Proceedings of ITC-CSCC 2000, Pusan, Korea

Performance of a Multi-Code CDMA Scheme on Non-Gaussian Noises in Power Line Communication Channels*

Sung Ju Na and Yoan Shin†
School of Electronic Engineering
Soongsil University
Seoul, 156-743, Korea

†E-mail : yashin@logos.soongsil.ac.kr

Abstract : In this paper, we propose to exploit a multi-code CDMA scheme for power line communication (PLC) systems, and its performance on non-Gaussian impulse and harmonic noises is presented. The proposed multi-code CDMA scheme utilizes convolutional coding and block interleaving to combat with the non-Gaussian noises, and simulation results indicate effective alleviation of these noises, and thus significant bit error rate improvement by the proposed scheme even under strict restriction of frequency band allowed in PLC systems.

1. Introduction

Recently, there has been much interest in home networking of various digital home information terminals and appliances which can provide high speed data exchange among themselves as well as external internet access. For effective deployment of home networks, several physical layer solutions such as RF, infrared and wirelines are being considered. Despite their advantages, some of these approaches manifest critical drawbacks. For instance, infrared approach requires line-of-sight links for reliable data transmission, while wireline approaches usually need expensive deployment cost. As an alternative to these approches, power line communication (PLC) systems are actively studied [1].

The PLC systems utilize ease-to-access, in-building power lines that are already installed abundantly in most residential and business buildings, so that cost and effort of network deployment becomes minimal. However, the power lines exhibit quite poor characteristics as communication channels. First of all, some strict frequency band restriction for specific communication uses is imposed. Moreover, the power line channels usually show random fluctuation of impedance and attenuation according to time and location of measurement. Also, in addition to background white Gaussian noise, non-Gaussian noises such as impulse and harmonic noises which significantly degrades the system performance, are commonly encountered [2, 3, 4].

Direct sequence-code division multiple access (DS-CDMA) [5] has been widely applied to PLC systems mainly thanks to its robust nature against narrowband non-Gaussian noises and interferences [6, 7, 8]. However, strict limitation of usable frequency band in the PLC systems does not allow enough processing gain [5] in some cases, which restricts effective performance gain achieved by the DS-CDMA schemes. In this paper we propose to exploit a multi-code CDMA scheme [9] with convolutional coding and block interleaving [10] for the PLC systems, which is considered as a modem technology in the third generation wireless IMT-2000 systems, and performance of the proposed scheme on non-Gaussian impulse and harmonic noises under some frequency band restriction is verified. Since multi-code CDMA schemes serial-to-parallel convert input data into multiple lower rate data channels multiplexed by orthogonal Walsh codes, processing gain can be significantly increased as compared to DS-CDMA systems. This paper is organized as follows. Section 2 presents the proposed multi-code CDMA scheme for compensation of non-Gaussian noises in PLC channels. In Section 3, noise models used in the simulation is described, and the performance of the proposed scheme is verified by computer simulation. Finally, Section 4 concludes the paper.

2. Proposed Multi-Code CDMA Scheme

Figure 1 shows block diagram of the proposed transmitter. In the figure, the M input bits of bit duration T_b are converted into M parallel bits d_j ($j = 0, \cdots, M-1$) of duration MT_b each by passing through the serial-to-parallel converter ("S/P"). Each d_j is encoded by a convolutional encoder of code rate r ($0 < r < 1$) followed by a block interleaver to yield encoded signal $y_j(t)$ of bit duration rMT_b, and further modulated (i.e., multiplied) by the j-th ($j = 0, \cdots, M-1$) Walsh sequence $w_j(t)$ of bit duration rT_b. The signals $y_j(t)w_j(t)$ ($j = 0, \cdots, M-1$) are summed together, spread by a pseudo noise (PN) signature sequence $c(t)$ of chip duration $T_c \triangleq rMT_b/N$ with period NT_c, and

*This work was financially supported by the Electrical Engineering & Science Research Institute (EESRI) under the grant #98-042.

finally modulated by a main carrier with carrier frequency of f_c. Hence, the transmit signal $x(t)$ for time duration $T_w \triangleq rMT_b$ can be expressed as

$$x(t) = \sum_{j=0}^{M-1} y_j(t)w_j(t)c(t)\cos 2\pi f_c t \ (t \in [0, T_w)) \quad (1)$$

where the signature sequence $c(t)$ is written as

$$c(t) = \sum_{m=0}^{M-1} \left[\sum_{i=0}^{rMT_b/T_c - 1} c_i \psi(t - mT_b - iT_c) \right] \quad (2)$$
$$(t \in [0, T_w))$$

In (2), $c_i \in \{+1, -1\}$ is the i-th chip of the PN code, and $\psi(\cdot)$ is a unit rectangular pulse defined in $[0, T_c)$. For the proposed multi-code CDMA transmitter, the processing gain G_p is obtained as

$$G_p = \frac{MT_b}{T_c} = \frac{MN}{r} \quad (3)$$

which is M time larger than that of DS-CDMA systems.

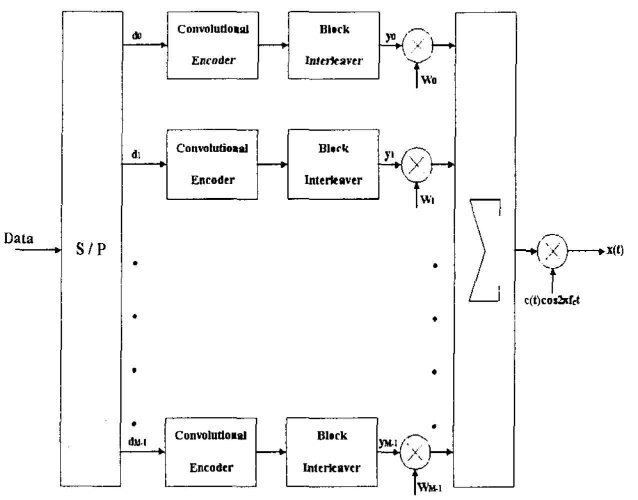

Figure 1: Block diagram of the proposed multi-code CDMA transmitter.

Figure 2 depicts block diagram of the proposed receiver where converse functions of the transmitter such as de-interleaver and Viterbi decoder are performed. In particular, this figure shows a correlator-type structure by mainly considering background and non-Gaussian noises in the channel. A Rake receiver can be employed if fading characteristic of the channel should be also dealt with. By only considering attenuation and additive noises in the PLC channels, the received signal $r(t)$ is expressed as

$$r(t) = \alpha x(t) + n(t)$$
$$= \alpha \sum_{j=0}^{M-1} y_j(t)w_j(t)c(t)\cos 2\pi f_c t + n(t) \quad (4)$$
$$(t \in [0, T_w))$$

where α $(0 < \alpha < 1)$ is the attenuation factor, $n(t)$ is all the noise components of the channel, and perfect estimation of transmission delay is assumed. The output $r_o(t)$ of the lowpass filter (LPF) is then described as

$$r_o(t) = \frac{\alpha}{2} \sum_{j=0}^{M-1} y_j(t)w_j(t)c^2(t) + n_o(t) \ (t \in [0, T_w)) \quad (5)$$

where $c^2(t) = 1$ for $c(t) = \pm 1$, and

$$n_o(t) \equiv \mathrm{LPF}\{n(t)c(t)cos 2\pi f_c t\} \quad (6)$$

with lowpass filtering operation $\mathrm{LPF}\{\cdot\}$.

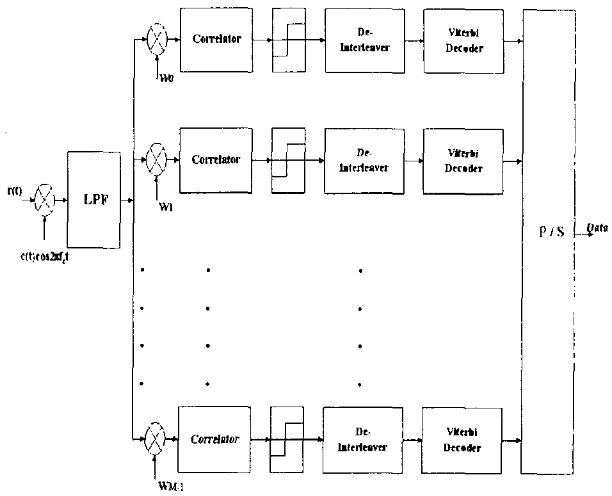

Figure 2: Block diagram of the proposed multi-code CDMA receiver.

The signal $r_o(t)$ is copied to M branches and the decision statistic z_k of the k-th branch $(k = 0, \cdots, M-1)$ obtained as the output of the correlator, is expressed as

$$\begin{aligned} z_k &= \frac{1}{T_w} \int_0^{T_w} r_o(t)w_k(t)dt \\ &= \frac{\alpha}{2} \sum_{j=0}^{M-1} y_k \left(\frac{1}{T_w} \int_0^{T_w} w_j(t)w_k(t)dt \right) \\ &\quad + \frac{1}{T_w} \int_0^{T_w} n_o(t)w_k(t)dt \\ &= \frac{\alpha}{2} y_k + n_{ko} \end{aligned} \quad (7)$$

In Eq. (7), orthogonality of the Walsh sequences and the fact that the bit duration rMT_b of $y_j(t)$ is equivalent to a period of M-bit Walsh sequence $w_j(t)$, are exploited. Also in the equation, the noise component n_{ko} is defined as

$$n_{ko} \equiv \frac{1}{T_w} \int_0^{T_w} \mathrm{LPF}\{n(t)c(t)cos 2\pi f_c t\} w_k(t)dt \quad (8)$$

Table 1 summarizes specifications of the proposed multi-code CDMA scheme. Note that, according to Korean as well as Japanese PLC regulations, the allowed

Table 1: Specifications of the proposed multi-code CDMA scheme.

	Specifications
Modulation	BPSK
Data rate	6.8 kbps ($T_b = 0.147$ msec)
Walsh code	8×8 ($M = 8$)
Convolutional code	Code rate $r = 1/2$ Constraint length $K = 3$
PN code	m-sequence with period $N = 127$ Chip rate $N/rMT_b = 215.9$ kbps
Carrier frequency	230.04 kHz
Frequency band (null-to-null)	14.14 kHz - 445.94 kHz

frequency band is assumed to be in the range of 10 kHz - 450 kHz. The generator polynomials of the convolutional code are given in Eqs. (9) and (10), while Eq. (11) represents that of the PN code used in the system.

$$g_{\text{conv}}^{(1)}(x) = 1 + x + x^2 \quad (9)$$

$$g_{\text{conv}}^{(2)}(x) = 1 + x^2 \quad (10)$$

$$g_{\text{PN}}(x) = 1 + x + x^2 + x^3 + x^7 \quad (11)$$

3. Computer Simulations

To investigate performance of the proposed multi-code CDMA scheme, computer simulation was performed. We have considered background noise, non-Gaussian impulse and harmonic noises as channel impairments. For background noise, additive white Gaussian noise (AWGN) with two-sided power spectral density (psd) of $N_0/2$ (W/Hz) was considered [2]. The harmonic noise $n_h(t)$ was modeled as

$$n_h(t) = \sum_{k=1}^{3598} A_k \cos(2\pi k f_0 t + k\theta_0) \quad (12)$$

where A_k, according to the measured results reported in [4], can be well expressed as a Gaussian random variable representing the amplitude of the k-th harmonic component whose mean is 22 dB larger than the psd of the background noise and variance is 6 dB. Also, $f_0 \equiv 60$ Hz is the fundamental frequency of residential power carrier, and θ_0 is the phase modeled by a uniform random variable defined in $[0, 2\pi)$. Note in Eq. (12) that index k ranges from 1 to 3598, so that the largest harmonic frequency becomes $3598 \times 60 = 215.88$ kHz due to baseband-equivalent modeling of the system actually employed in the simulation. Figure 3 shows psd of the harmonic noise modeled by Eq. (12) with additive background noise, which is depicted around the 225-th harmonic frequency of 13.5 kHz. The figure indicates that the psd of the simulated harmonic noise given by Eq. (12) is closely matched to that of actually measured harmonic noise whose psd in the same frequency range as of Fig. 3 is reported in [4]. We modeled impulse noise according to the measurement results given in [2]. From [2], impulse noise on typical intra-building PLC channels has a period of approximately 8.3 msec (i.e., 120 Hz) with equally-likely impulse duration of approximately 40 μsec or 80 μsec. Moreover, amplitudes of impulses are 5 or 10 times larger than root-mean-square values of background noises and their probabilities of occurrences are approximately equal.

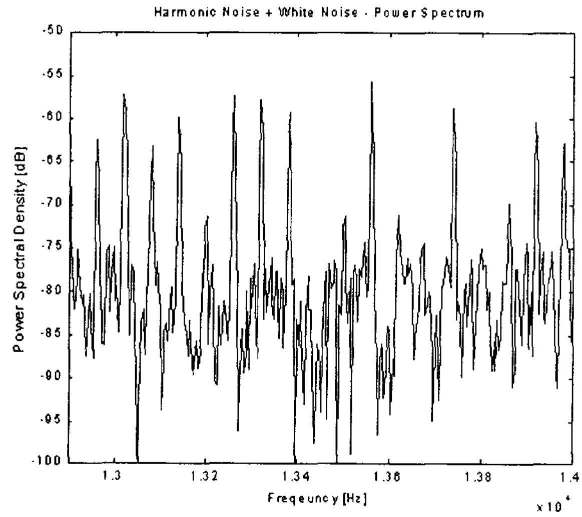

Figure 3: Power spectral density of the harmonic noise modeled by Eq. (12) with additive background noise.

Figure 4 depicts bit error rate (BER) curves versus signal-to-noise ratio E_b/N_0 of the proposed multi-code CDMA scheme for various noise conditions in the PLC channels. The figure indicates that, as expected, the combination of harmonic and impulse noises degrades the system performance, yielding about 5 dB loss in signal-to-noise ratio at the BER of 10^{-4} as compared to the case where background AWGN is only considered. However, when comparing with the system without any coding, effectiveness of the proposed scheme is highlighted. Figure 5 compares BER curves of the proposed multi-code CDMA scheme ("Coded") and a multi-code CDMA scheme without convolutional coding and interleaving ("Uncoded"), where both harmonic and impulse noises are considered with background noise. In the figure, BER performances of the coded and uncoded systems for background noise only are also included for the purpose of comparison. From the figure, the uncoded system suffers from error floor even in the case of large signal-to-noise ratio, E_b/N_0, while the proposed multi-code CDMA scheme achieves significant performance improvement. Thus, the simulation results indicate that the proposed multi-code CDMA scheme with convolutional coding and interleaving effectively mitigates non-Gaussian narrowband impulse and harmonic noises often encountered in PLC channels even under strict restriction of frequency band allowed.

4. Conclusion

The proposed multi-code CDMA scheme for PLC systems utilizes convolutional coding and block interleaving to combat with non-Gaussian noises. Simulation results indicate effective alleviation of these noises, and thus significant bit error rate improvement by the proposed scheme even under strict restriction of frequency band allowed in PLC systems. For future work, the proposed multi-code CDMA scheme with a Rake-type receiver needs to be investigated to cope with fading characteristic of the PLC channels.

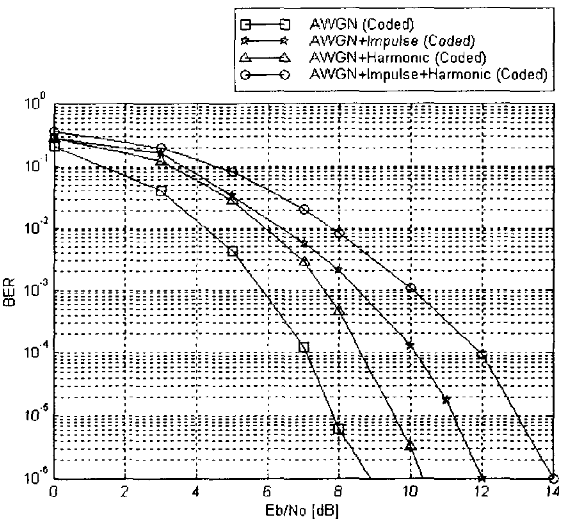

Figure 4: Bit error rate (BER) curves of the proposed multi-code CDMA scheme for various noise conditions in the PLC channels.

References

[1] D. Radford, "Spread-spectrum data leap through AC power wiring," *IEEE Spectrum*, vol. 33, pp. 48-53, Nov. 1996.

[2] M. Chan and R. Donaldson, "Amplitude, width, and interarrival distributions for noise impulses on intrabuilding power line communication networks," *IEEE Trans. Electromag. Compat.*, vol. 31, pp. 320-323, Aug. 1989.

[3] R. Vines, *et al.*, "Noise on residential power distribution circuits," *IEEE Trans. Electromag. Compat.*, vol. 26, pp. 161-168, Nov. 1984.

[4] J. O'Neal, "Substation noise at distribution-line communication frequencies," *IEEE Trans. Electromag. Compat.*, vol. 30, pp. 71-77, Feb. 1988.

[5] A. Viterbi, *CDMA: Principles of Spread Spectrum Communication*, Addison-Wesley, 1995.

[6] R. Khono, *et al.*, "An adaptive canceller of cochannel interference for spread-spectrum multiple-access communication networks in a power line", *IEEE Jour. Sel. Areas Commun.*, vol. 8, pp. 691-699, May 1990.

[7] M. Nakagawa, "Consumer communications based on spread spectrum techniques," in *Code Division Multiple Access Communications* (S. G. Glisic and P. A. Leppanen, Eds.), pp. 283-297, Kluwer Academic Publisher, 1995.

[8] C. Hensen, "High rate data communication via power distribution network using DS-CDMA technique," *Proc. Int'l Conf. Universal Personal Commun. (ICUPC '97)*, vol. 2, pp. 805-808, San Diego, USA, Oct. 1997.

[9] F. Adachi, *et al.*, "Coherent multicode DS-CDMA mobile radio access," *IEICE Trans. Commun.*, vol. E79-B, pp. 1316-1325, Sep. 1996.

[10] B. Sklar, *Digital Communications*, Prentice Hall, 1988.

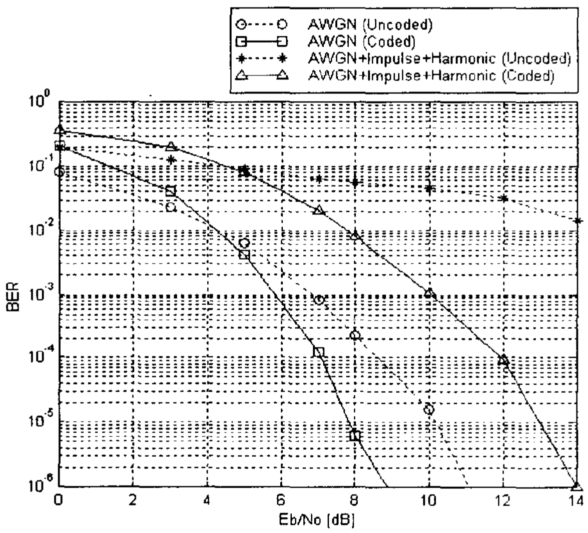

Figure 5: BER curves of the proposed multi-code CDMA scheme ("Coded") and a multi-code CDMA scheme without convolutional coding and interleaving ("Uncoded"), where both harmonic and impulse noises are considered with background noise.