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## Downlink Cooperative MIMO in Urban Macrocell Environments

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## Abstract

In this paper, we study the potential benefits of downlink cooperative MIMO systems in cellular macrocell environments using a coherent measurement setup. Our results reveal that one of the two measured routes can leverage comparable signal strengths from the cooperating base stations to the mobile station and provide up to two-fold single user bitrate gain at the 50% cumulative probability level.

## Introduction

Despite the huge potentials of MIMO technology, its actual performance benefits largely depend on the intended application. In cellular systems, both the mobile station (MS) and the base station (BS) can be the limiting factor of MIMO performance. For the MS, the primary issue is compactness, which limits the number of antennas that can be implemented for achieving independent fading across the antennas. Recent studies on the topic focus on the use of different techniques that can reduce the coupling among closely spaced antennas or harmonize the antenna-channel interaction [1].

On the other hand, BSs often have limited angular spread, due to their elevated positions. The angular spread problem can be addressed by distributing the antennas over multiple BS sites. Recent papers studied the behavior of distributed MIMO antenna systems in the context of intra and inter BS site correlation properties [2], [3], channel rank enhancement [4], capacity improvements [3], [4] and inter BS interference vs cooperation [5].

In this paper, we investigate the potential benefits of a cooperative MIMO system by evaluating the downlink single user performance for two extensive drive routes in an urban macrocellular environment. Three BS sites are employed. Our motivation is the following: Given that different path loss and shadow fading can contribute to large variations in signal strengths from different BSs, it is of interest to operators to determine if the increased cost and complexity of implementing a cooperative cellular system is justified.

To our knowledge, this is the first investigation of its kind for macrocell environment based on coherent measurements of multiple base stations to single (multiple-

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antenna) mobile channels. A similar macrocell measurement campaign involving two base stations and one mobile user was performed in [2]. However, due to equipment limitations, the measured channels in [2] had phase uncertainties. On the other hand, the coherent multi-BS measurements in [5] were performed for a microcell environment.

## Measurement Setup and Channel Normalization

The considered urban macrocell environment is the built up area within Kista (also called "Mobile Valley"), Stockholm, Sweden (see Figure 1). Three BS sites of one antenna each (of 45° linear polarization) are used. The main lobe of each BS antenna pattern is approximately directed towards the centroid of the triangle formed by the BSs at its corners. The MS is a measurement van, with two dipole and two loop antennas that are mounted on top of the van. The BS transmits reference symbols over a bandwidth of 20 MHz for a center frequency of 2.66 GHz. These are measured by the MS and are used to estimate the $4 \times 3$ MIMO channel matrices over 432 frequency bins. The MS continuously logs the channel, as the van drives along a pre-defined drive route. Two drive routes are measured, and they include line-of-sight, obstructed line-of-sight, as well as highly shadowed scenarios. The GPS positions of the MS are logged simultaneously with the channels, so that each channel measurement can be associated with a geographical coordinate.

In order to study the benefit of BS cooperation, the measured MIMO channels at each measurement point are normalized by the BS-to-MS SIMO link with the strongest power. Therefore, the reference signal-to-noise ratio (SNR) for channel capacity is assumed to apply to the strongest BS-to-MS link. The total transmit power of the three BSs is then set at thrice (or 6 dB) higher than that needed to produce the reference SNR for the strongest link. For the case of waterfilling, the transmit power of the three BSs can be shared in any proportion.

## Results and Analysis

The single user capacity performance of four different system setups and two drive routes are given in Figure 2. In order to mitigate fast fading in the capacity results, moving average is performed over 10 wavelengths. It can be seen from Figures 2(a) and 2(b) that even at the low SNR of 0 dB, optimal power allocation with waterfilling is able to provide about twice the capacity over the entire routes, as compared to the single BS-MS case. It should be noted that the increase in capacity is largely an effect of the three times higher total transmit power. The minimum level of the red curves indicates where the gain is solely a result of this power increase. However, in practise, this strategy increases interference in the network. Nevertheless, equal transmit power allocation is also beneficial for some portions of route 1 and most of route 2. By plotting the capacity of the best BS-MS link at each measurement position assuming that the other BS-MS links are interferers, it is confirmed that the benefit of equal-power cooperation is maximum when the capacity with interference is at its lowest points, indicating that the MS receives comparable signal powers from multiple base stations. As can be expected, the capacity gain of waterfilling

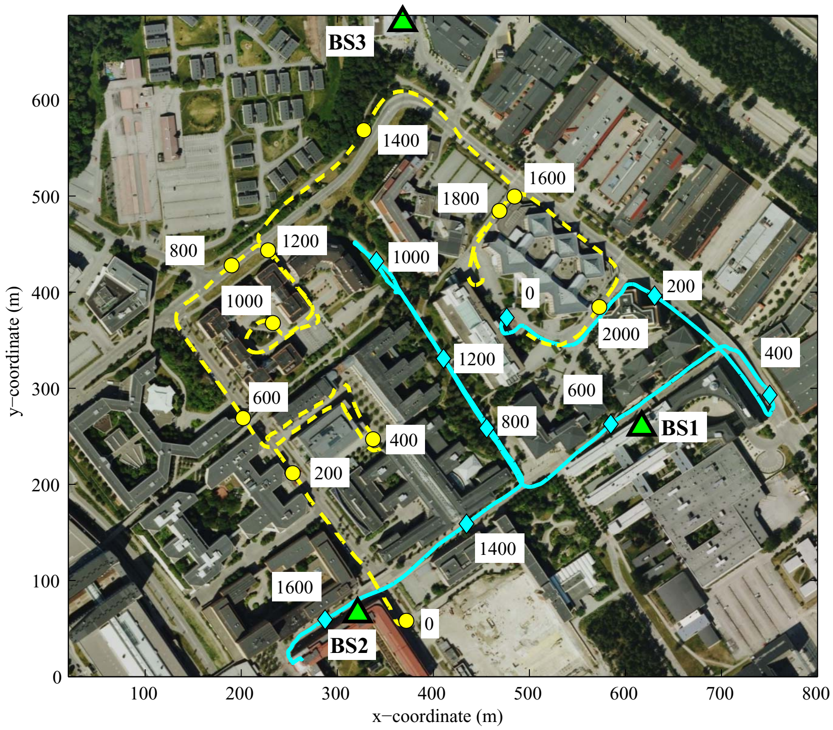


Figure 1: Location of BSs and route 1 (- -) and route 2 (—) of MS. Distances (in meters) from starting points are indicated by ● and ♦ markers.

over equal-power allocation is small at the higher SNR of 20 dB, as seen in Fig 2(c) and 2(d). The capacity gain of cooperation is even more pronounced, since the equal power strategy is now approximately optimal.

## Conclusions

In this paper, some preliminary results from a multi-base station measurement campaign are presented. The focus is on evaluating downlink capacity improvements for cooperative MIMO systems in urban macrocell environments. Our findings indicate that cooperation can facilitate significant capacity gains, motivating potential deployment of such distributed MIMO systems. In particular, one drive route gives more than 100% mean capacity gain at the 50% cumulative probability level. It should be noted that the herein presented results focus on capacity for a single user. A more detailed analysis, including multiuser capacity, is planned for a journal publication.

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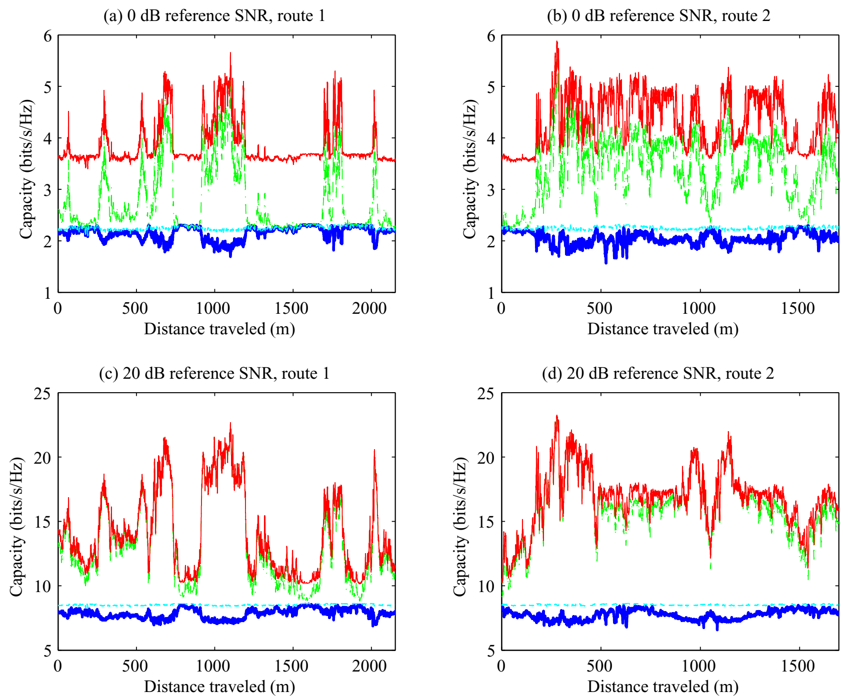


Figure 2: Capacity with interference for best link (—) ≤ Capacity for best single user link (- -) ≤ 4 × 3 capacity for equal power allocation (- · -) ≤ 4 × 3 capacity for waterfilling (—).


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