Study of different mechanisms providing gain in MIMO systems

Kati Sulonen, Pasi Suvikunnas, Jarmo Kivinen, Lasse Vuokko, Pertti Vainikainen, *member IEEE*
HUT, Radio Laboratory, SMARAD Center of Excellence
P.O. Box 3000, FIN-02015 HUT, Finland
e-mail: kati.sulonen@hut.fi
Phone: +358 9 451 2230, Fax: + 358 9 451 2152

***Abstract*— In this paper, measurements are used as the experimental basis for evaluation of MIMO antenna configurations at 2.15 GHz. At the transmitting fixed station, the effects of increasing the number of channels and increasing the inter-element spacing in MIMO systems are studied. The goal of the paper is to find out how MIMO channels could be exploited better. We have performed radio channel sounder measurements using antenna arrays of directive and dual-polarized elements. Three potential MIMO environments have been included in the study. We found that increasing the distance between transmitting antenna elements or increasing the number of elements decreases eigenvalue spread and improves MIMO performance.**

Keywords- MIMO, antenna configuration, eigenvalue spread, angles of arrival of incident field

I. Introduction

Multi-Input Multi-Output (MIMO) systems can provide radio channels capable of transferring parallel information within the same bandwidth, and increase the attainable capacity [1, 2]. In this paper, measurements are used as the experimental basis for evaluation of MIMO antenna configurations. The goal of the paper is to find out how MIMO channels could be exploited better and at the same time to continue the work of the paper [3].

Both the propagation environment and the antenna configurations affect MIMO performance. Effects of different directive and omnidirectional multi-antenna configurations on capacity were studied in [3]. Two different propagation environment types, indoor picocellular environment and outdoor microcellular environment, provided different results, the picocellular environment being better in capacity comparison. Based on that study, receiving antenna elements with orthogonal polarizations are equally effective with the co-polarized elements in capacity comparison. As mentioned in [4], the dual polarized elements can be compact solutions to add diversity dimension with low correlation between antenna ports. In some cases, dual-polarized elements result in relatively high power unbalance between antenna ports that deteriorates the power gain in MIMO channel [4].

In this paper, the effect of three different propagation environments on MIMO performance in downlink is studied by calculating the eigenvalues of normalized instantaneous channel correlation matrices. The eigenvalues enable an estimation of independent sub-channels in MIMO channel. At the fixed station (FS), the effects of increasing the number of transmitting (Tx) channels and increasing the inter-element spacing on the eigenvalue spread are studied.

In Section II the measurement system and the environments used in the work are described. The calculation of the eigenvalues is presented in Section III. Section IV presents the results and discussion of the results and Section V concludes the work.

II. Measurements

We have performed radio channel sounder measurements with antenna arrays at both ends of the radio channel [5]. At the transmitting FS we used a linear antenna array of eight directive and dual-polarized antenna elements from which different number of elements were selected in the post processing of the measurement data. The Tx element spacing was 0.5 λ but in picocellular environment it was 0.7 λ. The antenna array of 32 directive and dual-polarized elements, similar to the elements of the Tx array, located on the sphere was used at the receiving mobile station (MS). One dual-polarized element consists of two orthogonal channels (ch), θ- and ϕ-polarized feeds [3]. In our study, we select groups of four receiving (Rx) elements from the spherical antenna array (see Fig. 1). Similar groups of elements in five azimuth orientations are included in the analysis here.

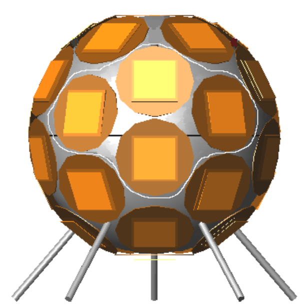
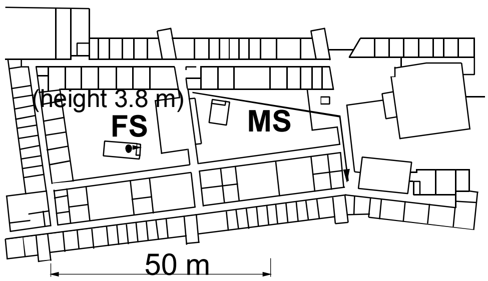


Figure 1. A group of four elements selected from the spherical antenna array.

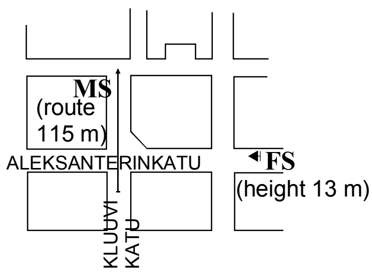
Potential MIMO environments, indoor picocell inside a building and outdoor microcell and small macrocell in downtown Helsinki, are included in the study. The maps of the routes are in Fig. 2.

The work was partially founded by Academy of Finland, Graduate School in Electronics, Telecommunications, and Automation. Financial support from HPY foundation, Nokia Foundation, Foundation for Commercial and Technical Sciences, Foundation of Technology (Finland), and Finnish Society of Electronics Engineers is gratefully acknowledged.

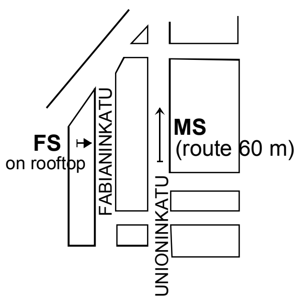
The measured angles of arrival of incident field on the same routes calculated according to [6] are presented in Fig. 3 Fig. 4, and Fig. 5. The elevation angle 0^o equals to the horizontal level. Negative values are downward and positive upwards. The azimuth angle 0^o is the moving direction marked by arrowheads in Fig. 2. Here, the positive azimuth angles are on the left hand side and negative on the right hand side.



a) Picocell



b) Microcell



c) Macrocell

Figure 2. Maps of the environments.

As shown in Fig. 3, in picocellular environment the radio waves arrive at the MS slightly above the horizontal level (elevation = 0^o). In azimuth, the turn in the moving direction can be seen at the distance of about 30 m.

In microcellular environment the angle of arrival is around 0^o in elevation and the streets determine the azimuth distribution, which can be noticed in comparing the map of Fig. 2b with Fig. 4.

In macrocellular environment (Fig. 5), the FS is located on a rooftop level and the signals arrive at the MS at the elevation angles of close to 20^o. In azimuth, the directions of arrival are from negative angles indicating that the signals have reflected from the wall opposite to the FS direction (see map in Fig. 2c).

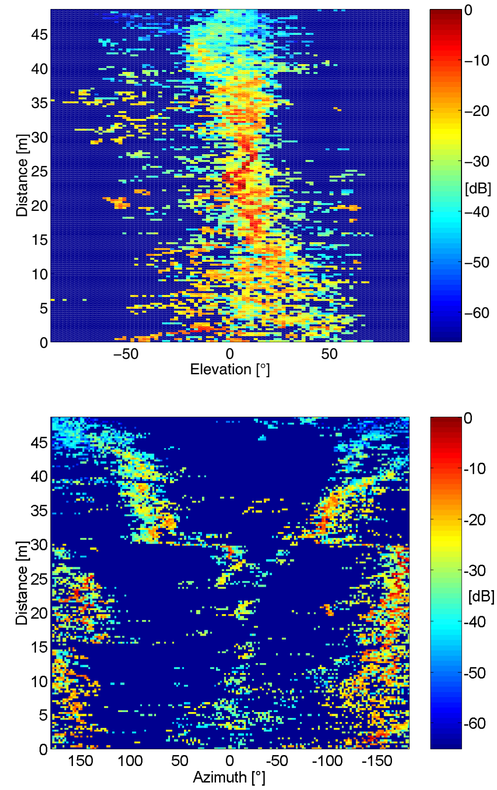


Figure 3. Incidence angles at the MS in the picocellular environment indoors.

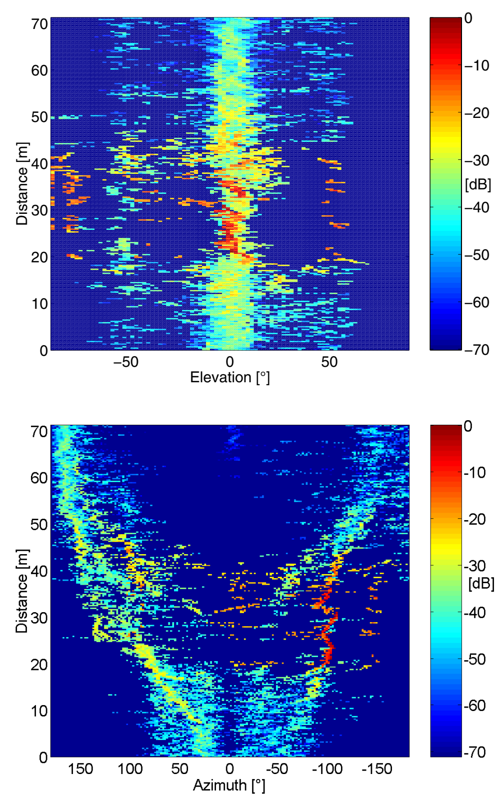


Figure 4. Incidence angles at the MS in the microcellular environment.

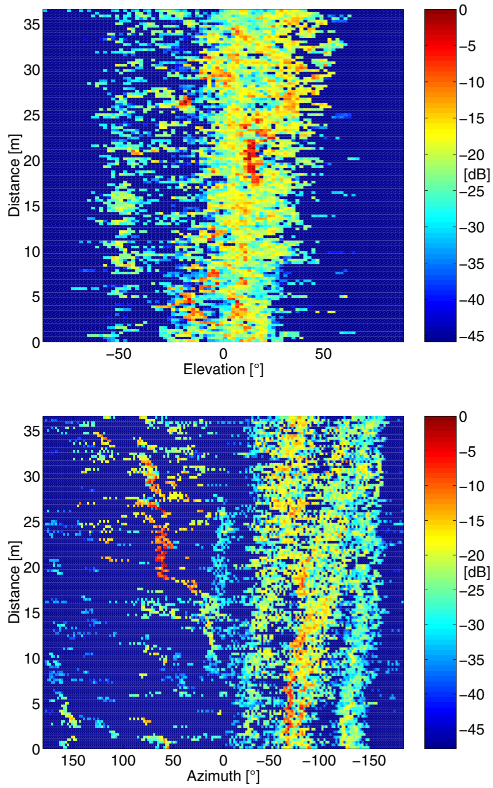


Figure 5. Incidence angles at the MS in the macrocellular environment.

III. EIGENVALUE DISTRIBUTIONS

The eigenvalues of normalized instantaneous channel correlation matrix are used here to study and distinguish the effects of different transmitting antenna configurations on MIMO performance. The eigenvalues have been calculated using the eigenvalue decomposition of the normalized instantaneous correlation matrix [7] and equal power allocation at the Tx. The normalized correlation matrix was calculated according to [3]

$$\overline{R}_{norm} = \frac{\overline{H}^H \overline{H}}{\frac{1}{n_t} E\left\{ \sum_{t=1}^{n_t} H_{1,t}^* H_{1,t} \right\}} \quad (1)$$

where $()^H$ is complex conjugate transpose, $()^*$ is complex conjugate, E{} is expectation operator over the sliding window of 35 snapshots, and n_t is the number of transmitting antenna elements. $\overline{H}$ is the narrowband complex channel matrix obtained from impulse responses by at first removing noise and then using coherent summing in the delay domain. The channel gain used in normalization was calculated by taking the mean power over vertically polarized transmitting elements and the receiving discone antenna and averaging over a sliding window of about 1 m, corresponding to 7λ, in order to mitigate the effects of slow fading.

The eigenvalue spread [8] of $\overline{R}_{norm}$ at the probability level of 50 % is calculated according to

$$EVSpread = \lambda_{\max}[dB] - \lambda_{\min}[dB] \quad (2)$$

λ_{max} and λ_{min} are the smallest and the largest eigenvalues at the probability level of 50 %, respectively. The *EVSpread* of the studied cases and that of the isotropic, identically and independently distributed sensors, called i.i.d, are in Table 1.

IV. RESULTS

Antenna aperture can be enlarged in two different ways, by adding more antenna elements or increasing the inter-element spacing of antenna elements. We have studied MIMO systems consisting of antenna arrays with different number of elements at the FS and at the MS.

Fig. 6 presents the cdfs of the eigenvalues of $\overline{R}_{norm}$ in cases where inter-element spacing at the Tx is enlarged. In that study, we have used two dual-polarized Tx elements (4 ch) and four Rx elements (8 ch).

As the distance between Tx elements is enlarged, which increases the opportunity to utilize the complexity of the propagation environment, the eigenvalue spread is decreased and the capacity increases. There is a relatively large difference between the environments if the eigenvalue spread of $\overline{R}_{norm}$ is considered. The effect of spacing of antenna elements on eigenvalue spread is more significant outdoors than indoors. If the environment is scatter-rich enough the effect of antenna configuration on eigenvalue spread is of minor importance as can be seen in the results of the indoor picocellular environment in Table 1.

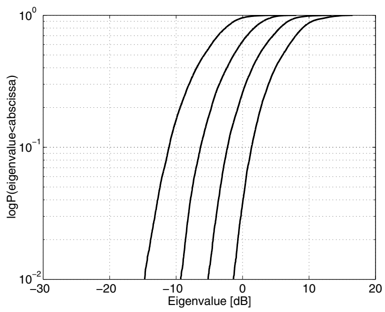
TABLE I. EIGENVALUE SPREAD AT 50 % PROBABILITY LEVEL

EVSpread [dB]	Tx spacing 0.7 λ /0.5λ	Tx spacing 3.5 λ /2.5λ	2 Tx elements	6 Tx elements
picocell	12	11	20	10
microcell	20	14	28	17
macrocell	18	11	26	14
i.i.d.	9	9	18	7

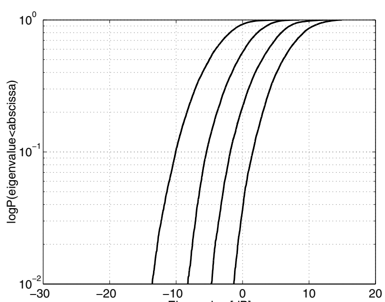
In Fig. 6c and Fig. 6e, most probably the effect of using vertical and horizontal polarizations can be seen as dividing the eigenvalues clearly in two groups, the stronger and the weaker pairs of values. According to [3], using elements with orthogonal polarization in receiving seems as good as using co-polarized elements if two polarizations are used in the transmission.

In Figure 7, the effect of increasing the number of antenna elements on cdfs of eigenvalues of $\overline{R}_{norm}$ are drawn. At the MS, we had four elements from which two θ-polarized feeds and two ϕ-polarized feeds were selected (one feed per element). At the FS, it is possible to install more antenna elements than at the MS and accordingly, we have studied the cases of using either two adjacent elements (4 ch) or six adjacent elements (12 ch) at the FS. In the figures we clearly see that the highest cdf curve remains at the same power level although more elements are added at the Tx. Adding more elements increases the level of the lower eigenvalue curves and thus, decreases the *EVSpread* in Table 1 and increases the attainable capacity, which is presented in Fig. 11 in [3]. Both the Tx diversity gain and array resolution increase as elements are added. On the other hand, the complexity of the system increases if more elements are added which is a drawback.

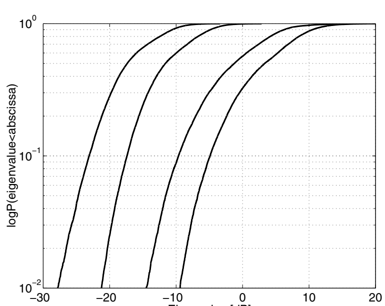
Antenna aperture can be enlarged in two different ways, by adding more antenna elements or increasing the inter-element spacing of antenna elements. According to this study, the effect of increasing the number of elements is more beneficial than enlarging the spacing between antenna elements from eigenvalue spread point of view (see Table 1).



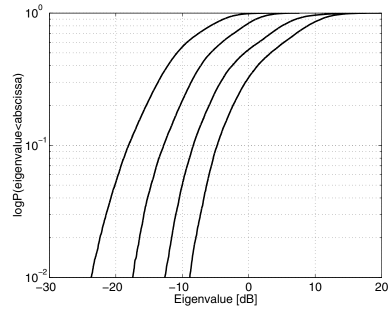
a) Picocell, Tx distance 0.7 λ



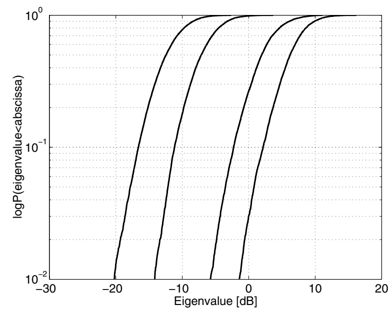
b) Picocell, Tx distance 3.5 λ



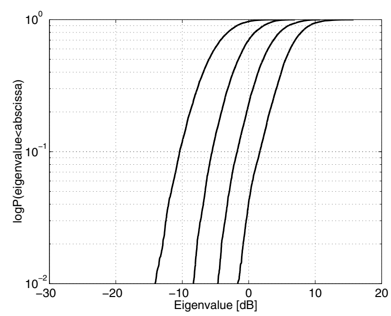
c) Microcell, Tx distance 0.5 λ



d) Microcell, Tx distance 2.5 λ



e) Macrocell, Tx distance 0.5

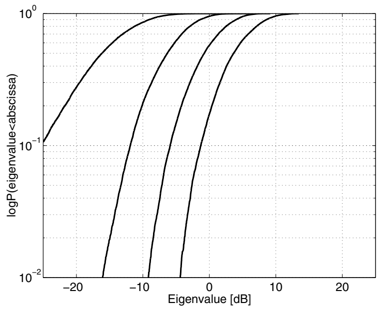


f) Macrocell, Tx distance 2.5

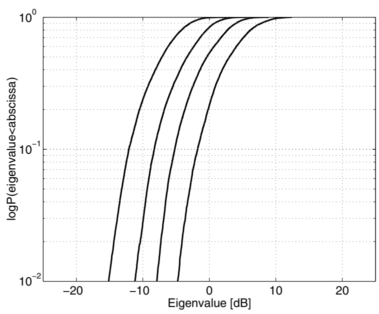
Figure 6. Effect of increasing the interelement spacing on eigenvalues. We had 4×8 channels MIMO system with dual-polarized elements.

V. Conclusion

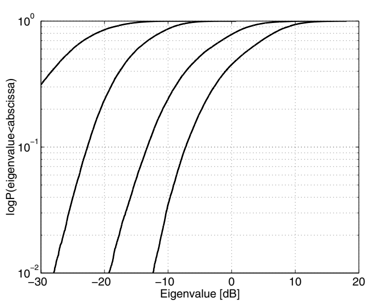
Increasing the distance between Tx antenna elements increases resolution by narrowing the main beam, which results in decreased eigenvalue spread and increased capacity here. The effect of Tx element spacing on MIMO performance is smallest in picocellular indoor environment. In addition to increasing resolution, adding more elements at the Tx antenna configuration increases Tx diversity, which can be seen as sharper eigenvalue curves. The effect of element spacing on MIMO performance is the strongest in picocellular indoor environment. When comparing three environments, the smallest eigenvalue spread is indoors. In some cases as the inter-element spacing is decreased the eigenvalues are divided into two groups, the stronger and the weaker values probably because of using two orthogonal polarizations.



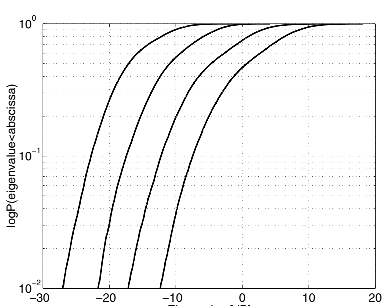
a) Picocell, 4×4 MIMO



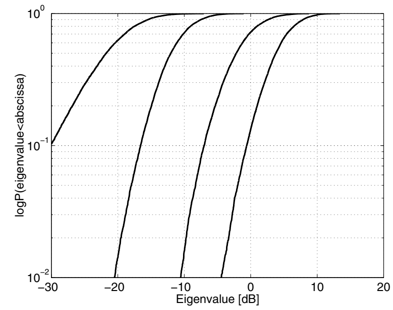
b) Picocell, 12×4 MIMO



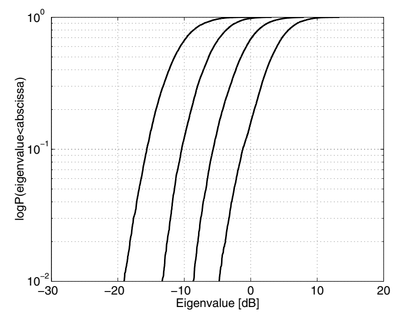
c) Microcell 4×4 MIMO



d) Microcell, 12×4 MIMO



e) Macrocell, 4×4 MIMO



f) Macrocell, 12×4 MIMO

Figure 7. Effect of increasing the number of Tx channels on eigenvalues. Four Rx channels used in all cases.

REFERENCES

[1] G. J. Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas," *Bell Labs Technical Journal*, pp. 41–59, Autumn 1996

[2] D.-S. Shiu, G. J. Foschini, M. J. Gans, J. M. Lahn, "Fading Correlation and its effect on the capacity of multielement antenna systems," *IEEE Trans. Commun*., vol. 48, pp. 502–513, March 2000.

[3] K. Sulonen, P. Suvikunnas, L. Vuokko, J. Kivinen, P. Vainikainen, "Comparison of MIMO antenna configurations in picocell and microcell environments", *IEEE Journal on Selected Areas in Communications, special issue on MIMO systems and Applications*, vol. 21, Nr. 5, pp. 703- 712, June 2003.

[4] J. P. Kermoal, L. Schumacher, F. Fredriksen, P. E. Mogensen, "Polarization diversity in MIMO radio channels: Experimental validation of a stochastic model and performance assessment," in *Proc. IEEE 54th Vehicular Technology Conference*, vol. 1, Fall 2001, pp. 22–26.

[5] J. Kivinen, P. Suvikunnas, D. Perez, C. Herrero, K. Kalliola, P. Vainikainen, "Characterization system for MIMO channels," in *Proc. 4th Int. Symp. Wireless Personal Multimedia Communications*, Sept. 2001, pp. 159-162.

[6] K. Kalliola, H. Laitinen, K. Sulonen, L. Vuokko, P. Vainikainen, "Directional Radio Channel Measurements as Mobile Station in Dirfferent Radio Environments at 2.15 GHz," *4th European Personal Mobile Communications 2001 -Conferenc*e, Vienna, Austria, CD-ROM ÖVE 27 (ISBN 3-85133-023-4), paper n:o 113.pdf., February 2001.

[7] J. P. Kermoal, P. E. Mogensen, S. H. Jensen, J. B. Andersen, F. Fredriksen, T. B. Sorensen, K. I. Pedersen, "Experimental investigation of multipath richness for multi-element transmit and receive antenna arrays," in *Proc. IEEE 51th Vehicular Technology Conference*, vol.3, 2000, pp. 2004–2008.

[8] S. Haykin, Adaptive Filter Theory, 3rd Edition, Prentice Hall, USA, 1996, 989 p.

