Review on OFDM a Brief Survey

Vishal Pasi*, Prateek Nigam, Dr. Vijayshri Chaurasia****

* Digital Communication Scholar RKDF Ist Bhopal
** Electrical Engineering Scholar AISECT University Bhopal

Abstract- Orthogonal frequency-division multiplexing (OFDM) effectively mitigates intersymbol interference (ISI) caused by the delay spread of wireless channels. Therefore, it has been used in many wireless systems and adopted by various standards. In this paper, we present a comprehensive survey on OFDM for wireless communications. We address basic OFDM and related modulations, as well as techniques to improve the performance of OFDM for wireless communications, including channel estimation and signal detection, time- and frequency-offset estimation and correction, peak-to-average power ratio reduction PAPR, intercarrier interference (ICI) and multiple-input–multiple-output (MIMO) techniques. We also describe the applications of OFDM in current systems and standards.

Index Terms- Channel estimation , frequency-offset estimation, intercarrier interference (ICI), multicarrier (MC), multiple input–multiple-output (MIMO) orthogonal frequency-division multiplexing (OFDM), peak-to-average power reduction, timeoffset estimation, wireless standards.

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is a multicarrier multiplexing technique, where data is transmitted through several parallel frequency sub channels at a lower rate. It has been popularly standardized in many wireless applications such as Digital Video Broadcasting (DVB), Digital Audio Broadcasting (DAB), High Performance Wireless Local Area Network (HIPERLAN), IEEE 802.11 (WiFi), and IEEE 802.16 (WiMAX). It has also been employed for wired applications as in the Asynchronous Digital Subscriber Line (ADSL) and power-line communications.

The ever increasing demand for very high rate wireless data transmission calls for technologies which make use of the available electromagnetic resource in the most intelligent way. Key objectives are spectrum efficiency (bits per second per Hertz), robustness against multipath propagation, range, power consumption and implementation complexity. These objectives are often conflicting, so techniques and implementations are sought which offer the best possible trade off between them. The Internet revolution has created the need for wireless technologies that can deliver data at high speeds in a spectrally efficient manner. However, supporting such high data rates with sufficient robustness to radio channel impairments requires careful selection of modulation techniques. Currently, the most suitable choice appears to be OFDM (Orthogonal Frequency Division Multiplexing). One of the main reasons to use OFDM is to increase the robustness against frequency selective fading or narrowband interference. In a single carrier system, a single fade or interferer can cause the entire link to fail, but in a multicarrier system, only a small percentage of the subcarriers will be affected. Error correction coding can then be used to correct for the few erroneous subcarriers. The concept of using parallel data transmission and frequency division multiplexing was published in the mid-1960s [1, 2].

OFDM is a special case of multi-carrier modulation. Multi-carrier modulation is the concept of splitting a signal into a number of signals, modulating each of these new signals to several frequency channels, and combining the data received on the multiple channels at the receiver [3]. In OFDM, the multiple frequency channels, known as sub-carriers, are orthogonal to each other [4].

II. BASIC OFDM

Let $\{sn,k\}^{N-1}_{k=0}$ with $E|s_{n,k}|^2 = \sigma^2_s$ be the complex symbols to be transmitted at the *n*th OFDM block, then the OFDM modulated signal can be represented by

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

where *Ts*, Δ*f*, and *N* are the symbol duration, the sub-channel space, and the number of sub-channels of OFDM signals, respectively. For the receiver to demodulate the OFDM signal, the symbol duration should be long enough such that $Ts\Delta f = 1$, which is also called the orthogonal condition since it makes $e^{-j2\pi k\delta ft}$ orthogonal to each other for different *k*. With the orthogonal condition, the transmitted symbols $s_{n,k}$ can be detected at the receiver by

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

if there is no channel distortion.

The sampled version of the baseband OFDM signal *s*(*t*) in (1) can be expressed as

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

which is actually the inverse discrete Fourier transform (IDFT) of the transmitted symbols $\{sn,k\}^{N-1}_{k=0}$ and can efficiently be calculated by fast Fourier transform (FFT). It can easily be seen that demodulation at the receiver can be performed using DFT instead of the integral in (5).

A cyclic prefix (CP) or guard interval is critical for OFDM to avoid interblock interference (IBI) caused by the delay spread of wireless channels. They are usually inserted between adjacent OFDM blocks.

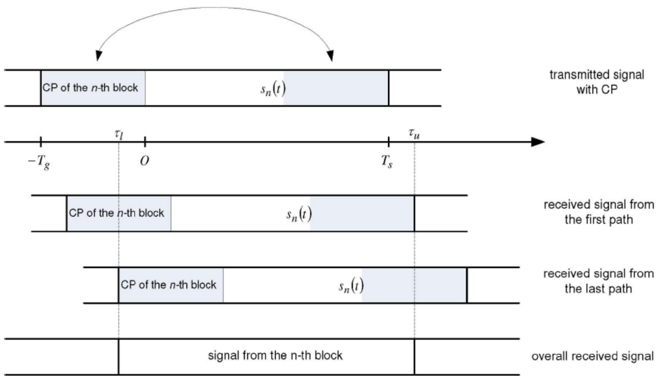

Fig. 1 shows the function of the CP.

Fig. 1 shows the function of the CP Without the CP, the length of the OFDM symbol is *Ts*, as shown in (1). With the CP, the transmitted signal is extended to $T = Tg + Ts$ and can be expressed as

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

It is obvious that ˜*sn*(*t*) = *sn*(*t* + *Ts*) for −*Tg* ≤ *t* ≤ 0, which is why it is called the CP.
The impulse response of a wireless channel can be expressed by [6].

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

where *τi* and *γi* are the delay and the complex amplitude2of the *i*th path, respectively. Then, 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*) represents the additive white Gaussian noise (AWGN) at the receiver. As demonstrated in Fig. 1, *xn*(*t*) consists of only the signal component from the *n*th OFDM block when *τl* ≤ *t* ≤ *τu*, where *τl* = −*Tg* + *τM*, *τu* = *Ts* + *τm*, *τm* = min*i{τi}*, and *τM* = max*i{τi}*; otherwise, the received signal consists of signals from different OFDM blocks.
If *τl* ≤ 0 and *τu* ≥ *Ts*, then

$$\begin{aligned} x_{n,k} &= \frac{1}{T_s}\int_0^{T_s} x_n(t) e^{-j2\pi f_k t} dt \\ &= \frac{1}{T_s}\int_0^{T_s} \left\{ \sum_i \gamma_i \bar{s}_n(t-\tau_i) + n(t) \right\} e^{-j2\pi f_k t} dt \\ &= H_k s_{n,k} + n_k \end{aligned}$$

for 0 ≤ *k* ≤ *N* − 1 and all *n*, where *Hk* denotes the frequency response of the wireless channel at the *k*th subchannel and is defined as

$$H_k = \sum_i \gamma_i e^{-j2\pi k \Delta f \tau_i}$$

It can be proved that *nk* are *independent identically distributed* complex circular Gaussian with zero mean and variance *σ*2*n*. With *Hk*, transmitted symbols can be estimated. For single carrier systems, the received signal is the convolution of the transmitted sequences or symbols and the impulse response of wireless channels in addition to AWGN, whereas the impact of the channel is only a multiplicative distortion at each sub channel
for OFDM systems, which makes signal detection in OFDM systems very simple and is also one of the reasons why OFDM is very popular nowadays.

III. CHANNEL ESTIMATION

In OFDM systems, CSI can be estimated using training symbolsknown at both the transmitter and the receiver. The training symbols may be inserted at different subchannels of different OFDM blocks, as shown in Fig. 2(a). These training symbols are more often called pilots. The CSI corresponding to the pilot subchannels is first estimated, and then, that corresponding to the data-bearing subchannels is obtained by interpolation.

This is called pilot-aided channel estimation (PACE) [7]–[9].

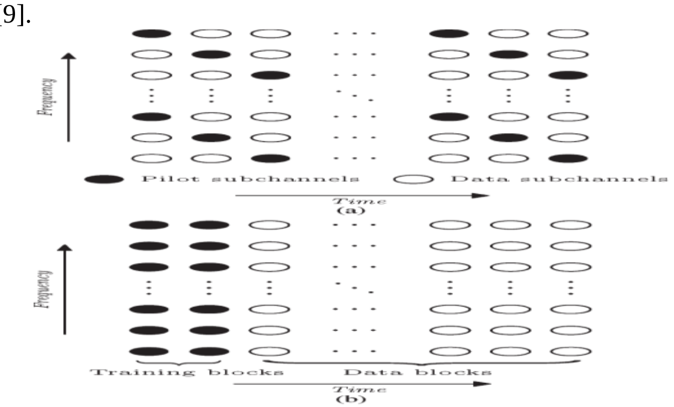

Fig. 2. Typical training blocks and comb pilots. (a) Comb pilots. (b) Preamble.

In addition to interleaving the training symbols and the informative symbols by such frequency-division multiplexing, they may also be superimposed, which can be regarded as a special form of pilots [10]. This kind of training symbols are usually called superimposed pilots, which were first proposed to phase synchronization and originally called spread-spectrum pilots [48] and were later applied for channel estimation. On the other hand, all training symbols may be arranged at the first (or couple of) OFDM blocks, as shown in Fig. 2(b). The training blocks in this case are sometimes called preamble. The CSI corresponding to the training blocks are first estimated, and that corresponding to the subsequent data blocks can be tracked and further improved with the help of the demodulated data. This is called decision-directed channel estimation (DDCE) [11], [12].

1)*Pilot-Aided Channel Estimation:* Using pilot tones to estimate channel coefficients was first proposed in [13]. The two major issues of pilot-aided channel estimation are pilot design and interpolation.

2) *DDCE:* For DDCE, CSI at the preamble block(s) is first estimated and then used to demodulate and detect the symbols at the next data block. CSI can be tracked by using detected symbols or data, either hard decision or soft decision, as shown in [14]–[16]. For systems with error-correction coding, redundancy in coding can be exploited by iteratively performing soft symbol decision and channel estimation [15], [17].

3) *Comparison:* DDCE methods fit in systems operating in static or quasi-static channels. It particularly fits in systems in a slot transmission mode, such as wireless cellular systems. Initial channel estimation is provided with the training blocks and is then followed by tracking or prediction. Their major advantage is that they are able to provide high spectrum efficiency by using detected data as pilots. However, error propagation will be induced in fast fading channels [18].

IV. TIME ANDFREQUENCY VARYING IMPAIRMENT MITIGATION

In this section, we will address time- and frequency-varying impairment mitigation. Frequency-varying impairments are caused by the timing offset between the transmitter and the receiver or the delay spread due to a multipath of wireless channels. As shown in (5), the impact of delay spread is a multiplicative channel distortion on the demodulated signal if the CP or guard interval is long enough, which can easily be mitigated once CSI is estimated. The impact of timing offset is much simpler than that of delay spread. If the timing offset τ is less than the CP, then it will cause a phase rotation of $2\pi k\Delta f\tau$ to the symbol at the kth subchannel [4]. If the timing offset exceeds the CP, then IBI will be generated, in addition to the phase rotation. The phase rotation due to the timing offset is different for different subchannels. This property can be exploited to estimate the timing offset. We will address how to estimate the timing offset and compensate for its impact later on in this section.

1) ***Timing-Offset Estimation and Correction:*** The timing offset can be estimated with pilot- and nonpilot-aided techniques. After the timing offset is estimated, its integer part, which is a multiple of the sampling interval, is used to adjust the starting position of the FFT window, and its (residual) fractional part will generate a phase offset and can be compensated at each subchannel when we cancel the impact of the delay spread of wireless channels [16].

2) ***Frequency-Offset Estimation and Correction**:* From the perspective of its impact and signal processing, the CFO can be divided into integer and fractional parts. The integer part of the CFO is a multiple of the subchannel space Δf, which will cause a symbol or subchannel shift, that is, the transmitted symbol in one subchannel is shifted to another at the receiver. The fractional part results in the loss of orthogonality among subchannels and generates ICI. Once the CFO is estimated, its impact can completely be canceled in the time domain by multiplying the received signal $x(t)$ by the frequency shift factor $e{-}j2\pi\delta ft$.[19]

3) ***Mitigation of ICI Caused by the Doppler Spread**:* ICI may be caused by the CFO, phase noise, timing offset, and Doppler spread [20], [21], [22], [23]. However, ICI induced by the first three impairments can completely be compensated or corrected. Since the Doppler spread or shift is random, we can only mitigate its impact. The existing ICI mitigation techniques include frequency equalization, ICI self-canceling, time-domain windowing, coding, extanded kalman filter, unscaned kalman filter etc.

As we can see from (8), ICI in the frequency domain in OFDM systems is similar to ISI in the time domain in singlecarrier systems. Consequently, those approaches dealing with ISI in single-carrier systems can immediately be used here. It is well known that matrix inversion is required to calculate the coefficients of an equalizer. To reduce its high complexity, various methods have been developed. In [24], the channel matrix is partitioned into block diagonal matrices by exploiting the fact that the frequency response within a symbol duration will linearly vary with time when the duration of an OFDM symbol is much less than the channel coherence time. In [25], a time domain successive interference cancellation (SIC) detector is presented to remove ICI, which is similar to SIC widely used in multiuser detection.

***4) PAPR Reduction**: As* indicated before, the OFDM signal has a large PAPR. A traditional method dealing with the large PAPR is to back off the operating points of nonlinear power amplifiers; however, it severely reduces the efficiency of the power amplifiers. Therefore, by exploiting the special characteristics of the OFDM signal, various approaches have been proposed to cope with the issue. They include clipping and filtering [26], [27], selected mapping (SLM) [28]–[30], partial transmit sequence (PTS) [31], etc. To reduce the PAPR of an OFDM signal, a clipper can directly be used. However, such nonlinear processing will cause in-band distortion and out-of-band radiation . If the out of band interference is filtered out, then the PAPR of the clipped signal will regrow [26]. Therefore, if clipping and filtering are repeated several times, then both the PAPR and out-of-band radiation will be reduced, as proposed in [27]. However, the clipping and filtering techniques are unable to remove the inband distortion. The technique is improved in [31] by limiting the distortion of each subchannel.

V. OFDM-RELATED MODULATION AND ACCESS TECHNIQUES

There are many other modulation or access techniques related to OFDM. MC modulation is a general category of modulation to which OFDM belongs. A single-carrier system with frequency-domain equalization (SC-FDE) and energy spreading transform (EST)-based modulation are two block transmission schemes that exploit the CP to mitigate the delay spread of wireless channels, which share the same spirit as OFDM. Furthermore, based on OFDM, many access techniques have been developed. MC-CDMA and OFDM access (OFDMA) are two of the examples. In this section, we will briefly describe MC modulation, SC-FDE, EST-based modulation, MC-CDMA, and OFDMA.

VI. MIMO TECHNIQUES IN OFDM

MIMO techniques or space–time processing can be used in wireless communications for diversity gain and capacity improvement [32]–[33]. Recent books [34]–[35] have given a comprehensive introduction of MIMO techniques. Here, we focus on special issues when MIMO techniques are used with OFDM. Most of MIMO techniques are developed for flat fading channels. 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, turns out to be a very promising choice for future high-data-rate transmission over broadband wireless channels. The earliest work in MIMO-OFDM can be found in [36] and [37]. Since that time, MIMO-OFDM has become a very popular area in wireless communications, particularly in the past several years [38]. In this section, we only very briefly provide an introduction of the topic.

VII. APPLICATIONS

During the past decade, OFDM has been adopted in many wireless communication standards, including European digital audio broadcasting, terrestrial digital video broadcasting, and satellite–terrestrial interactive multiservice infrastructure in China. In addition, OFDM has been considered or approved by many IEEE standard working groups, such as IEEE 802.11a/g/n, IEEE 802.15.3a, and IEEE 802.16d/e.

The applications include wireless personal area networks, wireless local area networks, and wireless metropolitan networks. Currently, OFDMA is being investigated as one of the most promising radio transmission techniques for LTE of the *3rd Generation Partnership Project* (3GPP), International Mobile Telecommunications—Advanced Systems. Before introducing the major features of several OFDM applications, we briefly describe the design guideline of OFDM for wireless communications.

VIII. CONCLUSION

In this paper, we have briefly described OFDM for wireless communications. We start with the basic principle of OFDM and techniques to deal with impairments in wireless systems, including channel estimation, timing- and frequency-offset estimation, ICI mitigation, and PAPR reduction. Then, we introduced related modulation and access schemes, such as OFDM, SC-FDE, EST-based modulation, MC-CDMA, and OFDMA.

We have also summarized the MIMO techniques for OFDM and the wireless applications of OFDM. The OFDM-related technique has been invented over 40 years ago. OFDM for wireless communications has intensively been an active research area in the past 10 years. It is not our intention and is impossible either to provide an exhaustive literature search in the area through this paper. Due to page limit, we do not include performance optimization in OFDM systems, techniques on joint channel, time- and frequency offset estimation, or applications other than wireless.

REFERENCES

[1] Chang R.W, synthesis of band limited orthogonal signal for multichannel data transmission, Bell syst. Tech., Vol. 45, pp.1775-1796, Dec. 1996.

[2] Salzberg, B.R, performance of an efficient parallel data transmission system, IEEE trans. Com., Vol. Com-15, pp. 805-813, Dec. 1967.

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

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

[5] L. J. Cimini, Jr., "Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing," IEEE Trans. Commun., vol. COM-33, no. 7, pp. 665–675, Jul. 1985.

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

[7] 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.

[8] 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.

[9] 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.

[10] 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.

[11] 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.

[12] 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.

[13] R. Negi and J. Cioffi, "Pilot tone selection for channel estimation in a mobile OFDM system," IEEE Trans. Consum. Electron., vol. 44, no. 3, pp. 1122–1128, Aug. 1998.

[14] V. Mignone and A. Morello, "CD3-OFDM: A novel demodulation scheme for fixed and mobile receivers," IEEE Trans. Commun., vol. 44, no. 9, pp. 1144–1151, Sep. 1996.

[15] S. Y. Park, Y. G. Kim, C. G. Kang, and D. E. Kang, "Iterative receiver with joint detection and channel estimation for OFDM system with multiple receiver antennas in mobile radio channels," in Proc. IEEE Global Telecommun. Conf., Nov. 2001, vol. 5, pp. 3085–3089.

[16] S. ten Brink, F. Sanzi, and J. Speidel, "Two-dimensional APP channel estimation and decoding for OFDM systems," in Proc. IEEE Global Telecommun. Conf., Nov. 2000, vol. 2, pp. 741–745.

[17] L. Jarbot, "Combined decoding and channel estimation of OFDM systems in mobile radio networks," in Proc. IEEE Veh. Technol. Conf., May 1997, vol. 3, pp. 1601–1604.

[18] S. Kalyani and K. Giridhar, "Mitigation of error propagation in decision directed OFDM channel tracking using generalized m estimators," IEEE Trans. Signal Process., vol. 55, no. 5, pp. 1659–1672, May 2007.

[19] P. Moose, "A technique for orthogonal frequency division multiplexing frequency offset correction," IEEE Trans. Commun., vol. 42, no. 10, pp. 2908–2914, Oct. 1994.

[20] Y. (G.) Li and L. J. Cimini, "Bounds on the interchannel interference of OFDM in time-varying impairments," IEEE Trans. Commun., vol. 49, no. 3, pp. 401–404, Mar. 2001.

[21] P. Moose, "A technique for orthogonal frequency division multiplexing frequency offset correction," IEEE Trans. Commun., vol. 42, no. 10, pp. 2908–2914, Oct. 1994.

[22] M. Speth, S. A. Fechtel, G. Fock, and H. Meyr, "Optimum receiver design for wireless broad-band systems using OFDM—Part I," IEEE Trans. Commun., vol. 47, no. 11, pp. 1668–1677, Nov. 1999.

[23] M. Russell and G. L. Stüber, "Interchannel interference analysis of OFDM in a mobile environment," in Proc. IEEE Veh. Technol. Conf., Jul. 1995, vol. 2, pp. 820–824.

[24] W. G. Jeon, K. H. Chang, and Y. S. Cho, "An equalization technique for orthogonal frequency-division multiplexing systems in time-variant multipath channels," IEEE Trans. Commun., vol. 47, no. 1, pp. 27–32, Jan. 1999.

[25] Y.-S. Choi, P. J. Voltz, and F. A. Cassara, "On channel estimation and detection for multicarrier signals in fast and selective Rayleigh fading channels," IEEE Trans. Commun., vol. 49, no. 8, pp. 1375–1387, Aug. 2001.

[26] X. Li and L. J. Cimini, "Effects of clipping and filtering on the performance of OFDM," IEEE Commun. Lett., vol. 2, no. 5, pp. 131–133, May 1998.

[27] J. Armstrong, "Peak-to-average power reduction for OFDM by repeated clipping and frequency domain filtering," Electron. Lett., vol. 38, no. 5, pp. 246–247, Feb. 2002.

[28] D. J. G. Mestdagh and P. M. P. Spruyt, "A method to reduce the probability of clipping in DMT-based transceivers," IEEE Trans. Commun., vol. 44, no. 10, pp. 1234–1238, Oct. 1996.

[29] R. W. Bäuml, R. F. H. Fischer, and J. B. Huber, "Reducing the peak average power ratio of multicarrier modulation by selected mapping,"

[30] Proc. Inst. Elect. Eng.—Electron. Lett., vol. 32, no. 22, pp. 2056–2057, Oct. 1996.

[31] P. V. Eetvelt, G. Wade, and M. Thompson, "Peak to average power reduction for OFDM schemes by selective scrambling," Proc. Inst. Elect. Eng.—Electron. Lett., vol. 32, no. 21, pp. 1963–1964, Oct. 1996.

[32] S. H. Müller and J. B. Huber, "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences,"Proc. Inst. Elect. Eng.—Electron. Lett., vol. 33, no. 5, pp. 368–369, Feb. 1997.

[33] S.-K. Deng and M.-C. Lin, "Recursive clipping and filtering with bounded distortion for PAPR reduction," IEEE Trans. Commun., vol. 55, no. 1, pp. 227–230, Jan. 2007.

[34] V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space–time codes for high data rate wireless communication: Performance criteria and code construction," IEEE Trans. Inf. Theory, vol. 44, no. 2, pp. 744–764, Mar. 1998.

[35] J.-C. Guey, M. P. Fitz, M. R. Bell, and W.-Y. Kuo, "Signal design for transmitter diversity wireless communication systems over Rayleigh

[36] fading channels," IEEE Trans. Commun., vol. 47, no. 4, pp. 527–537, Apr. 1999.

[37] E. G. Larsson and P. Stoica, Space–Time Block Coding for Wireless Communications. Cambridge, U.K.: Cambridge Univ. Press, 2003.

[38] E. Biglieri, R. Calderbank, A. Constantinides, A. Goldsmith, A. Paulraj, and V. H. Poor, MIMO Wireless Communications. Cambridge, U.K. Cambridge Univ. Press, 2007.

[39] 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.

[40] 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.

[41] M. Jiang and L. Hanzo, "Multiuser MIMO-OFDM for next-generation wireless systems," Proc. IEEE, vol. 95, no. 7, pp. 1430–1469, Jul. 2007.

AUTHORS

First Author – Vishal Pasi, Digital Communication Scholar RKDF Ist Bhopal, pasivishal@yahoo.in

Second Author – Prateek Nigam, Electrical Engineering Scholar Aisect University Bhopal

Third Author – Dr.Vijayshri Chaurasia,Manit Bhopal.