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Space-Time Carrier Interferometry Techniques with Low-density Parity Check Code for High-speed Multimedia Communications

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ABSTRACT

Carrier interferometry code is considered as a promising scheme that provides significant performance improvement via frequency diversity effect. Space-time coding is commonly employed to achieve a performance gain through space diversity. The combination of these techniques and forward error correction coding will lead to enhanced system capacity and performance. This paper presents a low-density parity check (LDPC) coded space-time orthogonal frequency division multiplexing (OFDM) transmission scheme with carrier interferometry code for high-capacity and high-performance mobile multimedia communications. Computer simulations demonstrate that the proposed mobile multimedia transmission system offers a considerable performance improvement of approximately 9dB in terms of Eb/No in the Rayleigh fading channel with relatively low delay spread, in comparison with space-time OFDM. Performance gains are further increased, comparing with traditional OFDM systems.

Keywords: Carrier Interferometry Code, Space-Time Codes, OFDM, LDPC

1. INTRODUCTION

OFDM transmission converts a high-speed serial input data stream into a low-speed parallel data stream over a number of subcarriers. The bandwidth of each subcarrier in OFDM needs to be smaller than the coherence bandwidth. This constraint is required to ensure that each subcarrier is considered as a narrowband transmission channel that undergoes flat fading. Therefore, OFDM exhibits high resistance against channel delay and thus is suitable for high-speed data transmission [1]. Indeed, OFDM has been adopted for a wide variety of applications, such as IEEE 802.11a and HIPERLAN/2 standards[2,3]. However, because each symbol arrives at the receiver with an independent fade, the performance of OFDM is often poor in deep fades. To compensate for this performance degradation, interleaving and channel coding are commonly used.

In future ubiquitous environments, a sophisticated mobile transmission system with high frequency efficiency (10b/s/Hz), high data rate (100Mbps or 1Gbps) and high-capacity is needed [4]. For an OFDM-based transmission system to meet these requirements, an OFDM with space- time coding has been proposed [5]. In addition, space-time OFDM combined with carrier interferometry (CI) codes was presented [6]. Adaptive OFDM with carrier interferometry codes has also been considered to further improve throughput and capacity[7]. The OFDM with carrier interferometry codes (CI/OFDM) is considered attractive as it offers frequency diversity through carrier interferometry codes without increasing system complexity and reducing throughput. The main idea of the carrier interferometry codes is to transmit each symbol with unique phase offsets over all available sub-

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carriers, instead of transmitting one symbol for each subcarrier.

Gallager [8] introduced a class of linear codes, known as low-density parity check (LDPC) codes, and presented iterative probabilistic decoding algorithm. Later, Tanner extended Gallager's probabilistic decoding algorithm to the more general case where the parity-checks are defined by subcodes, instead of simple single parity-check equations [9]. Earlier, it was shown that LDPC codes have a minimum distance that grows linearly with the code length and that errors up to the minimum distance could be corrected with a decoding algorithm with almost linear complexity. It was shown that irregular LDPC codes outperform turbo codes of approximately the same length and rate, when the block length is large [10]. The LDPC code of a rate 1/2 with a block length of 10,000,000 achieved a record 0.0045 dB away from the Shannon limit for binary transmission over an AWGN (Additive White Gaussian Noise) channel [11].

This paper considers an irregular LDPC code and space-time CI/OFDM to form a LDPC-coded space-time CI/OFDM for a high-capacity and high-performance mobile multimedia system. This system offers a power- and bandwidth-efficient transmission scheme for multimedia-rich mobile communication systems. In Section II, the principle of CI code is briefly presented. Section III describes the LDPC coded space-time CI/OFDM system. Computer simulations and their results are presented in Section IV. Finally, conclusions are drawn in Section V.

2. PRINCIPLE OF CI CODED TRANSMISSION

Carrier interferometry code is widely considered in multicarrier transmission systems as a performance-enhancing technology via frequency diversity effect. The CI code is defined as [6]

$$p(t)=\sum_{n=0}^{N-1}\cos(2\pi n\Delta f t) \tag{1}$$

Δf is frequency separation between subcarriers and is set to be $1/T_s$, where T_s is symbol period. It is found that the CI code has one mainlobe at t = $1/\Delta f$ and several sidelobes. N is the number of subcarriers. One of the most important properties of the CI code lies in correlation function. The correlation function of $p(t)$ is obtained as

$$\begin{aligned}R(\tau)&=\frac{1}{2\Delta f}\sum_{n=0}^{N-1}\cos(2\pi n\Delta f\tau)\\&=\frac{1}{2\Delta f}\frac{\sin(N\pi\Delta f\tau)}{\sin(\pi\Delta f\tau)}\cos(\pi(N-1)\Delta f\tau)\end{aligned} \tag{2}$$

This correlation function becomes zero at τ = $n/N\Delta f$ and $(2n-1)/2(N-1)\Delta f$, n = 0, 1, ..., $N-1$. In total, there are $2N-1$ zeroes when N is an odd number and $2N-3$ zeroes when N is an even number. The existence of many zeroes in the correlation function is exploited in multi-carrier transmission. That is, separating the CI codes with specified phase offsets will ensure orthogonality between the CI codes.

When the CI codes are applied in an OFDM-like multicarrier transmission systems, it is readily seen that the frequency diversity effect will yield via an optimum combining process at the receiver. Figure 1 illustrates the CI coded OFDM transmitter. Note that the CI coding (or often called CI modulation) is performed on each symbol over all available subcarriers in an OFDM block with pre-defined phase offsets determined by Eq.(2). At the receiver, each symbol is separated by the symbol-specific phase offset. The phase offsets used in the study is [6]

$$\Delta\theta_k=\frac{2\pi}{N}k,\quad k=0,1,\ldots\ldots,N-1 \tag{3}$$

Therefore, the CI coded transmit symbol can be written as

$$s(t)=\sum_{k=0}^{N-1}c_k\sum_{n=0}^{N-1}\cos\left(2\pi n\Delta f t-\frac{2\pi nk}{N}\right) \tag{4}$$

where c_k is the kth symbol. The transmitted symbol will undergo mobile radio transmission where attenuation, delay and interference will

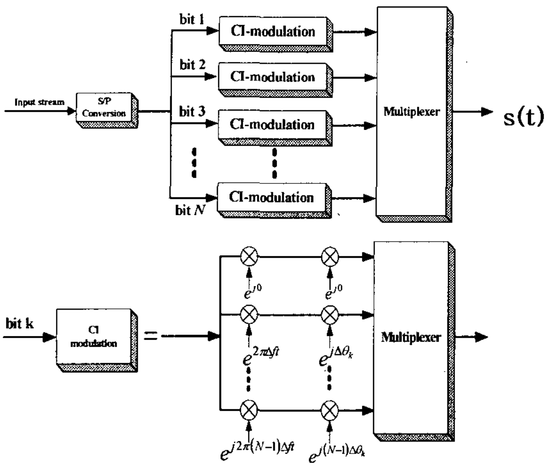

Fig. 1. CI/OFDM Transmitter.

occur. In addition, it will be affected by additive white Gaussian noise. Therefore, the received signal is then

$$r(t)=\sum_{k=0}^{N-1}c_k\sum_{n=0}^{N-1}\alpha_n\cos\left(2\pi n\Delta f(t-\tau_n)-\frac{2\pi nk}{N}+\phi_n\right)+n(t) \tag{5}$$

where α_n is channel fade on nth subcarrier, ϕ_n is channel phase of nth subcarrier, τ_n is channel delay on nth subcarrier and $n(t)$ is additive white Gaussian noise signal.

The received signal is now subject to a detection process to exploit frequency diversity effect from all available subcarriers. Among many combining techniques, the minimum mean square error (MMSE) detection is found to be optimum in a multicarrier transmission scheme and its detail is described in [12].

3. LDPC-CODED SPACE-TIME CARRIER INTERFEROMETRY OFDM

Based on the present CI/OFDM system, we present space-time coding combined with a LDPC code. The principle of the LDPC coding is well documented [8,13]. Instead, we focus on describing the principle of a space-time CI/OFDM transmission scheme. It should be noted that the detection strategy of the CI/OFDM needs to be modified to include a space-time decoding process. First, we consider a detection process for the Alamouti transmit diversity scheme [14] applied to OFDM with 2 transmit and receive antennas. Then we modify this to accommodate the MMSE detection of the CI codes in the space-time CI/OFDM.

In the Alamouti transmitter, input OFDM data symbols are divided into the two groups. That is,

$$s_k(m,j)=\begin{cases}c_k(m), & j=1\\ c_k(m+1), & j=2\end{cases} \tag{6}$$

$$s_k(m+1,j)=\begin{cases}-c_k^*(m+1), & j=1\\ c_k^*(m), & j=2\end{cases} \tag{7}$$

where j is the index of transmit antenna, k is the carrie index of OFDM transmission and m is time period.

In the receiver, assuming two receive antennas, the received signal is expressed as

$$r_k(m,i)=\sum_{j=1}^{2}h_k(m,i,j)s_k(m,i)+n_k(m,i) \tag{8}$$

where i is the index of the receive antenna, $h_k(m, i, j)$ is a complex fade factor during the transmission from the jth transmit antenna to ith receive antenna at time m.

The received data symbols $r_k(m, i)$ and $r_k(m+1, i)$ become the received estimates $\tilde{c}_k$ and $\tilde{c}_k(m+1)$ through a combining process.

$$\begin{aligned}\tilde{c}_k(m)&=r_k(m,1)h_k^*(m,1,1)+r_k(m,2)h_k^*(m,2,1)\\&+r_k^*(m+1,1)h_k(m+1,1,2)+r_k^*(m+1,2)h_k(m+1,2,2)\end{aligned} \tag{9}$$

$$\begin{aligned}\tilde{c}_k(m+1)&=r_k(m,1)h_k^*(m,1,2)+r_k(m,2)h_k^*(m+1,2,2)\\&-r_k^*(m+1,1)h_k(m+1,1,1)-r_k(m+1,2)h_k(m+1,2,1)\end{aligned} \tag{10}$$

The symbol * denotes complex conjugate operation. This detection scheme thus derived is valid for the space-time OFDM system. In the proposed LDPC-coded space-time CI/OFDM system, we need to perform CI decoding as well as space-time decoding. The decoding process of the proposed system is, therefore, described as follows. The Alamouti combining process as described in

Eq.(9) and Eq. (10) is first undertaken. This process facilitates space-time diversity effect on the system performance. The second decoding process is the CI decoding that is implemented via the minimum mean square estimation (MMSE). If we combine Eq.(9) and (10) with Eq.(5) and make some mathematical manipulation, we obtain

$$\tilde{c}_k(m)=\left[\sum_{i=1}^{2}\sum_{j=1}^{2}h_k^2(m,i,j)\right]c_k(m) + \sum_{l=0,l\neq k}^{N-1}\left[\sum_{i=1}^{2}\sum_{j=1}^{2}h_k^2(m,i,j)\right]c_l(m)\cos\left(\frac{2\pi nk}{N}+\Delta\theta_k-\frac{2\pi nl}{N}-\Delta\theta_l\right) + n_k(m) \tag{11}$$

$$\tilde{c}_k(m+1)=\left[\sum_{i=1}^{2}\sum_{j=1}^{2}h_k^2(m+1,i,j)\right]c_k(m+1) + \sum_{l=0,l\neq k}^{N-1}\left[\sum_{i=1}^{2}\sum_{j=1}^{2}h_k^2(m+1,i,j)\right]c_l(m)\cos\left(\frac{2\pi nk}{N}+\Delta\theta_k-\frac{2\pi nl}{N}-\Delta\theta_l\right) + n_k(m+1) \tag{12}$$

Therefore, the decision variable C_k is then

$$C_k=\sum_{k=0}^{N-1}\tilde{c}_k\frac{\frac{1}{\sqrt{2}}H}{\frac{N}{2}H^2+\frac{No}{2}H} \tag{13}$$

where H is given by

$$H=\sum_{i=1}^{2}\sum_{j=1}^{2}h_k^2(m,i,j) \tag{14}$$

In other words, the transmitted LDPC-coded space-time CI/OFDM data are generated by first applying an LDPC code to the input binary data. The LDPC-coded data are modulated using a BPSK scheme. The BPSK modulated data are submitted to the space-time CI/OFDM transmitter as described above. It should be noted that the space-time coding can be applied to the LDPC-coded CI/OFDM data without loss of generality as it can be treated as an independent process.

4. SIMULATIONS

In this paper, the LDPC coded space-time CI/OFDM system has been developed using the SPW simulation platform [15]. We have first simulated the performance of an irregular LDPC code (1008, 504) with a rate of 1/2 in an AWGN (Additive White Gaussian Noise) environment. The number of iteration is set to 100 and BPSK modulation is used. Figure 2 shows the BER performance of the LDPC code. It can be seen that it shows no errors at Eb/No values higher than 2dB. This performance is only 0.06dB worse at a BER of 10^{-3} than the previous reports [10]. This LDPC code is employed for the present system to further enhance the BER performance of the proposed system.

Figure 3 shows the top-level block diagram of the proposed system developed on SPW simulation platform. The first block is a composite block that encompasses the data source block, LDPC encoding, BPSK modulation and CI coded OFDM signal generation. Thus, the output of the first block is the LDPC encoded CI-OFDM signal and this is then passed to the space-time encoder, where the space-time encoding will take place as mentioned in Section III.

Figure 4 shows a block diagram of the mobile radio channel. In the present simulation, we limit the number of paths in the channel to 6. The output of the mobile radio channel block is passed to the receiver, where the reverse operation basically occurs. It is assumed that the channel state information is available at the receiver. As described

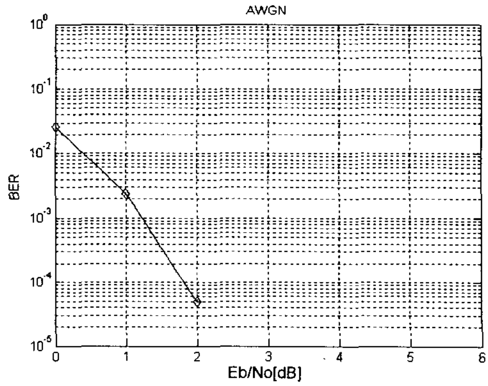

Fig. 2. Performance of the LDPC code in AWGN.

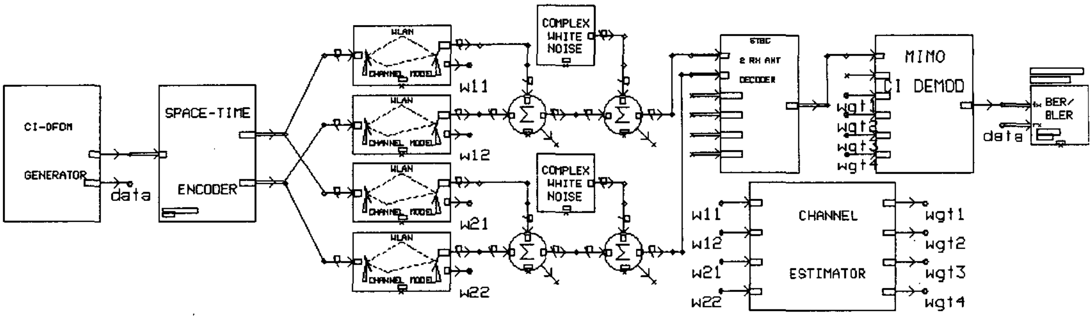

Fig. 3. Top-level block diagram of the LDPC-based space-time CI/OFDM system.

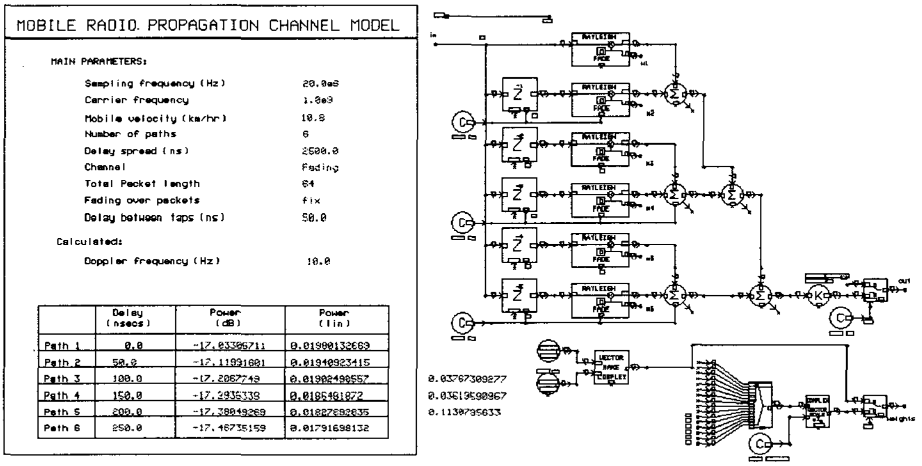

Fig. 4. Block diagram of mobile radio channel.

in Eq (11) and Eq. (12), space-time decoding via maximum likelihood detection and the minimum mean square error detection for the CI codes are implemented in the receiver to extract the transmitted symbols. Finally, a bit error rate is computed.

By making use of this system developed on the SPW, we have analyzed the performance of the proposed system under two channel scenarios: highly dispersive channel with a delay spread of 2500ns and moderately dispersive channel with a delay spread of 100ns.

4.1 Performance Comparison at the Delay Spread of 100ns

For the evaluation of the proposed system, we use an exponential delay profile [16] to create a frequency selective fading channel with a specified delay spread. The simulation parameters are as follows. We use a BPSK scheme for all simulations and the number of subcarriers is 64. The maximum Doppler frequency is 10Hz and the guard interval is 800ns. Figure 5 shows the BER performance of the proposed LDPC coded space-time CI/OFDM system in this relatively low dispersive channel. The figure also shows the performances of OFDM, space-time OFDM and CI/OFDM for comparison purpose under the same channel condition. It is clear that the LDPC coded space-time CI/OFDM presents superior performance, due to the combined effect of frequency and space diversity. It notes that the LDPC coded space-time CI/OFDM shows bit errors only at a SNR value of 0 dB.

4.2 Performance Comparison at the Delay Spread of 2500ns

A further performance analysis has been conducted

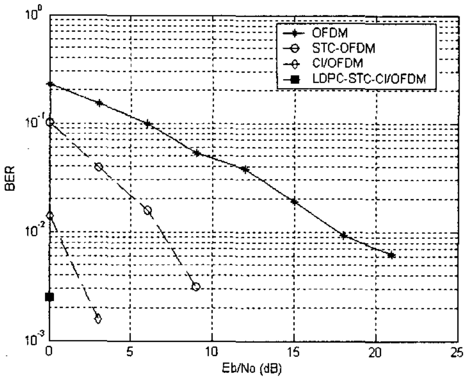

Fig. 5. Performance results for delay spread 100ns.

in a relatively high dispersive channel. The delay spread of this channel is now 2500ns. Figure 6 shows the BER performance for this channel. It can be seen that even with the presence of high delay spread, its performance shows improvements over other traditional schemes. For example, at the SNR value of 3dB, the performance improvement is more than an order of the magnitude over the STC-OFDM system. As CI/OFDM is known to be robust against high delay spread, we have also compared with the CI/OFDM. It is found that the proposed system still outperforms its performance. This superiority is a direct result from the constructive combining of the two diversity techniques. Therefore, suffice it to say that the proposed system is robust against dispersive channel behavior. This robustness will pave the way for a high-throughput, high-performance mobile multimedia transmission system.

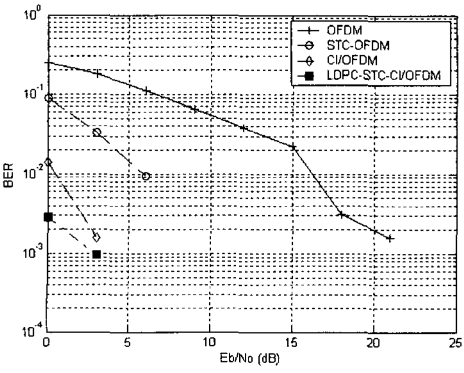

Fig. 6. Performance results for delay spread 2500ns.

5. CONCLUSIONS

This paper has considered a LDPC coded space-time CI/OFDM as a future high-speed high-performance mobile multimedia system. The proposed system achieves the frequency diversity from CI/OFDM as well as the space diversity from space-time encoding. This combined effects of frequency and space diversity together with a LDPC code yield a significant performance gain and robustness against channel dispersion. In addition, performance comparison demonstrates that the proposed system offers superior performance to existing multicarrier transmission systems. The benefits from the combined diversity effects are achieved at the expense of slightly increased complexity at the receiver.

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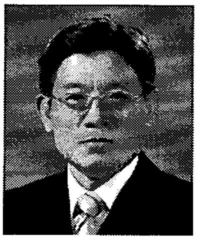

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