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SMART ANTENNA BASED DS-CDMA SYSTEM DESIGN FOR THIRD GENERATION MOBILE COMMUNICATION

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Abstract—The third generation promises increased bandwidth up to 384 Kbits/s for wide area coverage up to 2 Mbits/s for local area coverage. A smart antenna technique has been developed specifically to meet the bandwidth needs of 3 G [5, 7, 12, 14]. Smart beamforming provides increased data throughput for mobile high speed data application. Here in this paper we worked on MVDR Beamforming scheme for continuing demand for increased bandwidth & better quality of services. Adaptive minimum variance beamforming can be easily implemented to increase capacity as well as suppressing co-channel interference & to enhance the immunity to fading. The computer simulation carried out in MATLAB platform shows the signal processing technique optimally combines the components in such a way that it maximizes array gain in the desired direction simultaneously minimize it in the direction of interference [1, 3, 15, 16].

1. INTRODUCTION

The use of an antenna array adds an extra dimension and makes the utilization of spatial diversity possible. This is due to the fact that the interferers rarely have the same geographical location as the user, and therefore they are spatially separated. Different from Omni-directional antenna system and sectored antenna system, adaptive antenna array system referred in Fig. 1, combine an antenna array and a digital signal processor to receive and transmit signals in a directional manner. Thus the beampattern at the base station can be adaptively changed. The beamformer has to satisfy two requirements. 1. Steering capability whereby the desired signal is always having found the maximum gain. 2. The effect of sources of interferences is minimized [4, 6–8]. An improvement in the system capacity in a multipath environment can be achieved by combining a set of beamformer & a RAKE combiner.

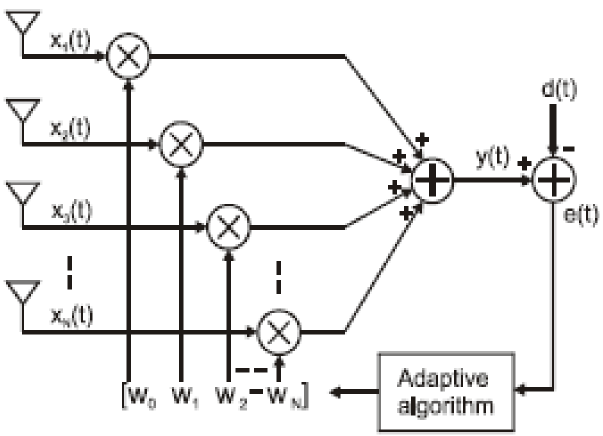

Figure 1. Adaptive antenna with adaptive processor.

There are two minimum variance beamformer configurations for the base station receiver in direct sequence code division access (DSCDMA) system depending upon the chip & symbol configuration. In symbol based configuration, spatial diversity is exploited after dispreading & interferer components are rejected, based on both their power and code correlation with the signal of interest (SOI). The symbol based configuration is very efficient method to reject higher interfering strength components. Fig. 2 shows the adaptive antenna array with adaptive processor which focuses all transmitted power to the user and only "looks" in the direction of the received signal. This ensures that the user receives the optimum quality of services

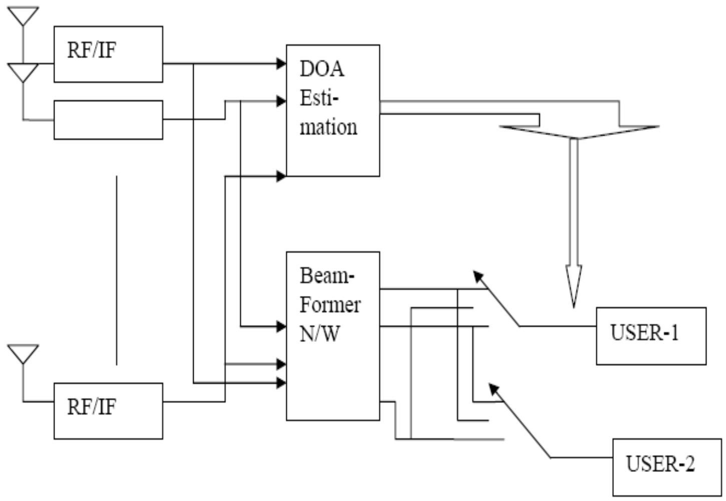

Figure 2. Beamformer & DOA estimation.

and maximum coverage for a base station. Adaptive antenna array incorporate more intelligence into their control system to estimate the signal of choice. Adaptive antenna monitor their environment and in particular, the response of the data path between the user and the base station [10, 11, 14, 15]. This information is then used to adjust the gains of the data received or transmitted from the array to maximize the response of the user. This dynamic adaptation of the antenna array response provides focused beams to specific users and a new mechanism for multi-user access to the base station. The fundamental operation carried out in adaptive arrays is to pass the data stream from each antenna through an adaptive finite impulse response filter. As per example when we have four antenna elements in a narrow band environment such that the adaptive filter results in a single multiplication, we realize processing requirements approach one-half billion multiple accumulates per second (MAC's) for a sample rate of 105 mega sample per second. This sample rate is for a single beam doesn't include the processing requirement for adaptive update algorithm, so in this case we want to support multiple beams & achieve finer beams by increasing the number of antennas, we could quickly exhaust the processing capability of a standard processor architecture as we reach processing requirements of several billion MAC's per second.

By using FPGA's, we have powerful DSP devices for handling these high performance requirements at sampled data rates, further more we can take advantage of the FPGA flexibility for directly handling acquisition control and other DSP function such as digital down conversion, demodulation & matched filtering.

2. SMART ARRAY CONFIGURATION

Smart antenna implemented in the IMT-2000 mobile telecommunication systems to achieve a high system capacity. The following problems become critical when expanding the use of W-CDMA in the telecommunication.

1) Interference in low transmission rate signals caused by high transmission rate signals. The number of users who use low transmission rates while high transmission rate communication is in progress will decrease because the high transmission rate signals will cause a large amount of interference in the low transmission rate signals.

2) There will be stronger demands to increase the number of users a base station (BS) can accommodate. The number of users a BS can accommodate is limited by the mutual interference from the users' signals and other factors [9]. Moreover, the area of a W-CDMA cell is smaller than that of a second-generation mobile communications system due to the restriction of transmission power. Therefore, to expand the use of W-CDMA, it will be necessary to increase the number of users that a base station can accommodate and also increase the cell area. To solve these problems, we developed a smart sensor array technology for a W-CDMA base station that reduces the amount of interference that is received [2, 3, 5–7]. Smart array makes it possible to increase the number of users. It also makes it possible to cover the same area with a smaller number of base stations.

3. THE ALGORITHMS FOR SMART ANTENNA TEST BED

The performance simulation relied on theoretical analysis depending upon mathematical model and assumption. The construction of the test bed is designed into two parts of DOA estimation and beamforming.

3.1. MVDR Beamforming Scheme for Smart Antenna Test Bed

Frequency domain snapshot consists of signal & noise components; $X(\omega) = X_s(\omega) + N(\omega)$. Signal vectors can be represented by

$X_s(\omega) = F(\omega)v$, where v is array manifold vector and $F(\omega)$ represents the frequency domain snapshots; the noise snapshot $N(\omega)$ is a zero mean random vector with spectral matrix $S_n(\omega) = S_c(\omega) + \sigma_\omega^2 I$. We process $X(\omega)$ with a matrix operation $W^H(\omega)$. The dimension of $W^H(\omega)$ is 1^*N. The first criterion of interest is called distortionless criterion. In the absence of noise $Y(\omega) = F(\omega)$, i.e., we wish to minimize the variance of $Y(\omega)$ in the presence of noise. We represent $Y(\omega) = F(\omega) + Y_n(\omega)$ and minimize $E[|Y_n(\omega)|^2]$. The constraint of no distortion implies $W^H(\omega)^* v = 1$. The mean square of output noise is $E[|Y_n|^2] = W^H(\omega)S_n(\omega)W(\omega)$. In this case we have taken the minimum variance unbiased estimate $E[Y(\omega)] = F(\omega)$. Now we would impose a Lagrange multiplier

$$F \triangleq W^H(\omega)S_n(\omega)W(\omega) + \lambda(\omega)^* \left[W^H(\omega)^* v - 1\right] + \lambda^*(\omega)\left[v^H W(\omega) - 1\right] \tag{1}$$

The complex gradient with respect to $W^H(\omega)$ and solving we have

$$W_0^H(\omega) = -\lambda(\omega) v^H S_n^{-1}(\omega) \tag{2}$$

where

$$\lambda(\omega) = -[v^H S_n^{-1}(\omega)v]^{-1};\ W_0^H(\omega) = \Lambda(v^H)S_n^{-1}(\omega) \tag{3}$$

And $\Lambda = [v^H S_n^{-1} v]^{-1}$. The output of the optimum distortion less matrix is the maximum likelihood estimate of $F(\omega_m)$ and can be used to generate $f(t)|_{ml}$. The MVDR filter provides the ML estimate of signal $f(t)$ when signal wave number is known and $S_n(\omega)$ is known. Hence

$$W_{\text{MVDR}}^H \triangleq W_0^H(\omega) = \Lambda(\omega) v^H S_n^{-1}(\omega) \tag{4}$$

The array gain at a particular frequency ω is given by the ratio of signal spectrum to noise spectrum at the o/p of the distortion-fewer filters compared to the ratio of the input. The input SNR at each sensor is $\frac{S_f(\omega)}{S_n(\omega)}$ and array gain comes

$$A_c = \frac{N^2}{v^H \rho_n(\omega) v} \tag{5}$$

Here $\rho_n(\omega)$ is the normalized spectral matrix. In the side lobe region the MVDR Beamformer offers significant improvement for large INR and gives acceptable beam pattern. In the outer side lobe region the beam pattern of MVDR beam-former starts to degenerate, the

HPBW region, the MVDR beam-former generates a solution that distorts the main lobe and is sensitive to model mismatch. Fig. 3 shows a single channel of a smart array system which consists of various RF components connected with a dedicated FPGA processor.

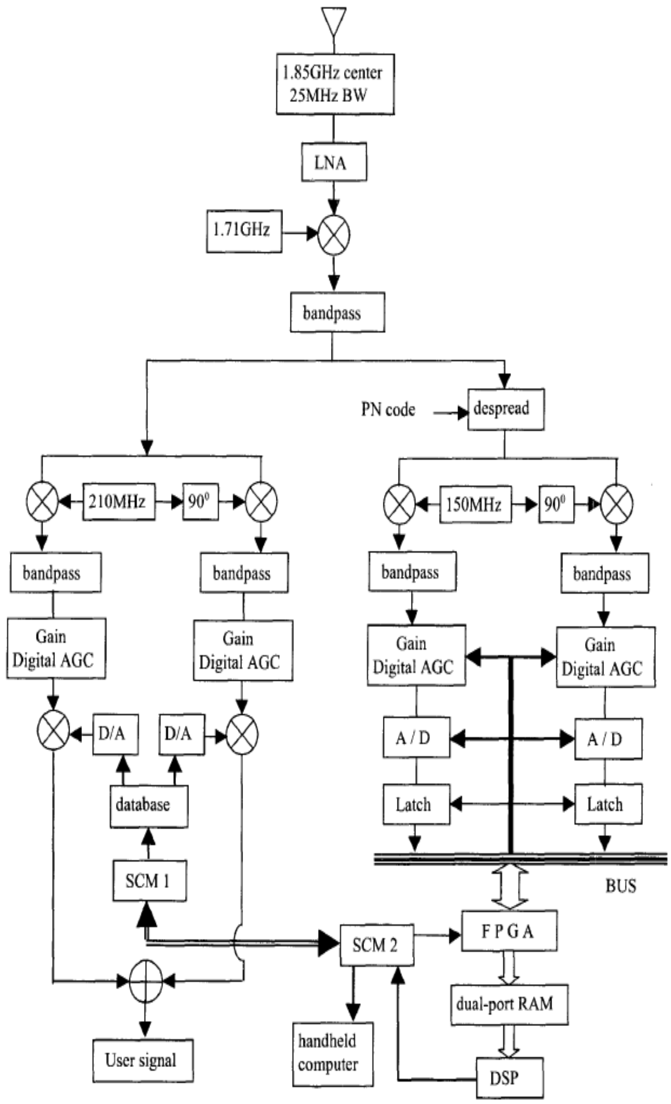

Figure 3. One channel of the smart antenna.

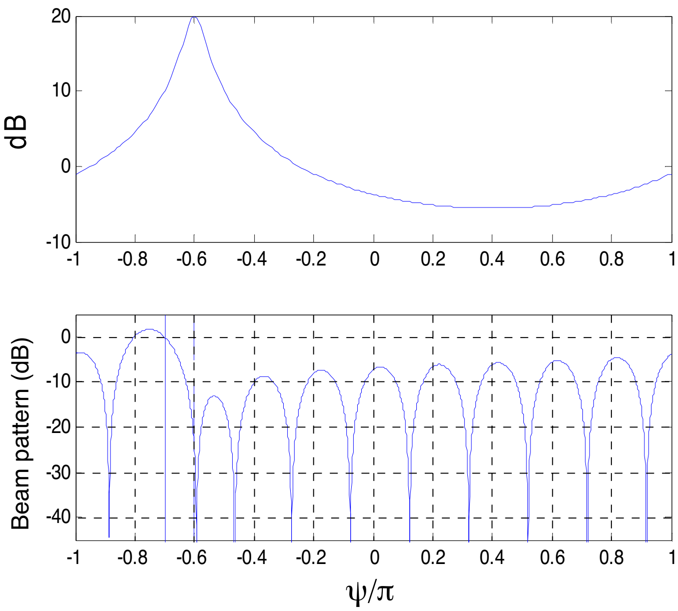

Figure 4. Optimum beampattern autoregressive interference in the absence of white noise when $\phi = -0.6\pi$.

Fig. 4 illustrates the case when multiple plane waves desired signals are present. Array generates multiple beams to maintain the link. Fig. 5 indicates normalized array gain of MVDR Beamformer in the presence of mismatch when single plane wave interferer is present with INR=10 dB.

3.2. DOA estimation:

MUSIC algorithm estimate direction-of-arrival (DOA) of a user. However, the MUSIC spatial spectrum does not estimate the signal power associated with each arrival angle and MUSIC fails when impinging signals are highly correlated. We present max Eigen value algorithm which has performances of the peak of spectrum corresponding directly with main signal, good ability of resisting multipaths and lower computational complexity. Fig. 6 shows the array estimated the desired signals coming from 30° & 60° respectively.

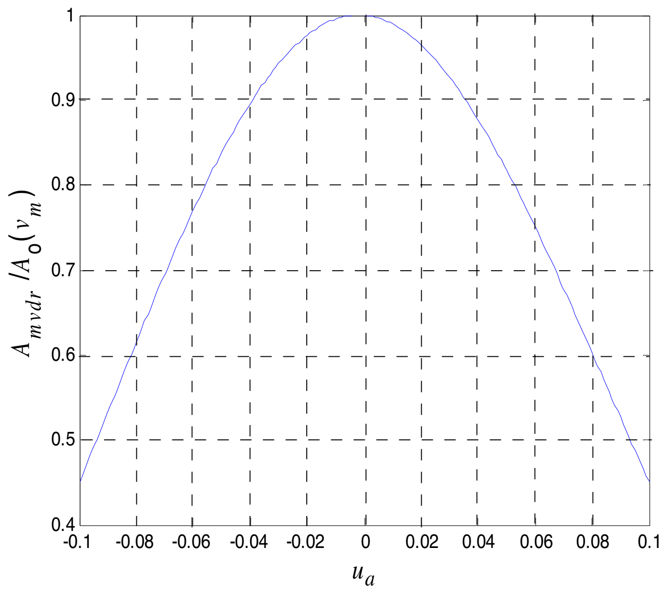

Figure 5. Array gain of beamformer (MVDR).

4. MVDR FOR MULTIPLE PLANE WAVE INTERFERERS

Here D different paths are considered which are normalized to steering and sum devices corresponding to the D interfering noises. The transform of the interfering noise can be written as

$$N_c(\omega) = \sum_{i=1}^{D} N_i(\omega)v \quad \text{and} \quad S_{n_c}(\omega) = \sum_{i=1}^{D}\sum_{j=1}^{D} S_{n_i n_j}(\omega)vv^H \tag{6}$$

which is a N^*D dimensional matrix and $V_I = [v(k_1)v(k_2)\dots v(k_D)]$. So the composite array manifold $S_I = \begin{bmatrix} S_{11}(\omega)\dots S_{21}(\omega)\dots \\ \dots \\ \dots S_{DD}(\omega) \end{bmatrix}$; and this is the interference spectral matrix. We assume that the signal and interference are statistically independent.

$$S_n = \sigma_\omega^2 I + V_I S_I V_I^H \tag{7}$$

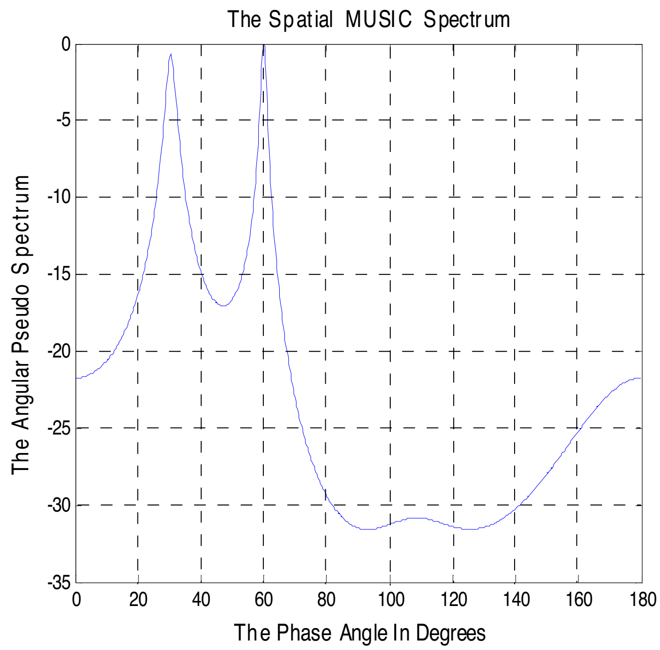

Figure 6. Plot of angular pseudo spectrum with phase angle for spatial MUSIC when the channel signal to noise ratio: 20 dB & the signal arrival phase angle: 30, 60 degree.

Using the matrix inversion lemna we have;

$$S_n^{-1} = \frac{1}{\sigma_\omega^2} I - \frac{1}{\sigma_\omega^2} V_I \left(I + S_I V_I^H \frac{1}{\sigma_\omega^2} V_I \right)^{-1} S_I V_I^H \frac{1}{\sigma_\omega^2} \tag{8}$$

We have

$$W_0^H = \Lambda v_s^H S_n^{-1} = \frac{N\Lambda}{\sigma_\omega^2} \left[\frac{V_s^H}{N} - \rho_{SI} H_{oc} \right] \tag{9}$$

where

$$H_{oc} \triangleq \left[I + \frac{S_I}{\sigma_\omega^2} v_I^H v_I \right]^{-1} \frac{S_I}{\sigma_\omega^2} v_I^H \tag{10}$$

this is a D^*N dimensional matrix filter whose output is the minimum mean square error estimate $n_I(t)$ in the absence of desired signal, $\rho_{SI} = \frac{v_s^H v_I}{N}$ a 1^*D dimensional spatial correlation matrix. The optimum receiver is estimating the directional noise vectors and then subtracting the component of the estimate that is corrected with the desired signal.

5. MVDR FOR MULTIPLE PLANE-WAVE SIGNALS

We have already introduced $X(\omega) = v_s F(\omega) + N(\omega)$ where $v_s = [v(\omega : k_1) \ldots v(\omega : k_D)]$ and $F(\omega) = \begin{bmatrix} F_1(\omega) \\ \cdot \\ F_D(\omega) \end{bmatrix}$ are the Fourier transform of an unknown non random signal vector. The processor $W^H(\omega)$ is a D^*N distortion less matrix processor $W^H(\omega) = \begin{bmatrix} W_1^H(\omega) \\ \cdot \\ W_D^H(\omega) \end{bmatrix}$; suppressing the ω dependence the distortion less criterion implies $W_1^H vF = F_1$; $W_2^H vF = F_2$; and $W_D^H vF = F_D$. These set of equations must be satisfied for arbitrary F, it places D constrains on each W_i. This implied $W_1^H v_1 = 1$; $W_1^H v_2 = 0$ and simultaneously $W_1^H v_D = 0$. For ith beamformer $W_1^H v_j = \delta_{ij}$ where $\ldots, i, j = 1, \ldots, D$. Therefore, the ith beamformer is distortion less with respect to the ith signal and put a perfect null of the other D-1 signals. The output noise of the ith beamformer $\sigma_{ni}^2 = W_i^H S_n W_i$. We would try to minimize σ_{ni}^2 subject to D constrainon W_i.

Define,

$$G_i = W_i^H S_n W_i + \sum_{j=1}^{D} \lambda_{ij}^* \left(W_i^H v_i - \delta_{ij} \right) + \sum_{j=1}^{D} \lambda_{ij} \left(v_i^H w_i - \delta_{ij} \right) \quad (11)$$

where $i = 1, \ldots, D$ minimizing we have,

$$W_i^H S_n + \lambda_{ij} v_j^H = 0 \quad (12)$$

$$\text{or,} \qquad W_i^H = -\lambda_{ij} v_j^H S_n^{-1} \quad (13)$$

Now we define Λ a D^*D matrix whose i, jth element is λ_{ij}. $\Lambda = -[V^H S_n^{-1} V]^{-1}$ and finally the optimum distortion less beamformer is

$$W_{d0}^H = \left[V^H S_n^{-1} V \right]^{-1} V^H S_n^{-1} \quad (14)$$

Figure 7 shows Comparison of MVDR, conventional and Null steering beam pattern taking the number of antenna elements 10. MVDR maximizes the output SNR does not require knowledge of directions and power levels of interferences as well as the level of the

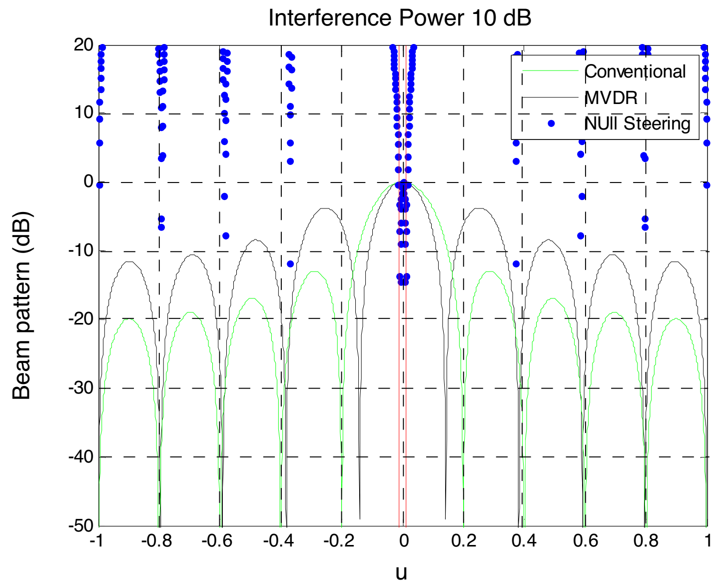

Figure 7. Comparison of MVDR, conventional and null steering beam pattern with $N = 10$.

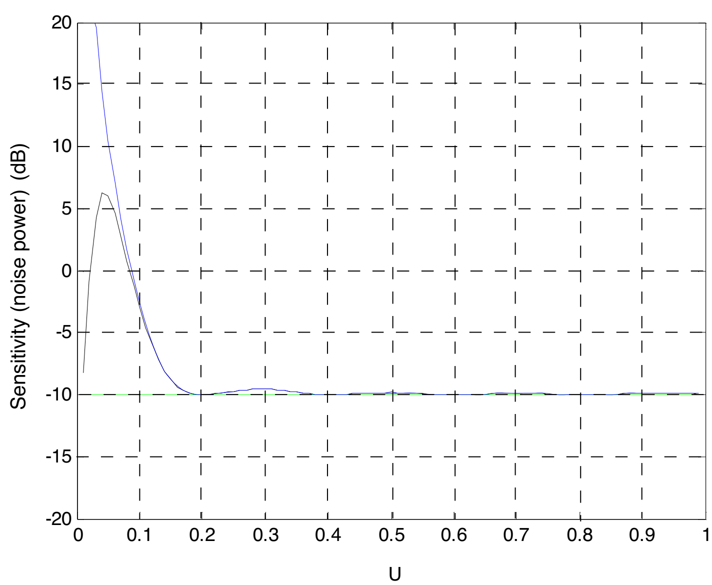

Figure 8. Sensitivity function (inverse of noise gain) vs u_i for linear array of 10 elements.

background noise power to maximize the output SNR. Fig. 8 shows the variation of sensitivity for MVDR, Null steering & conventional beamformer. We want the array processor to be very sensitive to directional constraints, whenever it finds slight changes in the environment it should adjust the weights accordingly, the algorithm may be summarized in the flow chart of the Fig. 9.

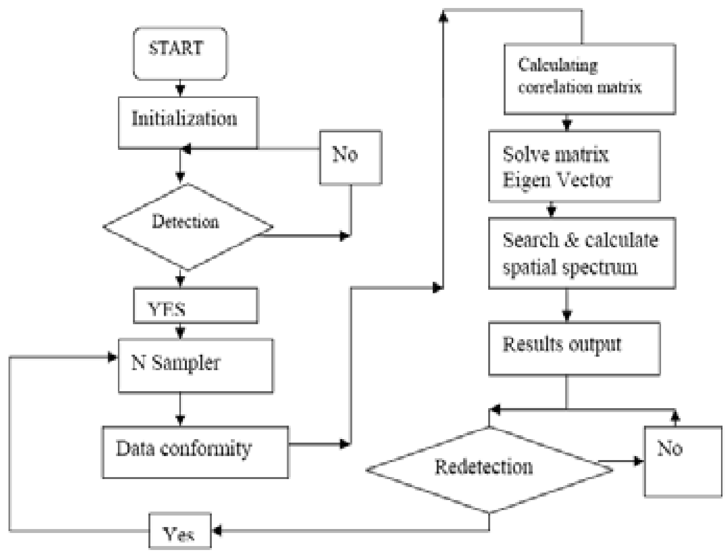

Figure 9. Software flow in FPGA module for adaptation.

6. CONCLUSION

We have simulated a multipath environment, taken that the mobile unit move at a distance of 50 to 100 meter away from test bed and round by center of test bed. Here we have taken two user, user1 as example with 0 dB power at angle 30° (DOA) and user2 with 6 dB of power and having DOA 60° respectively. By our smart antenna test bed at experimental locale it can be seen the MUSIC algorithm can estimate consistently with desirable result. After estimation of DOA's of different signals, may be fed to beamforming network. Fig. 5 shows the MVDR Beamformer average gain. Two simulated beampattern of antenna array indicate that the array is capable of steering the beam in the direction of the users whereby creates null in the direction of interferer.

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