Channel Coding Gain Studies Over Ka Band Satellite Systems at Venezuelan Amazonian Area

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Abstract. The signals in Ka band are seriously degraded by various climate phenomena, where the rainfall is the main cause of attenuation at high frequencies. An important portion of the Venezuelan Satellite footprint is dedicated to provide services over the Amazonian area. In the Amazon, the rain attenuation is a significant limitation for satellite communications. In order to keep the satellite services operating in normal conditions, it is important to mitigate the attenuation losses due the heavy rain. An efficient way to compensate the rain attenuation is using coding gain, specifically, channel codes gain combined with the spread spectrum gain from the CDMA system. The basic principle is to generate sufficient gain to compensate the rain attenuation in order to receive the same Carrier to Noise Ratio (C/N₀) level, similar to clear sky conditions, even in presence of rain. The research aims at simulating the codes performance and combines its advantages with the CDMA method features against the channel loss. The main purpose, is to receive the same bit error rate of BER=10⁻⁶ with lower values of E_b/N₀.

Introduction

The Amazonian area is protected by international environment regulations. The common wire guided communications system cannot be built according to international regulations. The satellite is the best method to provide communications services at the Amazonian area. However, the Ka band can suffer significant degradation due to the rainfall [1]. Normally, the Ka band signals for the Venezuelan Satellite can be exposed to about 20 dB of rain attenuation for a 99.9% of service availability [2]. CDMA is a type of access to the satellite based on spread spectrum techniques. The CDMA has the advantage that is not limited in power, but limited in bandwidth [3]. Not only using the spread spectrum techniques is possible to obtain gain in order to compensate the channel attenuation. Actually only use the spread spectrum gain to compensate the attenuation of the signals is not the most efficient way, because the bandwidth is limited onboard the satellite. The spread spectrum gain depends on the relation between the bit rate and chip rate. Increasing the spread spectrum gain implies high chip rate and more bandwidth occupied [4]. The attenuation for the Ka band signals is very high and cannot be compensated only with the spread spectrum gain. The spread spectrum gain necessary to compensate the channel attenuation normally could exceed the maximum bandwidth onboard the satellite. The Additional gain can be obtained from error correction codes. The received signal is related to the carrier to noise ratio. The carrier to noise ratio required is defined by the E_b/N₀ for a given information rate [5]. The carrier to noise ratio and E_b/N₀ are normally proportional for uncoded signals but not for encoded signals. The error control codes provide the same level of carrier to noise ratio (C/N₀) at lower values of E_b/N₀. The error control codes help to obtain the required bit error rate using lower power [6]. The reduction of power requirement is called the code gain. There is several kind of codes used today to optimize the communications systems performance, especially to mitigate the channel effects [7]. This research focuses on analyzing the codes performance in order to combine its advantages with the CDMA features. The purpose is to study the error correction gain margins against the channel loss. The code selection was done according to the successful performance in previous space missions and the error correction codes used inside the Venezuelan earth stations. Each gain from the codes will be combined with the spread spectrum gain to compensate the channel attenuation.
System Gain Model

Code Division Multiple Access (CDMA)

The basic principle of CDMA model is shown in the Figure 1. The information signal \( p(t) \) and the chip signal \( c(t) \) are the input of a multiplier, here the output is an spread signal \( p(t)c(t) \). The spread signal \( e(t) \) is modulated by a BPSK modulator and transmitted at the uplink frequency.

![Figure 1. CDMA basic principle.](image)

Because the transmitted signal \( c(t) \) is synchronized with the received signal \( e_d(t) \), then \( c^2(t) = 1 \), thus, the received signal is:

\[
e_d = c^2(t)p(t)cosw_d \quad (1)
\]

Suppose that every channel "K" has the same power "Pr", then there are \( K-1 \) channels which introduce noise:

\[
N_0 = \frac{(K-1)Pr}{R_b} \quad (2)
\]

\[
E_b = \frac{Pr}{R_b} \quad (3)
\]

\[
\frac{E_b}{N_0} = \frac{B_n}{(K-1)R_b} \quad (4)
\]

For BPSK, \( B_n \) is about \( BIF = (1+\rho)R_{ch} \):

\[
\frac{E_b}{N_0} = \frac{(1+\rho)R_{ch}}{(K-1)R_b} \quad (5)
\]

The term \( R_{ch}/R_b \) is called processing gain \( G_p \):

\[
G_p = \frac{R_{ch}}{R_b} \quad (6)
\]

Error Control Coding

The probability of receiving a wrong information bit, is called bit error probability \( (P_e) \). In a digital transmission, the probability of receiving errors can be reduced by increasing \( E_b/N_0 \), but it is not true for every cases [5]. From the practical point of view, there are some limitations to this approach. Given a bit rate \( R_b \), \( E_b/N_0 \) is proportional to \( C/N_0 \) according to the equation:

\[
\frac{C}{N_0} = \frac{E_b}{N_0} + R_b \quad (7)
\]

The error performance is normally defined as the bit error rate (BER), which is the error rate at the output of the detector. If no method of error control coding is used, the message is called uncoded message [5]. A typical representation of an uncoded message transmission can be observed in the block diagram of Figure 2 (a). If a method of error control coding is used the message is called coded message [5] and the transmission structure is shown in the block diagram of the Figure 2 (b).
Suppose a Hamming code \( n=7 \) and \( k=3 \) with \( t=1 \) is transmitted with BPSK modulation, the BER vs \( E_b/N_0 \) is shown in Figure 2. The advantage of using codes is that the probability of an error occurrence is usually much lower than the probability of error if it is not used. This is normally known as coding gain [3]. Mathematically:

\[
\text{Code Gain} = \frac{E_b}{N_0} (\text{uncoded}) - \frac{E_b}{N_0} (\text{coded})
\]

(8)

**Simulation and Results**

**Simulation of Code Division Multiple Access (CDMA) Gain**

The bandwidth for Venezuelan satellite transponders in Ka band is 120 MHz. Thus, the maximum spread spectrum gain over a bandwidth of 120 MHz, using a typical roll factor of 0.3 and an information rate \( R_b=2.048 \) MHz is about 16.54 dB, according to CDMA gain formula (6). Additional gain must be obtained from codes. The gain is obtained by setting \( R_{ch}=10R_b \) in the CDMA gain formula.

In satellite communication a BER about \( 10^{-6} \) is considered sufficient for most of the services. The CDMA simulated gain is about 9.53 dB which it is very close to the theoretical value of 10 dB.
Simulation of Reed Solomon Concatenated with Convolutional Codes

The simulation uses Reed Solomon codes as outer codes and convolutional codes as inner codes according to the scheme shown in Figure 4. The message of 188 bytes is encoded using Reed Solomon codes resulting in a codeword of 204 bytes. After the Reed Solomon encoder, the bytes are converted to bits in order to use a convolutional encoder. The input of the convolutional encoder is a codeword with a code length of 8*204=1632 bits. Because the convolutional encoder code rate is 1/2, the codeword after the convolutional encoder has 1632*2=3264 bits. The data is modulated using BPSK modulation and transmitted through an AWGN channel.

The reception is done using the inverse process. The convolutional decoder (Viterbi) receives the 3264 bits decoding the data and converting it to a codeword of 1632 bits. The 1632 bits are converted to 204 bytes. The Reed Solomon Decoder output has 188 bytes which are compared with the original data. The results are shown in Figure 4. The simulations results show that for a BER=10^{-6}, the gain is about 7.5 dB. The CDMA or spread spectrum must provide 12.5 dB to compensate 20 dB of attenuation. According to the CDMA Gain formula (6), R_{ch}=18R_b is necessary.

Simulation of Turbo Code

The simulation is executed according to the scheme shown in Figure 6. The input of the turbo encoder is a codeword with a code length of 1024 bits. The encoder output is a codeword of 3084 bits due the code rate is about 1/3. The data is modulated using BPSK modulation and transmitted into an AWGN channel. The reception has the inverse process. The turbo decoder 3084 received bits and get a codeword of 1024 bits. The decoder output use LLR (Log-Likelihood Ratio) to decode the data. The decoder output is compared with the original data. The Turbo codes with a typical length of 1024 bits are commonly used in the Venezuelan ground station. The results are shown in Figure 5. The simulations results show that for a BER=10^{-6}, the Turbo code transmission has a gain of about 9 dB. For compensation 11 dB with R_{ch}=13R_b is necessary.
Simulation of Low Density Parity Check (LDPC) Codes

The LDPC codes base the simulation on the DVB standard. The Figure 8 shows the block diagram of the simulation. The LDPC code length is $n=64800$ bits and the message length is $k=58320$ with a code rate of $9/10$. The parity check matrix is define by the DVB standard for a code rate of $9/10$. The LDPC encoder receive a message length of $58320$ bits. The encoder output is a codeword of $64800$ bits with a code rate of $9/10$. The data is modulated using BPSK modulation and transmitted over an AWGN channel.
The LDPC decoder receive 64800 bits and get the message of 58320 bits. The decoder estimate the output using Log-Likelihood Ratio. The decoder output is compared with the original data. The transmission is done for different values of $E_b/N_0$ and SNR. The results are shown in Figure 6. The Venezuelan Satellite services do not use yet LDPC codes. However, this is a code commonly used around the world and with the best performance until now, for that reason was chosen in this research. The LDPC simulation got an amazing result with a gain about 10 dB. The rain attenuation of 20 dB, need a CDMA gain of 10 dB with $R_{ch} \approx 10R_b$.

**Conclusion**

Satellite communication systems operating at Ka band frequencies are sensitive to the rain, especially at the Amazon. For that reason, service providers need to consider the use of appropriate error correction codes and some access techniques, to keep the satellite link during severe rain fade. The selection of appropriate mitigation techniques can improve the communication system performance by transmitting a signal that is resistant to various kinds of imperfect channel response such as those caused by noise or attenuation. There is several kind of code used today to optimize the communications systems performance, especially to mitigate the channel effects. The error control codes can be combined with the spread spectrum features and obtain the enough gain margins against the rain attenuation. Turbo codes and LDPC codes have a very good energy efficiency because they are very close to the theoretical limit predicted by Shannon and for that reason are popular for satellite applications. In the simulation, Reed Solomon and Convolutional Codes need more additional gain because has the lowest code gain. More gain from the CDMA scheme imply use more bandwidth. The LDPC codes has the highest gain and use less bandwidth. Less bandwidth occupied means better services quality in term of transmission speed. Thus, the best information rate can be achieved for the highest codes gain.

**References**


