COMPARISON OF MEASURED MIMO CAPACITIES AT 2 AND 5 GHz

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ABSTRACT

MIMO radio channel measurements at 2 and 5 GHz frequencies are compared in terms of channel capacity. Both measurements are done in the same microcellular environment including line-of-sight and non line-of-sight samples with similar antenna array configurations. The comparison is done for dual-polarized 8x4 and 4x4 MIMO setups, which were chosen from larger measurement arrays by antenna selection. The results show that with higher frequency the multipath richness and capacity of the channel are slightly higher. However if the path loss difference is taken into account the 2 GHz frequency will result in higher capacity due to the smaller path loss.

INTRODUCTION

Multiple-input multiple-output (MIMO) systems are proposed as a way to increase spectral efficiency in future wireless communication systems. MIMO systems operating between 2 and 5 GHz will probably be utilized in the future. Standardization of MIMO WLANs is in progress - e.g. IEEE 802.11n standard, which will be applicable in both bands, maybe also in others. First commercial MIMO Wireless Local Area Networks (WLAN) operating at 2.4 GHz and 5 GHz frequency bands has already been presented. Mostly they are based on the IEEE802.11n pre-standard. Proposals for 4G radio interface include MIMO configuration as an option.

A MIMO radio system increases spectral efficiency, thus transmission capacity, by utilizing parallel transmission channels in the same frequency band through spatial signal processing. However, the number and strength of the available parallel channels depend heavily on the propagation environment. Lots of research has been done in this field, both theoretical and empirical. However the impact of the frequency of operation has not been studied much, a recent exception being [1], where indoor measurements were analyzed. The scope of this paper is to study and compare the attainable capacity and occurrence of parallel MIMO channels in a microcellular environment at two different carrier frequencies - 2 and 5 GHz.

DESCRIPTION OF THE EQUIPMENT AND THE MEASUREMENTS

Several radio channel measurement campaigns have been carried out with the radio channel sounder of Helsinki University of Technology (TKK). The sounder was first built for measuring single-input single-output (SISO) channels, but was later on extended to support MIMO measurements, first with 2.15 GHz and later with 5.3 GHz [2][3][4]. The transmitter part of the sounder transmits a known PN-sequence, and the channel impulse response is obtained by calculating the cross-correlation of the transmitted and received sequence, or signal. To support MIMO, both the receiver and the transmitter are equipped with fast RF switches. Measuring one complete wideband MIMO matrix takes about 1 ms, therefore it is possible to measure continuous mobile routes by sampling the channel while the receiver is moved slowly. The channel was sampled 4-5 times for every moved wavelength.

In this study we use MIMO measurements done in the same environment and with very similar antenna array configurations but with different frequencies. The propagation scenario was microcellular with both the transmitter and the receiver below the rooftop level. The measured data consist of continuous measurement routes in both line-of-sight (LOS) and non line-of-sight (NLOS) cases with distance of a few hundred meters from the base station. The measured data with 2 GHz and 5 GHz frequencies consist of 4500 and 9900 separate snapshots, respectively. See Fig. 1a for the map of the measurements.

In order to obtain narrow band channel matrices from the wideband measurements, noise floor was removed from the measured impulse responses with a threshold cut and a complex sum was taken from the remaining samples. The threshold was determined adaptively from the noise floor level. Signal to noise ratios of the measurements were typically around 20 dB.

Although the antenna arrays itself were slightly different between the frequencies, comparable arrays can be generated by choosing certain subsets of the whole arrays. The linear zigzag base station array which was used with 2 GHz frequency can be constructed as a subset of the planar 4x4 array used with 5 GHz frequency. The antenna separation in the base station arrays was 0.5λ in both directions. Similarly, the smaller 5 GHz semi-spherical array can be constructed as a subset from the 2 GHz full spherical array. The similarity of the arrays and the propagation environment is extremely important for the sake of fair comparison, since the capacities of MIMO systems depend on both antenna array configurations and propagation channels [5]. Otherwise the comparison is not rigid. Also the post-processing and normalization of the received power has to be exactly the same.

To perform the comparison, subsets of the arrays were used to produce arrays of realistic size. Fig. 1b gives illustrations of the antenna arrays and the generated array setups by antenna feed selection. 4x4 and 8x4 MIMO setups were chosen for the comparisons, first number presenting the number of feeds in the fixed base station acting as the transmitter. All setups were dual-polarized at both ends of the link. For 8 transmit feeds all 4 dual-polarized elements were used, and for 4 transmit feeds elements 1 and 4 were used. At the mobile end, the setup was chosen to be two nearby placed dual-polarized elements, which is close to an array that could be implemented in a real small-sized MIMO radio. The geometries of the arrays were the same with both frequencies.

Since the antenna array elements were directive also at the mobile end, receiving array subsets were constructed to several directions. Due to the spherical and symmetric shape of the arrays, this could be done and exactly similar arrays could be constructed to 5 different directions. All the directions are included as independent samples in the comparison. This corresponds to rotating the mobile array in every measurement position and to get average overall user orientations.

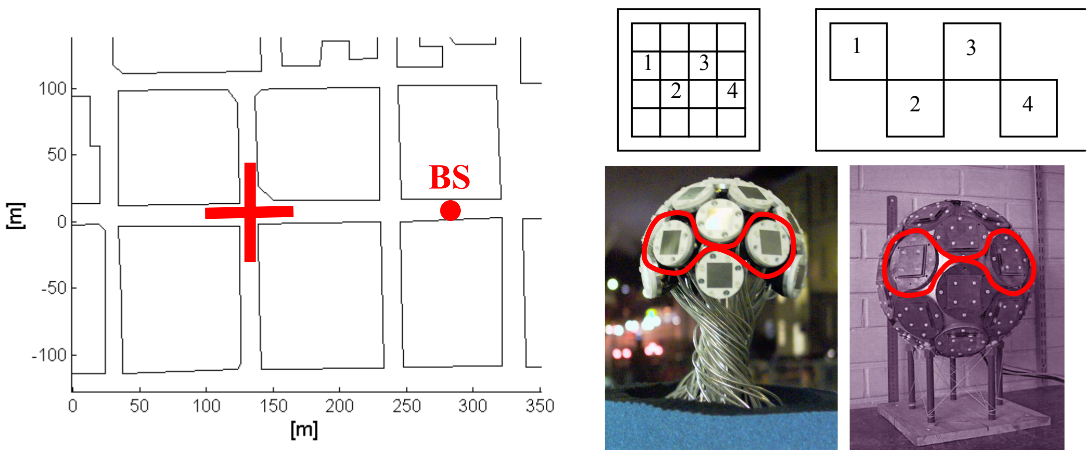

Fig. 1. (a) *Map of the measurement routes and the BS location (b) used antenna arrays and antenna selections.*

COMPARISON METHODOLOGY AND DEFINITIONS

When considering the attainable MIMO capacity, several factors can be taken into account. In addition, the important factors may depend on system level implementations – e.g. if there is power control which keeps a constant SNR or if the SNR is directly a function of path loss if no interference is assumed. These result in different capacities. Also the capacity may be different in uplink and downlink direction; although the radio channel is reciprocal, the transmitted powers or numbers of active elements may not be equal. Because of these reasons, the normalization of the channel matrices has to be considered carefully.

All 4 dual-polarized transmitting elements and a complete ring of 5 dual-polarized receiving elements were used as an omnidirectional reference for the power normalization. The idea of this normalization was that the elements in the receiving array form a uniform ring of elements over the azimuth angle. Therefore the azimuth directions of the arriving powers do not affect the normalization.

When moving along the measured route, the receiver observes a fading radio channel. To preserve the small-scale fading of the channel, the power normalization was done by removing a sliding average of the powers. The window length for the averaging was chosen to be 5.5 m – which corresponds to ~40 λ or 200 snapshots with the 2 GHz carrier frequency and to ~100 λ or 500 snapshots with the 5 GHz carrier frequency.

The normalized channel matrices, denoted by H, can directly be used to calculate the outage capacities by applying the MIMO capacity equation (1) presented in [6] to each instantaneous channel matrix.

$$C = \log_2 \left| I + \frac{\rho}{n_T} HH^* \right| \text{ [bit/s/Hz]} \quad (1)$$

where ρ denotes the SNR. Outage capacities were calculated for SNR range 10-30 dB from the mean power in the area – that is the normalization power – and for 50%, 90%, and 99% outage levels. Outage capacity is defined so that, e.g. for 90% outage level the attainable capacity at least the outage capacity for 90% of the time.

In the results the main questions are, whether the higher frequency provides more capacity through higher multipath richness – and if it does, will it be lost due to the expected higher path loss. From the measurements it was concluded that the path losses are the same for both frequencies except for the constant difference directly due to the carrier frequency. With the 2.15 GHz and 5.3 GHz frequencies there is a constant $\Delta P_L = 20\log_{10}(2.15 \text{ GHz}/5.3 \text{ GHz}) = -7.8$ dB difference in received powers when same transmit powers are used.

The multipath richness is studied with two separate analyses. We first calculated the relative strengths of the instantaneous eigenvalues of the H matrices by normalizing the values by the strongest eigenvalue of the snapshot. This allows studying intuitively the strengths of the available parallel channels. Further, we utilized a parameter $I_{mux}=K^*\log_2(m_g/m_a)$ where m_g is the geometric mean and the m_a is the arithmetic mean of the eigenvalues, and $K=\min\{n_T, n_R\}$. presented in [7]. The I_{mux} directly shows how many bit/s/Hz are lost compared to the optimal case, when all the eigenvalues are equal, and therefore reflects the efficiency of the spatial multiplexing due to the multipath richness.

RESULTS

In the analysis we concentrated on 8x4 and 4x4 setups and the differences between the frequencies. All the results are divided into LOS and NLOS cases, since the dominating propagation phenomenon is considered to be very different in these different cases. Outage capacities of a 4x4 MIMO system with SNR levels from 10 to 30 dB and outage levels 50%, 90%, and 99% are presented in Fig. 3 for microcellular NLOS and LOS environments. Both studied frequencies, 2 and 5 GHz, are included in the same graphs. The path loss difference has not been taken into account in the Figs.

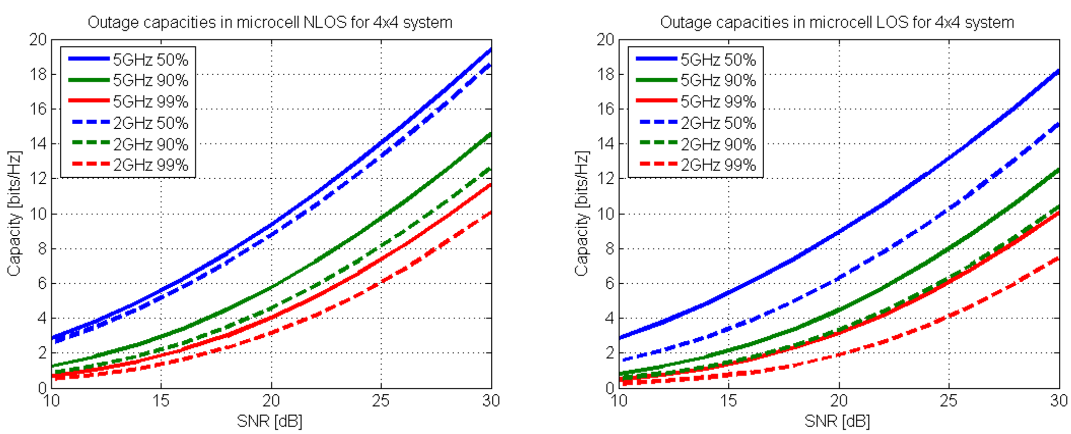

Fig. 3. *Outage capacities for a 4x4 system in (a) NLOS microcell and (b) LOS microcell.*

In the results the outage capacities are slightly higher with the higher carrier frequency. This happens in both LOS and NLOS environments, but surprisingly the capacity grows more in the LOS environment. The capacities in the NLOS environments are a bit higher than in the LOS environments. Numerical values for outage capacities for 90% probability level are presented in Table 1 for different cases and SNR values. Somewhat contradictively, in another study conducted indoors higher capacities have been reported for the lower frequency [1].

The strengths of the eigenvalues were studied and plotted as CDFs of the relative strengths of each eigenvalue. The graphs show the relative strengths of the available parallel MIMO channels due to the scattering richness. For an example, see Fig. 4a for the ratios of the eigenvalues in a NLOS 4x4 case. The strongest eigenvalue is always one. Curves for 4x4 i.i.d. are included for reference. The eigenvalues with 5 GHz frequency are a bit stronger than with 2 GHz. The 4th eigenvalue is much weaker than the others. When the 8x4 setup was used instead of the 4x4, the results were similar except that the 4th eigenvalue is much stronger, up to 5-10 dB in lower probability levels. This is due to the increased diversity of the larger array and happens similarly with both frequencies and largely explains the slightly higher capacities with the 8x4 setup over the 4x4 setup.

Table 1. *Outage capacities for 90% outage level for 8x4 end 4x4 MIMO systems with 10-30 dB SNR.*

SNR [dB]	LOS 8x4 2 GHz	LOS 8x4 5 GHz	LOS 4x4 2 GHz	LOS 4x4 5 GHz	NLOS 8x4 2 GHz	NLOS 8x4 5 GHz	NLOS 4x4 2 GHz	NLOS 4x4 5 GHz
10	0.5	0.8	0.5	0.8	0.9	1.3	0.9	1.2
20	3.3	4.4	3.3	4.5	4.6	6.0	4.6	5.7
30	10.5	12.8	10.4	12.5	12.9	15.5	12.6	14.6

Fig. 4b shows the loss of capacity compared to the ideal case where all eigenvalues are equal. Smaller loss in capacity means higher multipath richess of the channel or smaller eigenvalue dispersion of the channel. It can be seen that the richess is higher with higher frequency, as can also be seen from the strengths of the eigenvalues.

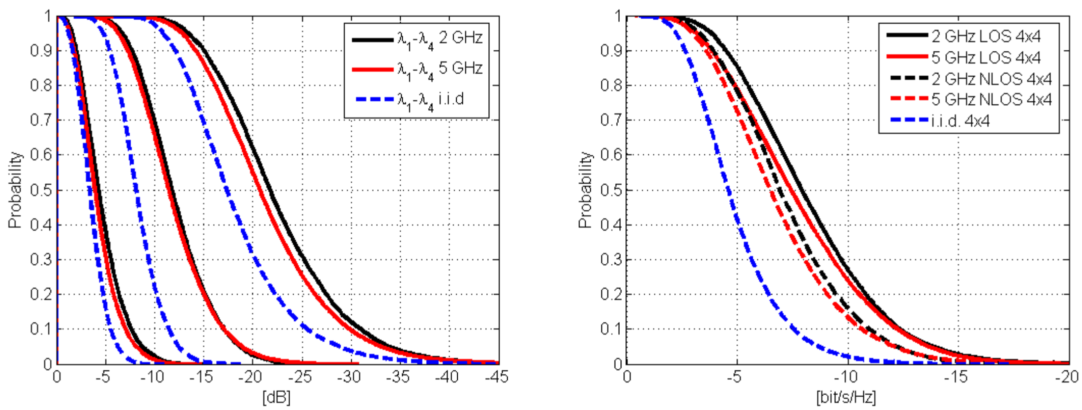

Fig. 4. (a) Ratios of eigenvalues compared to the strongest in NLOS (b) loss of capacity compared to equal eigenvalues.

CONCLUSIONS

The results show that the attainable MIMO capacity is slightly higher with higher frequency in microcellular environments. With 5 GHz frequency compared to 2 GHz the same capacity can be achieved with ~3 dB lower SNR if 90% outage level is used. The difference is due to the higher multipath richness at 5 GHz. However, if the difference in path loss is taken into account and the same transmission power and noise power levels are assumed, the capacity of 2 GHz system is higher since the path loss with 5 GHz is ~8 dB higher resulting in that much lower SNR in the receiver. Therefore the capacity loss due to the path loss outweighs the benefit from the higher multipath richness.

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