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SEPARATION OF WIDEBAND SIGNALS USING ADAPTIVE ANTENNA ARRAY CONTROLLED BY A SOFTWARE DEFINED RADIO SYSTEM

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Abstract :

This paper is concerned with introducing a robust software defined radio system that adaptively controls the beam pattern of a linear antenna array. This adaptation is performed for cancellation of interference signals and simultaneous extraction of the signal of interest (SOI) to correctly recognize its modulation type in order to take the appropriate counter action later. This counter action varies among signal analysis, monitoring, jamming…etc. This capability is achieved when the SOI and interference signals are either narrowband or wideband. Interference signals may be mutually correlated or mutually uncorrelated with the SOI. Computer simulations using an additive white Gaussian noise (AWGN) channel show that the proposed software defined radio system succeeds to completely extract the SOI and correctly recognize its modulation type at 10 dB signal to noise ratio and -3 dB signal to interference ratio.

I-Introduction:

Today, software defined radio receiver offers a number of advantages over traditional radio receiver designs that use either analog components, application specific integrated circuits (ASICs), or other fixed digital hardware [1,2]. Software defined radios can be dynamically reprogrammed in order to handle different air interferences and to support upgrades. The advent of highly compact and inexpensive digital computer makes that it is possible to exploit well known results from statistical detection, estimation, and control theories to develop array systems that automatically respond to any change in the signal environment. Signal reception using antenna arrays has an attractive solution to the severe problems of signal detection and estimation in dense environment. Antenna array offers a mean of overcoming the directivity and beam width limitations compared to the case of using single sensor for reception [2,3]. This kind of array systems is called adaptive antenna array (AAA) or smart antenna systems. AAA systems are currently the subject of extensive investigation as means for reducing the vulnerability of the reception of desired signals in presence of interference (in radar, sonar, and communication systems). Most of AAA systems have a set of operations and capability limits. Some of important limits are the bandwidth of the intercepted signals that supposed to deal with and the possibility to analyze the intercepted signals content in a post processing step [2,3].

The aim of this paper is to build a software defined radio system that uses a set of developed algorithms to perform three main processes on the intercepted signals by an adaptive antenna array. These processes are: (1) Estimation of direction of arrival (DOA) of the intercepted signals by using cyclic MUSIC algorithm, (2) Separation of the desired signal using a complementally transformed minimum variance (CTMV) nulling algorithm, and (3) Modulation recognition (MR) of SOI by using an algorithm based on the constellation shape as a robust signature of the single tone digitally modulated signals.

The proposed DOA estimation algorithm offers a modification to most subspace based DOA estimation algorithms that depend basically on narrowband signals assumption. The basic idea of this modification is the replacement of conventional correlation matrix by a cyclic one [4, 5, 6, 7]. The performance analysis of cyclic MUSIC algorithm compared with conventional MUSIC one is introduced in [8]. CTMV algorithm is required only to null the cyclically correlated interference signals where the cyclically uncorrelated ones are inherently removed depending on the cyclostationarity concept. CTMV algorithm is capable of putting nulls in the DOAs of the correlated or uncorrelated interference signals provided that their DOAs are known [9, 10]. The proposed modulation recognition approach exploits or uses the constellation shape of the single tone digitally modulated signals (MASK, MPSK, and MQAM) as a robust signature of its modulation type [11].

The paper is organized as follows: Section II describes the proposed SDR system scheme and introduces its signal and system models. Section III introduces briefly the proposed Cyclic MUSIC algorithm for DOA estimation of both narrowband and wideband signals. Section IV presents the proposed CTMV algorithm for extraction of SOI and nulling the interference ones. Section V summarizes the proposed algorithm for MR of the extracted signal, which has been introduced deeply in [11]. Section VI presents the simulations and performance evaluation of the proposed system. Finally, the conclusions are provided in section VII.

II-The proposed SDR system and its data model

The functional block diagram of the proposed software defined radio system [2,3] is shown in Fig.1.

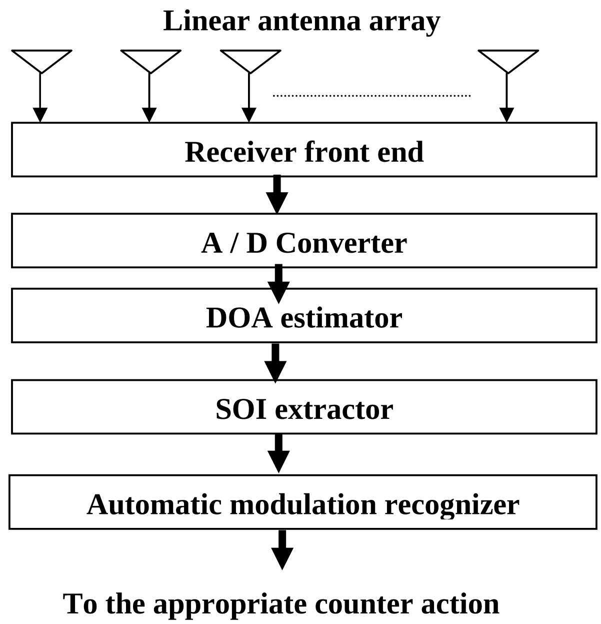


Fig.1. Functional block diagram of common software defined radio system

SDR system comprises five main blocks. The receiver front end is susceptible for down conversion of the intercepted radio frequency (RF) into an intermediate frequency (IF). The A/D converter is used to convert analog signal to digital signal at suitable sampling rate. After conversion, the intercepted signals are used to form the input covariance matrix of the array. This covariance matrix shows the correlation among the intercepted signals at antenna elements in the array. Then the covariance matrix is analyzed by an eigen decomposition algorithm in order to estimate the DOAs of the SOI and interference signals. Once the information of the DOAs is obtained, it is possible to compute the optimum weights that control AAA beam pattern to extract SOI while putting nulls in DOAs of undesired signals. An automatic MR algorithm processes extracted signal in order to decide about its modulation type then the suitable counter action is taken.

Suppose there are a (known / estimated) number of signals $s_1(t),............,s_q(t)$ [9, 12] all centered on a known frequency, say f_c, impinging on M-elements antenna array with DOAs ϕ_i, $i=1,2,.....,q$. These signals may be uncorrelated, as for the signals coming from different signal sources, or can be fully correlated as happens in multipath propagation, where each path forms a scaled and time-delayed version of the original transmitted signal, or can be partially correlated due to the noise corruption. The intercepted signal by the i^{th} element of the array is a superposition of the complex envelope of all the impinging signals, $\tilde{s}_k(t)\ \forall k=1,2,......,q$, and AWGN signal, $\tilde{n}_i(t)$,of variance σ_n^2. Therefore, the intercepted signal on the i^{th} element of the array is given by:

$$x_i(t) = \sum_{k=1}^{q} \tilde{s}_k\left(t+\frac{(i-1)}{c}d\ \sin\phi_k\right)+\tilde{n}_i(t)\ \ \forall i=1,2,.....,M \qquad (1)$$

Also, the input data vector for narrowband incident signals may be expressed as [8]:

$$\mathbf{x}(t) = \sum_{i=1}^{q} \mathbf{a}(\phi_i)\tilde{s}_i(t) + \mathbf{n}(t) \tag{2}$$

where $\mathbf{a}(\phi_i)$ is the steering vector of the ith incident signal with DOA ϕ_i

$$\mathbf{a}(\phi_i) = \begin{bmatrix} 1 \\ e^{\frac{-j2\pi}{\lambda} d \sin(\phi_i)} \\ \cdots\cdots \\ e^{\frac{-j2\pi}{\lambda}(M-1) d \sin(\phi_i)} \end{bmatrix} \tag{3}$$

In matrix notation, (2) becomes

$$\mathbf{x}(t) = \mathbf{A}(\phi)\mathbf{s}(t) + \mathbf{n}(t) \tag{4}$$

where $\mathbf{A}(\phi)$ is the M x q matrix of the steering vectors

$$\mathbf{A}(\phi) = [\,\mathbf{a}(\phi_1), \ldots\ldots\ldots\ldots\ldots\ldots, \mathbf{a}(\phi_q)]^T \tag{5}$$

$\mathbf{n}(t)$ is the complex envelope vector of an AWGN signals along the array elements ,

$$\mathbf{n}(t) = [\,\tilde{n}_1(t), \ldots\ldots\ldots\ldots, \tilde{n}_M(t)\,]^T \tag{6}$$

and $\mathbf{s}(t)$ is the complex envelope vector of the incident signals

$$\mathbf{s}(t) = [\tilde{s}_1(t), \ldots\ldots\ldots\ldots\ldots, \tilde{s}_q(t)]^T \tag{7}$$

The flow chart of the proposed SDR system is shown in Fig.2. The intercepted signal is down converted and digitized to form a digitized IF output signal at the output of A/D converter. Then, the IF signal is processed by a cyclic MUSIC algorithm in order to estimate DOA of the SOI. By exploiting cyclostationarity, the cyclic correlations of only signals with the same cyclic frequency can be extracted and the cyclic correlations of stationary additive noise and all other co-channel interference signals with different cyclic frequencies are nulled out [13]. Thus, if all interference signals are cyclically uncorrelated with SOI in an AWGN environment, the cyclic MUSIC algorithm spatial spectrum has only one peak that corresponds to DOA of SOI [4, 5, 6, 7]. Consequently, using a nulling algorithm to extract the SOI is not effective. However, if some of the interference signals are mutually cyclically correlated with SOI, the cyclic MUSIC algorithm produces only DOAs of the SOI and its cyclically correlated interference signals. Consequently, CTMV nulling algorithm is used to extract SOI and puts nulls in DOAs of interference signals. Once the SOI is extracted, it is processed in order to recognize its modulation type. Processing of the extracted signal includes obtaining its analytic form followed by calculating its complex envelope. The real and imaginary parts of the calculated complex envelope are used to construct the constellation shape that is related to the SOI. This constellation shape represents the input data to the used MR algorithm. Once the modulation type of SOI is correctly recognized, the appropriate counter action is used.

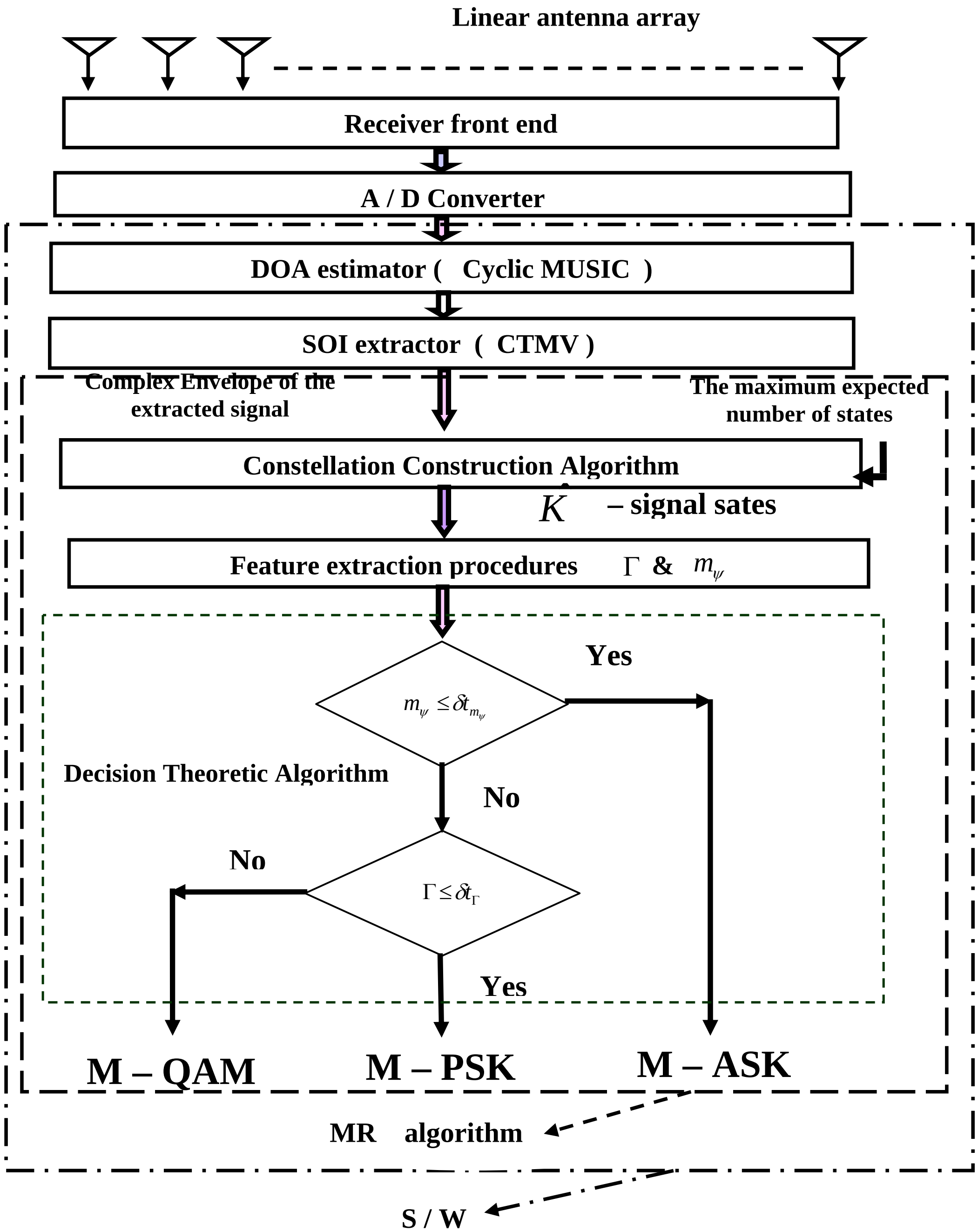


Fig.2. The flow chart of the proposed software defined radio system

III-The Proposed Algorithm for DOA Estimation

Cyclostatioarity is a physical phenomenon that describes a probabilistic model for certain random data that involves certain periodicity model. For example, the utilized signal periodicity in communication telemetry, radar, and sonar arises from sampling, scanning, modulation, multiplexing, and coding operations [13]. Starting from the general data model for the array output signal, which is defined by equation (1), the cyclic correlation of the intercepted signal by each sensor is given by [4, 5, 6, 7]:

$$R_{x_i}^{\alpha}(\tau) = < x_i(t+\tau/2)\, x_i^H(t-\tau/2)\, e^{-j2\pi\alpha t} >$$
$$= <[\sum_{k=1}^{q} \tilde{s}_k(t+\frac{(i-1)}{c} d\sin\theta_k) + \tilde{n}_i(t)][\sum_{k=1}^{q} \tilde{s}_k^*(t+\frac{(i-1)}{c} d\sin\theta_k) + \tilde{n}_i^*(t)] e^{-j2\pi\alpha t} > \quad (8)$$

Assume that q source signals are mutually cyclically uncorrelated. This means that cyclic cross correlation of any pair of source signals is zero at each cyclic frequency α of interest. i.e. $R_{s_i s_j}^{\alpha}(\tau) = 0 \;\; \forall\; i, j \in \{1,2,.....,q\}\,;\; i \neq j$. Moreover, if there exist $d_\alpha \leq q$ source signals sharing the same cyclic frequency, where α is known or estimated [7, 13], then there exist only d_α mutually cyclically correlated signals have cyclic frequency α i.e. $R_{s_i s_i}^{\alpha}(\tau) \neq zero \quad \forall\; i \in \{1,2,.....,d_\alpha\}$. Finally, assume that noise source signals are not be cyclically correlated with themselves and with other source signals at the cyclic frequency of interest α. From all previous assumptions,

$$R_{x_i}^{\alpha}(\tau) = \sum_{k=1}^{d_\alpha} R_{s_k}^{\alpha}(\tau)\, e^{j2\pi f_o \frac{(i-1)}{c} d\sin\theta_k} \qquad \forall\; i = 1,2,..............., M \quad (9)$$

By collecting the correlation functions, given by (9), in a vector form $\mathbf{R}_X^{\alpha}(\tau) = [R_{x_1}^{\alpha}(\tau),............, R_{x_M}^{\alpha}(\tau)]^T$, $\mathbf{R}_X^{\alpha}(\tau)$ can be re-expressed as [6]:

$$\mathbf{R}_X^{\alpha}(\tau) = \mathbf{A}(\alpha)\,\mathbf{R}_S^{\alpha}(\tau) \quad (10)$$

where $\mathbf{R}_S^{\alpha}(\tau) = [R_{S1}^{\alpha}(\tau), R_{S2}^{\alpha}(\tau), ..., R_{S_{d\alpha}}^{\alpha}(\tau)]^T$, $\mathbf{A}(\alpha)$ is the array steering matrix which is represented as:

$$\mathbf{A}(\alpha) = [\mathbf{a}_1(\alpha),............., \mathbf{a}_{d_\alpha}(\alpha)] \quad (11)$$

and $\mathbf{a}_k(\alpha)$ is the k^{th} source steering vector, which is given by

$$\mathbf{a}_k(\alpha) = [1, e^{j2\pi\alpha \frac{(i-1)}{c} d\sin\theta_k}, ..., e^{j2\pi\alpha \frac{(i-1)}{c}(M-1) d\sin\theta_k}]^T \quad (12)$$

Since $\mathbf{R}_X^{\alpha}(\tau)$ is independent of the intercepted signal center frequency, f_o, Therefore, whether the original data, which is collected at each sensor individually, is narrowband or wideband, the cyclic correlation of data exactly obeys the narrowband data model ,given by (4) with cyclic frequency α as a center frequency. Thus, it is possible to estimate the sources DOAs by applying conventional narrowband algorithms on $\mathbf{R}_X^{\alpha}(\tau)$. Once the DOAs of SOI and interference signals are estimated, CTMV nulling algorithm is used to extract SOI.

IV-The proposed nulling algorithm

CTMV beamformer performs the following processes:

(1)- It estimates the sources directions to construct a transformation, $\mathbf{T}$, to remove the desired signal coming from DOA ϕ_1 and retain the coherent interference signals coming from DOAs ϕ_i, i= 2,3,….q. This transformation is constructed so as to minimize the difference between the original and transformed data subject to a set of complement constraints [10].

(2) - The transformed data (which contain only interference and noise) are then sent to a regular minimum variance distortion less response beamformer (MVDR) which compute the weight vector, W, yielding the maximum output SINR [10,14]. Thus, the beamformer

performs a mutual cancellation for the coherent interferences solely. Thus, this optimum weight vector will be the solution of the following problem:

$$\min_{\mathbf{w}} E\left\{ \left| \mathbf{W}^H \mathbf{T}\mathbf{x} \right|^2 \right\} \equiv \mathbf{W}^H \mathbf{T}\mathbf{R}_x \mathbf{T}^H \mathbf{W}$$
$$\textit{subject to} \quad \mathbf{W}^H \mathbf{a}(\hat{\phi}_1) = 1 \tag{13}$$

where $\mathbf{R}_x$ is the input covariance matrix, which takes the form $\mathbf{R}_X = E\{\mathbf{x}(t)\mathbf{x}^H(t)\}$. Assuming the noise samples are independent identically distributed with covariance $\sigma_n^2 \mathbf{I}_n$, where $\mathbf{I}_n$ is the identity matrix. Solving (13) directly raises two problems. First, $\mathbf{T}$ is not full rank such that the complementally transformed (CT) correlation matrix $\mathbf{T}\mathbf{R}_x\mathbf{T}^H$ is singular. Second, the noise component in $\mathbf{T}\mathbf{R}_x\mathbf{T}^H$ (which is $\sigma_n^2 TT^H$) is no longer the same as in the original $\mathbf{R}_x$ (which is $\sigma_n^2 I$). These problems suggest that the CT correlation matrix must be modified into a full rank matrix by replacing its noise part with $\sigma_n^2 \mathbf{I}$ [10].

$$\overset{\approx}{\mathbf{R}}_x = \mathbf{T}\mathbf{R}_x\mathbf{T}^H - \sigma_n^2 \mathbf{T}\mathbf{T}^H + \sigma_n^2 \mathbf{I} \tag{14}$$

Then by replacing $\mathbf{T}\mathbf{R}_x\mathbf{T}^H$ by $\overset{\approx}{\mathbf{R}}_x$, the CTMV weight vector is given by [10]:

$$W = \frac{1}{\mathbf{a}^H(\hat{\phi}_1)(\overset{\approx}{\mathbf{R}}_x)^{-1}\mathbf{a}(\hat{\phi}_1)} (\overset{\approx}{\mathbf{R}}_x)^{-1}\mathbf{a}(\hat{\phi}_1) \tag{15}$$

V-The proposed MR algorithm

The flow chart of the proposed MR algorithm is shown in Fig.(2). The complex envelope of the extracted signal and the maximum expected number of its signal states are considered as the input data to be processed by the proposed MR algorithm. The proposed hybrid algorithm consists of two algorithms which are connected to each other through a feature extraction process. The first algorithm is the constellation construction algorithm in order to construct the constellation shape from the complex envelope data of the extracted signal. Tow key features are extracted only from the graphical positions of the signal states of the constructed constellation shape by using conventional signal processing tools. The first key feature, m_ψ, is the average of $\hat{K}$ signal states phases. However, the second key feature Γ is the ratio between the amplitude of each constructed signal state and the average of $\hat{K}$ signal states amplitudes, m_A. The key features threshold values are chosen to be $\delta t_{m_\psi} = \frac{\pi}{4}$ and $\delta t_\Gamma = 0.1415$ [11]. The second algorithm is a decision theoretic algorithm, which uses the extracted features to decide about the modulation type of the extracted signal that has the constructed constellation shape. A complete description of the constellation construction algorithm is presented in [11].

VI-Simulation work

a- Simulation of test signals and system parameters:

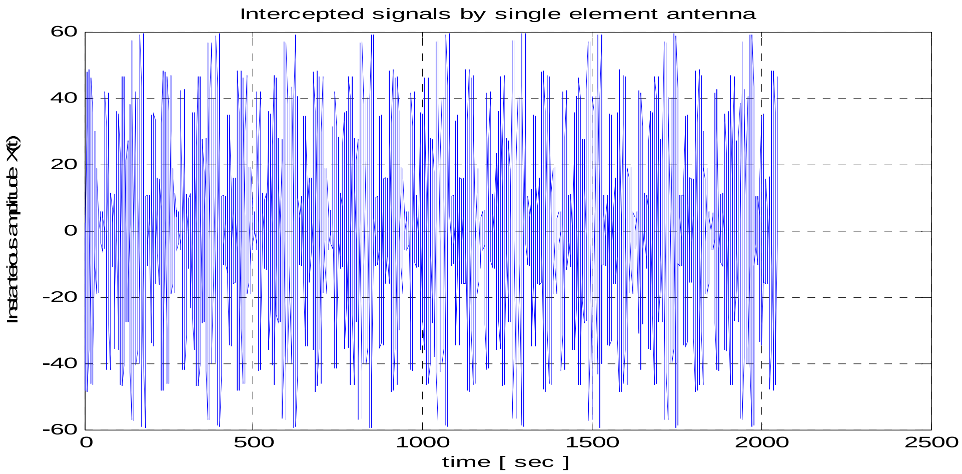
Since the proposed modulation recognition approach deals only with single tone digitally modulated signals, test signals of those types are generated in order to integrate the simulation work along the entire layered software defined radio system. According to the specification of the intercept receiver, the signal is down converted to IF frequency, f_{IF}, of 150 KHz with sampling rate, f_s, of 1200 KHz. The modulating digital symbol sequence duration is chosen to be 1.707 msec (equivalent to N= 2048 samples). The simulated signals are chosen to be real, which can be expressed as:

$$S_j(i) = A_j \; COS\left(\frac{2\pi \, f_{IF} \, i}{f_s} + \Psi_j\right); \; \forall 1 \le i \le N_b \; and \;\; j = 0,1,2,.....,K-1; \; K = 2,4,8,.. \qquad (16)$$

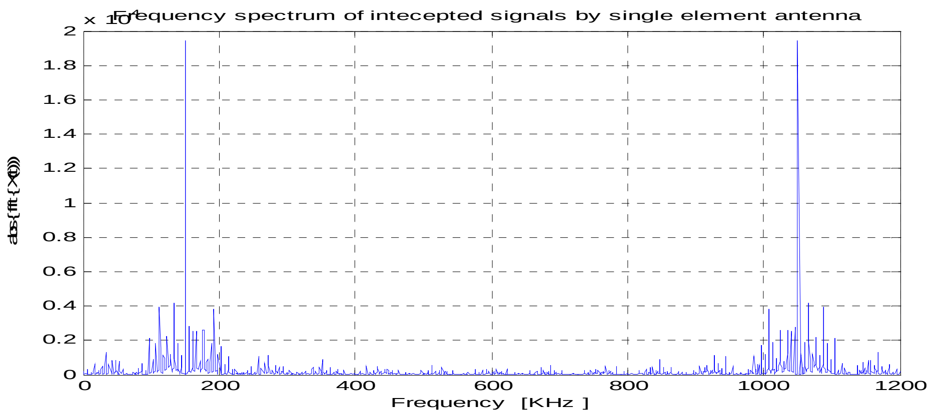
where K is the number of signal states that must be a modulo2 number and N_b is the number of samples per symbol duration, which is equivalent to the ratio between the sampling frequency, f_s, and the symbol rate, r_s. Also, in simulation of wideband signals, the measure of the bandwidth of the incident signal to be narrow or wide is defined as the ratio of the bandwidth of the complex base band signal and its carrier frequency [6,14]. So, the simulated signal is called a wideband signal if this ratio is larger than 0.2 [6,14]. The simulated signals are assumed to have the same carrier frequency and an equal power which is 10 dB relative to the background white Gaussian noise and SIR= -3dB. Moreover, In cyclic MUSIC algorithm, it is assumed that the cyclic frequency of SOI and the optimal lag time, at which the source cyclic correlation $R_s^{\alpha}(\tau)$ achieves its maximum, are known or estimated [6,14,15]. The employed array is 11-element non-uniform linear array with the following inter-element spacing [-7.5 -6.3 -5 -3.47 -1.55 -1.17 0.24 4.33 5 6.5 7.3]. These spacings are calculated relative to the wave length of SOI carrier frequency. The complete system is simulated using MATLAB software Ver.6.3 [16].

b- Performance evaluation of proposed software defined radio system

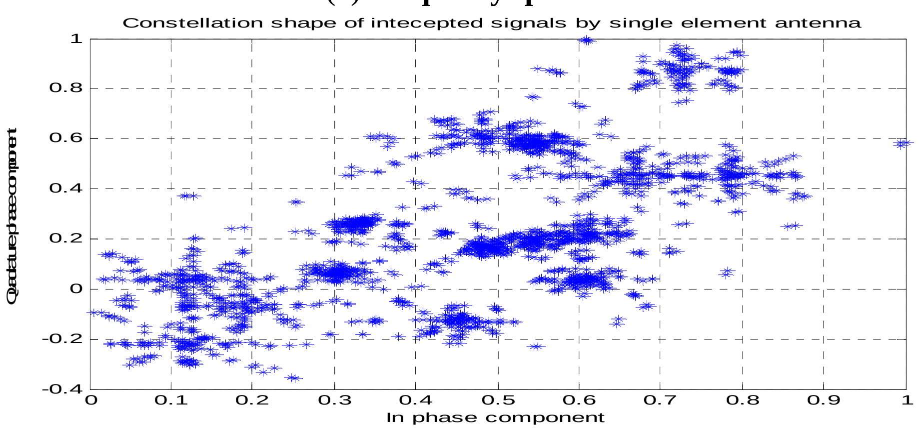
In order to illustrate the problem status that is solved by using the proposed software defined radio system. Fig.3.a. and Fig.3.b. show the intercepted superimposed signal, at SNR= 10 dB and SIR= -3dB, in both time and frequency domains if the interception receiver has a single element antenna. Also, Fig.3. shows the constellation shape of that signal. It is clear that it is difficult to separate the SOI from this superimposed signal. This complicated state can be solved by using an antenna array to sample the intercepted signals in space. The proposed software defined radio system changes the complex weight multiplier coefficients values by which the AAA beam pattern is controlled. The following subsections represent some cases of study for evaluating the performance of the proposed software defined radio system under different assumptions of the intercepted signals. These assumptions consider the intercepted signals are either cyclically correlated or cyclically uncorrelated with SOI and have a wide bandwidth.



(a) **Instantaneous amplitude**



(b) **Frequency spectrum**



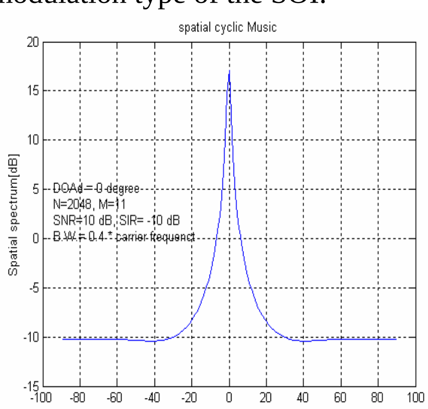
(c) **Constellation shape**

Fig.(3) Intercepted signal characteristics when using single element antenna at SNR= 10 dB and SIR= -3dB

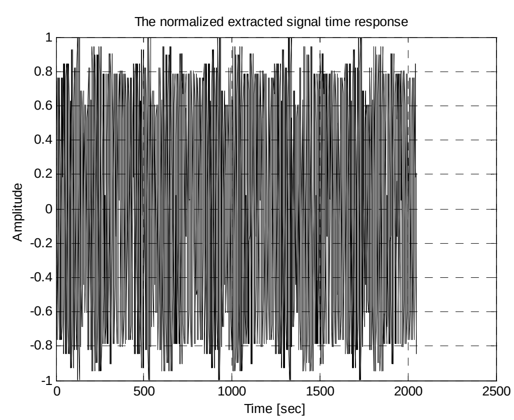
Subsection c presents the performance evaluation of the proposed software defined radio system in presence of cyclically uncorrelated wideband signals environment however Subsection d presents the performance evaluation of the proposed software defined radio system in presence of cyclically correlated wideband signals environment.

C - Cyclically uncorrelated signals environment

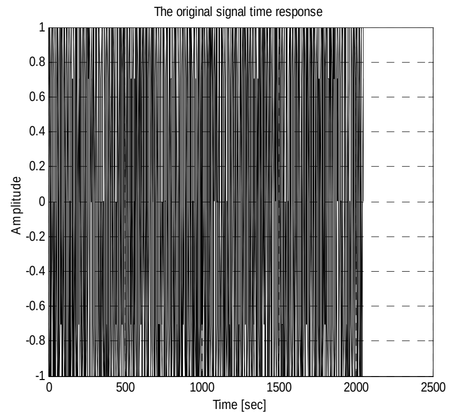
A computer simulation is carried out to evaluate the performance of the proposed software defined radio system when the incident signals on the antenna array are wideband cyclically correlated with SOI. The array parameters do not change from that are indicated in subsection a . The array is illuminated by three signals of the same carrier frequency. The desired signal is chosen to be 8-PSK with $\frac{f_s}{15}$ bit rate such that its complex base bandwidth is 0.5 of the carrier frequency and its DOA is 0^o. The first interference signal is chosen to be 8-QAM with $\frac{f_s}{20}$ bit rate such that its complex base bandwidth is 0.4 of the carrier frequency and its DOA is 40^o. The second interference signal is chosen to be 8-QAM with $\frac{f_s}{25}$ bit rate such that its complex base bandwidth is 0.3 of the carrier frequency and its DOA is -40^o. Consequently, the three simulated signals have different cyclic frequencies and verify the wide bandwidth condition. Thus, the simulated signals are wideband cyclically uncorrelated. The three signal sources are assumed to have equal power of 10 dB relative to the background AWGN and SIR= -3 dB. Fig.4.a. shows the cyclic MUSIC spatial spectrum where only one peak corresponding to the SOI at 0^o DOA. Since the two interference signals are cyclically uncorrelated with SOI, their cyclic correlations are zero and are not appear in the spatial cyclic spectrum. The steering vector of the antenna array that gives the previous cyclic MUSIC spectrum is considered as the needed weighting vector to separate SOI signal without using any nulling algorithm. Thus, an integration process is done in case of intercepting a set of cyclically uncorrelated signals at the antenna array. Fig.4.b. shows the normalized instantaneous amplitude of extracted signal. Fig.4.c. shows the instantaneous amplitude of original SOI. Fig.4.d. shows the intercepted signal frequency spectrum. Fig.4.e. shows the extracted signal frequency spectrum. Fig.4.f. shows the original SOI frequency spectrum. Consequently, the extracted signal is fed to the MR layer in order to recognize its modulation type. Fig.4.g. shows the constellation shape of the extracted signal which is processed by constellation construction algorithm within MR layer. Fig.4.h. shows the constructed constellation shape of the extracted signal which is processed by the decision algorithm in MR layer. From this figure, it is clear that the signal is 8-PSK signal, which is again matches the modulation type of the SOI.



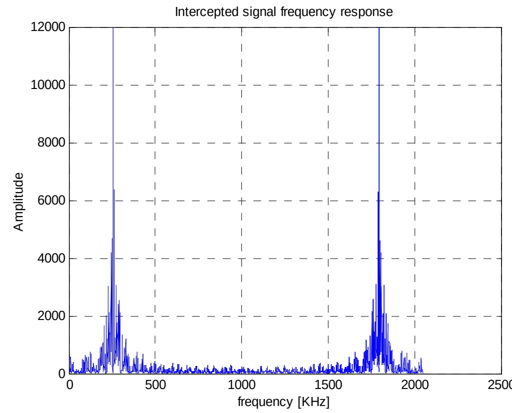
(a)- **The cyclic MUSIC spatial spectrum [-40 0 40]**



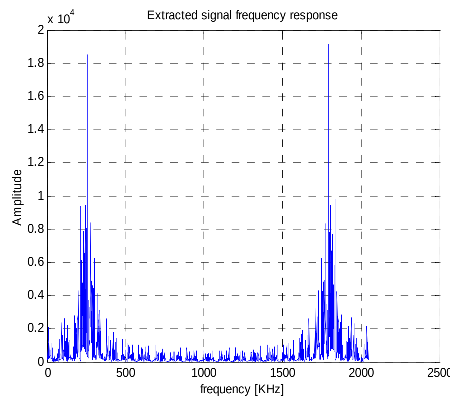
(b) **The normalized instantaneous amplitude of extracted signal**



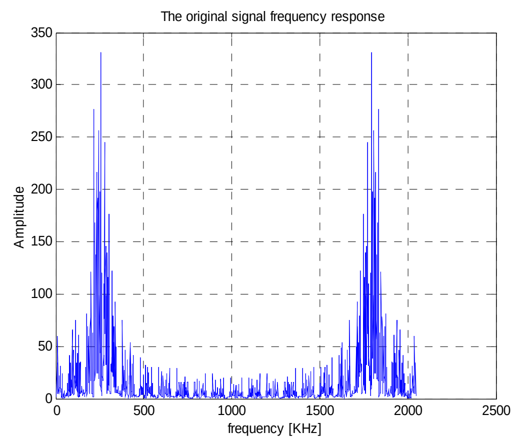
(c) **The instantaneous amplitude of original SOI**



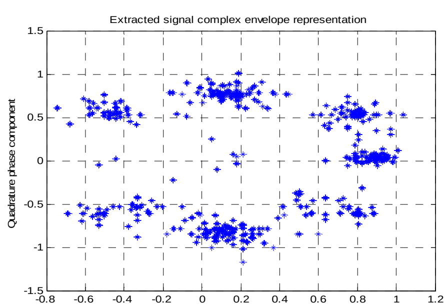
(d) **The intercepted signal frequency spectrum**



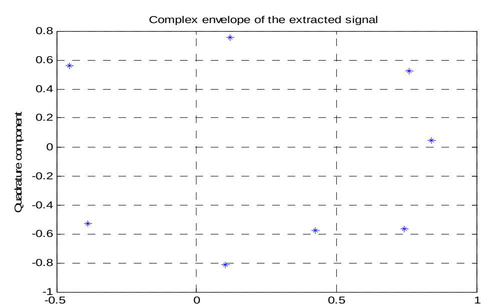
(e) **The extracted signal frequency spectrum**



(f) **The original SOI frequency spectrum**



(g) **The constellation shape of the extracted signal**

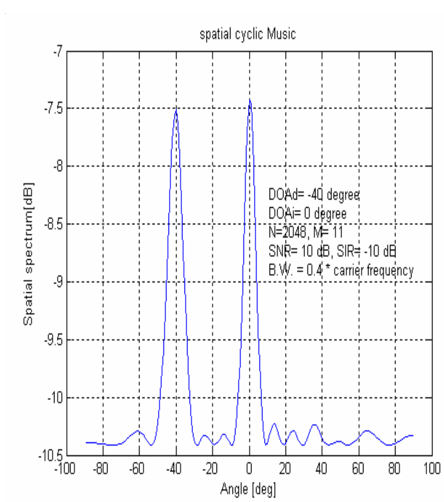


(h) **The constructed constellation shape of the extracted signal**

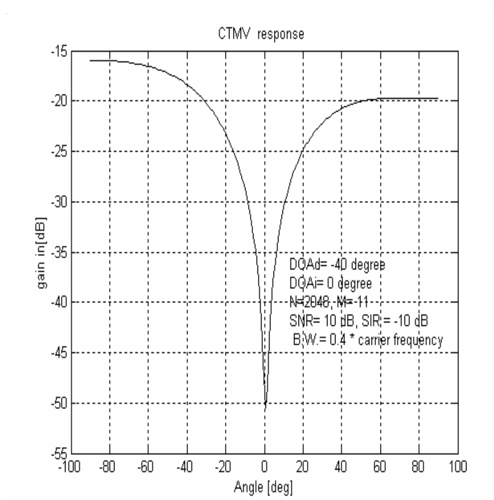
Fig.(4) Software defined radio system performance in presence of two wide band cyclically uncorrelated signals with SOI by using cyclic MUSIC algorithm

d- Cyclically correlated signals environment

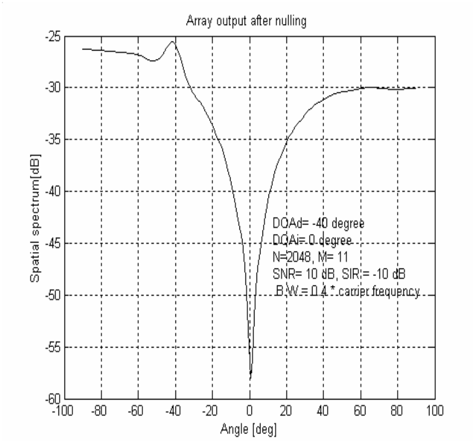
A computer simulation is carried out to evaluate the performance of the proposed software defined radio system when the incident signals on the antenna array are wideband cyclically correlated with SOI. The array parameters do not change from that are indicated in subsection a . The array is illuminated by two 8-PSK signals of the same carrier frequency and $\frac{f_s}{15}$ bit rate such that their complex base bandwidth is 0.4 of the carrier frequency. Consequently, the two simulated signals have the same cyclic frequencies and verify the wide bandwidth condition. Thus, the simulated two signals are wideband cyclically correlated. The desired signal DOA is -40^o and the interference cyclically correlated signal DOA is 0°. A third interference signal is simulated as 8-QAM signal with the same carrier frequency and $\frac{f_s}{20}$ bit rate such that its complex base bandwidth is 0.4 of its carrier frequency. Consequently, it has a different cyclic frequency and verifies wide bandwidth condition. Thus, it is a wide band cyclically uncorrelated with SOI and its DOA is 40^o. The three signal sources are assumed to have equal power of 10 dB relative to the background AWGN and SIR= -3 dB. Fig.5.a. shows the cyclic MUSIC spatial spectrum where only two peaks appear in the graph. After spectrum search of the peaks, the estimated values are [0^o, -40^o] which are the DOAs of the simulated cyclic correlated signals. From cyclostionarity concept, the cyclically uncorrelated interferer signal does not appear. By using the estimated DOAs information, the optimum weight vector for the separation of SOI is calculated by using CTMV algorithm. Fig. 5.b. shows the CTMV spatial spectrum where it maximizes SNR in SOI direction, 0^o and puts a null on the interferer direction 40^o. Fig.5.c. shows the result signal spatial spectrum which is the output of the signal separation layer. Fig.5.d. shows the normalized instantaneous amplitude of extracted SOI. Fig.5.e. shows the instantaneous amplitude of original SOI. Fig.5.f. shows the intercepted signal frequency spectrum. Fig.5.g. shows the extracted SOI frequency spectrum. Fig.5.h. shows the original SOI signal frequency spectrum. Consequently, the extracted signal is fed to the MR layer in order to recognize its modulation type. Fig.5.i. shows the constellation shape of the extracted signal which is processed by constellation construction algorithm within MR layer. Fig.5.j. shows the constructed constellation shape of the extracted signal which is processed by the decision algorithm in MR layer. From this figure, it is clear that the signal is 8-PSK signal, which is again, matches the modulation type of the SOI.



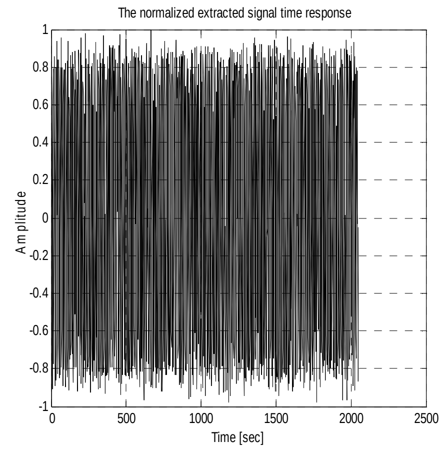
(a) **The cyclic MUSIC spatial spectrum [-40 0 40]**



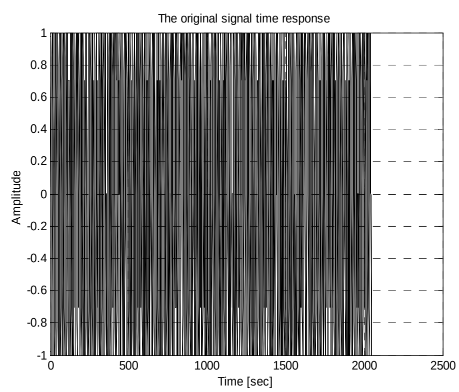
(b) **The CTMV spatial spectrum SOI direction at -40**



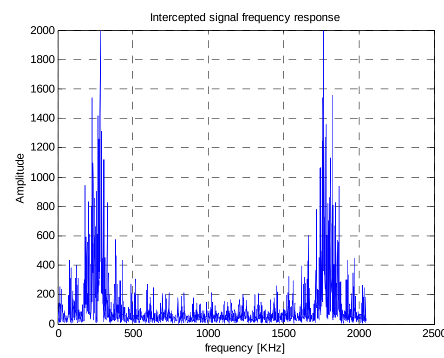
(c) **The output signal of the signal separation layer**



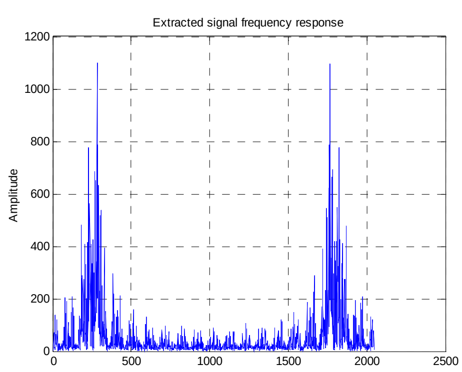
(d) **The normalized instantaneous amplitude of extracted signal**



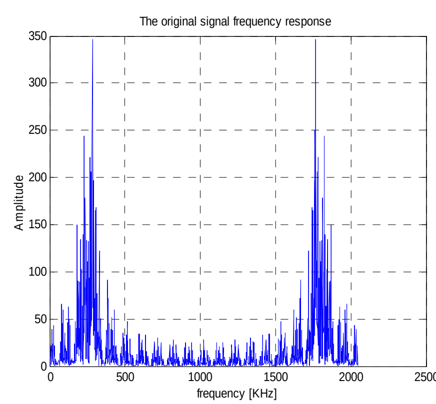
(e) **The instantaneous amplitude of original SOI signal**



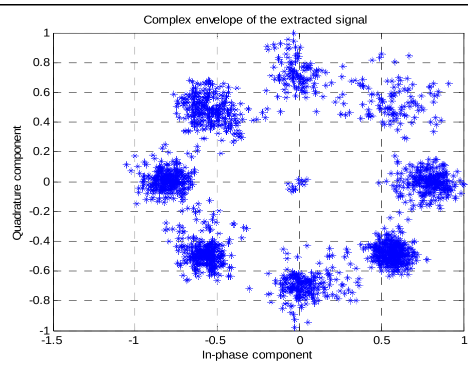
(f) **The intercepted signal frequency spectrum**



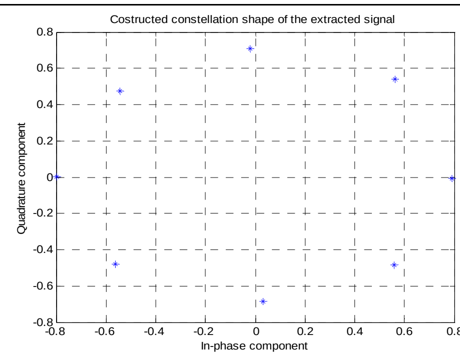
(g) **The extracted signal frequency spectrum**



(h) **The original SOI frequency spectrum**



(i) **The constellation shape of the extracted signal**



(j) **The constructed constellation shape of the extracted signal**

Fig.(5) Software defined radio system performance in presence of two wide band cyclically correlated signals and one wide band cyclically uncorrelated signal by using cyclic MUSIC algorithm

VII-Conclusions

A robust software defined radio system has been introduced to adaptively control the beam pattern of a linear antenna array. The purpose of this adaptive control is to cancel interference signals and to extract the SOI in order to recognize its modulation type preparing to take the appropriate counter action. The overall AAA system performance analysis has been carried out using computer simulations. The performance measures considered for analysis included the capability to resolve, extract, and correctly recognize the modulation type of wideband signals either they are cyclically correlated or cyclically uncorrelated with the interference signals. It has been found that: the AAA system has been succeeded to resolve, extract, and correctly recognize the modulation type of wideband SOI in presence of either cyclically correlated or cyclically uncorrelated wideband interference signals at SNR=10 dB and SIR=-3dB.

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