

PERFORMANCE OF COFDM FOR LEO SATELLITE CHANNELS IN GLOBAL MOBILE COMMUNICATIONS

W.A.C. Fernando , R.M.A.P. Rajatheva

Telecommunications Program, SAT , Asian Institute of Technology

P.O.Box - 4, Klong Luang 12120, Pathumthani, Thailand

Tele. - +66-2-524-5746 , Fax. +66-2-524-5730

E-Mail - rajath@ait.ac.th

Abstract - The growing interest in orthogonal frequency division multiplexing (OFDM) research motivated us to propose OFDM for satellite communications. In this paper, convolutional coding (CC) and Trellis coded modulation (TCM) are combined with OFDM for Rician fading channel according to the specifications given by the Iridium system. Here, bit error rate (BER) performance of OFDM with 8-PSK and 16-QAM modulation techniques along with two different coding schemes are considered for a LEO satellite channel. Results are analyzed with two frequency bands. i.e. Ka and L band. Results show that there is no significant difference of BER performance between two frequency bands considered. Trellis coded OFDM gives the best performance compared to convolutional coded OFDM. Peak to average power ratio (PAPR) can be reduced approximately by 1.5 dB with the help of partial transmit sequence technique(PTS).

I INTRODUCTION

In recent years OFDM has gained a lot of interest in diverse digital communication applications [1,2]. This has been due to its favourable properties like high spectral efficiency and robustness to channel fading. Today, OFDM is mainly used in digital audio broadcasting (DAB), digital video broadcasting (DVB) and other high-speed data applications for both wireless and wired communications. In the third generation mobile communication systems like universal mobile telecommunication systems (UMTS) and future public land mobile telecommunication systems (FPLMTS), OFDM is one of the scheme under consideration [3].

Convolutional coding has become widespread in the design of digital transmission systems as an error control scheme. Trellis coded modulation (TCM) is a spectral efficient coding scheme proposed by Ungerboeck [4]. TCM can provide coding gain without any bandwidth expansion. Application of these coding schemes to OFDM is quite suitable because, with proper interleaving, coded modulations can provide a diversity effect through exploitation of the multipath nature of the fading channel. Thus, the suitability of coded OFDM (COFDM) for LEO satellites in global mobile communications, is considered in this paper.

Section 2 describes an overview to the simulated COFDM system and section 3 presents the parameters for simulations. Results are presented in section 4 and conclusions are given in section 5.

II SYSTEM MODEL

A. COFDM SIMULATED SYSTEM MODEL

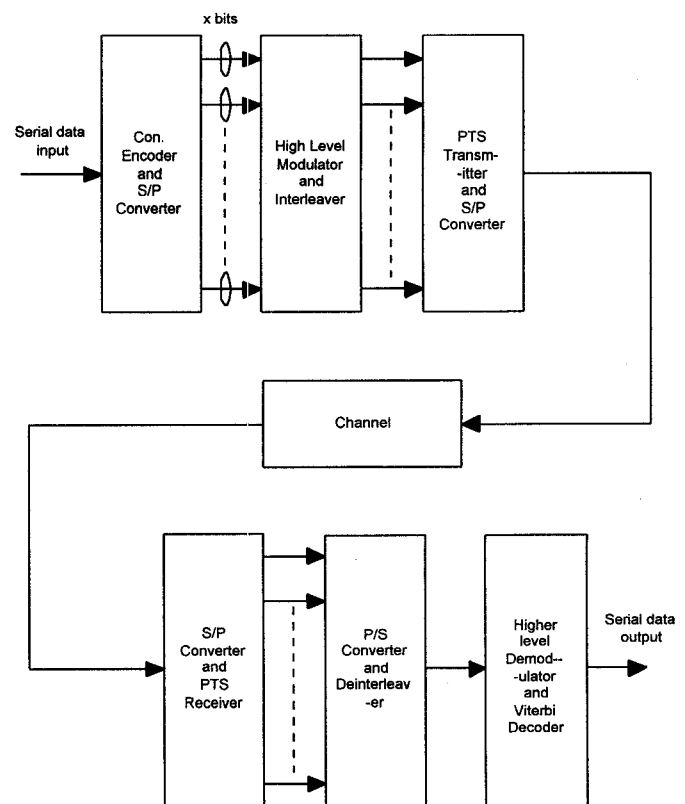


Fig. 1 Convolutional coded OFDM system model

Figure 1 shows the basic transmitter structure used for convolutional coded OFDM model. Convolutional encoder is placed at the very first stage and then output serial bit stream is converted to parallel bit stream (block length M , size of M is depend on the modulation scheme used) at the serial to parallel (S/P) converter. Out of M bits, x bits [$M = 512 \times x$] are

applied to signal mapper and digitally modulated output is available at the signal mapper output. Output of the signal mapper will then be applied to PTS based IFFT processor which will perform four IFFT sets. Each IFFT set is multiplied by a rotation factor ($I, -I, j, -j$) [8] at the stage of phase rotation such that peak to average power will be minimised for a transmitted block. Finally output of the phase rotation block will be sent to parallel to serial (P/S) converter to make the output a serial data stream.

At the receiver, using serial to parallel (S/P) converter, data sequence is converted back to parallel sequence and it is applied to FFT processor. The output will be rearranged such a way that it will give the correct output as at the signal mapper (transmitter side) output by removing phase rotation factors, which are introduced at the transmitter. Then, the output will be decoded by minimising Euclidean distance between the received signal point and the points of the constellation according to the modulation scheme. Data sequence is converted back to a serial data sequence. Finally, Viterbi decoder is used to decode the convolutional coded data stream. It should be noted that, during the simulation, the effect of equaliser and guard interval have not been considered. Apart from that, perfect synchronisation and perfect channel estimation have also been assumed at the receiver.

For trellis coded OFDM simulated system model, transmitter side of the model is same as the case of convolutional coded OFDM system model except that TCM encoder replaces the convolutional encoder. Ungerboeck encoder is used for 8-PSK, 16-QAM modulation schemes with proper coded and uncoded bits. At the receiver the processing will be similar up to the output of the FFT processor as in the case of convolutional coding. Replacing demodulator and Viterbi decoder in the convolutional coded OFDM model places TCM decoder.

B. LEO Satellite Channel Model

In this paper, flat fading Rician channel model [5] is used as the OFDM based satellite channel. It should be noted that this channel model is the channel model for a sub channel in the OFDM system. This model is justified since the duration of each subchannel is very large compared to the serial bit duration and the existence of direct line of sight path between the user and the satellite in most cases.

C. Peak to Average Power Ratio (PAPR) and Partial Transmit Sequence (PTS)

The peak to average power ratio for a single carrier system depends on the signal constellation and the roll-off factor of pulse shaping filter. When using OFDM in transmission systems, the transmit signal will occasionally exhibit very high peaks. Therefore, nonlinearities may get overload by high

signal peaks, causing intermodulation among subcarriers. If power amplifiers are not operated with large power back off, it is impossible to keep the out-of-band power below specified limits. This situation leads to very inefficient amplification and expensive transmitters so that it is highly desirable to reduce PAPR. To achieve the above objective, several proposals are proposed [6,7]. Since all these proposals suit only for specific applications, partial transmit sequence (PTS) [8], is considered here.

In this paper, four sub-blocks are considered and also rotation factors were also chosen according to [8]. Multilevel modulated signal block (512 in this paper) is divided in to four sub-blocks (128). Phase rotation is introduced such that the peak-average power ratio is minimised. In the receiver, 512 point FFT is performed and the output is divided in to four sub-blocks which are similar to the transmitter side sub blocks. Finally phase rotation factors are removed and hence the signal set is recovered.

III SPECIFICATIONS

- Transmission Bit rate (Iridium System)

L-Band	= 50Kbits/S
Ka-Band	= 3.125Mbits/S

- Carrier Frequency (Iridium System)

- * User and Messaging Communications

L-Band	= 1.62125 GHz
--------	---------------

- * Ground Segment

Ka-Band	= 29.2 GHz
---------	------------

- Satellite Speed = 27,100 km/hr (Iridium System)

- No of Sub-Channels = 512

- Rician Parameter (K) = 2

- Signal Power (Signal to noise ratio (SNR)) is defined at the output of the IFFT processor

- CC Encoder (Generator Matrix)

$$G = [1011011, 1111001]$$

- TCM Encoder (Ungerboeck 8 state Encoder) [4]

IV SIMULATION RESULTS

A. BER Performance for CC-OFDM

In CC-OFDM, uncoded system is defined as the channel with 256 sub-channels. This is because of the coding rate has been selected as 1/2. This ensures that the source rate is fixed

against both coded and uncoded systems. Modulation scheme for each uncoded system is same as the respective coded scheme.

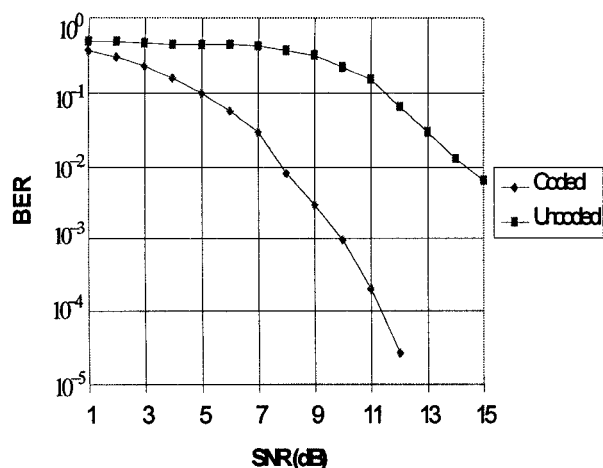


Fig. 2 BER performance for 8-PSK for Ka Band

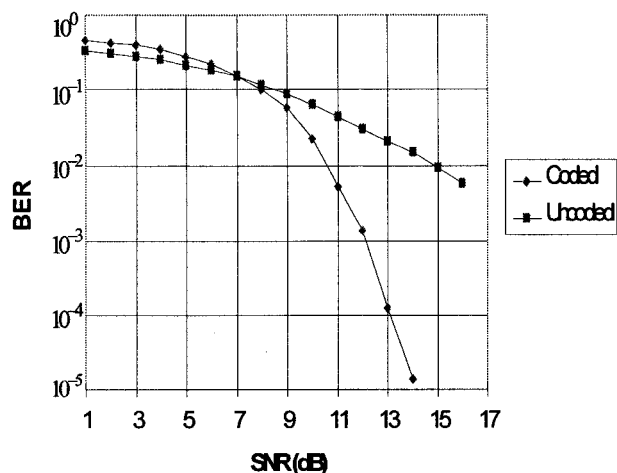


Fig. 3 BER performance for 16-QAM for Ka Band

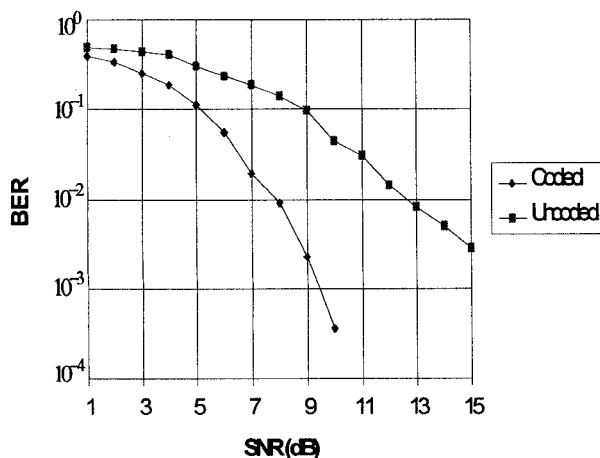


Fig. 4 BER performance for 8-PSK for L Band

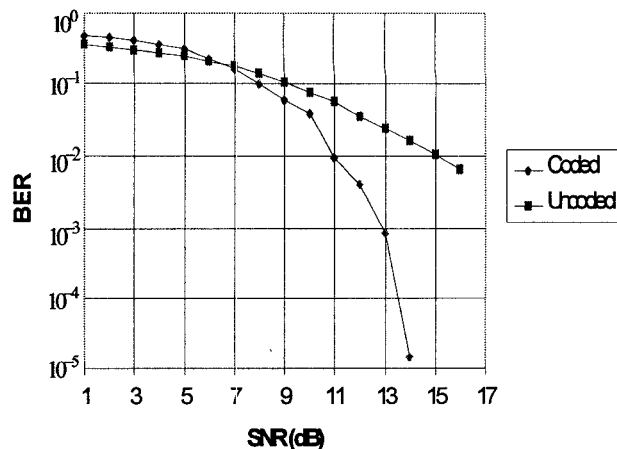


Fig. 5 BER performance for 16-QAM for L Band

Table 1 Comparison of coding gain for different modulation schemes

Modulation Scheme and Frequency Band	Coding Gain at 10^{-2} over Uncoded System	Coding Gain at 10^{-4} over Uncoded System
8-PSK (Ka)	6.2 dB	>3.8 dB
16-QAM (Ka)	4.5 dB	>3.0 dB
8-PSK (L)	4.8 dB	>4.0 dB
16-QAM (L)	4.0 dB	>2.8 dB

Table 1 shows the summarised results of the results plotted for both Ka band and L band. Coding gain is analysed at BER of 10^{-2} and 10^{-4} . BER of 10^{-2} is considered for voice applications whereas 10^{-4} is considered for data applications. It can be noticed that coding gain is increasing for higher SNR. There is not much significant difference of the coding gain between Ka band and L band. BER performance for both Ka and L band indicates that coding gain is high for higher SNR and for higher modulation schemes. It can also be noticed that the performance of the uncoded system is degrading for higher modulation schemes irrespective of the frequency band. Because of this, higher coding gains are possible for higher modulation schemes at high SNR values.

B. BER Performance for TCM-OFDM

BER performance of TCM-OFDM system is compared against its respective conventional uncoded system. This is same as the uncoded system used for comparison for AWGN channels and fading channels [4]. 8-PSK uncoded OFDM is the conventional uncoded system for 16-QAM TCM-OFDM system. Similarly for 8-PSK TCM-OFDM system, 4-PSK is the uncoded system. For all uncoded system, the number of sub channels are also same as the coded system.

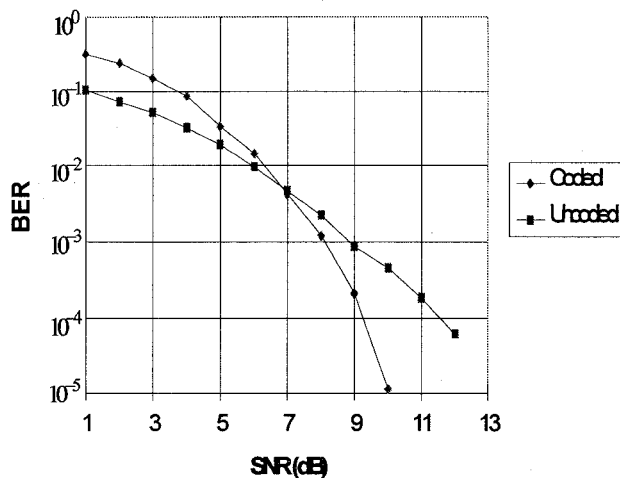


Fig. 6 BER performance of 8-PSK for Ka Band

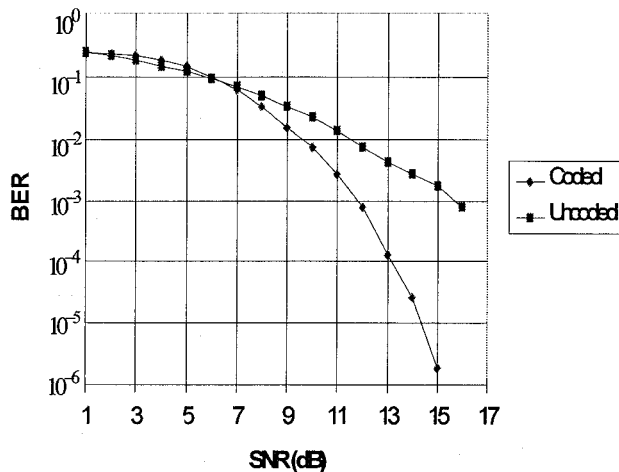


Fig. 7 BER performance of 16-QAM for Ka Band

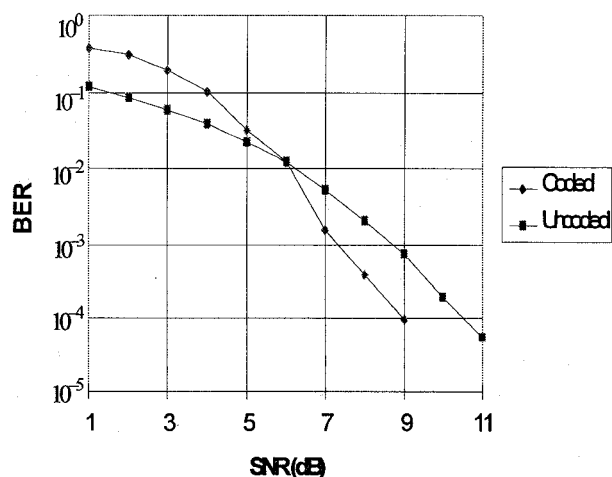


Fig. 8 BER performance of 8-PSK for L Band

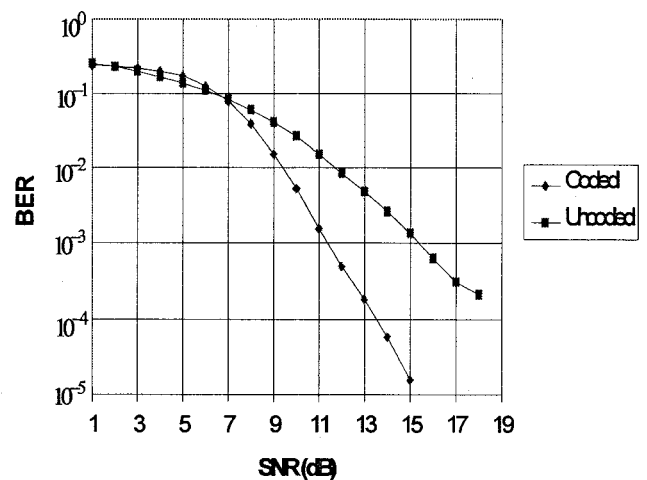


Fig. 9 BER performance of 16-QAM for L Band

Table 2 Comparison of coding gain for different modulation schemes

Modulation scheme and frequency band	Coding Gain at 10^{-2} over uncoded system	Coding Gain at 10^{-4} over uncoded system
8-PSK (Ka)	-0.4 dB	2.2 dB
16-QAM (Ka)	2.0 dB	>4.0 dB
8-PSK (L)	0.1 dB	1.5 dB
16-QAM (L)	2.2 dB	>4.0 dB

Results are summarised in Table 2 for Ka band and L band. This indicates that coding gain is increased for higher modulation schemes for both Ka band and L band. Also it can be noticed that coding gain is increased for higher values of SNR as in the convolutional coded OFDM. Results show that high coding gain is possible for higher modulation schemes irrespective of the frequency band. During the simulations, BER performance of several configurations of 8-state encoder model is analysed. It has been found that Ungerboeck encoder for fading channels gives the best performance for OFDM as well. Here also coding gain is presented for both cases as in the case of convolutional coding. It should be noted that for voice communications, there is not much significant difference between coded 8-PSK system and uncoded 4-PSK system performance. But, for 16-QAM coded system gives better performance against their uncoded systems. However, coded systems are much more superior at BER 10^{-4} against their uncoded system.

C. Peak to Average Power Ratio (PAPR)

Table 3 shows the PAPR variation with coding and PTS. There are two cases considered here. i.e. PAPA with PTS and PAPR without PTS. It is observed that the significance of the CC and TCM for PAPR is very small [9]. Irrespective with the modulation schemes PTS can reduce PAPR nearly by 1.5dB. For single frequency network (SFN), (i.e. without OFDM) PAPR for 16-QAM is 2.55 dB whereas for 8-PSK it is zero. This indicates that the difference of PAPR between SFN and OFDM for higher rectangular modulation schemes, will be getting smaller and smaller [9].

Table 3 PAPR with and without PTS for different modulation schemes with CC and with TCM

Modulation and coding Scheme	PAPR with PTS and with coding	PAPR without PTS and with coding
8-PSK (CC)	6.96 dB	8.30 dB
16-QAM (CC)	6.67 dB	7.31 dB
8-PSK (TCM)	6.97 dB	8.35 dB
16-QAM (TCM)	6.88 dB	8.37 dB

V CONCLUSIONS

In this paper, 8-PSK and 16-QAM modulation techniques and two different coding schemes are considered with OFDM for a LEO satellite channel. Results are analysed with two frequency bands. i.e. Ka and L band. Coding gain is considered at two different values of BER. These two levels of BER are selected because BER of 10^{-2} is considered for most of the voice communication applications and 10^{-4} can be considered for data communication applications. Results show that there is no significant difference of BER performance between two frequency bands considered. In TCM-OFDM, it should be noted that for voice communications, there is not much significant difference between coded 8-PSK system and uncoded 4-PSK system performance. But, for 16-QAM system coded system gives better performance against their uncoded systems. However, coded systems are much more superior at BER 10^{-4} against their uncoded system. But for CC-OFDM, considerable coding gain is possible for both voice and data applications irrespective of modulation scheme.

High Peak to average power ratio can be reduced approximately by 1.5 dB with the help of partial transmit sequence technique. Even though the simulation results are limited to LEO satellites, it is very easy to extend the simulations with slight modifications for other systems such as terrestrial communications, GEO and MEO communications and also for any other mobile links.

REFERENCES

1. Cimini L.J.Jr., *Analysis and Simulation of a Digital Mobile Channel Using Orthogonal Frequency Division Multiplexing*, IEEE Transactions Communications, Vol. COM-33, pp.665-675, July 1985.
2. Zou, W.Y., Wu, Y., *COFDM: An Overview*, IEEE Transactions Broadcasting, pp.1-8, March 1995.
3. Donald P., *Standardisation of the Satellite Component of the UMTS*, IEEE Personal Communications, pp.68-74 October 1995.
4. Ungerboeck, G., *Trellis Coded Modulation with Redundant Signal Set*, IEEE Communications Magazine, Vol. 27, , pp.5-21, February , 1987.
5. Steele, R., *Mobile Radio Communications*, Pentech Press, 1992.
6. Wulich, D, *Reduction of Peak to Mean Ratio of Multicarrier Modulation Using Cyclic Coding*, Electronic Letters, Vol.32, No.5, pp. 432-433, February 1996.
7. Friese, M., *Multicarrier Modulation with Low Peak-to-Average Power Ratio*, Electronic Letters, Vol. 32, No. 8, pp. 713-714, April 1996.
8. Müller and Huber, J.B., *OFDM with Reduced Peak-to-Average Power Ratio by Optimum Combination of Partial Transmit Sequence*, Electronic Letters, Vol. 33, No.5, pp. 368-369, February 1997.
9. Fernando, W.A.C. *Performance of COFDM for LEO satellite Channels in Global Mobile Communications*, Masters Thesis, Asian Institute of Technology, Bangkok, Thailand, December 1997.