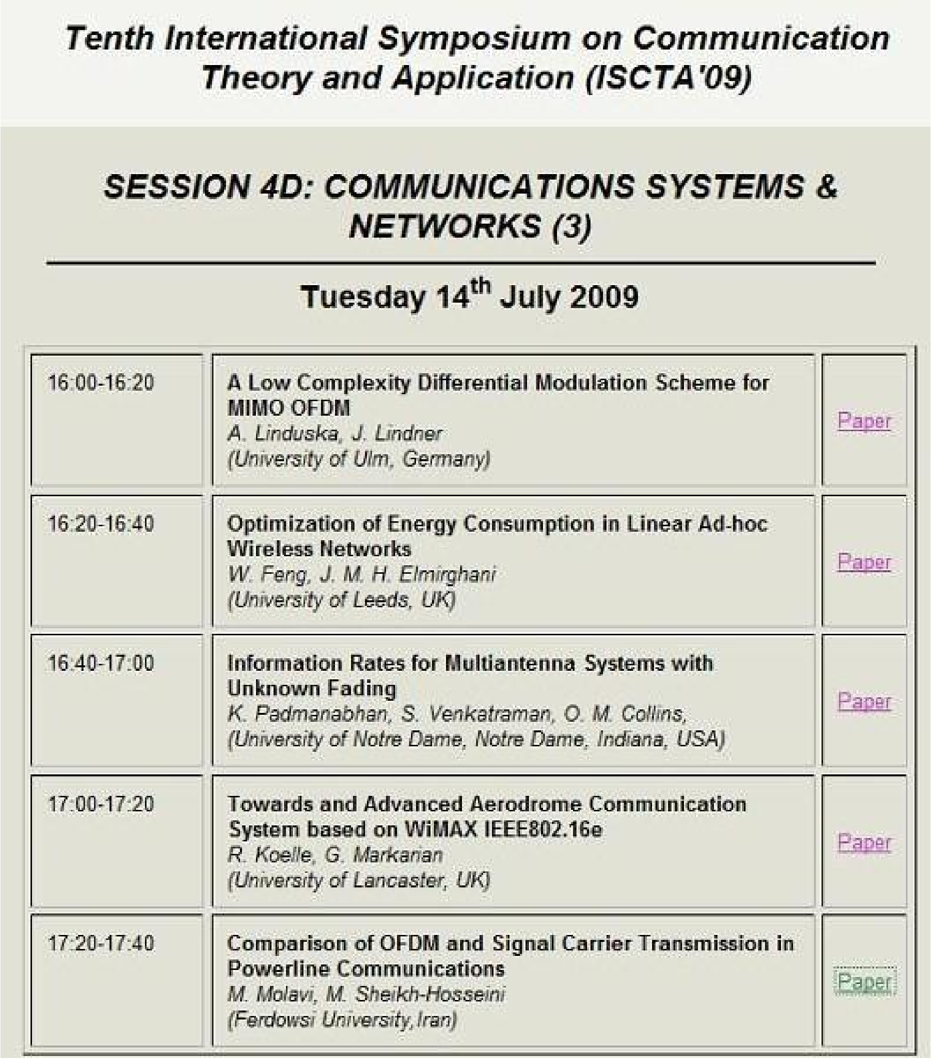

Tenth International Symposium on Communication Theory and Application (ISCTA'09)

SESSION 4D: COMMUNICATIONS SYSTEMS & NETWORKS (3)

Tuesday 14th July 2009

16:00-16:20	**A Low Complexity Differential Modulation Scheme for MIMO OFDM** *A. Linduska, J. Lindner* *(University of Ulm, Germany)*	Paper
16:20-16:40	**Optimization of Energy Consumption in Linear Ad-hoc Wireless Networks** *W. Feng, J. M. H. Elmirghani* *(University of Leeds, UK)*	Paper
16:40-17:00	**Information Rates for Multiantenna Systems with Unknown Fading** *K. Padmanabhan, S. Venkatraman, O. M. Collins,* *(University of Notre Dame, Notre Dame, Indiana, USA)*	Paper
17:00-17:20	**Towards and Advanced Aerodrome Communication System based on WiMAX IEEE802.16e** *R. Koelle, G. Markarian* *(University of Lancaster, UK)*	Paper
17:20-17:40	**Comparison of OFDM and Signal Carrier Transmission in Powerline Communications** *M. Molavi, M. Sheikh-Hosseini* *(Ferdowsi University,Iran)*	Paper

Comparison of OFDM and Single Carrier Transmission in Power Line Communications

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Abstract- **Orthogonal frequency division multiplexing (OFDM) is a suitable candidate for broadband power line communications (PLC). It has shown that the Bit Error Rate (BER) performance of Single Carrier Transmission with Frequency Domain Equalization (SCT-FDE) is close to OFDM in broadband wireless systems. In this paper we investigate the BER performance of SCT employing time and frequency domain decision feedback equalization techniques in PLC. Our simulation results are compared with OFDM systems for different impulsive noise scenarios**

Keywords- ***I*** **Orthogonal frequency division multiplexing, Power line communication, Single carrier transmission, Time and frequency domain decision feedback equalization**

I. INTRODUCTION

Utilizing the power line for data transmission has been the subject of interest for many years. Ability of power lines in high speed data transmission has made them attractive for many different applications like high speed internet transmission services, computer networks design, and etc. However, there are some challenges for communications over power lines such as electromagnetic compatibility issues, noise, attenuation, and multipath propagation [1], [2]. The main reasons causing bit errors in Power Line Communication (PLC) are multipath echoes and impulsive noises [2].

The noises in power line channels are classified into five different categories [3], [4]: Colored background noise, narrowband noise, periodic impulsive noise asynchronous to the mains frequency, periodic impulsive noise synchronous to the mains frequency, and asynchronous impulsive noise. The first three noises are stationary and considered as background noises. The last two noises are time-variant and categorized as impulsive noises [4]. The Power Spectral Density (PSD) of impulsive noise is considerably higher than the background noise at most frequency, causing bit or burst errors [1], [4].

The impedance mismatching in the PLC channels causes multipath signal propagation. Hence, the result is a multipath scenario with frequency selective fading [1], [5]-[6]. Different models for PLC channels have been proposed [5]. Among them, the proposed echo model in [5] has been used most by different researches [1], [2] and [5].

The properties of Orthogonal Frequency Division Multiplexing (OFDM) like its, resistance against multipath effects and impulsive noise, bandwidth efficiency, elimination of Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI), make it attractive for PLC systems [1]. Bit Error Rate (BER) performance of OFDM systems in PLC channels have been considered and simulated in [2], [7]-[9]. The impacts of multipath echoes and impulsive noise on performance of PLC were considered in [2].

OFDM systems suffer from high Peak to Average Power Ratio (PAPR), subcarriers synchronization and complexity [1]. Single Carrier Transmission (SCT) has shown to be an alternative technique for OFDM systems in broadband wireless systems and it has less complexity and lower PAPR compared with OFDM. Lower PAPR in SCT lead to cheaper power amplifier than that is used in OFDM systems [10]-[12]. Fig. 1 shows different categories of SCT systems. Depending on time or frequency domain equalization, SCT is divided into two categories: Single-Carrier Transmission with Time Domain Equalization (SCT-TDE), and Single-Carrier Transmission with Frequency Domain Equalization (SCT -FDE). Each category based on equalization techniques, is classified into two groups: linear and nonlinear. In this work, only the Single Carrier Transmission with Time Domain Decision Feedback Equalization (SCT-TDDFE) and Single Carrier Transmission with Frequency Domain Decision Feedback Equalization (SCT-FDDFE) systems are investigated.

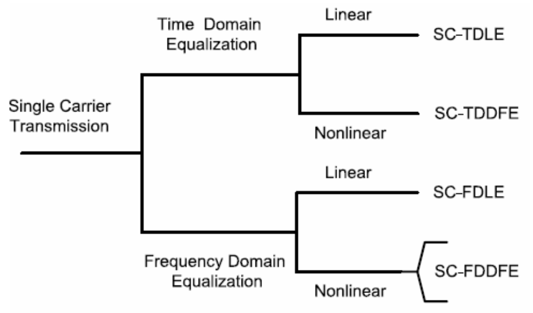

Figure 1. Different categories of single carrier transmission system

There are two types of SCT-FDDFE systems: One type of them was presented in [12], [13] in which the feedforward and backward filters are implemented in the frequency and time domain, respectively. According to results in [12], the BER performance of this system is worse than OFDM system without using channel coding, and it performs close to OFDM in presence of channel coding. Another type of SCT-FDDFE was suggested in [10], [11] and [15], [16] that both feedforward and backward parts are implemented in frequency domain. The BER performance of this system is better than that of OFDM for both coded and uncoded cases [10], [11].

Comparison of OFDM and SCT-FDDFE systems in [10]-[12] has been made in wireless systems. As the characteristics of channel and noise in PLC are different from wireless systems, this paper compares the BER performance of coded SCT-TDE and SCT-FDE systems under the effects of impulsive noise and multipath PLC channel. Then the simulation results are compared with OFDM systems.

This paper is organized as follows; in section II the general structures of OFDM, SCT-FDE and SCT-TDE are presented. Then SCT-FDDFE system is described and coefficients of filters are calculated. In sections III and IV the channel and noise models in PLC systems are described. In section V the simulation results are presented. Finally, section VI contains the conclusions.

II. SYSTEM MODEL

Fig. 2 shows the general transceiver block diagrams of OFDM and SCT-FDE systems. Both OFDM and SCT-FDE systems use Cyclic Prefix (CP) in transmitter for reducing ISI, and utilize one Fast Fourier Transform (FFT), and one Inverse FFT (IFFT) block in there structures. OFDM systems utilize IFFT and FFT blocks in transmitter and receiver side, respectively, and decision was made in frequency domain signal. In SCT-FDE systems both FFT and IFFT operations are used in receiver side. IFFT operation is located between equalization and decision, and spreads the noise over all the samples in time domain. Decision signal in this system is in time domain. While in SCT-TDE systems, the input data is coded and modulated in transmitter, and then enters the channel. At the receiver, the received signal is fed to an equalizer block and decision was made based on equalizer output. CP, FFT, and IFFT blocks do not use in these systems.

A. SC-FDFDE transmission model

Fig. 3 shows the receiver structure of SCT-FDDFE system that both feedforward and backward filters are implemented in frequency domain. In this structure the received signal block enters FFT operation, and then the FFT output signal is multiplied by feedforward coefficients of the equalizer. The resulting signal block feeds to IFFT operation, and the first decision for transmitted signal are made based on the IFFT output signal by threshold detector. When the receiver makes a first decision, the decision block is fed to a feedback filter and an iterative DFE is implemented.

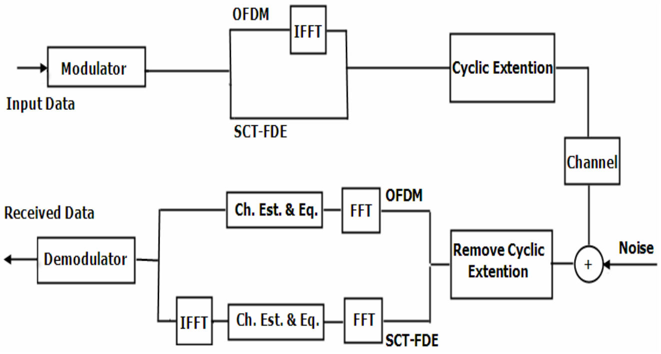

Figure 2. Transceiver block diagram of OFDM and SC-FDE systems

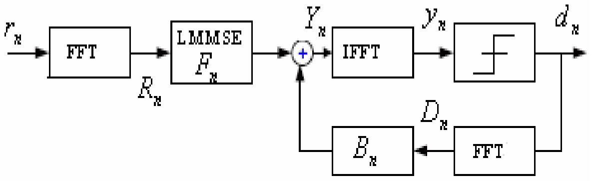

Figure 3. Block diagram of SC- FDDFE system [11]

Optimization of this iterative DFE was presented under the MMSE criterion in [15]. At the l^{th} iteration, the output of DFE $Y_n(l)$ was given by (1):

$$\begin{aligned} & Y_n(l) = F_n(l)R_n + B_n(l)D_n(l-1) \\ & \qquad for \quad n = 1,2,...,N \end{aligned} \tag{1}$$

$R_n(l)$, $F_n(l)$, and $B_n(l)$ are the output signal of FFT, coefficient of the feedforward and Feedback filters at the l^{th} iteration, respectively. $D_n(l-1)$ is the frequency domain decision at the previous iteration. Coefficient sets of the feedforward and Feedback filters for initial equalizer decisions are as follows:

$$F_n(0) = \frac{H_n^*}{\left|H_n\right|^2 + \sigma_n^2 / \sigma_a^2} \quad n = 1,2,...,N \tag{2}$$

$$B_n(0) = 0 \quad n = 1,2,...,N \tag{3}$$

Where σ_n^2 and σ_a^2 are the noise power and the power of the transmitted data symbol, respectively. H is N point FFT of impulsive response $h(t)$, and H_n is n^{th} sample of it. The feedforward and feedback coefficients for the rest of the iterations are calculated by (4) and (5) respectively.

$$F_n(l) = \frac{H_n^*}{\sigma_w^2/\sigma_a^2 + (1-\alpha_{l-1}^2)|H_n|^2} \quad n = 1,2,\ldots,N \tag{4}$$

$$B_n(l) = \alpha_{l-1}[H_n F_n(l) - \frac{1}{N}\sum_{n=1}^{N} H_n F_n(l)] \\ for \quad n = 1,2,\ldots,N \tag{5}$$

Where α_l parameter is decreased exponentially and given by (6):

$$\alpha_l = 1 - \frac{\sqrt{l}}{\sqrt{L}} \tag{6}$$

And L is the total number of iterations.

III. CHANNEL MODEL

Several different models were presented for power line channel in literatures [5]. The channel model in this paper is based on proposed echo model in [5]. The impulse response function of channel can be described as follows [2]:

$$\mathrm{h(t)} = \sum_{\mathrm{m=1}}^{\mathrm{M}} \beta_{\mathrm{m}} \delta(\mathrm{t} - \tau_{\mathrm{m}}) \tag{7}$$

M is the total number of path components in the channel impulse response. β_{m} and τ_m are the amplitude and arrival time of the m^{th} multipath components, respectively. In PLC systems it was assumed that channel response is time-invariant and remains constant during the transmission of data [2], so the parameters β_{m} and τ_{m} are constant in the simulation process and are shown in Table 1.

IV. NOISE MODEL

Noises in power line are categorized into two general groups; background noise and impulsive noise [4]. To analyze the PLC system, background noise is modeled as an Additive White Gaussian Noise (AWGN) w_k with mean zero and variance σ_w^2, and the impulsive noise is modeled as the product of two random processes and is given by (8):

$$i_k = b_k g_k \tag{8}$$

Where g_k is the white Gaussian process with mean zero and variance σ_i^2, and b_k has the Poisson process and is the arrival of the impulsive noise, which means the arrival of the impulsive noise follows the Poisson process with a rate of λ units per second [2]. So in this model each transmitted data symbol is hit independently by an impulsive noise with a probability distribution b_k and random amplitude g_k [15]. The behavior of impulsive noise is researched and modeled in [4]. According to these measurement impulsive noise is classified into three different scenarios, the first scenario was captured during the evening hours in a transformer substation in an industrial area and is named “heavily disturbed” scenario, the second is “medium disturbed” scenario that was recorded in a transformer substation in a residential area with detached and terraced houses, and the third scenario was recorded during nighttime in an apartment located in a large building, is “weakly disturbed” scenario [4]. The parameters of three impulsive noise scenarios are presented in Table 2. IAT is the inter-arrival time of the impulsive noise, which is the reciprocal of the arrival rate λ, and T_{noise} is he average impulsive noise duration time. The inter-arrival time is the distance between two impulsive events.

V. SIMULATION RESULTS

Our simulation results of the BER performance of OFDM, SCT-TDDFE and SCT-FDDFE systems in PLC for coded and uncoded cases, under the effects of AWGN noise, weakly, medium and heavily disturbed impulsive noise scenarios, are presented. In this paper similar to [2], the impulsive noise to AWGN power ratio Γ is assumed to be constant and equal to 20dB. The BER performance curve versus the average bit energy to the average AWGN noise power E_b / N_0 has been calculated. BPSK Modulation in OFDM subcarriers and single carrier systems with 1/2 rate convolution coding and hard decision viterbi decoding have been employed. In Fig. 4 the BER performances of OFDM, SCT-TDDFE and SC-FDDFE systems are compared in presence of AWGN noise only. In Figs. 5, 6 and 7 besides AWGN noise, the impulsive noise with weak, medium and heavy disturbance are also considered. In these Figs. no channel coding has been employed. From Fig. 4 it is seen that when only AWGN noise exists, the BER performance of SCT-FDDFE is better than OFDM at all E_b / N_0. However, for AWGN plus impulsive noise in Figs. 5, 6 and 7, the results show that when the disturbance of impulsive noise is weak, SCT-FDDFE is superior to OFDM at all E_b / N_0. Also, when the disturbance of impulsive noise is medium or heavy, SCT-FDDFE performs better than OFDM at E_b / N_0 lower than 22dB. For all cases in Figs. 4, 5, 6 and 7 results show that the BER performance of OFDM is better than SCT-TDDFE at all E_b / N_0.

Table 1
PARAMETERS OF THE IMPULSE RESPONSE OF PLC MULTIPATH CHANNEL [2]

L	β_m	τ_m (μs)
1	0.2	0
2	0.1	0.4
3	0.02	0.6
4	0.01	0.7

TABLE 2
PARAMETERS OF THE IMPULSIVE NOISE SCENARIOS [2]

impulsive noise scenario	IAT(s)	T_{noise} (ms)
heavily disturbed	0.0196	0.0641
medium disturbed	0.9600	0.0607
weakly disturbed	8.1967	0.1107

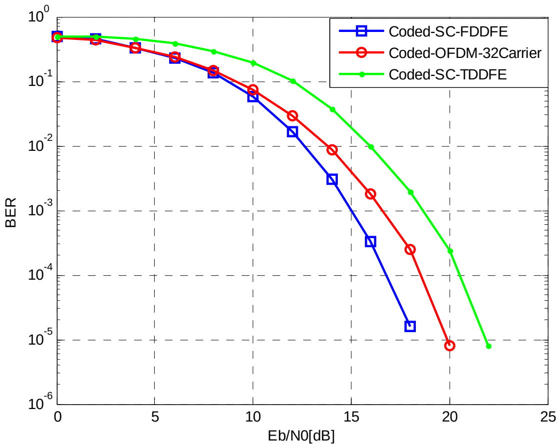

Figure 4. BER performances comparison of SC-FDDFE, OFDM, and SC-TDDFE systems for AWGN noise scenario

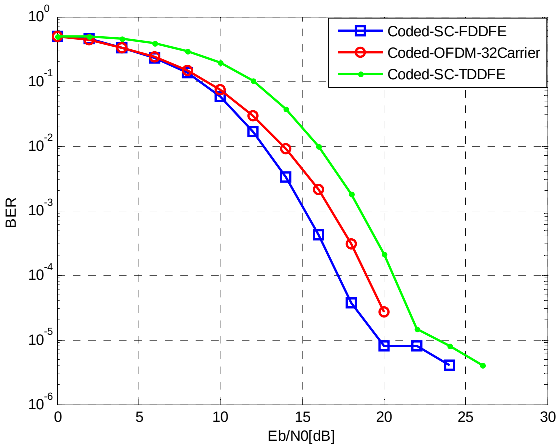

Figure 5. BER performances comparison of SC-FDDFE, OFDM, and SC-TDDFE systems for weakly disturbed impulsive noise scenario

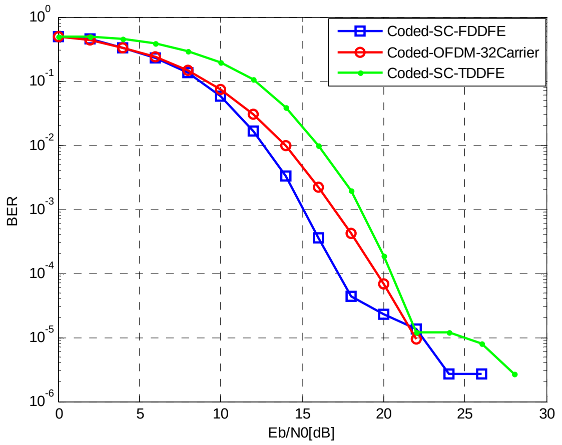

Figure 6. BER performances comparison of SC-FDDFE, OFDM and SC-TDDFE systems for medium disturbed impulsive noise scenario

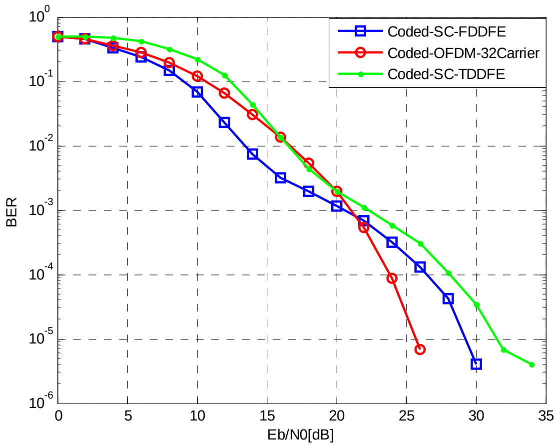

Figure 7. BER performances comparison of SC-FDDFE, OFDM, and SC-TDDFE systems for heavily disturbed impulsive noise scenario

VI. CONCLUSION

In this paper, single carrier transmission with time and frequency domain equalization techniques in PLC channels has been investigated. The BER performances of these systems have been simulated and compared with the OFDM system. We showed that in presence of AWGN and weakly disturbed impulsive, single carrier transmission with frequency domain equalization is superior to OFDM at all E_b/N_0. Also, when the disturbance of the impulsive noise is medium or heavy, SCT-FDDFE performs better than OFDM at E_b/N_0 lower than 22dB. Also, we showed that the BER performance of OFDM is better than SCT-TDDFE at all cases.

REFERENCES

[1] E. Biglieri, "Coding and modulation for a horrible channel," *IEEE Commun. Mag.*, vol. 41, no. 5, pp. 92–98, May 2003.

[2] Y. H. Ma, P. L. So, and E. Gunawan, "Performance analysis of OFDM system for broadband power line communications under impulsive noise and multipath effects," *IEEE trans. power del.*, Vol. 20, no. 2, pp. 674-682, Apr. 2005.

[3] O. G. Hooijen, "A channel model for the residential power circuit used as a digital communications medium," *IEEE Trans. Electromagn. Compat.*, vol. 40, no. 4, pp. 331–336, Nov. 1998.

[4] M. Zimmermann and K. Dostert, "Analysis and modeling of impulsive noise in broad-band powerline communications," *IEEE Trans. Electromagn. Compat.*, vol. 44, no. 1, pp. 249–258, Feb. 2002.

[5] M. Zimmermann and K. Dostert , "A multipath model for the powerline channel," *IEEE Trans. Commun.*, vol. 50, no. 4, pp. 553–559, Apr. 2002.

[6] M. Zimmermann and K. Dostert, "A multi-path signal propagation model for the powerline channel in the high frequency range," *in Proc. 1999 ISPLC Conf*, pp. 45–51.

[7] J. Anatory, N. Theethayi, M. Kissaka, and N. Mvungi, "Broadband powerline communications: performance analysis," *Enformatika Trans. on Engineering, Computing and Technology*, Vol. 18, pp. 250-254, 2006.

[8] E. Del Re, R. Fantacci, S. Morosi, and R. Seravalle, "Comparison of CDMA and OFDM techniques for downstream power-line communications on low voltage grid," *IEEE Trans. Power Del.*, vol. 18, no. 4, pp. 1104–1109, Oct. 2003.

[9] P. Amirshahi, S. M. Navidpour, and M. Kavehrad, "Performance analysis of uncoded and coded OFDM broadband transmission over low voltage powerline channels with impulsive noise," *to appear in IEEE Transactions on power delivery* 2006.

[10] T. J. S. Khanzada, A. R. Ali, and A. S. Omar, " Study of variable channel length for single carrier transmission with decision feedback equalizer," in Proc. IEEE Radio and Wireless Symposium 2008, pp. 267–270, Orlando USA, Jan. 2008.

[11] T. J. S. Khanzada, A. R. Ali, and A. S. Omar, "The Effect of coding on OFDM and single carrier transmission with decision feedback equalizer," in Proc. CNSR 2008, pp. 59-63, May 2008.

[12] N. Benvenuto and S. Tomasin, "On the Comparison between OFDM and single-carrier modulation with a DFE using a frequency-domain feedforward filter," I*EEE Trans. Commu.*, vol. 50, no. 6, pp. 947 – 955, June 2002.

[13] D. Falconer, S. L. Ariyavisitakul, A. Benyamin-Seeyar, and B. Eidson, "Frequency domain equalization for single carrier broadband wireless systems," *IEEE Commun. Mag.*, vol. 40, no. 4, pp. 58–66, Apr. 2002.

[14] F. S. Agathe and H. Sari, "New results in iterative frequency-domain decision-feedback equalization," *In Proc. 14th European Conference on Signal Processing (EUSIPCO 2006)*, Florence, Italy, Sep. 2006.

[15] N. Benvenuto and S. Tomasin, "Block iterative DFE for single-carrier modulation," *Electronics Letters*, vol. 38, no. 19, pp. 1144 – 1145, Sep. 2002.

[16] A. M. Chan and G. W. Wornell, "A class of block-iterative equalizers for intersymbol interference channels: fixed channel results," *IEEE Trans. Commun*, 2001, vol. 49, no. 11, pp. 1966–1976.

[17] J. G. Proakis, *Digital communications*, 4th ed. New York: McGraw- Hill, 2001.

[18] M. Ghosh, "Analysis of the effect of impulsive noise on multicarrier and single carrier QAM systems," *IEEE Trans. Commun.*, vol. 44, no. 2, pp. 145–147.