Improved Successive Stream Selection with Quantized Channel in Heterogeneous Networks

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***Abstract*—This paper focuses on different distortion metrics in order to analyze the influence of the imperfect channel state information (CSI) on the improved successive stream selection algorithm that manages the interference in a heterogeneous network. The presented approach initially selects the streams from the user of the pico cell, continuing with the strongest streams among the remaining streams that increase the sum rate and satisfy the constraint that at least one stream is selected from each user. In order to reduce the interference, the channel matrices of the remaining streams are projected orthogonally to the virtual transmit and receive channels of the selected stream. The impact of the quantization distortion on the precoding and postcoding design is examined. The performance of two distortion metrics which are the Chordal distance and the Euclidean distance are compared for different number of quantization bits. The performance evaluations are obtained by considering different locations of small cells with respect to the macro cell.**

***Keywords*—Heterogeneous networks, stream selection, quantized channel, distortion metrics**

I. INTRODUCTION

Future wireless networks have to provide high data rate services due to the increasing demand for the applications and the utilizations of wireless networking. However, today's conventional networks do not have the potential to meet these demands with sufficiently good solutions. Therefore, the recent researches focus on heterogeneous networks since they provide a large number deployment of smaller cells with different transmit power levels in the coverage of the conventional macro cell.

Despite the advantages of the heterogeneous networks, users can experience severe interference since small cells share the same spectrum with the macro cell. To handle the interference, different approaches are investigated. Interference Alignment (IA) is one of the interference mitigation techniques that align interfering signals in time, frequency, or space. The IA studies are started by focusing on K pair interference channels and it has been shown that the capacity of the network linearly grows as the size of the network increases without any bound [1]. However, analytical solutions of IA are difficult to obtain for large scales of networks. In order to perform IA in practical systems, iterative and distributed IA approaches have been studied in [2]. Another study on IA solutions has been presented in [3] where a stream selection procedure has been performed by successively selecting the least interfering streams to be in the null space of the previously selected ones. Furthermore, IA approaches have been extended for cellular networks [4], [5]. In addition, IA has been studied for heterogeneous networks to handle the problems caused by the coexistence of macro and small cells [6], [7].

However, all these studies assume that CSI is available at all nodes in order to design precoders for aligning the interference. Since this assumption is not realistic for practical systems, two methods are developed to obtain CSI, which are reciprocity and feedback. Obtaining CSI by using reciprocal channel is achieved by utilizing iterative algorithms with local channel knowledge at each transmitter and receiver [8]. Reciprocity is more suitable for time division duplex (TDD) systems, however it requires calibration of RF devices that complicates the implementation of reciprocity. On the other hand, CSI feedback methods are based on sending the CSI to the transmitters through designated feedback channels [9]. In these systems, receivers estimate the channel coefficients by using the training sequences. After the estimation, receivers feed the information back to the transmitters, so that the precoders can be calculated to align the interference. However, feedback introduces some distortion to the CSI due to the quantization. Chordal distance [10], [11] and Euclidean distance [12] are the most utilized metrics to obtain the quantized CSI. There are different channel quantization methods implemented in the literature related with limited feedback approaches for IA. Grassmannian line packing [13] and random vector quantization (RVQ) [11] are the most studied quantization methods.

In this paper, we propose an improved stream selection algorithm that aligns the interference for heterogeneous networks. The streams are initially selected from the users of pico cells, continuing with the strongest streams that increases the sum rate. If it is not possible to select a stream that positively contributes to the sum rate, a stream that decreases the sum rate the least is selected. The process is repeated until each user receives at least one stream. The constructed stream sequences are compared and the sequence leading to the greatest sum rate is chosen. The main aim is to increase the overall capacity of the system by designing the precoding and decoding matrices while mitigating the interference and assigning at least one stream per each user. In addition, the effect of the quantized channel obtained via RVQ on the proposed interference alignment method is examined in this paper.

The rest of this paper is organized as follows. Section II describes the system model. In Section III the proposed algorithm

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with the quantized CSI is presented. Section IV summarizes different distortion metrics. Simulation results are given in Section V and finally the paper is concluded in Section VI.

II. SYSTEM MODEL

In this study, a K-pair heterogeneous network composed of $K-1$ pico base stations (BSs) and one macro BS with N_{T_k} transmitter antennas and N_{R_k} receiver antennas is considered as seen in Figure 1. For the sake of simplicity, macro BS - macro user pair is determined as the pair $k=1$, and pico BS - pico user pairs are kept in set $k \in \Gamma = \{2, ..., K\}$. The transmission channel matrix is $\mathbf{H}_{kk}$ with dimension $N_{R_k} \times N_{T_k}$. The interference channel from transmitter j to user k is given as $\mathbf{H}_{kj}$. Each element of the channel matrix includes channel effects such as path loss and multipath fading. The interference channel from transmitter j to user k is given as $\mathbf{H}_{kj}$. The received signal at user k as

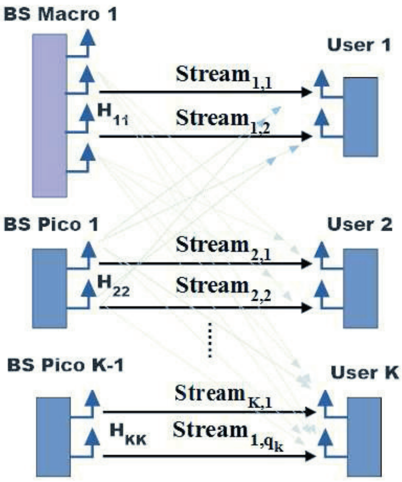

Fig. 1. System Model for MIMO Heterogeneous Network

$$y_k = \mathbf{H}_{kk}\tilde{\mathbf{T}}_k\mathbf{x}_k + \sum_{j=1, j\neq k}^{K} \mathbf{H}_{kj}\tilde{\mathbf{T}}_j\mathbf{x}_j + \mathbf{n}_k \tag{1}$$

where, for each receiver k, $\mathbf{n}_k$ is a $N_{R_k} \times 1$ vector which represents additive white Gaussian noise with zero mean and variance of σ^2 . $\tilde{\mathbf{T}}_k$ is the precoding matrix of transmitter k with dimension $N_{T_k} \times q_k$, and transmitter k can transmit using q_k independent streams with $q_k \leq \min(N_{R_k}, N_{T_k})$. $\mathbf{s}_k$ is the symbol vector with dimension of $q_k \times 1$ and denoted as $\mathbf{s}_k = [s_{k,1} \ ... \ s_{k,q_k}]^T$. In addition, the maximum total number of streams in the network is $r = \sum_{k=1}^{K} q_k$. Received signals are decoded by multiplying with postcoding vectors, $\tilde{\mathbf{D}}_k$, of dimension $q_k \times N_{R_k}$. Thus, the decoded data symbols are given by

$$\hat{\mathbf{y}}_k = \tilde{\mathbf{D}}_k\mathbf{y}_k \tag{2}$$

In order to obtain channel direction information (CDI), the channel matrix between transmitter i and receiver k is normalized by its Frobenius norm as $\bar{\mathbf{H}}_{ki} = \frac{\mathbf{H}_{ki}}{\|\mathbf{H}_{ki}\|_F}$. It is assumed that the channel gain, $\|\mathbf{H}_{ki}\|_F$, is perfectly known at all transmitters. Therefore the quantized CSI, $\tilde{\mathbf{H}}_{ki}$, can be obtained at the transmitters and the details regarding to the calculation of the quantized CSI is given in IV-B. The sum rate is calculated as follows.

$$\tilde{\text{SR}} = \sum_{k=1}^{K}\sum_{i=1}^{q_k} \log_2(1 + \text{SI}\tilde{\text{N}}\text{R}_{ki}) \tag{3}$$

where the signal to interference noise ratio (SINR) of the i^{th} stream of the k^{th} user is given by

$$\text{SI}\tilde{\text{N}}\text{R}_{ki} = \frac{\tilde{\mathbf{d}}_k^{iH}\tilde{\mathbf{H}}_{kk}\tilde{\mathbf{t}}_k^{i}\tilde{\mathbf{t}}_k^{iH}\tilde{\mathbf{H}}_{kk}^{H}\tilde{\mathbf{d}}_k^{i}}{\tilde{\mathbf{d}}_k^{iH}\tilde{\mathbf{B}}_{ki}\tilde{\mathbf{d}}_k^{i}} \tag{4}$$
$$\forall k = 1, ..., K, \quad \forall i = 1, ..., q_k$$

where $\tilde{\mathbf{t}}_k^{i}$ is the precoding vector with the size of $N_{T_k} \times 1$ and $\tilde{\mathbf{d}}_k^{i}$ is the post-coding vector with the size of $N_{R_k} \times 1$. The interference plus noise covariance matrix for the considered stream q of the k^{th} receiver, $\tilde{\mathbf{B}}_{ki}$, is defined as

$$\tilde{\mathbf{B}}_{ki} = \sum_{j=1}^{K}\sum_{q=1}^{q_j} \tilde{\mathbf{H}}_{kj}\tilde{\mathbf{t}}_j^{q}\tilde{\mathbf{t}}_j^{qH}\tilde{\mathbf{H}}_{kj}^{H} - \tilde{\mathbf{H}}_{kk}\tilde{\mathbf{t}}_k^{i}\tilde{\mathbf{t}}_k^{iH}\tilde{\mathbf{H}}_{kk}^{H} + \sigma^2\mathbf{I}_{N_{R_k}} \tag{5}$$
$$\forall k = 1, ..., K, \quad \forall i = 1, ..., q_k$$

The main objective is to mitigate the interference while finding the best stream allocation scheme over BS-user pairs. The stream allocation scheme which increases the total sum rate of the network while guaranteeing at least one stream selection from each user, i.e., service guaranteed, can be formulated as follows.

$$\left\{(\tilde{\mathbf{T}}_k^{*}, \tilde{\mathbf{D}}_k^{*})\right\}_{k=1,...,K} = \underset{\tilde{\mathbf{T}}_k, \tilde{\mathbf{D}}_k}{\text{argmax}} \ \tilde{\text{SR}} \tag{6a}$$

$$s.t. \quad d_k \geq 1 \quad k = 1, ..., K \tag{6b}$$

where d_k is the number of assigned streams for user k.

III. THE PROPOSED IMPROVED SUCCESSIVE NULL SPACE STREAM SELECTION

In this paper, the selection of the strongest streams with a contribution to the sum rate is proposed by performing orthogonal projections to the null space of the selected stream incrementally. The key point of this approach is to determine the stream sequences that give the highest sum rate among all the stream sequences initialized by the pico streams. In the following sections, both interference mitigation and stream selection procedures are explained in detail.

A. Interference Alignment Procedure

Interference alignment solutions for stream selection algorithms align the interference after each stream selection step. There are two kinds of interference among the streams. First one is the interference from the selected stream to the remaining streams and the second one is the interference to the selected stream from the remaining streams. Therefore, two types of virtual channels are defined as Virtual Receiving Channels (VRCs) and Virtual Transmitting Channels (VTCs) [3]. Precoding and postcoding matrices are constructed from the precoding and postcoding vectors corresponding to the selected streams, and they are expressed as $\tilde{\mathbf{V}}_{k^*} = [\tilde{\mathbf{v}}_{k^*}^{1}, \tilde{\mathbf{v}}_{k^*}^{2}, ..., \tilde{\mathbf{v}}_{k^*}^{N_{R_k}}]$ and $\tilde{\mathbf{U}}_{k^*} = [\tilde{\mathbf{u}}_{k^*}^{1}, \tilde{\mathbf{u}}_{k^*}^{2}, ..., \tilde{\mathbf{u}}_{k^*}^{N_{T_k}}]$, respectively.

After the virtual channels related to the selected stream of user k are obtained, the impact of this stream to the remaining streams is reduced by the orthogonal projections. More precisely, the space spanned by the remaining potential beamformers of each user $j \neq k$ is projected orthogonally to the corresponding VRC and VTC of the selected stream belonging to user k. The vectors of the projected matrices $\tilde{\mathbf{H}}_{jj}^{\perp}$, $\forall j \neq k$, are in the null space of all previously selected streams. At each iteration i, the interference from the remaining streams to the selected stream is reduced by projecting the channel matrices $\tilde{\mathbf{H}}_{kk}^{\perp}$ orthogonally to the VRC, and the interference to the remaining streams from the selected stream is reduced by projecting the channel matrices orthogonally to the VTC.

The projection matrix, $\mathbf{P}_{\mathbf{x}}^{\perp} = \mathbf{I} - \frac{\mathbf{x}\mathbf{x}^H}{\|\mathbf{x}\|^2}$ is parallel to vector $\mathbf{x}$. The interference alignment procedure is summarized in Alg. 1.

Alg. 1 Interference Alignment Algorithm

```
Project orthogonally to VRC, $\tilde{\mathbf{u}}_{k^*}^{l^*H}\tilde{\mathbf{H}}_{k^*k^*}$
    $\tilde{\mathbf{H}}_{kk}^{\perp} = \tilde{\mathbf{H}}_{kk}^{\perp}\mathbf{P}_{\tilde{\mathbf{u}}_{k^*}^{l^*H}\tilde{\mathbf{H}}_{k^*k}}^{\perp}$ for $k = 1, ..., K$ where $k \neq k^*$
Project orthogonally to VTC, $\tilde{\mathbf{H}}_{k^*k^*}\tilde{\mathbf{v}}_{k^*}^{l^*}$
    $\tilde{\mathbf{H}}_{kk}^{\perp} = \mathbf{P}_{\tilde{\mathbf{H}}_{kk^*}\tilde{\mathbf{v}}_{k^*}^{l^*}}^{\perp}\tilde{\mathbf{H}}_{kk}^{\perp}$ for $k = 1, ..., K$ where $k \neq k^*$
Compute the SVD of projected matrices
    $\tilde{\mathbf{H}}_{kk}^{\perp} = \tilde{\mathbf{U}}_k\tilde{\mathbf{S}}_k\tilde{\mathbf{V}}_k^H$ for $k = 1, ..., K$
Update
    $\tilde{\mathbf{T}}_{k^*} = [\tilde{\mathbf{T}}_{k^*}\ \tilde{\mathbf{v}}_{k^*}^{l^*}]$ and $\tilde{\mathbf{D}}_{k^*}^H = [\tilde{\mathbf{D}}_{k^*}^H\ \tilde{\mathbf{u}}_{k^*}^{l^*}]$
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B. Stream Selection Procedure

Before starting the stream selection, streams are identified using the singular values which are computed by applying singular value decomposition (SVD) to all channels, $\tilde{\mathbf{H}}_{kk} = \tilde{\mathbf{U}}_k\tilde{\mathbf{S}}_k\tilde{\mathbf{V}}_k^H$. The aim is to construct stream paths with a number of pico cell streams. The initialization set that only includes pico user streams is Ξ.

After the first stream is selected from pico streams, the selection procedure continues with the maximum singular value which increases the sum rate is chosen at each iteration from the set Ω, which keeps the track of all the available streams. If such a stream cannot be selected at iteration i, a stream that causes the minimum sum-rate decrease is selected from a user with no selected streams. The iteration continues until no more streams can be selected. The selected streams are kept in a set denoted as Ψ. The Ω and Ψ sets are updated in each iteration of the proposed algorithm, Improved Successive Null Space Stream Selection (ISNSSS), as the selected stream is taken from the set Ω and put into the set Ψ.

In order to share the power of the corresponding cell type among the selected streams, a correction coefficient, $\alpha_k = P_k/d_k$, is defined for the channel matrix of user k with the transmit power P_k.

IV. CHANNEL QUANTIZATION METHODS

Different channel quantization strategies are implemented to design the feedback channels. A codeword is selected

Alg. 2 Improved Successive Null Space Stream Selection (ISNSSS)

```
Construct the initialization set $\Xi$
    $\Xi = \left\{(k, l)|\ k \in \Gamma \text{ and } l = 1, ..., \mathbf{rank}(\tilde{\mathbf{H}}_{kk})\right\}$
Start constructing stream sequences
for each stream $(k^*, l^*) \in \Xi$ do
    1. Initialize the variables
        $\Psi = \emptyset$; $i = 1$; $d_k = 0$; finish $=$ FALSE and
        $\tilde{\mathbf{H}}_{kk}^{\perp} = \tilde{\mathbf{H}}_{kk}$ for $k = 1, ..., K$
    2. Compute the SVD of all couples
        $\tilde{\mathbf{H}}_{kk} = \tilde{\mathbf{U}}_k\tilde{\mathbf{S}}_k\tilde{\mathbf{V}}_k^H$ for $k = 1, ..., K$
    3. Set the stream to be selected initally $(k^*, l^*)$
        $\Psi = \Psi \cup (k^*, l^*)$
        $d_{k^*} = d_{k^*} + 1$
    4. Perform Algorithm 1.
    5. Compute the SVD of weighted matrices
        $\alpha_k\tilde{\mathbf{H}}_{kk}^{\perp} = \tilde{\mathbf{U}}_k\tilde{\mathbf{S}}_k\tilde{\mathbf{V}}_k^H$ for $k = 1, ..., K$
    6. Construct $\Omega = \left\{(\tilde{\mathbf{S}}_k)(l, l)|k = 1, ..., K \text{ and } l = 1, ..., \mathbf{rank}(\tilde{\mathbf{H}}_{kk}^{\perp})\right\}$
    7. Increment $i = i + 1$
    8. Continue selecting streams
    while finish $=$ FALSE do
        8.1. Compute the $\tilde{\mathrm{SR}}_{\Psi}$
        8.2. Select a stream
            Construct the set of streams which increases the sum-rate
                $\Omega' = \left\{\tilde{\mathbf{S}}_k(l, l) \in \Omega|\ \tilde{\mathrm{SR}}_{\Psi\cup(k,l)} > \tilde{\mathrm{SR}}_{\Psi}\right\}$
            if $\Omega' \neq \emptyset$ then
                $(k', l') = \text{arg max } \Omega'$
            else
                Construct the set of streams which decreases the sum-rate the least from the users with no stream
                $\Omega_k^{''} = \begin{cases} \emptyset, & \text{if } d_k \neq 0, \\ \left\{\tilde{\mathbf{S}}_k(l, l)|\ l = \text{arg min}\left\{\tilde{\mathrm{SR}}_{\Psi\cup(k,l)} - \tilde{\mathrm{SR}}_{\Psi}\right\}\right\}, & \text{if } d_k = 0, \end{cases}$
                    for $k = 1, ..., K$
                $\Omega^{''} = \Omega_1^{''} \cup \ldots \cup \Omega_K^{''}$
                if $\Omega^{''} \neq \emptyset$ then
                    $(k', l') = \text{arg max } \Omega^{''}$
                else
                    finish $=$ TRUE
                end if
            end if
        8.3. Continue stream selection
        if finish $=$ FALSE then
            8.3.1. Update
                $\Psi = \Psi \cup (k', l')$
                $d_{k'} = d_{k'} + 1$
            8.3.2. Perform Algorithm 1.
            8.3.3. Compute the SVD of weighted matrices
                $\alpha_k^i\tilde{\mathbf{H}}_{kk}^{\perp} = \tilde{\mathbf{U}}_k\tilde{\mathbf{S}}_k\tilde{\mathbf{V}}_k^H$ for $k = 1, ..., K$
            8.3.4. Reconstruct $\Omega$
            8.3.5. Increment $i$
                $i = i + 1$
        end if
    end while
    9. Set the power of the selected streams for each user-BS pair
        $\tilde{\mathbf{T}}_k = (P_k/d_k)\tilde{\mathbf{T}}_k$ for $k = 1, ..., K$
    10. Check if a greater sum-rate is achieved and set the variables
        if $\tilde{\mathrm{SR}} > \tilde{\mathrm{SR}}_{\max}$ then
            $\tilde{\mathbf{T}}_k^* = \tilde{\mathbf{T}}_k$, $\tilde{\mathbf{D}}_k^* = \tilde{\mathbf{D}}_k$ for $k = 1, ..., K$
            $\Psi^* = \Psi$, $\tilde{\mathrm{SR}}_{\max} = \tilde{\mathrm{SR}}$
        end if
end for
```

by the receivers from a codebook which is known by both transmitters and receivers based on the distortion metric. Then the CDI can be obtained by the transmitters according to the index of the chosen codeword that is fed back from receivers to transmitters. Different distortion metrics are provided the quantized CDI as in the following.

A. Codebook Design

For both distortion metrics, each codebook contains 2^{N_d} codewords which are randomly generated, where N_d is the codebook size. The codewords are independent and isotropically distributed over the unit sphere.

B. Quantization Metrics

First the normalized channel matrix, $\bar{\mathbf{H}}_{ki}$, $\forall k$, $\forall i$, is vectorized as $\bar{\mathbf{h}}_{ki} = vec(\bar{\mathbf{H}}_{ki})$ where $\bar{\mathbf{h}}_{ki} \in \mathbb{C}^{N_{T_k} N_{R_k} \times 1}$. Afterwards, the codebook is generated using RVQ as $\mathbf{C}_k = \left\{\mathbf{c}_k^1 \ldots \mathbf{c}_k^c \ldots \mathbf{c}_k^{2^{N_d}}\right\}$ where $\|\mathbf{c}_k^c\| = 1$ for $\forall c$ and $\mathbf{c}_k^c \in \mathbb{C}^{N_{T_k} N_{R_k} \times 1}$. Consequently, a codeword that minimizes the following distance metrics is selected for the CDI quantization. Then, it is reshaped as $\mathbf{C}_k^{j*} \in \mathbb{C}^{N_{R_k} \times N_{T_k}}$. Accordingly the quantized channel, $\tilde{\mathbf{H}}_{ki}$, is calculated as $\tilde{\mathbf{H}}_{ki} = \mathbf{C}_k^{j*} \times \|\mathbf{H}_{ki}\|_F$.

a. Chordal Distance Metric (M1): The codeword $\mathbf{c}_k^{j*}$ that minimizes the Chordal distance metric is chosen by

$$\mathbf{c}_k^{j*} = \min\, d(\bar{\mathbf{h}}_{ki}, \mathbf{c}_k^j) \tag{7}$$

where $d(\bar{\mathbf{h}}_{ki}, \mathbf{c}_k^j) = \sqrt{1 - \left|\bar{\mathbf{h}}_{ki}^H \mathbf{c}_k^j\right|^2}$.

b. Euclidean Distance Metric (M2): The codeword $\mathbf{c}_k^{j*}$ that minimizes the Euclidean distance metric is choosen by

$$\mathbf{c}_k^{j*} = \min\, d(\bar{\mathbf{h}}_{ki}, \mathbf{c}_k^j) \tag{8}$$

where $d(\bar{\mathbf{h}}_{ki}, \mathbf{c}_k^j) = \left\|\bar{\mathbf{h}}_{ki} - \mathbf{c}_k^j\right\|$.

V. PERFORMANCE RESULTS

The performance of the proposed algorithm is evaluated in a heterogeneous network illustrated in Figure 2. There are 2 pico cells deployed symmetrically under the coverage of macro cell. Pico cells are equipped with 2 transmit antennas and macro cell is equipped with 4 transmit antennas. Each cell has one user that is randomly placed inside the cell coverage area and there are 2 receive antennas at each user. System parameters used in the simulations are listed in Table I.

The macro BS is located at $(0, 0)$ and the pico BSs are initially placed at $(500, 0)$ and shifted with the pico user along the X-axis towards the cell edge. The location of the pico cells are identified using the ratio d/R where R is the macro cell radius and d is the distance between macro and pico BSs. Since pico cells are practically deployed at cell edges of the macro cells, the distance is taken as $\Delta \geq 0.5$, where Δ is a distance threshold in order to determine the cell edge zones.

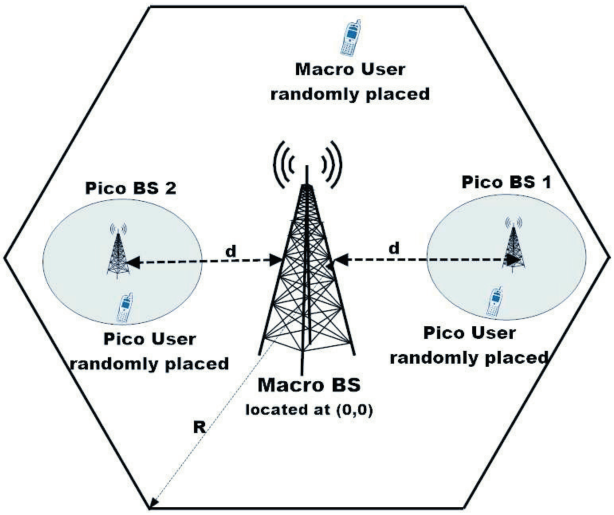

Fig. 2. Scenario A: Picocells are symmetrically deployed

TABLE I. SYSTEM PARAMETERS

Parameter Name	Parameter Value
Macro Cell Transmit Power	43dBm
Pico Cell Transmit Power	24dBm
Bandwidth	10MHz
Carrier Frequency	2.1GHz
Noise Power	-174dBm/Hz
Macro Cell Radius	1000m
Pico Cell Radius	100m
Path loss (for macro)	$L_p = 128.1 + 37.6log10(R(km))$dB
Path loss (for pico)	$L_p = 140.7 + 36.7log10(R(km))$dB

The behavior of ISNSSS algorithm depending on the position of one pico cell is analyzed in [14] by implementing exhaustive stream selection algorithm that searches all possible stream sequences. In the study of [15], ISNSSS algorithm is analyzed for two pico cells without satisfying the constraint given in Equation (6b). In this study, differently, ISNSSS algorithm allocates at least one stream to each user. It has been observed that the probability of selecting the first stream from the pico users is greater than selecting it from the macro user. Therefore the streams of the pico cells are initially selected.

The most challenging drawback of the exhaustive search is the complexity that depends on the number of streams. In terms of the invoking number of Alg. 1 in each stream selection, the complexity of the exhaustive search where all possible stream sequences according to the constraint given in Eq. (6b) are included can be formulated as

$$\sum_{i=K}^{r} \left(\underbrace{\left(i! \left[\prod_{k=1}^{K} \binom{q_k}{1} \right] \binom{r-K}{i-K} \right)}_{\substack{\text{The total number of} \\ \text{stream sequences of length } i}} \times \underbrace{i}_{\substack{\text{The number of invoking Alg. 1} \\ \text{for each stream sequence}}} \right).$$

On the other hand, the complexity of the ISNSSS algorithm is $(\sum_{k=2}^{K} (q_k \times k)) \times (r \times K)$. Consequently, Alg. 1 is invoked 24 times by ISNSSS and 51408 times by exhaustive search which is a considerable decrease in complexity by the proposed algorithm.

The performance results of algorithm ISNSSS with both metrics *M1* and *M2* are given in Figure 3. It can be seen that Chordal distance metric performs approximately 1 bps/Hz better than Euclidean distance metric for different number of quantization bits. In addition, the performance results of

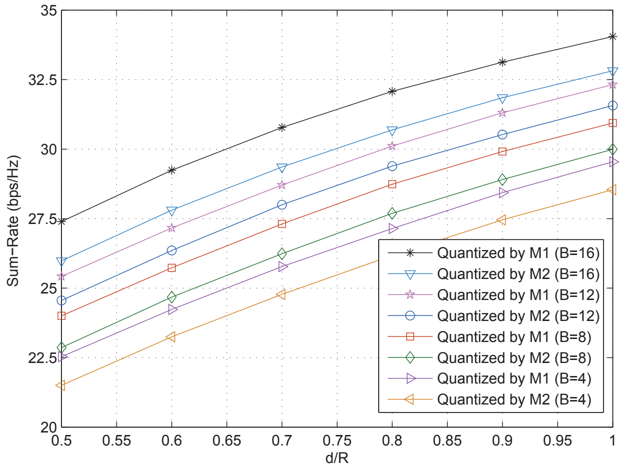

Fig. 3. The comparison of two metrics for ISNSSS with different B values.

the proposed algorithm with the quantized channel state information by 16 bits are compared to the exhaustive search, successive null space stream selection (SNSSS) [3], max-SINR and min-Leak [2] using metric *M1*. The performance results can be seen in Figure 4. It can be observed that the sum rate of the proposed algorithm is 4 bps/Hz improved when compared to SNSSS approach.

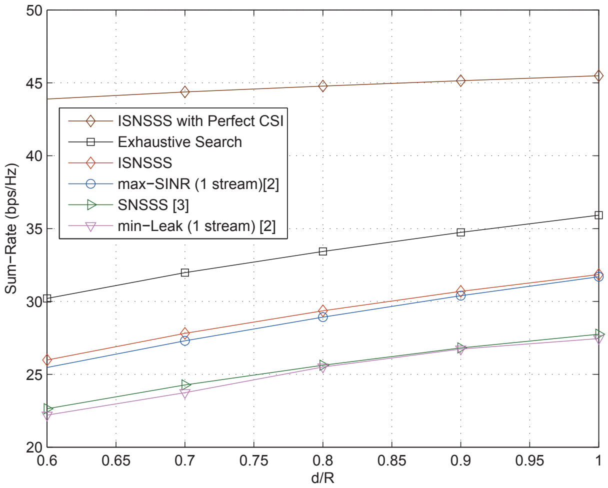

Fig. 4. The comparison of different algorithms with $B = 16$ using distortion metric *M1*.

VI. CONCLUSION

In this paper, we have presented an improved stream selection method through quantized channel for heterogeneous networks in order to deal with the interference among different cell types. The proposed algorithm handles the interference between the selected streams by performing orthogonal projections after selecting each stream. The precoders and postcoders have been obtained utilizing the quantized CDI through two distortion metrics. The performance of the algorithm has been evaluated by varying the positions of pico BSs. The results indicate that the proposed algorithm with quantized channel achieves higher sum rate than the existing algorithms for the same number of feedback bits by getting closer to the upper bound set by the exhaustive search while achieving a significantly lower complexity. Moreover, it is observed that the Chordal distance yields better performance than the Euclidean distance since the codewords and normalized channel are lying in the non-Euclidean space of Grassmann manifolds.

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