ENHANCING THE MIMO CHANNEL CAPACITY IN MANHATTAN-LIKE SCENARIOS

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ABSTRACT

In this paper the channel capacity of Multiple Input Multiple Output (MIMO) wireless systems within a Manhattan-like scenario is studied. Three Base Stations (BSs) placement models are proposed in this work, so as to enhance the channel capacity of the wireless system. The evaluation of the proposed BSs arrangements is performed using a simulator with realistic underlying models (test scenario, radio propagation and mobility models). Simulation results show that all the proposed placement models have a superior performance when compared with the traditional BSs placement model. In particular, one of the proposed BSs dispositions requires the use of less BSs, which means greener communications and less hardware costs.

***Index Terms*—** Channel Capacity, Manhattan-like Scenarios, Radio Resource Management, Wireless Networks

1. INTRODUCTION

Recently many operators have adopted the Long Term Evolution (LTE) technology, which makes use of Multiple-Input Multiple-Output (MIMO) systems [1]. MIMO systems promise high spectral efficiencies by enabling a spatial multiplexing gain [2,3]. This adoption improves the system performance when compared with older technologies, like Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications Systems (UMTS), namely by enhancing the channel capacity [4].

Other minor decisions that a network operator makes can have a great impact on the system performance. For example, one of the main issues is where and how to place the Base Stations (BSs). Path loss is of course one of the main factors to be considered, but it should not be the only one. If MIMO systems are used, the azimuthal antenna array orientation has a significant effect of on the system performance, namely channel capacity [5–7]. In addition, the real mobility pattern should also be considered, since the use of more radio resources in zones where people spend more time, while removing some resources from less crowded areas, leads to a better average system performance.

The goal of the work described in this paper is to enhance the channel capacity of Manhattan-like scenarios, considering pedestrian users equipped with a MIMO system. The following new ideas are explored:

- new BSs placement models are proposed, which either greatly increase the average channel capacity of the whole system or slightly increase the system performance but require less BSs;
- minor adjustments (BSs antennas orientation) are proposed to already installed networks, enabling a better system performance with a very small marginal cost.
- a realistic approach is adopted by using simulations with realistic underlying models.

The evaluation of a cellular network depends on a variety of factors, such as the scenario of implementation, the technology that will be used, the mobility of the users, etc. From an economic perspective, it is advisable to simulate the network prior to field testing and network implementation, in order to assess its performance, limitations and to prevent a bad investment. To this end, several simulation models have been adopted. However, for simplicity reasons, some of these models use unrealistic assumptions. While this procedure simplifies the analysis, it often leads to the well known gap between theory and practice. To overcome this issue, it is important to guarantee that valid and realistic underlying models are used in the whole simulation process.

The first model to take into account is the test scenario. Although this model is highly specific for each real case, for urban scenarios a Manhattan-like structure is present most of the times due to urban planning. This means that a Manhattan-like test scenario model is valid in many real urban scenarios.

Next, the technology that a network operator will use has a high impact on which channel models should be considered. While the MIMO adoption is attractive from a user experience point of view, it raises some challenges in terms of channel simulations, because the use of traditional path loss models, like the Okumura-Hata model or the Walfisch-Ikegami model [8], is not enough to assess the true MIMO

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performance. In this case, it is necessary to use a Directional Channel Model (DCM), which is able to properly simulate the spatial differences of the radio channel, its time-variant characteristics and the frequency-selective responses, key aspects of MIMO wireless wideband channels. A survey about DCMs can be found in [9].

Another import aspect that must be taken into account is the mobility model used within the wireless systems simulations. Some mobility models were included in the set of test scenarios for system simulations of UMTS defined by the European Telecommunications Standards Institute (ETSI) [10]. Other mobility models assume random walk [11, 12], Brownian motion [13] or take into account from which side a user leaves a cell so as to compute the cell change probability [14]. Nevertheless, these mobility models make unrealistic assumptions, i.e., they do not capture the moving-in-groups behavior of the society, conscious traveling (where users tend to keep their directions towards a destination) and smart traveling (choose the most attractive route from the user point of view, like shopping streets). More realistic models can be found in [15] (yet lacking smart traveling), [16] (for the vehicular case) and [17] (for pedestrian mobility).

Following this introduction, section 2 describes the considered simulations models. Section 3 presents the different BSs placements studied in this paper, while the channel capacity obtained through simulation is given in section 4. Finally, conclusions are presented in section 5.

2. SIMULATION MODELS

2.1. Test Environment

In this paper the downtown of Lisbon city (also known as *Baixa Pombalina*), Portugal, is used as test environment. It is a Manhattan-like structure in central Lisbon, which was completely rebuilt after the Great Earthquake of 1755, with streets flanked by uniform neoclassical buildings. This was one of Europe's first great examples of neoclassical design and urban planning. A satellite view of the downtown is presented in Fig. 1, with the test scenario delimited by the dashed lines.

2.2. Mobility Model

The scope of this work is to study the user experience in terms of channel capacity for pedestrians that cross the downtown at the Morning Busy Hour (MBH). Therefore, the pedestrian mobility model described in [17] is used in the simulations. This is a model for outdoor scenarios that captures realistic features like moving-in-groups, conscious traveling and smart traveling.

Fig. 2 depicts the pedestrian traffic load at the MBH for the test environment under consideration. As can be seen, the traffic is concentrated on four vertical streets, whereas the other three vertical streets and the horizontal streets have a very low traffic load. This traffic pattern

Fig. 1. Downtown of Lisbon city

high/low/high/low/high combined with perpendicular low traffic streets is not unique to Lisbon's downtown; it is very common in many urban environments because a building usually has only one facade (corresponding to high traffic streets) surrounded by secondary accesses and the rear of the building (corresponding to low traffic streets).

2.3. MIMO Channel Model

For a MIMO system with n_R antennas at the receiver, the received signal vector $\vec{s_R}(f)$ can be written as

$$\vec{s_R}(f) = [s_{R,1}(f), s_{R,2}(f), \ldots, s_{R,n_R}(f)]^\top \qquad (1)$$

where $s_{R,i}(f)$ represents the signal at the i^{th} antenna element, f corresponds to the carrier frequency and $[\cdot]^\top$ stands for the transpose operation. Likewise, the transmitted signals from n_T antenna elements at the transmitter define the vector $\vec{s_T}(f)$. The signals $\vec{s_T}(f)$ and $\vec{s_R}(f)$ are related by

$$\vec{s_R}(f) = \mathbf{H}(f)\vec{s_T}(f) + \vec{n}(f) \qquad (2)$$

where $\vec{n}(f)$ denotes the additive white Gaussian noise vector and $\mathbf{H}(f) \in \mathbb{C}^{n_R \times n_T}$ represents the instantaneous MIMO radio channel matrix.

To simulate the radio environment, an implementation of the COST 273 DCM validated for microcells scenarios is used [18], but the path loss model part is replaced by the model described in [19], because it is more realistic for the test environment under consideration. After obtaining the channel

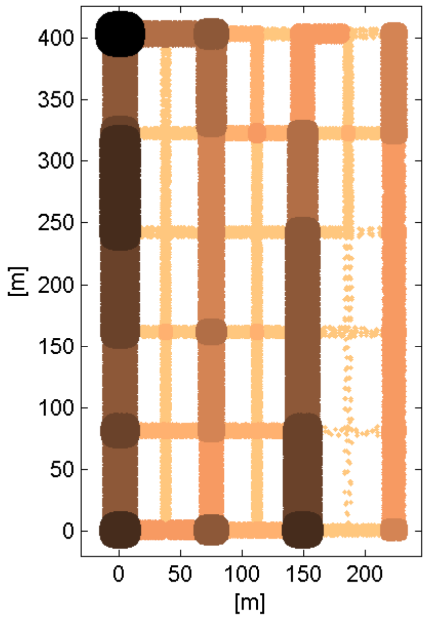

Fig. 2. Test environment pedestrian traffic load at the MBH (darker/wider street segments represent a higher traffic load)

impulse responses given by the DCM, a Fourier transform is applied in order to compute the $(r,t)^{\text{th}}$ component of $\mathbf{H}(f)$.

2.4. MIMO Capacity

The knowledge of Channel State Information (CSI) at the transmitter yields higher MIMO spatial multiplexing gains [20]. Unfortunately, obtaining CSI at the transmitter is not an easy task [21], hence in this work only systems without CSI at the transmitter will be considered, which means that the MIMO capacity expressed in bit/s/Hz is given by [2, 3]

$$C = \log_2 \det \left(\mathbf{I}_{n_R} + \frac{P_T}{\sigma_n^2 n_T} \mathbf{H}\mathbf{H}^\dagger \right) \qquad (3)$$

where P_T corresponds to the total transmit power, σ_n^2 represents the noise power, $\mathbf{I}_{n_R}$ denotes the identity matrix of size n_R and $(\cdot)^\dagger$ stands for the conjugate transpose operation.

Defining $\mathbf{W} = \mathbf{H}\mathbf{H}^\dagger$ as the channel correlation matrix, since $\mathbf{W} \in \mathbb{C}^{n_R \times n_R}$ is an Hermitian nonnegative-definite matrix and thus has n_R real non-negative eigenvalues, i.e., $\gamma_1, \ldots, \gamma_{n_R} \geq 0$, the channel capacity (3) can be rewritten as

$$C = \sum_{i=1}^{n_R} \log_2 \left(1 + \frac{P_T}{\sigma_n^2 n_T} \gamma_i \right) \qquad (4)$$

Expressions (3)–(4) do not account for the frequency-selective feature of a wireless wideband channel. This feature makes the MIMO channel matrix frequency-dependent. One way to cope with this issue is to split the channel bandwidth into Q flat-fading subchannels, represented by $\mathbf{H}(f_q)$, where f_q denotes the q^{th} subcarrier frequency. These different subchannels can be seen as parallel channels, yielding a channel capacity of [20]

$$C = \frac{1}{Q} \sum_{q=1}^{Q} C_q = \frac{1}{Q} \sum_{q=1}^{Q} \sum_{i=1}^{n_R} \log_2 \left(1 + \frac{P_T}{\sigma_n^2 n_T} \gamma_{i,q} \right) \qquad (5)$$

where C_q corresponds to the q^{th} subchannel capacity and $\gamma_{i,q}$ represents the i^{th} eigenvalue of $\mathbf{W}_q = \mathbf{H}(f_q)\mathbf{H}^\dagger(f_q)$.

3. BASE STATIONS PLACEMENT

3.1. General Characteristics

Before deploying the BSs in an environment, it is important to know the different configurations that the wireless system has. Here we present the settings that would be used in a real scenario similar to our test environment.

One of the LTE configurations was chosen for system simulation: a 2×2 MIMO antenna setting with a total bandwidth of 20 MHz (which corresponds to 1200 subchannels) [1]. We consider uniform linear arrays for both ends of the wireless system, BSs and Mobile Stations (MSs), because this array shape showed to be superior to other array geometries in terms of the MIMO system performance [6]. The antenna elements in each array are separated by 1.0λ and 0.5λ for the BSs and MSs cases, respectively (typical microcell and handset sizes), and the operating frequency is set to 2 GHz. We also consider that the BSs and the MSs have their antenna arrays at a 10 m and 1.5 m heights, respectively.

The downlink scenario is assumed from now on. In this situation, each BS emits with a total power of 43 dBm [22] and its antennas are omnidirectional with a gain of 6 dBi [23]. The MSs have omnidirectional antennas with a gain of 0 dBi [23], along with a noise power and a sensitivity of -98 dBm and -121 dBm, respectively (both per subchannel) [24].

3.2. Traditional Model

The traditional BSs placement for the test environment is depicted in Fig. 3. It is based on the BSs disposition for the Manhattan-like structure described in [10], where all street segments have Line-of-Sight (LoS) to at least one BS. We assume that each of the 20 BSs has its antenna arrays parallel to the building where it is located, due to aesthetic aspects.

3.3. Enhanced Traditional Model

Following the conclusions of [7], the BSs antenna arrays should be oriented perpendicularly to the building where they are located, so that more street segments are located inside high capacity regions. Hence, the enhanced traditional (E-traditional) model proposed in this work has the same BSs placement as the one presented previously but with the antenna arrays rotated by 90 degrees in the azimuthal plane.

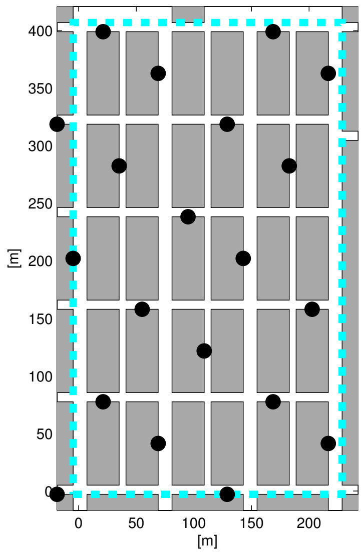

Fig. 3. BSs placement - traditional model

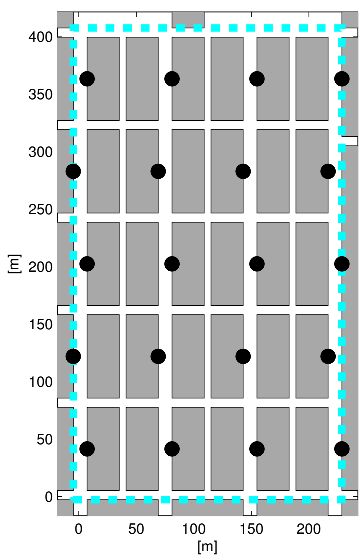

Fig. 4. BSs placement - model A

3.4. Proposed Model A

Based on the mobility models results presented in Fig. 2, we propose a new BSs placement model (denoted from now on as model A), which is depicted in Fig. 4. With this BSs arrangement we serve better the positions where the users spend more time with the same number of BSs as the traditional model, which means that we make a tradeoff: street segments with low traffic load are served in worse conditions. In addition, the BSs antenna arrays are oriented perpendicularly to the building where they are located, for the reasons described in the previous subsection.

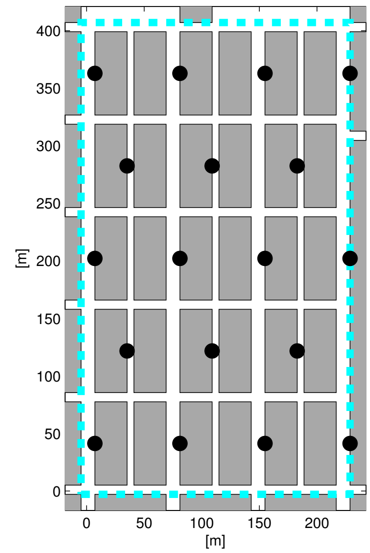

Fig. 5. BSs placement - model B

3.5. Proposed Model B

The proposed placement model A implies that the vertical streets segments without BSs are only served when a transmitted radio signal from a BS suffers at least two diffractions. This behavior can lead to a very poor wireless service coverage for those areas. To try to overcome this issue, we propose the BSs placement model depicted in Fig. 5 (denoted from now on as model B), again with the BSs antenna arrays oriented perpendicularly to the building where they are located. In this case, only the horizontal street segments do not have LoS to any BS, although a radio signal from a BS has to suffer only one diffraction to reach those zones. Another important characteristic of this model is that less BSs are used compared with the previous models (18 vs. 20).

4. SIMULATION RESULTS

The following results are based on more than 2 millions MSs positions generated by the mobility model. The obtained channel capacity complementary cumulative distribution is presented in Fig. 6, while the average channel capacity $\overline{C}$ of the whole system is provided in Table 1.

As can be seen, the enhanced traditional model allows to increase the channel capacity with just a minor adjustment of the antenna arrays orientation on the BSs. The results also show that although for about 15 % of the users the proposed model A is the worst choice, this model significantly increases the average channel capacity of the whole system. Finally, the proposed model B can be seen as the right choice when comparing channel capacity vs. network hardware costs: this models shows a superior performance when compared with the enhanced traditional model, while at the same time less BSs are used.

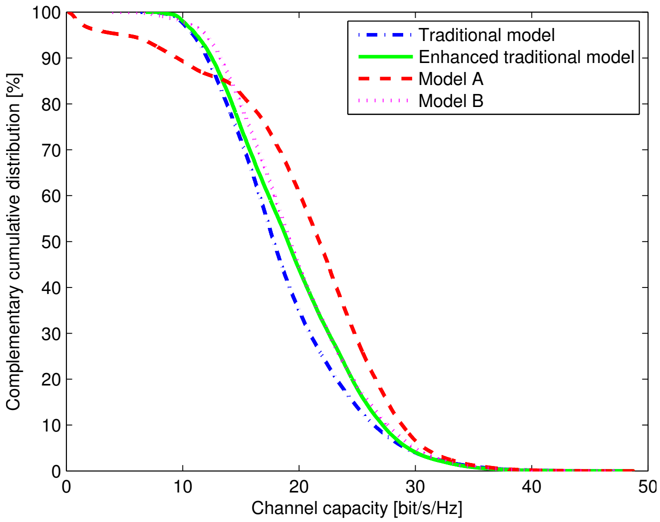

Fig. 6. Complementary cumulative distribution of the channel capacity

Model	Traditional	E-traditional	A	B
$\overline{C}$ **[bit/s/Hz]**	18.7	19.5	20.7	19.9

Table 1. Average channel capacity

5. CONCLUSIONS

In this paper three BSs placement models were proposed, in order to enhance the MIMO channel capacity in Manhattan-like scenarios. All models were evaluated using a simulator that generates realistic frequency-selective channel realizations and realistic mobility patterns, both validated for the real test scenario chosen. This special attention to the simulation details tries to minimize the gap between theory and practice.

Based on the obtained results, we can conclude that all the proposed models are a valid approach to increase the channel capacity of the wireless system, showing superior performance when compared with the traditional BSs placement model. In addition, two of the proposed models are specially attractive from a network operator perspective: one only requires minor adjustments to an already installed network, while the other requires less BSs than the traditional placement model, meaning greener communications and less hardware costs.

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