http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (11): 2225-2230, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.2225.2230

A Low-density Parity-check Codes LDPC based Hybrid Multiuser Detection Method for DS-UWB System

Zhendong Yin, Xiaohui Liu, Meihang Chen and Zhilu Wu
School of Electronics and Information Engineering, Harbin Institute of Technology, Harbin, Heilongjiang 150001, China

Abstract: With the development of ultra wideband (UWB) technologies, the multiple access UWB system has been a hot research topic. In this article, an efficient multiuser detector based on Low-Density Parity-Check Codes (LDPC) codes is proposed for direct-sequence ultra-wideband systems in Inter-satellite communication. To implement the hybrid receiver, code mapping and K-means clustering proposed by the author to further eliminate the multiuser interference and provide better detection performance. LDPC codes can achieve performance approaching the Shannon limit when decoded using an iterative probabilistic algorithm. In addition to their simple descriptions of code structure and fully parallelizable decoding implementations, such codes have attracted much attention particularly in the field of coding theory. Simulation results show the proposed new hybrid multiuser receiver possesses better detection performance.

Key words: DS-UWB, LDPC, multiuser detection, code mapping

INTRODUCTION

Along with the rapid development of space craft technology and it has become a hotspot in spaceflight research area. Inter-satellite communication is an important component and the key technology in this system. And the Ultra wideband (UWB) is an attractive wireless communication technology for its characteristics of high transmission rate, large message capacity, low power density, high interference resistance and confidentiality and strong multi-path resolution and so on (Yang and Giannakis, 2004).

In recent years, multiple access UWB communications has been a hot research topic as the development of UWB technologies. In UWB communication systems, the multiple access approaches are commonly divided into two paths: time hopping (TH-UWB) and direct sequence (DS-UWB) (Oppermann *et al*., 2005; Zhang *et al*., 2003). When using DS technique, Pseudo Noise (PN) code is applied to spread the data bit into multiple chips, just as in conventional DS spread spectrum systems and the users are separated by independent PN code. All the users transmit their own information in the same channel simultaneously and in the receiver, the base-band signals of each user are obtained by the matched filter. Hence, it is necessary to use multiuser detection (MUD) to alleviate the multiple access interference (MAI).

More study about MUD put forward to solve the problem of MAI are established. The algorithm of the Optimum Multiuser Detection (OMD) based on Maximum Likelihood Sequence Detection (MLSD) was proposed by Verdu (1986). The OMD can completely eliminate the MAI at the price of extremely high computational complexity. A code-aided interference suppression method was introduced for NBI restriction in DS-UWB systems (Wang *et al*., 2010). Adaptive MUD methods using the Recursive Least Square (RLS) principles were studied in (Biradar *et al*., 2008; Ahmed and Yang, 2010). More and more sub-optimal MUD algorithms have been put porward in literatures in recent years. A recursive multiuser detection is proposed for DS-UWB systems proposed in (Zhang *et al*., 2005), which can provide near-optimal performance relative to the maximum likelihood detector with reduced computation complexity. Wu *et al*. (2011), proposed a Joint Multiuser Detection Algorithm of Correlation Detection and Artificial Fish Swarm Algorithm (CD-AFSA-MUD), the BER performance of CD-AFSA-MUD is also close to that of OMUD, furthermore, its convergence rate and the ability to resist Near-far Effect are superior to those of other MUD algorithms.

Inspired by the study aforementioned, a new hybrid multiuser receiver for DS-UWB systems are propose in this study, which based on LDPC codes, matched filters and error-bit recognizers. Space craft DS-UWB

Corresponding Author: Zhendong Yin, School of Electronics and Information Engineering, Harbin Institute of Technology, Harbin, Heilongjiang 150001, China

communication are some difficult problems to be solved such as far communication distance, low signal-to-noise ratio and high bit error rate request. Research the LDPC code as the encoding manner in inter-satellite channel after determining the communication condition. The coding and decoding methods of LDPC code are introduced. The error-bit recognizer is composed of a bit mapping algorithm and K-means clustering, which can identify the wrong bits among the candidate received base-band bits set output from the matched filters. What is more, the proposed hybrid MUD algorithm has a low computational complexity than normal sub-optimum MUD methods.

SYSTEM MODEL

Consider a DS-UWB system with K-user Additive White Gaussian Noise (AWGN) channel and assume each user employs the binary phase-shift key (BPSK) modulation.

In order to make the transmitted power as low as possible, the first-order Gaussian pulse is the best choice (Yin *et al*., 2010). So in this study, the first-order Gaussian pulse is used as the UWB pulse waveform. And the expression of the pulse waveform is:

$$p(t) = A\left[1 - 4\pi\left(\frac{t - t_d}{\tau_m}\right)^2\right]\exp\left[-2\pi\left(\frac{t - t_d}{\tau_m}\right)^2\right] \quad (1)$$

where, t_d and τ_m are the pulse center and the pulse shape parameter, respectively.

The kth user's signal transmitted can be described as the following:

$$x_k(t) = \sum_{i=1}^{M}\sum_{j=0}^{N_c-1} b_k(i)c_k(t-(i-1)T_s)p(t-(i-1)T_s - jT_c) \quad (2)$$

where, BPSK symbols $b_k(i)\in\{-1,1\}^M_{i=1}$ are spread with the specific PN codes $c_k(t)$, which are the binary bit stream valued only by -1 or 1. M is the length of bits per packet. T_s represent the symbol duration. Consider that each BPSK symbol can be subdivided into N_c chips with the duration T_c and N_c equals T_s/T_c.

In each chip, a monocycle p(t) is transmitted with the duration of T_p to represent the sign of the chip. The received signal from all users can be written as:

$$r(t) = \sum_{i=1}^{M}\sum_{j=0}^{N_c-1} A_k b_k(i)c_k(t-(i-1)T_s)p(t-(i-1)T_s - jT_c) + n(t) \quad (3)$$

where, n(t) is zero-mean additive white Gaussian noise (AWGN) with the unilateral power spectral density of N_0 A_k is the signal amplitude.

In the receiver, the traditional receiver of a DS-UWB system consists of a pulse demodulator and a group of matched filters corresponding to each user. Regarding the signal r(t) as the input of the group of matched filters.
Let vector $y= [y_1, y_2,\ldots, y_K]^T$ denote the output of the group of matched filters and vector $b^* = [b^*_1, b^*_2,\ldots, b^*_K]^T$ denote the output of sign detectors, so the output of the matched filters can be expressed as follows.

$$y= RAb+n \quad (4)$$

$$b^* = \text{sgn}(y) \quad (5)$$

where, the vector $n = [n_1, n_2,\ldots, n_K]^T$ denotes the output of the AWGN from each user's corresponding matched filter, $b = [b_1, b_2,\ldots, b_K]^T$ denotes the correct bits of each user, $R = (r_{ij})_{K\times K}$ denotes the cross-correlation matrix, which:

$$r_{ij} = \sum_{l=0}^{N_c-1} c_i(l)c_j(l)$$

and $A = \text{diag}(A_1, A_2,\ldots, A_K)$.

Furthermore, the whole receiver is constituted of matched filters and an error-bit recognizer which embraces a bit mapper, a K-means classifier. The main principle of detection will be demonstrated in next section.

LDPC CODING

The block diagram of the transmitter is shown in Fig. 1. The most obvious path to the construction of an LDPC code is by means of the construction of a low-density parity-check matrix with prescribed properties. A large number of design techniques exist in the literature and introduced a more prominent one in this section, albeit at a superficial level. The design approaches target different design criteria, including efficient encoding and decoding, near-capacity performance, or low-error floors.

The original LDPC codes due to Gallager are regular LDPC codes with an H matrix of the form:

$$H = \begin{bmatrix} H_1 \\ H_2 \\ \vdots \\ H_{\omega_c} \end{bmatrix} \quad (6)$$

where, the submatrices H_d have the following structure. For any integers μ and ω_γ than greater than 1. Each submatrix H_d is $\mu\times\omega_\gamma$ with row weight ω_γ and column weight 1. The submatrix H_1 has the following specific form: for I = 1,2,...,μ, the row contains all of its ω_γ 1's in

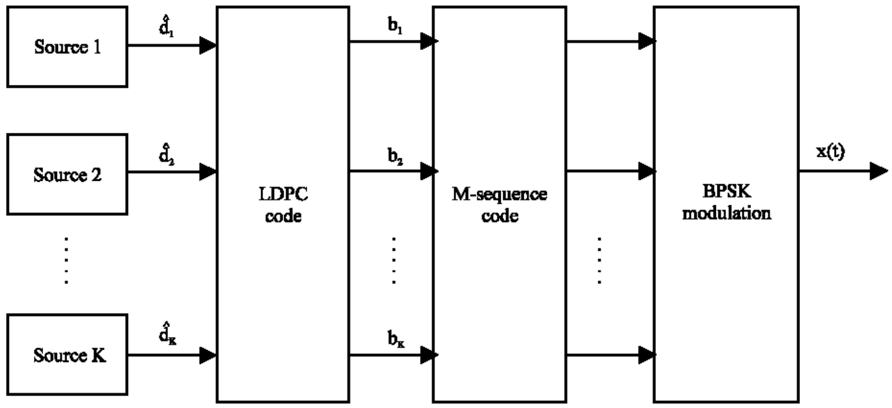

Fig. 1: Block diagram of the transmitter

columns (i-1)ω_γ+1 to i ω_γ The other submatrices are simply column permutation of H_1. It is evident that H is regular, has dimension $\mu\omega_c\times\mu\omega_\gamma$ and has row and column weights ω_γ ã and ω_c, respectively. The absence of length-4 cycles in H is not guaranteed, but they can be avoided via computer design of H. Gallager showed that the ensemble of such codes has excellent distance properties provided $\omega_\gamma>\omega_c = 3$. Further, such codes have low-complexity encoders since parity bits can be solved for as a function of the user bits via the parity-check matrix. Gallager codes were generalized by Tanner (1981) and were studied for application to code-division multiple-access communication channel in (Sorokine *et al*., 2000).

PROPOSED HYBRID RECEIVER BASED ON LDPC

The block diagram of the receiver is shown in Fig. 2. Where vector $b^* = [b^*_1,b^*_2,\ldots,b^*_K]^T$ denotes the candidate codes set =which is taken as the initial sample used by K-means clustering, vector $\hat{}d = [\hat{}d_1,\hat{}d_2,\ldots,\hat{}d_K]^T$ denotes the final output of the receiver.

The procedure of the method is presented by the following steps:

- Firstly, map the received bits into a feature space to make the error codes and the right ones different in some properties and easy to distinguish. Then, make judgments and pick out the error codes in some approaches in the feature space
- In this study, the first stage is corresponding to the code mapping and the second stage, the error-code recognizer, the method of amplitude judgment is corresponding to K-means clustering

CODE MAPPING

This section proposed a mapping function to map the candidate codes set output from the matched filter to a one-dimensional feature space. According to the theory of OMD (Verdu, 1986), the optimum detection result satisfies:

$$\hat{b}_{OMD} = \arg\{\max_{b\in(-1,1)} (2b^{*T}Ay\text{-}b^{*T}Hb^{*})\} \tag{7}$$

where, H is ARA and R is $(r_{ij})_{K\times K}$ denotes the cross-correlation matrix which is diagonal element dominant let:

$$F(b) = \frac{1}{2}b^T Hb\text{-}b^T Ay \tag{8}$$

According to Eq. 7, if the elements in b are all correct, the value of function F(b) will achieve the minimum. But, it is not appropriate for function F(b) to be the mapping function. And, it is better to calculate the derivative of function F(b) to decrease the order of mapping function. Making a partial derivation of Eq. 8, get:

$$\frac{\partial F}{\partial b} = Hb\text{-}Ay \tag{9}$$

Then get a K-order linear equations given as follows:

$$\begin{cases} \dfrac{\partial F}{\partial b_1} = \sum_{j=1}^{K} A_1 A_j r_{1j} b_j - A_1 y_1 \\ \dfrac{\partial F}{\partial b_2} = \sum_{j=1}^{K} A_2 A_j r_{2j} b_j - A_2 y_2 \\ \quad\ldots \\ \dfrac{\partial F}{\partial b_K} = \sum_{j=1}^{K} A_K A_j r_{Kj} b_j - A_K y_K \end{cases} \tag{10}$$

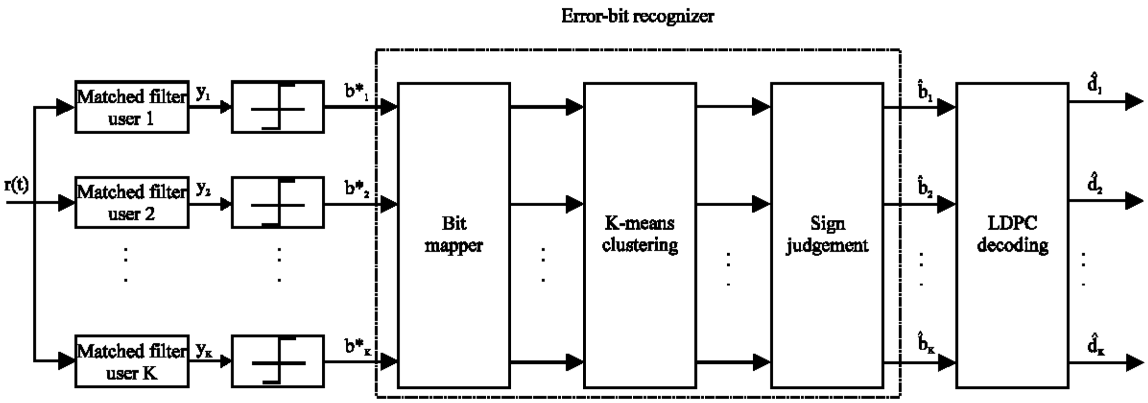

Fig. 2: Block diagram of receiver with matched filter and error-code recognizer

Now, take into account that multiple access interference (MAI) is the main interference resource which largely affects the performance of the system. Let:

$$L(b_i)=\sum_{j=1}^{K} A_iA_jr_{ij}b_j - A_iy_i, i=1, 2,......, K. \quad (11)$$

Bring the candidate codes set b* into Eq. 11, there are two situations illustrated as follows:

- No wrong code in b*

Under this condition, if the elements in b* are all correct. And in the condition of high SNR, bringing Eq. 7 to $L(b_k)$, can get that $L(b_k) = -A_in_i \sim N(0, A_i^2N_cN_0/2)$ ($k = 1,2,\ldots,K$) when there is no error bit in the candidate codes set b*.

- Wrong codes exist in b*

Presume b^*_i ($i\in[1, K]$, $i\in N$) is the wrong code in other words, $-b^*_i$ is the correct code), the other codes are correct. Substituting it to the ith Eq. 10, get:

$$\begin{aligned} L(b_i^*) &= \sum_{\substack{j=1\\ j\neq i}}^{K} A_iA_jr_{ij}b_j^* - A_iy_i + A_i^2r_{ii}b_i^* \\ &= \sum_{\substack{j=1\\ j\neq i}}^{K} A_iA_jr_{ij}b_j^* - A_iy_i + A_i^2r_{ii}(-b_i^*) + 2A_i^2r_{ii}b_i^* \\ &= 2A_i^2N_cb_i^* - A_in_i \end{aligned} \quad (12)$$

As for k which does not equal i, get:

$$L(b_k^*) = 2A_iA_kr_{ik}b_i^* - A_kn_k, k=1, 2,....., K \quad (13)$$

According to (12) (13), when the ith user's code is wrong, then get $|L(b^*_i)| >> |L(b^*_k)|$, $k = 1,2,\ldots,K$, $k\neq i$.

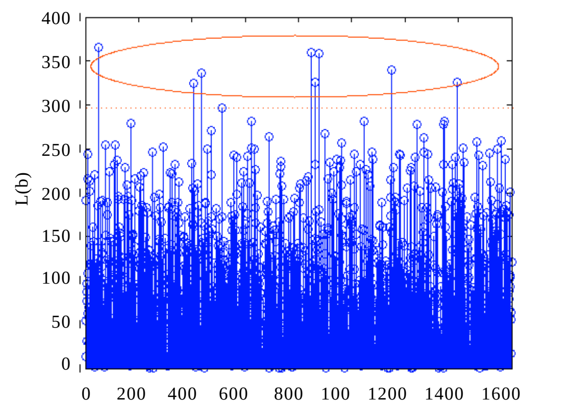

Fig. 3: Relationship between code numbers and mapping function $|L(b^*_k)|$

Therefore, the function $L(b^*)$ can obviously differentiate the wrong codes and the right codes through the absolute value of it. In addition, $L(b^*)$ is a Kth-order linear equations which can get the result of $L(b^*)$ without complex computations. In conclusion, it is appropriate to set $|L(b^*)|$ as the mapping function in the hybrid MUD algorithm.

In the feature space, the characteristic value of the function mapping will fluctuate around their mean expectations because of the noise. And the fluctuation range is decided by SNR. Fig. 3 shows an example of the feature space mapping in the scenario of 10 users, with 6dB signal-to-noise ratio (SNR) and without ISI.

K-MEANS CLUSTERING

K-means clustering (Kanungo *et al*., 2002) is a popular unsupervised clustering algorithm based on the partition of data, which can make classifications without training samples. In this study, the sample set in the feature space $|L(b^*_k)|$ (k = 1,2,…,K) is classified into two categories as follows:

- Cat. 1: $|L(b^*_k)|$ which denotes the error code b^*_k
- Cat. 2: $|L(b^*_k)|$ which denotes the right code b^*_k

Sometimes, all of the codes in the candidate set are correct and sorted into cat. 2 along with an empty set of cat. 1. In this situation, some specific measures should be taken into account in order to make the K-means clustering feasible.

Let m_1 and m_2 be the mean value of cat. 1 and 2 And the error sum of squares J_k is defined to serve as the criterion of the clustering. In the one-dimensional feature space, the parameters m_1, m_2 and J_k can be defined as follows:

$$m_1 = \frac{1}{N_1}\sum_{i=1}^{N_1}\left|L(b_i^{(1)})\right| \tag{14}$$

$$m_2 = \frac{1}{N_2}\sum_{i=1}^{N_2}\left|L(b_i^{(2)})\right| \tag{15}$$

$$J_k = \sum_{i=1}^{2}\sum_{L(b)\in cat_i}\left|\,|L(b^{(i)})| - m_i\right|^2 \tag{16}$$

where, N_1 and N_2 denote the number of elements in cat. 1 and 2, $L(b^{(1)})$ and $L(b^{(2)})$ represent the elements attributed to cat.1 and 2.

The process of code-error recognition using K-means clustering is listed by the following steps:

Step 1: Choose the initial cluster centres of m_1 and m_2. Generally, the initial cluster centres of m_2 can be set as 0 and that of m_1 can be set as a considerably larger number according to the concrete situation

Step 2: For each sample $|L(b^*_k)|$(k = 1,2,…,K) in the feature space, calculate the distance to both mean values of the two categories:

$$\rho_j(k) = \left|\,|L(b_i^*)| - m_j\right|, j = 1,2 \tag{17}$$

Step 3: If $\rho_1(k) = \rho_2(k)$, b_k will be classified into cat. 2 and regarded as a right one; otherwise, b_k will be classified into cat. 1 and regarded as a wrong code

Step 4: Update the value of m_2 by (15). Check the number of N_1, if N_1= 0, maintain the initial value of m_1; else, update the value of m_1 by (14)

Step 5: Update the error sum squares J_k by (16)

Step 6: If the value of J_k does not change after two continuous iterations, then the algorithm has converged and the procedure is terminated. Otherwise go to step 2

SIMULATION RESULTS AND DISCUSSION

In this section, simulation results are presented in order to show the superiority of the hybrid multiuser detector that is based on LDPC with respect to both system performance improvement reductions.

First, factor the situation with a specific number of users under different SNR conditions. There are five kinds of detectors to be simulated: matched filter receiver, hybrid multiuser receiver, OMD receiver, matched filter based on LDPC and hybrid multiuser based on LDPC. The UWB pulse is the first-order Gaussian pulse and the pulse width is 0.1 ns. Gold sequences of length L = 31 are used as spreading sequences and there are 10 users in the asynchronous DS-UWB system in AWGN channels and the range of SNR output from the receiver is 0dB~6dB. The curves of BER performance versus SNR are depicted in Fig. 4a.

As shown in Fig. 4a, on the whole, the BER performance of the hybrid multiuser receiver is superior to that of the matched filter receiver. But in conditions of low SNR, the detection performance of the hybrid multiuser receiver and the OMD receiver can not satisfy the need of communication. So the hybrid multiuser based on LDPC are proposed, the detection performance is much better than that of the other detectors (approximately 2~4 orders of magnitude higher). Hence, the conclusion was reached that the proposed detector is fit for low SNR conditions. Secondly, consider another situation with different numbers of transmitters under the same SNR conditions (SNR = 2dB). The other simulation environments are as same as previous section. To make the comparison apparent, the algorithms of the matched filter receiver, the matched filter based on LDPC and the hybrid multiuser based on LDPC are simulated. The computer simulation results are shown in Fig. 4b.

Figure 4b shows that, under the stated specific SNR conditions, the hybrid multiuser receiver based on LDPC is still able to give a superior detection performance when there are many transmitters occupying the same channel simultaneously, which indicates that the BER performance of the hybrid multiuser receiver based on LDPC is not sensitive to the channel capacity. This is one of the great advantages of this type of receiver.

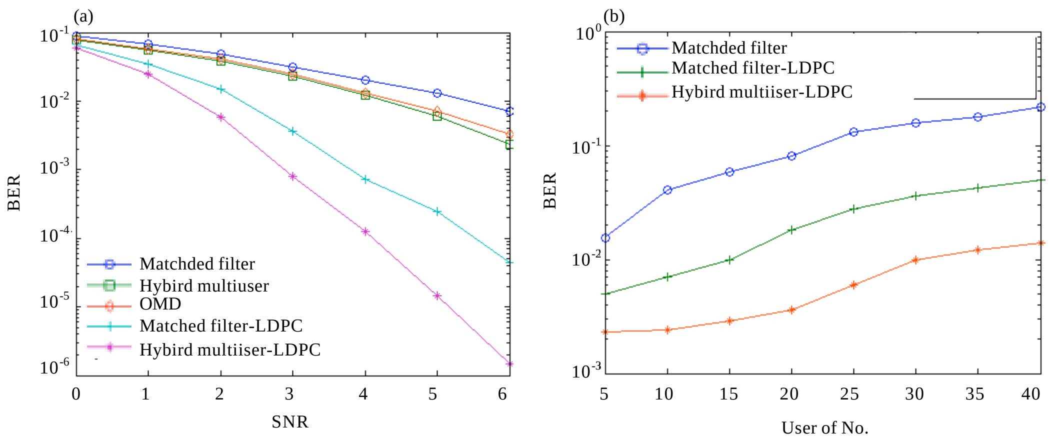

Fig. 4(a-b): BER performance under different condition (a) Different SNR conditions (b) Different user numbers

CONCLUSION

In this study, a new hybrid multiuser receiver is proposed based on LDPC code for DS-UWB system. The algorithm embraces two parts. One is LDPC coding and another is code mapping and K-means clustering. The simulation results show that the new hybrid multiuser detection can increase the number of users and reduce the bit error rate. Compared to the OMD, the hybrid MUD has lower computational complexity that increases linearly with the number of users. The proposed algorithm could be a powerful and an ideal choice for the physical layer design of the ad-hoc wireless network, especially when it is applied for formation flying. So the proposed hybrid approach can be an efficient method to solve the interference problem.

REFERENCES

Ahmed, Q.Z. and L. Yang, 2010. Reduced-rank adaptive multiuser detection in hybrid direct-sequence time-hopping ultrawide bandwidth systems. IEEE Trans. Wireless Communic., 9: 156-167.

Biradar, G.S., S.N. Merchant and U.B. Desai, 2008. Performance of constrained blind adaptive DS-CDMA UWB multiuser detector in multipath channel with narrowband interference. Proceedings of the International Conference on Global Telecommunications, November 30-December 4, 2008, New Orleans, USA., pp: 1-5.

Kanungo, T., D.M. Mount, N.S. Netanyahu, C.D. Piatko, R.S. Angela and Y. Wu, 2002. An efficient k-means clustering algorithm: Analysis and implementation. IEEE Trans. Pattern Anal. Mach. Intell., 24: 881-892.

Oppermann, I., M. Hamalainen and J. Iinatti, 2005. UWB: Theory and Applications. 1st Edn., Johs Wiley and Sons, West Sussex, ISBN-13: 978-0470869178 Pages: 248.

Sorokine, V., F.R. Kschischang and S. Pasupathy, 2000. Gallager codes for CDMA applications: Part I (2000). IEEE Trans. Commun., 48: 1660-1668.

Tanner, R.M., 1981. A recursive approach to low complexity codes. IEEE Trans. Inform. Theory, 27: 533-547.

Verdu, S., 1986. Minimum probability of error for asynchronous gaussian multiple-access channels. IEEE Trans. Infom. Theory, 32: 85-96.

Wang, C., M. Ma, R. Ying and Y. Yang, 2010. Narrowband interference mitigation in DS-UWB systems. IEEE Signal Proc. Lett., 17: 429-432.

Wu, Z., Z. Zong, Z. Yin and X. Chen, 2011. Joint multiuser detection of CD and AFSA in DS-UWB communication systems. Inform. Technol. J., 10: 422-427.

Yang, L.Q. and G.B. Giannakis, 2004. Ultra-wideband communications: An idea whose time has come. IEEE Signal Process. Maga., 21: 26-54.

Yin, Z., Z. Shi, J. Liang and Z. Wu, 2010. Design of unmanned aerial vehicle space communication links based on DS-UWB. Inform. Technol. J., 9: 1713-1718.

Zhang, W., X. Shen and Q. Bin, 2003. Ultr wideband wireless communications. Wireless Communic. Mobile Comput., 3: 663-685.

Zhang, Y., W. Lu and T.A. Gulliver, 2005. Recursive multiuser detection for DS-UWB systems. Proceedings of the Pacific Rim Conference on Communications, Computer and Signal Processing, August 24-26, 2005, Department of Electrical and Computer Engineering, USA., pp: 534-537.