Buletinul Ştiinţific al Universităţii "Politehnica" din Timişoara

Seria ELECTRONICĂ şi TELECOMUNICAŢII
TRANSACTIONS on ELECTRONICS and COMMUNICATIONS

Tom 53(67), Fascicola 2, 2008

Directivity Pattern for Linear Arrays

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Abstract – Wireless communications have seen a substantial improvement thru the development of some techniques which were proposed in order to obtain a growth of the data transfer rate, yet not implying a high consume of energy or a larger bandwidth.
In this article we will analyze the influence which parameters of an array have upon the directivity obtained in this case. The performance evaluation is based upon computer simulation of the directivity pattern. We will consider as reference the linear array.
Keywords: MIMO, linear arrays.

I. INTRODUCTION

Wireless communications are at the present moment one of the most evolved techniques for long distance data transmission. A wireless network enables the interconnection of more users which may find themselves in the same building, a group of nearby buildings or even at a larger distance. By using electromagnetic waves, the wireless devices transmit and receive data through the air interface, thus eliminating the necessity of cables and transforming the network into a mobile one.[1]

This technology permits the exchange of data between users without a cable connection. This leads to a high mobility of the users as well as the possibility of multiple connections.

The access techniques for a wireless network targeted a growth in the number of users and the insurance of an increasingly high speed transfer rate. Thus the multiple access technique with frequency division (FDMA) gives way to the division of the total frequency domain - assigned to the wireless network - in several sub domains or channels which are sufficiently distanced in frequency. As a result, the signals coming from different users will not interfere and each user will transmit on its own frequency channel.

Another access technique is the time division multiple access (TDMA), implying that each user will have access to the communication channel only a limited period of time. In order to improve the capacity of a wireless network, the code division multiple access technique was developed. Within this technique, each user receives a code which will enable his transmission.

Due to the signal propagation on the air interface, the wireless networks are mainly defined by two phenomena: signal fading and signal interference.

Signal fading arises due to the fact that a transmitted signal can propagate itself on multiple channels. Signal interference, on the other hand, appears due to multiple users within the same signal area. In order to reduce this phenomenon, several solutions have been developed, all of them having as guideline the transmission of a signal with a level adequate for a particular user, and a lower level signal for the other users (null if possible). Such a solution may be achieved with the help of arrays.

In this article we will analyze the influence of the array parameters on the directivity pattern obtained in this case. The performance assessment is based on computer simulation of the directivity pattern. We will consider as reference the linear array.

II. LINEAR ARRAYS

Wireless communications have seen a substantial improvement thru the development of some techniques which were proposed in order to obtain a growth of the data transfer rate, yet not implying a high consume of energy or a larger bandwidth. One of these techniques consists in using the multiple antennas for creating for creating a Multiple Input Multiple Output (MIMO) system. Multiple antennas utilized on the transmitting as well as at the receiving end, enable the obtaining of a MIMO system, which has as characteristic an increased spectral efficiency as opposed to that of the classic, one antenna systems.

Radio channels are a very efficient transmission environment; nevertheless these are affected by the fading signals of the receiver antenna due to the multiple transmissions as well as the interference signal caused by the signals of other users. One potential solution to this phenomenon, which affects the radio transmission, is to use a diversity receiver capable to process (ideally, in an independent manner) several replica of the transmitted signal.

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A point to point, narrowband, transmission system which has M_t transmission antennas and M_r receiver antennas is presented in Fig.1. [2]

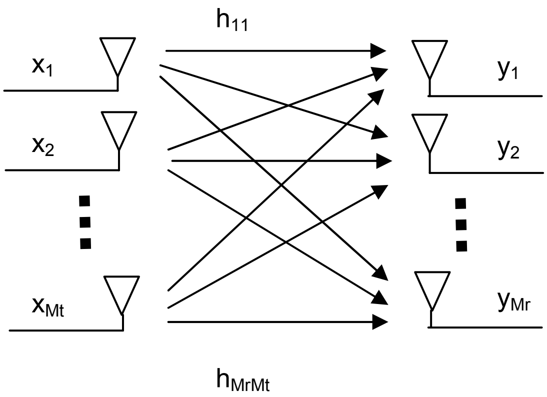


Fig.1. MIMO system

This system can be described in the discrete temporal domain with the following function:

$$y = H * x + n \qquad (1)$$

where y is the received symbols vector at the M_r receiver antennas side, $y = \left[y_1, y_2, \ldots, y_{M_r}\right]^T$, H is the channel matrix

$$H = \begin{pmatrix} h_{11} & \cdots & h_{M_t} \\ \vdots & \ddots & \vdots \\ h_{M_r1} & \cdots & h_{M_rM_t} \end{pmatrix}$$

and h_{ij} is the gain from the transmission antenna *j* to the receiver antenna *i*; x represents the transmitted symbols vector by the M_t transmission antennas, $x = \left[x_1, x_2, \ldots, x_{M_t}\right]^T$, whereas n represents the noise vector, $n = \left[n_1, n_2, \ldots, n_{M_r}\right]^T$. Each transmitted signal will broadcast along the wireless channel and will reach the M_r receivers; therefore each output end of the channel will represent a linear superposition of the input ends, reduced and affected by noise. From (1) we can observe that a replica of the transmitted signal by each antenna is added to the received signal at each antenna. Although the versions of the transmitted signals are combined at the level of each receiver antenna, there is a diversity gain due to the existence of M_r, replicas of the transmitted signal.
The signals that are fed to the various elements of the array are processed in order to obtain one single signal at the output end of the array(Fig.2.). This signal combining process at the output of the various elements is called beamforming. [2]

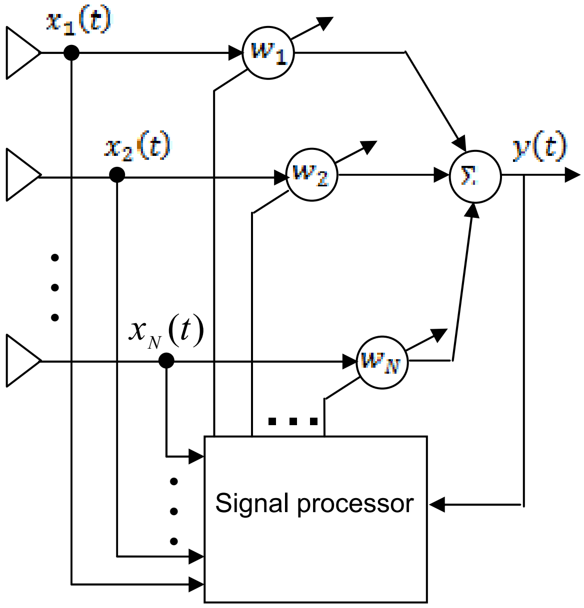


Fig.2. Adaptive arrays

The array is used to spatially identify each user. According to location of the users in the signal coverage area of the array the so called directivity characteristic can be identified. The structure of the signal processor depends upon the available information quantum or which can be predictable at the base station. This information includes the modulation and signal type, the number of channels thru which the reception can be made, arrival direction and delay of the signals arriving on the multiple channels, and the complexity of the environment through which the transmission is made.

The basic structure of a beamformer consists in a linear array, with equally distanced elements. Each transmitted signal will be multiplied by a set of complex weightings, their number equaling those of the antennas (elements) in that particular array. In a transmission such as this, the signals transmitted by different elements in the array, which each distinguish themselves by phase, due to the distance between these antennas (elements), as well as amplitude, due to the different weightings multiplied by the transmitted signals of the array.

In case of an array with N elements, at the input of each sensor there will be a delayed replica of the transmitted signal.

A linear array is shown in Fig.3.[4]

The N elements are positioned on the z axis distanced equally, d. We consider this array to be positioned in the center of the Cartesian system.

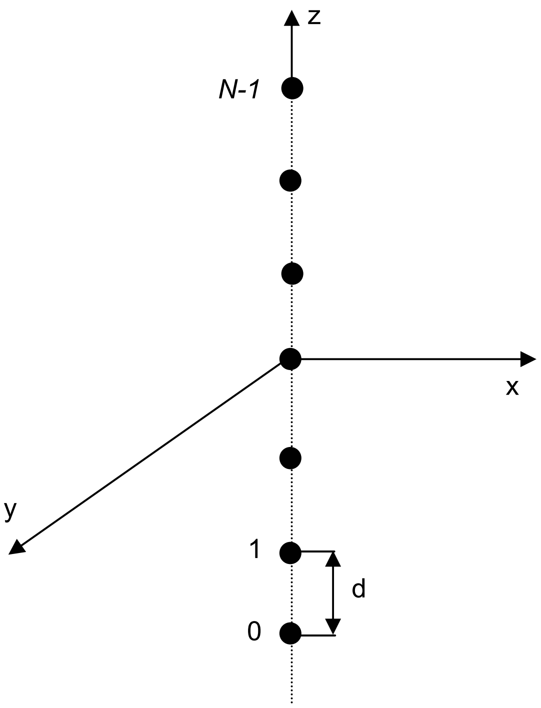


Fig.3. Linear array

The uniform weightings are:

$$w_n = \frac{1}{N}, \quad n = 0,1,\ldots,N-1 \qquad (2)$$

The position of the elements will be:

$$p_{z_m} = \left(m - \frac{N-1}{2}\right) * d, m = 0,1,\ldots,N-1 \qquad (3)$$

Defining

$$v_k(k_z) = \begin{bmatrix} e^{-jk_z p_0} \\ e^{-jk_z p_1} \\ \vdots \\ e^{-jk_z p_{N-1}} \end{bmatrix} \qquad (4)$$

as a vector which highlights all the spatial characteristics of the linear array, we can define the radiation pattern of an array considering the propagation of the plane-wave in a homogeneous environment :

$$B_k(k_z) = w^H v_k(k_z) \qquad (5)$$

in which $k_z = -\frac{2\pi}{\lambda}\cos\theta$ is the wave number, and $w^H = [w_0^* \ w_1^* \ldots w_{N-1}^*]$ is the weighting vector. Upon replacing (3) and (4) in the (5) we will obtain the radiation pattern for a linear array:

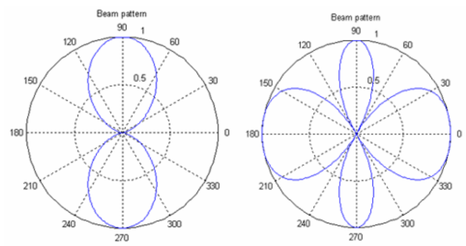
$$B_\theta(\theta) = e^{-j(\frac{N-1}{2})\frac{2\pi d}{\lambda}\cos\theta} \sum_{n=0}^{N-1} w_n^* e^{jn\frac{2\pi d}{\lambda}\cos\theta}, \quad 0 \le \theta \le \pi \qquad (6)$$

For a linear array the radiation pattern can be described as follows:

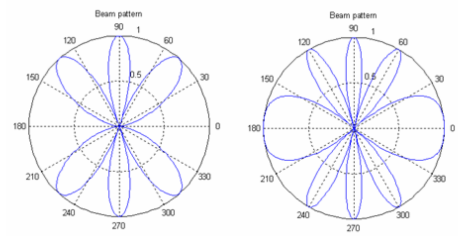
$$B_\theta(\theta) = \frac{1}{N} \frac{\sin(\frac{N}{2} * \frac{2\pi}{\lambda} * d * \cos\theta)}{\sin(\frac{1}{2} * \frac{2\pi}{\lambda} * d * \cos\theta)}, 0 \le \theta \le \pi \qquad (7)$$

III. SIMULATION RESULTS AND DISCUSIONSS

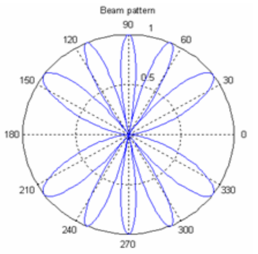
The directivity pattern for a linear array, similar with the one presented in Fig.3, can be influenced by the number of elements and the distance between these elements. There was a program made for an array as such, which permits the modification of these two parameters. In Fig.4 the radiation pattern for a linear array consisting of two elements, placed at a distance of $\frac{\lambda}{2}$ (a), λ (b), $\frac{3\lambda}{2}$ (c), 2λ (d), $\frac{5\lambda}{2}$ (e) from one another.



a) b)



c) d)

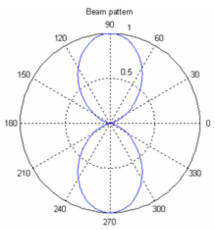


e)

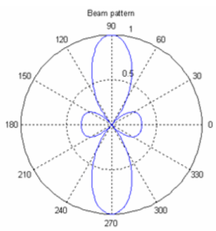
Fig. 4. The influence of the distance between elements upon the directivity pattern.

We can observe that by modifying the distance between these elements, secondary sidelobes appear at the same intensity as the primary lobes. Also, by modifying the distance between the elements by $\frac{\lambda}{2}$, the direction of the radiation shifts with $\frac{\pi}{2}$. The number of the secondary sidelobes increases with the growth of the distance between the elements.

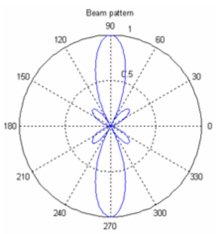
The influence of the element number upon the directivity pattern is presented in Fig.5.



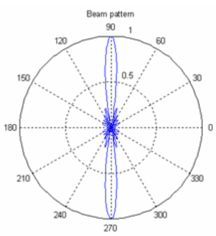
a) N=2, d=0,5λ



b) N=3, d=0,5λ



c) N=4, d=0,5λ



d) N=10, d=0,5λ

Fig.5. The influence of the element number upon the directivity pattern.

By increasing the number of elements of a linear array we can observe the appearance of secondary lobes, having their amplitude decreasing in intensity. With using more elements, the width of the primary lobes decreases, which leads to a more targeted linear array.

IV. CONCLUSIONS

Object of the present study was the influence of the parameters of a linear array over the directivity pattern. Therefore, by using a larger number of elements, we can obtain a more precise directivity pattern. Arrays represent a very efficient method to improve the performances of mobile communication systems, attenuating the interferences and directing the primary lobe in the direction of the mobile station. This leads to the growth of the system capacity and also the coverage area of one cell.

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