CONVOLUTIONAL CODED GENERALIZED DIRECT SEQUENCE SPREAD SPECTRUM

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ABSTRACT : We investigate the worst-case performance of coded ordinary and coded generalized direct sequence spread spectrum (DSSS) systems in a communication channel corrupted by an unknown and arbitrary interfering signal of bounded power. We consider convolutional codes with Viterbi decoding in order to compare the performance of coded ordinary and coded generalized DSSS systems. For the generalized DSSS system, we use a pulse stream of +1,-1 and 0 as the spreading sequence, which is different from ordinary DSSS system which uses the typical sequence with pulse values of +1 and -1.
A C program for performing Monte-Carlo simulations is written in order to evaluate and compare the performance of coded ordinary and coded generalized DSSS systems. Plots of the worst-case error probability versus signal-to-interference ratio are presented for different code rates and constraint lengths of the convolutional code. Simulation results of the worst-case performance of ordinary and generalized DSSS show that generalized DSSS consistently performs appreciably better than ordinary DSSS. Simulation is performed for various code rates, various constraint lengths of the convolutional code and various lengths of the convolutional interleaver. Over all these simulations, it is observed that the difference between ordinary and generalized DSSS gets more pronounced as the channel gets worse.
KEYWORDS: DSSS, viterbi algorithm, spread spectrum.

1.INTRODUCTION

It all started when Guglielmo Marconi invented wireless telegraph. From then on wireless communications has gone through lots of inventions. Particularly during the past twenty years, the mobile radio communications industry has grown by orders of magnitude, fueled by digital and RF circuit fabrication improvements, new large-scale circuit integration, and other miniaturization technologies which make portable radio equipment smaller, cheaper, and more reliable. Digital switching techniques have enabled the large scale deployment of affordable, easy-to-use radio communication networks. The innovations will continue at an even greater pace in the coming years.
In our daily life we come across a wide array of communication devices, the most common being the cellular phone, GPS, radio, television and wireless internet. Although there is rapid growth in wired communications, the biggest challenges lie in developing wireless systems. Research is being done to improve the robustness of the channel and provide error free transmission in a wireless communication system.
With the inventions in wireless personal communications field over the last several years, the method of communication known as spread spectrum has gained a great deal of importance. Spread spectrum involves the spreading of the desired signal over a bandwidth much larger than the minimum bandwidth necessary to send the information signal. It was originally developed by the military as a method of communication that is less sensitive to intentional interference or jamming by third parties, but has become very popular in the realm of personal communications recently. Spread spectrum methods can be combined with multiple access methods to create code division multiple access (CDMA) systems for multi-user communications with very good interference suppression. Two very common types of spread spectrum schemes that are in use today are direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS). Usually FHSS devices use less power and are cheaper, but DSSS systems have better performance and are more reliable. In this paper we will also consider a newer, more robust class of proposed spread spectrum systems called generalized spread spectrum. Detailed description of a spread spectrum communication system is presented in this paper.
Channel coding is used to reduce the errors caused during transmission. Block codes and convolutional codes are the two widely used methods for channel coding. The work in this paper relates to applying convolutional codes to ordinary and generalized DSSS in order to compare their worst-case performance.

2. Direct sequence spread spectrum system

2.1 Spread-Spectrum Communication Systems

Spread spectrum communications is one of the widely used data communication schemes nowadays.These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference and jamming, and to prevent detection. It has many features that make it suitable for secure communications, multiple access scenarios, and many other properties that are desirable in a modern communication system.

Spread Spectrum is a method of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information. It employs direct sequence, frequency hopping or a hybrid of these, which can be used for multiple access and/or multiple functions. This technique decreases the potential interference to other receivers while achieving privacy. Spread spectrum generally makes use of a sequential noise-like signal structure to spread the normally narrowband information signal over a relatively wide band of frequencies. The receiver correlates the received signals to retrieve the original information signal. The band spread is accomplished by means of a code which is independent of the data and synchronized reception with the code at the receiver is used for de-spreading. In spread spectrum the signal that has a limited defined bandwidth is spread to occupy a higher bandwidth, with its power spread over a wide range, by multiplying that signal with a higher frequency sequence. The spreading will significantly reduce the possibility of corrupting the data, intentionally or unintentionally. This is one of the main features of spread spectrum, the interference suppression capability. When the spread signal is interfered by additive white Gaussian noise (AWGN), we will not notice any significant improvement if we choose spread spectrum. But, when an intentional noise is applied, it is usually band limited to the range we are using. When we spread the signal, the intentional noise (usually termed the jammer) will make one of two choices. It will either spread its band limited power spectral density over the new bandwidth, which will reduce its effect on our signal, or stay at its original bandwidth, which will cause it to affect only a portion of our data. Such effect might be further reduced by error correction coding at the receiver end. This means that in both cases, the choice of spreading will reduce the jammer's effect significantly. While the typical interference encountered by a modern spread spectrum signal will not be arising from a jammer, the idea of a jammer has been historically used to illustrate the interference suppression capability of spread spectrum. Some of the more interesting and desirable properties of spread spectrum can be summarized as:

- Good anti jamming performance.
- Low power spectral density.
- Interference limited operation, i.e. the whole frequency spectrum is used.
- Multi path effects are reduced considerably with spread spectrum applications.
- Random access probabilities, i.e. users can start their transmission at any time.
- Privacy due to the use of unknown random codes.
- Multiple access, i.e. more than one user can share the same bandwidth at the same time.

Spread spectrum systems are classified according to the ways that the original data is modulated by the PN code. The most commonly employed spread spectrum techniques are the following:

Direct Sequence Spread Spectrum (DSSS): In DSSS, the baseband signal is multiplied by a pseudorandom code or pseudonoise (PN) signal, which has a higher bit rate than the original signal. This will spread the spectrum of the baseband signal.

Frequency Hopping Spread Spectrum (FHSS): Frequency-hopping spread spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both the transmitter and the receiver. This will result in modulating different portions of the data signal with different carrier frequencies. This technique makes the data signal hop from one frequency to another over a wide range and this hopping rate is a function of the information rate of the signal. The specific order in which frequencies are occupied is a function of a code sequence. The transmitted spectrum of a frequency hopping is different from that of the direct sequence system.

Hybrid System (DS/FFH): This is a combination of both the direct sequence and frequency hopping techniques. Here, one data bit is divided over frequency hop channels i.e. carrier frequencies. In each frequency hop channel one complete PN code is multiplied with the data signal.

In this paper, the emphasis is going to be on the DSSS System. A detailed description of DSSS system is given in next section.

2.2 Direct Sequence Spread Spectrum Digital Communication Systems

Direct sequence spread spectrum is one of the most widely used spread spectrum techniques. The basic elements of DSSS digital communication system are illustrated in Figure 1. We observe that in addition to the basic elements of a conventional digital communication system, a spread spectrum system includes two identical pseudorandom sequence generators, one interfacing with the modulator and the other with the demodulator. As with all spread spectrum schemes, DSSS uses a unique code to spread the baseband signal, allowing it to have all the advantages of spread spectrum techniques. A random or pseudonoise signal is used to spread the baseband signal, causing fast phase transitions in the carrier frequency that contains data.The spreading sequence is a pulse stream with pulse values of +1, -1. After spreading the base-band signal, the resulting spread signal is then modulated and transmitted through the specified medium. Binary phase shift keying (BPSK) is a widely used digital modulation scheme for spread spectrum systems and we use the same in this paper.

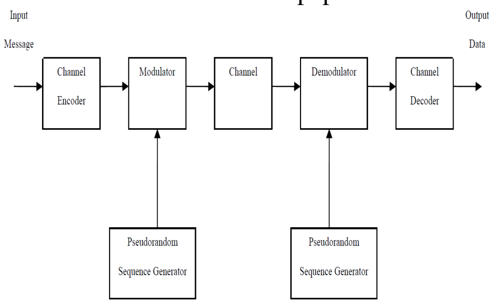


Figure 1: Model of DSSS digital communication system

3. Communication System model

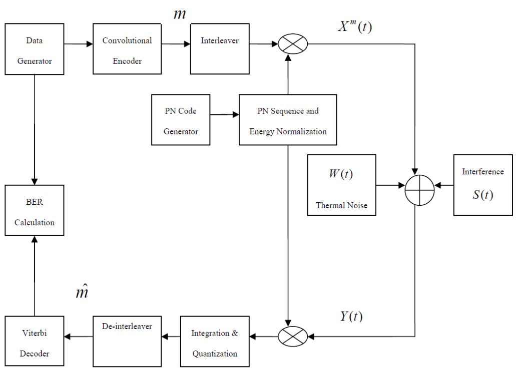


Figure 2: Communication System model

The communication system block diagram is shown in Figure 2. The data generator gives out $5 \times K$ bits, where K is the constraint length of the convolutional encoder. We have chosen the message length as $5 \times K$ since it is the decoding depth of the Viterbi decoder used in this. The convolutional encoder converts these bits into $L = (5 \times K)/r$ encoded symbols by adding some redundancy for error checking at the receiver, where r is the code rate of convolutional encoder. The transmitter generates L coded symbols every T seconds. The encoded symbols are then transmitted by DS modulation with N pseudo-noise chips per code symbol.

The N pseudonoise chips are generated randomly using a PN generator and the sequence generated is from {-1, 0, +1} for generalized DSSS and from {-1, +1} for ordinary DSSS. These randomly generated chips are then multiplied with a normalization factor (equal to 1 for ordinary DSSS) in order to account for the energy lost due to the "0" chip in the generalized sequence. Assume that a given transmitted message of length L is called message m. The basic channel model is illustrated in Figure 3. Here we replace x(t) by $x^n(t)$ to show the dependence of the transmitted signal on the message m. During transmission, $x^m(t)$ is corrupted by two independent, additive noise processes so that

$$Y(t) \cong x^m(t) + W(t) + S(t), 0 \le t < T$$

is received. Here W(t) is a white Gaussian noise process with one-sided power spectral density N_0 W/Hz and S(t) is an arbitrary signal independent of m and W(t).

The codeword associated with message m are $x^m = (x_0^m, \ldots\ldots x_{L-1}^m)$ for convolutional coded generalized direct-sequence spread spectrum. The symbols are convolutional or pseudorandom interleaved to form an interleaved code waveform

$$Z^m(t) \cong \sum_{i=0}^{L-1} x_i^m u(t - J_i T_s), 0 \le t < T$$

where $u(t) = 1$ in the interval [0, TS) and vanishes outside, and $TS = T/L$ is the symbol duration. In equation the index sequence {$J0$, …., JL-1} represents interleaving of the symbols, where {$J0$, …., JL-1} = {$C0$, …., CL-1} for convolutional interleaving and {$J0$, …., JL-1} = {$P0$, …., PL-1} for pseudorandom interleaving.

The interleaved code word is binary phase-shift (BPSK) modulated and DS spread by the PN sequence.

$$X^m(t) \cong c\sqrt{2E/T}\, \cos(wt)\, C(t)\, Z^m(t), 0 \le t < T$$

Where E is the energy per code word at the receiver , $T_c = T_s / N$ is the chip duration , w is the carrier frequency with $w > 2\pi T_c^{-1}$, and C(t) is the spreding waveform

$$C(t) \cong \sum_{i=0}^{NL-1} A_i v(t - iT_c), \qquad 0 \le t < T.$$

Here,v(t) is a low-pass chip waveform that satisfies $\int_0^{T_c} v^2(t)\, dt = T_c$ and vanishes outside the interval [0,T_c).

The pseudo-noise sequence { A_i } is modeled as an independent identically distributed sequence of random variables which satisfy $P_r\{A_i = +1\} = p_r\{A_i = 0\} = P_r\{A_i = -1\} = 1/3$ for generalized DSSS and

$Pr\{Ai= +1\} = Pr\{Ai= -1\} = 1/2$ for ordinary DSSS, and they are independent of $\{J0, \ldots, JL\text{-}1\}$. Therefore, the energy normalization constant c takes the form as with $c = \sqrt{\frac{NL}{u}}$,where u represented the total number of non-zero chips per L encoded symbols in the PN sequence.
The deinterleaver at the receiver end can be represented as

$$Z^{\hat{m}}(t) \cong \sum_{l=0}^{L-1} x_l^m u(t - B_l T_s), 0 \le t < T$$

where $u(t) = 1$ in the interval $[0, TS)$ and vanishes outside, and $TS = T/L$ is the symbol duration. In equation the index sequence $\{B0, \ldots, BL\text{-}1\}$ represents deinterleaving of the symbols, where $\{B0, \ldots, BL\text{-}1\} = \{D0, \ldots, DL\text{-}1\}$ for convolutional deinterleaving and $\{B0, \ldots, BL\text{-}1\} = \{Q0, \ldots, QL\text{-}1\}$ for pseudorandom de-interleaving.
During channel simulation in order to avoid the overhead of interleaving and deinterleaving, we directly interleave the interference in the channel while adding it to the signal as described in Figure 3. In such a situation the deinterleaved signal at the receiver end can be represented as

$$\hat{Y}(t) \cong x^m(t) + W(t) + S(t), 0 \le t < T$$

Where w(t) is a zero-mean white Gaussian noise process with one-sided power spectral density N_0W/Hz and S(t) is an interleaved unknown and arbitrary interfering signal. The signal S(t) represents interference from sources with unknown statistics, such as multiple-access interference, jamming and impulsive noise. In this paper, we consider a communication situation in which nothing is known about S(t) except that it is independent of$\{A_i\}$,W(t), $\{J_o,\ldots,J_{L-1}\}$, $\{B_{0,\ldots\ldots}B_{L-1}\}$ and that its energy is constrained. Therefore S(t) may be random or deterministic, narrow-band or wide-band, stationary or time-varying, Gaussian or non-Gaussian.

4. SIMULATION OF CODED GENERALIZED DSSS COMMUNICATION SYSTEM

In order to avoid the overhead of interleaving and de-interleaving process as described in Figure 2, we directly interleave the interference in the channel while adding it to the signal which is described in Figure 3. The steps involved in simulating a spread spectrum communication system using convolutional coding and Viterbi decoding are as follows:

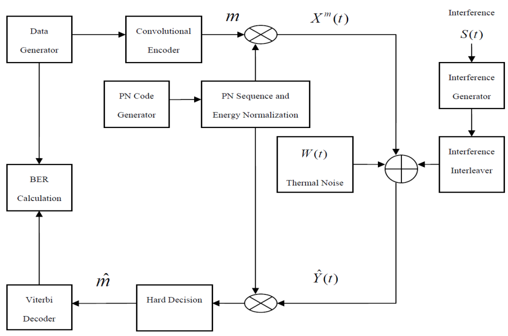


Figure 3: Simulated System Model

Generate the data to be transmitted through the channel.In our case it is always in blocks of 5 × (constraint length) i.e. 5 × *K* binary data bits.

Convolutionally encode the data and map the one/zero channel symbols onto an antipodal baseband signal, producing transmitted channel symbols i.e.
L = (5×K) / r symbols where r is the code rate of encoder.
Multiply the baseband signals with normalized (for generalized DSSS) pseudonoise code sequence of length *N*. Here the symbols get converted into chips.
Now distribute the interference over *D* chips out of total *N*×*L* chips using convolutional or pseudorandom interleaving, later the simulation result maximizes over all the values of *D*.
Multiply the received noisy chips with the same generalized pseudonoise code sequence used at the transmitter and later perform 1-bit quantization of the received channel symbols which is termed as hard-decision; here chips are converted back to symbols.
Perform Viterbi decoding on the quantized received channel symbols which results in binary data bits.
Compare the decoded data bits to the transmitted data bits and count the number of errors in order to calculate the BER of the communication system for the given value of *D*.
Maximize calculated BER over all values of *D* to find the worst-case BER.

In this paper we accurately model the effects of interference even by bypassing the steps of modulating the channel symbols onto a transmitted carrier, and then demodulating the received carrier to recover the channel symbols. We choose this method because it avoids complexity and at the same time it will not affect the performance of the system.

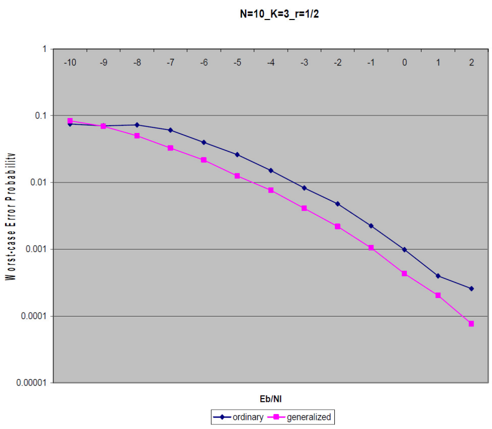
5. PROGRAMMING IN C RESULTS

In this section we compare the worst-case performance of convolutional codes with the same constraint length and see how they perform as code rate varies. All the codes in this section are used with a chip sequence length of N = 10, decoding depth of 5K and convolutional interleaving with the number of rows as 5.

The codes shown in Figures 4, 5, 6, and 7 have the same constraint length of K = 3. They have code rates of r = 1/2, 1/3, 1/5 and 1/7 respectively. Comparing the performance at 10^{-3} level, we get Table.

TABLE: VARYING CODE RATE (R)

Code	Code Rate (r)	Generalized (dB)	Ordinary (dB)	Gain
Figure 6.1	1/2	-0.5	0.5	1
Figure 6.2	1/3	-2	-0.6	1.4
Figure 6.3	1/5	-2.5	-1.0	1.5
Figure 6.4	1/7	-4	-2.4	1.6



Firure 4: code rate,r=1/2

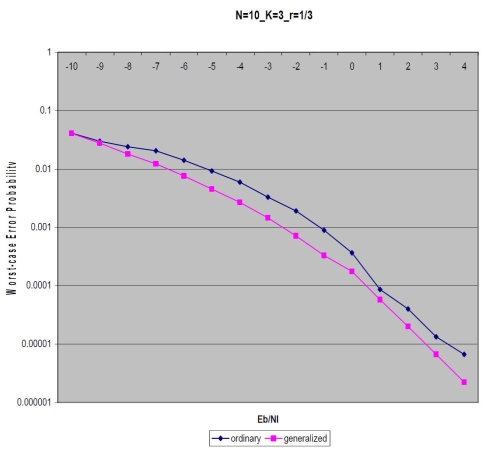


Figure 5: code rate , r=1/3

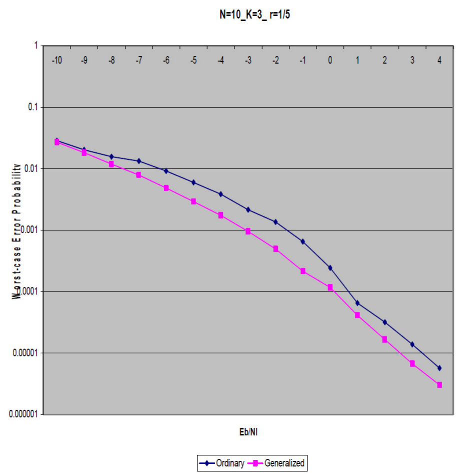


Figure 6: code rate , r=1/5

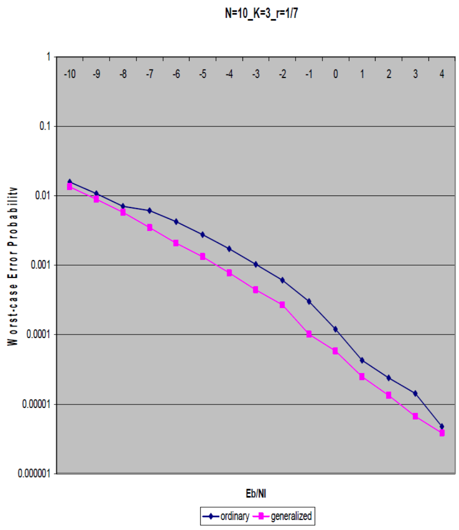


Figure 7: code rate , r=1/7

6. CONCLUSION

Simulation results of the worst-case performance of ordinary and generalized DSSS show that generalized DSSS performs consistently better than ordinary DSSS. This observation has been well known and studied. Other observations are:

Performance of codes with same constraint length improves as code rate decreases, at the same time the difference between two systems increases. It is expected that decreasing code length (increasing redundancy) would result in better performance. It is interesting to also see that the difference between ordinary and generalized DSSS increases with decreasing code length, as stipulated by Hizlan [2].

7. FUTURE WORK

Although the objectives of the paper have been attained, there are a few fundamental recommendations for future work We planning to implement BER for following constraint and comparare Ordinary DSSS Simulation results with generalized DSSS performance.

1. Same Code Rate and with Varying Constraint

2. Same Code Rate and Constraint Length with Varying Chip Length

3. Same Code Rate and Constraint Length with Varying Interleaver

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