Effect of Wideband Signals on Smart Antenna

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Abstract

Over the last few years, wireless cellular communications has experienced rapid growth in the demand for provision of high data rate wireless multimedia services. For a fixed bandwidth of spectrum there is a fundamental limit on the number of radio channels that are realized by wireless communication systems. Anticipating such limits, considerable amount of work has to be done on the use of time, frequency, and coding techniques to increase the capacity. This motivates the need to find ways to improve the spectrum efficiency of wireless communication systems. Smart antennas have emerged as a promising technology to enhance the spectrum efficiency of present and future wireless communications systems by exploiting the spatial domain. The aim of this paper is to investigate smart antenna applications for Direct Sequence Code Division Multiple Access (DS-CDMA) systems and to study the effect of wideband signals on smart antenna.

Keywords—*DS CDMA, Adaptive antenna, smart antenna, SDMA, DOA.*

1. Introduction

CDMA is chosen as the platform since it has been adopted as the air-interface technology by the Third Generation (3G) wireless communication systems as CDMA system offers greater capacity improvement than time division multiple access (TDMA).The limitation of CDMA system is interference due to inter cell, intra cell and co channel interference as all subscribers uses same frequency. This limitation can be compensated using smart antenna. Following are the basic types of smart antenna.

1.1 Switched beam antennas

It has several selectable beams each beam covers certain part of cell area. This can be accomplished using feed network referred to as beam former & most commonly used beam former is Butler matrix. Butler matrix provides one orthogonal beam per antenna element. Thus switched beam antenna has pre-determined fixed beam pattern with greatest sensitivity located in the centre of the beam & less sensitivity elsewhere. The receiver selects the beam that provides greatest signal enhancement & interference reduction. The advantage of this system is that it is easy to implement but drawback is switched beam antenna systems are effective only in low to moderate co-channel interfering environments owing to their lack of ability to distinguish a desired user from an interferer, e.g. if a strong interfering signal is at the center of the selected beam and the desired user is away from the center of the selected beam, the interfering signal can be enhanced far more than the desired signal with poor quality of service to the intended user. The switched beam antenna has another drawback that is locking into the wrong beam due to multi path fading or interference.

1.2 Adaptive antennas

In an adaptive array, signals received by each antenna are weighted and combined using complex weights (magnitude and phase).Fully adaptive system use advanced signal processing algorithms to locate and track the desired and interfering signals to dynamically minimize interference and maximize intended signal reception. The main difference between switched beam and an adaptive array system is that the former uses beam steering (providing maximum gain in the direction of user)only, while the latter uses beam steering and nulling (providing minimum gain in the direction of interferer and providing maximum gain in direction of user). The main role of smart antennas is to mitigate Multiple Access Interference (MAI) by beamforming (i.e. spatial filtering) operation. Therefore, irrespective of a particular wireless communication system, it is important to consider whether a chosen array configuration will enable optimal performance. Adaptive antenna array systems have been played a central role in removing narrowband multiple-access interference (MAI) in wireless communications. However, for practical applications the channel bandwidth must be large therefore, the required bandwidth is becoming wider and can bring significant deteriorations of the narrowband adaptive systems. These performance degradations are mainly caused by the fact that the inter-element phase shift becomes a function of the frequency while the adaptation weights are kept independent of frequency. This paper specifically deals with the effects of wideband CDMA signals on the narrowband adaptive system.

The term antenna means it is a metallic device (as a rod or wire) for radiating or receiving radio waves. In the context of “adaptive antenna” the term “antenna” has an extended meaning. Along with a number of radiating elements, it consists of a combining/dividing network and a control unit.

The conceptual block diagram of a smart antenna system is shown in Figure 1. The system can be identified with following three main blocks: (i) array antenna (ii) complex weights and (iii) adaptive signal processor. The array antenna consists of number of identical antenna elements which are placed in linear or circular configuration. The individual antenna patterns are assumed to be identical. The complex weights multiply the signals received at the different antenna elements and then summed up. The complex weights are continuously adjusted by the adaptive signal processor which uses all available information such as pilot or training sequences or knowledge of the properties of the signal to calculate the weights, the effect of this is adaptive antenna not only does beamforming but also beam steering that is the main beam tracks the desired user and/or nulls are placed in the direction of interferers .Thus the complete system is referred as smart antenna.

1.3 SDMA (Spatial division multiple accesses)

SDMA is a MIMO (Multiple-Input and Multiple-Output, a multiple antenna schematic architecture)-based wireless communication network architecture. It is suitable for mobile ad-hoc networks, which enables access to a communication channel by identifying the user location and establishing a one-to-one mapping between the network bandwidth division and the identified spatial location.

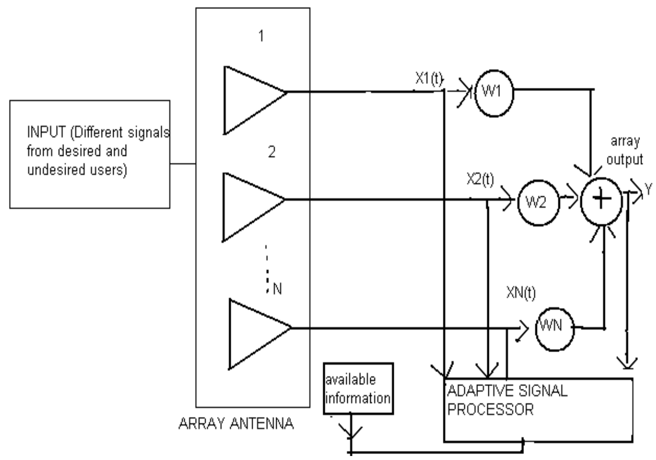

Fig 1: Block diagram of adaptive antenna

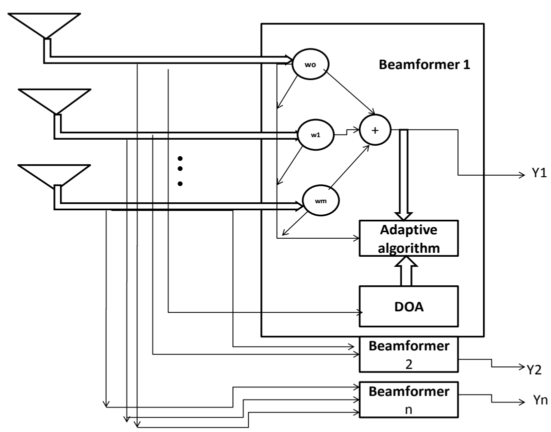

Fig. 2: Block diagram of SDMA system.

SDMA is the most sophisticated utilization of smart antenna technology. It creates different beam for each user. This means more than one user can be allocated to same physical communication channel in the same cell simultaneously with only an angle separation. This is accomplished as shown in fig. 2, it uses n parallel beam formers which operates independently at the base station, each beamformer has its own adaptive beamforming algorithm and own direction of arrival algorithm. The weights are controlled by algorithms while time delay of each users signal is determined by DOA ideally each beamformer creates a maximum towards each of its desired users while nulling other users (interferers).

2. Working of adaptive antenna

Users signal is received through antenna elements. The signal arrives at each antenna element at different time. Algorithms like least mean square (LMS), MUSIC (multiple signal classification) calculate direction of arrival at different time delays. Adaptive antenna system can tune out unwanted interference by placing nulls towards SNOI (signal not of interest).and concentrate on desired user by placing beam towards signal of interest (SOI).

The following example shows the exact working of smart antenna using LMS algorithm. [2]. LMS algorithm is used to estimate optimal weights of an array. The algorithm updates the weights at each iteration by estimating the gradient of the quadratic MSE (mean square error) surface, and then moving the weights in the negative direction of the gradient by a small amount. The constant that determines this amount is referred to as the step size. When this step size is small enough, the process leads these estimated weights to the optimal weights. The convergence and transient behavior of these weights along with their covariance characterize the LMS algorithm [14].

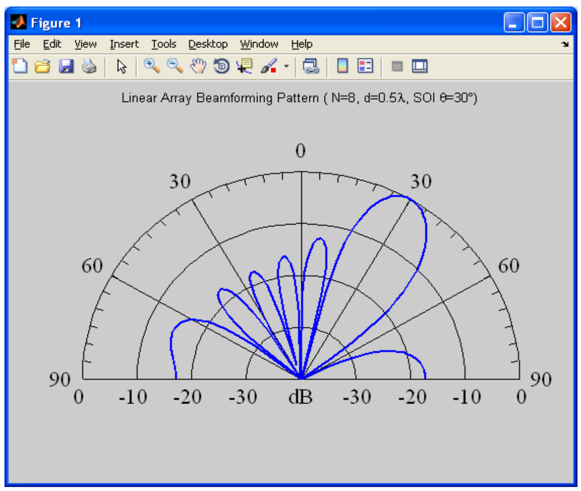

Fig.3 : Beamforming pattern

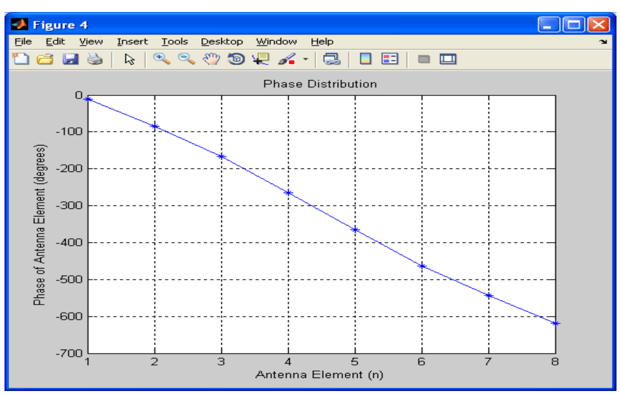

Fig 4 : Phase distribution

The system shown in above figure 3 works well for narrow band system; but for practical applications of mobile communication instead of narrow band system wideband spectrum is used. The wideband system is obtained by spreading the spectrum.

Table 1: Different parameters used in LMS algorithm

Parameter	Value
Array type	Linear
Spacing between elements	0.5λ
Number of elements in array	8
Pilot signal amplitude(signal of interest)	1
Pilot signal direction	30
Interference signal direction	60
Number of data samples	500
Value of step size μ	0.01

Spread spectrum[3] is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information: the band spread is accomplished by means of a code which is independent of the data, and synchronized reception with the code at the receive is used for de-spreading and subsequent data recovery. Spread Spectrum uses wide band, noise-like signals .As Spread Spectrum signals are noise-like, they are hard to detect. Spread Spectrum signals are also hard to Intercept or demodulate.

The spread spectrum technique has following advantages.

- Anti-jamming (A/J)
- Anti-interference (A/I)
- Low Probability of Intercept (LPI)
- Code Division Multiple Access (CDMA)
- Message Privacy

When smart antenna system is used for wideband system and when the signal bandwidth exceeds a certain central frequency percentage, the use of wideband FM signals results in a significant deterioration of the narrowband system performance. This is due to the fact that the inter-element phase shift is a function of frequency and its value varies across the bandwidth. This results in performance degradation as the null depth starts reducing as frequency increase this leads to multiple access interference (MAI)[3]

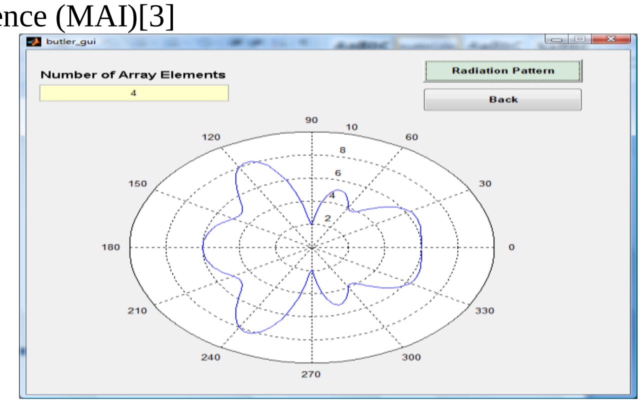

Fig.5 Radiation pattern for wideband system.

The above figure 5 shows if the smart antenna is used for wideband systems (500 MHz with carrier frequency 2 GHz) null depth reduces significantly which results in performance degradation. As the null depth is reduced it results in Multiple Access Interference (MAI) and side lobes can not be used significantly for other users' .Thus the performance of smart antenna to utilize spectrum efficiently is unsatisfactory for wideband signals.

To avoid this performance degradation frequency compensation method must be used.
Different frequency compensation methods [4].

- Spectral decomposition
- Focalization
- Interpolation

In spectral decomposition method signal received by each antenna element is converted to intermediate frequency and by using band pass filter signal is decomposed into non overlapping narrow bands.

In focusing technique the decomposed signals are rearranged such that for all frequencies direction matrix is constant for the common bandwidth of received signal. The method which is used in this paper is interpolation technique which is combined with constant modulus algorithm. Many communication signals have the constant modulus (CM) property: FM, PM, FSK, PSK If these are corrupted by noise/interference, the CM property is lost.CMA algorithm is a blind adaptation scheme i.e. it does not require training sequence instead one or more properties of transmitted signal are used for estimation.

2.1The interpolation technique

In this technique the array response can be kept unchanged by translating an array by a factor ***a*** and reducing the frequency by the same factor. The complete bandwidth of the incident wideband signal is divided into multiple narrow bands, and each narrow band is assumed to be received by a different array. For wideband direction finding applications it assumes that a constant matrix exists in such a way that

$$\mathbf{Ba(\theta) = a^{\wedge}(\theta)}$$

- ***a(θ)*** is the real array
- *a^(θ)* the virtual array and
- ***B*** the interpolation matrix

This can be calculated by performing a least square fit. For each frequency, a single interpolation matrix is computed. For wideband direction finding applications, the conventional **MUSIC (**multiple signal classification) algorithm or similar techniques can then be applied to the composite covariance matrix.

MUSIC algorithm: It is a simple direction of arrival method (DOA) the method estimates the noise subspace from available samples. This can be done either by eigenvalue decomposition of the estimated array correlation matrix or singular value decomposition of the data matrix with its N columns being the N array signal vector samples, also known as snapshots. Once the noise subspace has been estimated, a search for M directions is made by looking for steering vectors that are as orthogonal to the noise subspace as possible. This is normally accomplished by searching for peaks in the MUSIC spectrum For the adaptive algorithms, instead of calculating the composite covariance matrix, the outputs of virtual arrays are summed directly to provide the data to be weighted, following fig 6 shows MUSIC spectrum

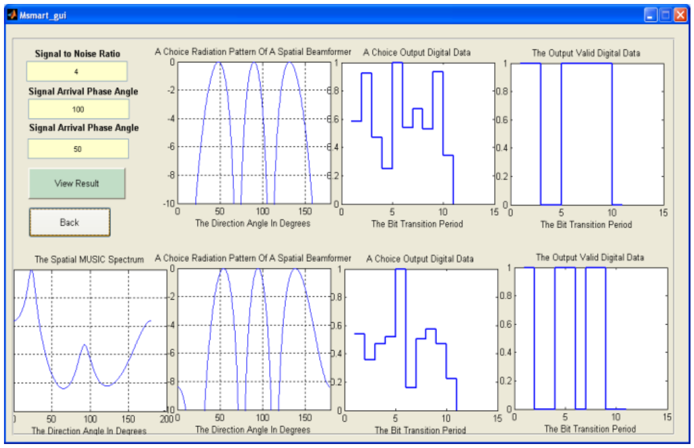

Fig. 6. MUSIC spectrum

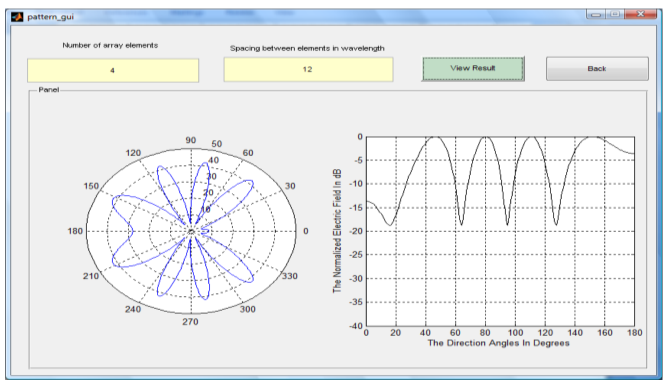

Fig. 7. Radiation pattern for interpolation technique

Fig.7. shows radiation pattern for smart antenna at wideband with the use of interpolation technique. As complete wideband signal is divided into various narrow bands and each band is received by each virtual array, the smart antenna performs well for wideband application. This fig shows that the reduction on null depth as compared to fig 5 is compensated. Increase in null depth reduces MAI significantly .The side lobes can be used for different users and available spectrum is used efficiently.

2.2.Advantages of adaptive antenna

Increased range/coverage: The area in which communication between mobile and base station is possible is called as coverage area. The range extension is best suited for rural areas where user density is low and it is desirable to cover as much area with a few base stations as possible. The adaptive antenna gain compared to single element antenna can be increased by an amount equal to number of array element.

Increased capacity: Omni directional antenna radiates equally in all direction while due to directional properties of adaptive antenna it radiates in the direction of desired user therefore interference to co-channel cells is also reduced .Because of this reason capacity is increased.
Security: It is more difficult to tap a connation, since the intruder has to be position himself in the same direction of arrival as the user.
Reduction of handoff: There is no need for splitting the cells for the sake of capacity increase, and in consequence less amount of handoff.
Reduction in transmitted power: In case of omnidirectional antenna large amount of power is wasted as it radiates in all directions while this wastage is much less in case of adaptive antenna as power is radiated in required direction only. This reduction in transmitted power reduces interference towards other users; also there is low handset power consumption.

3. Applications of smart antenna

- Dual band options for the 2.40 to 2.49 GHz and 4.9 to 5.9 GHz frequency for Wi-Fi.
- Mobile communication: smart antenna is being inserted into 2.5 generation (GSM-EDGE) and third generation (IMT 2000) mobile According to "WARC-92 frequencies for IMT-2000" resolution: "The bands 1885-2025 MHz and 2110-2200 MHz are intended for use, on a worldwide basis, by administrations wishing to implement International Mobile IMT-2000). Enhanced Data rates for GSM Evolution (EDGE Telecommunications-2000 ,DECT system in 1.88_1.90GHz)
- Interference suppression
- Direction finding
- MIMO
- Satellite communication(26.5 -40 GHz ka band)
- Military RADAR application 2 - 3 GHz (s band)
- GPS(1575.42 MHz , 1227.60 MHz)

4. Conclusions

The use of adaptive antennas helps to use the available frequency spectrum efficiently by reducing the interference. It is shown that as the spreading factor increases the interference rejection cannot be successfully achieved with the existing narrowband system. It is expected that the requirement imposed on the wideband CDMA systems in terms of capacity will necessitate advanced signal processing solution for wideband interference suppression. The use of adaptive arrays to reject wideband interferences and track wideband signals have been proven to be more performant if frequency compensation is used. Simulation results have shown that the techniques permit to improve system performances by readjusting the main lobe’s direction toward the signal’s DOA and increasing the interference null depth. Although these results may not be optimal, they, however, present a significant improvement in performance over the uncompensated system. However the performance of adaptive antenna degrades if wideband spectrum is used. The frequency compensation method must be used to avoid this performance degradation.

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