The comparison methods of different geometric configurations of adaptive antenna arrays

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Abstract

In this paper we investigate comparison methods of different geometric configurations of adaptive antenna arrays for mobile communications. The investigated antenna configurations were linear, semicircular, rectangular, wing and zigzag array. All considered antenna arrays consisted of seven antenna elements with an inter-element spacing of half wavelength. The Geometry─based Stochastic Channel Model (GSCM) [1] for macrocellular environment was used in our simulations. The uniform linear array performed best by using correlation as the comparison criteria. The worst result was achieved for zigzag array.

1 Introduction

Small scale fading of the mobile radio channel is normally Rayleigh distributed because of multipath propagation in wideband communications systems. The antenna receives different delayed copies (different multipath components) from the same signal. Different multipath components show usually different angles of arrival, signal amplitude as well as signal phase. The optimum performance under such propagation conditions is achieved by detecting all multipath components coherently. There are two different methods to increase the performance of the antenna in mobile radio channels. One can apply adaptive antennas [2] and use different diversity methods [3].

Adaptive antennas offer many good features against conventional antennas. By using adaptive antennas different multipath components arriving in different angles can be separated and interfering signals can be suppressed. Because of these reasons smart antennas can be used e.g. for range extension or link quality improvement [2]. In CDMA-systems, with smart antennas, less transmission power is needed and therefore the multiple access interference is reduced which directly boosts the system capacity.

Antenna diversity has been widely used to combat multipath fading in wireless mobile communications. Different antenna diversity methods like space diversity, polarisation diversity and radiation pattern diversity are traditionally used to increase the signal quality, range of cell and capacity of the channel. The applications of these diversity methods have mainly been studied and used in base stations. Several combining methods for different diversity branches are available in literature, e.g. selection combining, equal-gain combining, maximum-ratio combining and optimum combining. Antenna diversity has some advantages compared to other diversity methods. Antenna diversity does not consume spectral efficiency but on the other hand extra equipment (antenna, combiner) is required [3].

In the diversity sense the requirements for correlation properties are different than in the adaptivity sense. The success of diversity techniques depends strongly on the degree to which the signals on the different diversity branches are uncorrelated. The lower the correlation between antenna elements are the higher is possible diversity gain with the antenna array [4]. For adaptive arrays this requirement is opposite. In this paper we compare different geometrical antenna array configurations in sense of the correlation properties of the antenna elements by simulations.

2 Data model and figure of merit

Different delayed versions of the transmitted signal are received at every antenna element. Every antenna element receives a different version from the incoming signal because of space selective fading caused by multipath propagation. The received data vector is [5]

$$\overline{u(t)} = \begin{bmatrix} u_0(t) & u_1(t) & \dots & u_{M-1}(t) \end{bmatrix}^T \quad , \tag{1}$$

where M indicates the number of antenna elements. The data vector of every antenna element can be expressed as

$$u_m(t) = \sum_{i=0}^{L-1} \alpha_{i,m} s(t - \tau_{i,m}) \, , \tag{2}$$

where $\alpha_{i,m}$ and $\tau_{i,m}$ denote the complex amplitude and the path delay of the i-th multipath component at the m-th antenna element, respectively. Further $s(t)$ is transmitted signal and L is the amount of multipath components. These signals should be as uncorrelated as possible that maximal diversity gain could be obtained. The autocorrelation matrix of the data vector is

$$R = E\left[\overline{u(t)}\,\overline{u(t)}^H\right], \tag{3}$$

where $E[\bullet]$ denotes the expectation operator. It is possible to compare correlation properties between different antenna configurations based on the correlation matrix if the amount of channel states is large enough. A figure of merit is declared by using the diagonality of the matrix as a comparison criteria. In a totally uncorrelated situation this matrix gets diagonal. The norm of a matrix can be specified based on its largest eigenvalue [6]:

$$\|R\| = \left| \sqrt{\lambda_{\max}(R^H R)} \right| . \tag{4}$$

The figure of merit proposed in this paper is based on the comparison of diagonality properties of correlation matrices. The diagonality of a matrix is declared according to

$$\alpha = \frac{\|R_{nulled}\|}{\|R\|}, \tag{5}$$

where α is the figure of merit, $\|R\|$ is the norm of the original correlation matrix and $\|R_{nulled}\|$ is the norm of the correlation matrix with nulled (zero) main diagonal. According to this definition the figure of merit is zero if all elements are uncorrelated with each other, which is relatively impossible in practice. With the investigated antenna configurations (antenna spacing is only λ/2) there is normally always some correlation between the antenna elements.

3 Simulation results

Five different antenna configurations were compared in this paper. The antenna configurations containing seven antenna elements were linear (1), semicircular (2), rectangular (3), wing (4) and zigzag (5) array. Antenna element spacing for every array was $\lambda / 2$. The antenna configurations used in simulations are illustrated in Fig. 1.

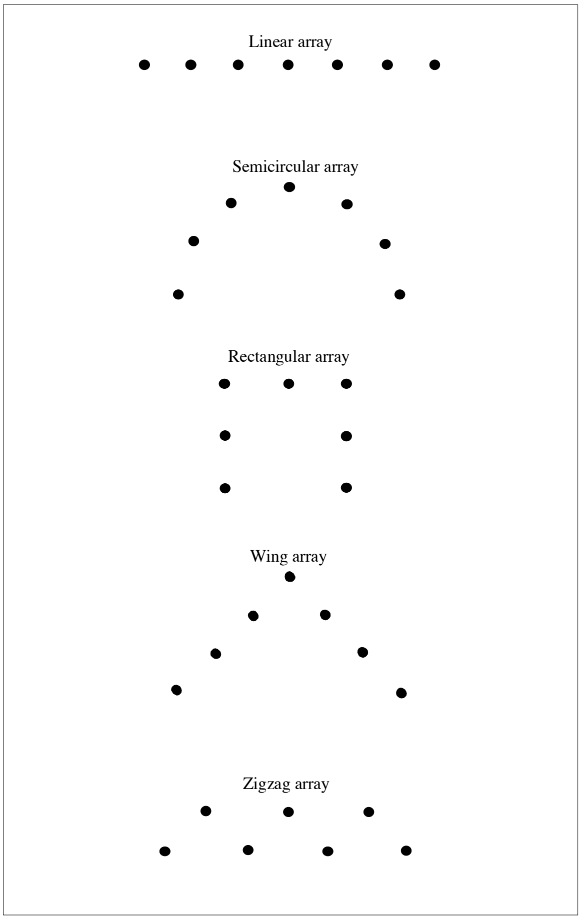

Figure 1: *Investigated antenna configurations*

The simulations were performed for one single user. For simulation we used the Geometry–based Stochastic Channel Model [1] with macrocellular configuration. This scattering model consists of two scattering discs with 20 scatterers each, which present the local scattering near the mobile and one dominant reflection area far off the mobile's position. The geometrical principle of the GSCM is illustrated in Fig. 2. The mobile stations are randomly placed within the cell area (-90° to 90° from antenna broadside). The scatterers are randomly distributed around the mobile station inside the local scattering disc as well as inside the far scattering cluster. The complex reflection coefficients of the scattering points have a magnitude distributed uniformly within [0,1] and a phase distributed uniformly within [0,2π]. The cell radius was chosen to be 1500 meters and minimum distance from mobile to base station was set to 50 meters.

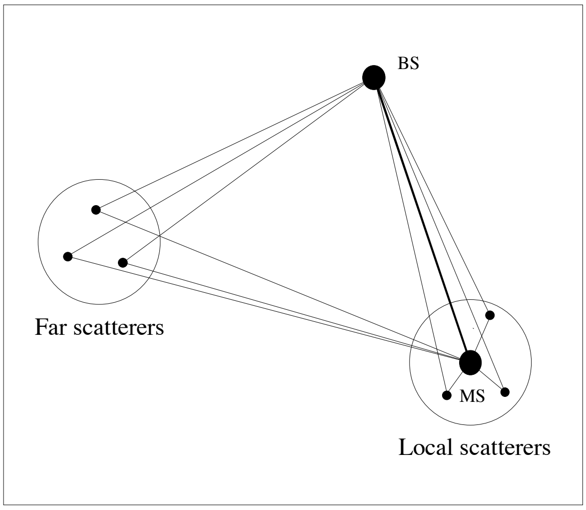

Figure 2: *The basic principle of the Geometry-based Stochastic Channel Model (GSCM)*

The carrier frequency for uplink was 1.950 GHz and symbol duration was 0.244 μs, which is close to symbol duration used in WCDMA. A transmission bandwidth of 5 MHz was assumed. 5000 different random channel states were simulated and as a result the figures of merit were acquired. The same channel states were used for all antenna configurations. As a consequence there is no statistical fluctuation in the results of different array geometries and the comparison of several antenna configurations is easy. The mean value, standard deviation and standard error were calculated for the figures of merit for three different sectors to study also the directive properties of the configurations. These sectors were:

- -90° to -60° and +60° to +90°,
- -60° to -30° and +30° to +60°,
- -30° to +30°.

The numbers of the channel states for these subsectors were 1708, 1648 and 1644, respectively. In addition to this all calculations were also performed for the whole area (-90° to 90° with 5000 channel states). The antenna elements were assumed to be omnidirectional. Mutual coupling effecting the signal correlation between the antenna elements was not taken into account. The results from the simulations are introduced in Tables 1-4 and the corresponding sectors are illustrated in Figures 3-6.

Table 1: *Mean, standard deviation and standard error from different figures of merit for different antenna elements in sector -90° to 90°. The number of the channel states was 5000.*

Ant.	(1)	(2)	(3)	(4)	(5)
Mean	0.8290	0.8332	0.8374	0.8337	0.8398
St.d.	0.0179	0.0126	0.0103	0.0121	0.0103
St.e.	0.0003	0.0002	0.0001	0.0002	0.0001

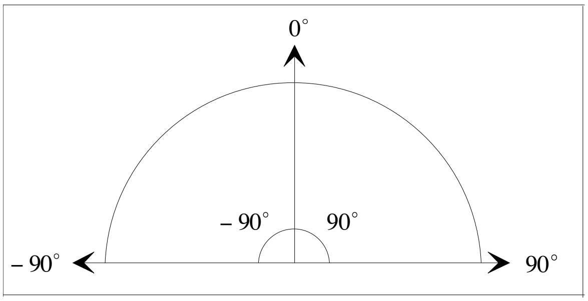

Figure 3: *Sector used in the simulations of Table 1*

Table 2: *Mean, standard deviation and standard error from different figures of merit for different antenna elements in sector -30° to +30°. The amount of the channel states was 1708.*

Ant.	(1)	(2)	(3)	(4)	(5)
Mean	0.8179	0.8274	0.8360	0.8282	0.8349
St.d.	0.0168	0.0135	0.0105	0.0130	0.0108
St.e.	0.0002	0.0002	0.0001	0.0002	0.0002

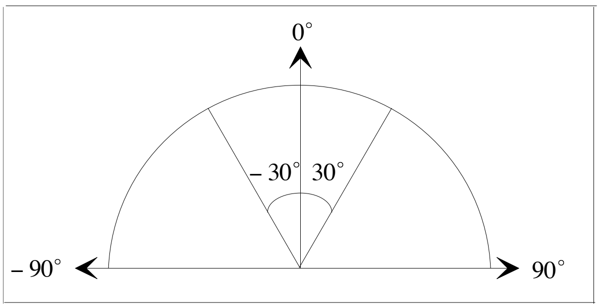

Figure 4: *Sector used in the simulations of Table 2*

Table 3: *Mean, standard deviation and standard error from different figures of merit for different antenna elements in sector -60° to -30° and +30° to +60°. The amount of the channel states was 1648.*

Ant.	(1)	(2)	(3)	(4)	(5)
Mean	0.8263	0.8328	0.8373	0.8333	0.8395
St.d.	0.0159	0.0120	0.0107	0.0115	0.0099
St.e.	0.0002	0.0002	0.0002	0.0002	0.0001

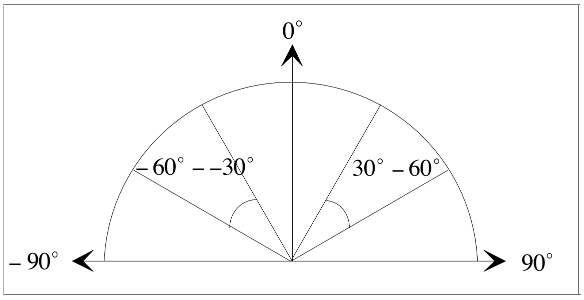

Figure 5: *Sector used in the simulations of Table 3*

Table 4: *Mean, standard deviation and standard error from different figures of merit for different antenna elements in sector -90° to -60° and +60° to +90°. The amount of the channel states was 1644.*

Ant.	(1)	(2)	(3)	(4)	(5)
Mean	0.8434	0.8395	0.8389	0.8398	0.8452
St.d.	0.0089	0.0086	0.0095	0.0083	0.0070
St.e.	0.0001	0.0001	0.0001	0.0001	0.0001

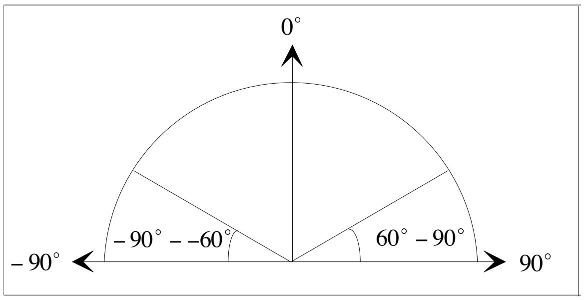

Figure 6: *Sector used in the simulations of Table 4*

According to these simulations the best correlation properties were achieved by using the uniform linear antenna array. One exception from this was rectangular array in sector -90° to -60° and +60° to +90°. The poorest result was achieved for the zigzag array. It can be seen from the results that the standard deviation decreases with increasing mean from the figures of merit. Because of this the standard deviation from the figures of merit for the zigzag array was the smallest. It can also be seen from the result of standard errors (small enough) that the convergence of simulations is adequate. Because of this the amount of different channel states used in the simulations is sufficient. According to these results size of the antenna array aperture seen from different directions is strictly related to the correlation between antenna array elements (bigger aperture → lower correlation).

4 Conclusions

A comparison of the signal correlation between different antenna elements was made for five different antenna configurations to compare their performance in sense of diversity gain. The considered antenna configurations were linear, semicircular, rectangular, wing and zigzag array. The simulations were performed for four different sectors. The best correlation properties (the lowest correlation) were achieved for the uniform linear antenna array and the worst result for the zigzag array, respectively. According to these results size of the antenna array aperture seen from different directions is strictly related to the correlation between antenna array elements (bigger aperture → lower correlation).

References

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