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Effect of antenna properties on MIMO-capacity in real propagation channels

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Abstract: In this paper, experimental investigations are performed to compare different MIMO antenna configurations at the mobile and base stations. The goal is to provide new information on the effects of antenna properties on MIMO performance. At the mobile station, the effect of using different elements in arrays is studied. Further, at the base station, the effects of increasing the number of elements and increasing the inter-element spacing in MIMO systems are studied. Three potential MIMO environments, indoor picocell, outdoor micro- and macrocell, have been included in this study.

We found that the type of MS antenna element has a significant effect on the achieved MIMO capacity, especially indoors. We also found that increasing the distance between Tx antenna elements or increasing the number of elements decreases the spread of eigenvalues and, thus, increases MIMO capacity. In addition, adding more elements at Tx increases, of course, the Tx diversity. In comparing with microcellular and small macrocellular environments, the smallest eigenvalue spread is in indoor picocell.

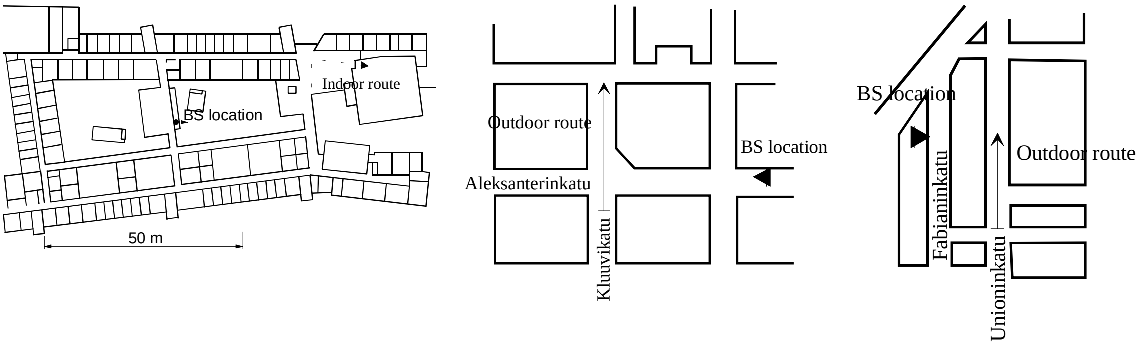
1 Introduction

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 provide new information on the effects of MS and BS antenna properties on MIMO performance. The eigenvalue spread of instantaneous channel correlation matrix and related Shannon capacity are used as measures in analysis.

2 Measurement system and environments

A horizontal zigzag antenna array (interelement spacing 0.5 λ) and a linear antenna array (interelement spacing 0.7 λ) of eight directive and dual-polarized antenna elements were used at the BS in indoor and outdoor environments, respectively. The spherical antenna array of 32 directive and dual-polarized antenna elements located on the sphere was used at the receiving (Rx) MS [3]. One dual-polarized element consists of two orthogonally polarized channels. Antenna arrays at the BS and MS were connected to the transmitter and to the receiving wideband radio channel sounder [5], respectively, with high-speed RF-switches [4].

Three potential MIMO environments, indoor picocell, outdoor microcell and small outdoor macrocell, were included in the measurements. The indoor measurement was performed on the second floor in Computer Science Building in Otaniemi, where the MS carried by the trolley was moved from a hall into a room. BS was located at a height of 5.2 m. The direction of motion of the MS and the broadside directions of the BS antenna arrays are marked by arrowheads as pictured in Fig. 1 a. In downtown Helsinki the BS was located below rooftop level, at a height of 13 m, pointing along the street Aleksanterinkatu at the microcell measurement. The MS was moved along the street Kluuvikatu and across an intersection of Aleksanterinkatu and Kluuvikatu as illustrated in Fig. 1 b. At the small macrocell measurement the BS was located on the roof of Pukeva building pointing cross the street Fabianinkatu. The trolley was moved along Unioninkatu as illustrated in Fig. 1 c.



a) picocell b) microcell c) small macrocell

Figure 1: Measurement routes

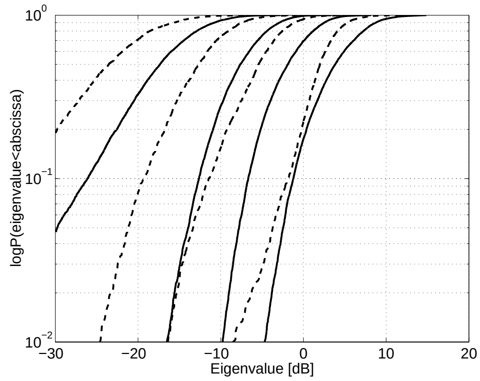
3 Analysis methods

Two methods have been used in our measurement based MIMO analysis: in the first method, we select groups of elements from the antenna arrays used in measurements [6]. In this method, one vertically polarized BS antenna element and discone antenna at the MS were used for the normalization. In the second method, the incident waves have been estimated by beamforming method [3] at the mobile station and weighted by different virtual dipole antenna arrays [6]. In this method, normalization was performed over all connections of MIMO system.

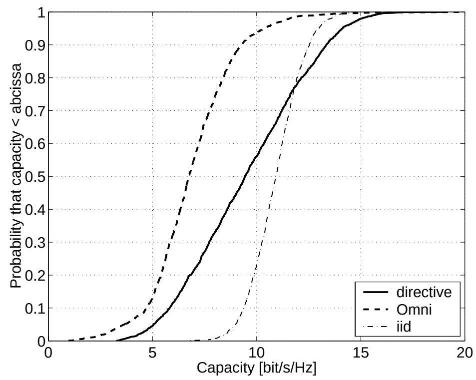
The spread of eigenvalues of instantaneous channel correlation matrix and related Shannon capacity [1,2] are used as measures to analyze the effect of antenna properties on MIMO systems. The eigenvalues have been calculated using the eigenvalue decomposition of the normalized instantaneous channel correlation matrix and equal power allocation. The eigenvalues are used here to study and distinguish the effects of different antenna configurations on MIMO performance. In capacity calculations a SNR of 10 dB was used.

4 Effect of RX array gain

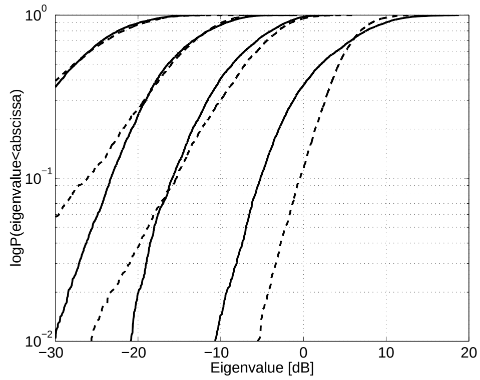
The array with directive (patch antenna: G = 7.8 dBi) and omnidirectional (vertical dipole: G = 2.15 dBi) antenna elements have been selected in such a way that the antenna polarization (theta polarization in that case), number of antenna elements and the analyzed measurement route remains and only the element directivity varies. In the case of directional elements the Rx array is also rotated in five azimuth directions. 4×4 MIMO antenna configurations were compared in the three environments. CDFs of capacity values and eigenvalues are presented in each environment for antenna arrays with directive and omnidirectional antenna elements in Fig. 2. Iid capacity results are presented as a reference. In addition to this AOA analysis in azimuth and elevation direction is presented in Figs. 3,4 and 5 for the support of achieved results.



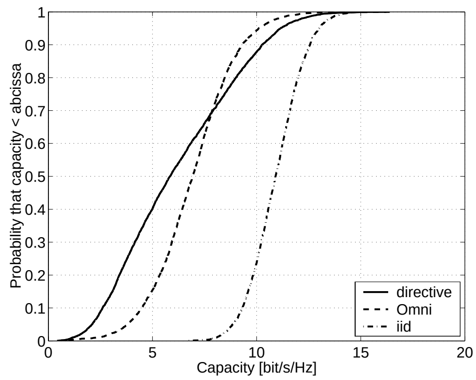
a) Indoor picocell: Eigenvalues



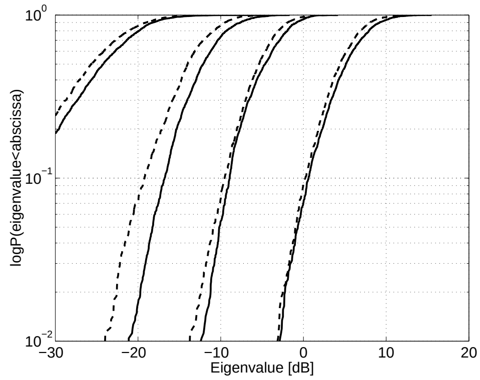
b) Indoor picocell: Capacity



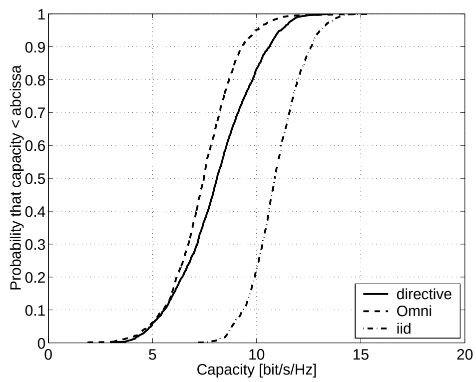
c) Outdoor microcell: Eigenvalues



d) Outdoor microcell: Capacity

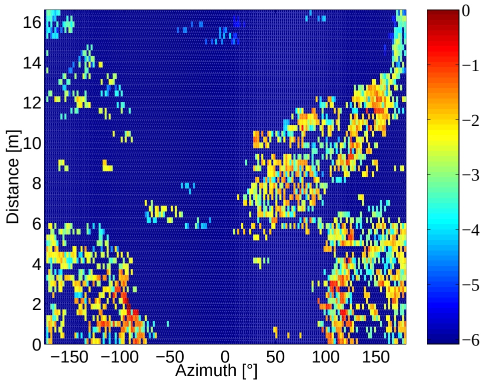


e) Outdoor macrocell: Eigenvalues

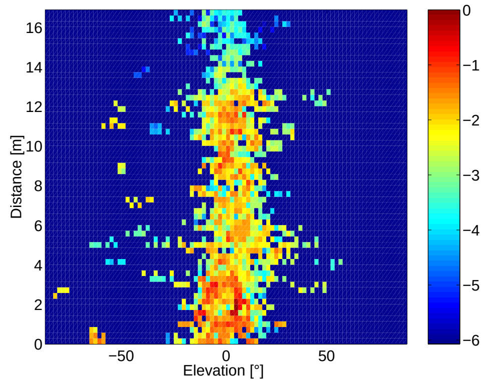


f) Outdoor macrocell: Capacity

Figure 2: Comparison of eigenvalues and capacities between directive and omnidirectional elements in 4× 4 MIMO systems. Solid and dashed lines corresponds directive and omnidirectional elements, respectively.

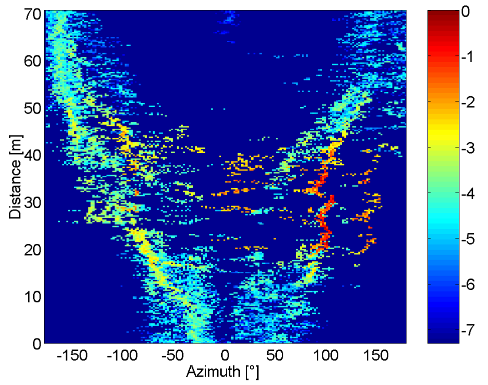


a) Azimuth AOA

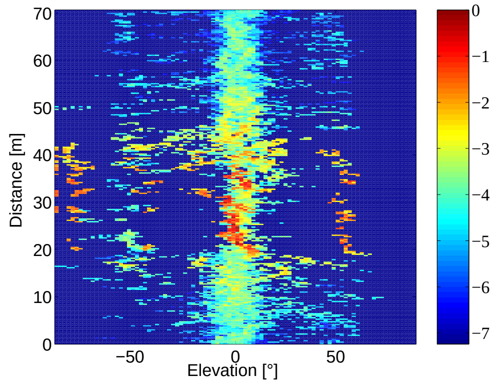


b) Elevation AOA

Figure 3: AOA in picocell environment

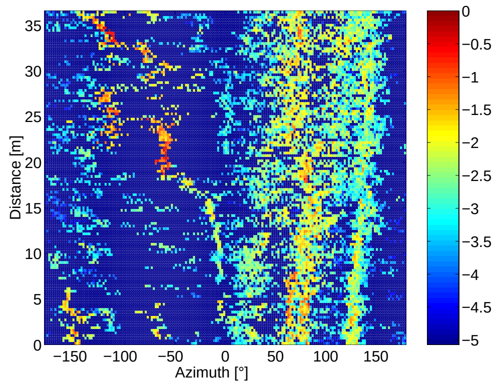


a) Azimuth AOA

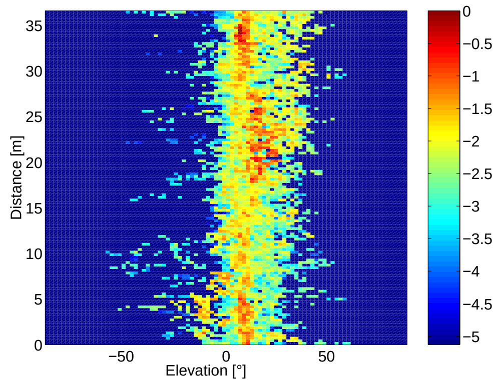


b) Elevation AOA

Figure 4: AOA in microcell environment



a) Azimuth AOA

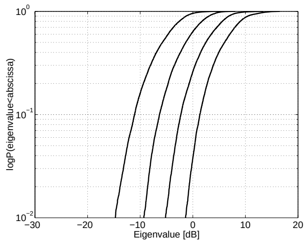


b) Elevation AOA

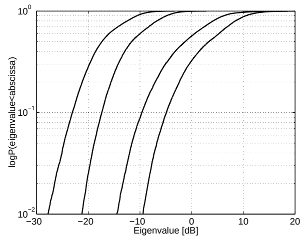
Figure 5: AOA in macrocell environment

5 Effect of TX antenna configuration

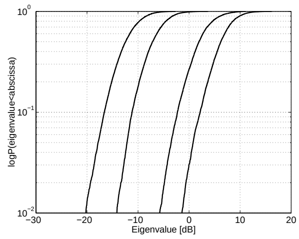
At the base station, the effects of increasing the inter-element spacing and increasing the number of Tx channels in MIMO systems are studied. Both polarizations (theta and phi) are used at both ends of the link in this study. Fig. 6 presents cdfs of eigenvalues in cases where inter-element spacing is enlargened. Fig. 7 presents cases where the number of Tx elements is increased.



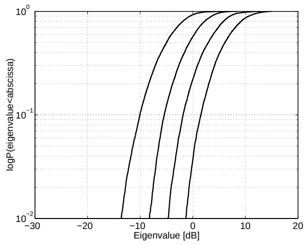
a) Picocell, Tx distance 0.7 λ



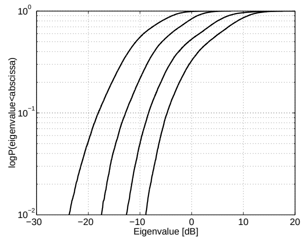
c) Microcell, Tx distance 0.5 λ



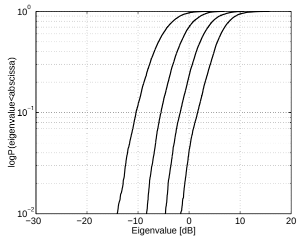
e) Macrocell, Tx distance 0.5 λ



b) Picocell, Tx distance 3.5 λ

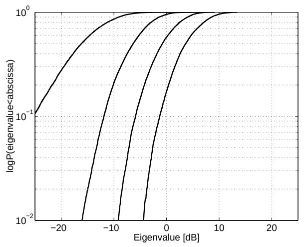


d) Microcell, Tx distance 2.5 λ

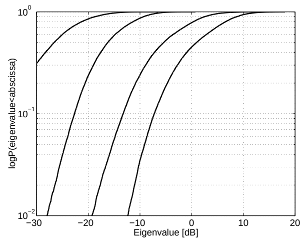


f) Macrocell, Tx distance 2.5 λ

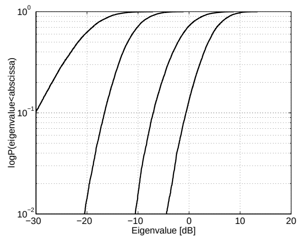
Figure 6: Effect of increasing the interelement spacing on eigenvalues. 8×4 dual polarized MIMO system, where one element consists of two orthogonally polarized feeds.



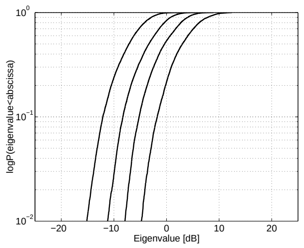
a) Picocell, 4 Tx channels



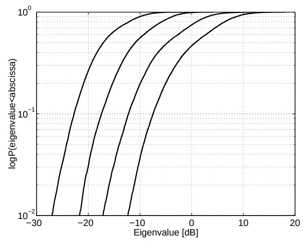
c) Microcell, 4 Tx channels



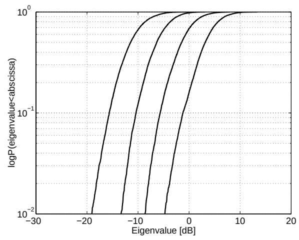
e) Macrocell, 4 Tx channels



b) Picocell, 12 Tx channels



d) Microcell, 12 Tx channels



f) Macrocell, 12 Tx channels

Figure 7: Effect of increasing the number of Tx channels on eigenvalues. 4 Rx channels used in all cases.

6 Conclusion

The variance of capacity values in the case of directive elements (*G*=7.8 dBi) of Rx arrays is larger than that of omnidirectional elements (*G*=2.15 dBi) in all investigated environments. At the picocell environment directive elements perform better than omnidirectional ones. AOA in azimuth direction is rather wide (Fig. 3a) and thus, all five Rx orientations of arrays with directive elements can offer significant capacity increment. Further, the Tx and the Rx were located at the same height and AOA in elevation direction is surprisingly narrow (Fig. 3b). Therefore, the directivity of patch antenna elements increases the achieved capacity. In addition to this the slightly different orientation of beams between antenna elements caused by spherical shape of array increases MIMO capacity as can be seen from the comparison of eigenvalue spread (Fig. 2a).

At the microcell environment AOA in azimuth direction is narrow (Fig. 4a) because the signal propagates in the street canyon. Therefore, only one of the five Rx orientations provides a good performance in the case of directive elements especially in crossroads where LOS situation occurs. In addition to this AOA in elevation direction is wide (Fig. 4b) and because of that the directivity of patch antennas is not maximally exploited. This situation is the most beneficial for the arrays of dipole elements compared to other investigated environments because of above mentioned reasons.

At the macrocell environment AOA is wide in azimuth direction (Fig 5a). However, in the latter half of the route some dominant signal components arrive at the azimuth angle of -50° − -120°. Like at the microcell case this situation is beneficial only for one orientation of Rx array in the case of directive elements. However, because of narrower AOA in elevation direction (Fig 5b) as compared to macrocell the array with directive elements performs slightly better than the array with dipole elements. No significant difference of MIMO gain between arrays is found in this environment.

Increasing the distance between Tx antenna elements increases resolution by narrowing the main beam, which results in decreased spread of eigenvalues and increased capacity. This effect can clearly be seen from the results of micro- and macrocell environments (Fig. 6b and c). Whereas, at picocell environment (Fig. 6a) the difference of results is minor probably for the reason of sufficient correlation stage caused by complicated propagation environment. Adding more elements at the Tx antenna configuration increases Tx diversity, which can clearly be seen as decreased spread of eigenvalues and sharper eigenvalue curve (Fig. 7). When comparing three environments, the smallest spread of eigenvalues is indoors if the results of chapters 4 and 5 are considered.

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