Implementation and Evaluation of Chaos-Based Communication System

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Abstract– Gabor Division Spread Spectrum System (GD/SSS) has been proposed by extending spread spectrum system using the codes in both of time domain and frequency domain. Such two-dimensional spreading, realizes robust communication systems against the noises and the interferences. In this paper, we optimize the two-dimensional spreading codes to improve the performance of the GD/SSS. Our simulation results show that the proposed codes have better performance than OFCDM. In order to verify the effectiveness of such a system using two-dimensional spreading, we implement the GD/SSS using the software defined radio technology and evaluate the BER performance using the implemented systems. By our experiments, we confirm that our implemented GD/SSS works correctly and it is clarified that GD/SSS improves the BER lower than the conventional CDMA.

1. Introduction

The direct sequence spread spectrum (DS/SS) is a system, multiplying the spreading code to data sequences, to spread them on a wide frequency band. The receiver side decodes the transmitted data by multiplying by the spreading code. When we apply the DS/SS to multiplexing of multiple data sequences, using spreading codes having less interference to each other, the DS/CDMA can be realized. Although the Gold code has been used as the spreading code in current systems, the system using the chaotic sequence has been shown to have lower bit error rate (BER) than those with conventional spreading codes [1, 2]. In particular, the DS/CDMA using the chaotic codes having negative autocorrelation is effective, that has been shown experimentally and mathematically [3, 4]. In such systems, the signal to interference ratio (SIR) can be improved by a Gaussian filter [5].

Based on the spread spectrum systems, the GD/SSS (Gabor Division spread spectrum system) [6, 7, 8, 9] has been proposed. It spreads the data symbols on the frequency domain, as well on the time domain as the DS/SS. The GD/SSS has a two-dimensional spread system that is expected to robust communication system [6, 7, 8, 9].

In this paper, in order to optimize the performance of the GD/SSS, we apply the algorithm of creating two-dimensional spreading codes to improve the correlation properties [10]. We evaluate the performance of the system using such optimized spreading codes. Further, we implement this system on a real device to evaluate the system performance. In this paper, we implement the GD/SSS using the GNU Radio software platform running on the Universal Software Radio Peripheral (USRP) device. We investigate the performance of the GD/SSS carefully by simulations and real experiments.

2. GD/SSS [6, 7, 8, 9]

GD/SSS is a two-dimensional spread system using the spreading codes on time and frequency domain [6, 7, 8, 9]. Figure 1 shows the relationship in GD/SSS between the data length and the tip width as the width of one of the spreading code. In Figure 1, the thick lines represent each data symbol, and the thin lines represent the chip width of the spreading codes. Figure 1 is spreading code length in time and frequency domain is four, and the data length is also four in time and frequency domain.

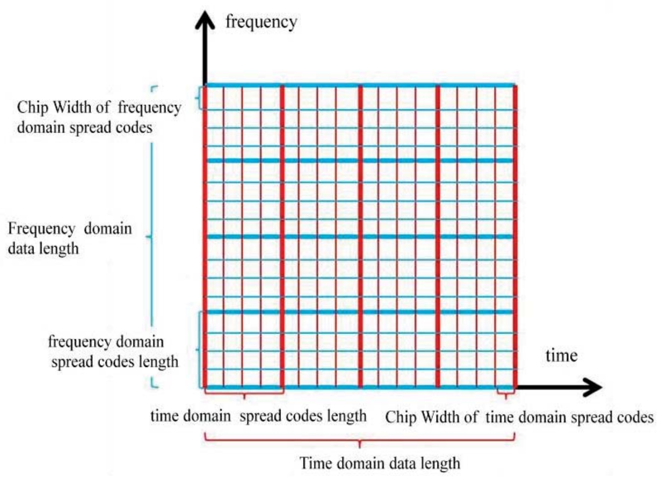

Figure 1. Spreading data symbols on time and frequency domains by the GD/SSS.

GD/SSS is expected to be robust against the noise and the interference. In the wireless communication system using the spreading codes, it is necessary to synchronize the receiver to the receiver signal.

The transmitted signal of the GD/SSS is generated based on the template waveforms on the time domain and frequency domain, which are defined by the following equations,

$$u_m^{TD}(t) = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} X_m z(t - mT_c)\exp(-j\pi m T_c), \quad (1)$$

$$U_{m'}^{FD}(f) = \frac{1}{\sqrt{N'}} \sum_{m'=0}^{N'-1} X'_{m'} Z(f - m'F_c)\exp(-j\pi m' F_c), \quad (2)$$

where $u_m^{TD}(t)$ is time domain template waveform, and $U_{m'}^{FD}(f)$ is frequency domain template waveform.

$N, N', X, X', z, T_c, F_c$ are the length of the spreading code on the time domain, that on the frequency domain, the spreading code on the time domain, that on the frequency domain, the Gaussian function, the width of the chip on the time domain , and that on the frequency domain, respectively.

The transmitted waveform of the GD/SSS, $s^{GD}(t)$ can be represented as follows,

$$s^{GD}(t;\mathrm{X},\mathrm{X}') = \sum_q d_q^{GD} T_{qT,q'F} v^{GD}(t;\mathrm{X},\mathrm{X}'), \quad (3)$$

$$v^{GD}(t;\mathrm{X},\mathrm{X}') = \frac{1}{\sqrt{N'}} \sum_{m=0}^{N-1} X_m T_{mT_c,0} u_m^{FD}(t;\mathrm{X}'), \quad (4)$$

where d_q^{GD} are the transmitted data. T is an operator representing the time-frequency shift, defined by

$$T_{\tau,\upsilon} x(t) = x(t-\tau) e^{j2\pi\upsilon(t-\upsilon/2)}, \quad (5)$$

$$T_{\upsilon,-\tau}^{f} X(f) = X(f-\upsilon) e^{-j2\pi\tau(f-\upsilon/2)}, \quad (6)$$

when the receiver receives the transmitted signal generated by the above equations, first the receiver has to synchronize to the receiving signal $r(t)$ by calculating the correlation between the receiving signal and the time and frequency domain template waveforms used for the transmitted signal, by following equations.

$$c_{\tilde{p},n}^{GD}(\mu,\hat{t}_d) = \left\langle r^{GD}(t;\mathbf{X},\mathbf{X}'), T_{\hat{t}_d,\mu} T_{pT,p'F} T_{nT_c,0} u_n^{FD}(t;\mathbf{Y}') \right\rangle, \quad (7)$$

$$C_{\tilde{p},n'}^{GD}(\sigma,\hat{f}_D) = \left\langle R^{GD}(f;\mathbf{X},\mathbf{X}'), T_{\hat{f}_D,-\sigma}^{f} T_{p'F,-pT}^{f} T_{n'F_c,0}^{f} U_n^{TD}(t;\mathbf{Y}') \right\rangle, \quad (8)$$

where

$$\langle r(t), s(t) \rangle = \int_{-\infty}^{\infty} r(t)\bar{s}(t)dt, \quad (9)$$

time and frequency domain synchronization can be achieved by finding μ and σ corresponding to the largest c^{GD} and C^{GD}. When the difference between the highest value and the second highest value is small, the detection of correct synchronization point becomes difficult. Therefore, it is important to use the code having sharp peak in those correlation values.

3. Effectiveness of the two-dimensional optimized code

3.1. Optimization of the two-dimensional code

In order to maximize the different between the highest and the second highest values of correlation, we have proposed optimization method of the two dimensional spreading code in Ref. [10]. This method searches the spreading codes that maximize the rate of the highest correlation value at the synchronized point over that of the second highest peak. As the objective function of this optimization, we use the sum of squares of the rate on the time and frequency domain. In order to maximize this objective function, in this paper, we apply a heuristic exchange of each bit of the code. For the initial state, randomly generated code sequences are prepared for both time and frequency domains. For this pairs of codes, objective function is calculated. One bit of the codes is selected and calculated the objective function for the code that the selected bit is inverted. When the objective function is increased by this inversion, the codes are updated by inverting the selected bit. Repeating this updates, we obtain the codes maximizing difference between the peak and the second peak correlation values [10].

3.2. Effectiveness of the optimized two-dimensional codes

In order to confirm the effectiveness of the optimized two-dimensional spreading codes for the GD/SSS and we evaluate the BER performance. As a conventional scheme using time domain spreading and multiple channels, we introduce the OFCDM for the comparison. Figure 2 shows the BER performance of those schemes, with setting length of the time and frequency domain spreading codes 16.

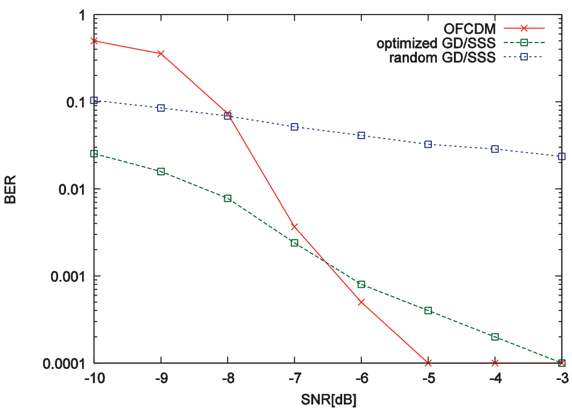

Figure 2. Comparison of GD/SSS and OFCDM.

From Fig. 2, the GD/SSS has good BER performance when the SNR is low. Further, we confirm that the optimized spreading codes much improve the BER performance of the GD/SSS.

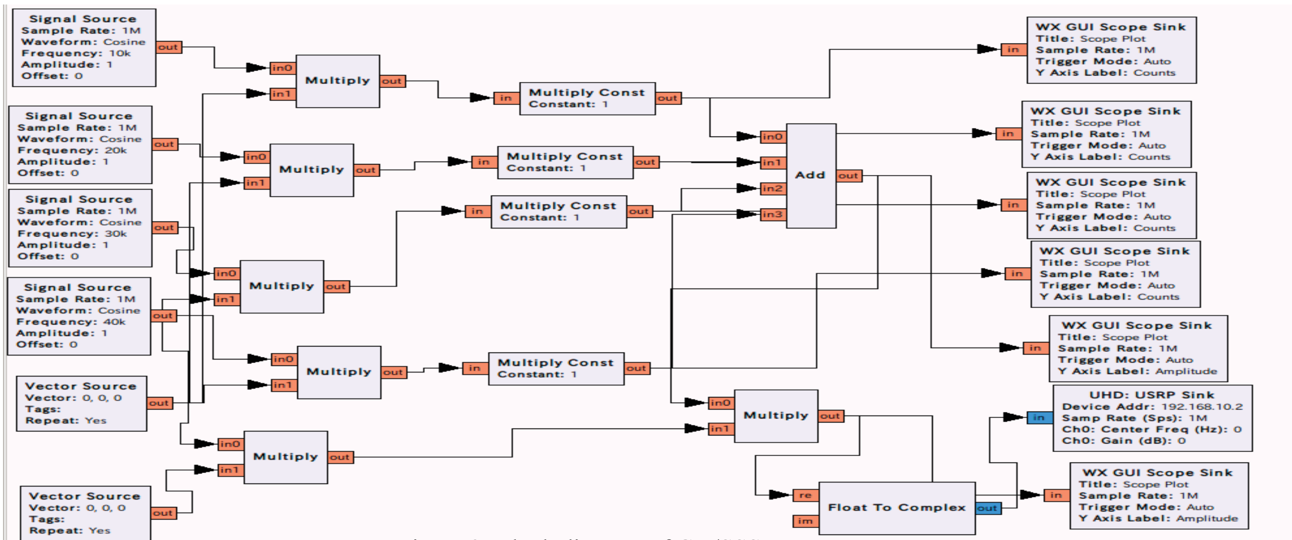

Figure 3. Block diagram of GD/SSS.

4. Implementation of GD/SSS using Software Defined Radio

Previous section shows effectiveness of GD/SSS by computer simulation. In this paper, we implemented GD/SSS on a software defined radio system, and evaluated the performance of GD/SSS. The software defined radio system enables implementation of various modulation schemes by performing signal processing on the software rather than on the hardware.

In this paper, we use GNU Radio and Universal Software Radio Peripheral (USRP) as the software defined radio. GNU Radio is software platform to implement software of the software defined radio. Various modules for signal processing written C++ can be connected by Python realize a wireless communication system. The USRP is a hardware that can be used as a radio front end of the GNU Radio. The USRP is composed of a main board and a daughter board. Frequency conversion, transmitting and receiving are performed on the daughter board, and the A/D conversion is performed on the main board. We use USRP N210 to implement the GD/SSS. Figure 3 shows GD/SSS developed by the GNU Radio. The length of the frequency domain spreading is four. Figure 4 shows an example of the transmitted waveform of the developed GD/SSS. Using the implemented GD/SSS on the software defined radio, we evaluate the BER performance. We have also implemented the conventional DS/SS for the comparison. Figure 5 shows the result of the performance evaluation by the experiments using the developed system. Time domain spreading code length is fixed at thirty-two, and several values of the length of the frequency domain spreading are tested.

The results in the Fig. 5 show that the GD/SSS has lower BER, especially in the cases that the SNR is low. We confirm effectiveness of the GD/SSS not only by computer simulation but also by the actual experiments using a real implemented communication system.

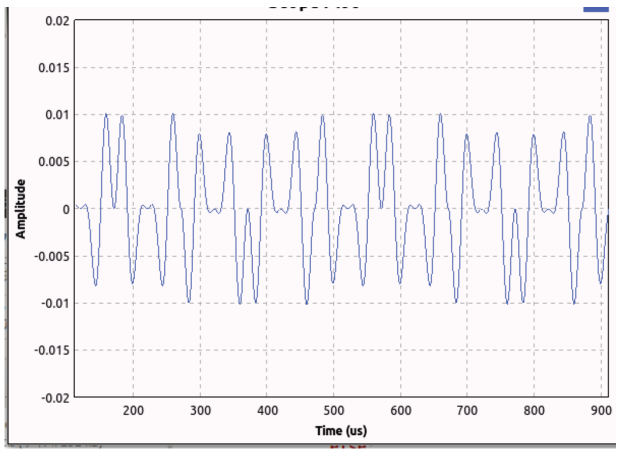

Figure 4. transmitted waveform of GD/SSS creating implemented system.

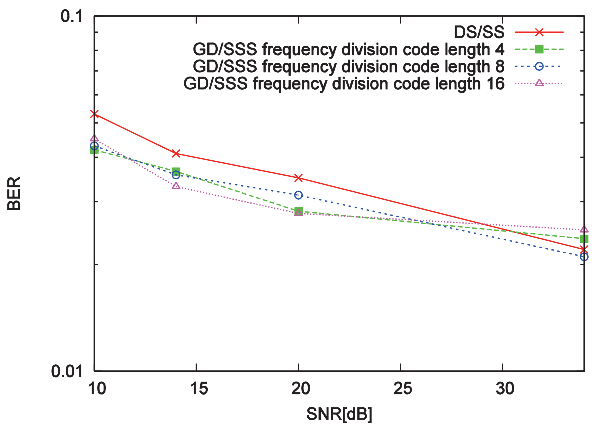

Figure 5. Implemented GD/SSS of noise resistance.

5. Conclusion

In this paper, we evaluated the effectiveness of GD/SSS by a simulation and a real communication device. By optimizing the spreading codes of two-dimensional GD/SSS, we show the BER performance becomes better than the conventional modulation scheme using time and frequency domain, such as the OFCDM. Furthermore, we implemented the GD/SSS using the GNU Radio and the USRP, and demonstrate its performance. By experiments using the system, we confirm the effectiveness of the GD/SSS, which uses the time and the frequency domain spreading.

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