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"Smart Antenna for High Speed Wireless Communication System"

Nidhi Jain[a], R.P.Yadav[b]
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Abstract

Third generation (3G) mobile communication systems will provide services supporting high-speed data network and multimedia applications in addition to voice applications. The Smart antenna technique is one of the leading technologies that help to meet the requirement by such services to radio network capacity. Resource management schemes such as power control, handoff and channel reservation/assignment are also essential for providing the seamless services with high quality. Smart antenna techniques will help to enhance the capability of resource management through more efficient and flexible use of resources. In this paper, a multi-cell CDMA simulator is developed for investigating the gain from smart antenna techniques in both bit error rate (BER) performance improvement and enhancement to resource management schemes. Our study shows that smart antenna techniques can significantly improve the performance of the system and help to build more powerful and flexible resource management schemes. With eight array elements, the system capacity can be increased by a factor of four. Power control command rates can be reduced through the tradeoff with the interference reduction by smart antennas.

1. Introduction

1.1 Overview of Smart Antenna Technique:

The term "Smart Antenna" means any antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals. Smart Antenna (SA) techniques employ Digital Beam Forming (DBF) originated in the sonar and radar communities. Instead of generating an omni-directional beam pattern, a smart antenna can point one beam to a particular direction from which the desired user signal comes and nulls the interfering signals from other users[1].

1.2 Smart Antenna Evolution:

The advent of low cost digital signal and general-purpose processors and innovative algorithms have made smart antenna systems practical. The evolution can be divided into three phases[2][3]:

- Smart antennas are used on uplink only. By using a smart antenna to increase the gain at the base station, both the sensitivity and range are increased. This concept is called High sensitivity receiver (HSR) and is in principle not different from the diversity techniques implemented in mobile communication systems.
- In the second phase, directed antenna beams are used on the downlink direction in addition to HSR. So, the antenna gain is increased both on uplink and downlink, which implies a spatial filtering in both directions. This is called spatial filtering for interference reduction (SFIR). In second generation system GSM, which is a TDMA/FDMA system this interference reduction results in an increase of the capacity or the quality in the system. In CDMA based systems, due to non-orthogonality between the codes at the receiver, the different users will interfere with each other. This is called Multiple Access Interference (MAI) and its effect is a reduction of the capacity in the CDMA network. An interference reduction provided by smart antennas translates directly into a

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Paper Title: Performance Evaluation of Smart Antenna for Broadband Wireless Communication System
Authors: Nidhi Jain, R.P.Yadav

Dr. NIDHI JAIN
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Jaipur-302015

Dear Dr. Nidhi Jain,

It is our great pleasure to inform you that on the basis of the recommendation of Review Committee, your above mentioned paper has been accepted for Oral Presentation in IAW 2010, subject to pre-registration of the presenting author before **March 31, 2010**. Please convey the message of acceptance of your paper to all its co-authors.

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We look forward to seeing you at **Puri** in May 2010.

With warm regards,

Sincerely,

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Antenna Week Chair,
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Smart Antenna greatly influences the performance of broadband wireless communication Systems. Spatial Multiplexing technique in smart antenna increases the performance of broadband wireless systems. Smart antenna technology provides range extension, increased data rate, higher network capacity and better service quality. In this paper, we present a Broadband smart antenna which points its main beam towards desired direction of the array and suppresses interference and noise coming from other than look direction of the array. The DOA estimation algorithms can use the signal space derived by spectral spatial smoothing to estimate the DOA of the received signals and the DOA based beamforming algorithms generate the weighting vector to mitigate the multipath fading, increase the diversity gain, and suppress the co-channel interference of different devices. Finally simulation results show the suppression capabilities of the smart antenna. The future research and application on broadband smart antenna systems are briefly indicated.

1. Introduction

In today's mobile communication systems radio frequency spectrum is a limited resource. One of the major problems of future mobile communication system is the rapid increase in the demand for different broadband services and applications. To overcome this limitation considerable research is going on to use the given frequency bands as efficient as possible. The deployment of smart antennas is one way to increase spectrum efficiency in mobile communication systems. Two or more users can be served at the same frequency, time and code which directly lead to an increase in capacity.

Despite the advantages of wireless access, there remain a number of critical issues to be resolved before Broadband wireless system can successfully penetrate the market. The chief concerns are spectrum efficiency, network scalability, self-installable directional antennas, and reliable non-line of sight operation. Smart antennas (SA) offer a powerful tool to address these problems.

An Antenna is smart only when it can recognize and track the signal of a particular mobile telephone while suppressing interfering signals [2-4]. A smart antenna is a digital wireless communications antenna system that takes advantage of diversity effect at the source (transmitter), the destination (receiver), or both [1]. Diversity effect involves the transmission and/or reception of multiple radio frequency (RF) waves to increase data speed and reduce the error rate.

Due to the actual need for increasing channel capacity, the required bandwidth is becoming wider and wider, which brings significant deteriorates of the narrowband smart antenna systems because the inter-element phase shift becomes a function of frequency while the adaption weights are kept independent of frequency [5]. The narrowband smart antenna system is therefore not able to follow the frequency variation of the incident signals. In other words, the narrowband weighting scheme is impossible to handle broadband signals. To improve the performance, the adaptation should take into account the frequency dependence of inter-element phase shift. The processing behind each element must be able to provide a weight that varies with frequency.

In the following sections we will discuss configuration of smart antenna system in section II. Then direction of arrival and Broadband beamforming algorithm is explained in section III. The performance of these techniques is given by simulation in section IV. In the end, conclusion and future work are given in section V.

2. Configuration of Broadband Smart Antenna System:

A Smart antenna consists of an antenna array of N elements, a Radio unit, a beamforming network and a signal processing unit. The radio unit consists of N down converters corresponding to N array elements and an analog to digital conversion (ADC). The down converters take the RF signal received at the corresponding antenna elements and convert the signals to baseband, then send them to the ADC to digitize it before sending them further to the signal processing unit and beamforming network.

Broadband signals use a combination of spatial filtering with temporal filtering on each branch of the array. [6]. The desired angle and frequency characteristic of the array are the key design parameters of the beamformer. The undesired frequency characteristic of the antenna elements can be compensated by the beamformer. The configuration of it is given in Fig.1.

With regard to spatial filtering, the signals received by the individual antenna elements are multiplied by weights. For time processing, a tapped-delay-line (TDL) is used on each element of the array. The TDL allows each element to have a phase response that varies with frequency, compensating for the fact that lower frequency signal components have less phase shift for a given propagation distance, whereas higher frequency components have greater phase shift as they travel the same length [7-8].

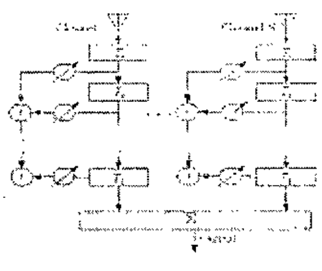

Fig.1 Space-time signal processor

3. Direction of arrival and Broadband beamforming Algorithm:

Spatial reference beamforming may not use of embedded training sequences. Instead, the DOA of the impinging waves are used to synthesize beams steered at the wanted signal with nulls directed to other co-channel users. The DOA estimation is a key element in our smart antenna processing scheme. The results of DOA estimation are then used by the array to design the adaptive beamformer, which is used to maximize the power radiated towards users [5]. As a result, we can infer that a successful design of an adaptive array depends highly on the performance of the DOA algorithm.

The core of the smart antenna is the selection of the smart algorithms. Using each algorithm we can adjust the weights of the antenna arrays to form certain amount of adaptive beams to track corresponding users automatically. An adaptive beamformer, consists of multiple antennas; complex weights, the function of which is to amplify (or attenuate) and delay the signals from each antenna element; and a summer to add all of the processed signals, in order to tune out the signals not of interest, while enhancing the signal of interest. Hence, beamforming is sometimes referred to as spatial filtering, since some incoming signals from certain spatial directions are filtered out, while others are amplified. The output response of the uniform linear array is given by:

$$Y(n) = w^H x(n)$$

where w is the complex weights vector and x is the received signal vector given in [9]. The complex weights vector W is obtained using a tapped delay line processing for an LMS array algorithm. The algorithm updates the weights at each iteration by estimating the gradient of the quadratic surface and then moving the weights in the negative direction of the gradient by a small amount. The constant that determines this amount is called step size. When this step size is small, process leads these estimated weights to the optimal weights.

Consider a four element adaptive array using the LMS algorithm to provide the adaptive weight adjustments. If W is the column vector of array weights, R_{xx} is the correlation matrix of input signals to each adaptive weight and r_{xd} is the cross-correlation vector between the received signal vector x(t) and the reference signal d(t).

$$W_{opt} = R_{xx}^{-1} r_{xd}$$

The optimum array weight vector that minimize $E\{\epsilon^2(t)\}$, where

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Consider the tapped delay line employing real weights and each signal $x_i(t)$ is just a time delayed version of $x_1(t)$, it follows that

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In this section, we present the results of the simulation. The simulation is based on MATLAB. Fig.2 shows the spectrum for 2 users with no. of elements in the sensor array is 4. Here peaks show the true direction of arrival signal.

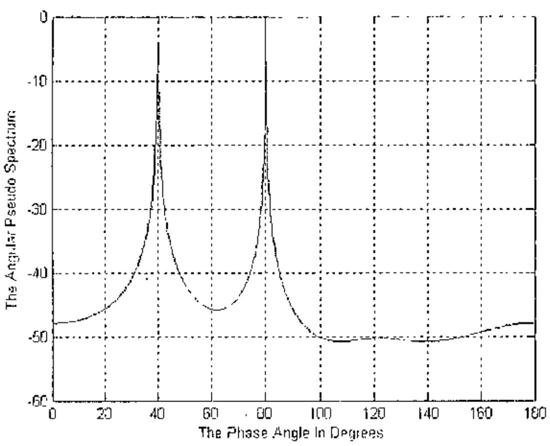

Fig.2. Spectrum for 2 users with number of elements is 4

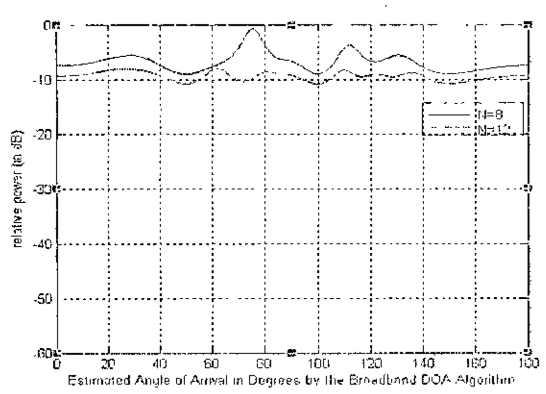

Fig.3. Spectrum for different values of number of elements

To analyze the performance of the DOA algorithm we compared in two cases. Fig 3 shows that when the number of elements in the sensor array is increased from N=8 to N=12, the performance of the system improves. This takes the form of sharper peaks and lower noise floor in the angular spectrum. Fig.4 shows that the performance of the smart antenna system improves also when the spacing between the elements in the sensor array changes from $d = 0.4\lambda$ to 0.5λ where λ is the wavelength of the carrier signal.

For the smart antenna structure three consecutive antennas are placed at a distance $\lambda/2$. It is also assumed that each antenna element contains zero thermal noise and they are uncorrelated with each other Fig.5 shows the radiation pattern of LMS beamformer algorithm. Here main beam steered to 40 degree and null steered to -30 degree/50 degree.

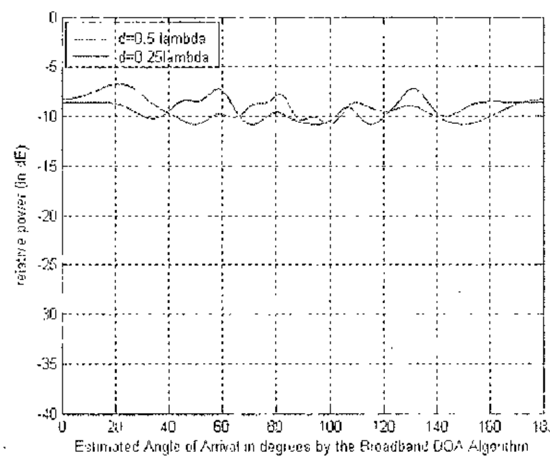

Fig 4 spectrum for different values of inter-element spacing

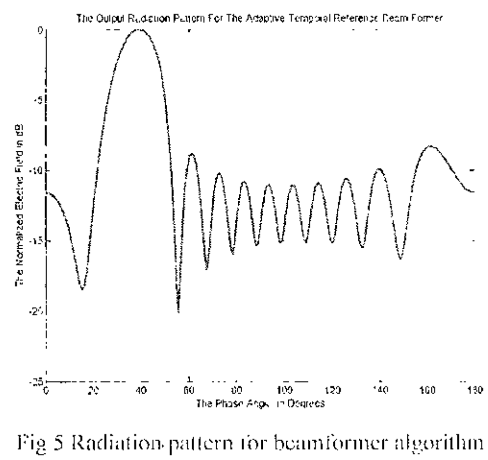

Fig 5 Radiation pattern for beamformer algorithm

The null is shown to provide an attenuation in exceed of 20 dB. Fig 6 shows the radiation response of the smart antenna for various SNR levels. As the SNR increases increase in the null depths are also noted. Shallow nulling is seen for lower level of SNR. Fig 7 shows that using a large value for the adaptive step size $\mu = 0.001$ yields better results when compared to a smaller step size $\mu = 0.0001$.

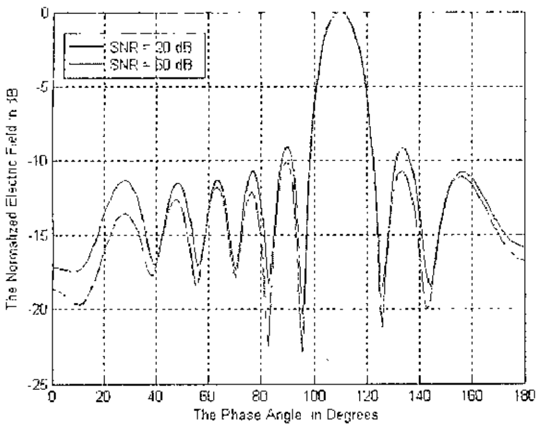

Fig 6 Radiation pattern for various SNR at 2.4 GHz

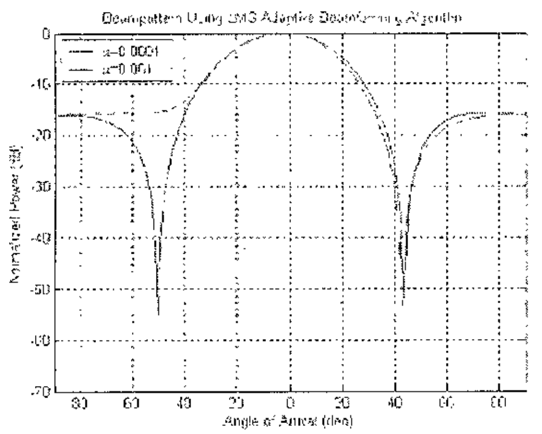

Fig 7 Array Beam pattern for different values of adaptive step size

6. Conclusions and Future work

The performance of an smart antenna for broadband applications was investigated. The beamforming properties and the behavior of the mean square error were investigated. The beamforming algorithm was then performed on the incoming signals with various SNR levels. Deep nulling of the interference had been observed for different frequency in the band [1.6 2.56] GHz for all SNR levels. It was also noted that as the SNR increased, the deeper the nulling would be. The mean square error of both the smart antenna was not the same for both cases. As expected the MSE decreased with increase the SNR of the channel.

However, we have to point out that a number of challenging problems remain unsolved. For example, little attention has been paid to the mutual coupling effect between the broadband smart antennas; it has a greatly negative effect on the broadband beamforming. Beamforming algorithms require a large number of computations which makes it difficult for them to keep up with the high data rates of today's wireless systems. Furthermore successful broadband wireless system need to be scalable, should have high spectrum efficiency, should offer high data rates and should be easy to deploy at the infrastructure and subscriber end. Smart antenna technology offers significant leverages to enable such features. The challenges are to develop and deliver a well designed broadband wireless system that captures the capabilities of SA technology without sacrificing robustness, simplicity and cost.

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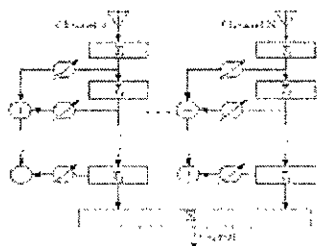

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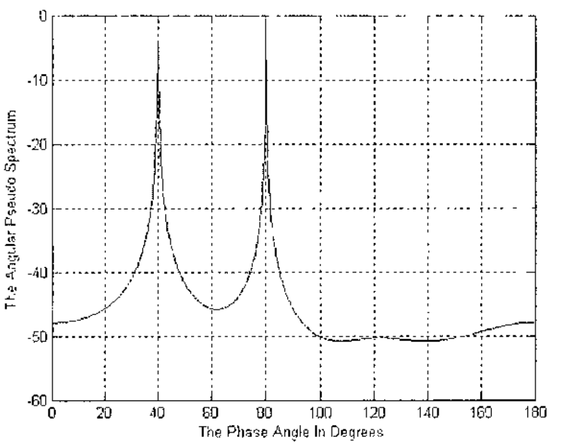

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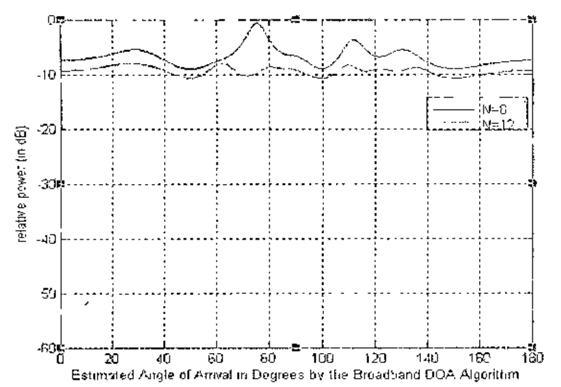

Fig.3. Spectrum for different values of number of elements

To analyze the performance of the DOA algorithm we compared in two cases. Fig 3 shows that when the number of elements in the sensor array is increased from N=8 to N=12, the performance of the system improves. This takes the form of sharper peaks and lower noise floor in the angular spectrum. Fig.4 shows that the performance of the smart antenna system improves also when the spacing between the elements in the sensor array changes from d = 0.4λ to 0.5 λ where λ is the wavelength of the carrier signal.

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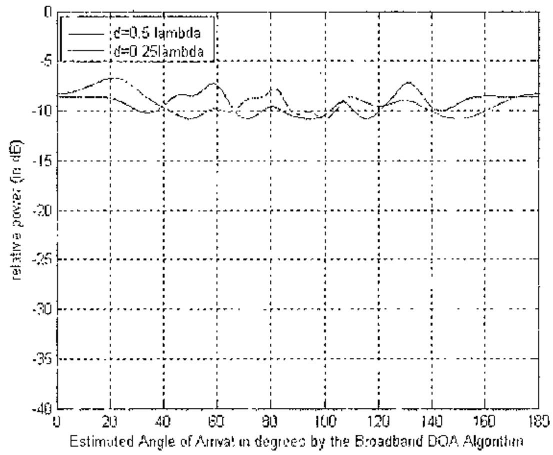

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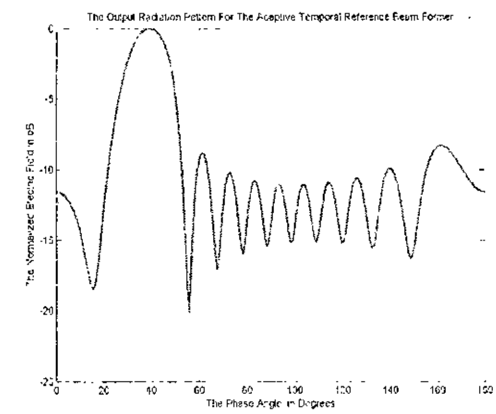

Fig 5 Radiation pattern for beamformer algorithm

The null is shown to provide an attenuation in exceed of 20 dB. Fig 6 shows the radiation response of the smart antenna for various SNR levels. As the SNR increases increase in the null depths are also noted. Shallow nulling is seen for lower level of SNR. Fig 7 shows that using a large value for the adaptive step size μ = 0.001 yields better results when compared to a smaller step size μ = 0.0001.

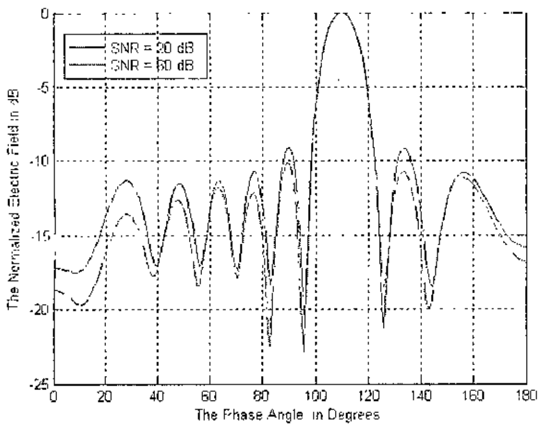

Fig 6 Radiation pattern for various SNR at 2.4 GHz

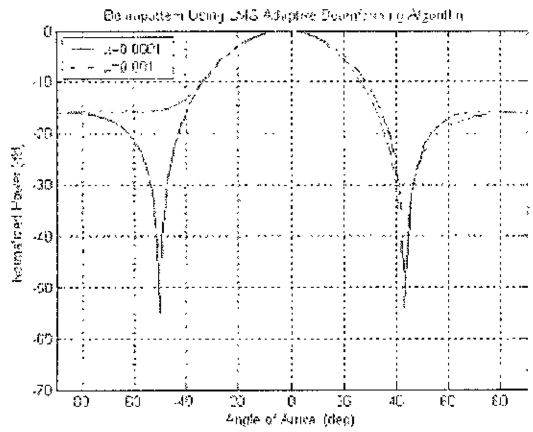

Fig 7 Array Beam pattern for different values of adaptive step size

6. Conclusions and Future work

The performance of an smart antenna for broadband applications was investigated. The beamforming properties and the behavior of the mean square error were investigated. The beamforming algorithm was then performed on the incoming signals with various SNR levels. Deep nulling of the interference had been observed for different frequency in the band [1.6 2.56] GHz for all SNR levels. It was also noted that as the SNR increased, the deeper the nulling would be. The mean square error of both the smart antenna was not the same for both cases. As expected the MSE decreased with increase the SNR of the channel.

However, we have to point out that a number of challenging problems remain unsolved. For example, little attention has been paid to the mutual coupling effect between the broadband smart antennas; it has a greatly negative effect on the broadband beamforming. Beamforming algorithms require a large number of computations which makes it difficult for them to keep up with the high data rates of today's wireless systems. Furthermore successful broadband wireless system need to be scalable, should have high spectrum efficiency, should offer high data rates and should be easy to deploy at the infrastructure and subscriber end. Smart antenna technology offers significant leverages to enable such features. The challenges are to develop and deliver a well designed broadband wireless system that captures the capabilities of SA technology without sacrificing robustness, simplicity and cost.

7. References

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