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주파수선택성 페이딩을 갖는 통신로에 격자부호 직교주파수분할 다중통신방식의 성능 분석

(An Analysis of Trellis-Coded Orthogonal Frequency Division Multiplex over Frequency-Selective Fading Channel)

서 희 종*, 張 克**

(Heejong Suh and Ke Zhang)

요 약

본 논문에서는 시간분산 통신로에 주파수선택성 페이딩과 다중경로 페이딩을 극복하기 위해서, 격자부호 변조와 OFDM을 결합한, 격자부호 직교주파수분할 다중통신방식(TC-OFDM) 시스템의 성능을 분석한다. 시간분산 통신로를 대상으로 부호율 2/3인 격자부호 8DPSK- OFDM의 BER 성능을 모의실험하고 분석한다. OFDM의 여러 반송파 수에 대한 격자부호의 설계를 논의한다. 실험결과, BER 10^{-3}에서 TC-OFDM 시스템은 부호화를 하지 않은 OFDM 시스템에 비해서 6 dB 부호이득을 얻을 수 있음을 알았다.

Abstract

In this paper, we review a trellis-coded orthogonal frequency division multiplex (TC-OFDM) system, which combines OFDM with trellis-coded modulation, for overcoming the frequency selective and multipath fading of time dispersive channels. We simulate and analyse the BER performance of rate 2/3 trellis coded 8DPSK-OFDM over time dispersive channels. Design of the trellis codes at different carrier numbers of OFDM is discussed. Results show that TC-OFDM system can provide 6 dB coding gain at a BER of 10^{-3} compared with OFDM system without coding.

Keywords : Orthogonal frequency division multiplex(OFDM), trellis-coded modulation (TCM), fading channel, DPSK

I. Introduction

In Digital Mobile Communication, the modulated signal is significantly influenced by multipath fading and Doppler frequency shifting, due to the presence of multipath propagation that would degrade the system performance. To solve this problem, the methods of suited digital modulation technology and effective channel coding have to be taken.

Recently, multicarrier modulation scheme, often called orthogonal frequency division multiplex (OFDM), has attracted increasing interest and received a lot of attention in the radio communication and multimedia communication [1,2,3,4], because of its simple structure, high spectral efficiency and inherent resistance to multipath fading. In Europe, OFDM modulation was standardized for digital audio broadcasting (DAB) and terrestrial digital video broadcasting in the mid 1990s [5,6]. Most recently, OFDM modulation has also been proposed for

* 정회원, 여수대학교 전자통신전기공학부
(Division of Electronic Communication and Electrical Engineering, Yosu National University)
** 북경석유화공학원 정보공학과
(Dept. of Information Engineering, Beijing Institute of Petro-Chemical Technology, China)
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wireless packet transmission with high data rate, known as wireless LAN as standardized in HIPER LAN/2 and IEEE 802.11a.

But only with the OFDM all the influences of the frequency selectivity can not be eliminated. To solve this, as one method, TC modulation method can be adopted, which can improve the performance of the communication system without adding the signal power and bandwidth[7].

In this paper, for studying the effects of frequency selective and multipath fading time dispersive channels we combine OFDM with trellis-coded modulation, analyse the BER performance of rate 2/3 trellis coded 8DPSK-OFDM over time dispersive channel [8], and discuss a design of trellis codes with the different carrier numbers of OFDM. With OFDM we can get a 6 dB coding gain at BER of 10^{-3} compared to OFDM system without coding.

In next Section, we explain a basic OFDM system, in Section III, the combination of Trellis-coded and OFDM is proposed, in Section IV there are simulation and its results, and in Section V we conclude. References are followed.

II. Orthogonal Frequency Division Modulation(OFDM)

In traditional digital communication system, the symbol sequence was modulated on a single carrier to be transmitted. So each symbol spectrum utilize all channel bandwidth. In OFDM system, which is a parallel transmission system, available bandwidth is partition into N subchannels, then the symbol duration is N times larger than that of the single carrier system with the same symbol rate. This reduces normalized delay spread significantly, hence is more robust to time dispersive wireless channel. Orthogonality among subcarriers is achieved by selecting the carrier frequencies such that each OFDM symbol interval contains integer number of period for all subcarriers. At receiver, by the orthogonality of subcarriers, the transmitted informa

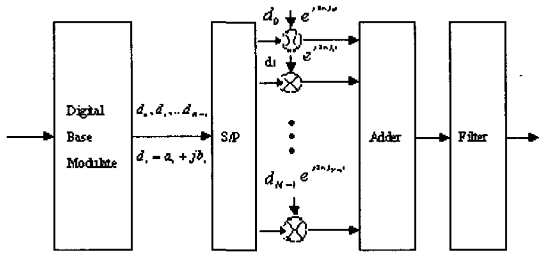

그림 1. 직교주파수분할 다중통신방식(OFDM) 방법
Fig. 1. Orthogonal frequency division multiplex(OFDM) method.

-tion can be nondestructively received in order to improve the system spectrum efficiency.

In Fig. 1, the basic OFDM is explained. Consi-dering the transmitted sequence in one period(d_0, $d_1, \cdots, d_{N-1}$), each symbol d_i modulated by base is a complex signal $d_i = a_i + jb_i$. The interval of series symbol sequence is $\triangle t = 1/fs$, where fs is system symbol transmission rate. After the transform from series to parallel (S/P), they modulate the subcarriers respectively($f_0, f_1, \cdots, f_{N-1}$). The N subcarriers take frequency division multiplex in total channel bandwidth, a interval of frequency between two closed ones is $1/T$, symbol period add to $N\triangle t$ from $\triangle t$, and the joint transmitted signal $D(t)$ can be written by its low-pass complex envelop :

$$D(t) = \sum_{i=0}^{N-1} (a_i + jb_i)(cosw_i t + jsinw_i t) = \sum_{i=0}^{N-1} d_i exp(jw_i t), \quad 0 \leqq t \leqq T \tag{1}$$

When $w_i = 2\pi\triangle f_i$, $\triangle f = 1/T = 1/N\triangle t$

In symbol period [0, T], the transmitted signal is inverse Discrete Fourier Transform(IDFT) of d_i, as follows.

$$D(t) = \sum_{i=0}^{N-1} d_i exp(j2\pi im/N) = IDFT\{d_i\}, \quad 0 \leqq m \tag{2}$$

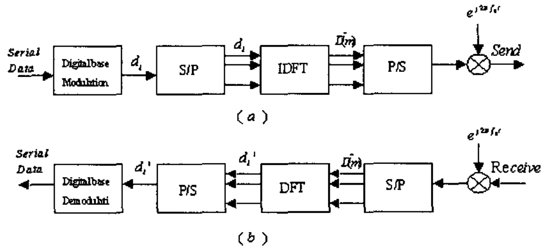

그림 2. OFDM 송신기와 수신기. (a) 변조기 (b) 복조기
Fig. 2. OFDM Transmitter and Receiver. (a) Modulator (b) Demodulator

Sampling $D(t)$ with rate at fs, there are N samples in a period. Let $t = m\triangle t$, sample sequence $\tilde{D}(m)$ can be written by IDFT of symbol sequence $(d_0,\ d_1, \cdots,\ d_{N-1})$,

$$\begin{aligned}\tilde{D}(m) &= \sum_{i=0}^{N-1} d_i exp\,(j2\pi m/N) \\ &= IDFT\{d_i\},\ 0 \leq m < N\end{aligned} \tag{3}$$

Thus, the system modulation and demodulation are equivalent to IDFT and Discrete Fourier Transform (DFT).

In Fig. 2(a) and Fig. 2(b), the diagram of a transmitter and a receiver are given respectively. As shown in Fig. 2, with IDFT, it is easy to achieve when DSP and FFT are taken.

Based on OFDM system, IDFT is used in the transmitter to achieve orthogonality among subcarriers, and a DFT is used in receiver. In this system, Guard time, which is cyclically extended, must be added in between OFDM symbols. That is longer than the maximum delay spread to total eliminate intersymbol interference. while mitigating the N symbol interference, OFDM can also spread the fading in total band.

Ⅲ. Trellis-coded OFDM

OFDM can effectively overcome the influence of frequency selectivity on system, and spread the multipath fading among symbols. But with this

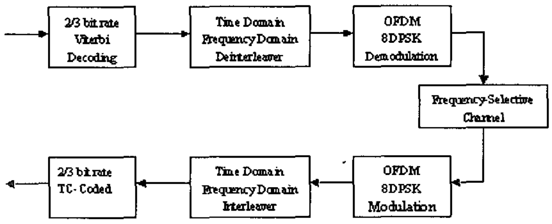

그림 3. TC-OFDM 시스템 도
Fig. 3. Diagram of TC-OFDM System.

OFDM, all the influences can not be eliminated. To solve this problem, an efficient channel coding scheme has to be used. We will adopt the trellis-coded modulation (TCM) method developed by Ungerboeck [7]. By combining the channel coding and modulation, the coding gain was improved.

Based on this knowledge, we combine the trellis-coded modulation and OFDM, in order to improve the transmission reliability and efficiency. The trellis-coded(TC)-8DPSK is explained, in this diagram trellis codes is either Ungerboeck or Costello code. The coding method is as follow : In each symbol period, the input information $x_i^0,\ x_i^1$ are 2 bits which is coded into 3 bits $z_i^0,\ z_i^1,\ z_i^2$ by trellis as the ith subcarrier. The $z_i^0,\ z_i^1,\ z_i^2$ are mapped onto modulation constellation. Selecting one of them be the modulated signal for the ith subchannel, the result state of ith subchannel become the initial state of the $(i+1)$th subchannel, then for the $(i+1)$th subchannel there will do coding.

So, the transmitted signal is as follows.

$$\begin{aligned}D(t) = \ \mathrm{Re}\Big\{ &\sum_{i=0}^{\infty} \sum_{k=0}^{N-1} \{d_{i,k} \\ &\exp(j2\pi f_k(t-iT))\} u(t-iT)\Big\}\end{aligned} \tag{4}$$

where $d_{i,k}$ is a complex sequence for kth subcarrier modulated by ith symbol ; $u(t)$ is unit step function. Because the fading is very slow, transmission rate of each subcarrier is considered as flat. Let channel factor be $h_{i,k}$ the frequency response of the kth subcarrier in

ith symbol period. Then, the received signal is

$$R(t) = \mathrm{Re}\left\{\sum_{i=0}^{\infty}\sum_{k=0}^{N-1} d_{i,k}h_{i,k}\times exp(j2\pi f_k(t-iT))u(t-iT) + n(t)\right. \quad (5)$$

In the equation (5), $d_{i,k}h_{i,k}$ is the demodulated output $r_{i,k}(\doteq d_{i,k}h_{i,k})$ of OFDM receiver by FFT without additive noise.

To restore the transmitted information $d_{i,k}$ cor-rectly, the transmission factor $h_{i,k}$ has to be estimated in receiver. In general, a pilot has to be inserted in each subcarrier, and the receiver gets estimate one from pilot signal to demodulate output. This approach can be considered as flat, and there will be accuracy if the estimate process could follow the slow variance of fading channel. Then, $\tilde{h}_{i,k} = h_{i,k}$ thus $\tilde{d}_{i,k} \approx d_{i,k}$.

In real time dispersive channel, the estimation for transmission factor is hardly adapted to time variance of channel. So, ideal information from channel output can not be gained. Where 8DPSK difference modulation is taken. Each subcarrier difference computation carried out between the current symbol period and previous one. The output of kth coder in ith period is mapped on 8PSK constellation, base modulated output is $b_{i,k} = e^{jn2\pi/8}$, where n is according to the output of trellis-coder, and then the current difference modulation output is

$$\begin{aligned} d_{i,k} &= b_{i,k}d_{i-1,k} \\ &= d_{i-1,k}e^{jn2\pi/8} \end{aligned} \quad (6)$$

When computing the kth subcarrier in the ith subchannel of OFDM, modulated output is as follows.

$$\begin{aligned} r_{i,k} &= d_{i,k}h_{i,k} \\ &= b_{i,k}d_{i-1,k}h_{i,k} \end{aligned} \quad (7)$$

Assume the channel transmission factor of one subcarrier in near symbol period is same if the channel fading vary slowly, i.e. $h_{i-1,k} \approx h_{i,k}$, then the output of difference decoder, $\tilde{b}_{i,k}$, is

$$\begin{aligned} \tilde{b}_{i,k} &= \frac{r_{i,k}}{r_{i-1,k}} \\ &= b_{i,k}\frac{h_{i,k}}{h_{i-1,k}} \approx b_{i,k} \end{aligned} \quad (8)$$

The equation (8) shows that the difference modulation need not insert pilot, and the receiver need not estimate the channel transmission factor for every subchannel. It reduce the computation complexity. And, difference demodulation only lie on the approximate flat between adjacent symbol periods for fading channel.

Ⅳ. Simulation and Results

In this section, we present some computer simulation results of BER performance on the TC-OFDM. The performance improvement of the TC-OFDM is investigated based on the Monte-Carlo method. In simulation, we adopted the fading channel model in [7] and let Rice factor be 5. In receiver, it is assumed that the output can restore ideally the carriers and the decoding is performed based on soft decision Viterbi decoder.

Fig. 4(a) show the bit error probability of the TC-OFDM system with the $N=64$ subcarriers number and Ungerboeck codes. At the 10^{-3} bit error rate (BER), the TC-OFDM system demonstra-tes improvement of 6 dB over the uncoded OFDM-QPSK system. Fig. 4(b) show the BER with Costello codes. Comparing with Fig. 4(a), the performance is better than that of Ungerboeck codes in same state. At BER 10^{-3}, the system of Costello codes improves the performance 0.5~1.5 dB over the system of Ungerboeck codes. Fig. 4(c) and (d) show the BER of TC-OFDM for subcarriers number $N=256$. These BER are better than that for $N=64$. When $N=256$, the system of Ungerboeck codes gains lower BER than that of Costello codes. When N is small, the average effects of fading in OFDM

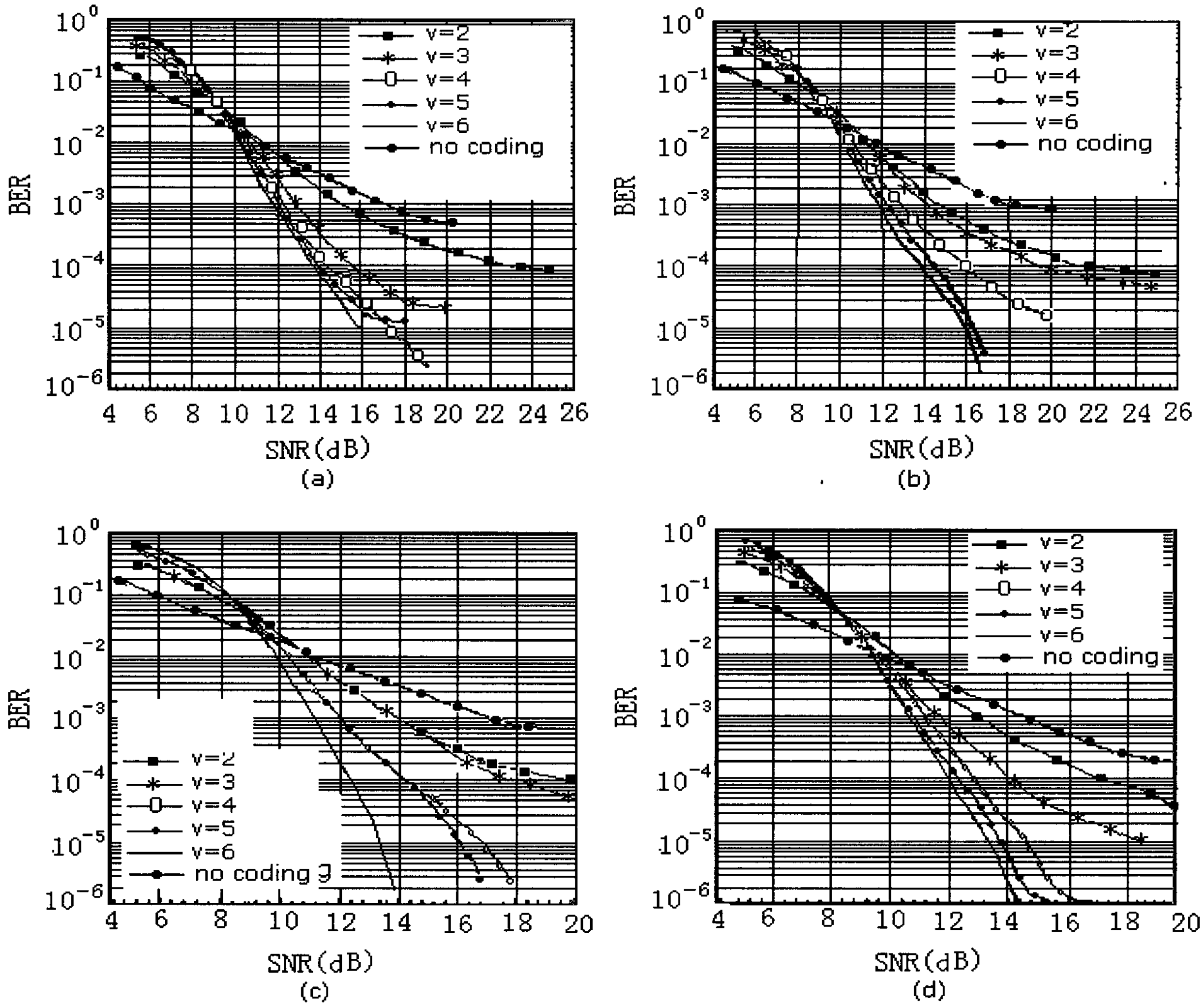

그림 4. TC-OFDM 시스템의 BER 성능 (a) Ungerboeck 부호, $N=64$
(b) Costello 부호, $N=64$ (c) Ungerboeck 부호, $N=256$ (d) Costello 부호, $N=256$

Fig. 4. BER performance of TC-OFDM system. (a) Ungerboeck codes, $N=64$
(b) Costello codes, $N=64$ (c) Ungerboeck codes, $N=256$ (d) Costello codes, $N=256$

is slight. Therefore the performance of Costello codes system is the optimum. But, as N improves, OFDM spread too many independent fading to reduce the correlative characteristic of complex envelope. When N is very large, the channel approaches Gaussian channel. Then the BER performance of this system mostly lie on the free Euclidean distance of TCM codes. Thus the better BER performance with Ungerboeck codes can be gained.

V. Conclusions

In this paper, we presented and studied the combination of OFDM and TCM in order to overcome the frequency-selective and multipath fading in time dispersive channel, and analysed the performance of TC-OFDM system. The computer simulation was done for rate 2/3 TC-8DPSK-OFDM system. The results show the main advantages of the system above mentioned, which are that it can overcome the frequency-selective fading and spread many kinds of interference, while randomizing the burst errors in fading channel. Therefore, in real systems, when the orthogonal subcarriers number is different, the suited TC-coded scheme can be selected, according to the average effect of OFDM over fading channel and the correlated states among the complex envelopes, to improve the BER perfor-mance and enhance the system spectral efficiency and reliability.

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저 자 소 개

서 희 종(정회원)
1975년 2월 한국항공대학 항공통신공학과 졸업
1997년 7월 중앙대학교 대학원 박사 졸업
1987년 5월 여수수산대학교 조교수,
현재 여수대학교 교수
<주관심분야: 컴퓨터 네트워크, 통신>

張 克
1985년 북경사범대학 졸업
2004년 8월 여수대학교 대학원 석사 졸업
1993년 7월~북경석유화공학원 정보공학과 강사
<주관심분야: 통신이론 >