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# 주파수공간블록부호화를 적용한 MIMO-OFDM 시스템을 위한 반복복호 기법

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# Iterative Decoding for LDPC Coded MIMO-OFDM Systems with SFBC Encoding

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## 요 약

본 논문에서는 주파수공간블록부호 (Space Frequency Block Code)를 적용한 다중송수신(Multiple Input Multiple Output)-OFDM(Orthogonal Frequency Division Multiplex) 시스템을 위한 반복복호 기법을 제시한다. 제시된 반복복호 기법은 zero-forcing 알고리즘과 LDPD 부호화 알고리즘을 터보 기법을 바탕으로 상호보완을 할 수 있도록 설계되었다. 시뮬레이션 결과에 의하면 고차원 변조방식을 적용한MIMO-OFDM 페이딩 채널에서 기존의 시스템과 비교하여 향상된 성능을 확인하였다

Key Words : LDPC, OFDM System, MIMO System

## ABSTRACT

A multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system using low-density parity-check (LDPC) code and iterative decoding is presented. The iterative decoding is performed by combining the zero-forcing technique and LDPC decoding through the use of the "turbo principle." The proposed system is shown to be effective with high order modulation and outperforms the space frequency block code (SFBC) method with iterative decoding.

## Ⅰ. Introduction

To provide high data rate and reliable communications for next generation mobile communication systems, OFDM is an effective technique that can be applied. By transmitting multiple signals in parallel on different mutually orthogonal subcarriers, robustness against frequency selective fading and high spectral efficiency are achieved using the OFDM modulation. Furthermore, by using multiple transmit and receive antennas, enormous capacity gain can be achieved in rich scattering environments [1]. It has been shown in [2], by combining the MIMO technique with error correction code through "turbo principle" [3], progressive performance improvement can be achieved for convolutional coded MIMO-OFDM systems. LPDC codes [4], originally invented by Gallager, has received much attention recently due to its low decoding complexity and performance

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approaching the Shannon limit. In this paper, we propose a receiver with iterative decoding scheme for LDPC coded MIMO-OFDM systems with SFBC encoding. The proposed receiver uses zero-forcing algorithm with LDPC decoder to iteratively detect and decode the transmitted data through an exchange of soft information increasing the overall performance.

## Ⅱ. System Model

There are three main approaches to MIMO channel modeling: The correlation or METRA model, the ray-tracing model, and the scattering model. The METRA model was used to simulate the MIMO channel in this paper. The METRA model characterizes spatial correlation by combining independent complex Gaussian channel matrices at the transmitter and receiver [8], [9]. For multipath fading, the ITU model [10] is used to generate the power delay profile and Doppler spectrum. Since this model is based on ITU's generalized tap delay line channel model, the model is simple to use and backward compatible with existing ITU channel profiles. The procedure for generating MIMO channel characteristics from the METRA model is shown in Fig. 1. The procedure is divided into two major phases. In the first phase, a correlation matrix is generated for each mobile station (MS) and base station (BS) based on the number of antennas, antenna spacing, number of clusters, power azimuth spectrum (PAS), azimuth spread (AS), and angle of arrival (AoA). These two correlation matrices are combined to create a spatial correlation matrix using the Kronecker product. In the second phase, a correlated signal matrix is created using fading signals derived from various Doppler spectra and power delay profiles, and a symmetrical mapping matrix based on the spatial correlation matrix. Some of the parameters that can be used in the METRA channel model are shown in table 1 (source: 3GPP TR 25.876).

Furthermore, we consider MIMO-OFDM systems with M transmitting and N receiving antennas. The data symbols are LDPC encoded using Richardson's parity check matrix [5] shown in Fig. 2, where A is (m-g)×(n-m), B is (m-g)×g, T is (m-g)×(m-g), C is g×(n-m), D is g×g, and E is g×(m-g) binary matrices.

Table 1. MIMO channel parameters

| | | Case A<br>Rayleigh<br>uncorrelated | Case B<br>Macrocell<br>Ped A | Case C<br>Macrocell<br>Veh A | Case D<br>Microcell/Bad-urban<br>Ped B |
|---|---|---|---|---|---|
| Number of paths | | 1 | 4 | 6 | 6 |
| PDP | | N/A | ITU Pedestrian A | ITU Vehicular A | ITU Pedestrian B |
| Doppler spectrum | | Classical | Classical | Laplacian | Laplacian |
| Speed(km/h) | | 3/40/120 | 3/40/120 | 3/40/120 | 3/40/120 |
| UE | Topology | N/A | 0.5λ spacing | 0.5λ spacing | 0.5λ spacing |
| | PAS | N/A | Path#1, Rician, K=6dB (Uniform over 360) | Laplacian, AS=35 (Uniform over 360) | Laplacian, AS=35 (Uniform over 360) |
| | DoM(deg) | N/A | 0 | 22.5 | -22.5 |
| | AOA(deg) | N/A | 22.5 | 67.5(all path) | 22.5(odd paths)<br>-67.5(even paths) |
| Node B | Topology | N/A | Uniform linear array:<br>1)0.5λ spacing<br>2) 4.0λ spacing | | |
| | PAS | N/A | Laplacian, AS=2°/5°<br>50° for 2° RMS angle spread per path<br>20° for 5° RMS angle spread per path | Laplacian, AS=2°/5°<br>50° for 2° RMS angle spread per path<br>20° for 5° RMS angle spread per path | Laplacian, AS=2°/5°<br>50° for 2° RMS angle spread per path<br>20° for 5° RMS angle spread per path |
| | AOA | N/A | | | |

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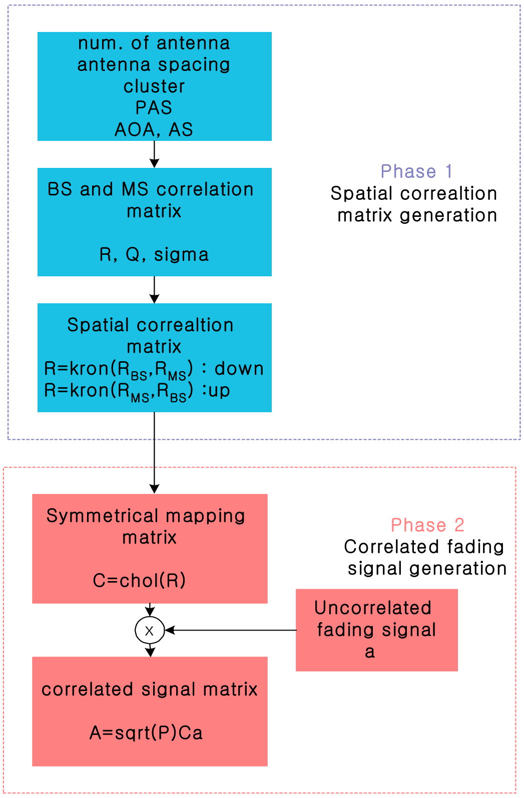

Figure 1. METRA MIMO model generation

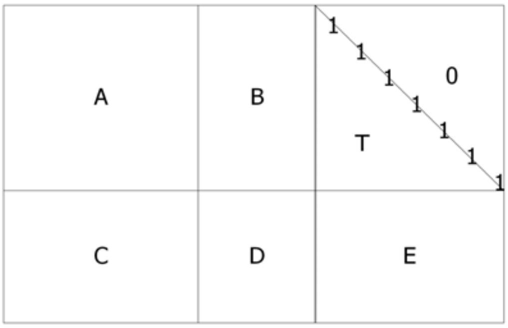

Figure 2. Richardson's parity check matrix

The LDPC encoded symbols are interleaved and SFBC [6] encoded across frequency $i$ and $i+1$ that can be expressed as

$$\mathbf{S} = \begin{bmatrix} d_1 & d_2 & d_3 & d_4 & \Lambda & d_{M-1} & d_M \\ -d_2^* & d_1^* & -d_4^* & d_3^* & \Lambda & -d_M^* & d_{M-1}^* \end{bmatrix}^T \qquad (1)$$

where $(\bullet)^{\mathrm{T}}$ and $(\bullet)^*$ represent transpose and conjugate operations. The symbols across the row 1 in (1) represents the SFBC encoded symbols on frequency $i$ and the symbols across the row 2 represents the SFBC encoded symbols on frequency $i$+1. As for the symbols across the columns j in (1), they represent the data to be transmitted using antenna j. The SFBC encoded symbols are transformed into OFDM symbols through IFFT operation and transmitted across M antennas. At the receiver, receive antenna receives MIMO signals. First, CP is removed from each received signals. Processed by FFT blocks, the time domain signals are transformed into frequency domain signals. Since we are processing subcarrier received signals, the received signal is represented as

$$\mathbf{R} = \mathbf{H}^k \mathbf{X}^k + \mathbf{Z}^k \qquad (2)$$

where $\mathbf{R} \in \Sigma^{\mathrm{N \times T}}$ is the received signal, and

$$\mathbf{H}^k = \begin{bmatrix} h^k{}_{1,1} & h^k{}_{1,2} & \Lambda & h^k{}_{1,M} \\ h^k{}_{2,1} & h^k{}_{2,2} & \Lambda & h^k{}_{2,M} \\ \mathrm{M} & \mathrm{M} & \mathrm{O} & \mathrm{M} \\ h^k{}_{N,1} & h^k{}_{N,2} & \Lambda & h^k{}_{N,M} \end{bmatrix}$$

is the channel with complex coefficients modeling random phase shift and channel gain, $\mathbf{X}^{\mathrm{k}} \in \Sigma^{\mathrm{M \times T}}$ is the transmitted SFBC signal, $\mathbf{Z}^{\mathrm{k}} \in \Sigma^{\mathrm{N \times T}}$ is the AWGN, T is the codeword length in frequency and $k = 1 \cdots L$.

## Ⅲ. Proposed System

Fig. 3 shows the proposed receiver with iterative decoding for LDPC coded MIMO-OFDM system with SFBC encoding. The signals transmitted from each transmitting antennas are received by $N$ antennas and transformed into frequency domain signals using FFT operation. The zero-forcing *a posteriori* probabilities(ZF-APP) detector contains a zero-forcing(ZF) detection unit and a log-likelihood ratio(LLR) computation unit. The ZF detection unit takes OFDM demodulated signal and SFBC decoding is done using a nulling matrix given by [2]

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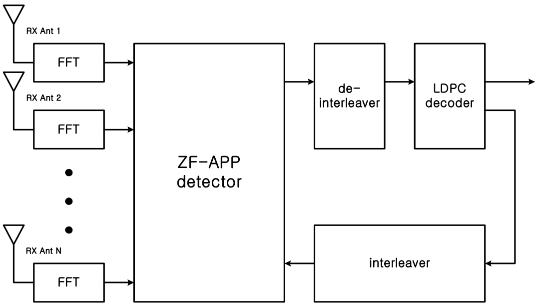

Figure 3. MIMO-OFDM receiver with iterative decoding

$$\mathbf{G}^k = (\mathbf{J}^{k^H}\mathbf{J}^k)^{-1}\mathbf{J}^{k^H} \qquad (3)$$

where $(\bullet)^T$ represents hermitian operation, and for 4×2 antenna configurations **J** can be expressed as

$$\mathbf{J}^k = \begin{bmatrix} h^k_{11} & h^k_{12} & h^k_{13} & h^k_{14} \\ h^k_{21} & h^k_{22} & h^k_{23} & h^k_{24} \\ h^{k^*}_{12} & -h^{k^*}_{11} & h^{k^*}_{14} & -h^{k^*}_{13} \\ h^{k^*}_{22} & -h^{k^*}_{21} & h^{k^*}_{24} & -h^{k^*}_{23} \end{bmatrix}$$

where $h_{ij}$ are independent complex Gaussian channel coefficients for $j^{th}$ transmit and $i^{th}$ receive antenna arrays. The LLR computation unit computes the LLR by using the ZF detection unit output and *a priori* information from the LDPC decoder in an iterative manner. The LLR for ith bit and jth transmitting antenna may be written as

$$L(b^i_j) = \log\frac{P(b^i_j = 0 \mid \mathbf{R})}{P(b^i_j = 1 \mid \mathbf{R})} = \log\frac{\sum_{X \in S_0} P(\mathbf{R} \mid \mathbf{X})P(\mathbf{X})}{\sum_{X \in S_1} P(\mathbf{R} \mid \mathbf{X})P(\mathbf{X})} \qquad (4)$$

where $S_0$ = {**X**: $b^i_j$ = 0} is the set of codewords X such that $b^i_j$ = 0. The LDPC decoder receives the deinterleaved LLR for each bit and estimates the value of each bit by using the sum-product algorithm.

## Ⅳ. Results

Simulations were performed using OFDM symbols with the number of subcarriers equal to 1024 and the carrier frequency set to 2GHz. The METRA channel model [7], which is based on independent transmitter and receiver spatial correlation matrices, with the ITU pedestrian A delay profile with mobile speed of 3km/h was used to model the MIMO channel. A regular 1/2 rate LDPC code using Richardson's H matrix as described in the previous section was employed. In addition, we assume perfect channel estimation and synchronization at the receiver. Fig. 4 shows the packet error rate (PER) results using the proposed ZF-APP detector with different iterations for 2×1 antenna configuration with 1/2 rate LDPC code and QPSK modulation. PER result using the conventional SFBC scheme with same 1/2 rate LDPC code is also shown for performance comparison. It is shown that the performance of ZF-APP is similar to the conventional SFBC scheme for the first iteration. However, with increasing iterations, we could see the performance improvement with ZF-APP detection. A PER of $10^{-3}$ is achieved at an Eb/No of ~ 6.2dB after three iterations. Fig. 5 shows the results for 2×1 antenna configuration

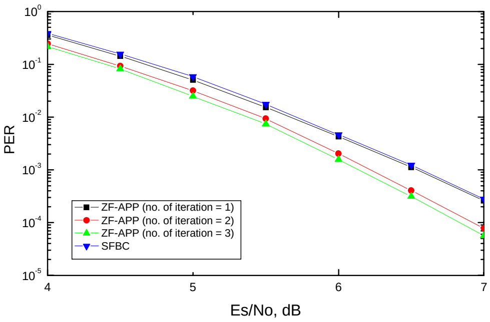

Figure 4. PER performance of MIMO-OFDM systems with QPSK modulation

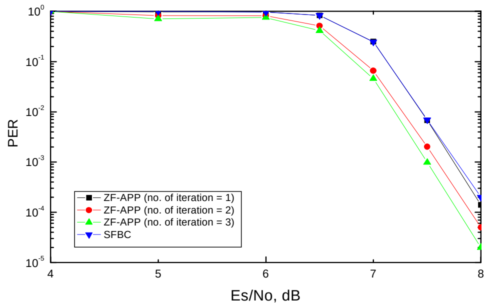

Figure 5. PER performance of MIMO-OFDM systems with 16-QAM modulation

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and 16-QAM modulation. We can observe that the ZF-APP outperforms the SFBC with increasing iterations and achieves PER of $10^{-3}$ at an Eb/No of ~7.4dB after three iterations using 16-QAM modulation.

## V. Conclusions

We have investigated the use of iterative decoding based on zero-forcing detection and LDPC decoding in a MIMO-OFDM environment. It was shown that the proposed scheme performs effectively with high order modulation and outperforms the SFBC method with iterative decoding.

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