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An LDPC-COFDM based High Speed Mobile Wireless Communication System

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Abstract

Coded Orthogonal Frequency Division Multiplexing (COFDM) is very well matched to the terrestrial channel, being able to cope with severe multi-path and the presence of co-channel narrowband interference. This paper presents an image and video transmission scheme based on COFDM for high speed mobile wireless communication system in which a good Rate-Compatible Low-Density Parity-Check codes structure is applied, this structure can provide a large range of supporting rates, and provide very good error performance, low decoding latency and low computational complexity at the decoder. The test experiment was made in television live transmitting to validate the designed system. The results show that our COFDM-based mobile wireless digital multimedia broadcasting system can transmit high definition image and video when it being equipped for 486Kilometre/Hour's high speed rail, The Channel Bit Error Rate <2.0E-4 and Carrier to noise ratio(C/N) >30dB when the output power at 30dBm.

Keywords: *Rate-Compatible Low-Density Parity-Check codes, image and video transmission, Coded Orthogonal Frequency Division Multiplexing*

1. Introduction

OFDM is a special form of multi-carrier transmission, where a single data stream is transmitted over a number of lower-rate sub-carriers. This technique is especially suitable for frequency selective channels and high data rates. One of the main reasons to use OFDM is to increase robustness against frequency-selective fading or narrowband interference. Moreover, the ingenious introduction of cyclic redundancy at the transmitter reduces the complexity to only FFT processing and one tap scalar equalization at the receiver [1]. OFDM-based communication systems "were first conceived and implemented in the 1960s, but it was not until their all-digital implementation with the FFT that their attractive features were unraveled and sparked widespread interest for adoption in various single-user and multiple access communication standards" [2]. In 1971, Weinstein and Ebert applied the discrete Fourier transform (DFT) to parallel-data-transmission systems as part of the modulation and demodulation process [3]. In 1981, An OFDM system was realized through multiplexed quadrature amplitude modulation (QAM) using DFT [4]. After the 1990s, Some systems of current applications using OFDM include General Switched Telephone Network (GSTN), Cellular radio, DSL & ADSL modems, Digital Audio Broadcasting (DAB) radio, Terrestrial Digital Video Broadcasting (DVB-T), High-Definition television (HDTV) terrestrial broadcasting, and the wireless networking standard IEEE 802.11 were implemented [5, 6].

As a special case of coded diversity used in OFDM, COFDM schemes is analogous to OFDM except that forward error correction (FEC) is applied to the signal before transmission [7]. FEC is able to overcome errors in the transmission due to loss of carriers from frequency selective fading, channel noise and other propagation effects. COFDM overcomes these problems of high speed data

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transmission in wireless environment while keeping intact the bandwidth utilization efficiency of normal OFDM [8, 9].

In this paper, a COFDM-based mobile wireless communication system for image and video transmission has been successfully realized using Rate-Compatible Low-Density Parity-Check codes (RC-LDPC).The organization of the paper is as follows: Section 2 introduces the principles of COFDM and its system model. In Section 3, we give a brief introduction to the implementation of a practical COFDM System for image and video transmission. Section 4 describes the test experiment in a high speed rail environment using designed COFDM system. Conclusions are given in Section 5.

2. Principles of COFDM and System Model

The basic principle of COFDM is to split a high-rate serial data stream into a set of lower-rate sub-streams to be transmitted simultaneously over a number of sub-carriers (SCs), each of a different frequency and these SCs are orthogonal to each other. The three main modules of the COFDM system are FEC coding/interleaving, IDFT/DFT and Cyclic prefix /Guard interval.

Figure 1 shows the block diagram of a simplex point-to-point transmission system using COFDM.

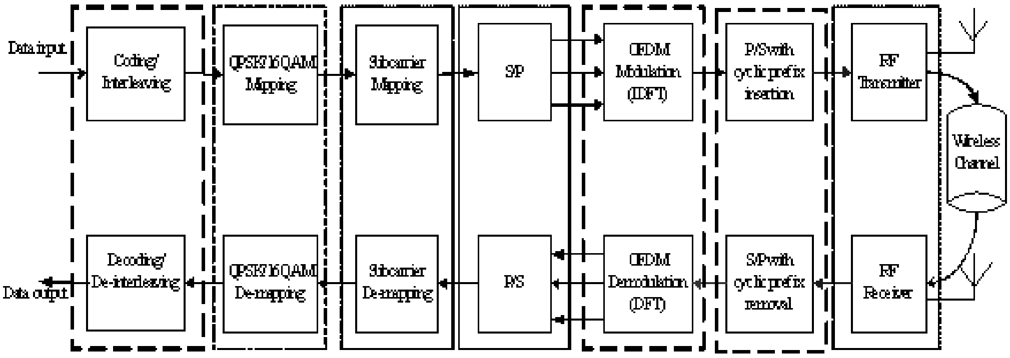


Figure 1. COFDM Block Diagram

2.1. FEC Coding and Interleaving

COFDM is invariably used together with FEC (channel coding), and almost always uses frequency and time interleaving. The frequency-selective radio channel may severely attenuate the data symbols transmitted on one or several SCs, leading to bit errors. Spreading the coded bits over the bandwidth of the transmitted system, an efficient coding scheme can correct for the erroneous bits and thereby exploit the wideband channel’s frequency diversity [1].

The reason why interleaving is used on COFDM is to attempt to spread the errors out in the bit-stream that is presented to the error correction decoder, because when such decoders are presented with a high concentration of errors the decoder is unable to correct all the bit errors, and a burst of uncorrected errors occurs.

LDPC codes have been shown to significantly outperform 3GPP turbo codes in the throughput requirement of the future LTE system [10]. In this paper we employ a good RC- LDPC codes structure, which similar to those proposed in Ref. [11] are suitable for high-speed together with efficient hardware implementation because their parity-check matrices have simple cyclic or quasi-cyclic structure, and the encoders can be implemented based on shift registers and modulo two adders. The encoding procedure is as follows:

Step 1, Pre-processing, The LDPC codes can be defined by a sparse binary parity check matrix $H_{m\times n}$ and all the rows are linearly independent, where m and n are the number of parity symbols and codeword symbols respectively.

Let the parity-check matrix H be represented as $H = \begin{pmatrix} A & B & T \\ C & D & E \end{pmatrix}$.

Then, H can be visualized through Figure 2, where the dimension of A is $(m-g)\times(n-m)$, B is $(m-g)\times g$, T is $(m-g)\times(m-g)$, C is $g\times(n-m)$, D is $g\times g$ and E is $g\times(m-g)$. Furthermore, the matrix T is a lower triangular with ones on the diagonal. In the triangularization, we shall choose g arbitrarily small.

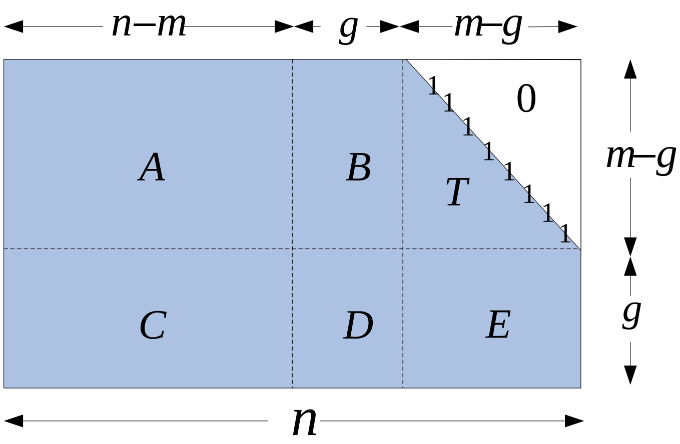


Figure 2. The Parity Check Matrix with Approximated Lower-triangular Structure

Suppose that the input information bit is k and the parity-check bits through encoding process is p_1, p_2, then these two parts can form a single codeword $w=(k, p_1, p_2)$, which satisfies $Hw^T = 0$.

Multiply H with the matrix Z from the left-hand side, thus we can get the matrix $\hat{H}$.

$$Z = \begin{pmatrix} I & 0 \\ -ET^{-1} & I \end{pmatrix} \tag{1}$$

$$\hat{H} = \begin{pmatrix} I & 0 \\ -ET^{-1} & I \end{pmatrix} \cdot \begin{pmatrix} A & B & T \\ C & D & E \end{pmatrix} = \begin{pmatrix} A & B & T \\ -ET^{-1}A + C & -ET^{-1}B + D & 0 \end{pmatrix} \tag{2}$$

Check whether $-ET^{-1}B + D$ is singular or not. If it is singular, rearrange the matrix with the previous columns until it is nonsingular.

Step 2, Encoding, from the equation $Hw^T = 0$, we obtain following equation:

$$\begin{cases} Ak^T + Bp_1^T + Tp_2^T = 0 \\ (-ET^{-1}A + C)k^T + (-ET^{-1}B + D)P_1^T = 0 \end{cases} \tag{3}$$

Solve the equation (3), we can get p_1 and p_2:

$$\begin{aligned} p_1^T &= -(-ET^{-1}B + D)^{-1}(-ET^{-1}A + C)k^T \\ p_2^T &= -T^{-1}(Ak^T + Bp_1^T) \end{aligned} \tag{4}$$

Thus, we can calculate the parity-check bits and obtain the codeword w.

2.2. The IDFT and the DFT

The IDFT and the DFT are used for, respectively, modulating and demodulating the data constellations on the orthogonal SCs. The Fast Fourier Transform (FFT) and the Inverse Fast Fourier Transform (IFFT) are the more efficient implementations of the DFT, which are utilized for the base-band COFDM modulation and demodulation process as showed in Figure 1.

The direct evaluation of an N-point DFT is done using the following formula:

$$X(k) = \sum_{n=0}^{N-1} x(n) \cdot e^{-(j2\pi nk/N)} \qquad 0 \le n \le N\text{-}1 \tag{5}$$

And its associated inverse is denoted by:

$$x(n) = \frac{1}{N} \sum_{n=0}^{N-1} X(k) \cdot e^{j\frac{2\pi}{N}kn} \qquad 0 \le n \le N\text{-}1 \tag{6}$$

Where N is the number of DFT points, k = 0, 1, 2…….N-1. DFT requires N^2 complex multiplications and N*(N-1) complex additions whereas use of FFT algorithm reduces the number of computations to the order of $(N \cdot \log_2^N)/2$ complex multiplications and $N \cdot \log_2^N$ additions. Moreover FFT algorithm works efficiently when N is a power of 2, therefore the number of sub-carriers is usually kept as power of 2. IFFT/FFT operation ensures that sub-carriers do not interfere with each other. IFFT is used at the transmitter to obtain the time domain samples of the multi-carrier signal. FFT is used to retrieve the data sent on individual sub-carriers. Therefore COFDM has a very simple implementation capability.

2.3. Cyclic Prefix and Guard Interval

To avoid inter symbol interference (ISI) caused by multi-path fading, a guard interval of length is inserted between every COFDM symbol. During this interval, a cyclic prefix is transmitted to avoid Inter-carrier Interference (ICI) [12, 13]. The Cyclic Prefix is a periodic extension of the last part of a COFDM symbol that is added to the front of the symbol in the transmitter, and is removed at the receiver before demodulation.

For simplicity, let’s assume that we have an OFDM transmission of two OFDM symbols with two loaded sub-carriers. In a multi-path fading channel, the received signal can be illustrated as Figure 3.

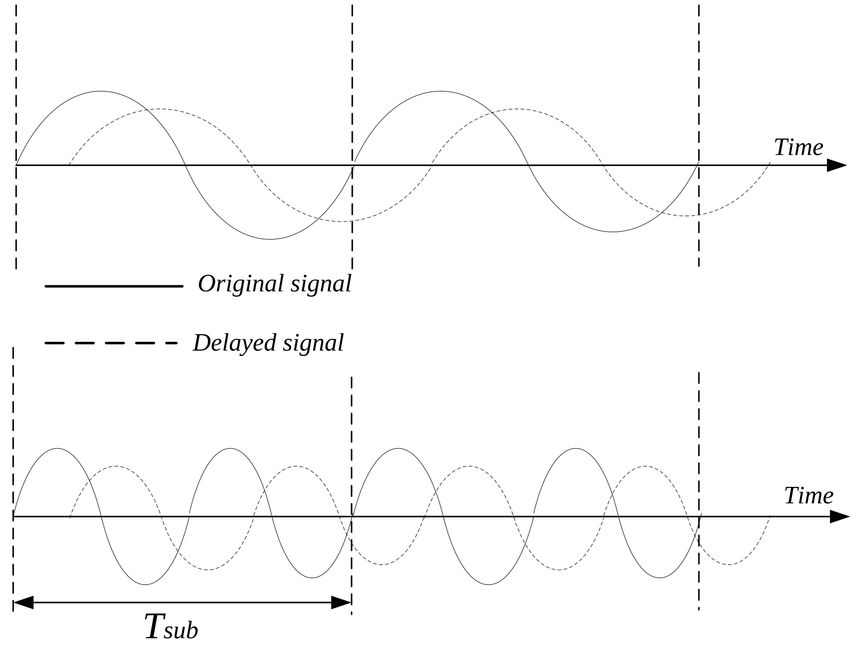


Figure 3.The Received Signal a Multi-path Fading Channel

Because we have a delayed copy of the original signal coming through our receive antenna, we can see that a portion of the first OFDM symbol creates interference with the second one, thus changing its amplitude and phase. On the low frequency sub-carrier, this effect is less dramatic but on the second sub-carrier there is no way to recuperate the information. The cyclic prefix can solve our problem. A cyclic prefix is a copy of a portion of the end of an OFDM symbol which is put in front of each transmitted OFDM symbol, as is shown in Figure 4.

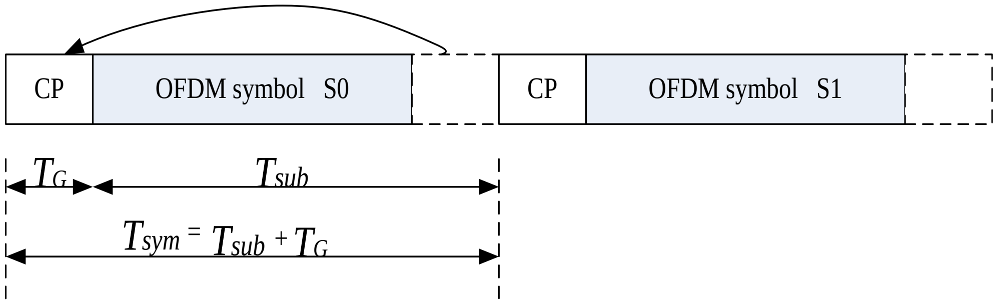


Figure 4. OFDM Symbol with CP

The disadvantage of the Cyclic Prefix is that there is a reduction in the Signal to Noise Ratio due to a lower efficiency by duplicating the symbol. However, it greatly reduces the ISI problem, as shown on the Figure 5.

We can easily see that the cyclic prefix of length TG on the second OFDM symbol absorbs the delayed portion of the first OFDM symbol. By eliminating the cyclic prefix portion of each OFDM symbol before decoding, all the samples processed by the FFT algorithm will belong to only one OFDM symbol, thus solving our ISI problem at the cost of a reduced data rate.

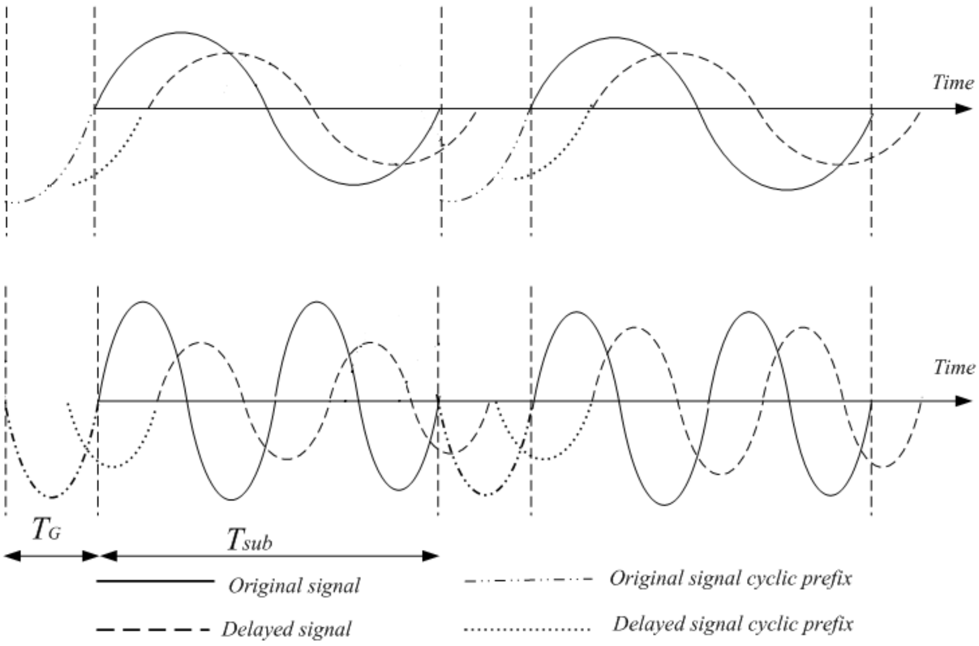


Figure 5. The Effect of the Length of Cyclic Prefix

3. Implementation

The implementation process of COFDM is as follows:

1) The input data bits are convolutionally encoded with a code rate R= 1/2, 2/3, 3/4 or 7/8, corresponding to the desired data rate.

2) The encoded data stream is bit-interleaved and then modulated using QPSK/16-QAM as per gray coded constellation mapping.

3) The complex symbols are modulated by OFDM modulator.

Mathematically, the OFDM signal is expressed as a sum of the prototype pulses shifted in the time and frequency directions and multiplied by the data symbols.

If we sample the transmitted continuous-time notation signal $s(t)$ at rate $1/T_s$ during time interval $n\tau_0 \le t < (n+1)\tau_0$ and normalize it by $\sqrt{\tau_0}$, then we can get:

$$\begin{aligned} s_n(k) \triangleq s(n\tau_0 + kT_s) &= \sum_{m=0}^{N-1} x_{m,n} e^{j2\pi mFkT_s} \\ &= \sum_{m=0}^{N-1} x_{m,n} e^{j2\pi\frac{mk}{N}} \end{aligned} \tag{7}$$

$n \in \mathbb{Z}$, $k = 0,1,\ldots,N-1$; $m = 0,1,\ldots,N-1$.

Where τ_0 is the OFDM symbol duration, $x_{m,n}$ denotes the baseband modulated information symbol conveyed by the sub-carrier of index m during the symbol time of index n.

The sampled transmitted signal $s_n(k)$ is the IDFT of the modulated baseband symbols $x_{m,n}$ during the same time interval. Therefore the OFDM modulator at the transmitter side can be replaced by an IDFT block.

Similarly, in the receiver, we sample the received signal $y(t)$ at the same rate $1/T_s$ normalize it by $\sqrt{\tau_0}$, then we can obtain the output of the l_{th} branch during time interval $n\tau_0 \le t < (n+1)\tau_0$.

$$\tilde{x}_n(l) = \sum_{m=0}^{N-1} y(n\tau_0 + mT_s)e^{-j2\pi\frac{ml}{N}}$$

$$= \sum_{m=0}^{N-1} y_n(m)e^{-j2\pi\frac{ml}{N}}$$

$n \in \mathbb{Z}$, $l = 0,1,\ldots,N-1$; $m = 0,1,\ldots,N-1$.

The demodulated symbol $\tilde{x}_n(l)$ is the DFT of the received signal $y_n(m)$.

Let $s_n = [s_n(0), s_n(1), \ldots, s_n(N-1)]^T$,

$x_n = [x_{0,n}, x_{1,n}, \ldots, x_{N-1,n}]^T$,

$y_n = [y_n(0), y_n(1), \ldots, y_n(N-1)]^T$,

Then $s_n = IDFT(x_n)$

$\tilde{x}_n = DFT(y_n)$

Consequently, the whole system of COFDM can be efficiently implemented by the FFT/IFFT module.

A Practical COFDM-based wireless communications system is designed based on TI processor TMS320DM642. The COFDM-based transmitter is shown in Figure 6.

In the implementation process of a practical system, we must pay more attention to some hardware related design considerations, which are often neglected in theoretical studies. For example, the transmission scheme must be able to cope with time-dispersive nature of the mobile channel. The signal should occupy as little bandwidth as possible and introduce a minimum amount of interference to systems on adjacent channels.

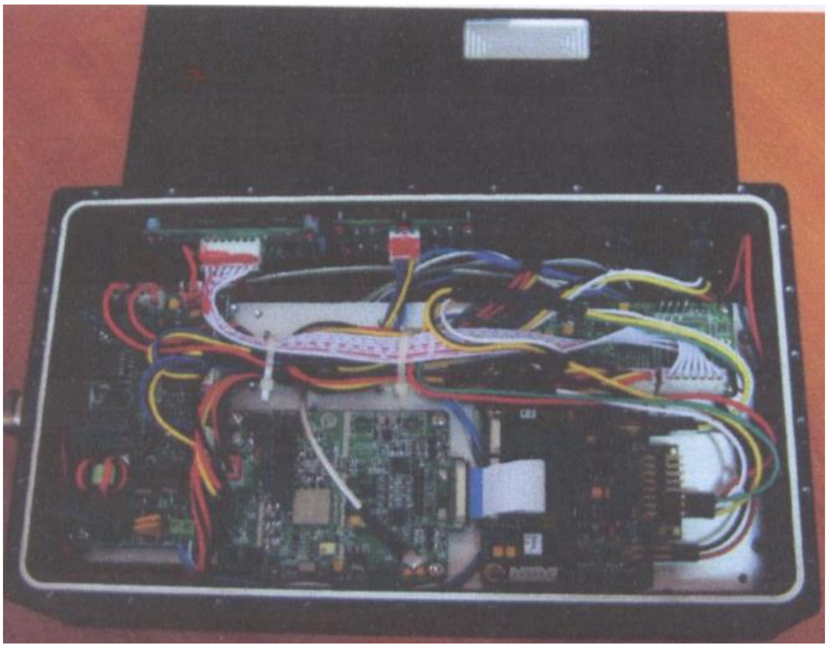


Figure 6. The Transmitter

4. Results

Table 1 Summarises the main parameters of our COFDM system.

Table 1. The Main Parameters of our COFDM System

Parameters	Values
Output frequency range	336MHz~344MHz
Radio frequency bandwidth	6/7/8MHz
The output power	18~33dBm-Adjustable, 1dBm-step by step
Carrier to noise ratio(C/N)	30dB @ 30dBm
Second harmonic	>52dBc
Encryption	AES/ALLTECH Basic Scrambling
Modulation method	COFDM
Modulation constellation	QPSK/16QAM/64QAM@ 6/7/8MHz
FEC	1/2,2/3,3/4,5/6,7/8
The carrier pattern	2K
Video coding	MPEG-2/MPEG-4
The input video signal	1Vp-p@75Ω,PAL
Video resolution	720×576(PAL) 720×480(NTSC)
Power flatness	All frequencies≤2dB,with in 8MHz≤0.5dB
Audio and video interface	BNC/RCA
Video rate	15Mbps(MAX)
CBER (Channel Bit Error Rate)	<2.0E-4

The PSA Series Spectrum Analyzer (Agilent E4440A) was used to test the output spectrum. The output spectrum of the proposed system is depicted in Figure 7.

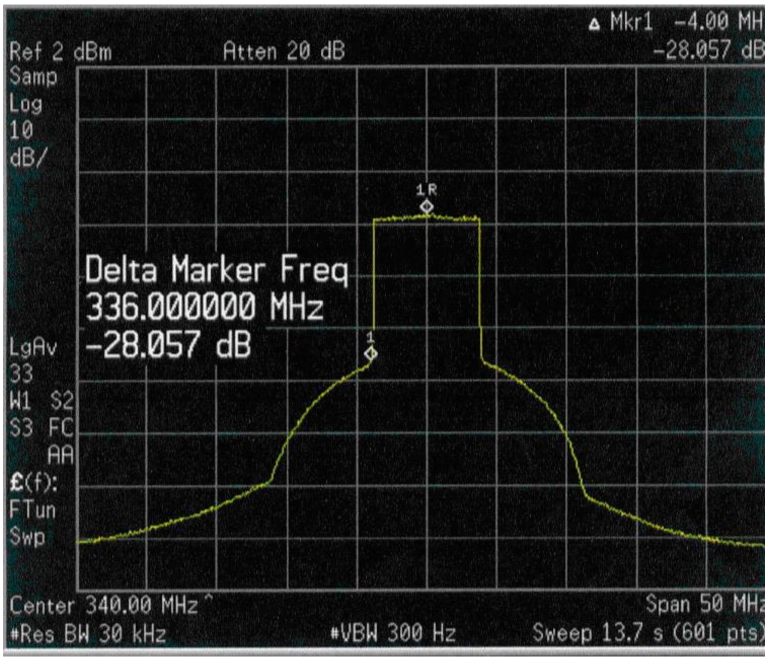
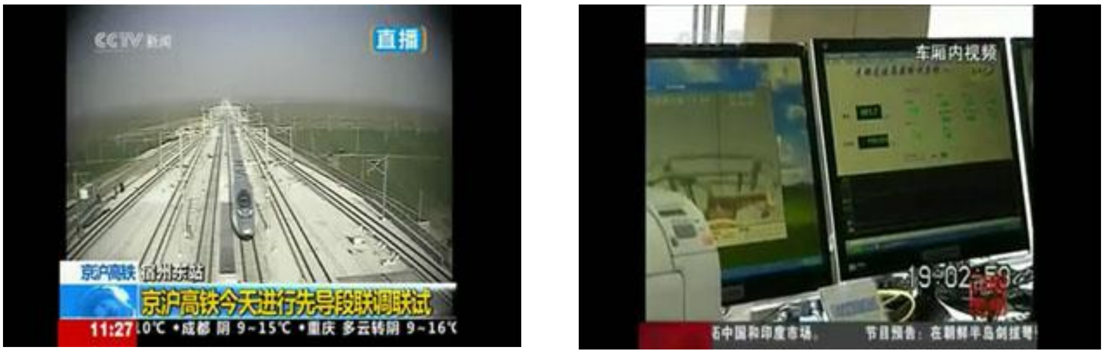


Figure 7. The Out Spectrum of our COFDM System

The designed system was used in China Central Television (CCTV) live coverage of the joint debugging from Xuzhou to Bengbu in Beijing-Shanghai high-speed railway. The results show that our COFDM-based mobile wireless communication system can transmit high definition image and video in 486Kilometre/Hour's high speed rail. The live images are shown in the Figure 8.



(a) Outside of Railway Carriage (b) Inside of Railway Carriage

Figure 8. The Live Images

5. Conclusions

We have described an LDPC-coded OFDM system, and a good RC LDPC code structure has been presented to provide a series of RC LDPC codes for a wide range of supporting rates.The wireless mobile digital multimedia broadcasting system which has the advantages such as it can realize the stable transmission of video with the high probabilities in the out-of-sight and blocked environments of city, mountain and building, it is suitable for high-speed transmission, high bandwidth, high code stream, high-quality audio and video. The test experiment was made in television live transmitting to validate the designed system. The results show that our COFDM-based mobile wireless communication system can transmit high definition image and video when it being equipped for 486Kilometre/Hour's high speed rail, The Channel Bit Error Rate <2.0E-4 and Carrier to noise ratio(C/N) >30dB when the output power at 30dBm.

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