Improvement of performance in cellular communications systems with the use of adaptive arrays

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Abstract – Smart antennas is a system consisting of antenna array and adaptive processor that can adjust the main lobe of the radiation diagram. The direction of main beam maximum and the beam width are determined by a pilot signal. The system can reject or attenuate interference signals or noises occurring outside the main lobe. This performance is obtained if the output signals of the elements of antenna array are properly combined to reduce the interference according to specified directions.

Keywords – Adaptive arrays, BER, Switched beam, Interference.

I. INTRODUCTION

The object of this paper is to present a part of the technology of smart antennas, used to improve the performance of radio communication systems. The assignment of smart antennas is an array of radiating elements, each one excited by a signal with amplitude and phase adjusted to control the format and the direction of main lobe and nulls of the radiation diagram.[1] With the control of the radiation diagram, smart antennas can reduce the effect of the interferences, to increase the amplitude of the desired signals and to guarantee increase in the reliability of some types of radio link. The improvement in quality is obtained by increasing the signal-to-noise ratio, reducing the adjacent channel interference or the interference of same channel used in different cells of a cellular telephony system, named as co-channels interference. It allows the reduction or even the suppression of interferences originated by multipath propagation. By reaching the control of the main beam maximum it can be used only the necessary power in each cell, leading to an energy save in the general equipment consumption .[2]-[4]

II. SMART ANTENNAS FEATURES

In radio communications systems, there are factors related to the transmission channel that produce degradation of the signal. There are alterations in the amplitude and form of the modulation signal, mainly in modern systems transmitting digital signals. A purpose of smart antennas systems is to supply resources to correct some bad effects in propagation. Among these difficulties, the co-channel and multipath interferences are critical problems that can damage the reliability of the radio link. [7][8] The co-channel interference appears in systems that use cellular architecture, because the same channels are simultaneously used in different cells and with the lesser possible distance to guarantee the quality of communication. Therefore, the base station that receives a signal from a mobile equipment in its cell also receives undesirable signals from other cells that use the same carrier frequency. There is a commitment between the degradation imposed for the co-channel interference and the reuse of frequencies.[7]

The management of the co-channel interference is an important factor in magnifying systems capacity. To mitigate this effect, smart antennas systems both appoint the radiation diagram maximum to the desired users and, in many situations, also guide null points of the radiation to undesirable users. The smart antennas systems often are presented in the form of structures with switched beam or adaptive arrays[1]. Systems of antennas with switched beam form multiples fixed main lobes, with adequate sensitivity to specified directions. The second type allows a dynamic control of the diagram format to fulfill the requirements of link. The performance of this model will be object of this presentation.

III. ADAPTIVE ARRAY

The advantages of a system of adaptive arrays are increase the gain of the desired signal, the orientation capacity of nulls in the undesirable signals directions, the reduction of the multipath effect and greater exploitation of the electromagnetic spectrum.[1][2] The fulfillment of all these factors guarantees a much better system performance. To radiate the resulting signal in the desirable user direction, it is necessary to adjust the amplitudes and the phases of the elements excitation sources, called sources weights. In traditional antennas arrays, the source control of the radiating elements permit the fields interact in space and construct the resulting diagram format.[5][6] The direction of the main lobe will depend on the relations among sources phases and amplitudes, to satisfy the link necessity. By modifying the element signal amplitude, it is possible to control the radiated power and the communication link length. Fig. 1 shows a system in which the antennas array is formed by L isotropic radiators. Although this type of antenna is not a realizable one, is possible to get the diagram of other structures from an array of isotropic antennas by means of the multiplication diagram principle.[5] To be possible the demanded communication, is necessary to locate the main lobe of the receiving system in direction to desired signal and the diagram nulls must be guided in the directions of the interferences.

As shown in Fig. 1, the complex weights (w_L) make the control on the array radiation diagram.[15] The signals that arrive on the elements, $x(t)$, depend on the angular position of the emitting source and include the noise of the system. For a specified element of array, the received signal can be described as

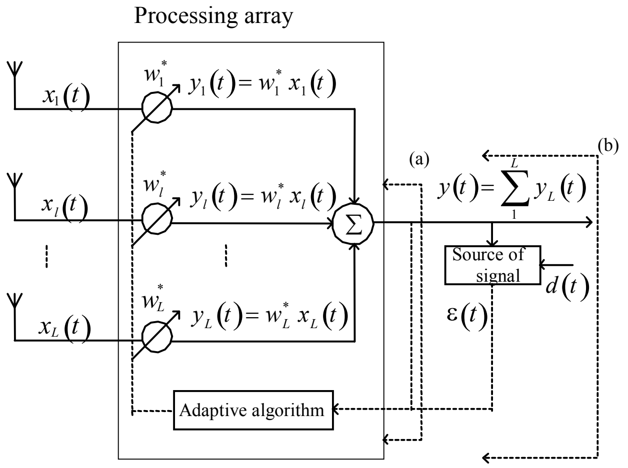

FIGURE 1.
STRUCTURE OF A BEAMFORMER WITH ADJUSTMENTS OF WEIGHTS .

$$x_l(t)=\sum_{\lambda=1}^{L} m_i(t)exp\{i2\pi f_o[t+\tau_\lambda(\phi_i,\theta_i)]\}+n_\lambda(t) \qquad (1)$$

where $m_i(t)$ represents a complex envelope, a function of the modulation, depending on communication system type and on access technique, such as the time division multiple access (TDMA), the code division multiple access (CDMA), the frequency division multiple access (FDMA).[14]

The term $n_\lambda(t)$ represents the noise on λ^{th} element of the array. In general, it involves random processes and it is compound by the environment noises and those ones generated in the electronic components of the transmission and reception equipments. It includes the residual noise in the antenna elements in absence of transmitted or received signal. The term $n(t)$ is close to the white noise, with power determined by the system bandwidth and variance.

The wave front delay in one elements of the array, $\tau_\lambda(\phi_i,\theta_i)$, is calculated by

$$\tau_\lambda(\phi_i,\theta_i)=\frac{d}{c}(\lambda-1)\cos(\phi_i,\theta_i) \qquad (2)$$

where index i indicates the angular position of i^{th} source of signal in the medium, c is the speed of the electromagnetic wave (3×10^8m/s) and λ is the order of the element of the array. [13] The distance between elements of array (d) is specified in function of the wavelength, usually $d\le\lambda/2$ as form to prevent the increase secondary lobes in the resulting array diagram.

In an environment as the described one, it must be guaranteed that the desired signal is always received and the interferences are reduced to minimum value. For obtaining this performance it is necessary to minimize the average power at output of the beamformer system. This is possible if the weights will satisfy the condition that its products with the position vector of the sources result in a unitary value. As the signals in basic band are represented by complex values, it must be used the conjugated values of the weights to attend this demand.[16] The output of the beamformer system of Fig. 1 are written in the form

$$y(t)=\sum_{l=1}^{L} y_l(t)=\sum_{l=1}^{L} w_l\, x_l(t) \qquad (3)$$

Using the matrix notation, (1), (2) and (3) can be write as

$$\mathbf{x}(\mathbf{t})=\begin{bmatrix} x_1(t) \\ x_2(t) \\ \vdots \\ x_L(t) \end{bmatrix} \qquad (4)$$

$$\mathbf{w}=\begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_L \end{bmatrix} \qquad (5)$$

$$y(t)=\mathbf{w}^H\mathbf{x}(\mathbf{t}) \qquad (6)$$

in which H indicate the transposed of the conjugated complex of the array elements weights. The vectors **x**(t) and **w** indicate the signals arriving at the array and the elements weights. The direction vector of desired signal is represented as : [12]

$$\mathbf{a}(\theta_i,\phi_i)=\mathbf{a}_i=\begin{bmatrix} 1 \\ e^{-j\Delta\psi_2(\theta_i,\phi_i)} \\ \vdots \\ e^{-j\Delta\psi_L(\theta_i,\phi_i)} \end{bmatrix} \qquad (7)$$

where $\Delta\psi_i(\theta_i,\phi_i)$ is the phase displacement given by

$$\Delta\psi_i(\theta_i,\phi_i)=2\pi f_o\,\tau_{\lambda\,i} \qquad (8)$$

The resultant radiation diagram is found by

$$f(\theta,\phi)=\sum_{\lambda=1}^{L} w_\lambda e^{-j\Delta\psi_\lambda(\theta,\phi)} \qquad (9)$$

where $f(\theta,\phi)$ it is the array factor, that is, the radiation diagram of an isotropic antennas array. [2][5][6]

IV. ADAPTIVE BEAMFORMER ALGORITHMS

The adaptive algorithms provide a way to optimize the values of the weights to directed the main lobe for the desired signal source. They must adjust the weight values as a function of the position change of desired signal.[12] There are many types of algorithms used in adaptive process. The sampling matrix inversion algorithm (SMI) estimates the weight values as a function of the number of samples of the received signal. The least means square algorithm (LMS) uses a reference signal, or a training sequence, to recognize the signal, determines the error and to achieve the weights adjustments [14]. The scheme of the LMS algorithm is in Fig. 1 with start analysis from the (b) part, where d(t) is the signal reference and ε(t) the error value. The module constant algorithm (CMA) uses a blind adaptation and does not need the reference signal to achieve weight adjustments. They are used in communication systems that have constant envelope signals [1] and its design is shown in Fig. 1, with comments made from the (a) part.

V. COMPUTER SIMULATIONS

In a situation where it is desired the cancellation of interference signal, a computer simulation with the use of the Matlab® program was made. Three sources electromagnetic environment, with two interferences and one desired signal was assumed. The beamformer with four radiating elements was used, as in Fig. 2. The radiation diagram was formed with the null aiming for the positions $\phi_2 = 80^\circ$ and $\phi_3 = 130^\circ$, the undesirable signals. The main lobe appoints its maximum to $\phi_1 = 50^\circ$. The results had been obtained through the program presented in the appendix, elaborated from the equations that define the desired signal direction Fig. 3 shows the radiation diagram in polar coordinates system, normalized with respect to the maximum value. The main lobe was slightly displaced of desired direction , but its null angles are according to directions of undesirable signal sources. The vector weight of the beamformer showed in Fig. 2 is determined through the equations

$$\mathbf{w}^H = \mathbf{e}^T \mathbf{A}^{-1} \tag{10}$$

$$\mathbf{w}^H = \mathbf{e}^T \mathbf{A}^H \left(\mathbf{A}\,\mathbf{A}^H\right)^{-1} \tag{11}$$

$$\mathbf{e} = [1 \quad 0 \quad 0 \ldots 0_i]^T \tag{12}$$

$$\mathbf{A} = [\mathbf{a}_0 \;\; \mathbf{a}_1 \;\; \ldots \;\; \mathbf{a}_i] \tag{13}$$

where **e** represents the positions of maximum and nulls. The **A** matrix is formed by the direction vectors of the desired and interference signals. [14]

VI. INCREASING SYSTEM CAPACITY

The capacity increase of the system through adaptive antennas can be proven by Shannon's expression. Then, for a channel with bandwidth B and additive white Gaussian noise (AWGN), the capacity is

$$C = B \cdot log_2(1+SNR) \tag{14}$$

where C represents the transmission rate in bits/s and SNR is the signal-to-noise ratio.

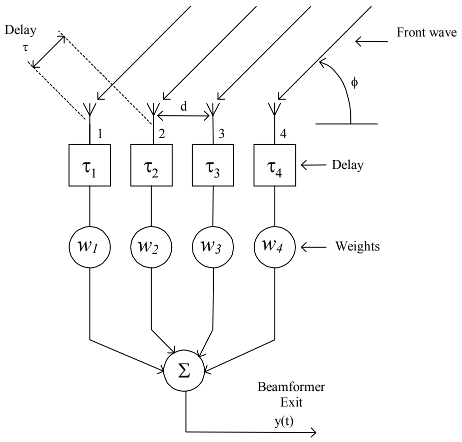

FIGURE 2.
THE BEAMFORMER STRUCTURE WITH NULLS IN DIRECTION OF INTERFERENCE SIGNALS AND THE MAIN LOBE FOR THE DESIRED SIGNAL.

Radiation diagram

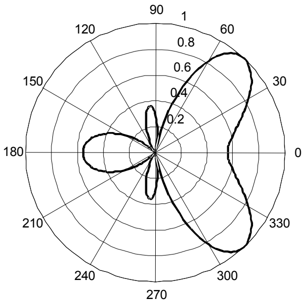

FIGURE 3.
RADIATION DIAGRAM OBTAINED WITH STRUCTURE OF FIG. 2.

In a antennas array with L elements, the total power of arrival signal is divided in L equal parts and deliver for all channels.[9] Then, the capacity of each channel is

$$C_{ant} = B\,log_2\left(1 + (SNR/L)\right) \tag{15}$$

and the maximum transmission rate will be the sum of all terms:

$$C = L\,B\,log_2\left(1 + (SNR/L)\right) \tag{16}$$

Fig. 4 shows the spectrum efficiency, express in bits/s/Hz, as a function of the signal/noise ratio and the number of elements of the array.

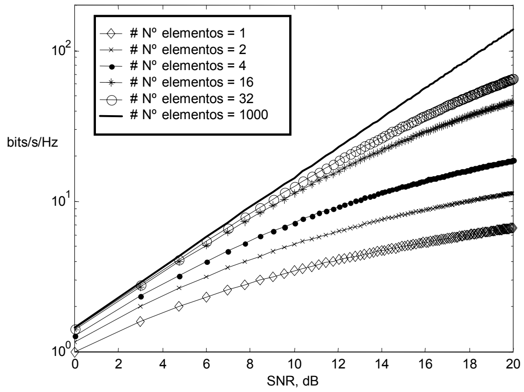

FIGURE 4.
SPECTRUM EFFICIENCY LIMITS AS A FUNCTION OF THE SNR AND THE NUMBER OF RADIATORS ELEMENTS.

VII. CONCLUSIONS

The development of smart antennas has been a very important technology because this system is a possible solution to improve the performance of radio communications link. One of the main applications is in mobile systems in order to provide ways for the solution of problems related to the channel bandwidth, the number of available channels and to cancel interference signals caused for multipath and other sources.

Simulations made in computer prove that with the use of this technology it allows an increase up to 300% in capacity of systems that use the TDMA access technique and up to 500% for CDMA systems.[1] The smart antennas are not restricted to the modulation type or protocol used. It is compatible with all the wireless communication systems. Some companies had carried through exhausting tests in radio-base stations and obtained satisfactory results for several communication systems. [10]-[11]

APENNDIX

Matlab® program for calculation of radiation diagram for an adaptive array.

```
clear all
phi1 = pi*50/180;
phi2 = pi*80/180;
phi3 = pi*130/180;
a1 =[ 1 exp(-i*pi*cos(phi1)) exp(-i*2*pi*cos(phi1)) exp(-
i*3*pi*cos(phi1)) ].';
a2 =[ 1 exp(-i*pi*cos(phi2)) exp(-i*2*pi*cos(phi2)) exp(-
i*3*pi*cos(phi2)) ].' ;
a3 =[ 1 exp(-i*pi*cos(phi3)) exp(-i*2*pi*cos(phi3)) exp(-
i*3*pi*cos(phi3)) ].';
a = [a1 a2 a3];
e = [1 0 0 ].';
y=(a)*(a')
s = pinv(y)
t = (e.')*(a')
w = t*s
W = w';
phi = linspace(0+eps,2*pi+eps,300);
fat = W(1,1)+(( W(2,1))*exp(i*pi.*cos(phi)))+((W(3,1)
)*exp(i*2*pi.*cos(phi)))+((W(4,1))*exp(i*3*pi.*cos(phi)));
fatnorm = fat./max(fat);
figure (1)
polar(phi,abs(fatnorm))
figure (2)
plot(phi*180/pi,abs(fatnorm))
grid
```

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