Analysis of Efficiency for Space-Time Processing of Signals from Subscriber Stations in Implementation of Space-Time Division Multiple Access

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***Abstract* — It is shown that implementation of the method of space-time division multiple access with the individual space-time processing of subscriber stations signals which is reduced to the use of group elements of adaptive antenna array and the establishment of parallel procedures of assessing values of vector of weighting coefficients on the number of simultaneously working stations.**

Keywords—space-time division multiple access, space-time processing, beamforming, multi-beam antenna, vector of weighting coefficients

I. INTRODUCTION

The simplest and clearest method of organizing the implementation of space-time division multiple access (SDMA) may be the use of multi-beam antenna on the base station which forms the beams. Within each of the beams it is available to send signals from subscriber stations (SS), which are localized in a dedicated space (Figure 1). This scheme may be implemented using a circular antenna array (CAA), and corresponding forming directivity pattern scheme, for example, the Butler matrix.

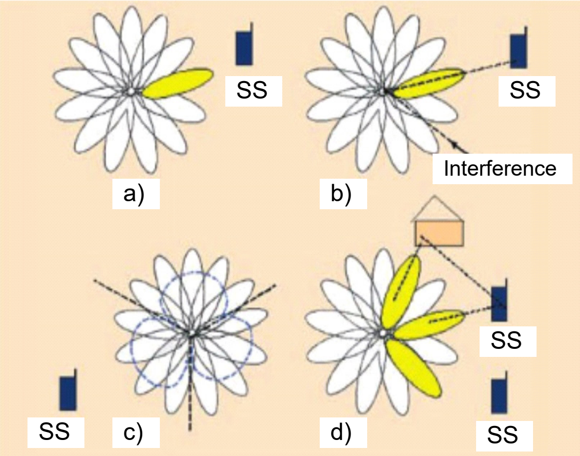

Fig. 1. Options of organization of multi-beam antenna

This scheme is relatively simple, and the adjacent beams (beamforming CAA) are well isolated from each other.

The multi-beam antenna (MBA) works well in an environment when azimuths are known on the corresponding stations, and the reception of their signals is carried out within the main selected lobe maximum of beamforming pattern.

Application of this scheme with MBA fixed lobes for mobile communications of cellular system is not constructive because azimuth of SS can constantly change and there will be a loss of communication in the case where the direction of arrival of the signal SS goes beyond maximum of the given beamforming pattern lobe.

Furthermore, in the transition from one beam to another it is necessary to implement appropriate manipulations with the control algorithm and handover procedure.

Thus the scheme of fixed lobe of beamforming pattern is not suitable for the SDMA tasks, it requires the implementation of SDMA in the view of dynamics of the SS azimuthal parameter (Figure 1).

To ensure the SDMA at azimuth movements SS we may offer MBA beamforming pattern, which is adjusted in accordance with the dynamics of the spatial variation of the SS received signals, however large volumes of calculations for solutions of electrodynamic problem in real time seem unrealistic.

It is designed as a method based on the organization of individual SDMA for each session of SS and the signals of other speakers are seen as interfering.

Thus, the N -number of parallel beamforming patterns according to the amount of signals are organized with respect to the number of received SS. A separate SDMA algorithm for each SS is organized.

Let us consider the algorithms of space-time signal processing suitable for implementation of Individual SDMA in terms of the dynamics changes of spatial parameters of the received signals in more details.

II. SDMA ALGORITHM WITH FINDING OF INDIVIDUAL ASSESSMENT VALUES FOR VECTOR OF WEIGHTING COEFFICIENTS OF BASE STATION ADAPTIVE ARRAY

The method of space-time processing which is selected for SDMA decision involves the finding of the individual assessment vector of weighting coefficients (VWC) W_i for each i -th oriented correspondent.

Estimation algorithm W_i, $i=\overline{1,N}$ is implemented in the form of i-parallel procedures performed during the communication session with the i-th SS (Fig. 2)

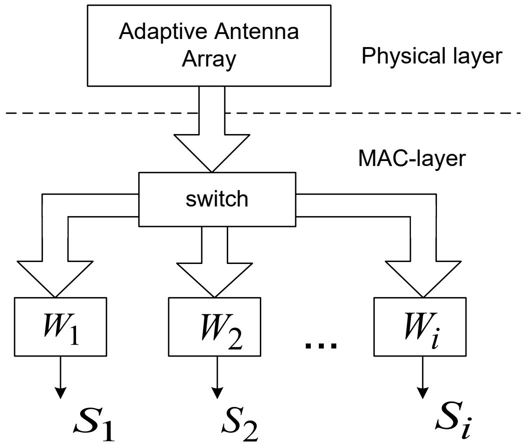

Fig. 2. The scheme SDMA of finding VWC individual assessment values of the base station

With this method of space-time processing all signals of other SS working in this frequency channel are interfering with reception of this particular SS, which is accordingly treated W_i.

In this connection it is interesting to analyze the effectiveness of space-time processing (STP) method in dependence on the adaptive antenna array (AAA) parameters and signal interference situation, spatial and polarization useful parameters of processed signals and other SS perceived as interference.

If these are [1] completely known parameters of signals and interferences, all the considered STP algorithms are equally effective for the Signal to the total Interference and Noise power Ratio criteria (SINR):

$$h=\frac{Pc}{P_n+P_ш}. \qquad (1)$$

To analyze the SINR we represent the covariance matrix of the input signals in the form of $R_{xx}=\sigma_{шi}^2$ - thermal noise power in the frequency band; P_c, P_n - respectively the signal power and the power of each of the n-interferences.

The phase shift signals and interferences on i-elements of AAA are represented as:

$$\psi_i=\vec{k}_c\cdot\vec{z}_i, \qquad (2)$$

$$\psi_{ni}=\vec{k}_{ni}\cdot\vec{z}_i. \qquad (3)$$

where $\vec{k}_c, \vec{k}_{ni}$ respectively, the vector of wave front of the signal and the n-th interference; $\vec{z}_i$ - the vector of n-th antenna element coordinates.

In the view of SINR at the output of the (AAA) that operates in accordance with the Minimum Mean Square Error (MMSE) criterion we have

$$\eta=P_c\vec{V}_c P_{nn}^{-1}\vec{V}_c^{+}. \qquad (5)$$

Obviously, since scaling VWC does not change SINR, then the expression (   ) is true for the maximum output power of the SINR criteria.

It is easy to show that in the case of interference for the VWC optimal value the expression is true [2]:

$$\vec{W}_{onm}=k\left\{\vec{V}_c^{+}-\frac{P_1\vec{V}_c\vec{V}_1^{+}}{\sigma_{mi}^2+P_1\vec{V}_1\vec{V}_1^{+}}\vec{V}_1^{+}\right\}. \qquad (6)$$

Using the notation $\vec{V}_i\vec{V}_j^{+}=\rho_{ij}$, we obtain

$$\vec{W}_{onm}=k\left\{\vec{V}_c^{+}-\frac{P_1\rho_{c1}}{\sigma_{mi}^2+P_1\rho_{11}}\vec{V}_1^{+}\right\}. \qquad (7)$$

Taking into account the expressions (6) and (7) we get the expression for the SINR output

$$\eta=\frac{P_c\rho_{cc}}{\sigma_{mi}^2}\left\{1-\frac{P_1\left|\rho_{c1}\right|^2}{(\sigma_{mi}^2+P_1\rho_{11})\rho_{cc}}\right\}. \qquad (8)$$

The magnitude ρ_{1c} is the scalar product of vectors $\vec{V}_c$ and $\vec{V}_1$ its absolute value can be expressed

$$\left|\rho_{1c}\right|=\left|\vec{V}_1\right|\left|\vec{V}_c\right|\cos\gamma=\sqrt{\rho_{11}}\sqrt{\rho_{cc}}\cos\gamma, \qquad (9)$$

where γ - generalized angle between $\vec{V}_c$ and $\vec{V}_1$ in complex vector space. (In (9) the notation $\left|\vec{V}_1\right|=\sqrt{\vec{V}_1\vec{V}_1^{+}}=\sqrt{\rho_{11}}$, $\left|\vec{V}_c\right|=\sqrt{\vec{V}_c\vec{V}_c^{+}}=\sqrt{\rho_{cc}}$ is used)

We introduce the notation

$$\alpha_{ij}=\frac{\vec{V}_i\vec{V}_j}{\left|\vec{V}_i\right|\left|\vec{V}_j\right|}=\frac{\rho_{ij}}{\sqrt{\rho_{ij}}\sqrt{\rho_{jj}}},\ i,j=C\ ορ\ 1,2,...n. \qquad (10)$$

Then the expression for the output SINR can be represented as

$$\eta=\frac{P_{\Sigma c}}{\sigma_{mi}^2}\left\{1-\frac{P_{n\Sigma}}{\sigma_m^2+P_{n\Sigma}}\left|\alpha_{1c}\right|^2\right\}, \qquad (11)$$

where

$$P_{\Sigma c}=P_c\sum_{i=1}^{m}\left|A_c^i\right|^2. \qquad (12)$$

$$P_{nc}=P_1\sum_{i=1}^{m}\left|A_{n1}^i\right|^2. \qquad (13)$$

where A_c^i and A_{n1}^i - are determined by the expressions (2) and (3). We define α_{ij} as the coefficient of the spatial correlation (CSC) by analogy with [3]. (Obviously, the CPC is uniquely expressed through $\cos\gamma$).

Using expressions (11) we estimate the upper and lower value SINR. Obviously, the maximum value of SINR is given by

$$\eta_{\max} = \frac{P_{\Sigma c}}{\sigma_{mi}^2}. \tag{14}$$

Maximum value of SINR is achieved when the interference is suppressed to zero and CSC $\alpha_{1c} = 0$.

It is known that in the absence of interfering signals STP algorithms are equally effective, since they are all focused on the coherent sum of the useful signals in noise in accordance with the obtained estimates of vector weight coefficients.

The expression (14) shows that the maximum SINR does not depend on AE location and source of the interference but it is determined by AE directional characteristic and polarization of the useful signal. In these circumstances VWC has the best representation

$$\vec{W}_{onm} = k\vec{V}_c^{+}. \tag{15}$$

Therefore, if all A_c^i are the same (AE are identically and identically oriented), the useful signal at the outputs of all the AE is in phase and coherently summed, as in usual AAA.

In the case when A_c^i are not the same, the useful signal is still summed coherently, however SINR decreases.

The values A_c^i may be different even in the case when all the AEs are identical and have the same orientation.

For example, this occurs when placing the AAA of base station on the roof of the building when A_c^i change due to the dispersion from the various parts of the conductive surface [4].

To assess the lower value SINR we assume that the power of noise at the output of AAA is significantly greater than the thermal noise power

$$P_{n\Sigma} >> \sigma_{mi}^2. \qquad 16)$$

In this case, the expression (11) is simplified and takes the form

$$\eta \approx \frac{P_{\Sigma c}}{\sigma_{mi}^2}\left\{1 - \left|\alpha_{1c}\right|^2\right\}. \qquad 17)$$

From the expression (17) we see that on the output AAA SINR depends on the $\eta_{\max}$ and $\left|\alpha_{1s}\right|$ and does not depend on interference power. The equation (17) defines a lower value SINR. Using expressions (14), (16), we obtain

$$\frac{P_{\Sigma c}}{\sigma_{mi}^2}\left\{1 - \left|\alpha_{1c}\right|^2\right\} < \eta \le \frac{P_{\Sigma c}}{\sigma_{mi}^2} \tag{18}$$

Dependence of the normalized value on the SINR $\left|\alpha_{1c}\right|$ is shown in Fig. 3. (normalized SINR $\eta_n = \dfrac{\eta}{\eta_{\max}}$ varies $[1 \div 1 - \left|\alpha_{1c}\right|^2]$).

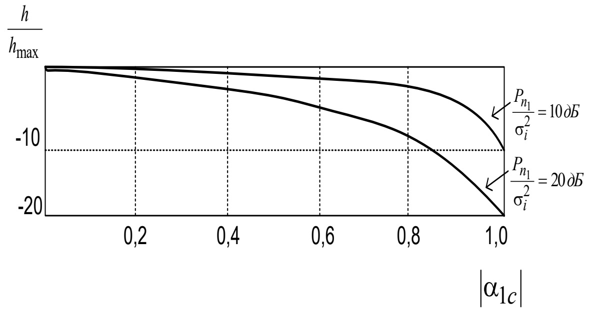

Fig. 3. Dependence of the normalized value on the SINR

From the analysis of dependencies (Fig.3) it is shown that for small values $\frac{P_{n\Sigma}}{\sigma_{mi}^2}$ SINR is generally close to the upper limit, and for large values to the $\frac{P_{n\Sigma}}{\sigma_{mi}^2}$ bottom limit.

However, regardless of the $\frac{P_{n\Sigma}}{\sigma_{mi}^2}$ SINR always approaches the upper boundary if $\left|\alpha_{1c}\right| << 1$. Hence reducing the value of the CSC $\left|\alpha_{1c}\right|$ the performance of the AAA in the steady state can be significantly improved.

III. Conclusions:

Method of space-time division multiple access is very promising, because it allows to increase the number of simultaneous correspondents on the same frequency channel.

Implementation of the method of space-time division multiple access with the individual space-time processing of SS signals is reduced to the use of AAA group and the establishment of parallel procedures of assessing VWC values on the number of simultaneously working stations.

Under the individual space-time signal processing of a particular station, the signals of other stations are perceived as interfering.

The effectiveness of the reception at the STP with SDMA depends on the relative orientations of the arrival directions of the interfering stations and their relative level. The upper and lower values of signal levels according to sum of interferences are obtained.

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