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Performance Comparison of Various Spreading Codes in Spread Spectrum Modulation in Ranging Techniques.

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Abstract

In this paper, performance of an asynchronous, bi-phase coded multiple access direct sequence spread spectrum system is studied when the spreading codes used are Maximum length, Gold and small Kasami codes. The parameters for comparison of the asynchronous DS/SSMA system are two namely, the signal-to-noise-ratio (SNR) at the output of the receiver and the average interference paramater (AIP). It was observed that the AO/LSE and LSE/AO phase optimization criteria did not give any significant advantage over the nonphase-optimized spreading codes. Also not observed is any remarkable difference between the performance of Gold, Kasami and M-sequence codes of equal period and set size. This difference is only remarkable to some extent when the code length chosen is small e.g. 31,63 etc. The SNR performance of Gold, Kasami and M-sequence of sufficiently long periods are close to that of the purely random and independent binary sequence of same length.

Keywords: *Multiple access, phase optimization, signal to noise ratio, average interference parameter.*

1. Introduction

Spread spectrum is a popular modulation technique adopted in military communication and ranging applications. It not only provides a secure method of transmission, but also enhancement in range resolution is achieved. Thus many errors pertaining to range measurement system are reduced. In part I of this paper briefly described are spread spectrum systems, types of spread spectrum system and its properties that make it popular in military described briefly in this section. Part II of this paper is a review of some popular codes used in spread spectrum system. Desired properties of spreading codes, implementation and mathemqatics behind their generation are the topics that are discussed in part II. Some guidelines are also given for choosing efficient codes that are suitable for ranging applications. Part III presents some simulatin results and based upon them, performance of codes of different length in different conditions are compared. The system model used in this paper is based on the work of Sarawate and Pursley [1,2]. This work is the extensin of the work reported previously in [5,6,7,8,9 & 10]. This paper ends in section IV with a brief cnclusion and discussion on the scope of further research.

2. Spread Spectrum System

2.1 Technique

One definition of spread spectrum communication technique is “Spread-spectrum is a means of transmission in which signal occupies a bandwidth in excess of the minimum necessary to send the information; the band spread is accomplished by a code which is independent of the data and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery.”

The “code” in this definition is a pseudorandom code that is mixed with the data to “spread” the signal. Thus for the spread signal to appear noiselike, the code needs t6o be random but reproducible. This is an apparent contradiction since a truly random signal is unpredictable. Nevertheless, pseudorandom number generation is statistically random, repeatable and well understood. In order to recover the spread signal, both the transmitter and the receiver must know the coding sequence and be able to synchronize to one another. Thus the spreading code is a pseudorandom sequence and is called thepseudonoise (PN) code.

2.2 Types of Spread Spectrum

There are many ways to spread the bandwidth of the signal: *Frquency hopping, Time hopping, Direct sequene (DS), Hybrid system*

2.3 Military Application

Some properties of SS system

- Selective addressing capability
- Code division multiplexing
- Low density power spectra
- Message screening
- High resolution ranging
- Interference rejection

Due to the low probability of intercept (LPI), anti-jam/interference (AJ) characteristics, the most popular applications of SS are in fields where security is an important consideration. Also, multiple access enables many users to operate at the same time without much interference. The coded modulation characteristics uniquely qualify SS for navigation- from the standpoints of both range measurements and direct finding. DS-SS is the most preferred form for ranging.

2.4 Ranging

Any RF signal is subject to fixed rate of propagation or in other words its speed of propagation is same as that of the speed of light in vacuum (3 x 10^8m/s). The time difference between starting of transmission and end of reception is when multiplied by the speed of the signal sent, gives the distance of the object (target). Echo range measurement system that is used in radar works on this principle. An unmodulated carrier is delayed precisely the same amount of time as a spread spectrum signal traveling the same distance. But, spread spectrum signals have an advantage that its phase is easily resolvable. The basic resolution is one code chip; the higher the chip rate, the better the measurement capability.

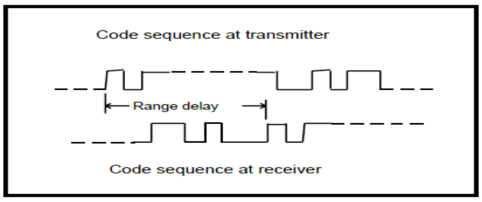

Figure 1 Code-seq. comparison at TX & RX

3. Spreading Code

3.1 Properties

The code used should possess certain properties.

- It must appear deterministic
- It must appear random to a listener
- The correlation of two different codes (cross-correlation) should be small.
- The correlation of a code with a time-delayed version of itself (auto-correlation) should equal 0 for any time delay other than zero in order to reject multi-path interference.
- The code must have a long period

3.2 Choice of Code

In BPSK transmission, bandwidth is a direct function of the code chip rate. Code repetition rate is simply

R_{Rep}= Clock rate(chips/sec) / Code length(chips)

This repetition rate determines the line spacing in the RF output spectrum. Hence, it is an important consideration in a system design. Another important criterion is that the period of the code must be very large. Table 1 lists various code lengths for a 1-Mcps-chip rate. Other consideration should be that the choices of code rate and code length determine the relationship of the repetition rate to the information baseband and use of the system for ranging. The code used in a direct sequence system should be adjusted for repetition rate and length such that noise does not pass into the demodulator especially under jammed conditions. A properly chosen code can not only improve resolution but also can ease range measurement problem. If the chip rate is chosen in such a way that an integral number of code chips are accumulated for each mile of delay, a simple count of code offset can be used to measure range. Clock rates that are integral multiple of 161,875Hz-produce code at rates that are integrally related to the speed of propagation of RF signal. This relationship may be derived as follows:

Speed of light in vacuum is c = 2.997926 x 10^8 m/s
1 nautical mile = 1.852 x 10^3 meter
The clock rate (wavelength = 1nmi) = c/R = 2.997926 x 10^8 / 1.852 x 10^3 = 161,875 Hz

The clock rate for 1 statute mile resolution would be 186,333 Hz. Table 1, 2 list the rates and sequence length that should be used for various range resolutions.

Table 1: Code sequence periods for various m-sequence lengths, 1-Mcps rate

Sequence Length	*Sequence Period*
127	1.27x10^{-4} sec
255	2.55 x 10^{-4} sec
511	5.11 x 10^{-4} sec
1023	1.023 x 10^{-4} sec
2047	2.047 x 10^{-4} sec
4095	4.095 x 10^{-4} sec
8191	9.191 x 10^{-4} sec
131071	1.31 x 10^{-1} sec
524287	5.24 x 10^{-1} sec
8388607	8.388 sec
134217727	13.421 sec
2147483647	35.8 min
879609302207	101.7 days
2305843009213693951	7.3 x10^4 yr
618970019642690137449562111	1.95 x 10^9 yr

Table 2: Chip rates for various basic range resolutions

Basic accuracy	*Nautical mile*	*Statute mile*
0.1 mile	1.61875Mcps (608ft/ch.)	1.86333Mcps (528ft/ch.)
0.05 mile	3.23750Mcps (304ft/ch.)	3.72666Mcps (264ft/ch.)
0.02 mile	8.09375Mcps (121ft/ch.)	9.19665Mcps (105ft/ch)

Among the biggest problems in code generation are (1) finding feedback logic that gives the desired code length and (2) checking the code once a sequence generator has been constructed to ensure that it is operating properly. Tables of feedback connections and irreducible polynomials have been generated [12] [13] [14].

3.3 Description of popular codes

3.3.1 M-sequence: M-sequence codes are widely used in ranging and communication applications. They have certain properties such as:

- 1-A sequence has 2^{n-1} ones & 2^{n-1}-1 zeros.
- 2-Stastical distribution of ‘1’s & ‘0’s is well defined and same.

- 3-There is In general,2^{n-3} runs of '1's & 2^{n-3} runs of '0's of length one.
- 4- Periodic autocorrelation of a ±1 m-sequence is 1 or -1/N
- $N=2^n-1$, n=number of registers
- 5- Modulo-2 addition of a sequence with phase shifted replica of itself results in another replica of itself with phase-shift.
- 6-Every possible state of the n-stage generator exists at sometime during generation of complete code cycle and for one clock interval only.

Two types of implementation of the code are Galois and Fibonaci.

3.3.2 Gold sequence: Gold sequences are constructed by the XOR of a preferred pair of m-sequences with the same clocking. They have well-defined cross correlation properties and only simple circuitry is needed to generate large number of unique codes.

3.3.3 Kasami codes: Kasami codes have popular use in 3G wireless schemes. They can be classified as (1) large Kasami set or (2) small Kasami set. Small kasami set has family size (M) $=2^{n/2}$ and period = N = 2^n-1. Their maximum cross-correlation is $2^{n/2}-1$. Large kasami set contains both gold sequence and small set of kasami sequences as subset. Its period is N= 2^n-1. Maximum cross-correlation is $2^{(n+2)/2}$.

3.3.4 JPL ranging codes: The JPL (Jet Propulsion Laboratory) ranging codes are constructed by modulo-2 addition of two or more maximal linear sequences whose lengths are relatively prime to one another. Often a clock term is also modulo-2 added to other sequences (the clock is a short maximal sequence in itself). There are several advantages to such a technique: (a) very long codes used for unambiguous ranging over long ranges are available; (b) these long codes are generated by a relatively small number of shift register stages; and (c) synchronization of a receiver can be accomplished by separate operations on the component codes. This can greatly reduce the time required for synchronization.

4. Result

4.1 Performance Comparison

There is a need for fixed PN code sets for test purposes from the standpoint of numerical analysis and simulation of an asynchronous direct sequence system and its sub-system units. An agreement on test sequence sets and their initial phases for fixing the probability distribution function of the multiple-access interference (MAI) random variable is necessary. Five types of phase optimization criteria namely auto-optimal least sidelobe energy (AO/LSE), least sidelobe energy auto-optimal (LSE/AO), maximum sidelobe energy auto-optimal (MSE/AO), cross-optimal minimum mean square cross-correlation (CO/MSQCC), minimum mean square cross-correlation cross-optimal (MSQCC/CO) are chosen [15]. The modulation used in the system is BPSK. In this approach it is assumed that all phase-shifts, time delays and data symbols are mutually independent and equally distributed random variables. It is shown in [1] that the signal-to-noise power ratio (SNR) at the output from an asynchronous DS/SSMA receiver of the jth user can be expressed in terms of the asynchronous multiple access interference (Q_a) and the SNR of the AWGN channel (E_b/N_o):

$$\mathrm{SNR}_j = \left\{ \frac{N_0}{2E_b} + Q_a \right\}^{-1} \tag{1}$$

The SNR at the output of the receiver is one of the most important measures of average performance. [1] Multiple access interference (MAI) can be expressed in terms of the average interference parameter (AIP) of K simultaneous and asynchronous interfering users. The AIP value, $r_{i,j}$ depends on the aperiodic cross-correlation function $C_{i,j}$ between the desired (j) and undesired (i) code of period p.

$$Q_A = \frac{1}{6p^3} \sum_{i=1, i\neq j}^{K} r_{i,j} \tag{2}$$

$$r_{i,j} = 2\mu_{i,j}(0) + \mu_{i,j}(1) \tag{3}$$

$$\mu_{i,j}(n) = \sum_{1=1-p}^{1-p} C_{i,j}(1) C_{i,j}(1+n) \tag{4}$$

The parameter $r_{i,j}$ and $\mu_{i,j}(n)$ are of considerable importance in SS system, as they can be used as a criterion for comparing spreading sequences [4]. Also, the SNR of a DS-SS receiver can also be approximated in the following manner [1]

$$SNR_j = \left\{ \frac{N_0}{2E_b} + \frac{K-1}{3p} \right\} \tag{5}$$

SNR curves based on Equation (1) were calculated using five optimization criteria for 13 sets of Gold, Kasami (both small and large sets) and m-sequences of lengths 31. . . 511. First, some general observations are summarized. It can be concluded from Figures 7-11 that a phase optimization criterion of any kind does not yield any appreciable advantage unless the system parameter E_b/N_o is greater than 10 dB. Below that value, the AWGN dominates. (In order to improve the resolution between curves the E_b/N_o axis was chosen to begin from the value 10 dB; note also that $\mathrm{SNR}_j = 2E_b/N_o$ when there is no MAI). Consequently, there is no sense in trying to improve the CDMA capability of a code set by means of a phase optimization rule of any kind when the crucial system parameter E_b/N_o<10 dB. In such cases, the only reason why optimization might be performed is to improve the code synchronization capability (i.e., the side-lobes of the odd ACF are minimized using either the AO/LSE or the LSE/AO criterion).

It can also be concluded from Figures 7–11 that phase optimization begins to lose its importance as the code length increases. The phase optimization problem then seems to become more academic than practical, as the attainable benefit is probably not worth the effort, since the computational load increases. If the code length is 255 or longer, there is no great difference between the AO/LSE, LSE/AO, MSE/AO and CO/MSQCC criteria.

It is also found that there is no noticeable difference in SNR performance between families of unoptimized Gold, Kasami and M-sequences with equal period and set size. The SNR approximation curve (dashed) of equation 4 is used as a fixed standard for comparisons. A small marginal difference can be observed only with the code sets of short period (31…63chips), the difference between the sets for Gold and Kasami sequence of period 63 (figure 12 & 13) for example is only a fraction of decibel in favour of the Kasami sequences. No logical difference in favor of any code family can be perceived when the code period is longer than 63.

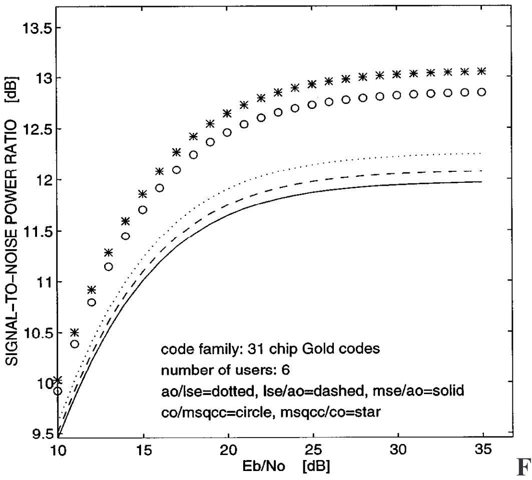

Fig 2 Gold code of length 31

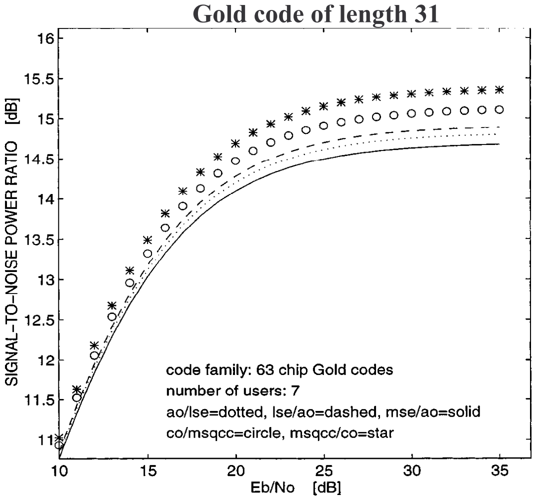

Fig 3 Gold code of length 63

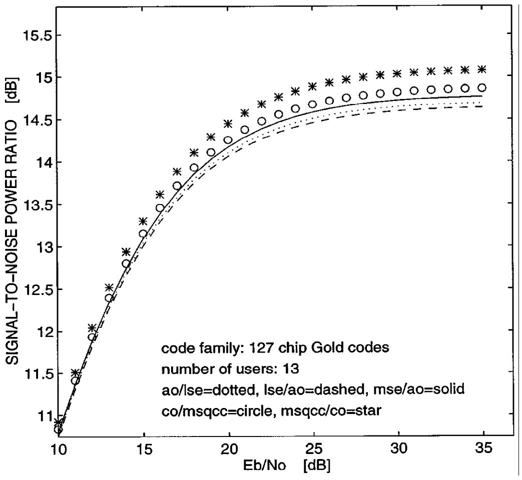

Fig 4 Gold code of length 127

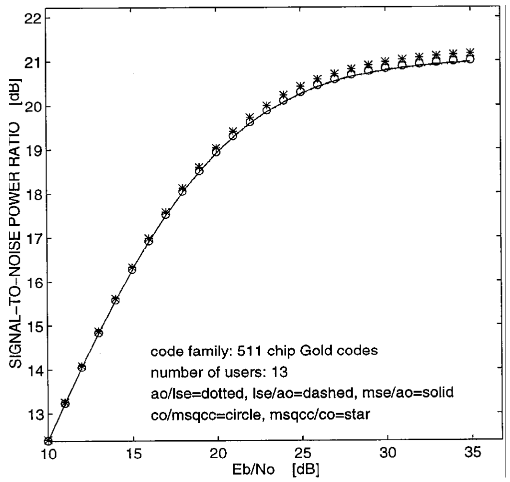

Fig 5 Gold code of length 511

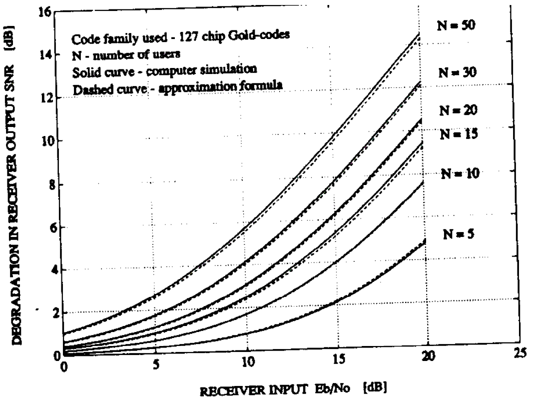

Fig 6 SNR of Gold code of length 127(unoptimized)

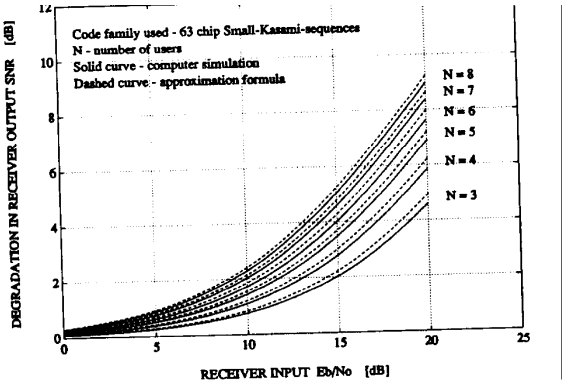

Fig 7 SNR of small-kasami of length 63(unoptimized)

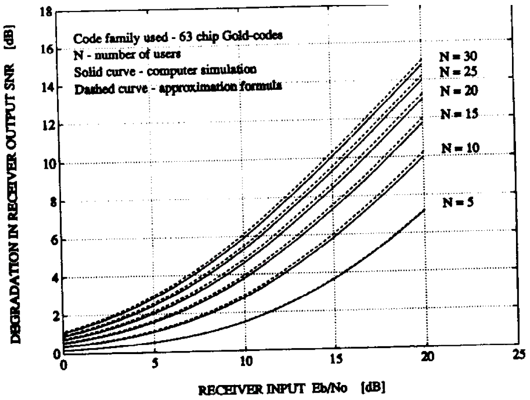

Fig 8 SNR of Gold code of length 63(unoptimized)

5. Conclusion

5.1 Conclusion

The paper presents few results regarding the SNR performance of most conventional linear spreading code families. The performance curves can be used in preliminary spread spectrum design and spreading code design. It is found that the AO/LSE and LSE/AO optimization criteria for sequence phases do not yield any significant advantage in decibels for the average SNR performance of a direct sequence spread spectrum system as compared to unoptimized code sets if minimization of the MAI is the main goal. There are also no appreciable difference in performance between sets of Gold, Kasami and M-sequences of equal period and set size. Finally, it is found that the sets of Gold, Kasami and M-sequences of sufficiently long period tend to behave like pure random sequences of equal length with respect to their average SNR results.

5.2 Further scope of research

The results of this paper can be used for preliminary system design and also for spreading code design. In the present work, more emphasis is given on linear codes. Though these codes do not provide robust security to the system, this drawback can be remedied by designing the code in cryptographically secure techniques. Performance of various multi-user receivers such as the decorrelator, the minimum mean square error (MMSE) receiver, the multistage parallel interference cancellation receiver, the successive interference cancellation receiver, and the decorrelating decision feedback receiver can be compared with these codes in various conditions. The work can also include fading effects, channel characteristics, signal-to-noise ratio etc.

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