QUALITY OF SERVICE ORIENTED SPATIAL PROCESSING IN THE MANHATTAN GRID

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ABSTRACT

In this paper, we investigate Quality of Service based MIMO spatial processing in the Manhattan scenario. To model the requirements arising from the individual users, we apply specific traffic and mobility models for metropolitan areas that represent user movement and service requirements in an adequate way. These demands result in an individual signal to interference and noise requirement that has to be fulfilled for each user on the physical layer. Thus, in a first step we analyze the interference among users on a 4-way junction on the downlink and show that it should not be ignored. Based on this observation, we propose the *target SINR sensitive Channel Representative Interference Cancelation* (TSS-CRIC) scheme. It groups the users in a street and calculates a *channel representative*. The latter, as a virtual user, reflects the spatial features of all users in the group. Moreover, it is tailored in such a way that the precoding computed on its basis achieves the individual Quality of Service requirements and is able to adapt itself as the users move through the scenario. These advantages justify the higher computational complexity compared to a scheme that achieves similar results with respect to pure interference suppression.

1. INTRODUCTION

The Manhattan grid as specified in [1] is a common basis for simulations of wireless communications systems in urban environments. For this scenario, specific traffic [2] and mobility models [3] exist that appropriately reflect both user movement (direction, velocity) and service requirements (data rate, packet delay, bit error probability) for future applications.

These models build the basis for our Quality of Service (QoS) oriented spatial processing. In order to fulfill the requirements on the application layer, we map them into equivalent Signal to Interference and Noise Ratio (SINR) requirements on the physical layer. To achieve these requirements for the different user positions, first the interference situation in the specific Manhattan environment has to be carefully investigated.

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Many papers deal with the interference arising in the Manhattan scenario. Most authors use simplified models due to the large computational complexity required in considering interference explicitly in the simulations or ignore it completely. For example, the authors of [4] distinguish between areas with line of sight connection to an interfering base station and thus with high interference and areas with minimal or no interference due to large shadowing effects of buildings in the Manhattan scenario. The areas are defined on a purely geometrical basis, taking neither reflections, diffraction nor other spatial effects into account. On the other hand, other schemes assume that the interference is so large that more resources than necessary are spent. For instance, in [5], a two-hop cell with four relay nodes (RNs) is investigated. On the first hop, the base station (BS) transmits the data to four RNs. These are placed as depicted in Fig. 1. The interference between the different RNs on the downlink is not considered further. Instead, the scheme proposed in [5] exclusively allocates time slots for each transmission to a RN. Estimating the interference here offers a high potential of saving resources, because the exclusive allocation of time slots is not necessary. Additionally, the authors in [5] focus on multi-user interference between users that are served from *different* RNs. Losses in capacity through multi-user interference between users in neighboring street canyons that are served by the *same* RN are not investigated.

In this contribution, we show that the interference between users in different streets of a 4-way junction cannot be neglected. We develop a new method, the *target SINR sensitive Channel Representative Interference Cancelation* (TSS-CRIC), to spatially suppress multi-user interference and simultaneously serve users with individual SINR requirements. The proposed method is compared to a scheme that stiffly steers one beam into the middle of each street, referred to as *fixed beams* scheme in the following. We show that for static user positions and without additional SINR constraints both schemes are able to suppress the interference and the *fixed beams* scheme even outperforms our *target SINR sensitive* CRIC scheme. However, considering the case where individual requirements are investigated, the *target SINR sensitive* CRIC scheme clearly outperforms the *fixed beams* scheme for both static and moving users.

After a detailed description of the traffic and mobility models, the user routing and grouping as well as the mapping of the requirements to SINR values in Section 2, we describe the *target SINR sensitive* CRIC scheme in Section 3. Section 4 shows the simulation results for both schemes, the *fixed beams* and the *target SINR sensitive* CRIC scheme in terms of static user position simulations without and with individual SINR requirements and for moving users with individual SINR requirements. Finally, in Section 5, the conclusions are drawn.

2. TEST SCENARIO

The scenario under investigation is a Manhattan grid as depicted in Fig. 1. Both BS (depicted through a dark green square) and RNs (displayed with light green circles) are under the rooftop and are placed in the street crossings. They are equipped with eight directional antennas, which are arranged in four uniform linear arrays, one for every street. The user terminals (UTs) possess two antennas each.

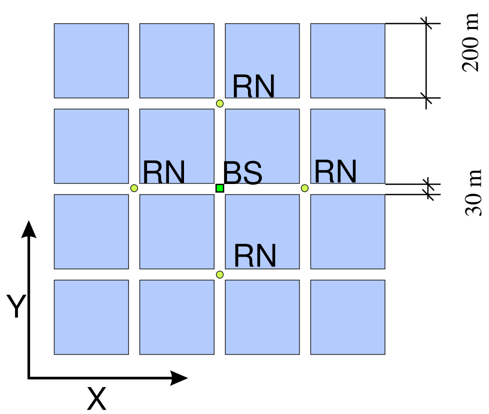

Fig. 1. The investigated Manhattan scenario.

2.1. System Description

Mobility Model

We simulate the user movement (direction, velocity) with the help of different mobility models described in [3]. There, for the Manhattan scenario a so called *Pathway Mobility Model* is used. This restricts the user movement to predefined paths, in the case of the Manhattan Grid the streets between the buildings. In the beginning, the direction of a user moving through the street is chosen randomly. At a crossing, a user keeps straight on with a certain probability P_{straight}, in our case $P_{\mathrm{straight}} = 0.5$. The turn probability is the same for both directions and can be calculated as $P_{\mathrm{turn}} = (1 - P_{\mathrm{straight}})/2$.

Regarding the velocity, we differentiate between vehicles and pedestrians, which move in different ways. Pedestrians move slowly and with random speed. Since pedestrians do not stop or accelerate rapidly, dependencies between the velocities of different temporal snapshots have to be taken into account. Therefore, the *Gauss-Markov Mobility Model* is used. It models the velocity as a Gauss-Markov stochastic process. The correlation over time is expressed with the help of a memory constant α

$$V_{\mathrm{t}} = \alpha V_{\mathrm{t}-1} + (1-\alpha)\nu + \sigma\sqrt{1-\alpha^2}W_{\mathrm{t}-1} \qquad (1)$$

where V_{t} and $V_{\mathrm{t}-1}$ is the velocity for timestep t and $t-1$, ν is its asymptotic mean, σ is the standard deviation and $W_{\mathrm{t}-1}$ is a uncorrelated random Gaussian process $\sim \mathcal{N}(0, \sigma^2)$. Notice that in the general case the velocity can differ in x- and y-direction and hence a 2-dimensional Gauss-Markov process has to be applied. In the specific geometry of the Manhattan grid, users move either in the x- or in the y-direction and thus a one-dimensional Gauss-Markov process is sufficient.

On the other hand, vehicles are much faster and have at least two favored speeds: 50 km/h if normal movement is assumed, and no speed, e.g., for stops at traffic lights or parking. A change of velocity occurs with nearly constant acceleration. To model these attributes, the *smooth Random Mobility Model* is used. In this model, the distribution of the user velocity is chosen such that the favored speeds have a high probability and for the remaining time a uniform distribution is assumed. To provide a smoother change of speed, not the speed itself, but the acceleration is chosen from a uniform distribution $\sim \mathcal{U}(0, \beta_{\mathrm{max}})$, where β_{max} is the maximum acceleration possible. The velocity varies until the target speed is reached or a speed change occurs and a new acceleration is chosen.

Traffic Model

To model the traffic characteristics (requirements, session duration) in the scenario, we specify three parameters for each user as QoS requirements, namely the bit error rate (BER), the data rate (R), and the maximum packet delay (Δ_{P}). These requirements depend on the service the user requests (e.g. Voice over IP - VoIP, video streaming). To assign different services to the users, we apply a traffic model for metropolitan areas as described in [2]. There, according to certain probabilities, the users are divided into different service classes. In contrast to the model in [2], we restrict the investigations to the five most probable service classes. The used service classes, their probabilities and their requirements are listed in Table 1. The time a user requires a specific service, the so called session duration, is randomly chosen from a certain distribution which differs for each service class [2].

	VoIP	Audio	Video	FTP	HTTP
Prob [%]	39.6	6.1	16.9	13.3	24.1
BER	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
R [kbps]	64	128	5000	2000	512
Δ_{P} [ms]	100	100	200	200	200

Table 1. Considered service classes, usage probabilities (Prob [%]) and QoS requirements for the service classes in the implemented traffic model.

User Routing

On the downlink, the data transmission is organized in two time slots (see Fig. 2). In the first, the BS transmits data to the

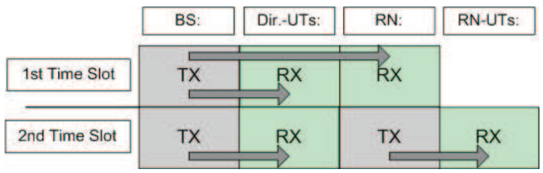

Fig. 2. Timing in the two-hop network. Dir.-UTs are users directly served by the BS where as RN-UTs are served by the RNs.

direct users (Dir.-UTs) and serves the RNs with the data for the remaining users (RN-UTs). In the second, the direct users are again served by the BS and the RNs transmit the data to the indirect users. In this paper, we focus on the second time slot and investigate the interference arising when the UTs are served via RNs. The decision, whether a user is served directly or via one RN, is based on a singular value decomposition (SVD) of the channel matrices from every user to the RNs and the BS, namely $\boldsymbol{H}_{\mathrm{RN,UT}} \in \mathbb{C}^{2\times 8}$ and $\boldsymbol{H}_{\mathrm{BS,UT}} \in \mathbb{C}^{2\times 8}$, respectively

$$\begin{aligned} \boldsymbol{H}_{\mathrm{BS,UT}} &= \boldsymbol{U}_{\mathrm{BS,UT}}\, \boldsymbol{\Sigma}_{\mathrm{BS,UT}}\, \boldsymbol{V}^{H}_{\mathrm{BS,UT}} \\ \boldsymbol{H}_{\mathrm{RN,UT}} &= \boldsymbol{U}_{\mathrm{RN,UT}}\, \boldsymbol{\Sigma}_{\mathrm{RN,UT}}\, \boldsymbol{V}^{H}_{\mathrm{RN,UT}}. \end{aligned} \tag{2}$$

Since we focus on *dominant eigenmode transmission* [6], only the strongest eigenmode is considered for routing purposes. A user is routed to a RN instead of being routed directly to the BS, if the strongest singular value of $\boldsymbol{H}_{\mathrm{RN,UT}}$ is greater than the strongest singular value of $\boldsymbol{H}_{\mathrm{BS,UT}}$. Notice that we do not consider the fact that every multi-hop system experiences throughput losses compared to a single-hop connection, which would require that routing to a RN includes an offset in the channel quality to balance these losses. This is neglected here as we want to assess the improvement due to interference suppression only.

User Grouping

In the CRIC scheme, the users that are served by one RN are divided into groups. The grouping is performed with respect to the urban topology, i.e., one group per street. Thereby, we avoid computationally complex scheduling algorithms that find groups of spatially well separable users. Corresponding to the four street canyons that are served by one RN, four different groups are possible. The information, how the users are distributed in the four streets is again gained with a SVD of $\boldsymbol{H}_{\mathrm{RN,UT}}$. In this case, the eight transmit antennas are subdivided into four antenna pairs, according to the four streets. The SVD is applied on each of these channel subsets. The users belong to the street for which the channel subset possesses the strongest singular value. Within a group, the users are separated via CDMA. The code length is variable, dependent on the number of users per group. Perfect synchronization of the CDMA system is assumed.

Mapping Of QoS Parameters To SINR Values

In order to satisfy the QoS requirements set by the application layer, we first convert them into an SINR requirement that can be taken into account by the transport oriented layers. As forward error correction scheme, we use *bit-interleaved coded modulation* with *iterative decoding* [7]. Table 2 lists the available modulation schemes and code rates. We combine this scheme with a packet retransmission scheme (*Chase Combining*) on the data link layer, i.e., in case of an erroneous transmission, the same packet as used for the initial transmission is retransmitted. The retransmitted packets are combined with the initial transmission in order to achieve a high error correction capability. Because we investigate highly time critical applications, we restrict the number of retransmissions to one. In this case, it can be shown [8] that the gain of a packet retransmission can be approximated as a 3 dB shift of the required SINR with respect to a certain error probability. Due to signaling overhead and packet headers that have to be taken into account, we enlarge the data rate requirement listed in Table 1 by 10 %. The system performance is simulated in terms of the BER of all possible Modulation and Coding Schemes (MCS) for an Additive White Gaussian Noise (AWGN) channel. To find all MCS that are able to fulfill the requirements, in a first step all combinations able to achieve the data rate are chosen. The SINR required to meet the target BER after packet retransmissions, i.e., including a 3 dB shift for each retransmission, is estimated by using the AWGN BER curves. Finally, the MCS with the lowest SINR requirement is selected. Table 3 lists the SINR requirements for the different service classes.

Modulation	BPSK, QPSK, 16-QAM, 64-QAM
Coding	uncoded, $8/9$, $4/5$, $2/3$, $1/2$, $1/3$

Table 2. Possible modulation schemes and code rates for the adaptive coded modulation in the simulated Scenario

Service class	VoIP	Audio	Video	HTTP	FTP
SINR [dB]	0	0	24	1	11

Table 3. SINR requirement for each service class that has to be fulfilled by the physical layer in order to achieve the requirements for this service class.

3. SPATIAL PROCESSING

To fulfill the SINR requirements, we need a spatial processing scheme which on the one hand suppresses interference while on the other hand also serves specific user positions with specific SINR requirements. In the following, we introduce the *target SINR sensitive Channel Representative Interference Cancelation* method. In combination with SMMSE [9], this scheme suppresses the interference between users in different streets of a 4-way junction on the downlink and simultaneously serves users with their individual SINR requirements. To demonstrate the necessity of an interference cancelation scheme, we define a technique which completely ignores the interference between streets. Additionally, we compare our method to the *fixed beams* scheme that stiffly directs one beam into each street, and thus, overcomes the interference between the street canyons.

The Interference-to-Signal-Ratio (ISR) is calculated based on simulations as follows. Let i and j be users in different streets and let further $\mathcal{K}_g$ denote the set of users in the same group as user j. The interference power I_j, experienced by user j, is equal to

$$I_j = \sum_i ||\boldsymbol{d}_j^T \boldsymbol{H}_{j,i} \boldsymbol{m}_i x_i||_2^2, \quad \forall i \neq j, \forall i \notin \mathcal{K}_g. \tag{3}$$

The data symbol x_i is precoded with a specific precoding vector $\boldsymbol{m}_i$ and is decoded with the decoding vector $\boldsymbol{d}_j$. The term $\boldsymbol{H}_{j,i}$ denotes the channel between the RN that serves the interfering user i and the interfered user j. Since we focus on interference between users that are served by the same RN, $\boldsymbol{H}_{j,i}$ is simply the channel from the serving RN to user j. In the general case of multiple data streams per user, the following approximation is often used

$$||\boldsymbol{D}_j^T \boldsymbol{H}_{j,i} \boldsymbol{M}_i \boldsymbol{x}_i||_2 \leq ||\boldsymbol{D}_j^T \boldsymbol{H}_{j,i} \boldsymbol{M}_i||_{\mathrm{F}} ||\boldsymbol{x}_i||_2, \tag{4}$$

where the precoding and decoding vectors are now matrices. This can also be applied to the more specific case of *dominant eigenmode transmission*. In our data model we assume the norm of the data to be upper bounded by one. Hence, the interference power I_j is upper bounded by

$$I_j \leq \sum_{i=1}^{N} ||\boldsymbol{d}_j^T \boldsymbol{H}_{j,i} \boldsymbol{m}_i||_{\mathrm{F}}^2 \quad \forall i \neq j, \forall i \notin \mathcal{K}_g. \tag{5}$$

The signal power S_j of user j is the power of its equivalent channel and is upper bounded by

$$S_j \leq ||\boldsymbol{d_j} \boldsymbol{H}_{j,j} \boldsymbol{m}_j||_{\mathrm{F}}^2. \tag{6}$$

Therefore, the resulting ISR_j in percent for the j-th user is then

$$\mathrm{ISR}_j = \frac{I_j}{S_j} \cdot 100\,\%. \tag{7}$$

No Interference Suppression

In this strategy, the interference between neighboring streets of one street crossing is neglected on the downlink, and perfect channel state information (CSI) at the transmitter and the receiver is assumed. In this case, the optimum strategy for each user is *dominant eigenmode transmission* [6]. This is referred to as the *no interference cancelation* scheme.

Fixed Beams Scheme

If the interference between neighboring streets of one RN is taken into account, the different user groups have to be separated, e.g., spatially. A simple way to suppress the interference between the street canyons is to steer one beam into the middle of each street and give all transmit power to the two antennas that belong to the street canyon. In this case the modulation matrix for the different street canyons has non zero values in the rows of the antennas that belong to the street canyon and zeros otherwise. If street canyons without users exist, the corresponding transmit antennas are switched off. As decoding scheme, minimum mean square error (MMSE) filtering is applied.

Channel Representative Interference Cancelation

Another possible way to suppress interference is the use of SMMSE [9] as the precoding scheme in combination with MMSE filtering as the decoding scheme. SMMSE calculates the precoding matrix to separate users based on their channels. If the number of users increases, the performance of SMMSE decreases more and more and computational complex scheduling algorithms are necessary. As an alternative to avoid this, we group the users in the same street of a crossing and then, for each group, calculate a channel representative. The latter, as a virtual user, reflects the channels of all users in the street canyon. This guarantees that the virtual users can be well separated via SMMSE. Let us now consider one group only, denoted by the index g, where the corresponding users are identified by the index $1 \leq k \leq K_g$, where K_g denotes the number of users in the group. The channel representative $\widehat{\boldsymbol{H}}_g$ is obtained from a linear combination of the users' channels. Its energy is normalized to the weighted sum of the energy of the single users channels. It is defined as

$$\begin{aligned} \widehat{\boldsymbol{H}}_g &= \frac{\sum_{k=1}^{K_g} \boldsymbol{w}_g(k) \{||\boldsymbol{H}_k||_{\mathrm{F}}^2\}}{||\widetilde{\boldsymbol{H}}_g||_{\mathrm{F}}^2 \sum_{k=1}^{K_g} \boldsymbol{w}_g(k)} \widetilde{\boldsymbol{H}}_g \\ \widetilde{\boldsymbol{H}}_g &= \sum_{k=1}^{K_g} \boldsymbol{w}_g(k) \cdot \boldsymbol{H}_k, \end{aligned} \tag{8}$$

where $\boldsymbol{w}_g(k)$ is the k-th element of the weighting vector $\boldsymbol{w}_g \in \mathbb{R}^{K_g \times 1}$. The latter is chosen in such a way that each user can be served with its individual SINR to fulfill the QoS requirements raised by the application. If it is not possible to achieve the requirement for all users, the method should balance the discrepancy for all users, to guarantee fairness. Since the noise cannot be influenced through the choice of the *channel representative*, the optimization is carried out with respect to the Signal to Interference Ratio (SIR). To efficiently estimate the individual SIR, we write the k-th user's channel as a sum of two terms, namely $\boldsymbol{H}_{k_{||}}$ and $\boldsymbol{H}_{k_{\perp}}$. They are obtained by projecting the k-th user's channel $\boldsymbol{H}_k$ into the signal and null space of $\widehat{\boldsymbol{H}}_g$, respectively. The signal subspace is the row space of the channel representative, whereas the null space is its orthogonal complement. While $\boldsymbol{H}_{k_{\perp}}$ carries mostly interference, $\boldsymbol{H}_{k_{||}}$ carries the useful signal. Therefore, we approximate the SIR of user k as

$$\mathrm{SIR}_k = ||\boldsymbol{H}_{k_{||}}||_{\mathrm{F}}^2 / ||\boldsymbol{H}_{k_{\perp}}||_{\mathrm{F}}^2.$$

On the one hand, the SINR for all users under a maximum power constraint should be maximized; on the other, each user should preferably achieve its individual SINR target and, in case the requirements cannot be fulfilled, the discrepancy should be balanced for all users. Thus we calculate the ISR for each user k and multiply it with its individual SINR requirement $\mathrm{SINR}_{\mathrm{req}_k}$ divided by the sum of all SINR requirements $\mathcal{S}_{\mathrm{SINR}}$. The resulting ratio should preferably be the same for all users to guarantee fairness

$$\begin{aligned}\frac{\mathrm{SINR}_{\mathrm{req}_1}}{\mathcal{S}_{\mathrm{SINR}}} \frac{||\boldsymbol{H}_{1_{\perp}}||_{\mathrm{F}}^2}{||\boldsymbol{H}_{1_{||}}||_{\mathrm{F}}^2} = &\quad \frac{\mathrm{SINR}_{\mathrm{req}_2}}{\mathcal{S}_{\mathrm{SINR}}} \frac{||\boldsymbol{H}_{2_{\perp}}||_{\mathrm{F}}^2}{||\boldsymbol{H}_{2_{||}}||_{\mathrm{F}}^2} \dots \\ = &\quad \frac{\mathrm{SINR}_{\mathrm{req}_{K_g}}}{\mathcal{S}_{\mathrm{SINR}}} \frac{||\boldsymbol{H}_{K_{g_{\perp}}}||_{\mathrm{F}}^2}{||\boldsymbol{H}_{K_{g_{||}}}||_{\mathrm{F}}^2}.\end{aligned}$$

Hence, we define the following cost function

$$\begin{aligned}J(\boldsymbol{w}) = &\sum_{k=1}^{K_g} \frac{\left|\left|\boldsymbol{H}_{k_{\perp}}(\boldsymbol{w})\right|\right|_{\mathrm{F}}^2}{\left|\left|\boldsymbol{H}_{k_{||}}(\boldsymbol{w})\right|\right|_{\mathrm{F}}^2} \quad + \\ &\frac{c}{\mathrm{MED}\{\mathrm{SIR}(\boldsymbol{w})\}} \mathrm{VAR}\left(\frac{\mathrm{SINR}_{\mathrm{req}_k}}{\mathcal{S}_{\mathrm{SINR}}} \frac{\left|\left|\boldsymbol{H}_{k_{\perp}}(\boldsymbol{w})\right|\right|_{\mathrm{F}}^2}{\left|\left|\boldsymbol{H}_{k_{||}}(\boldsymbol{w})\right|\right|_{\mathrm{F}}^2}\right).\end{aligned} \tag{9}$$

where $\mathrm{VAR}\{\mathbf{a}\}$ is defined as the variance of all values of $\mathbf{a}$. The first summand of $J(\boldsymbol{w})$ accounts for the sum SIR while the last reflects the fairness of the solution, i.e., the SIR discrepancy among users. The term $\mathrm{MED}\{\mathrm{SIR}(\boldsymbol{w})\}$ is the median of all SIRs and, together with a constant c, normalizes the different ranges of the two terms. The constant c is defined empirically. By minimizing equation (9) we obtain a weighting vector $\boldsymbol{w} = \boldsymbol{w}_{\mathrm{fair}}$

$$\boldsymbol{w}_{\mathrm{fair}} = \arg\min_{\boldsymbol{w}} J(\boldsymbol{w}). \tag{10}$$

Unfortunately, there is no closed form solution for the problem in (10). Therefore, a numerical optimization method is required such as using the Hessian or Jacobian of the cost function or the method of steepest descent. Without loss of generality, we can define the additional constraint

$$\boldsymbol{w}_g(k) \geq 0 \quad \forall \;\; k \in \{1, 2, \dots K_g\}. \tag{11}$$

As a starting point for the optimization, we choose the weights for each user k as

$$\boldsymbol{w}_{\mathrm{start}}(k) = \sqrt{\frac{\mathrm{SINR}_{\mathrm{req}_k}}{\mathcal{S}_{\mathrm{SINR}}}}.$$

As already mentioned, SMMSE is used to separate the different user groups so that the precoding matrix for the RNs in the second time slot is calculated based on the channel representatives. Notice that the users in the same street canyon are served with the same precoding vector, and that at most, four different precoding vectors exist, one for every street of the 4-way junction. The MMSE filtering at the receiving UT is not calculated based on the channel representative but on the actual channel between the RN and the UTs, thus assuming perfect channel state information at the receiver. Moreover, we apply *dominant eigenmode transmission*. The interference that each UT experiences is calculated according to (5).

4. RESULTS

In this section, we show the comparison between our scheme and the *fixed beams* scheme for static user simulations with and without individual SINR requirements and for moving users with individual requirements. Both methods are simulated with the same transmit power resources at the transmitters. Moreover, in order to prove the necessity of interference cancelation in general, we show the interference arising for static user positions if the *No Interference Cancelation* scheme is applied. In a first step we assess the Interference-to-Signal-Ratio (ISR) as defined in (7) at the user positions depicted in Fig. 3, averaged over 20 independent channel realizations per user position. The BS and the four RNs are equipped with 8 antennas each, whereas the UTs possess two antennas. We use the B1 WINNER channel model for the metropolitan area, as described in [10]. As transmit antennas, we use directional antennas with a front-to-back ratio of 12 dB. The interference is calculated according to (5). The following three schemes are compared: the *SIR achieving* CRIC scheme with an equal SINR requirement for all user positions, the non iterative *fixed beams* scheme, and the *No Interference Cancelation*, where interference is neglected. To obtain a realistic insight into the impact of multi-user interference in such a scenario, we consider several realizations of the users' positions. Each realization represents an independent operating condition and is characterized by 16 users located randomly on the grid of red dots shown in Fig. 3. Fig. 4

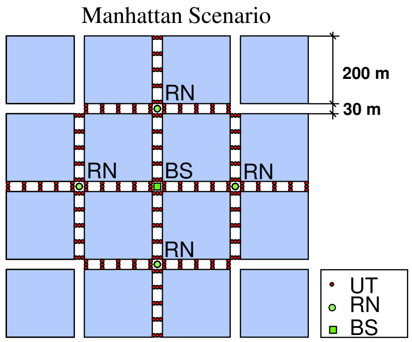

Fig. 3. The red dots indicate the static user positions investigated with respect to interference without individual SINR requirements in the Manhattan scenario

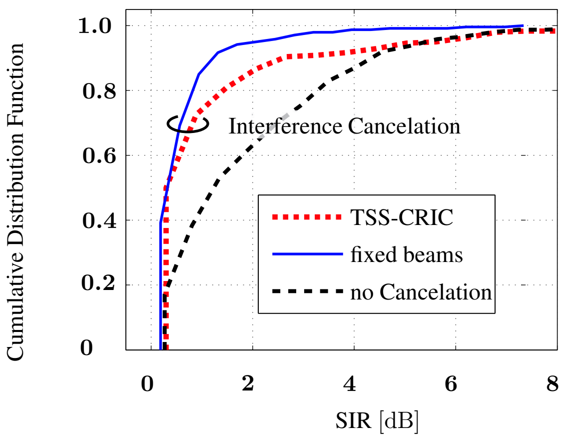

Fig. 4. CDF of SIR values for static interference investigations without individual SINR requirements for the *no interference cancelation* scheme (black dashed line - noCanc), the *target SINR sensitive* CRIC scheme (red dotted line - TSS) and the *fixed beams* scheme (blue solid line - FB)

shows the Cumulative Distribution Function (CDF) of the average SIR ratios at the different user positions. It can be seen that in general interference has to be taken into account in the Manhattan scenario. Both schemes that suppress interference achieve a remarkably better performance than the one without interference suppression. The simpler *fixed beams* scheme behaves even better than the proposed method (TSS-CRIC) if no individual SINR requirements have to be fulfilled. To make the simulations more realistic, in a first step we still simulate static user positions but take the individual SINR requirements into account which arise with respect to the applications listed in Table 3. We define two groups of users, namely the *near users* group and the *far users* group around one transmitter, as displayed in Fig. 5. We assess an individual SINR requirement that holds for all users in the group. Afterwards, we randomly choose one user from each group. Thus, each simulation consists of one *near* and one *far user* with different SINR requirements each. Taking these individual SINR requirement into account, power can be shifted from the user that has a low SINR requirement to the one with the high SINR demand. Thus the resources can be spend more reasonably. To evaluate the results for both schemes, we build the CDF for all users in the *near users* and the *far users* group separately. First, for all pairs of users, we assume that the user in the *near users* group runs a video application with a requirement of 24 dB, whereas the *far user* perfoms HTTP and requires an SINR of 1 dB. Notice that this requirements are long term requirements that should hold over a least one packet length. Thus, we average over 100 temporal snapshots to exclude small scale fading effects. Fig. 6 shows the CDFs of the achieved average SINRs for the *near users* group (nearUT) and the *far users* group (farUT) for the *fixed beams* scheme (blue curve - FB) and the *target SINR sensitive* CRIC scheme (red curve - TSS). The grey area shows the enhance-

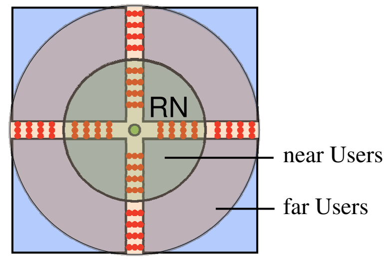

Fig. 5. investigated user positions if individual SINR requirements are taken into account

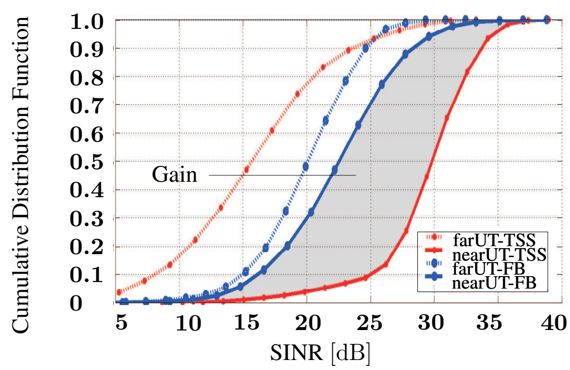

Fig. 6. CDFs for the *fixed beams* scheme and the *target SINR sensitive* CRIC scheme if the *near users* run video streaming with an SINR requirement of 24 dB and the *far users* apply HTTP with an SINR requirement of 1 dB.

ment of the average SINRs for the users that run the application with the high average SINR requirement of 24 dB. Although the gains of the approach in this case are promising, a much more challenging scenario emerges, when the *far user* runs the high SINR requirement application. Fig. 7 shows the CDFs of the achieved average SINRs for the *fixed beams* scheme (blue curve - FB) and the *target SINR sensitive* CRIC scheme (red curve - TSS). Although the CRIC scheme

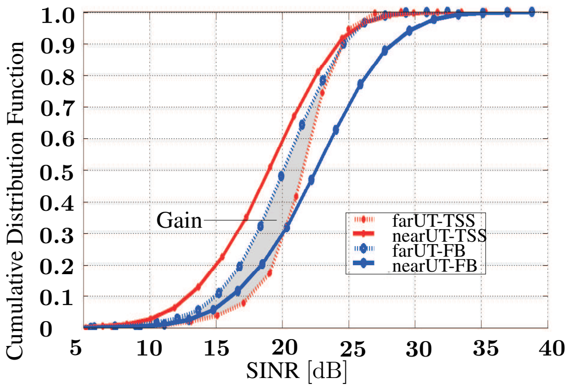

Fig. 7. CDFs for the *fixed beams* scheme and the *target SINR sensitive* CRIC scheme if the *far users* run video streaming with an SINR requirement of 24 dB and the *near users* apply HTTP with an SINR requirement of 1 dB.

is not able to fulfill the SINR requirement completely, it improves the CDF for the *far users* (grey area). This is achieved by shifting power from the *near users* to the *far users* and thus reducing the gap between the required SINR and the actual achieved SINR remarkably, compared to the *fixed beams* scheme. Notice that in this case, the CDF of the *far users* exceeds the CDF of the *near users* group in case of the CRIC method. Both results show that for static user simulations our scheme clearly outperforms the *fixed beams* scheme. Up to this point, we only investigated static user positions and defined the requirements for these users. The most difficult but also most realistic test case occurs, if users move randomly with different speeds according to the proposed mobility models through the test scenario and run applications randomly chosen by the applied traffic model. We simulate 20 users moving over 10 seconds and 100 channel realizations. For each second, we simulate 100 temporal snapshots and average over them. We count the users that do not reach their individual average SINR requirement for each second and each channel realization separately. Fig. 8 shows the percentage of dissatisfied users divided into the different applications for the *fixed beams* scheme (FB - represented through blue bars) and the *target SINR sensitive* CRIC scheme (TSS - represented through red bars). It can be seen that the proposed scheme reduces the amount of dissatisfied users for nearly all

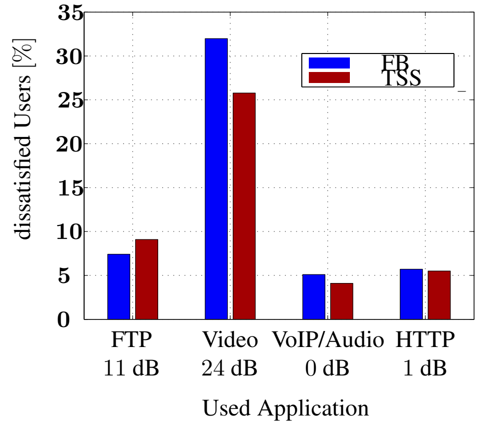

Fig. 8. Percentages of dissatisfied users for the *fixed beams* scheme and the *target SINR sensitive* CRIC scheme if users move freely through the scenario according to the mobility model and individual SINR have to be fulfilled.

investigated user applications. Especially in case of the video streaming application, only 25 % of the users do not achieve the high SINR requirement instead of 32 % dissatisfied users in case of the *fixed beams* scheme. Only in case of the FTP application, the fixed beams approach achieves a slightly better performance than the CRIC scheme. This is due to the fact that our method balances the mismatch between required and achieved users due to fairness reasons. Notice that the gains that reduce the gap between the required and achieved average SINR as depicted in Fig. 7 are not taken into account in this simulation.

5. CONCLUSIONS

In this paper we show that the interference in the Manhattan scenario, although often assumed to be negligible, indeed plays a role and should be considered when managing the spatial resources available. Based on this observation, the users in one street of a 4-way junction are grouped to take advantage of the specific topology of the Manhattan grid. We present two methods that are able to suppress the interference arising between the streets of a 4-way junction. The first method, the *fixed beams* scheme stiffly directs one beam into the middle of each street. It serves as a comparison for our QoS based spatial processing method called *target SINR sensitive* CRIC scheme. We show that for purely static user position simulations without additional SINR requirements, the *fixed beams* scheme outperforms the proposed *target SINR sensitive* CRIC scheme. However, remarkable gains can be achieved with the *target SINR sensitive* CRIC scheme if individual SINR demands are taken into account for both, static and freely moving users. All results are based on realistic traffic and mobility models.

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