Results from a MIMO Channel Measurement at 300 MHz in an Urban Environment

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ABSTRACT

Wireless multiple-input multiple-output (MIMO) communications using the 300 MHz band is attractive for peer-to peer communications because it combines the good coverage of a low-carrier-frequency system with the high data rates enabled by MIMO. In order to design and evaluate such systems, knowledge of realistic propagation conditions is required.

In this paper, we present results of a MIMO channel measurement campaign for 300 MHz peer-to-peer systems. Measurements are performed in an urban environment, using antenna arrays mounted on the roofs of two cars. We present the MIMO capacity along the measured route and compare this to that of a conventional single-input single-output (SISO) system. In the measured scenario, a 7x7 MIMO system typically has a capacity 4-6 times higher than that of a SISO system.

1.0 INTRODUCTION

The Swedish Armed Forces is undergoing a process of change in which mission-based force is developed and ready to be deployed anywhere trouble arises. During the Cold War, the Swedish Armed Forces' most important tasks were to protect Sweden's borders and being ready to combat an armed attack. The world looks very different today and the tasks and capabilities are changing to meet new threats that have arisen. Today it is essential to achieve battlefield awareness and information superiority for mission success. The services needed in a mobile tactical wireless network to achieve this have high demands on communication capacity. For instance, the distribution of situation awareness data, which is likely to be a prioritized service, will lead to an increased data flow in the command and control system. The increased demands on services provided in the network require higher capacity both in the tactical communication network and on individual communication links. Multiple-Input Multiple-Output (MIMO) antenna systems is a promising technique for achieving substantially increased capacities and robustness in future tactical wireless networks.

The Swedish Armed Forces' international operations are becoming increasingly important, with international forces split into a number of missions in various parts of the world. The environment the forces are working in can be fundamentally different ranging from desert to urban multi-million cities. One of the more challenging environments for a wireless tactical communication system is the urban environment with problems such as shadowing and multipath.

Multiple-input multiple-output (MIMO) systems have been shown to offer a large capacity increase over single-input single-output (SIMO) systems for wireless communication in fading environments [1, 2]. In theory the capacity increases linearly with the minimum of the number of transmit and receive antennas.

However, in real environments, the achievable capacity depends on the radio-channel characteristics. For tactical military wireless communication, frequencies in the upper VHF and lower UHF range could be very attractive. The propagation characteristics in this band are benign, because due to the large wavelength waves can easily diffract around obstacles [3]; this property is especially important in peer-to-peer networks, where line-of-sight (LOS) exists only rarely. Furthermore, the frequency is high enough to allow terminals with multiple antenna elements, at least for vehicular terminals. It is therefore of high interest to analyze the channel properties and investigate the potential of MIMO peer-to-peer systems operating at frequencies around 300 MHz. Most of the MIMO channel measurements in the literature have been performed at significantly higher frequencies (mostly 2 and 5 GHz) for mobile or wireless personal communication systems.

The remainder of the paper is organized as follows; Sec. 2 describes a measurement campaign for MIMO channels. In Sec 3. the measured transfer function is shown and compared to a flat-earth model. The temporal behaviour of the capacity is shown in Sec. 4. Also a connection between received power and capacity is analysed in Sec. 4. Finally, the conclusions in Sec. 5 wrap up the paper.

2.0 MIMO MEASUREMENT CAMPAIGN

In this paper we present results from a MIMO measurement campaign at 300 MHz. The measurements analyzed in this paper are a part of a larger measurement campaign in Linköping, consisting of three different transmitter locations and several receiver routes. In this paper, results from one transmitter location and receiver routes within a limited area are presented.

During the measurements the propagation was measured between terminals with low antenna heights. The transmitter (Tx) and the receiver (Rx) were both placed in cars with the antenna arrays mounted on top of each car. The antenna heights were approximately 1.8 and 2.1 meters above the ground for the Tx and Rx, respectively. The distance between the Tx and Rx ranged from 50 m to 250 m. During the measurements, the Tx was stationary, at the Linköping Castle courtyard, about 18 meters from the castle, while the Rx was driven along seven measurement routes. In figure 1 the Tx position is marked with a circle labeled Tx and the routes are labeled R1-R7. The driving directions are indicated by arrows.

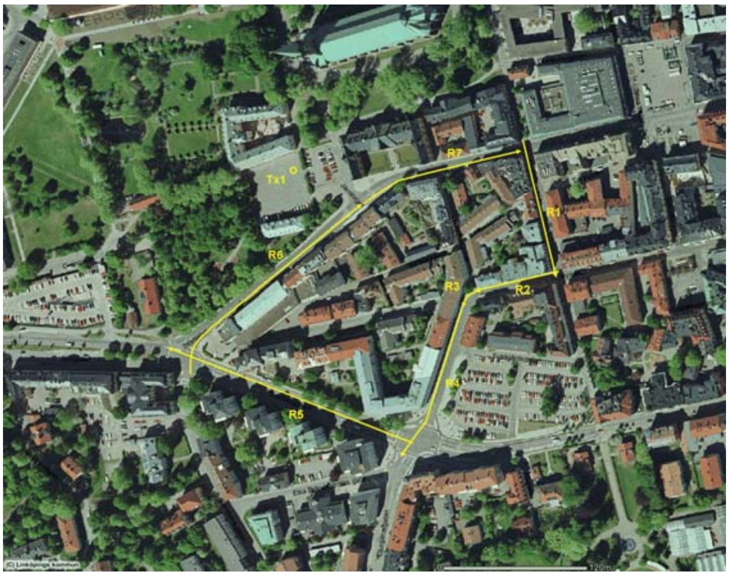


Figure 1. Aerial photograph of the measurement area.

The seven routes enclose an area of several blocks in central Linköping. The buildings are typically 3 to 6 storey houses. For the majority of the Rx positions, the LOS path between Tx and Rx are blocked by buildings. LOS, or near LOS, propagation conditions only occur at the last part of route 6 and at the beginning of route 7. The ground elevation vary about 7 meters within the area, with the highest position at the end of route 5, and the lowest at the end of route 1, which has a small downhill slope. Route 2, 3, and 4 are almost flat, while route 5 is uphill and has its steepest slope half-way along the route. Route 6 is slighly downhill, and so is the first quarter of route 7, which latter part turns into a rather steep slope down to the end of the route. The lengths of the different routes (R1-R7) are 120, 73, 19, 128, 214, 206 and 138 m, respectively. In the following, when we refer to distances, we mean driving distances along the route, not distance between Tx and Rx.

The channel measurements were performed with the RUSK LUND channel sounder [4,5] owned by Lund University, Sweden. The channel sounder sequentially measure the transfer function between all combinations of transmit and receive antenna elements within a short time. In our measurements, two identically vertically polarized antenna arrays were used at the transmitter and the receiver. Each antenna consists of a seven element uniform circular dipole array (UCDA), with one additional center element located in an elevated position with respect to the UCDA. Additionally, a cylindrical reflector is placed in the center of the UCDA giving each element a directional radiation pattern. The measurements were performed at centre frequency 285 MHz with a signal bandwidth of 20 MHz divided into 257 frequency subchannels.

3.0 TRANSFER FUNCTION

The mean channel transfer function between the transmitter and receiver was calculated for all positions along the measured routes by averaging the received power over all frequency sub-channels, and over all combinations of transmitter and receiver antenna elements. In figure 2, the measured mean transfer function is shown, as well as the transfer function obtained from a simple flat-earth (two-ray) propagation model whose propagation loss is [3]

$$L_{FE} \approx \left(\frac{d^2}{h_{Tx} h_{Rx}} \right)^2 ,$$

where d is the propagation distance, h_{tx} and h_{rx}, the transmitter and receiver antenna height, respectively. In our measurements d varies between 20 and 250 meters and the antenna heights are 1.8 and 2.1 meters, as mentioned earlier.

The measured transfer function for all routes is shown in figure2. In order to limit the number of subfigures route 2, 3, and 4 are merged and shown in the same plot; this also applies to route 6 and 7. The measurements start at route 1 in an intersection that the receiver moves over and then continues on a street surrounded by buildings. The measured transfer function decreases rapidly in the beginning of the route as the receiver is shadowed by the building. On route 2, 3 and 4 the variations in the transfer function over distance is low. The measured and modeled transfer functions are quite similar. However, the measured transfer function is about 30 dB lower than the modeled. This can be expected since the conditions are non LOS (NLOS) and the direct path is shadowed by several buildings on all parts of route 2-4. On route 5 there are larger variations in the measured transfer function. Also, the difference between the measured and modeled transfer function varies over the route and becomes smaller at the end of the route. An explanation for this could be that at the end of route 5 there are no buildings near the receiver in the direction of the transmitter. A building shadows the direct path between the transmitter and receiver at the first part of route 6. As the receiver moves towards the transmitter and the shadowing building the difference between the measured and modeled transfer function increases. At a distance of about 150-160 m the receiver moves clear of the shadowing building and there is LOS. This shows as a rapid change in the transfer function. At the end of route 6 and beginning of route 7 there are no buildings between the transmitter and receiver. However, there are some deciduous trees near the road at the end of route 6 and these can affect the measured transfer function. There is also a thin hedge, about 2-3 meters high, at the transmitter side. Since the measurement was performed in the middle of September the trees did still have some leafs. After about 25 meters on route 7 the LOS component is shadowed by a building. This manifests itself as a larger difference between the modeled and measured transfer function as the receiver moves along route 7. However, there is no abrupt change in the transfer function. The explanation for this could be that the receiver slowly moves into the shadow from the building and at the same time there are contributions from reflected rays. Hence, the conditions could be described as a smooth transition from LOS, via near LOS, to NLOS conditions.

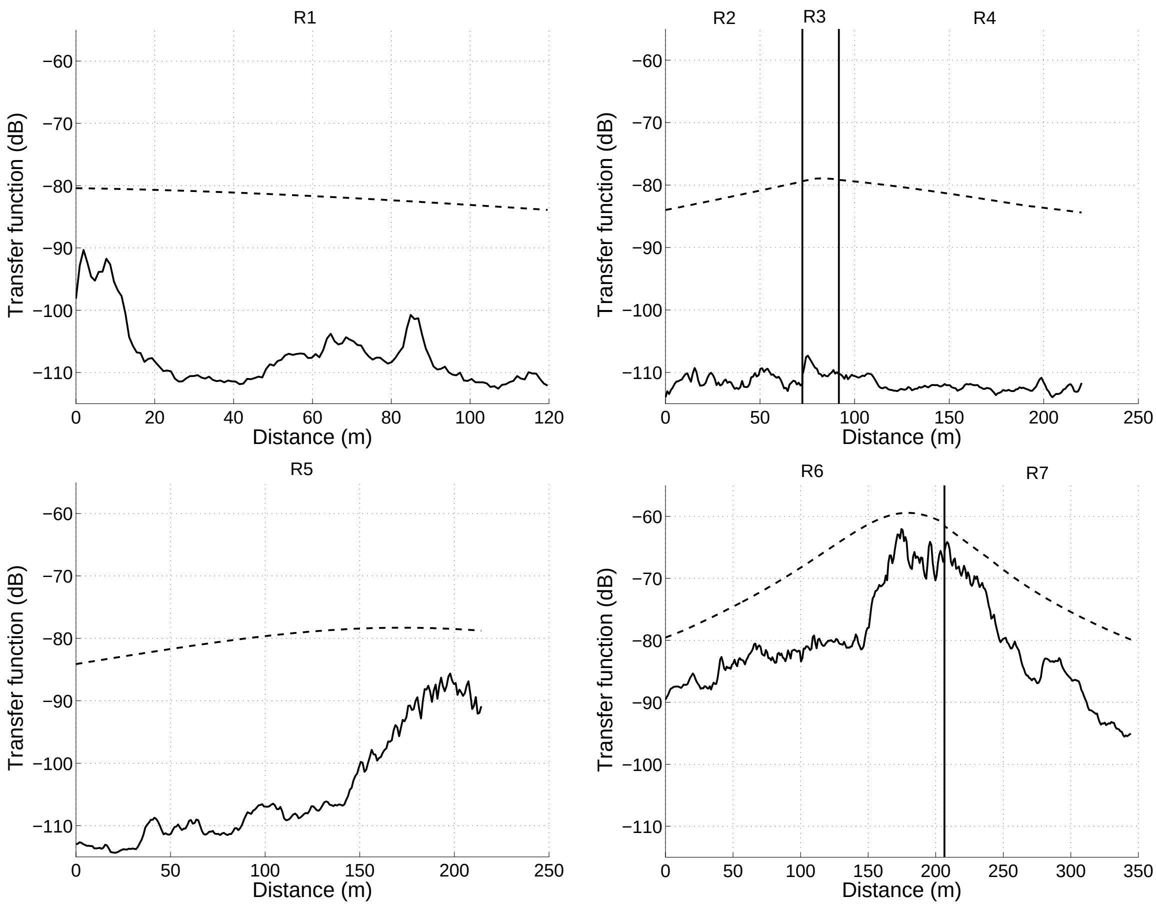


Figure 2. Mean channel transfer functions vs. driving distance along the routes. The solid lines are measured values and the dashed lines are for a flat earth model.

The difference between the modeled and measured transfer functions is plotted in figure 3. The flat-earth model is a simple model of the dependence of the distance between the transmitter and receiver and assumes LOS. Hence, the difference between the modeled and measured transfer functions should capture the part of the measured transfer function that depends on loss due to shadowing effects and give an indication of how deep into the shadowed region the receiver is. For example, the LOS conditions at the end of route 6 and beginning of route 7 shows as a small difference between the measured and modeled transfer function. It can also be noted that the flat-earth model yields an optimistic estimate of the received power for all measurement routes.

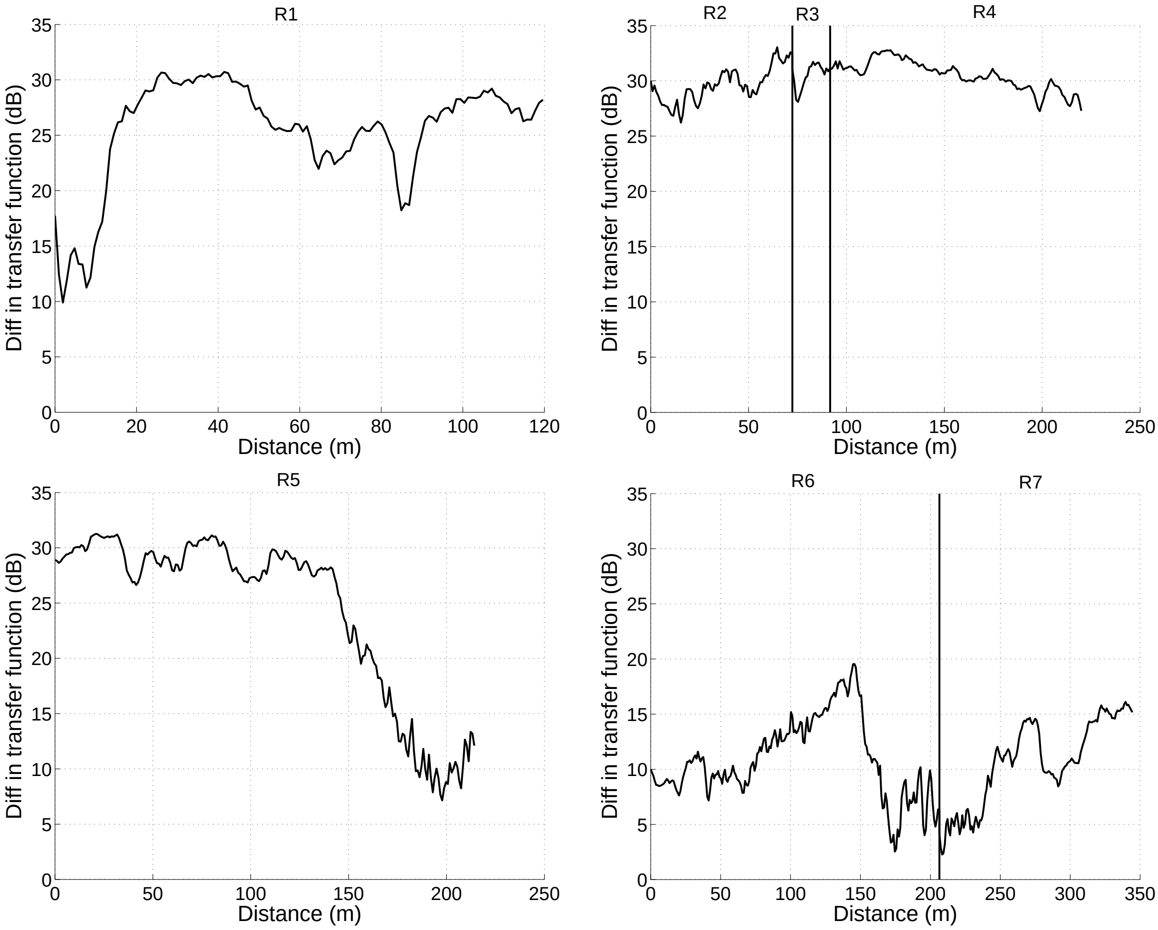


Figure 3. The difference between the modeled and measured transfer functions vs. driving distance along the routes. The transfer function is modeled with a flat-earth model.

4.0 CAPACITY

From the measured channel transfer matrix, *H*, the capacity can be calculated both for a MIMO-system and a SISO-system. It is interesting to compare the capacity for the two systems in order to see the possible capacity gains for a MIMO-system.

The narrowband MIMO capacity for a transmitter without channel state information is given by [2]

$$C_{MIMO} = \log_2 \det\left(I + \frac{\rho}{n_{tx}} HH^* \right),$$

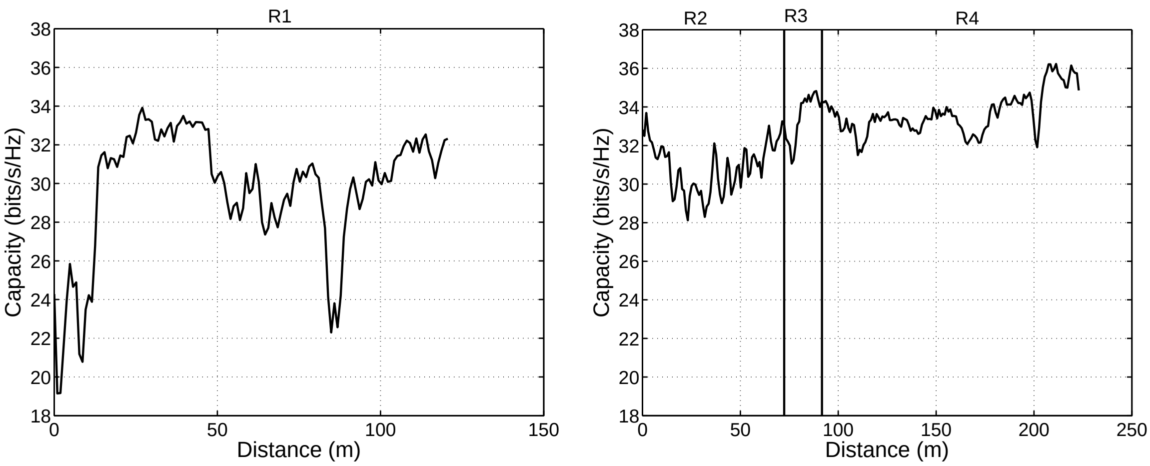
where det(·) is the determinant operator, $(\cdot)^*$ the Hermitian transpose, n_{tx} the number of transmit antennas, ρ the SNR, and I is the identity matrix. H is normalized such that the expected value of its squared Frobenius norm $E\left\{\|H\|_F^2\right\} = n_{\text{rx}} n_{\text{tx}}$, where n_{rx} is the number of receive antennas.

4.1 Results

The temporal behavior of the capacity (as a result of the receiver movement) is evaluated at a fixed SNR of 20 dB. The capacity along the routes is shown in figure 4. The mean capacity for the routes are 30, 31, 34, 34, 32, 29 respective 24 bits/s/Hz. For a corresponding SISO-system the mean capacity for the routes are about 6 bits/s/Hz. Hence, in the measured scenario, a 7x7 MIMO system typically has a capacity 4-6 times higher than that of a SISO system. Theoretically, the MIMO capacity gain for a channel transfer matrix with independent Rayleigh fading entries is 7 times the SISO capacity for a 7x7 MIMO system.

Comparing the capacity with the transfer function along the routes, the capacity tends to be higher when the transfer function is lower. See for example the low capacity at the beginning and after about 85 meters at route 1 and compare with the high transfer function at the same measurement points. The increase in the transfer function can be explained by the presence of gaps between buildings at both sides of the street. Another example of the dependence between the transfer function and capacity is the last part of route 6, after 150 meters, where the capacity decreases rapidly at the same time as the transfer function increases. This can be explained by the fact that the propagation conditions changes from NLOS to LOS. However, even for LOS conditions, i.e. last part of route 6 and route 7, the capacity is about 22 to 26 bits/s/Hz which is rather high, (compared to a SISO capacity of approximately 6 bits/s/Hz). The high capacity even for LOS conditions is an indication of presence of multipath due to reflections in buildings.

As mentioned previously, the difference between the modeled and measured transfer functions should capture the part of the measured transfer function that depends on diffraction or reflection of the waves. Hence, for a case when the difference between the transfer functions is small, i.e. LOS conditions, low capacity could be expected. Moreover, when the difference between the transfer functions is larger higher capacity could be expected. The major trends in the capacity curves can also be found in figure 3 where the difference between the modeled and measured transfer functions is shown. For example the local minimum in capacity at 0-10 m and 85 m at route 1 can also be found in figure 3. It can be concluded that the capacity for fixed (normalized) SNR experience stronger correlation to the difference between the modeled and measured transfer functions than to the measured transfer function only.



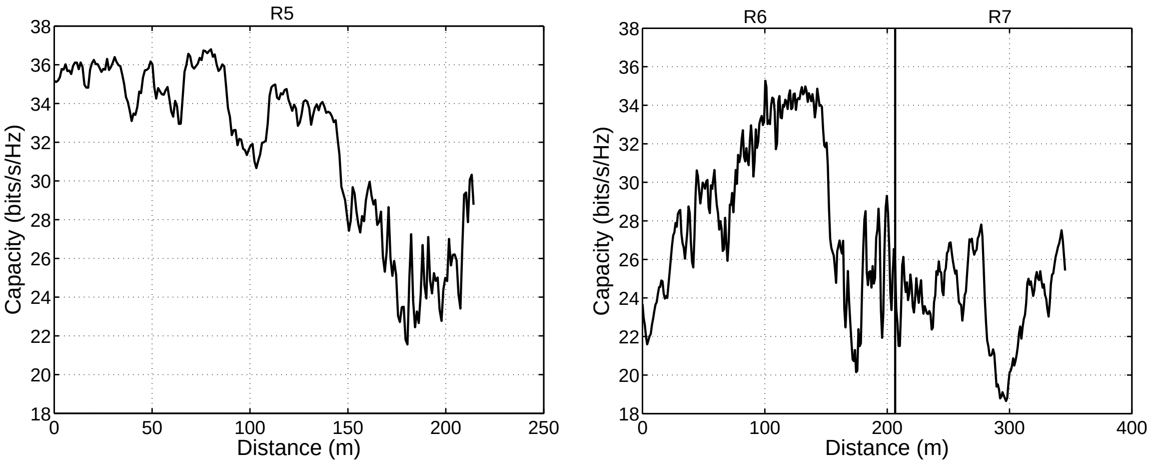


Figure 4. Mean capacity vs. driving distance along the routes for a fixed mean SNR of 20 dB.

5.0 CONCLUSIONS

In this paper, we have presented results from a MIMO peer-to-peer system channel measurement at 300 MHz in an urban environment. The measurements were performed in urban environments, using antenna arrays mounted on the roofs of two cars. For a channel transfer matrix with independent Rayleigh fading entries, the capacity increases linearly with the minimum of the number of transmit and receive antennas. However, in real environments, the achievable capacity depends on the radio-channel characteristics. We present the MIMO capacity along the measured route and compare this to that of a corresponding single-input single-output (SISO) system. In the measured scenario, a 7x7 MIMO system typically has a capacity 4-6 times higher than that of a SISO system. It is shown that there is a correlation between the capacity and the measured transfer functions. Even stronger correlation appears between the capacity and the difference between the flat-earth and measured transfer functions.

6.0 REFERENCES

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