Volume: 3 Issue: V Month of publication: May 2015

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

A perspective on Channel estimation in MIMO-OFDM wireless systems

Ruchi Gupta[1], Sumita Mishra[2]
Department of Electronics & Communication Engineering,
Amity School of Engineering and Technology (ASET), Amity University, Lucknow Campus, India

Abstract—Orthogonal frequency division multiplexing (OFDM) is a multiplexing technique which is widely applied in wireless communication systems because of its high data rate transmission capability and high bandwidth efficiency. This paper presents a comprehensive survey on OFDM for wireless communications. This survey will first review basic OFDM modulation along with techniques to improve the performance of OFDM in wireless communication. The combination of multiple-input multiple-output (MIMO) and OFDM has the potential to address the problem of interference in modern communication systems, and therefore particular emphasis is given to MIMO-OFDM. It also includes channel estimation which is essential for diversity combining in MIMO-OFDM systems. We conclude with the wireless applications of MIMO- OFDM systems.
Keywords—Channel estimation, Inter Carrier Interference (ICI), multicarrier (MC), orthogonal frequency division multiplexing (OFDM), multiple-input multiple-output (MIMO), and wireless standards.

I. INTRODUCTION

Now-a-days wireless communication systems are facing many problems. This include frequency fading, multipath fading, Inter Carrier Interference (ICI), Inter Symbol Interference (ISI) etc [1],[2]. Requirement of larger transmit power at high rate, spectral efficiency, low bit rate capacity are also a major cause. OFDM is an effective technique for high data rate wireless communication in multipath channels and fading environments at reasonable frequency in wireless channels [2]. Because of the nature of its high speed data transmission and effectiveness in combating the frequency selective fading channel, it is adopted by many standards [4], [5]. That includes Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), Asymmetric Digital Subscriber Line (ADSL), Wireless Local Area Network (WLAN), IEEE 802.11 a/g/n etc. OFDM is a case of multicarrier modulation which is based on the concept of splitting a signal into number of signals. After that it modulates these signals to several frequency channels and at receiver, combines the data received from multiple channels [6]. These multiple channels are orthogonal to each other and are known as sub carriers [3]. The major advantage of this scheme is its ability to convert a frequency selective fading channel into several flat fading channels with high spectral efficiency. This paper is organized as section I consists of a basic introduction. Section II presents a literature review. In section III basic OFDM model is described. In section IV channel estimation is described. A brief introduction on MIMO techniques for OFDM and its applications in current system and standards are discussed in section V and VI, respectively. Finally, we present our conclusion in section VII.

II. LITERATURE REVIEW

In 2014, Takahiro Natori, Nari Tanabe and Toshihiro Furukawa presented the channel gain estimation algorithm for the MIMO-OFDM system under the high speed movement environments. This method aims to achieve the robust MIMO-OFDM channel gain estimation by using only the Kalman filter from the canonical state space models. It consists of a state equation composed of channel gain and the colored driving source. It also includes an observation equation composed of the pilot symbols, channel gain and AWGN. The remarkable features of this method are that the channel gain estimation accuracy does not depend on the mobile speed, the number of channel path and the number of transmitting antennas. The proposed method can estimate the channel gain with reduced computational complexity of the traditional. Therefore, this method is the practical MIMO-OFDM channel gain estimation method [6].
In 2013, Peng Cheng, Zhuo Chen and Yun Rui discovered Channel estimation technique for an orthogonal frequency division multiplexing broadband system over a doubly selective channel that is very challenging. This is mainly due to the significant Doppler shift, which results in a time-frequency doubly-selective (DS) channel. Authors proposed a novel channel estimation system based on distributed compressive sensing (DCS) theory. The special decoupling form originating from a novel sparse pilot pattern is designed for such estimation, which results in an ICI-free structure and enables the DCS application to make joint

estimation of these vectors accurately. Combined with a smoothing treatment process, the proposed scheme can achieve significantly higher estimation accuracy than the existing ones, although with a much smaller number of pilot subcarriers. Results confirm its performance merits.

In 2012, The-Hanh Pham and Ying-Chang Liang, presented an OFDM-based system under unknown narrow-band interference. Authors proposed an iterative receiver to jointly estimate the channel information, which consists of channel coefficients and noise-plus-interference variances of each sub-carrier, and detect the transmitted signals. The simulation outcomes show that the proposed receiver provides an extremely close bit-error-rate (BER) to that of the case where perfect channel information is available at the receiver. The mean-square-error (MSE) of the estimated parameters given by the proposed algorithm achieves improvement in performance [2].

In 2011, M.K. Gupta, S Shrivastava, and Raghuvanshi, presented the channel estimation is a process of characterizing the effect of the transmission channel on the input signal. In this research work authors compare the performance of Least Square (LS) and Linear Minimum Mean Square Error (LMMSE) channel estimation technique for Wavelet based OFDM system. The channel estimation based on block type pilot arrangement is performed by sending pilots at every sub-channel and using this estimation for a specific number of following symbols. In this paper they used wavelet transform instead of fast Fourier transform (FFT), which have more bandwidth efficiency, less prone to Doppler shift [5].

In 2010, LI Yuhong, GE Ning and LU Jianhua proposed a Single carrier Ultra-wideband (SC-UWB) transmission scheme with MSE channel estimation. Mainly, a Direct sequence Binary phase shift keying (DSBPSK) has been used by this scheme to support high to moderate data rate applications that differentiates from Multi-band OFDM and Impulse radio (IR) UWB systems. Simulation results have demonstrated that, with base band time-frequency signal processing algorithms, the BER performance of the SC-UWB system over the IEEE 802.15.3a UWB Channel model III (CM3) is about 10-5 at Eb/N0 of 10.5dB. Also, the SC-UWB system exhibits a low power consumption and low implementation complexity because of its low Peak-to-average ratio (PAR) and modulation characteristics. It is clear that the proposed scheme is a good candidate for short range communications, particularly for low power and low cost applications for e.g., mobile terminals [12].

III. BASIC OFDM

Let $\{s_{n,k}\}_{k=0}^{N-1}$ with $E|s_{n,k}|^2 = \sigma_s^2$ be the complex symbols transmitted at nth OFDM block. Then OFDM modulated signal can be represented by

$$s_n(t) = \sum_{k=0}^{N-1} s_{n,k} e^{j2\pi k \Delta f t}$$

where $0 \leq t \leq T_s$. T_s, Δf and N are the symbol duration, the sub-channel space and the number of sub- channels of OFDM signals, respectively. In order to demodulate the signal at receiver, the symbol duration must be long enough such that $T_s \Delta f = 1$. This is known as the orthogonal condition because it makes the $e^{-j2\pi k \Delta f t}$ orthogonal to each other for different values of k. The transmitted symbols $s_{n,k}$ can be detected at the receiver from this condition as

$$s_{n,k} = \frac{1}{T_s} \int_0^{T_s} s_n(t)\, e^{-j2\pi k \Delta f t}\, dt$$

if there is no channel distortion. The sampled version of s(t) can be expressed as

$$s_n\left(m\frac{T_s}{N}\right) = \sum_{k=0}^{N-1} s_{n,k}\, e^{j2\pi k \Delta f m \frac{T_s}{N}} = \sum_{k=0}^{N-1} s_{n,k}\, e^{j\frac{2\pi m k}{N}}$$

which is actually the inverse discrete Fourier transform of the transmitted symbols $\{s_{n,k}\}_{k=0}^{N-1}$ and can be calculated by Fast Fourier Transform. Demodulation at the receiver can be easily performed using Discrete Fourier Transform instead of an integral as seen from the equation. A cyclic prefix or guard interval, for OFDM, is critical to avoid inter block interference caused due to delay

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

spread of the wireless channels and these are usually inserted between adjacent OFDM blocks.

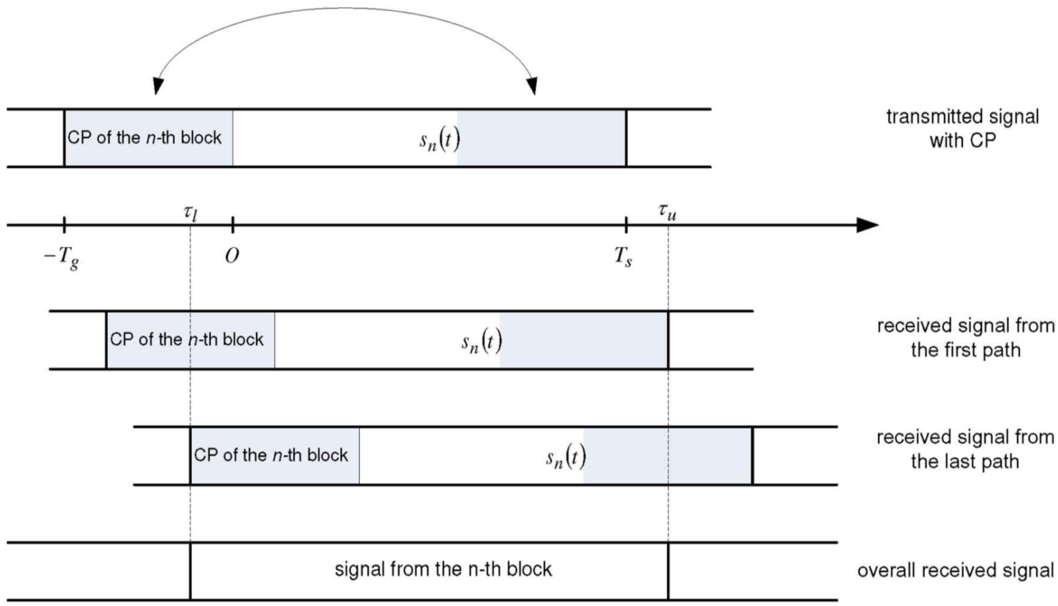

Fig. 1: Function of Cyclic Prefix

Figure 1 shows the function of Cyclic Prefix. Without CP, length of an OFDM symbol is T_s and with CP, it is extended to T = $T_g + T_s$ and can be expressed as

$$\tilde{s}_n(t) = \sum_{k=0}^{N-1} s_{n,k} e^{j2\pi k\Delta f t}$$

where $-T_g \leq t \leq T_s$. This is called CP because $\tilde{s}_n(t)=s_n(t+T_s)$ for $-T_g \leq t \leq 0$.

Also, the impulse response can be expressed by [9]

$$h(t) = \sum_i \gamma_i \delta(t-\tau_i)$$

where τ_i and γ_i are the delay and complex amplitude of ith path, respectively. The received signal can be expressed as

$$x_n(t) = \sum_i \gamma_i \, \bar{s}_n(t-\tau_i) + n(t)$$

where n(t) is additive white Gaussian noise at receiver. It is clear from the figure1 that $x_n(t)$ includes the signal component of nth OFDM block when $\tau_l \leq t \leq \tau_u$, where $\tau_l = -T_g + \tau_M$, $\tau_u = T_s + \tau_m$, $\tau_m = min_i\{\tau_i\}$ and $\tau_{M=} max_i\{\tau_i\}$. Otherwise, the received signal includes the signal from different OFDM blocks.

If $\tau_l \leq 0$ and $\tau_u \geq T_s$, then

$$x_{n,k} = \frac{1}{T_s}\int_0^{T_s} x_n(t)\, e^{-j2\pi f_k t}\, dt$$

Volume 3 Issue V, May 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

$$x_{n,k}=\frac{1}{T_s}\int_0^{T_s}\{\sum_i \gamma_i\,\bar{s}_n(t-\tau_i)+n(t)\}\,e^{-j2\pi f_k t}\,dt$$

$$x_{n,k}=H_k s_{n,k}+n_k$$

for $0\leq k\leq N-1$ and all n. H_k denotes the frequency response at kth sub channel and is defined as

$$H_k=\sum_i \gamma_i e^{-2\pi k\Delta f\tau_i}$$

and n_k is the impact of additive white Gaussian noise and it is defined as

$$n_k=\frac{1}{T_s}\int_0^{T_s} n(t)e^{-j2\pi f_k t}dt$$

The impact of the channel is only a multiplicative distortion at each sub-channel of OFDM system. Due to this, signal detection in OFDM is very simple and this is one of the reason why this technique is popular now-a-days.

IV. CHANNEL ESTIMATION

Channel estimation is used to obtain the channel state information to know the channel properties. In OFDM, the channel can be estimated by using the training symbol at both side of the transmitter and receiver and these symbols are called pilots.

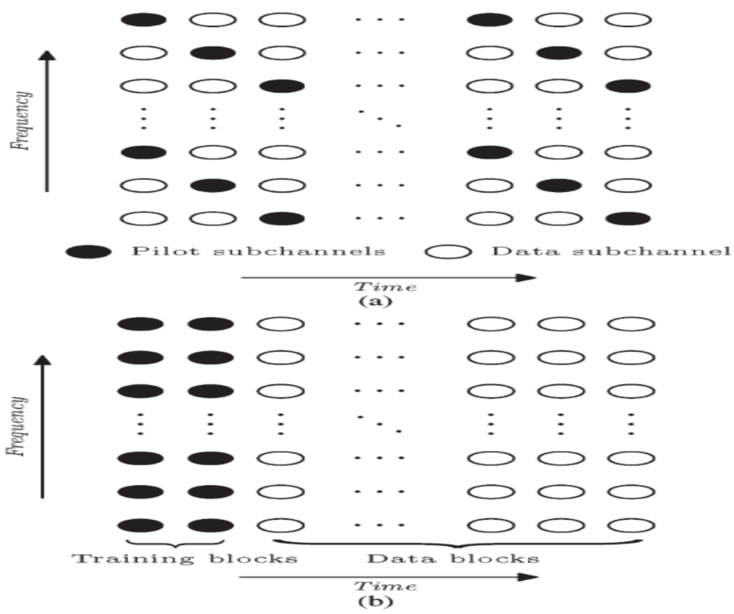

Fig. 2: Typical training blocks and comb pilots. (a)Comb pilots. (b)Preamble

The performance of channel estimation depends on the location, the number and the power of pilot symbols inserted into the blocks of OFDM. The CSI corresponding to the pilot sub-channels is estimated first. After that, CSI corresponding to the data bearing sub channels is obtained from interpolation. This is known as pilot aided channel estimation (PACE) [14]-[16]. In addition to interleaving the training symbols and informative symbols by such frequency division multiplexing, they might also get superimposed, and can be regarded as special form of pilots [15]. This kind of training symbols are known as superimposed pilots that were proposed for phase synchronization and they were originally called spread spectrum pilots [8].

On the other side, all the training symbols may be arranged at the first side of OFDM blocks as shown in Fig. 2(b). In this case, these training blocks are sometimes called preamble. The CSI corresponding to these training blocks are estimated first and those corresponding to subsequent data blocks can be tracked. They can be further improved with the help of demodulated data.This is known as decision-directed channel estimation (DDCE) [18], [19]. The major advantage of this scheme is that they are able to provide high spectrum efficiency by using detected data as pilots.

Channel estimation is a crucial and challenging issue in coherent modulation and its accuracy has a significant impact on the overall performance of communication system. The channel estimation in MIMO systems becomes more complicated in comparison with single-input single-output systems due to simultaneous transmission of signals from different antennas that cause co-channel interference. This issue highlights that developing channel estimation algorithm with high accuracy is an essential requirement to achieve the full potential performance of the MIMO-OFDM systems.

At present the channel estimation techniques on the MIMO-OFDM wireless communication system can be roughly classified into the following categories: the least squares algorithm (LS), the linear least mean-square error method (LMMSE), maximum likelihood method (ML) [25], [26] and all kinds of blind (completely blind or half blind) estimation methods. Among them the computational complexity of the least square method is low, and the estimation precision is vulnerable to the noise influence in the transmitting process, using the various channel statistics to modify the least squares estimating values can obtain a degree of performance improvement, but in the actual mobile environment, it is impossible to obtain a more realistic channel statistics information. The Linear least mean-square error method can obtain a good channel parameters estimation precision when the second order statistics of the channel is appropriately estimated approximately, but the realization of the whole estimation algorithm needs to solve the inversion operation of an large matrix whose orders are proportional to the number of the subcarriers and the number of the antennas, therefore the complexity of the system is very high. The maximum likelihood method uses Viterbi algorithm to realize the estimation of the channel response parameters, the needed calculation amount will increase rapidly with the increase of the channel matrix. The blind (or half blind) channel estimation method can improve the frequency utilization of the whole system at the maximum extent, which does not need to (or need only less number of) the pilot expenses, however the realization of the whole estimation algorithm needs a large number of actual transmitted data, and needs to use the iterative calculation method and the convergence rate of the algorithm limits the algorithm applied to the real time-varying wireless mobile environment.

V. MIMO TECHNIQUES IN OFDM

Most of the MIMO techniques are developed for flat fading channels. These techniques are used for diversity gain and capacity improvement. However, multipath will cause frequency selectivity of broadband wireless channels. Therefore, MIMO-OFDM, which has originally been proposed to exploit OFDM to mitigate ISI in MIMO systems, has now turns out to be a very promising choice for future high-data-rate transmission over broadband wireless channels [12], [13].

Basic MIMO-OFDM: A MIMO-OFDM system with M_t transmit antennas and M_r receive antennas is shown in figure 3.

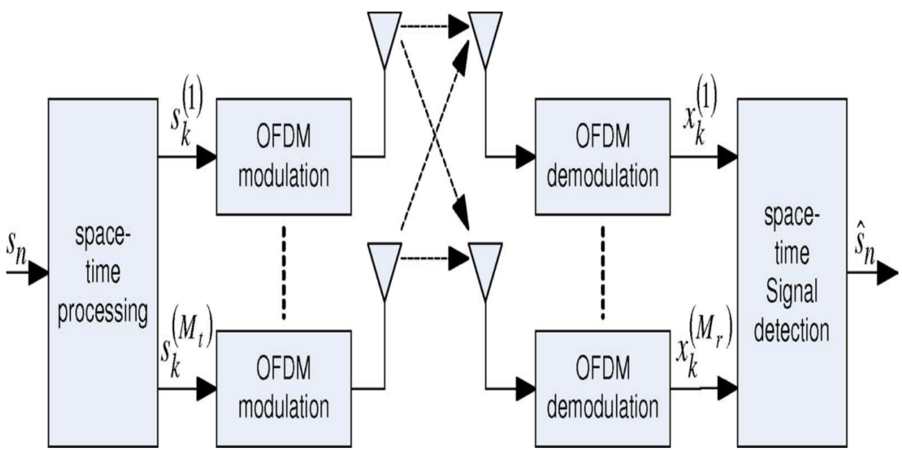

Fig. 3: MIMO-OFDM system

It is clear from the above figure that space time processing converts the data stream $\{s_n\}$ into M_t sub-streams $\{s_k^{(m)}\}$, through STC or simple multiplexing, for OFDM modulation and transmission through different antennas. If only a multipath of wireless channels is considered and the CP is long enough, the demodulated signal at each receive antenna is a superposition of those from different

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

transmit antennas and can be expressed as [13], [20].

$$x_k^{(i)} = \sum_{m=1}^{M_t} H_k^{(i,m)} s_k^{(m)} + n_k^{(i)}$$

for i=1, . . . ,M_r. Here $H_k^{(i,m)}$ denotes the frequency response at the *k*th sub-channel corresponding to the *m*th transmits and *i*th receive antenna, and $n_k^{(i)}$is the impact of channel noise at the *k*th sub-channel of the *i*th receive antenna, that is usually independent of different values of *k* and *i*, Gaussian and with zero mean. This equation can also be expressed in matrix form as

$$x_k = H_k s_k + n_k$$

where x_k, H_k, s_k and n_k, are the received signal vector, channel matrix, transmitted signal vector and noise vector at the *k*th sub-channel, respectively, and these are defined as

$$x_k = \left(x_k^{(1)} \ldots x_k^{(M_r)}\right)^T$$

$$s_k = \left(s_k^{(1)} \ldots s_k^{(M_t)}\right)^T$$

$$n_k = \left(n_k^{(1)} \ldots n_k^{(M_r)}\right)^T$$

$$H_k = \begin{pmatrix} H_k^{(1,1)} & \cdots & H_k^{(1,M_t)} \\ \vdots & \ddots & \vdots \\ H_k^{(M_r,1)} & \cdots & H_k^{(M_r,M_t)} \end{pmatrix}$$

This model can easily be generalized into MU MIMO-OFDM system model by combining several multiple-access technologies, such as OFDMA, TDMA, CDMA, or space-division multiple access [21]. For MU MIMO-OFDM systems, MU interference (MUI) also degrades performance.

VI. APPLICATIONS

OFDM is the most promising technique ofthis era. This technique is being adopted by many wireless standards that include terrestrial digital video broadcasting and European digital audio broadcasting in China. These also include wireless local area network, wireless metropolitan networks, wireless personal area networks etc. In addition to this, it has been approved by many IEEE standard groups that include IEEE 802.15.3a, IEEE 802.16d/e and IEEE 802.11a/g/n. Currently, OFDMA is being investigated as one of the most promising radio transmission techniques for Long Term Evolution (LTE) of the 3rd Generation Partnership Project (3GPP), International Mobile Telecommunications—Advanced Systems.

VII. CONCLUSION

This OFDM related technique has been introduced over 40 years ago. This technique has been chosen for various current and future communication systems all over the world in many applications. It can be used for high speed data transmission. In this paper, we have discussed OFDM for wireless communications. In OFDM, channel estimation is used for suppressing the interference and ensuring signal detection. Due to accurate channel estimation, OFDM is able to use the coherent detection for 3-dB signal to Noise ratio (SNR) gain over differential detection. We have also summarized the MIMO techniques for OFDM and wireless applications of OFDM. MIMO transmission greatly improves the capacity of wireless communications. Since OFDM can convert a frequency selective channel into parallel flat fading channels, it is natural to combine MIMO with OFDM to provide high rate data transmission over frequency selective channels. However, channel estimation in MIMO-OFDM systems are challenging tasks due to the presence of multiple transmits antennas.

VIII.ACKNOWLEDGMENT

The authors are thankful to Mr. Aseem Chauhan (Additional President, RBEF and Chancellor AUR, Jaipur), Maj. General K. K. Ohri (AVSM, Retd.) Pro-VC & Director General, Amity University, Uttar Pradesh Lucknow, Prof. S. T. H. Abidi (Director ASET, Lucknow Campus), Brig. U. K. Chopra (Director AIIT & Dy. Director ASET), Prof O. P. Singh (HOD, Electrical & Electronics) and Prof. N. Ram (Dy. Director ASET) for their motivation, kind cooperation, and suggestions.

REFERENCES

[1] William Y. Zou and Yiyan Wu, “COFDM: an overview”, IEEE Transactions on Broadcasting, vol.41, no.1, pp. 1-8, March 1995.

[2] Neil Weste and David J. Skellern, “VLSI for OFDM”, IEEE Magazine on Communications, pp. 127-131, October 1998.

[3] “CommsDesign – Enabling fast wireless networks with OFDM,”http://www.commsdesign.com/story/OEG20010122S0078, Accessed May 1, 2003.

[4] Dulal Haque, Rubaiyat Yasmin, Shaikh Enayat Ullah and M.A.F.M. Rashidual Hasan, “Performance evaluation of a concatenated interleaved FEC scheme based OFDM system”, Asian Journal of Information Technology, pp. 277-280, 2008.

[5] Ahmed Sghaier, Shawki Areibi and Bob Dony, “A pipelined implementation of OFDM transmission on reconfigurable platforms”, IEEE Canadian conference on Electrical and Computer Engineering, pp. 801-804, May 2008.

[6] White Paper: High-speed wireless OFDM communication systems, Wi-LAN Inc., February 2001.

[7] J. J. Beek, O. Edfors, M. Sandell, S. K. Wilson, and P. O. Börjesson, “On channel estimation in OFDM systems,” in Proc. IEEE Veh. Technol. Conf., Jul. 1995, vol. 2, pp. 815–819.

[8] D. Makrakis and K. Feher, “A novel pilot insertion–extraction technique based on spread spectrum affine precoders for reliable communications,” in Proc. Technicon, Miami, FL, 1987.

[9] R. Steele, Mobile Radio Communications. New York: IEEE Press, 1992.

[10] M. Morelli and U. Mengali, “A comparison of pilot-aided channel estimation methods for OFDM systems,” IEEE Trans. Signal Process, vol. 49, no. 12, pp. 3065–3073, Dec. 2001.

[11] P. Hoeher, S. Kaiser, and P. Robertson, “Two-dimensional pilot symbol-aided channel estimation by Wiener filtering,” in Proc. IEEE Int. Conf. Acoust., Speech Signal Process., Apr. 1997, vol. 3, pp. 1845–1848.

[12] G. G. Raleigh and J. M. Cioffi, “Spatio-temporal coding for wireless communications,” IEEE Trans. Commun., vol. 46, no. 3, pp. 357–366, Mar. 1998

[13] Y. (G.) Li, N. Seshadri, and S. Ariyavisitakul, “Channel estimation for OFDM systems with transmitter diversity in mobile wireless channels, IEEE J. Sel. Areas Commun., vol. 17, no. 3, pp. 461–471, Mar. 1999

[14] M. Morelli and U. Mengali, “A comparison of pilot-aided channel estimation methods for OFDM systems,” IEEE Trans. Signal Process, vol. 49, no. 12, pp. 3065–3073, Dec. 2001.

[15] P. Hoeher, S. Kaiser, and P. Robertson, “Two-dimensional pilot symbol-aided channel estimation by Wiener filtering,” in Proc. IEEE Int. Conf. Acoust., Speech Signal Process., Apr. 1997, vol. 3, pp. 1845–1848.

[16] Y. (G.) Li, “Pilot-symbol-aided channel estimation for OFDM in wireless systems,” IEEE Trans. Veh. Technol., vol. 49, no. 4, pp. 1207–1215, Jul. 2000.

[17] L. Tong, B. M. Sadler, and M. Dong, “Pilot-assisted wireless transmissions: General model, design criteria, and signal processing,” IEEE Signal Process. Mag., vol. 21, no. 6, pp. 12–25, Nov. 2004.

[18] O. Edfors, M. Sandell, J. Beek, S. K. Wilson, and P. O. Borjesson, “OFDM channel estimation by singular value decomposition,” IEEE Trans. Commun., vol. 46, no. 7, pp. 931–939, Jul. 1998.

[19] J. J. Beek, O. Edfors, M. Sandell, S. K. Wilson, and P. O. Börjesson,“On channel estimation in OFDM systems,” in Proc. IEEE Veh. Technol.Conf., Jul. 1995, vol. 2, pp. 815–819.

[20] Y. (G.) Li and G. Stüber, Orthogonal Frequency Division Multiplexing for Wireless Communications. Boston, MA: Springer-Verlag, Jan. 2006

[21] M. Jiang and L. Hanzo, “Multiuser MIMO-OFDM for next-generationwireless systems,” Proc. IEEE, vol. 95, no. 7, pp. 1430–1469, Jul. 2007.

[22] P. Hoeher and F. Tufvesson, “Channel estimation with superimposedpilot sequence,” in Proc. IEEE Globe Telecommun. Conf., Sep. 1999, vol. 4, pp. 2162–2166.

[23] B. Farhang-Boroujeny, “Pilot-based channel identification: Proposal for semi-blind identification of communication channels,” Electron. Lett., vol. 31, no. 13, pp. 1044–1046, Jun. 1995.

[24] F. Mazzenga, “Channel estimation and equalization for M-QAM transmissionwith a hidden pilot sequence,” IEEE Trans. Broadcast., vol. 46, no. 2, pp. 170–176, Jun. 2000.

[25] A. van Zelst and T. C. W. Schenk. “Implementation of a MIMO OFDM-based wireless LAN system,” IEEE Trans. Signal Process., vol. 52, pp. 483–494, 2004.

[26] G. L. Stüber, J. R. Barry, S. W. Mclaughlin, Y. Li, M. A. Ingram, and T. G. Pratt. “Broadband MIMO-OFDM wireless communications”, Proc. IEEE, vol. 92, no. 2, pp.271–294, 2004