DIRECTION OF ARRIVAL BASED INTERFERNCE REDUCTION AND CAPACITY ENHANCEMENT USING SMART ANTENNAS IN CDMA NETWORKS

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ABSTRACT

In this paper, the problem of estimating directions of arrival (DOAs) of multiple sources observed on the background of white noise by using MUtiple SIgnal Classification (MUSIC) algorithm is proposed. This demonstrates the systems user oriented steering abilities. Using this approach reduces the interference substantially and hence increases the capacity of the system. Smart antenna simulation is done by considering multiple paths with multiple directions of arrivals of signals. The simulations confirmed that smart system have an ability to distinguish between signals of interest and interferers by directing beams in the directions of the desired signals and nulls in the directions of the interferers.

INTRODUCTION

As the number of mobile subscribers increases rapidly, combined with a demand for more sophisticated mobile services requiring higher data rates, the operators are forced to investigate different methods to put more capacity into their networks. Smart antennas are foreseen as one of the more promising technologies for reducing interference and increasing capacity in CDMA networks. [1-3]. Further, CDMA is a multiple access interference limited system, any action that reduces the interference level increases more users in the system, higher bit-rates, improved quality for the existing users at the same bit-rates and extended cell range for the same number of users at the same bit rates, or any arbitrary combination of these [4-5].

DIRECTION OF ARRIVAL ESTIMATION

In a mobile environment, it is usually assumed that the scatterers surrounding the mobile station are approximately at the same height as or higher than the mobile. At the base station side, it is assumed that the base station antenna is deployed above the surrounding scatterers, typically mounted on masts placed on rooftops. The received signal at the mobile station arrives from all directions after bouncing from the surrounding scatterers. Thus, it is assumed that the angle of arrival (AOA) at the mobile station will be uniformly distributed between 0 and 2π. However, the AOA at the base station is quite different. Since the base station is deployed above the surrounding scatterers, most of the scattering occurs in the vicinity of the mobile station. Hence, the AOA at the base station is restricted to a smaller angular region.

The number of DOAs that can be estimated is smaller than the number of antenna elements. This is a major disadvantage in environments suffering from large angle spread. If large angle spread is present, then the point source model is not valid and inevitably many different DOAs correspond to a single signal source. In that case spatial structure methods require more antenna elements than the total number of impinging signals and their multipaths. *Spatial structure* methods directly estimate the DOAs of the impinging wavefronts. Once the DOAs are found, the weight vector necessary to separate the wavefronts can be determined via beamforming methods. In this paper, MUSIC algorithm is used to estimate the DoA of signals.

THE MUSIC ALGORITHM

MUSIC (MUltiple SIgnal Classification) algorithm is used to estimate DoA of signals. The structure of the exact covariance matrix with the spatial white noise assumption implies that its spectral decomposition can be expressed as

$$\Re_{xx}=AU_{ss}A^H+\Omega^2 I= U_s\Lambda_s U_s^H + \Omega^2 U_n U_n^H \qquad (1)$$

where, assuming $AU_{ss}A^H$ to be of full rank, the diagonal matrix Λ_s contains the L largest eigenvalues. Since the eigenvectors in U_n (the noise eigenvectors) are orthogonal to A, we have ,

$$U_n^H a(\theta)=0, \quad \theta\in \{\theta 1, \theta 2, \ldots\ldots\ldots \theta L\} \quad (2)$$

To allow for unique DoA estimates, the array is usually assumed to be unambiguous, that is, any collection of M steering vectors corresponding to distinct DoAs η_k forms a linearly independent set $\{a(\eta 1), \ldots, a(\eta M)\}$, where $L < M$. If $a(\cdot)$ satisfies these conditions and $\Re_{xx}$has full rank, then $AU_{ss}A^H$ is also of full rank. It then follows that $\theta 1, \ldots, \theta L$ are the only possible solutions to the relation in Eqn. (2), which could therefore be used to exactly locate the DoAs. In practice, an estimate $\Re_{xx}$of the covariance matrix is obtained and its eigenvectors are separated into the signal and noise eigenvectors. The orthogonal projector onto the noise subspace is estimated as

$$P^{\wedge}\perp_A = U_n^{\wedge}\, U_n^{\wedge H} \qquad (3)$$

The MUSIC spatial spectrum is then defined as

$$P_L(\theta)=[a^H(\theta)a(\theta)]/\{a^H(\theta)P^{\wedge}\perp_A a(\theta)\} \qquad (4)$$

Although $P_L(\theta)$is not a true spectrum in any sense (it is merely the distance between two subspaces), it exhibits peaks in the vicinity of the true DoAs as suggested by Eqn. (2). The performance improvement of the MUSIC estimator was so significant that it became an alternative to most existing methods. Thus, in contrast to the Beamforming techniques, the MUSIC algorithm provides statistically consistent estimates. The DOA's of each of the incident signals can be estimated by plotting the spatial spectrum given by $P_L(\theta\ )$.

Simulation cases of MUSIC algorithm

The following cases are considered for simulation-

Case I- varying the number of signals with the number of array elements kept constant.

Case 2- Varying the signal to noise ratio (SNR).

Case 3- Varying the number of time sampled used for finding the time averaged correlation matrix of the received signal.

Case 1- Varying the number of signals with the number of array elements kept constant. (No. of signals =2)

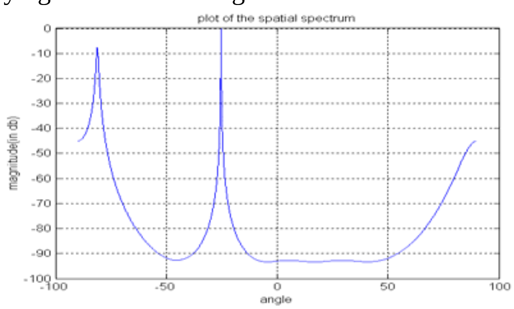

Fig1: Magnitude (db) Vs angle

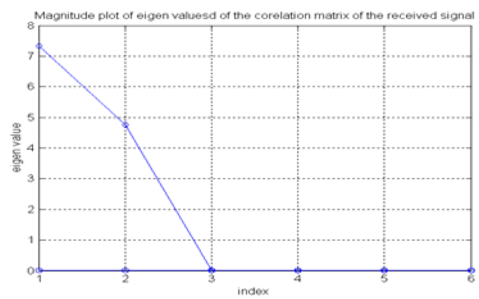

Fig 2: Eigen value Vs Index

ii) No of signals =3

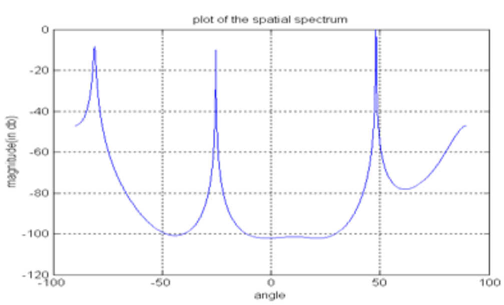

Fig 3 : Magnitude Vs angle

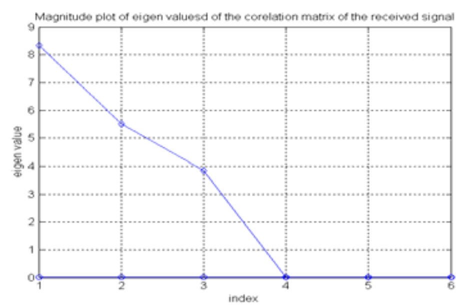

Fig 4 : Eigen value Vs Index

From the results (Figure 1-4) it's clear that MUSIC algorithm is efficient tool for the plot of spatial spectrum for estimate the number of incident signals and the angle of arrivals. But it will be only suitable for smaller number of signals. The number of incident signals can be calculated by counting the number of Eigen values above the noise floor.

Case 2- Varying the signal to noise ratio (SNR) (SNR=20)

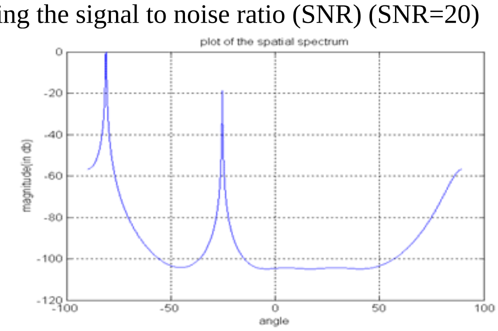

Fig 5 : Magnitude Vs angle

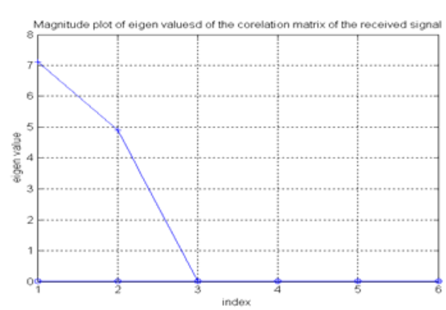

Fig 6 : Eigen value Vs Index

From the results (Figure 5-6) of case 2 it is cleared that for higher values of SNR resolving capabilities of MUSIC algorithm will be more pronounced than lower values of SNR.

Case 3- Varying the number of time sampled used for finding the time averaged correlation matrix of the received signal.
i) No of samples=100

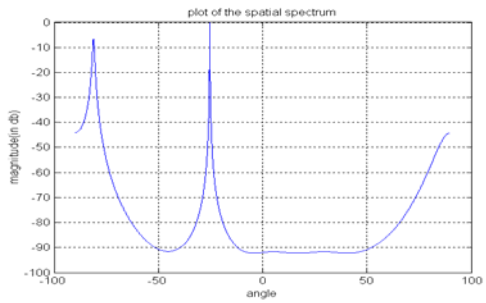

Fig 7 : Magnitude Vs angle

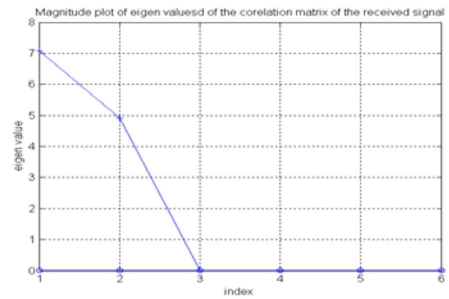

Fig 8: Eigen value Vs Index

From the results (Figures 7-8) of case 3 for large number of time samples the spatial resolution of MUSIC algorithm will be more.

SMART ANTENNA SIMULATIONS

For all adaptive array smart antenna simulations, the 5000 input signals of the training sequence have signed values of 1 or –1 to simulate a transmitter sending binary values. Although there are 5000 sampling instants, the results only show up to 150 intervals due to the extremely high rate of convergence of the system. The step-size parameter μ for the LMS algorithm is set to 0.008, to keep simulations as realistic as possible, for those simulations with more than one multipath, each multipath experiences a different gain, which contains both amplitude and phase components. It was found that the amplitude of the gain had the most effect on the system, with the phase having little to no effect.

The carrier frequency f_c of transmitted training sequences is set to 400 MHz, which means the value of the wavelength λ is set to 0.75m. To satisfy an element spacing *d* of λ/2 then means that *d* is set to 0.375m. For simulations with only one transmitted signal, the propagation delay from transmission to reaching the first antenna element is set to 100μs, and for those with a second transmitted signal, the second propagation delay is set at 150μs.

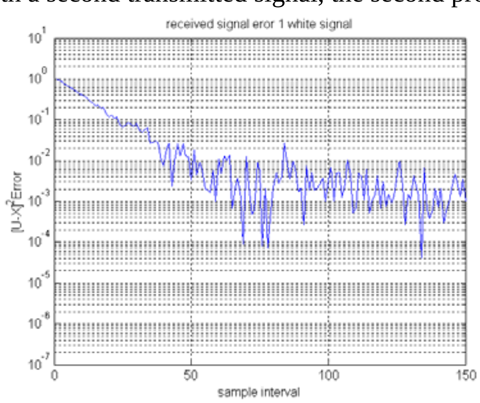

Fig 9. [U-X]^{2}error Vs Sample Interval

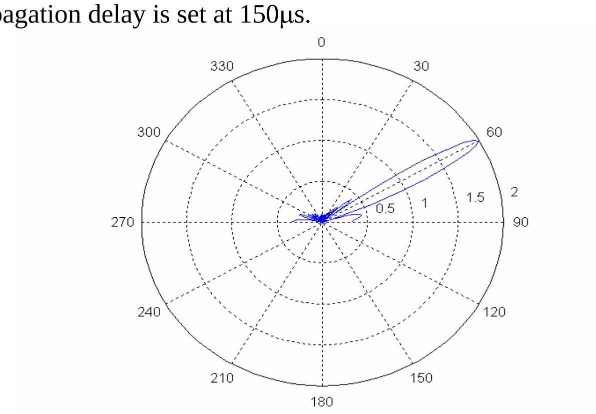

Fig 10. Beam Pattern Using Polar Graph

One White Signal with One DoA

To ensure that the system worked correctly, the first simulation investigated was the reception of one signal with the one path that arrives at the base station at an angle of 60^o. A gain with amplitude of 0.5 db was introduced to the input signal as it was propagated to the antenna. Figure 9 illustrates that the received signal error converges at approximately 54 db sample intervals and reaches 0.01 after 43 intervals. The mean received signal error after convergence lies approximately at 0.0006.

Figure 10 shows that beam pattern of the system correctly steers the main beam in the direction of 60^o with beam strength of 2. This is due to the signal experiencing a gain of amplitude 0.5, which reduces the power of the signal by half. To counter this, the beam adjusts its gain to the inverse of the signal power in order to receive a signal similar to the original signal.

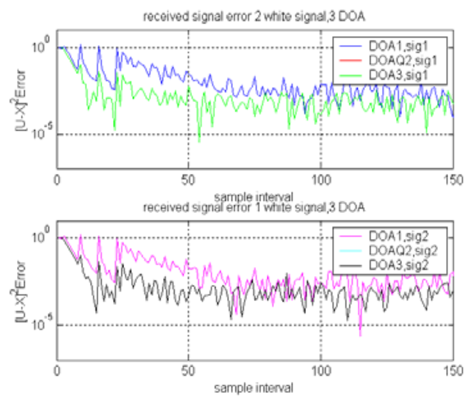

Fig 11 [U-X]^2 error Vs Sample Interval

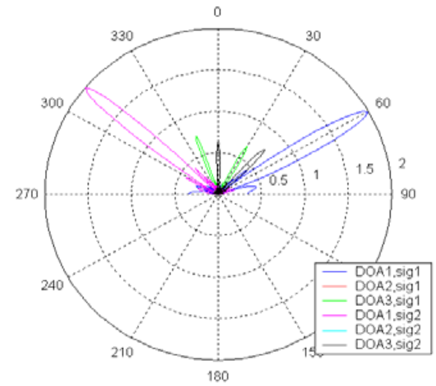

Fig 12 Beam Pattern Using Polar Graph

Two White Signals With Three DoAs

The final smart antenna simulation is the most complex and provided the most unexpected results. In this simulation we transmit 2 training sequences, each with three multipath components. However, second and third multipath components of each signal are both set to arrive at the antenna array one sample period behind the first multipath. Essentially, this means that the 2nd and 3rd multipath is arriving at the base station at the same time but from different directions.

From figure 11, although there were three multipaths for each signal in the system, only two sets of received signal errors are being displayed. That is, only four unique weight vectors exist. This is because the weight vectors for the second and third multipaths are exactly the same due to these signals arriving at the same time. This means that for multipath components of the same signal that arrive at the same time, only one weight vector is needed. Also, the mean received signal error of the 1st multipath of the 1st signal is roughly the same as for one signal with three multipaths, lying at approximately 0.003.

After this finding, it was expected that the main beam would either be directed in the direction of the closest multipath or the one with the greatest gain. However, the beam pattern shown in figure 12 displays the four different beam patterns but the patterns for the 3rd multipath of both signals have two main lobes in the correct directions of the 2nd and 3rd multipaths. The gains of these beams are half what they would normally be and swapped between the multipath components.

The smart antenna simulations confirmed that smart system have an ability to distinguish between signals of interest and interferers by directing beams in the directions of the desired signals and nulls in the directions of the interferers.

CONCLUSION

The smart antenna is a powerful technique to reduce multi-user interference and increase system capacity. In this paper, the problem of estimating directions of arrival (DOAs) of multiple sources observed on the background of white noise by using MUtiple SIgnal Classification (MUSIC) algorithm is proposed. This demonstrates the systems user oriented steering abilities. Using this approach reduces the interference substantially and hence increases the capacity of the system. Smart antenna simulation is done by considering multiple paths with multiple directions of arrivals of signals. The simulations confirmed that smart system have an ability to distinguish between signals of interest and interferers by directing beams in the directions of the desired signals and nulls in the directions of the interferers.

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