IJournals International Journal of Software & Hardware Research in Engineering
ISSN No: 2347-4890
Volume 3 Issue 1, January

Compressive Sensing Receiver with HIC

Priya Rathore[1]; Pratik Kumar Soni[2]; Virendra Verma

rathorepriya0307@gmail.com.com; pratik.k.soni@sims-indore.com[2];
virendra.verma@sims-indore.com[3]

ABSTRACT

In wireless communication, power efficiency and production cost are the two important parameters for designing a receiver. By using compressive sensing in the general CDMA receiver, the two above mentioned parameters can be improved. In this paper we have shown that, the performance can also be improved by introducing a hybrid interference cancellation scheme with compressive spread spectrum at the receiver side. The performance of proposed receiver is evaluated in terms of BER and E_b/N_0.

Keywords

Compressive Sensing, Hybrid Interference Canceller, Sparse Sampling, Spread Spectrum Receiver.

1. INTRODUCTION

One of the fastest growing technologies in the recent past is the Wireless personal communication technology. The most challenging part in any of these kinds of wireless technologies is that of the receivers. The receiver design decides the size, weight and cost of a mobile unit. Hence a receiver should be of petite size, with a reduction of weight and yet at an affordable cost. At the same time, the receiver should be efficient and must perform well under all circumstances. The conversion of a signal from analog to digital is a power costly operation in wireless devices. The necessary condition to perfectly recover the analog signal from its samples, is the Shannon-Nyquist theorem. The Shannon-Nyquist theorem states that the sampling frequency must be twice the bandwidth of the signal to correctly reconstruct the signal.

Recently a new concept has been developed in the signal processing community, by which a signal can be subsampled, is known as Compressive Sensing (CS) [1], [2]. A signal may be sampled at a rate lower than the Nyquist frequency, if it is sparse in some arbitrary basis may be in frequency or time. In wireless devices compressive sensing allows the receiver to sample below the dictated Shannon-Nyquist sampling rate, which may result an improvement in design parameters. Bernoulli, random Gaussian and Rademacher measurement schemes, as well as the Random Demodulator (RD) [3], [4] and the Modulated Wideband Converter [5] are some linear measurement schemes which are used to acquire the sampled signal.

In a CDMA system, by the presence of multi-user interference the performance of channel matched filter receivers are limited. By additionally introducing the Hybrid Interference Canceller in the DS-CDMA receiver structure performance can be modified. Thus receivers must be capable of suppressing these interferences. Interference suppression or interference cancellation can be done by subtracting the interfering users from the received signal, thus allowing an improved bit error rate performance. Here the problem of noise folding occurs, as we subsample the signal [6]. This problem can be further overcome by introducing quantization at the receiver side.

2. SIGNAL MODEL

First we consider a discrete signal model of a spread spectrum communication system. Uncoded information bits are sent in a slotted fashion, where an independent CDMA signal is comprised in each slot. At the receiver side, these slots are decoded sequentially and independently from each other. For each slot, a discrete QPSK baseband signal $x \in \mathbb{C}^{N\times 1}$ is defined as:

$$x = \Psi\alpha \ , \quad (1)$$

Where $\Psi \in S_\Psi \subset \{\pm 1\}^{N\times N}$ is an orthogonal or near orthogonal dictionary, which contains spreading waveforms for transmission. S_Ψ is the subset of $\{\pm 1\}^{N\times N}$ which contains orthogonal or near-orthogonal dictionaries and $\alpha \in \{\pm 1 \pm j, 0\}^{N\times 1}$ is a sparse vector, which selects spreading waveform(s) and QPSK constellation point(s) to send. Because we process only one slot at a time so here α is a vector. And we suppose that the signal amplitude is constant for each user within a slot. The enabling factor for the CS in any network is, suppose that α may be sparse in network, means the number of active users is smaller than the total number of possible users. Examples of such cases are mobile phone Θ networks and wireless sensor networks, where the number of active users is less. The following signal is observed at the receiver:

$$y = \Theta(x + w) = \Theta\Psi\alpha + \Theta w, \quad (2)$$

Where Θ is a measurement matrix, and $w \in \mathbb{R}^{N\times1}$ is Additive White Gaussian Noise (AWGN). The noise becomes the colored noise due to the noise folding, and affects the performance of demodulator. The Signal to Noise Ratio (SNR) is decreased by 3 dB because each time the sampling rate is reduced by one half [6] [7].

2.1 Spread Spectrum Dictionary

For single user spread spectrum applications mainly in military applications, the m- sequences are used. The desired cross correlation properties (ideally zero for all cyclic shifts) demands are not met by m-sequences, which is used in multi user systems. In a great extent Gold-sequences meet these demands and hence are used for multi user system applications.

The gold-sequence are generated by modulo-2 addition of two m-sequences of equal length and clocked by the same chip clock. If 'n' is the number of stages in each m-sequence, then the Gold-sequence length will be

$$N = 2^m - 1$$

It is called a maximum length sequence as its period is maximum length. The length is $2^m - 1$ rather than 2^m because we avoid the state where all cells are zero. Moreover, the two m sequences must be selected so that their periodic cross correlation is three-valued and takes on only the values $\{-1, -t, t-2\}$, where:

$$t = \begin{cases} 2^{(m+1)/2} + 1 \text{ for even m and} \\ 2^{(m+2)/2} + 1 \text{ for odd m} \end{cases} \quad (3)$$

These values meet the multi user system demand. Define Ψ is an N×N dictionary of Gold sequences, where each column signifies a possible code sequence. The information rate of the signal is much lower, only when α is sparse. By using CS it may be possible to further reduce the sampling rate. In this paper, we use Gold dictionary sizes: m = 10.

3. CSS MEASUREMENT MATRIX

CS scheme is developed to reduce the number of samples to obtain some desired signal. Linear sampling scheme is the heart of CS, called the measurement matrix. In case of classical receivers the measurement matrix Θ may be modeled as the identity matrix, such that signal x is sampled at the chip rate of each channel (I and Q). Here, classical receiver is denoted by Θ_1 =I, where the subscript 1 denotes no subsampling and I is the identity matrix of size N × N.

In CS another measurement matrix $\Theta_\kappa \in \mathbb{R}^{M\times N}$ is used which denotes CS measurement matrix, where is the subsampling ratio and M = N/κ. This measurement matrix maps the N-dimensional signal x to a M-dimensional signal y. Assume that x is sparse in some basis, then it is realizable to reconstruct the desired signal from the sampled M-dimensional signal y. Compressive Spread Spectrum (CSS) measurement matrix, new measurement scheme enabled by the CDMA [8] is easier to implement than the RD, but performs almost identically for spread spectrum systems. Theoretically Bernoulli or Rademacher distributed measurement matrix is generally used, but for practical implementation it is not well suited in wireless receiver. The other well-known measurement matrix structure is the Random Demodulator (RD) sampling structure, which is well suitable for practical implementation.

In the RD matrix [4], the measurement matrix is based on two matrices, D and H. First, let $\varepsilon_0, \varepsilon_1, \ldots, \varepsilon_N \in \{\pm1\}$ be the chipping sequence used in the RD for a signal of length N. The mapping x → Dx signifies the demodulation mapping with the chipping sequence, where D is the diagonal matrix:

$$D = \begin{pmatrix} \varepsilon_0 & & \\ & \ddots & \\ & & \varepsilon_N \end{pmatrix} \quad (4)$$

The accumulate-and-dump action performed after mixing is denoted by the **H** matrix. The numbers of samples are denoted by M. Here we assume that M divides N. Each sample is the sum of N/M consecutive entries of the demodulated signal. An M × N matrix performs this sampling action with N/M consecutive unit entries in the r^th^ row starting in column rN/M + 1 for each r = 0, 1 . . . M − 1. An example with M = 3 and N = 6 are:

$$H = \begin{pmatrix} 1\,1 & & \\ & 1\,1 & \\ & & 1\,1 \end{pmatrix} \quad (5)$$

Hence, to sample an analog signal, the RD is designed. Discrete representation is equivalent to:

$$y = HDx \quad (6)$$

where x is the input signal sampled at Nyquist rate and y is the output signal which is compressively sampled.

A chipping sequence is used to spread the signal across the frequency spectrum; therefore the information is aliased down into the lower frequency region, which remains untouched by the low-pass filtering. In the suggested receiver structure mixing is unneeded because at the transmitter the signal has already been spreaded. Hence the proposed receiver may be simplified to:

$$y = Hx \quad (7)$$

This is quite easy to implement in hardware than the RD. Comparing to the notation introduced for the measurement matrix in Section II we therefore use: Θ_κ = H.

A random-like dictionary matrix is introduced in the CDMA dictionary, which spreads the signal such that each sample contains a little bit of the original information signal [9]. This is similar to what the measurement matrix does in CS. Hence we don't use PRN sequence in measurement matrix. Therefore, the sampling process may be rewritten as

$$y = Hx = H\Psi\alpha = \Theta I\alpha \quad (8)$$

The measurement matrix now becomes $\Theta = H\Psi$, i.e. the subsampling matrix and the CDMA codes.

Here we are interested only in the sparse vector α rather than the reconstructed signal x. To achieve this reconstruction we choose the greedy algorithm Subspace Pursuit [10]. This algorithm is selected, because it performs well in terms of both reconstruction accuracy and running time.

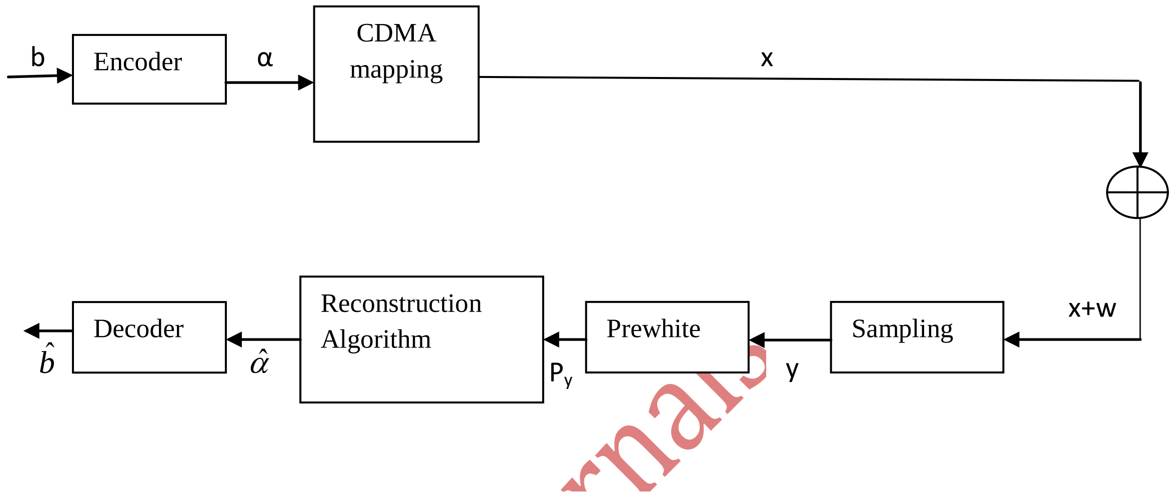

Fig. 1: Flow chart of numerical experiment

4. NUMERICAL EXPERIMENTS

In Fig. 1 a flow chart of the numerical experiment is shown. In which, we first encode a randomly generated bit sequence b to form the sparse vector α from Eqn. (1). Then the non-zero positions are drawn randomly from a uniform distribution. QPSK symbol is denoted by each non-zero position. To create a CDMA signal by using Gold dictionary, use sparse vector α as $x = \Psi\alpha$. Now signal is attacked by additive white Gaussian noise (AWGN). According to a chosen SNR value AWGN is generated. SNR is defined as follows:

$$\text{SNR}=\mathbb{E}\left[\frac{\|x\|_2^2}{\|w\|_2^2}\right] = \frac{\|x\|_2^2}{N\sigma^2} \quad (9)$$

where w ~ $\mathcal{N}$ (0, $\sigma^2 I$) with σ^2 the variance of the noise. At the receiver side, the sampling is done as in Eqn. (2). After prewhitening, the sparse vector can be reconstructed using the Subspace Pursuit algorithm. Which now include the P matrix, i.e. $A = P\Theta_\kappa\Psi$. Complexity of the system is increased by this prewhitening step, but this step is performed only for the Rademacher measurement matrix.

In the Rademacher measurement matrix for each slot, the A matrix must be generated anew because each time a new measurement matrix Θ_κ is generated. In The RD and CSS measurement matrices, rows are orthogonal so there is no need to generate anew matrix each time. After getting the sparse vector $\hat{\alpha}$, we are able to decode the original bit sequence $\hat{b}$. The theoretical performance for non-coherent MFSK is given by [14]:

$$P_b = \frac{M}{2(M-1)}\frac{1}{M}\sum_{\kappa=2}^{M}(-1)^\kappa\binom{M}{\kappa}\exp\left(\log_2(4)\frac{E_b}{N_0}\left(\frac{1}{\kappa}-1\right)\right) \quad (11)$$

where energy per bit per noise spectral density is denoted by $\frac{E_b}{N_0}$.

We use the noncoherent formula because the CDMA codes are QPSK modulated. Here we use Gold sequences with m=10 and different value of subsampling i.e. 2 and 4.

ijournals International Journal of Software & Hardware Research in Engineering
ISSN No: 2347-4890 Volume 3 Issue 1, January

4.1 INTERFERENCE CANCELLER

The performance of the DSSS receiver can be further improved by cancelling the interference from the multiple users'. The SIC [11] and PIC [12] are combined in proposed HIC. The successive interference cancellation receiver is simple in design, but its computational time is high, whereas the parallel interference cancellation receiver requires less computational time, but it's more complex in design. So here we have done a tradeoff between the computational time and complexity of receiver, to get the desired improvement in performance. HIC is designed with minimum number of iterations, with minimum complexity. The HIC receiver the first stage of cancellation is the PIC, where a few number of users have the decision statistic above a certain threshold are cancelled. Then the remaining users are passed through SIC i.e. the second stage of cancellation. Here the remaining users are cancelled one at a time, until the signal of desired user's is separated. Then to get the users' information, subtracted signal is given to a conventional receiver. Flow chart of HIC receiver is shown in fig. 2. In the HIC receiver the threshold or decision static plays important role [13].

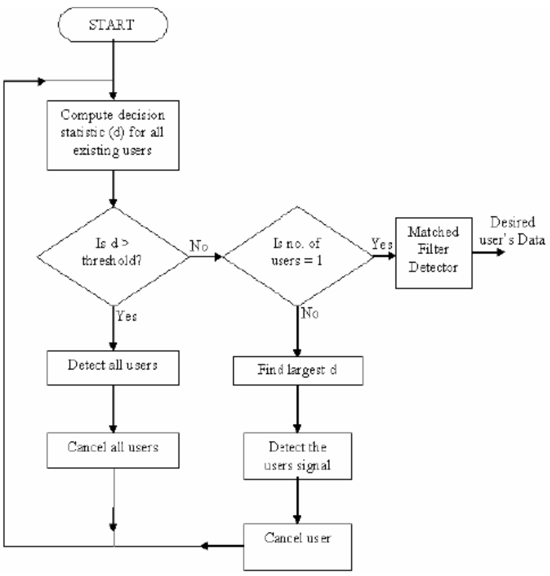

Fig. 2 Flow chart of HIC

The results are shown in fig. 3 and fig. 4. As can be seen, for m = 10 & k=2 without cancelling the interference, Rademacher, RD and especially the CSS measurement matrix seems to perform poorly. For high E_b/N_0 values there is more than the expected 3 dB loss per octave due to noise folding shown in Fig.4, m = 10 & k=4. This loss is almost exactly 3 dB per halving of the sampling rate. These results show that the CSS measurement matrix with interference canceller, though simpler than all the other measurement matrices, performs equally well in the above experiments for m = 10. For small dictionary sizes, its performance is worse. CS is here Rademacher measurement scheme.

5. CONCLUSION

In this work we applied CS to a general CDMA system. Here we have shown that by cancelling the interference at receiver side, a very simple measurement scheme can enable subsampling of the CDMA signal for multi user application. We show that the performance is affected negatively in BER performance, similar to other schemes. Furthermore, we have shown that power efficiency can be improved by taking fewer samples.

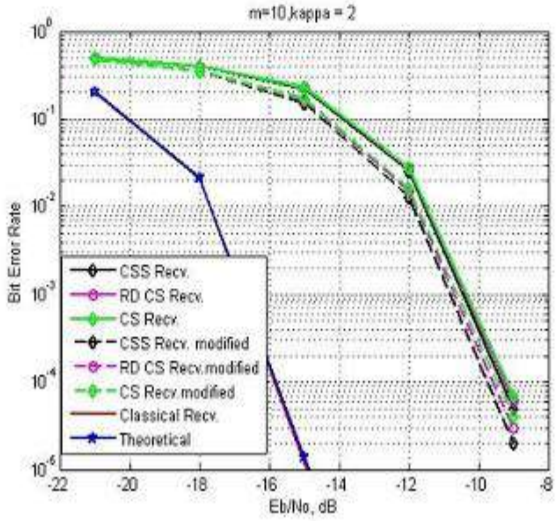

Fig. 3 BER Vs E_b/N_0 for m=10 & k=2

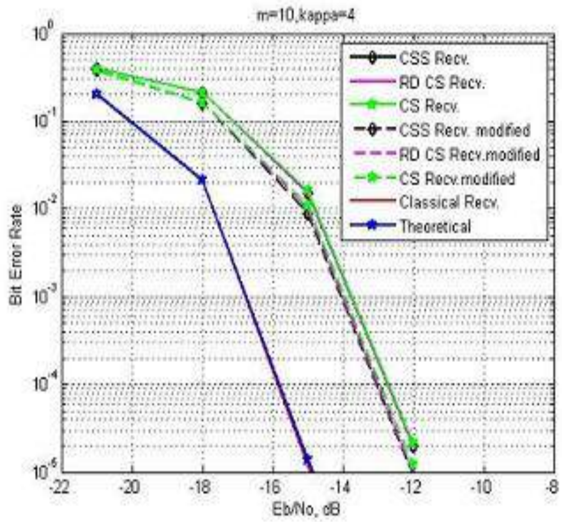

Fig. 4 BER Vs E_b/N_0 for m=10 & k=4

6. REFERENCES

[1] E. J. Candes, J. Romberg, and T. Tao, "Stable signal recovery from incomplete and inaccurate measurements," Applied Mathematics, vol. 59, no. 8, pp. 1207–1223, 2006.

[2] D. L. Donoho, "Compressed sensing," IEEE Trans. on Inf. Theory vol. 52, no. 4, pp. 1289–1306, Apr. 2006..

[3] S. Kirolos et al., "Analog-to-information conversion via random demodulation,"in IEEE Dallas/CAS Workshop on Design, Applications, Integration and Software, Oct. 2006, pp. 71–74.

[4] J. A. Tropp et al., "Beyond Nyquist: efficient sampling of sparse bandlimited signals," IEEE Trans. on Inf. Theory, vol. 56, no. 1, pp. 520–544, Jan. 2010.

[5] M. Mishali and Y. Eldar, "From theory to practice: Sub-Nyquist sampling of sparse wideband analog signals," IEEE J. of Sel. Topics Signal Process., vol. 4, no. 2, pp. 375–391, Apr. 2010.

[6] E. Arias-Castro and Y. C. Eldar, "Noise folding in compressed sensing," IEEE Signal Process. Lett., vol. 18, no. 8, pp. 478–481,

Aug. 2011.

[7] K. Fyhn et al., “Demodulating subsampled direct sequence spread spectrum signals using compressive signal processing,” in Proceedings of the 20th European Signal Processing Conference (EUSIPCO), Aug. 2012, pp. 2556 –2560.

[8] K. Fyhn et al, “ Compressive sensing for spread spectrum recievers” Wireless Communications, IEEE Transactions on vol. 12 , no. 5, April 2013, pp. 2334 – 2343.

[9] R. Gold, “Optimal binary sequences for spread spectrum multiplexing (Corresp.),” IEEE Trans. Inf. Theory, vol. 13, no. 4, pp. 619–621, Oct.1967.

[10] W. Dai and O. Milenkovic, “Subspace pursuit for compressive sensing signal reconstruction,” IEEE Trans. Inf. Theory, vol. 55, no. 5, pp. 2230– 2249, May 2009.

[11] P. Patel and J. Holtzman, “Performance comparison of a DS-CDMA system using a successive interference cancellation (IC) scheme and parallel IC scheme under fading”, *IEEE Transactions on Communication*, Vol. 48, No. 3,pp.139-147, Jan. 1996.

[12] Divsalar D, Mavin K. Simon, “Improved Parallel Interference Cancellation for CDMA”, IEEE Transactionson Communication, Vol. 46, No 2, pp. 258-268, Feb 1995.

[13] L.Nithyanandan and P.Dananjayan,”Hybrid interference cancellation receiver for DS CDMA system”,Proc.Tenth national conference on communications, NCC 2004 ,pp. 577-581, Jan 2004.

[14] B. Sklar, Digital Communications: Fundamentals and Applications, ser. Prentice Hall Communications Engineering and Emerging Technologies Series. Prentice-Hall PTR, 2001

