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# Model-Based Investigation on MIMO Channel Capacity in Main Street of Urban Microcells

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## 1 Introduction

The increasing demand for wireless communications has driven current systems to their limit capacities. In addition to that more services that require high data rates are expected by users. One way to increase the capacity is to shrink the cell to smaller ones. This has led to the concept of microcell. The high data rates demand wide bandwidth that is very scarce and expensive. Therefore, new technology on air interface techniques has to be developed. The new promising direction is multiple-input multiple-output (MIMO) concept that has shown astonishing increase in spectral efficiency [1].

Design of MIMO wireless communication systems requires detailed channel characterization. The more detailed knowledge we know about the propagation channel leads to a successful design of communication systems. Channel characterization can be carried out by field measurements, e.g. [2], or model-based. The field measurement is costly, time consuming and the results are site dependent. It also needs skilled personal. Due to the difficulties of measurement-based characterization, many researchers have used model-based characterization, e.g. [3]. The advantage of model based analysis is the flexibility in testing the influence of different parameters that can not be controlled in field measurements.

In this work, we present model-based study that investigates the influence of environment parameters on capacity of MIMO channel. The investigated parameters are street width, wall electrical characteristics and antenna array height as well as inter-element spacing. This investigation is carried out for both vertical polarization (VP) and horizontal polarization (HP).

## 2 Propagation channel model

A spatial variant multi-ray propagation model for main street radio wave propagation in a city street grid is developed in [4]. The propagation channel model is used in this study because it takes into account several physical environment parameters. The transfer function between $j^{th}$ transmit element and $i^{th}$ receive element is given by:

$$h_{i,j} = \sum_{k\equiv(S,g,m)} \Gamma_{i,j,k,VV,HH} \frac{\lambda}{4\pi r_{i,j,k}} \exp(\frac{-j2\pi}{\lambda} r_{i,j,k}) \qquad (1)$$

where a ray $k$ is represented by a set of three integers, $S$ for two sidewalls on the street, $g = 0, 1$ for ground reflection order, $m$ wall reflection order $m = 1$ up to $N$, $\Gamma_{i,j,k,VV,HH}$ is the $k^{th}$ ray co-polarized reflection coefficient for VP and HP,

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respectively, $r_{i,j,k}$ is the path length and $\lambda$ is the wave length. The ray parameters such as angle of arrival (AOA), angle of departure (AOD) and path length are given in closed form expressions. Details can be found in [4].

## 3 Results and discussion

The geometry of the urban microcellular environment under study is depicted in Figure 1. The base station (BS) is mounted below the rooftops with antenna height 8.7 m. A mobile station (MS) with antenna height 1.6 m moves from point A to point B. Through out the traveling route, channel realizations are computed every 0.1 m. The later presented simulation results were carried out at frequency 2 GHz with building street surface electrical parameters, relative permittivity $\epsilon_r = 5$ and conductivity $\sigma = 0.005$ S/m. The multipaths are simulated till $7th$ reflection order. Since one reflection order results in about 5 dB loss, higher reflection orders than 7 result in very weak paths that can not be detected by the current measurement systems. The MIMO setup is $4\times4$ uniform linear array (ULA) at both ends with $0.5\lambda$ inter-element spacing and broadside orientation. The channel capacity is calculated as in [1] with 20 dB average signal to noise ratio.

The environment parameter street width, has clear influence on spatial and temporal characteristics of multipath components. The wide street width will result in longer delay, large AOA and AOD and the vise versa for narrow street. It is of interest of this work to investigate the impact of this parameter on MIMO channel capacity. Figure 2 shows the mean capacity as a function of the street width. It can be noticed that higher MIMO channel capacity is obtained with VP. This is can be explained due to lower loss of multipath components from wall reflection compared to HP. It can be noticed that for both polarizations low capacity is obtained in narrow streets (2-5 m) and increases with street to some limit. For VP the highest capacity, about 19 b/s/Hz, is achievable at street width between 40 to 60 m. After 60 m street width the capacity starts to decrease slightly. The same trend is observed for HP, where the highest achievable capacity is about 18 b/s/Hz. The increase of MIMO capacity with street width can be explained due to the higher angular spread, which results in uncorrelated signals at antenna elements. For very wide street width the reflected path will suffer large attenuation due to very long propagation path length and at almost right angle reflection at wall surface, which causes a high loss and consequently less capacity.

The importance of studying the effect of wall electrical parameters on MIMO channel capacity comes from the fact that building surfaces are different from, for example, shopping area where glass is common, to office area or residential area where bricks are common. In this study we change the value of relative permittivity from 2, which represents some sort of glass like shopping area, to 15 which represents some sort of areas where large amount of high $\epsilon_r$ surfaces are used. The influence of wall relative permittivity on the mean capacity is shown in Figure 3. It can be noticed that the channel capacity is an increasing function of the wall relative permittivity for both polarizations. The high relative permittivity causes less loss in the reflected paths. Relative permittivity equal 5 represents a practical value for city street concrete walls [5].

In order to examine the multipath richness in the main street, the multipath reflection order is simulated up to $15th$. The number of multipath generated by the model is $(2N + 1)$ pairs of rays, e.g. when $N = 2$ or 7 the model generates 10 or 30 rays, respectively. Figure 4 shows the capacity of free space MIMO channel where $N = 0$ till rich multipath channel is reached when $N = 15$. We can see that the capacity increases considerably from $N = 0$ till about $N = 7$, and then increases slightly. This can be explained due to higher angular spread which results in uncorrelated channel but when the reflection order is beyond 7, the paths power becomes very weak as explained earlier.

From system point of view, it is important to know the effect of antenna height on MIMO channel capacity. Figure 5 shows the mean capacity variations as a function of the antenna height at both ends. When the influence of one end is investigated the height of the other end is kept fixed to the settings mentioned earlier. Changes in MIMO channel capacity due to antenna heights at both ends are not significant since the radio propagation takes place in azimuth direction, due to wall reflections. For both polarizations the variations are within 1 b/s/Hz. Changes of antenna height will result in variations mainly in elevation direction that is not resolvable by the broadside ULA in horizontal plane. The slight variations in the mean capacity might be due to changes in the ground reflected paths.

Figure 6 presents the effect of inter-element spacing at one end while fixing the spacing in the other end to $0.5\lambda$. The capacity is minimum for inter-element spacing less than $0.5\lambda$. This is due to the fact that the signals at antenna elements are highly correlated. As the spacing increases more than $1\lambda$ no significant increase in MIMO capacity can be noticed as the signals may have already been uncorrelated.

## 4 Conclusions

In this work we have studied the influence of environment parameters in addition to antenna height and spacing on MIMO channel capacity. The vertical and horizontal polarizations have been considered. In general the VP results in more MIMO channel capacity. The results could be useful to system designer for providing high data rate services.

## References


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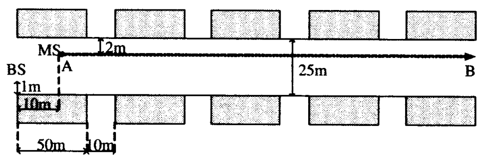


Figure 1: Environment geometry.

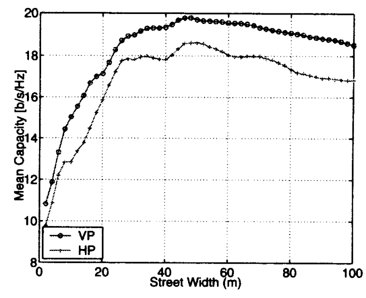


Figure 2: Capacity and street width.

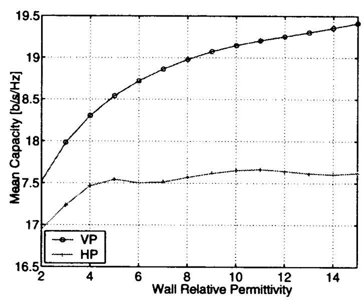


Figure 3: Capacity and wall relative permittivity.

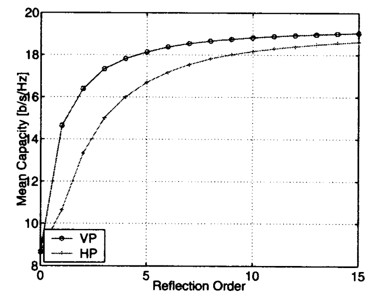


Figure 4: Capacity and reflection order.

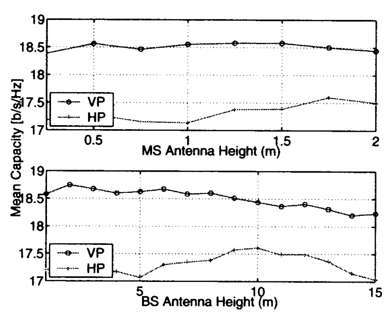


Figure 5: Capacity and antenna height.

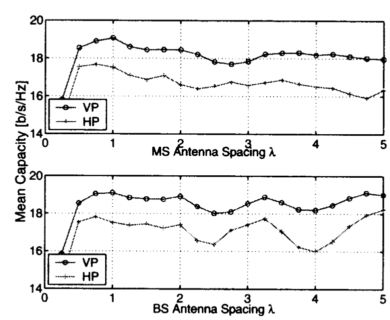


Figure 6: Capacity and antenna spacing.