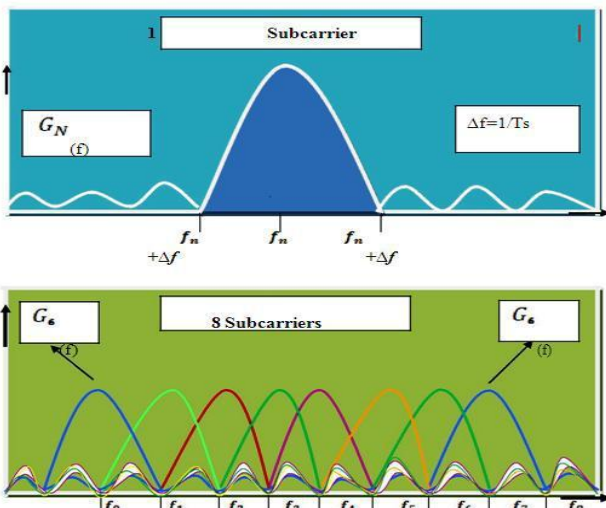


Fig.1. OFDM subcarriers in frequency domain

OFDM is used in many wireless applications today. Already it is used in different WLAN standards (e.g. HIPERLAN-2, IEEE 802.11a), Wireless Metropolitan Area Networks (WMAN), Digital Video Broadcasting (DVB), 3GPP-LTE, Asymmetric Digital Subscriber Line (ADSL) and power line communications.

Despite of OFDM advantages, it has a major potential drawback in the form of high Peak-to-Average Power Ratio (PAPR). The high PAPR has nonlinear nature in the transmitter and it degrades the power efficiency of the system.

2.2 Advantages and Disadvantages of OFDM System

There are some advantages and disadvantages of OFDM are summarized below:

2.2.1 Advantages of OFDM

Some of the advantages of an OFDM system are as follows:

The OFDM signal is robustness in multipath some of the advantages of an OFDM system are as follows:

- OFDM is computationally efficient to employ the modulation and demodulation techniques by using FFT.
- The OFDM signal is robustness in multipath propagation environment and more tolerant of delay Spread.
- OFDM is more resistant to frequency selective fading than single carrier transmission systems.
- OFDM system gives good protection against co-channel interference and impulsive parasitic noise.
- It is possible to use maximum likelihood detection with reasonable complexity.
- OFDM is a good candidate for CR because of its flexibility and adaptability [10].
- Orthogonality preservation procedures in OFDM are much simpler compared to CDMA/TDMA technique in multipath conditions [8].

2.2.2 Disadvantages of OFDM

Some of the disadvantages of an OFDM system are as follows:

- The OFDM signal suffers high peak to average power ratios (PAPR) of transmitted signal.
- OFDM is very sensitive to carrier frequency offset.
- It is difficult to synchronize when subcarriers are shared among different transmitters.

2.2.3 OFDM System Model

Whereas supplied into a channel encoder that data are mapped into BPSK/QPSK/QAM constellation.

The data symbols are converted from serial to parallel and using Inverse Fast Fourier Transform (IFFT) to achieve the time domain OFDM symbols. Time domain symbols can be represented as:

$$X_n = IFFT\{X_n\} = \frac{1}{N} \sum_{k=0}^{N-1} x_k e^{j2\pi kn/N}$$

where, x_k is the transmitted symbol on the k^{th} subcarriers N is the number of subcarriers. Time domain signal is cyclically extended to prevent Inter Symbol Interference (ISI) from the former OFDM symbol using cyclic prefix (CP).

The Digital to Analog Converter (DAC) is performed to convert the baseband digital signal into analog signal. This operation is executed in DAC block of diagram. Then, the analog signal is proceeded to the Radio Frequency (RF) frontend. The RF frontend performs operations after receiving the analog signal. The signal is up converted to RF frequencies using mixer and amplified by using Power Amplifier (PAs) and then transmitted through antennas. At the receiver side, the received signal is down converted to base band signal by RF frontend.

The analog signal is digitized and re-sampled by the Analog to Digital Converter (ADC). The ADC is used to digitize the analog signal and re-samples it.

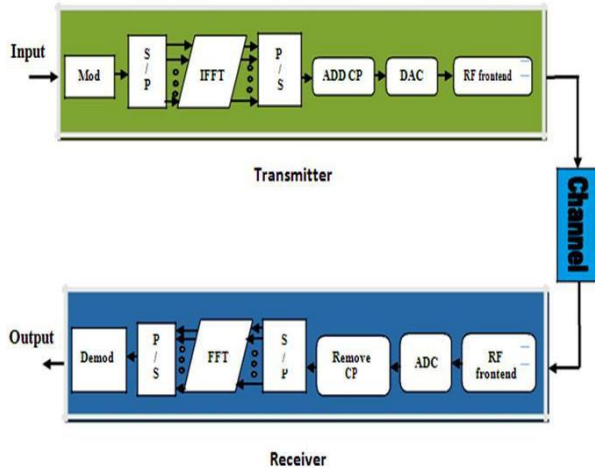


Fig.2. Basic OFDM Architecture

Cyclic prefix is removed from the signal in frequency domain. This step is done by the Fast Fourier Transform (FFT) block. The received symbols in the frequency domain can be represented as:

$$Y(k) = H(k) X_m(k) + W(k)$$

where, $Y(k)$ is the received symbol on the k^{th} subcarrier and $H(k)$ is the frequency response of the channel on the same subcarrier and $W(k)$ is the additive noise added to k^{th} subcarrier which is generally assumed to be Gaussian random variable with zero mean and variance. Thus, simple one tap frequency domain equalizers can be employed to get the transmitted symbols. After FFT signals are de-interleaved and decoded to recover the original signal.

2.4. Mathematical Definition of OFDM Signal

OFDM consists of multiple carriers. Each carrier can be presented as a complex waveform like:

$$S_c(t) = A_c(t)e^{j(\omega_c + \varphi_c)t}$$

Where

$A_c(t)$ is the amplitude of the signal $S_c(t)$.

$\varphi_c(t)$ is the phase of the signal $S_c(t)$.

The complex signal can be described by

$$x_n = \frac{1}{N} \sum_{n=0}^{N-1} A_n(t) e^{j(\omega_n + \varphi_n)t}$$

This is a continuous signal. Each component of the signal over one symbol period can take fixed values of the variables like:

$$\varphi_n(t) = \varphi_n$$

$$A_n(t) = A_n$$

where, n is the number of OFDM block.

T is a time interval and the signal is sampled by $1/T$ then it can be represented by

$$S_s(KT) = \frac{1}{N} \sum_{n=0}^{N-1} A_n e^{j(\omega_0 + \omega \Delta n)KT + \varphi_n}$$

Let $\omega_0 = 0$ then the signal becomes:

$$S_s(KT) = \frac{1}{N} \sum_{n=0}^{N-1} A_n e^{j(\omega \Delta n)KT + \varphi_n}$$

The signal is compared with general Inverse Fourier Transform (IFT):

$$g(KT) = \frac{1}{N} \sum_{n=0}^{N-1} G[\frac{n}{NT}] e^{j(\frac{2\pi nk}{N})}$$

The OFDM signal can be defined by Fourier Transform. The Fast Fourier Transform (FFT) can obtain frequency domain OFDM symbols and Inverse Fast Fourier Transform (IFFT) can obtain time domain symbols. They can be written as:

Fast Fourier Transform

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j(\frac{2\pi}{N})kn}$$

Inverse Fast Fourier Transform

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{j(\frac{2\pi}{N})kn}$$

III. MATHEMATICAL REPRESENTATION OF ML AND MMSE EQUALIZERS

3.1 Maximum Likelihood (ML) Equalizer

In this section we are discussing another equalizer called ML. Maximum Likelihood (ML) decoding which gives us an even better performance. We will assume that the channel is a flat fading Rayleigh multipath channel.

In a 2×2 MIMO channel, probable usage of the available 2 transmit antennas can be as follows:

1. Consider that we have a transmission sequence, for example $\{x_1, x_2, x_3, \dots, x_n\}$
2. In normal transmission, we will be sending x_1 in the first time slot, x_2 in the second time slot, x_3 and so on.
3. However, as we now have 2 transmit antennas, we may group the symbols into groups of two. In the first slot send x_1 and x_2 from the first and second antenna. In second time slot, send x_3 and x_4 from the first and second antenna, send x_5 and x_6 in the third time slot and so on.
4. Notice that as we are grouping two symbols and sending them in one time slot, we need only $\frac{n}{2}$ time slots to complete the transmission – data rate is doubled
5. This forms the simple explanation of a probable MIMO transmission scheme with 2 transmit antennas and 2 receive antennas.

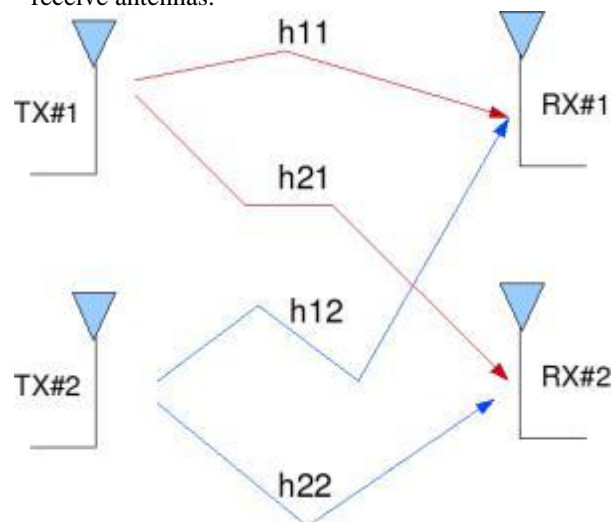


Fig.3. MIMO OFDM System

Let us now try to understand the math for extracting the two symbols which interfered with each other. In the first

time slot, the received signal on the first receive antenna is,

$$Y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1}, h_{1,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1$$

The received signal on the second receive antenna is

$$Y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1}, h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

Where,

y_1, y_2 are the received symbol on the first and second antenna respectively,

$h_{1,1}$ is the channel from first transmit antenna to first receive antenna,

$h_{2,1}$ is the channel from second transmit antenna to first receive antenna,

$h_{1,2}$ is the channel from first transmit antenna to second receive antenna,

$h_{2,2}$ is the channel from second transmit antenna to second receive antenna,

x_1, x_2 are the transmitted symbols and

n_1, n_2 is the noise on first and second receive antennas.

We assume that the receiver knows.

$h_{1,1}, h_{2,1}, h_{1,2}$ and $h_{2,2}$. The receiver also knows both y_1, y_2 . The unknowns are x_1 and x_2 .

For convenience, the above equation can be represented in matrix notation as follows:

Equivalently,

$$Y = Hx + n$$

1. The channel is flat fading – In simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication.

2. The channel experience by each transmit antenna is independent from the channel experienced by other transmit antennas.

3. For the i^{th} transmit antenna to j^{th} receive antenna, each transmitted symbol gets multiplied by a randomly varying complex number $h_{j,i}$. As the channel under consideration is a Rayleigh channel, the real and imaginary parts of $h_{j,i}$ are Gaussian Distributed having mean zero and variance $\sigma_{h_{j,i}}^2 = \frac{1}{2}$.

4. The channel experienced between each transmit to the receive antenna is independent and randomly varying in time.

4. On the receive antenna, the noise n has the Gaussian probability density function with $P(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(n-\mu)^2}{2\sigma^2}}$ with $\mu = 0$ and $\sigma^2 = \frac{N_0}{2}$

5. The channel $h_{j,i}$ is known at the receiver.

Maximum Likelihood (ML) Receiver: The Maximum Likelihood receiver tries to find x which minimizes $J = [y - Hx]^2$. Since the modulation is BPSK, the possible values of x_1 is +1 or -1 similarly x_2 also take values +1 or -1. So, to find the Maximum Likelihood solution, we need to find the minimum from the all four combinations of x_1 and x_2 .

The estimate of the transmit symbol is chosen based on the minimum value from the above four values.

if the minimum is $j_{+1,+1} \Rightarrow [1,1]$

if the minimum is $j_{+1,-1} \Rightarrow [1,0]$

if the minimum is $j_{-1,+1} \Rightarrow [0,1]$

if the minimum is $j_{-1,-1} \Rightarrow [0,0]$

Practical Implementation using MATLAB:

(a) Generate random binary sequence of +1's and -1's.

(b) Group them into pair of two symbols and send two symbols in one time slot

(c) Multiply the symbols with the channel and then add white Gaussian noise.

(d) Find the minimum among the four possible transmit symbol combinations

(e) Based on the minimum chose the estimate of the transmit symbol

(f) Repeat for multiple values of $\frac{E_b}{n}$ and plot the simulation and theoretical results.

3.2 Minimum Mean Square Error (MMSE)

Practical Assumptions:

1. The channel is flat fading – In simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication.

2. The channel experience by each transmit antenna is independent from the channel experienced by other transmit antennas.

3. For the i^{th} transmit antenna to j^{th} receive antenna, each transmitted symbol gets multiplied by a randomly varying complex number $h_{j,i}$.

As the channel under consideration is a Rayleigh channel, the real and imaginary parts of $h_{j,i}$ are Gaussian distributed having mean is zero and variance $\sigma_{h_{j,i}}^2 = \frac{1}{2}$.

4. The channel experienced between each transmit to the receive antenna is independent and randomly varying in time.

6. On the receive antenna, the noise n has the Gaussian probability density function with $P(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(n-\mu)^2}{2\sigma^2}}$ with $\mu = 0$ and $\sigma^2 = \frac{N_0}{2}$

7. The channel $h_{j,i}$ is known at the receiver.

Minimum Mean Square Error (MMSE) Equalizer:

Let us now try to understand the math for extracting the two symbols which interfered with each other. In the first time slot, the received signal on the first receive antenna is,

The received signal on the second receive antenna is,

$$Y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1}, h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

Where

y_1, y_2 are the received symbol on the first and second antenna respectively,

$h_{1,1}$ is the channel from first transmit antenna to first receive antenna,

$h_{2,1}$ is the channel from second transmit antenna to first receive antenna,

$h_{1,2}$ is the channel from first transmit antenna to second receive antenna,

$h_{2,2}$ is the channel from second transmit antenna to second receive antenna,

x_1, x_2 are the transmitted symbols and

n_1, n_2 is the noise on first and second receive antennas.

We assume that the receiver knows.

$h_{1,1}, h_{2,1}, h_{1,2}$ and $h_{2,2}$. The receiver also knows both y_1, y_2 . The unknowns are x_1 and x_2 .

For convenience, the above equation can be represented in matrix notation as follows:

Equivalently,

$$Y = Hx + n$$

The Minimum Mean Square Error

(MMSE) approach tries to find a coefficient W which minimizes the criterion,

$$E \{ [wy - x][wy - x]^H \}$$

Solving,

$$W = [H^H + N_0 I]^{-1} H^H$$

When comparing to the equation in Zero Forcing equalizer, apart from the $N_0 I$ term both the equations are comparable. In fact, when the noise term is zero, the MMSE equalizer reduces to Zero Forcing equalizer.

Practical Simulation Model

- (a) Generate random binary sequence of +1's and -1's.
- (b) Group them into pair of two symbols and send two symbols in one time slot.
- (c) Multiply the symbols with the channel and then add white Gaussian noise.
- (d) Equalize the received symbols
- (e) Perform hard decision decoding and count the bit errors.
- (f) Repeat for multiple values of $\frac{E_b}{N}$ and plot the simulation and theoretical results.

IV. CONCLUSION AND FUTURE WORK

In this paper we have discussed OFDM System which is most useful technology in these era, we have seen mathematical representations of this system and its combination with SDMA system. Where the multiuser detection is extremely important for a proper flow of data transmission therefore have discussed multiuser detection method like ML and MMSE. We have also discussed the how smart antenna systems used equalizers for spectrum frequency utilization and efficient communication. Smart antenna is basically used the SDMA-OFDM based communication architecture. Whereas the SDMA is subclass of MIMO. Optimal detection of multiuser system in OFDM resulted into efficient spectrum and power efficiently, as well as enhancing the BER, and PAPR ratios. MSSE and ML are the existing methods which are used mostly as multiuser detection system for SDMA-OFDM. However from many surveys we have seen the limitations and problems of these methods, hence for future work improved method should be presented for the detection of multiuser system.

REFERENCES

- [1] Brian S. Collins, "The Effect of Imperfect Antenna Cross-Polar Performance on the Diversity Gain of a Polarization- Diversity Receiving System," *Microwave Journal*, April 2000 .
- [2] R. Bhagavatula, R. W. Heath, Jr., and K. Linehan, "Performance Evaluation of MIMO Base Station Antenna Designs," *Antenna Systems and Technology Magazine*, vol. 11, no. 6, pp. 14 -17, Nov/Dec. 2008.
- [3] Lawrence M. Drabeck, Michael J. Flanagan, Jayanthi Srinivasan, William M. MacDonald, Georg Hampel, and Alvaro
- [4] Ming Jiang, S. Xin, and L. Hanzo, "Hybrid Iterative Multiuser Detection for Channel Coded Space Division Multiple Access OFDM Systems," *IEEE Transactions on Vehicular Technology*, Vol. 55, No. 1, Jan. 2006.
- [5] Ye Li, "OFDM and Its Wireless Applications: A Survey" *IEEE Transactions on Vehicular Technology*, vol. 58, no. 4, May. 2009.
- [6] Ming Jiang, Hanzo, L, " Multiuser MIMO-OFDM for Next-Generation Wireless Systems, " *Proceedings of the IEEE*, Vol. 95, No. 7, Jul 2007.
- [7] Nirmalendu Bikas Sinha, M. Nandy, R. Bera and M. Mitra, "Channel Estimation and Performance Enhancement of Hybrid Technology for Next Generation Communication System," *International Journal of Research and Reviews in Applied Sciences*, Vol.1, No 2, Nov. 2009.
- [8] Sheng Chan, Ahmad K. Samingan, Bernard Mulgew, and Lajos Hanzo, " Adaptive Minimum-BER Linear Multiuser Detection for DS-CDMA Signals in Mutipath Channels, " *IEEE Transactions on Signal Pracessing*, Vol. 49, NO. 6, Jun. 2001.
- [9] R. C. de Lamare and R. Sampaio-Neto, " Adaptive MBER Decision Feedback Multiuser Receivers in Frequency Selective Fading Channels" *IEEE Communications Letters*, Vol. 7, No. 2, Feb. 2003.
- [10] M. Jiang, J. Akhtman and L. Hanzo, " Iterative Joint Channel Estimation and Multi-User Detection for Multiple-Antenna Aided OFDM Systems, " *IEEE Transactions on Wireless Communications*, Vol. 6, Aug. 2007.