

Proposed Triple correlation receiver for CDMA

Dr.Mamdouh Gouda

Electronic & Communication Engineering
Misr university for Science & Technology
Cairo, Egypt
Dr_mamdouh2004a@yahoo.com

Abstract— Conventional intercept receivers based on second order signal processing are generally ineffective in detecting direct sequence spread spectrum signals if the spreading sequences are unavailable. Also the capacity of direct sequence code division multiple access is limited by multiple access interference. Previous work has shown that the triple correlation function is used to implement triple correlation receiver to detect direct sequence spread spectrum signals. In this receiver, the received signal is auto-triple-correlated at a particular lag such that the transmitted code acts as its own reference. In this paper, we study the conventional direct sequence CDMA system, the cross-correlation between codes of length 127. The study has been extended to calculate the triple correlation function for the same code. A proposed triple correlation receiver to detect the pervious codes is presented. Finally, a detailed study of triple correlation receiver in multiuser environment for direct sequence CDMA has been performed. The study ended with a comparison between conventional and triple correlation receivers with numerical examples illustrated.

I. INTRODUCTION

The code division multiple access (CDMA) is promising technology for future generation and the advent of third generation (3G) cellular systems based mainly on code division multiple access technology and the technological advancement in mobile computing hardware over the last decade have led to a renewal interest in multiuser detection [1] as a effective method to improve the throughput and quality of mobile cellular communication systems. It is known that the capacity of direct sequence code division multiple access (DS-SS) system is limited by multiple access interference (MAI). [2] The desired user's bits mainly receive interference from the past and future overlapping signals of different users along with their current signal because they are asynchronous. The detection problem [3] in an asynchronous channel is more complicated than in a synchronous channel. The bits of each user are aligned in time for synchronous channel. Assume there are k direct sequence users in a synchronous single path BPSK real channel; the baseband received signal can be expressed as:

$$r(i) = \sum_{j=1}^k A_j(i) c_j(i) d_j(i) + n(i) \quad (1)$$

Where $A_j(i)$, $c_j(i)$ and $d_j(i)$ are the amplitude, signature code waveform and modulation of the i th user respectively and $n(i)$ is additive white Gaussian noise(AWGN) with a two sided power spectral density of $N_0/2$ Watt/Hz. The power of the j^{th} signal is equal to the square of its amplitude, which is assumed to be constant over a bit interval. The modulation consist of

rectangular pulses of duration T_b (bit interval) which take a $d_k = \pm 1$ values corresponding to the transmitted data.

In section 2 we introduce the conventional DS-SS receiver, section 3 presents detection of DS-SS using Triple Correlation Receiver (TCR), section 4 discuss the performance of TCR in multiuser environment, and section 5 devoted to the result and conclusions.

II. CONVENTIONAL DS-SS SYSTEM MODEL

We assume a synchronous CDMA multiuser communication [4] system with binary signaling, non-orthogonal transmission and an AWGN channel. The communication system model is identical to the basic synchronous CDMA model described in introduction. The number of users in this system model is denoted by k and multiuser detector considered to be k -dimensional matched filter bank or conventional detector for the received signal described in equation (1) is a bank of matched filter as shown in figure.1

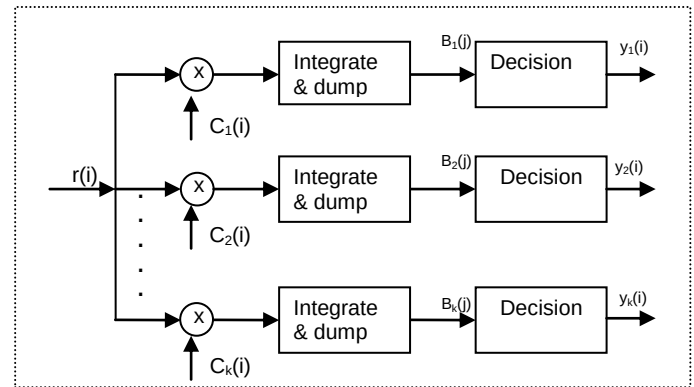


Figure 1. The conventional DS-SS detector using matched filters

The outputs of the matched filters are sampled at the bit times, which yield estimates of the transmitted data. The final decisions are made according to the signs of the outputs by decision operator. The operator defined as

$$y_j(i) = -1 \text{ if } B_j(i) < 0, \\ = +1 \text{ if } B_j(i) > 0 \quad (2)$$

We have seen from figure.1 that the conventional detector [5] follows a single user detector strategy, each branch detects one user without regarded to the existence of the other users. The success of this detector depends on the properties of the correlation between codes. We desire the auto-correlations (correlation between same code waveforms) to be much larger than cross- correlations (correlation between different code waveforms). The correlation value is

$$R_{j,k} = \sum_{i=1}^L c_j(i)c_k(i) \quad (3)$$

Here, if $j = k$, $R_{jj} = L$, (L is the length of the code and in our simulation, we use process gain equal L). The output of the k^{th} user's correlation for a particular bit interval is:

$$\begin{aligned} y_k(i) &= \sum_{i=1}^L r(i)c_k(i) \\ &= A_k d_k + \sum_{j=1}^{k-1} R_{j,k} A_j d_j + \sum_{i=1}^L n(i)c_k(i) \\ &= A_k d_k + MAI + z_k \end{aligned} \quad (4)$$

In other words, correlation with the k^{th} user itself gives rise to the recovered data term, correlation [6], [7] with all other users gives rise to multiple access interference (MAI), and correlation with the thermal noise yields the noise term z_k .

In this study we use m-sequence which is generated by the multi-stage Linear Feedback Shift Register (LFSR). The length of m-sequence is $L=2^n-1$ where n is the number of shift registers used [8]. We use codes of length 127. To obtain optimum recovery in conventional receiver, we need to select codes of low cross-correlation between each other. If we calculate the cross-correlation between generating polynomials $G(x) = x^7+x+1$ and $G(x) = x^7+x^6+x^4+x^2+1$, we find the cross-correlation takes 7 values and equal to -41, -17, -9, -1, 7, 15, 23. These results shown in figure 2. Another cross-correlation values between two different polynomials $G(x) = x^7+x+1$ and $G(x) = x^7+x^3+x^2+x+1$ is shown in figure 3 and has 3 values 1, 15, 17. Obviously, the choice of the codes in CDMA depends on minimum cross-correlation values. It is clear here that the cross-correlation between the generating polynomials [7, 1] and [7, 3, 2,1] is preferred due to its minimum cross-correlation value.

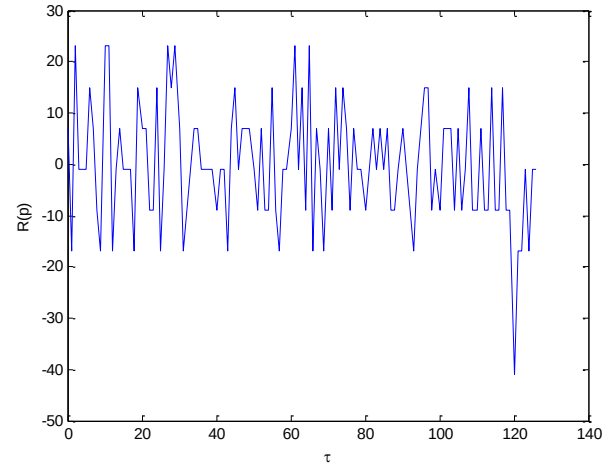


Figure 2. Cross-correlation between $G(x) = x^7+x+1$ and $G(x) = x^7+x^6+x^4+x^2+1$

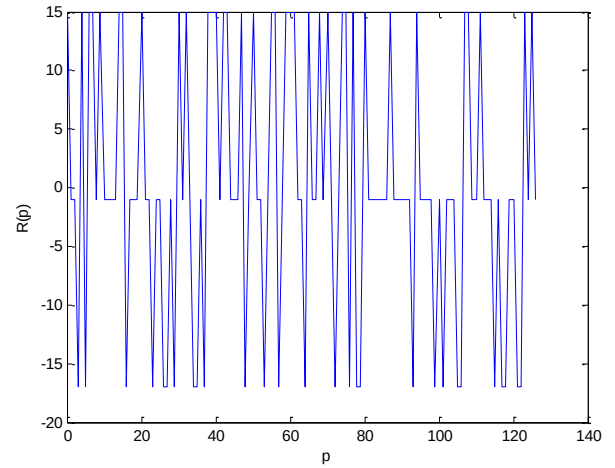


Figure 3. Cross-correlation between $G(x) = x^7+x+1$ and $G(x) = x^7+x^3+x^2+x+1$

III. TRIPLE CORRELATION DS-CDMA RECEIVER

In this section we introduce the TCR instead of conventional receiver that mentioned in the pervious section. TCR based on higher-order statistics where bispectral analysis is used for detection together with triple correlation for identification [9]. TCR consists of 2 delays unit connected in parallel where the received signal pass through those delay pairs and the output of those delay pairs is multiplied by the received signal. Figure 4 shows the block diagram of TCR.

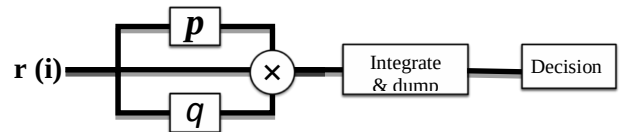


Figure 4. Block diagram of proposed TCR

Detection of DS-CDMA signals may be carried out in either time or frequency domain, Pseudo-Noise(PN) chip codes have triple correlation functions (TCF's) with unique peak locations, allowing them to be distinguished from each other and from actual noise, which has no peaks[9]. The TCF of an L-periodic m-sequence $c(i)$ is given by

$$R(p, q) = \sum_{i=1}^L c(i)c(i-p)c(i-q) \quad (5)$$

Where L is the length of the sequence, $R(p, q)$ has peaks at certain (p, q) values because of the shift and multiply property of m-sequences. [10]

According to the shift and multiply property for certain shift pairs (p, q) , $c(i-p)c(i-q) = c(i)$. So, for these pairs:

$$R(p, q) = L \quad (6)$$

For other pairs (p', q') , $c(i-p')c(i-q') = c_s(i)$, where $C_s(i) \neq c(i)$ but is still an m-sequence, and

$$R(p', q') = \sum_{i=1}^L c(i)c_s(i) = -1 \quad (7)$$

As illustrated in section 2, the generating polynomials $G(x) = x^7+x+1$ and $G(x) = x^7+x^3+x^2+x+1$ have low cross-correlation which make them preferable to be used in conventional DS-CDMA receiver. We will study the performance of TCR using the same generating polynomials, calculating MAI terms and then compare the results with the results of conventional receiver using the same generating polynomials.

First demand of TCR is to determine the available delay pairs for each polynomial. So, we need to calculate TCF for each polynomial and determine the location of peaks which are corresponding to the available delay pairs (p, q) . At the optimum delay, the maximum triple correlation value will equal to 127 (the length of the code), and for other delays it will equal to -1. Figure 5 shows the contour of x^7+x+1 , while figure 6 shows the contour of $G(x) = x^7+x^3+x^2+x+1$

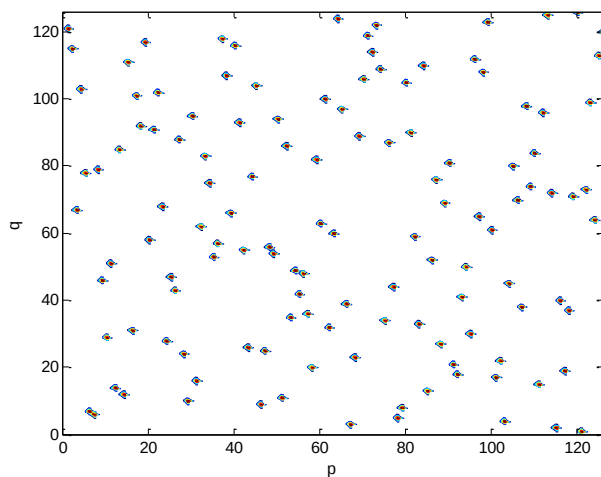


Figure 5. The Contour plot of TCF of $G(x)=x^7+x+1$.

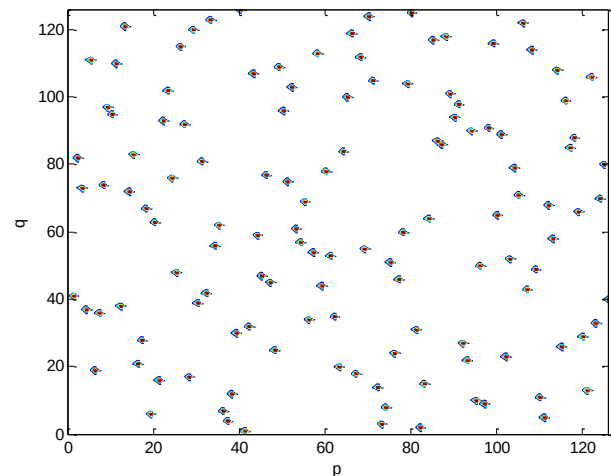


Figure 6. The Contour plot of TCF of $G(x)=x^7+x^3+x^2+x+1$.

The TCF useful for distinguishing m-sequences as each m-sequence has a unique set of TCF peaks [11]. The TCF $R(p, q)$ of each complete m-sequence has exactly one peak in each row and column, as illustrated in figure 5, 6. From the shown figures, we can obtain the positions of peaks which are corresponding to delay pairs for each generating polynomial. Table 1 shows the delay pairs for $G(x) = x^7+x+1$ and $G(x) = x^7+x^3+x^2+x+1$.

TABLE I. DELAY PAIRS FOR TWO GENERATING POLYNOMIALS OF LENGTH 127.

$G(x) = x^7+x+1$			$G(x) = x^7+x^3+x^2+x+1$		
(1,121),	(3,67),	(5,78),	(1,41),	(2,82),	(4,37),
(11,51),	(13,85),	(2,115),	(8,74),	(16,21),	(32,42),
(6,7),	(10,29),	(22,102),	(64,84),	(6,19),	(12,38),
(26,43),	(4,103),	(12,14),	(24,76),	(48,25),	(96,50),
(20,58),	(44,77),	(52,86),	(65,100),	(3,73),	(5,111),
(8,79),	(24,28),	(40,116),	(10,95),	(20,63),	(40,126),
(88,27),	(104,45),	(16,31),	(80,125),	(33,123),	(66,119),
(48,56),	(80,105),	(49,54),	(7,36),	(14,72),	(28,17),
(81,90),	(32,62),	(96,112),	(56,34),	(112,68),	(97,9),
(33,83),	(98,108),	(35,53),	(67,18),	(11,110),	(22,93),
(64,124),	(65,97),	(66,39),	(44,59),	(88,118),	(49,109),
(69,89),	(70,106),	(15,111),	(98,91),	(69,55),	(43,107),
(17,101),	(19,117),	(30,95),	(86,87),	(45,47),	(90,94),
(34,75),	(38,107),	(60,63),	(53,61),	(106,122),	(85,117),
(68,23),	(76,87),	(120,126),	(51,75),	(102,23),	(77,46),
(9,46),	(25,47),	(113,125),	(27,92),	(54,57),	(108,114),
(18,92),	(50,94),	(99,123),	(89,101),	(13,121),	(26,115),
(36,57),	(100,61),	(71,119),	(52,103),	(104,79),	(81,31),
(72,114),	(73,122),	(21,91),	(35,62),	(70,124),	(15,83),
(42,55),	(84,110),	(41,93),	(30,39),	(60,78),	(120,29),
(82,59),	(37,118),	(74,109),	(113,58),	(99,116),	(71,105),

IV. TRIPLE CORRELATION RECEIVER FOR MULTIUSER ENVIRONMENT

In the previous study for TCR, it shows the factors that effect on performance of TCR for single user [12]. In this paper we are concerning on the performance of TCR in multiuser environment. Figure 7 shows the multiuser detectors using TCR.

For simplicity, we design multiuser environment consists of 2 codes without data in noiseless channel such that each user transmit the code only. The TCR receive $v(i)$ where

$$v(i) = c_1(i) + c_2(i) \quad (8)$$

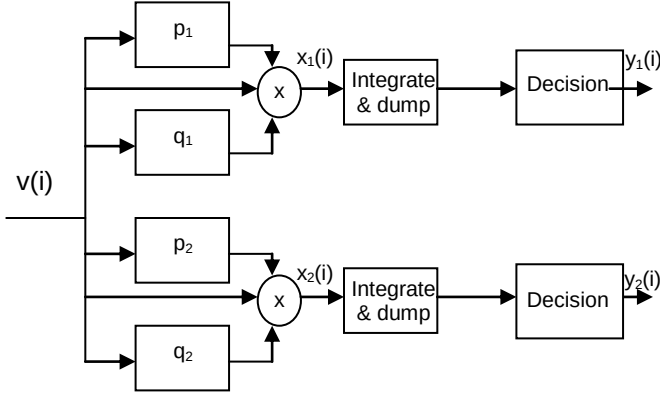


Figure 7. Multiuser TCR

The output of first TCR $x_1(i)$ is

$$\begin{aligned} x_1(i) &= [c_1(i - p_1) + c_2(i - p_1)][c_1(i) + c_2(i)] \\ &= c_1(i)c_1(i - p_1)c_1(i - q_1) + c_1(i)c_1(i - q_1)c_2(i - p_1) \\ &+ c_2(i)c_1(i - p_1)c_1(i - q_1) + c_2(i)c_2(i - p_1)c_1(i - q_1) \\ &+ c_1(i)c_1(i - p_1)c_2(i - q_1) + c_1(i)c_2(i - p_1)c_2(i - q_1) \\ &+ c_2(i)c_2(i - q_1)c_1(i - p_1) + c_2(i)c_2(i - p_1)c_2(i - q_1) \end{aligned} \quad (9)$$

The output of first TCR $x_2(i)$ is

$$\begin{aligned} x_2(i) &= [c_2(i - p_2) + c_1(i - p_2)][c_2(i) + c_1(i)] \\ &= c_2(i)c_2(i - p_2)c_2(i - q_2) + c_2(i)c_2(i - q_2)c_1(i - p_2) \\ &+ c_1(i)c_2(i - p_2)c_2(i - q_2) + c_1(i)c_1(i - p_2)c_2(i - q_2) \\ &+ c_2(i)c_2(i - p_2)c_1(i - q_2) + c_2(i)c_1(i - p_2)c_1(i - q_2) \\ &+ c_1(i)c_1(i - q_2)c_2(i - p_2) + c_1(i)c_1(i - p_2)c_1(i - q_2) \end{aligned} \quad (10)$$

The final outputs $y_1(i)$, $y_2(i)$ are calculated as follows:

$$\begin{aligned} y_1(i) &= \sum_{i=1}^L c_1(i)c_1(i - p_1)c_1(i - q_1) + \\ &+ \sum_{i=1}^L c_1(i)c_1(i - q_1)c_2(i - p_1) + \sum_{i=1}^L c_2(i)c_1(i - p_1)c_1(i - q_1) \\ &+ \sum_{i=1}^L c_2(i)c_2(i - p_1)c_1(i - q_1) + \sum_{i=1}^L c_1(i)c_1(i - p_1)c_2(i - q_1) \\ &+ \sum_{i=1}^L c_1(i)c_2(i - p_1)c_2(i - q_1) + \sum_{i=1}^L c_2(i)c_2(i - q_1)c_1(i - p_1) \\ &+ \sum_{i=1}^L c_2(i)c_2(i - p_1)c_2(i - q_1) \end{aligned} \quad (11)$$

$$\begin{aligned} y_2(i) &= \sum_{i=1}^L c_2(i)c_2(i - p_2)c_2(i - q_2) + \\ &+ \sum_{i=1}^L c_2(i)c_2(i - q_2)c_1(i - p_2) + \sum_{i=1}^L c_1(i)c_2(i - p_2)c_2(i - q_2) \\ &+ \sum_{i=1}^L c_1(i)c_1(i - p_2)c_2(i - q_2) + \sum_{i=1}^L c_2(i)c_2(i - p_2)c_1(i - q_2) \\ &+ \sum_{i=1}^L c_2(i)c_1(i - p_2)c_1(i - q_2) + \sum_{i=1}^L c_1(i)c_1(i - q_2)c_2(i - p_2) \\ &+ \sum_{i=1}^L c_1(i)c_1(i - p_2)c_1(i - q_2) \end{aligned} \quad (12)$$

From equation (11),(12), the desired signal is the first term, where $c_1(i)c_1(i-p)c_1(i-q)$ and $c_2(i)c_2(i-p)c_2(i-q)$ are equal 1 and the reminder terms are MAI. In order to obtain optimum recovery of the desired code, we choose codes that have high triple correlation value at certain delay pairs, and minimum cross-correlation values between codes.

To realize the TCR for two generating polynomials, [7, 1] and [7, 3, 2, 1] shown in figure 7, we choose the optimum delay pairs of each polynomial from table 1. The first TCR is designed to detect $G(x) = x^7 + x + 1$, the used delay pair is (6, 7). It is the optimum delay pair for the mentioned $G(x)$ because it satisfies 2 factors. First factor is the difference between the delay pair which is in this case (7-6=1), the second factor is the maximum value of the delay pair which is in this case (7), [12].

The second TCR is designed to detect the generating polynomial $G(x) = x^7 + x^3 + x^2 + x + 1$. The optimum delay pair for the mentioned generating polynomial is (6, 19) because it satisfied the same factors.

The output of the first TCR is

$$\begin{aligned}
 y_1(i) = & \sum_{i=1}^L c_1(i)c_1(i-6)c_1(i-7) + \\
 & \sum_{i=1}^L c_1(i)c_1(i-7)c_2(i-6) + \sum_{i=1}^L c_2(i)c_1(i-6)c_1(i-7) \\
 & + \sum_{i=1}^L c_2(i)c_2(i-6)c_1(i-7) + \sum_{i=1}^L c_1(i)c_1(i-6)c_2(i-7) \\
 & + \sum_{i=1}^L c_1(i)c_2(i-6)c_2(i-7) + \sum_{i=1}^L c_2(i)c_2(i-7)c_1(i-6) \\
 & + \sum_{i=1}^L c_2(i)c_2(i-6)c_2(i-7)
 \end{aligned} \quad (13)$$

The first term is the desired term and the reminder terms are MAI. Figure 8 and 9 shows the mesh and the contour plot of TCF of $y_1(i)$ respectively

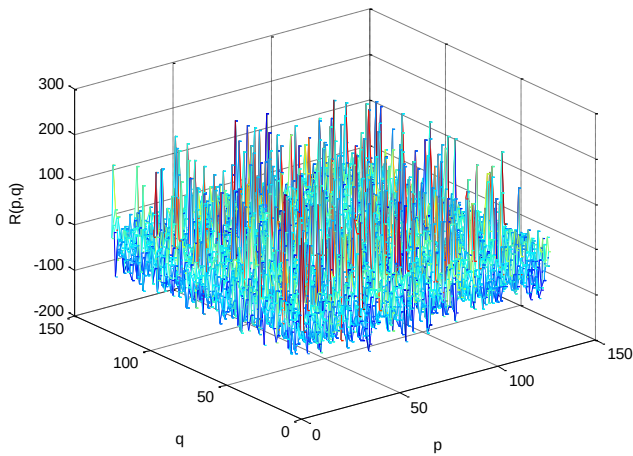


Figure 8. TCF of the output of the first TCR

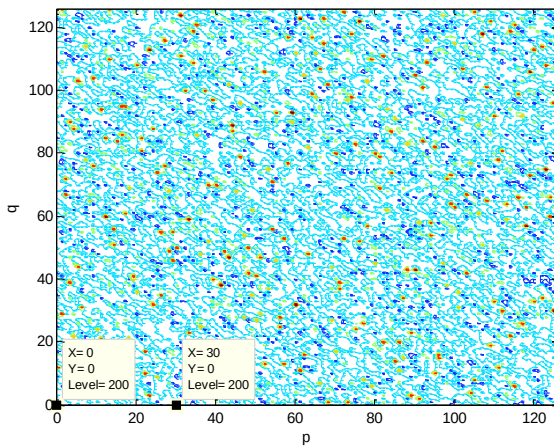


Figure 9. The contour of figure 8

As shown in figure 8, 9, each row or column consists of number of peaks and cross-correlation values. The number of peaks in each row or column is equal to the number of the received generating polynomials which are 2 in our example. The value of peaks is 200, while the cross-correlation's values between codes takes the following values ($\pm 8, \pm 24, \pm 56, \pm 40, \pm 72, \pm 88$). Figure 10 shows the first row as an example of TCF and shows the number of peaks in each row which are corresponding to the number of users.

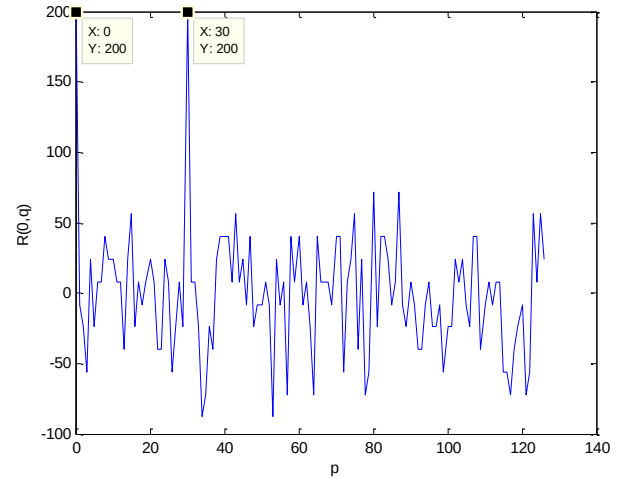


Figure 10. TCF of output of TCR for $q=0$

In figure 10, we notice that there are 2 peaks. First peak is at zero shift because zero shift is corresponding to the received signal after delayed by delay pair (6,7) and multiplied by the original received signal. The TCF at this point is maximum, and its value equal 200. There is also another peak at $p=30$ with maximum TCF value equal to 200. This value results from the addition of seven terms to the desired term in equation 13. To determine number of peaks and their positions clearly, a threshold greater than the maximum MAI; 100 in our case, is applied and shown in figure 11, 12 in mesh and contour respectively

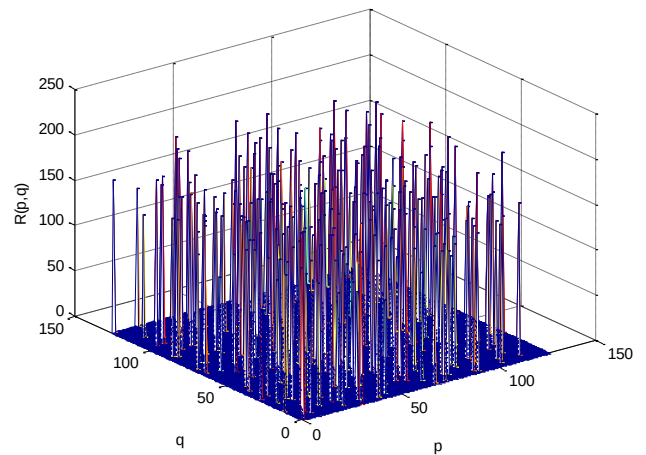


Figure 11. TCF of the output of the first TCR, threshold 100

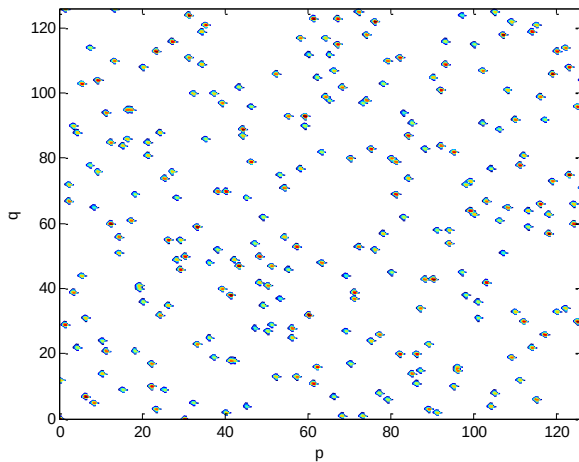


Figure 12. The contour of figure 11

Figure 11, 12 shows the peaks and its position after canceling MAI. From these figures, we can notice that each row or column contain 2 peaks corresponding to the 2 received codes. The total number of peaks is 252; each code has 126 peaks.

By comparing the conventional receiver and the TCR for our example, we find that, in conventional receiver, the ratio between the maximum cross-correlation values to the maximum autocorrelation values is $-17/127$. On the other hand, in the TCR, the ratio between the maximum value of cross-correlation between codes to the maximum value of TCF of the desired term shown in example that given in figure 10 is $88/200$. The result shows that the cross-correlation between codes in TCR is slightly higher than the cross-correlation in conventional receiver.

V. CONCLUSIONS

In TCR, The received signal is auto-triple-correlated at a particular lag, such that the transmitted code acts as its own reference. This is in contrast to a conventional coherent DS-CDMA receiver which requires synchronization of a local reference code to the received signal for demodulation to occur. In multiuser environment, the number of MAI terms in TCR is higher than that in conventional receiver and equal to 7 terms. In TCR the cross-correlation values between two codes have 12 distinguish values while in conventional receiver, the cross-correlation takes only 3 distinguish values. In conventional receiver, the ratio between the maximum cross-correlation values to the maximum autocorrelation values less than the ratio between the maximum cross-correlation values between codes to the maximum value of TCF of the desired term in the TCR. Finally, the number of users in CDMA can be detected and recognized from the number of peaks in each row or columns.

REFERENCES

[1] Lokesh Tharani, Dr. R.P.Yadav, "Performance evaluation of multistage multiuser detector for asynchronous DS-CDMA system" IEEE Proceeding of International Conference on Computational Intelligence and Multimedia Applications 2007 (ICCIMA-07), Vol IV, page no. 316-321, December 2007.

[2] Sergio Verdu, "Multi-user detection", Cambridge University Press.

[3] Duel-Hallen, J. Holtzman, and Z. Zvonar, "Multi-user detection for CDMA systems,". IEEE Personal Communications Magazine, April 1995.

[4] S. Moshavi, "Multi-user detection for DS-CDMA communications", IEEE communications magazine, Vol. 34, No. 10, page no. 124-136, October, 1996.

[5] H. V. Poor, S. Verdu, "Single-user detectors for multiuser channels," IEEE Trans. Comm. Vol. 36, no. 1, pp. 50-60, Jan. 1988.

[6] R. Lupas, S. Verdu, "Near-far resistance of multiuser detectors in asynchronous channels," , IEEE Trans. Comm. Vol. 38, no. 4, pp. 496-508, April 1990

[7] Tan F. Wong: "Spread spectrum & CDMA".www.wireless.ece.ufl.edu/twong/Notes/CDMA/ch6.

[8] Yunxiao Zu; "The Detection and Recognition of DS-SS Signals Using Higher-Order Statistical Processing", Signal Processing, The 8th International Conference on Volume 3, 16-20 2006.

[9] Estimation and identification techniques for DS/SS signals Gouda, M.; Adams, E.R.; Hill, C.J.; Industrial Electronics, Control and Instrumentation, 1997. IECON 97. 23rd International Conference on Volume 1, 9-14 Nov. 1997 Page(s):311 - 315

[10] Detection and blind identification of m-sequence codes using higher order statistics Batty, K.E.; Adams, E.R.; Higher-Order Statistics, 1999. Proceedings of the IEEE Signal Processing Workshop on 14-16 June 1999 Page(s):16 - 20

[11] E. R. Adams, M. Gouda & P. C. J. Hill, "Detection and characterisation of DS/SS signals using higherorder correlation", *Proceedings of IEEE 4th ISSSTA*, Mainz, Germany, Sep 1996, pp27-31.

[12] Gouda, Mamdouh; Abdin, Adel; Essawy, Essam; "Optimum detection of data modulated m-sequences using triple correlation receiver", Signals, Circuits and Systems, 2008. SCS 2008. 2nd International Conference on 7-9 Nov. 2008 Page(s):1 - 4.