Influence of Multiple Co-channel Interference on Hard-Limited Channel with Application of Convolutional Codes and Soft Decision Viterbi Decoding

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Abstract - **This paper presents the simulation analysis of BPSK (Binary Phase Shift-Keying) signal transmission over satellite system in the presence of multiple uplink and downlink co-channel interferences. The CC (convolutional codes) (2,1,3), (2,1,5) and (2,1,7) are used with soft decision Viterbi decoding. The emphasis is placed on determining the *BER* (bit error rate) improvement in the case of these codes implementation in the satellite system influenced by multiple co-channel interferences that can be very often the predominant destructive influence in such system.**

Keywords - **Satellite communications, Co-channel interference, Convolutional coding, Bit error probability.**

I. INTRODUCTION

The co-channel interference is one of the predominant limiting factors in the performance of digital satellite communication systems, [1-6]. This co-channel interference is usually produced by adjacent satellite or terrestrial radio relay links operating on the same carrier frequency. In addition, in order to double the information capacity of satellite systems, two orthogonally polarized electromagnetic waves are transmitted over the same radio frequency channel; i.e. the carrier frequencies of these waves are the same. Under real conditions in satellite communication systems, it is not possible to totally separate these two waves in the receiver; i.e. there is crosstalk between these orthogonally polarized waves. In other words, there is typical co-channel interference in the receiver, [1-6]. This interference can appear both at the satellite input (over uplink) and at the receiver ground station input (over downlink).

The influence of these interferences was considered in [5-6]. In those papers, the analysis included one interference per uplink and one interference per downlink, and numerical results were presented. The general method for analyzing the influence of multiple co-channel interference can be easily derived from previously mentioned papers, and other ones appeared in the literature. But, using this analytical approach including numerical integration, it is very difficult to obtain concrete numerical results for several co-channel interferences (greater than one per up- and down-link) because it must be compute multidimensional numerical integration over some special functions with considerable accuracy. In addition, the analyses in those papers were concerned only uncoded modulation formats.

The contribution of this paper is in determining the bit error probability P_e (*BER*) in detecting BPSK signal transmitted over a satellite link influenced of any number of co-channel interference (for example the results for ten interferences are presented). Except taking the uncoded BPSK signals into account, we also apply the convolutional coding with soft decision Viterbi decoding, since it is the standard technique for today's satellite communications, [4], and clearly present the improvements of system performance. The co-channel interference is modeled sufficiently general by unmodulated sinusoidal wave with constant amplitude and stochastic varying phase uniformly distributed in $(-\pi,\pi]$, [5-7]. The satellite station amplifier is modeled by a hard-limiter, [8], (the assumption is that input power-output power (AM/AM) and input power-output phase (AM/PM) conversion effects are compensated). Convolutional coding and soft Viterbi decoding algorithms are applied, as described in [9], [10].

II. SYSTEM MODEL AND ANALYSIS

After signal processing in the transmitting ground station (encoding data by classical convolutional encoder [9], and modulation process), the signal is emitted from transmitter to the satellite station. The bandpass filter at the satellite station input is wide enough to pass the useful signal without distortion and to limit the uplink noise to a bandwidth that is small compared to the filter central frequency. Other interferences that not occupy the same frequency range as the useful signal are cancelled by this filter. For our analysis we assume that the filter bandwidth is sufficient to not cause intersymbol interference. The satellite input signal can be written as, (Fig. 1),

$$\begin{aligned} s_i(t) = A_u \cos(\omega_0 t + \phi_0) + \sum_{j=1}^{N_1} A_{iuj} \cos\left[\omega_0 t + \theta_{iuj}(t)\right] + \\ + n_{Cu}(t)\cos(\omega_0 t) - n_{Su}(t)\sin(\omega_0 t) \end{aligned}, \tag{1}$$

where A_u, ω_0 and ϕ_0 are the useful signal amplitude, carrier frequency and phase, respectively. In the case of the BPSK modulation format application, ϕ_0 is 0 or π depending on binary one or binary zero is transmitted; A_{iuj}, ω_0 and $\theta_{iuj}(t)$ are the amplitude, carrier frequency and phase of the j-th co-channel interference $i_{uj}(t)$ (j=1,2,...,N_1) (there are N_1 co-channel interferences over uplink). Since we observe the influence of so-called co-channel interference, it should be noticed that the carrier frequencies of the useful signal and co-channel interference are quite equal. The co-channel

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interference amplitude is constant, while its phase is random variable uniformly distributed in (-π, π], [5-7],

$$p(\theta_{iuj})=\frac{1}{2\pi}, \qquad -\pi<\theta_{iuj}\le\pi, \qquad j=1,2,...,N_1. \qquad (2)$$

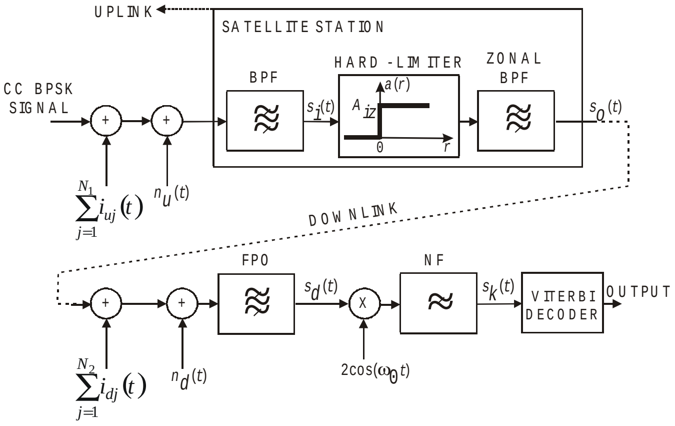

Fig. 1. Model of satellite system for transmission of convolutional encoded BPSK signals in the presence of multiple uplink and downlink co-channel interferences

$n_{Cu}(t)$ and $n_{Su}(t)$ are the quadrature components of the uplink narrowband zero-mean white Gaussian noise with bilateral power spectral density denoted by $N_0/2$.

The signal given by (1) can be re-written in the form

$$s_i(t)=r(t)\cos[\omega_0 t+\gamma(t)], \qquad (3)$$

where

$$r(t)=\left\{\left[A_u\cos\phi_0+\sum_{j=1}^{N_1}A_{iuj}\cos(\theta_{iuj}(t))+n_{Cu}(t)\right]^2+\right.$$
$$\left.+\left[A_u\sin\phi_0+\sum_{j=1}^{N_1}A_{iuj}\sin(\theta_{iuj}(t))+n_{Su}(t)\right]^2\right\}^{1/2},$$

$$\tan(\gamma(t))=\frac{A_u\sin\phi_0+\sum_{j=1}^{N_1}A_{iuj}\sin\theta_{iuj}(t)+n_{Su}(t)}{A_u\cos\phi_0+\sum_{j=1}^{N_1}A_{iuj}\cos\theta_{iuj}(t)+n_{Cu}(t)}. \qquad (4)$$

$r(t)$ and $\gamma(t)$ are the envelope and phase of the sum of the narrowband useful signal, N_1 co-channel interferences and Gaussian noise with zero mean value and bilateral power spectral density $N_0/2$. The ratio “useful signal energy per bit/noise power spectral density” over uplink is denoted by

$$(E_b/N_0)_u, \qquad (5)$$

The total ratio “useful signal power/co-channel interferences power” over uplink is denoted by

$$SIR_u=\frac{A_u^{\;2}}{\sum_{j=1}^{N_1}A_{iuj}^{\;2}}. \qquad (6)$$

The ideal zonal bandpass filter at the satellite station output totally removes the parasite spectral components produced by hard-limiter. Hence, all amplitude fluctuations of the output signal $s_o(t)$ are removed, while the phase of this signal is not distorted. The satellite output signal

$$s_o(t)=A_{iz}\cos[\omega_0 t+\gamma(t)]. \qquad (7)$$

is re-emitted to the receiver ground station. At the receiver front end, this signal is influenced by zero-mean white Gaussian noise with bilateral power spectral density $N_0/2$, and N_2 co-channel interferences. The receiving ground station input signal has the form

$$s_d(t)=A_d\cos[\omega_0 t+\gamma(t)]+\sum_{j=1}^{N_2}A_{idj}\cos[\omega_0 t+\theta_{idj}(t)]+$$
$$+n_{Cd}(t)\cos(\omega_0 t)-n_{Sd}(t)\sin(\omega_0 t) \qquad (8)$$

where the second term in the previous expression is the sum of N_2 downlink co-channel interferences. As in the case of the uplink, the j-th co-channel interference $i_{dj}(t)$ ($j=1,2,...,N_2$) amplitude is constant while its phase $\theta_{idj}(t)$ is stochastic variable uniformly distributed in (-π, π], [5-7].

$$p(\theta_{idj})=\frac{1}{2\pi}, \qquad -\pi<\theta_{idj}\le\pi, \qquad j=1,2,...,N_2. \quad (9)$$

$n_{Cd}(t)$ and $n_{Sd}(t)$ are the quadrature components of the narrowband Gaussian noise $n_d(t)$.

The ratio “signal energy per bit/noise power spectral density” over downlink is denoted by

$$(E_b/N_0)_d, \qquad (10)$$

The total ratio “signal power/co-channel interferences power” over downlink is denoted by

$$SIR_d=\frac{A_d^{\;2}}{\sum_{j=1}^{N_2}A_{idj}^{\;2}}. \qquad (11)$$

Under assumption that reference carrier signal in the receiver is $2\cos(\omega_0 t)$, [5-6], the signal at the Viterbi decoder input is

$$s_k(t)=A_d\cos[\gamma(t)]+\sum_{j=1}^{N_2}A_{idj}\cos[\theta_{idj}(t)]+n_{Cd}(t). \qquad (12)$$

The soft Viterbi decoding, [9-10], is performed and decision is made.

III. SIMULATION RESULTS AND DISCUSSION

On the basis of the analysis presented in Section II, using Monte Carlo simulation method, [11], numerical results are obtained and presented in Figs. 2-5 and Tables 1-4.

Fig. 2 and Table 1 illustrate how the system performance is influenced by different number of co-channel interferences. It can be noticed that if the number of interferences increases from 2 to 4, the *BER floor* decreases 6.5 times, while if the number of interferences increases from 8 to 10, the *BER floor* decreases 1.41 times, that is much less then in the previous case. It can be noticed that the total interference power (over up- and down-link) is constant, and that power is parted to different number of co-channel interferences.

On the basis of the Fig. 3 and Table 2, it is evident that even for relatively high values of bit error probability in the case of uncoded BPSK modulation format application, by using proper convolutional code scheme it is possible to decrease the bit error probability to the acceptable level for practical proposes.

Fig. 4 and Table 3 give the answer how much the downlink energy per bit/noise power spectral density ratio should be in order to achieve the desired bit error rate. In the case of uncoded signal application it is not possible to achieve the bit error probability of 10^{-4} regardless of increasing $(E_b/N_0)_d$ (for example, $P_e=1.44\cdot10^{-4}$ even for $(E_b/N_0)_d$=26dB). But with application of CC(2,1,3), CC(2,1,5) or CC(2,1,7) it is quite possible to reach even less values of bit error probability for very low values of $(E_b/N_0)_d$, that is illustrated in Fig. 4 and Table 3.

And finally Fig. 5 and Table 4 clearly illustrate improvements in bit error rate by applying CC(2,1,3).

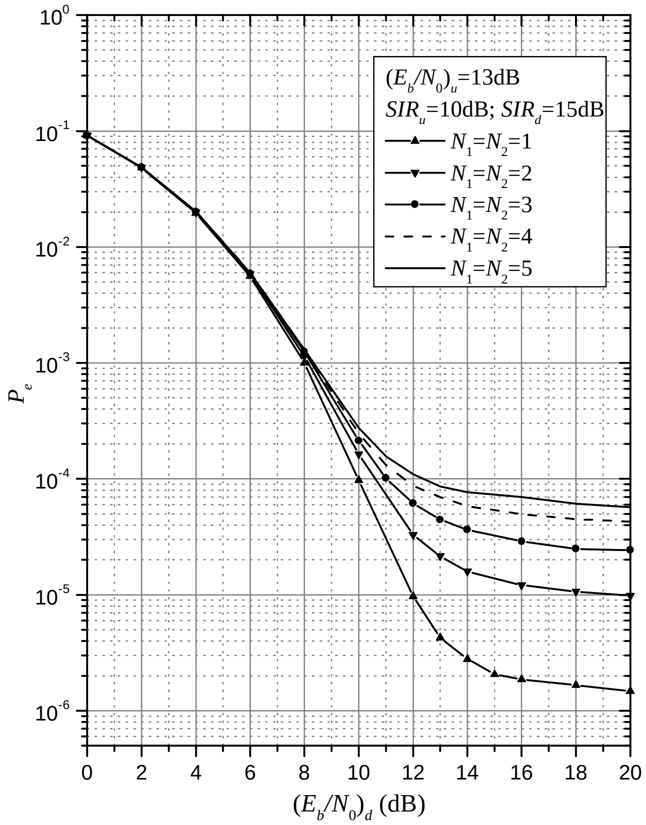

Fig. 2. System performance for various number of co-channel interferences

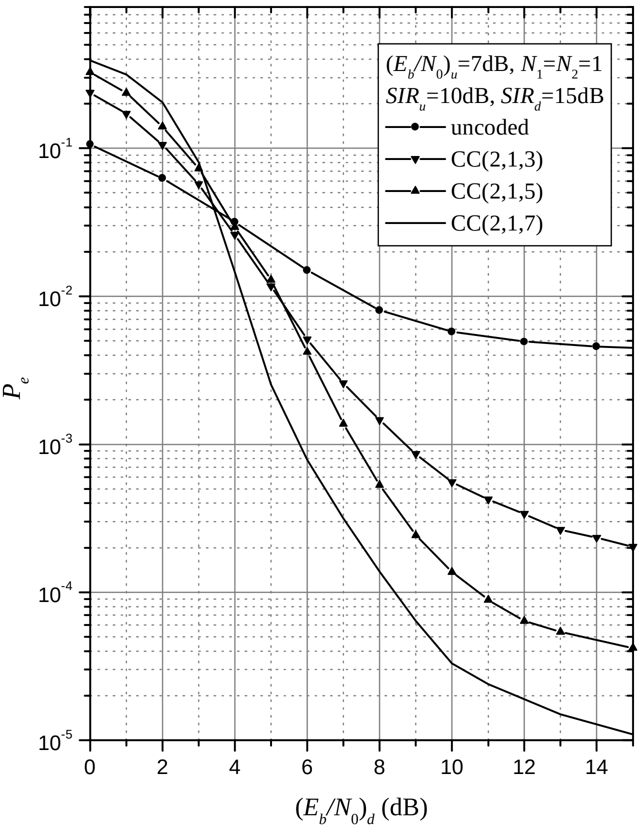

Fig. 3. System performance for various convolutional codes

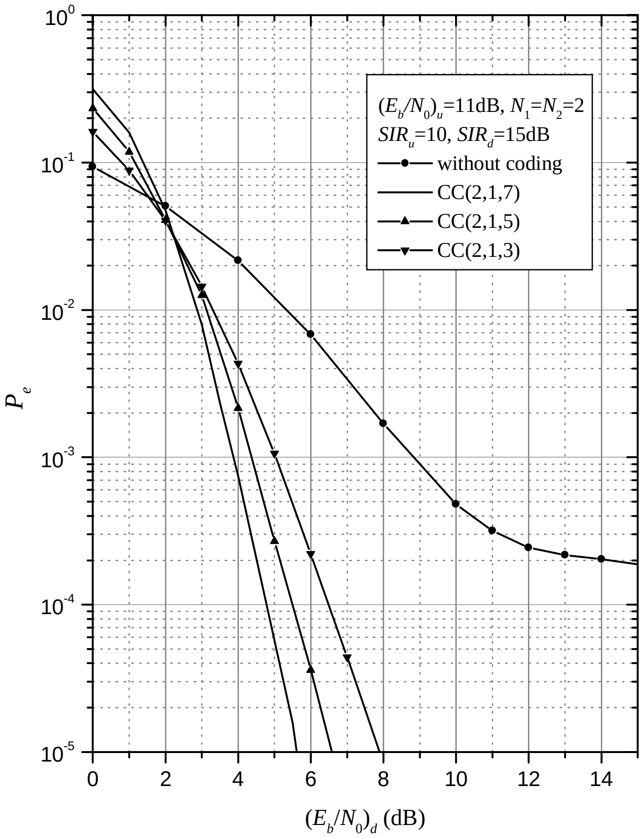

Fig. 4. System performance for various convolutional codes

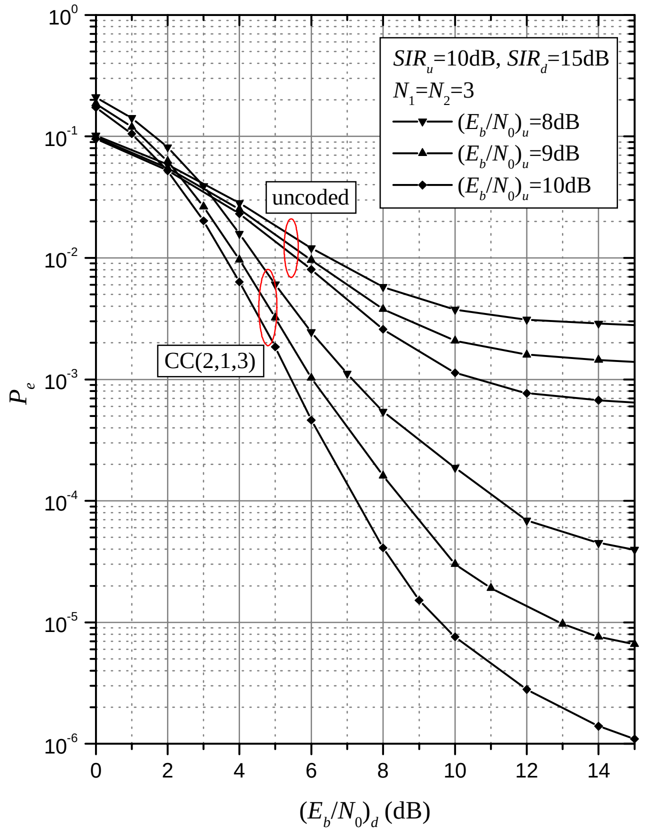

Fig. 5. Performance improvement using CC (2,1,3) in comparison with uncoded BPSK signal

TABLE 1
BER VALUES FOR DIFFERENT NUMBER OF CO-CHANNEL INTERFERENCES ($(E_b/N_0)_u$=13 dB , $(E_b/N_0)_d$=16 dB, SIR_u=10 dB, SIR_d=15 dB)

N_1=N_2	1	2	3	4	5
P_e	$1.9\cdot10^{-6}$	$1.2\cdot10^{-5}$	$2.9\cdot10^{-5}$	$4.9\cdot10^{-5}$	$7.0\cdot10^{-5}$

TABLE 2
SOME *BER* VALUES FOR UNCODED AND CC ENCODED BPSK SIGNALS ($(E_b/N_0)_d$=7 dB, ($(E_b/N_0)_d$=12 dB, SIR_u=10 dB, SIR_d=15 dB, N_1=N_2=1)

uncoded	CC(2,1,3)	CC(2,1,5)	CC(2,1,7)
$4.94\cdot10^{-3}$	$3.38\cdot10^{-4}$	$6.40\cdot10^{-5}$	$1.87\cdot10^{-5}$

TABLE 3
NEEDED $(E_b/N_0)_d$ (dB) FOR REACHING SOME *BER* VALUES IN THE CASE OF DIFFERENT CC CODES ($(E_b/N_0)_u$=11 dB, SIR_u=10 dB, SIR_d=15 dB, N_1=N_2=2)

P_e	uncoded	CC(2,1,3)	CC(2,1,5)	CC(2,1,7)
10^{-4}	impossible	6.51 dB	5.50 dB	4.73 dB
10^{-5}	impossible	7.89 dB	6.58 dB	5.58 dB

TABLE 4
BER VALUES FOR UNCODED AND CC(2,1,3) BPSK SIGNALS ($(E_b/N_0)_d$=14 dB, SIR_u=10 dB, SIR_d=15 dB, N_1=N_2=3)

$(E_b/N_0)_u$ (dB)	8	9	10
uncoded	$2.88\cdot10^{-3}$	$1.45\cdot10^{-3}$	$6.73\cdot10^{-4}$
CC(2,1,3)	$4.51\cdot10^{-5}$	$7.60\cdot10^{-6}$	$1.40\cdot10^{-6}$

IV. CONCLUSION

In this paper we present simulation approach in determining the performance of hard-limited satellite system in the presence of multiple uplink and downlink co-channel interferences. Using the real-life system energetic parameters, we determine the error probability in detecting both uncoded and convolutional encoded BPSK signals with soft Viterbi decoding. We give relevant discussions and notes regarding the results presented in the paper, that show how much the system performance can be improved by applying different CC codes in the observed satellite system.

All simulations were performed using software MATLAB 6.5 and Digital Visual Fortran Version 6 on PC Pentium 4 with Intel processor of 1.8 GHz and RAM of 256 MB. The developed simulator is very flexible and efficient and can be used in the further scientific researches that will include implementation of concatenation of Reed Solomon code as outer code and CC as inner code.

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