# A Study on the Bandwidth Efficient Self-Cancellation Scheme of Interchannel Interference (ICI) For OFDM Transmission Systems

**Gi Rae Kim and Yeon Ho Chung**

***Abstract***— This paper presents a bandwidth efficient self-cancellation scheme for interchannel interference (ICI) in OFDM transmission systems. Conventional self-cancellation schemes provide an excellent cancellation capability of ICI for relatively low frequency offsets. However, this capability is achieved at the expense of bandwidth efficiency and thus a higher modulation level is often used to compensate for desired throughput. By applying a partial differential coding (PDC) to the transmit data prior to the ICI self-cancellation, bandwidth efficiency is greatly improved by a factor of 2, while maintaining a string of data (+1, -1) alternately for the ICI self-cancellation in OFDM systems. Computer simulations show that the performance of the proposed scheme is comparable to the conventional self-cancellation scheme with slight performance degradation for relatively lower frequency offsets.

***Index Terms***—ICI, OFDM, PDC

## I. INTRODUCTION

OFDM supports high data rate using a large number of subcarriers. Each subcarrier is designed to undergo flat fading, thus avoiding an adverse effect of intersymbol interference. To achieve high performance in an OFDM transmission system, frequency synchronization is essential because otherwise it causes intercarrier interference (ICI) because of the lack of orthogonality between the subcarriers. The ICI results in performance degradation. There are various approaches for eliminating or reducing the ICI: frequency-domain equalization [1],[2], time-domain windowing [3],[4] and ICI self-cancellation scheme [5]. Among these schemes, the ICI self-cancellation scheme appears to be promising, due to its simplicity and effectiveness. The main idea of this scheme is to simply repeat each symbol with negative polarity and transmits over adjacent subcarriers. Thus, it achieves self-cancellation effect at the receiver because of similar ICI values between adjacent subcarriers [5].

However, this self-cancellation effect is attained at the expense of reducing the number of data transmitting subcarriers by halfband therefore the scheme suffers from reduced bandwidth efficiency and throughput.

This paper considers a partial differential coding for re-arranging the transmit data prior to the ICI self-cancellation scheme and the OFDM modulation. The differential coding is performed selectively only on the data that have no alternating data pattern of +1 and -1 for the self-cancellation. Thus, it is called a partial differential coding (PDC). By doing so, we attempt to maintain full bandwidth efficiency by making use of all available subcarriers for data transmission, while maintaining a data pattern of +1 and -1 alternately. In other words, the input data are re-arranged through PDC so that the input data appear to be repeated with negative polarity on adjacent subcarriers as required for the self-cancellation.

In Section 2, an analysis of interchannel interferenceis given with the self-cancellation scheme in detail. The bandwidth efficient self-cancellation is described in detail in Section 3. Simulations and results are provided in Section 4 and conclusions are drawn in Section 5.

## II. SELF-CANCELLATION SCHEME

One of the disadvantages of OFDM is its susceptibility to frequency mismatch. Due to Doppler shift, the frequencies between the transmitter and receiver are often mismatched, i.e. loss of synchronization, so that the performance of OFDM is greatly affected. The frequency mismatch, or the existence of frequency offset, can be modeled as a multiplicative factor introduced in the channel as shown in Figure 1.

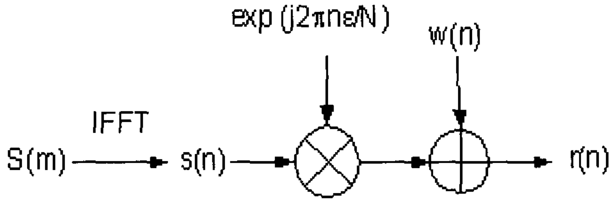

Fig. 1 Frequency offset model.

The received signal is given by

$$r(n) = s(n)e^{j2\Pi n\varepsilon/N} + w(n) \tag{1}$$

where ε is frequency error, s(n) is the transmit OFDM symbol, w(n) is the additive white Gaussian noise

---

Manuscript received November 3, 2006.

Gi Rae Kim is with Department of Electronics, Silla University, Korea

Yeon Ho Chung is with Department of Electronics & Telecommunication, Pukyong National University, Korea

sample and N is the number of subcarriers.

Therefore, the received symbol on subcarrier *k*, R(k), is written as

$$R(k) = s(k)C_0 + \sum_{l=0, l\neq k}^{N-1} S(k)C_{l,k} + n_k, k = 0,1,\ldots N-1 \tag{2}$$

S(k) is the transmitted symbol on subcarrier k, $C_{l,k}$ denotes the ICI coefficient between lth and *k*th subcarriers and nk is an additive noise sample. With some mathematical manipulation, $C_{l,k}$ can be found as

$$C_{l,k} = \frac{\sin(\pi(l+\varepsilon-k))}{N\sin\left(\frac{\pi}{N}(l+\varepsilon-k)\right)}\exp\left(j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)\right) \tag{3}$$

If there is no frequency error (ε = 0), then $C_0 = 1$.

The ICI self-cancellation scheme requires that the transmitted signals be constrained such that S(1) = -S(0), S(3)=-S(2), ⋯., S(N-1) = -S(N-2). Therefore, the received signals on subcarrier *k* and *k+1* are written as [5]

$$R'(k) = \sum_{\substack{l=0\\ l=even}}^{N-2} S(l)[C_{l,k} - C_{l+1,k}] + n_k$$

$$R'(k+1) = \sum_{\substack{l=0\\ l=even}}^{N-2} S(l)[C_{l,k+1} - C_{l,k}] + n_{k+1} \tag{4}$$

The ICI coefficient is then obtained as

$$C'_{l,k} = C_{l,k} - C_{l+1,k} \tag{5}$$

It can be seen that the values of *Cl,k'* are much less than *Cl,k* for most of the l-k values. Hence, the ICI components are much smaller in (5) than they are in (3).

The ICI self-cancellation scheme introduces redundancy in the received signal since each pair of subcarriers transmit only one data symbol. This redundancy is exploited to improve the system power performance and self-cancellation of ICI, while sacrificing bandwidth efficiency. The received signal at the *(k+1)*th subcarrier, where k is even, is subtracted from the *k*th subcarrier. That is,

$$\begin{aligned} R'(k) &= R'(k) - R'(k+1) \\ &= \sum_{\substack{l=0\\ l=even}}^{N-2} S(l)[-C_{l-k,1} + 2C_{l,k} - C_{l-k,-1}] + n_k - n_{k+1} \end{aligned} \tag{6}$$

Therefore, the ICI coefficient now becomes

$$C''_{l,k} = -C_{l-k,1} + 2C_{l,k} - c_{L-K,-1} \tag{7}$$

It is obvious that this ICI coefficient is much smaller than $C_{l,k}$ and $C_{l,k'}$. The ICI self-cancellation scheme, therefore, offers excellent performance of ICI cancellation.

In addition to the smaller ICI coefficients, the ICI self-cancellation scheme provides the improvement of the carrier-to-interference ratio (CIR). The CIR is given [5]

$$CIR = \frac{|C_k|^2}{\sum_{\substack{l=0\\ l\neq k}}^{N-1} |C_{l,k}|^2} = \frac{|C_0|^2}{\sum_{l=0}^{N-1} |C_l|^2} \tag{8}$$

This derivation assumes zero-mean transmit data and statistically independent symbols transmitted on the different subcarriers.

## III. BANDWIDTH EFFICIENT SELF-CANCELLATION

The ICI self-cancellation scheme has a disadvantage of bandwidthin efficiency as mentioned in the previous section. That is, it does not make full use of available subcarriers for data transmission. To alleviate this problem, one method is conceivable that a higher level modulation scheme is employed instead, to achieve full bandwidth efficiency as reported in [5]. However, this method does not make full use of the available subcarriers and will also cause performance degradation with a higher level modulation.

Another alternative is to perform a partial differential coding. This technique is considered in this paper. The main idea of this method is to re-arrange the transmit data using the differential coding to have the desired data arrangement as it would be with the ICI self-cancellation scheme. That is, by observing the transmit data, a differential coding is employed only to the data which do not have the desired data pattern, i.e. an alternating binary data of +1 and -1. The differential coding is used selectively for the transmit data. The algorithm is summarized as follows.

Step 1. Observe the transmit data, s(n)
Step 2. Identify the locations of s(n) that has a string of +1 or -1.
Step 3. Perform a differential coding at those positions and store the locations for use in the receiver.
Step 4. Perform the ICI self-cancellation scheme

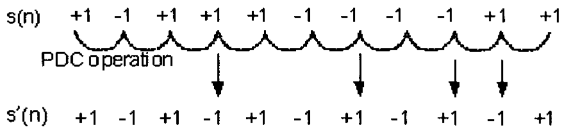

Fig. 2 Graphical representation of the PDC operation.

The PDC algorithm is graphically described in Figure 2. When the data (+1 or -1) repeats on adjacent subcarriers, the PDC operation is performed. In Figure 2, four PDC operations are performed in order to have a desired data pattern for the ICI self-cancellation.

The proposed OFDM system with a partial differential coding is depicted in Figure 3.

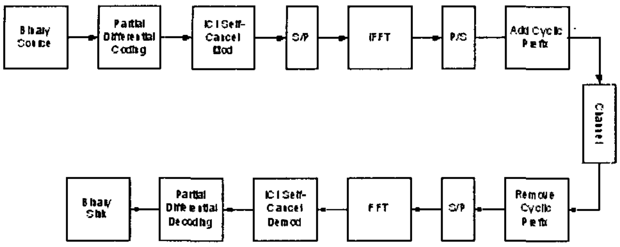

Fig. 3 Block diagram of the proposed system.

The bandwidth efficient ICI self-cancellation system begins with the PDC, followed by the ICI self-cancellation scheme. By converting serial data into parallel data, the IFFT operation is then performed on the input parallel data. After the cyclic prefix operation is completed, the data is transmitted over the mobile radio channel. At receiver, the cyclic prefix is first removed and the FFT is performed together with a conversion of the parallel data into serial data. The OFDM demodulated data undergoes the ICI self-cancellation demodulation, followed by the PDC decoding. At this point, the PDC location information is used for correct differential decoding. Note that the PDC location information is assumed to be transmitted error-free via a separate control channel.

## IV. SIMULATIONS AND RESULTS

In order to evaluate the performance of the proposed scheme, simulations have been conducted. The simplest way of evaluating the bandwidth efficient ICI self-cancellation scheme is to transmit the data through a channel with constant frequency offsets.

Simulation parameters are as follows. The number of subcarriers is 64 and a total of 384,000 data have been used for the evaluation of BER performance at a given Eb/No. The transmit data have been submitted to the additive white Gaussian noise channel (AWGN) with constant normalized frequency offsets of 0, 0.15 and 0.3. Figure 3 shows the BER performance for the standard OFDM with BPSK modulation. It is seen that as the frequency offsets increase, the performance becomes very poor, due to the frequency mismatch and subsequent loss of orthogonality between the subcarriers.

Figure 4 shows the performance of the ICI self-cancellation scheme proposed by Zhao et. al. [5] for comparison purpose. QPSK is employed for a bandwidth efficiency of 1 b/s/Hz. It is shown that the BER performance clearly indicates superior performance to the standard OFDM for all frequency offset values. However, this performance improvement is achieved at the expense of bandwidth efficiency and throughput. That is, in order to achieve a bandwidth efficiency of 1 b/s/Hz, QPSK modulation format was used instead of BPSK modulation scheme. This is because a half of the available subcarriers are used for the repetition of the data with negative polarity for the ICI self-cancellation.

The BER performance of the proposed scheme is shown in Figure 5. The proposed scheme uses QPSK modulation for all available subcarriers, thus increasing bandwidth efficiency by a factor of 2, in comparison with the Zhao'sself-cancellation scheme.

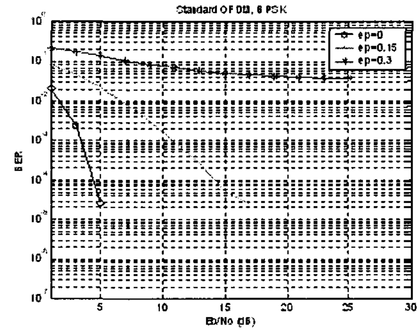

Fig. 4 BER performance of standard OFDM.

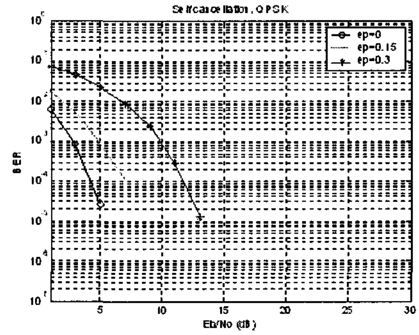

Fig. 5 BER performance of the ICI self-cancellation OFDM.

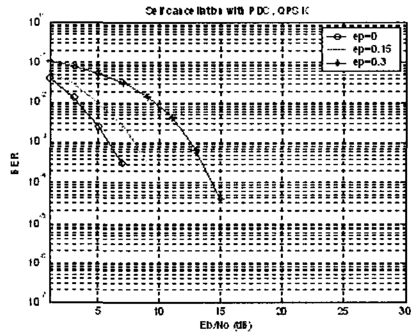

Fig. 6 BER performance of the ICI self-cancellation OFDM with the PDC.

This improvement in bandwidth efficiency is achieved by applying the PDC to the transmit data before the self-cancellation and the subsequent OFDM modulation. There is, however, a drawback in this scheme that although differential coding is employed selectively, the use of differential coding leads to performance degradation slightly as shown in Figure 5. Comparing with the performance of the ICI self-cancellation proposed by Zhao, the proposed scheme shows a loss of approximately 2dB at relatively low frequency offsets. For a higher frequency offset, the performance degradation appears to be more than 2dB. It is anticipated that the number of bit positions where the differential coding is performed plays an important role in degrading the BER performance. The more the differential coding is performed on the transmit data, the worse the performance of the proposed scheme will be in comparison to the Zhao's ICI self-cancellation scheme. Therefore, it can be said that there is a trade-off between bandwidth efficiency and the BER performance of the proposed scheme.

## V. CONCLUSIONS

A bandwidthefficient scheme for the ICI self-cancellation OFDM system is considered. Unlike the previously reported scheme that suffers from the loss of bandwidth efficiency, the proposed scheme offers full bandwidth efficiencythrough a partial differential coding, i.e. differential coding employed only where necessary on the transmit data for the self-cancellation. Due to the use of differential coding, it causes a degree of performance degradation slightly for relatively low frequency offsets. Therefore, for low frequency offsets, the proposed scheme is useful in terms of both bandwidth efficiency and BER performance. A more rigorousevaluation is deemed to be necessary for the scheme to be more viable. The performance evaluation of the proposed scheme under mobile radio propagation channel would be interesting. In addition, a more refined partial differential coding can be found to minimize the effect of the differential coding on the performance. This work is presently underway and promising results are being obtained.

## REFERENCES

[1] Ahn, J. and Lee, H. S., "Frequency domain equalization of OFDM signal over frequency nonselective Rayleigh fading channels," *Electron. Lett.*, vol. 29, no. 16, pp. 1476-1477, Aug. 1993.

[2] Dhahi N. A. et al., "Optimum finit-length equalization for multicarrier transceivers," *IEEE, Trans. Commun.*, vol. 44, pp. 5664, Jan. 1996.

[3] Li, R. and Stette, G., "time-limted orthogonal multicarrier modulation schemes," *IEEE Trans. Comm.*, Vol.43, pp.1269-1272, 1995.

[4] Muschallik, C., "Improving an OFDM reception using an adaptive Nyquist windowing," *IEEE Trans. Consumer Electronics,* Vol.42, pp.259-269, Aug. 1996.

[5] Zhao, Y. and Haggman, S.G., "Intercarrier Interference Self-Cancellation Scheme for OFDM mobile communication systems," *IEEE Trans. Comm.*, Vol.49, pp.1185-1191, July 2001.

[6] Y. Zhao and S.-G. Häggman, "Sensitivity to Doppler shift and carrier frequency errors in OFDM systems The consequences and solutions," Proc. *IEEE 46th Vehicular Technology Conf.*, Atlanta, GA, pp. 1564-1568 Apr. 28 May 1, 1996.

[7] P. H. Moose, "A technique for orthogonal frequency division multiplexing frequency offset correction," *IEEE Trans. Commun.*, vol. 42, pp.2908-2914, Oct. 1994.

[8] Y. Zhao, J.-D. Leclercq, and S.-G. Häggman, "Intercarrier interference compression in OFDM communication systems by using correlative coding," *IEEE Commun. Lett.*, vol. 2, pp. 214-216, Aug. 1998.

[9] J. G. Proakis, Digital Communications, 2nd ed. New York: McGraw-Hill, 1989.

**Girae Kim**
he has been on the faculty of Electronics Engineering Department at the Silla University, Busan, Korea since 1998. His areas of interest are microwave integrated circuits, packaging technology, analysis of crosstalk and interconnection problem on the multilayer PCB.

**Yeon Ho Chung**
he has been on the faculty of Electronics, Computer and Telecommunication Engineering Division at the Pukyong National University, Busan, Korea. His areas of interest are digital data communication and mobile communication.