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A Centralized Inter-Cell Rank Coordination Mechanism for 5G Systems

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***Abstract*—Multiple transmit and receive antennas can be used to increase the number of independent streams between a transmitter-receiver pair, or to improve the interference resilience property with the help of linear minimum mean squared error (MMSE) receivers. An interference aware inter-cell rank coordination framework for the future fifth generation wireless system is proposed in this article. The proposal utilizes results from random matrix theory to estimate the mean signal-to-interference-plus-noise ratio at the MMSE receiver. In addition, a game-theoretic interference pricing measure is introduced as an inter-cell interference management mechanism to balance the spatial multiplexing vs. interference resilience trade-off. Exhaustive Monte Carlo simulations results demonstrating the performance of the proposed algorithm indicate a gain of around 40% over conventional non interference-aware schemes; and within around 6% of the optimum performance obtained using a brute-force exhaustive search algorithm.**

***Index Terms*—5G, rank adaptation, random matrix theory, interference pricing, MMSE receivers, MIMO.**

I. Introduction

Multiple transmit and receive antennas, collectively known as MIMO, can improve the spectral efficiency of a wireless system by introducing spatial degrees of freedom (DoF) at the transmitter end. On the other hand, the linear minimum mean squared error (MMSE) receiver can suppress parts of the received interference signal by exploiting its structure. MIMO transmissions and the MMSE receiver are therefore foreseen to play a prominent role in improving the *spectral efficiency* of future wireless systems such as the fifth generation of cellular technology (5G) [1].

It is well known that utilizing some of the MIMO spatial DoFs for interference suppression result in better system level performance compared to the case where all spatial DoFs are used for transmitting/receiving desired data streams [2]. With MIMO transceivers, interference coordination can include coordinating the number of independent transmitted streams, also known as the transmission rank. When employed in tandem with MMSE receiver, rank coordination mechanisms are aimed at balancing the tradeoff between increasing the spatial diversity gain by transmitting over multiple streams, and/or improving the interference resilience by leaving more spatial DoFs for interference suppression by the MMSE receiver [2]–[4].

Several open-loop and closed-loop rank coordination algorithms for the long term evaluation (LTE) and LTE-Advanced (LTE-A) systems are presented and numerically evaluated in [3]. Alternatively, reference [2] proposes a method to select the rank that maximizes the mutual information given a target Block Error Ratio under the assumption of having perfect channel state information (CSI) and no inter-cell interference. The algorithms presented in [2], [3] are based on the signal-to-interference-plus-noise ratio (SINR), which requires knowledge of the interference covariance matrix (ICM). Due to the multitudes of matrix operations involved, estimating the SINR from the ICM requires accurate CSI, and is computationally costly [4]. Low complexity joint precoding matrix and rank selection algorithms for the LTE-A system are proposed in [4] that use an average channel information across the entire system bandwidth. The proposed algorithms select the rank that can deliver the highest throughput at the desired receiver by searching across all possible rank/precoding matrix combinations.

Most of the existing rank adaptation algorithms do not consider the interference management aspect of rank coordination. As such they can rather be considered *egoistic* instead of being *interference-aware*. With the 5G network poised to become increasingly dense, such myopic transmission is usually inefficient when considering the overall system-level performance [5]. Coordination among interfering cells is therefore necessary to better manage the interference, as exemplified for a multicell system in [6]. Such coordination becomes even more important in systems employing the MMSE receiver, where the number of interfering streams directly impact the interference suppression capabilities of the interfered receivers.

In this work, we propose a novel centralized interference-aware inter-cell rank coordination scheme. The interference suppression capability of the MMSE receiver is specifically considered when formulating the rank adaptation problem, which, to the best of our understanding, has not been considered in earlier contributions. More precisely, besides considering the performance at the desired receiver, the proposed algorithm takes into account the impact of the generated interference on the performance of the interfered receivers when selecting the transmission rank.

The remainder of this paper is organized as follows:

the system model and details the problem formulation are described in Section II. Section III presents the proposed interference aware rank adaptation algorithm. Results evaluating the performance of the proposed algorithm are presented in Section IV, followed by concluding remarks in Section V.

Notations: Matrices and vectors are respectively denoted by boldface symbols $\mathbf{H}$ (capital) and $\mathbf{h}$ (small letter). $\mathbf{I}_{M\times K}$ denotes the $M \times K$ dimensional identity matrix, while $(\cdot)^H$ denotes the Hermitian operator. $\mathcal{CN}(\mu, \sigma^2)$ represents the complex Gaussian distribution with mean μ and variance σ^2, while $\mathbb{C}$ represents the set of all complex numbers. $\mathcal{U}(a, b)$ denotes the uniform distribution with support between a and b, where $(a < b)$. All logarithms are base 2, unless stated otherwise.

II. System Model

Let us consider a narrowband multi user-MIMO time division duplexed (TDD) system with a number of cells. The access points (AP) in each cell are connected to a centralized controller node. We assume that L cells share a given time-frequency slot, with at most a single co-channel active user equipment (UE) in each of the selected cells. The set $\mathcal{L} = \{1, 2, \ldots, L\}$ denotes the set of all active cells in a given sub-band. We focus on the downlink direction throughout this paper, although the proposed framework can easily be extended to the uplink.

Each link in the lth cell is assumed to have N_l transmit antennas and M_l receive antennas. The transmitter-receiver pair in the lth cell communicates by transmitting $d_l \leq \min(M_l, N_l)$ streams over the N_l transmit antennas using an $N_l \times d_l$ linear precoding matrix $\mathbf{W}_l$. All cells are assumed to be time synchronized.

1) Signal Model: The received signal vector $\mathbf{y}_l$ at the receiver in cell l can be expressed as

$$\mathbf{y}_l = \sqrt{\rho_{ll}}\mathbf{H}_{ll}\mathbf{W}_l\mathbf{x}_l + \sum_{k\in\mathcal{L},k\neq l} \sqrt{\rho_{lk}}\mathbf{H}_{lk}\mathbf{W}_k\mathbf{x}_k + \mathbf{z}_l, \quad (1)$$

where $\mathbf{H}_{lk} \in \mathbb{C}^{M_l\times N_l} \sim \mathcal{CN}\left(0, \frac{1}{2}\right)$ denotes the channel matrix between the kth transmitter and the lth receiver. The vectors $\mathbf{x}_l \in \mathbb{C}^{d_l} \sim \mathcal{CN}\left(0, \frac{1}{2}\right)$ and $\mathbf{z}_l \in \mathbb{C}^{M_l} \sim \mathcal{CN}\left(0, \frac{1}{2}\right)$ represent the transmitted vector from the lth transmitter and the white Gaussian noise vector at the lth receiver respectively. The signal-to-noise ratio (SNR) of the channel between transmitter k and receiver l is given by ρ_{lk}. A block fading channel model is considered.

We assume that the lth transmitter can obtain $\mathbf{H}_{ll}$ by exploiting channel reciprocity. Alongside, the long-term channel statistics $\rho_{lk}\, \forall l, k \in \mathcal{L}$, and the identity of the scheduled active user in each time slot are also assumed to be known. All channel estimations are assumed fed to the centralized controller through a high-capacity delay-free backhaul link.

In order to entirely focus on the rank selection problem, we let the transmit precoder $\mathbf{W}_l = \mathbf{I}_{N_l\times d_l}$. Given a transmission rank, the precoder selection problem considering different design cirteria are thoroughly discussed in [7].

Support for MMSE Receiver in 5G: It is well known that an accurate estimation of the ICM is needed for the MMSE receiver operation. In LTE, pilot symbols sparsely inserted in the OFDM time-frequency grid can be used to estimate the ICM. The proposal in 5G is to use a specifically designed frame structure to support a more accurate ICM estimation [8].

A. Problem Formulation

The achievable rate of a user in cell l, as denoted by R_l, is a function of the transmission rank d_l. An optimization problem for finding the precoding matrices that maximize the network-wide sum performance measure, subject to a set of given constraints, can be formulated as

$$(P) \qquad \{\mathbf{W}_1^*, \mathbf{W}_2^*, \ldots, \mathbf{W}_L^*\} = \arg\max_{\mathbf{W}_l\in\mathcal{W}} \sum_{l\in\mathcal{L}} R_l.$$
$$\text{max Transmit Power constraint, } P_l \leq P_{max}$$

The problem is non-trivial since increasing one's own achievable rate by transmitting with a higher rank directly impacts the interference generated at, and subsequently the achievable rate of, the interfered users [9]. Given that the maximization is performed over the predefined set of precoding matrices $\mathcal{W}$, (P) is a combinatorial problem. Unfortunately, optimally solving through brute force search invovles a very large search space, and is not feasible in practice [9]. Alternately, the precoding matrix can be selected by independently searching across all the possible codebook entries at each user and selecting the one that maximizes a given performance measure. However, selecting the precoding matrices independently at each cell results in selfish and myopic transmission strategies that is inefficient from a sum network performance perspective [5], and still computationally exhaustive (e.g., requires $64 \times L$ computations, for the above example [4]). We therefore propose an efficient sub-optimal solutions of (P). The outline of the proposed solutions is summarized next, followed by detailed descriptions in the remainder of this paper.

B. Algorithm Outline

An accurate estimation of the ICM is required in order to calculate the achievable rate of the MMSE receiver [4]. However, the ICM can only be estimated after the actual data transmission, whereas the rank should be decided prior to the data transmission. This necessitates an efficient and direct SINR estimation method that circumvents the requisite of relying on the ICM for estimating the SINR. We propose to use results from random matrix theory to estimate the SINR as detailed in the following Section.

The second challenge is the inter-dependency of the transmission rank and the performance among the co-existing users. Mutual interference make the user rates coupled, and the overall network objective may not be concave

with respect to the transmission rank. The challenge is further exacerbated by the MMSE receiver, whose interference suppress capabilities depend on the strength and the number of the perceived interference streams [10]. To overcome this challenge, we propose to adopt interference pricing as a measure to control the interference impact of transmitting with multiple ranks. Such interference pricing mechanism has been efficiently used as an interference management technique for power control [11].

III. Proposed Centralized Interference-Aware Rank Selection Algorithms

An efficient estimation of the post-MMSE SINR, and an effective utility measure accounting for the interference generated at neighbouring receivers are the main building blocks of our proposed algorithm. These are first presented in this section, followed by details of the proposed interference-aware rank coordination algorithm.

A. Post MMSE-SINR Estimation

Considering the signal model presented in (1), the signal of interest at the ith stream of the lth receiver is can be decomposed as

$$\mathbf{y}_{l,i} = \underbrace{\sqrt{\rho_{ll}}\mathbf{g}_{ll,i}x_{l,i}}_{\text{desired signal}} + \underbrace{\sqrt{\rho_{ll}}\sum_{j\neq i, j=1}^{d_l}\mathbf{g}_{ll,j}x_{l,j}}_{\text{Intra-stream interf. (ISI)}} + \underbrace{\sum_{k\neq l, k\in\mathcal{L}}\sqrt{\rho_{lk}}\sum_{j=1}^{d_k}\mathbf{g}_{lk,j}x_{k,j}}_{\text{Inter-cell interf. (ICI)}} + \mathbf{z}_l, \quad (2)$$

where $\mathbf{g}_{lk,i}$ is the ith column of the $M_l \times d_k-$dimensional equivalent channel matrix $\mathbf{G}_{lk} \triangleq \mathbf{H}_{lk}\mathbf{W}_k$, while $x_{l,i}$ is the ith element of $\mathbf{x}_l$. Considering the MMSE receiver, the desired signal-to-interference-plus-noise ratio (SINR), $\gamma_{l,i}$, at the ith stream of the lth receiver is given by [12]

$$\gamma_{l,i} = \rho_{ll}\mathbf{g}_{ll,i}^H\left(\mathbf{I}_{M_l} + \mathbf{\Sigma}_{l,i}\right)^{-1}\mathbf{g}_{ll,i}, \quad (3)$$

where $\mathbf{\Sigma}_{l,i}$ is the interference covariance matrix. The corresponding achievable Shannon rate at the lth receiver can then be expressed as

$$R_l = \sum_{i=1}^{d_l}\log(1+\gamma_{l,i}). \quad (4)$$

By assuming the different transmitter sources to be mutually uncorrelated, the covariance matrix of the received interference signal is given as $\mathbf{\Sigma}_{l,i} = \frac{\rho_{ll}}{d_l}\sum_{j=1,j\neq i}^{d_l}\mathbf{g}_{ll,j}\mathbf{g}_{ll,j}^H + \sum_{k\in\mathcal{L},k\neq l}\frac{\rho_{lk}}{d_k}\mathbf{G}_{lk}\mathbf{G}_{lk}^H$.

The post-MMSE SINR of the desired signal can be expressed as[1] $\gamma = \rho\tilde{\mathbf{g}}^H\left(\mathbf{\Sigma}+\mathbf{I}_M\right)^{-1}\tilde{\mathbf{g}}$, where $\tilde{\mathbf{g}} \triangleq \frac{1}{d_l}\mathbf{H}_{ll,i}$. Let us consider the eigen-value decomposition (EVD) of $\mathbf{\Sigma}$ as given by $\mathbf{\Sigma} = \mathbf{T}\mathbf{\Lambda}\mathbf{T}^H$. The $M-$dimensional diagonal matrix $\mathbf{\Lambda} = \text{Diag}\left(\lambda_1, \lambda_2, \ldots, \lambda_M\right)$ contains the eigenvalues of $\mathbf{\Sigma}$, while the mth column of the unitary matrix $\mathbf{T}$ represents the eigenvector corresponding to the eigenvalue λ_m. Using the EVD of $\mathbf{\Sigma}$, and after some algebraic manipulations, the instantaneous SINR can be re-expressed as [12]

$$\gamma = \rho\sum_{m=1}^{M}\frac{|\vec{g_m}|^2}{\lambda_m+1}, \quad (5)$$

where $\vec{g_m}$ is its mth element of the vector $\vec{\mathbf{g}} \triangleq \mathbf{T}^H\tilde{\mathbf{g}}$. Note that, $\vec{\mathbf{g}}$ and $\tilde{\mathbf{g}}$ have the same statistical properties since $\mathbf{T}$ is unitary; i.e. $\vec{\mathbf{g}} \sim \mathcal{CN}(0, \frac{1}{2})$.

In order to circumvents the requisite of relying on the ICM to estimate the post MMSE-SINR, we propose to use the mean SINR expression as an estimate for instantaneous SINR. More specifically, using results from RMT to analyse the asymptotic behaviour of the eigenvalues of $\mathbf{\Sigma}$ appearing in (3), it is proposed in [13] that the post-MMSE SINR can be approximates as

$$\bar{\gamma} = \rho_{ll}\tilde{\gamma}, \quad (6)$$

where $\tilde{\gamma}$ is the only positive root of the following polynomial equation

$$\sum_{k\in\mathcal{K}}\frac{\rho_{lk}\beta_k}{1+\rho_{lk}\tilde{\gamma}} - \frac{1}{\tilde{\gamma}} + 1 = 0. \quad (7)$$

Note that, $\beta_k \triangleq \frac{d_k}{M}\,\forall k \in \mathcal{K}, k \neq l$, while $\beta_l = \frac{d_l-1}{M}$.

B. Pricing as an Interference Management Concept

The concept of 'pricing as a control parameter' from game theory is applied in this work to enforce the coexisting users to behave altruistically. Coexisting APs exchange specific interference aware control information known as *interference price*. Such information allows a transmitter to account for the utility of its transmission in a more comprehensive way by not only considering its own throughput, but also the loss in the interfered users' throughputs resulting from its own transmission [11].

1) Effective utility estimation: When a particular transmitter becomes active, it can achieve a certain throughput under the existing conditions, while simultaneously resulting in a certain amount of interference at the coexisting receivers. With all other conditions unchanged, the additional interference would in turn result in a reduction in the received SINR at the interfered receivers, thereby translating to a reduced throughput.

The '*effective utility*' measure is introduced to represent the contribution of a particular user to the total system sum rate. It is defined as the difference between the achievable throughput of a particular user and the estimated loss in the achievable throughputs of the interfered users due to the generated interference. Such an utility measure reflects a more socially beneficial utility from a system sum-rate perspective [11]. However, it must be noted that this is only an approximation by the AP, since it is not practically

[1]The indices are dropped henceforth for ease of presentation.

possible to know the exact interference produced by all the interferers at each victim receiver.

Estimating the Throughput Loss Due to a Change in the Interference Rank: Let γ_1 denote the instantaneous SINR of a particular link under a specific channel condition, and $R(\gamma_1) = \log(1+\gamma_1)$ be the corresponding achievable throughput. Suppose now that a particular interferer changes its transmission rank, resulting in a new SINR and throughput of γ_2 and $R(\gamma_2)$ respectively. The new throughput $R(\gamma_2)$ can be approximated in terms of the change in the interferer rank (Δd) using the first degree Taylor polynomial approximation as follows [14, Eq. (25.2.24)]

$$R(\gamma_2) \approx R(\gamma_1) + R'(\gamma_1)\Delta d, \tag{8}$$

where $R'(\gamma_1)$ is the derivative of the throughput w.r.t. the interferer rank evaluated at the SINR $= \gamma_1$. The actual throughput loss $Q = R(\gamma_1) - R(\gamma_2)$, can be approximated using Eq. (8) as $Q \approx -R'(\gamma_1)\Delta I$.

Interference Price: The interference price, α_{lk}, is introduced as a measure of the rate of change of the throughput at receiver l w.r.t. the rank from transmitter k, and is defined as $\alpha_{lk} = -\frac{\delta R(\gamma_l)}{\delta d_k}$. Let $\gamma_{l,i}$ be the instantaneous post-MMSE SINR at the ith stream of receiver l. Using the relation $R_l = \sum_i \log(1+\gamma_{l,i})$, let us further define $\gamma_l = \prod_i (1+\gamma_{l,i}) - 1$ as the effective SINR at receiver l. Considering the Shannon rate, the interference price at receiver l from transmitter k can be derived as

$$\alpha_{lk} = -\frac{\delta R(\gamma_l)}{\delta \gamma_l}\frac{\delta \gamma_l}{\delta d_k} = \frac{\log(e)}{1+\gamma_l}\kappa_{lk}, \tag{9}$$

where $\kappa_{lk} = -\frac{\delta \gamma_l}{\delta d_k}$. Directly evaluating κ_{lk} is not straightforward. We therefore propose to approximate κ_{lk} using the mean SINR expression in Eq. (6). Let $\bar{\gamma}_l(d_k)$ be the mean SINR at receiver l considering rank d_k of user k. We can then approximate κ_{lk} as

$$\kappa_{lk} \approx -\frac{\Delta \bar{\gamma}_l(d_k)}{\Delta d_k} = \begin{cases} \bar{\gamma}_l(d_k) - \bar{\gamma}_l(d_k+1) & d_k < M \\ \bar{\gamma}_l(d_k-1) - \bar{\gamma}_l(d_k) & d_k = M. \end{cases} \tag{10}$$

Effective Utility: The effective utility measure is a reflection of an individual user's contribution to the system sum throughput. Let Q_{kl} be the throughput loss at user k due to the transmission of user l. In other words, isolating the interference from user l results in an additional throughput of Q_{kl} at user k. Following Eq. (8) and using the introduced *interference price* measure, Q_{kl} can be approximated as $Q_{kl} \approx \alpha_{kl} d_l$. Since the mean post-MMSE SINR is used as an estimate of the achieved SINR, the estimated SINR per stream (when transmitting with more than one stream) is the same at each streams. Thus the *effective utility* of user l, transmitting with rank d_l, can be defined as

$$\Pi_l(\bar{\gamma}_l, d_l) = d_l \log\left(1 + \bar{\gamma}_l(d_l)\right) - \sum_{k \in \mathcal{L}, k \neq l} \alpha_{kl} d_l. \tag{11}$$

where $\bar{\gamma}_l(d_l)$, as given by Eq. (6), is the estimated mean SINR at receiver l considering the desired rank d_l.

C. Proposed Centralized Interference-Aware Rank Selection Algorithms

Having introduced efficient methods to estimate the post-MMSE SINR and the *effective utility* measure, we are now ready to present the proposed interference-aware RA algorithms. The message flow diagram of the proposed centralized interference-aware rank selection algorithm is presented in Fig. 1. The presented flowchart considers the downlink scenario as a specific example, though the proposed algorithm is equally valid for the uplink direction.

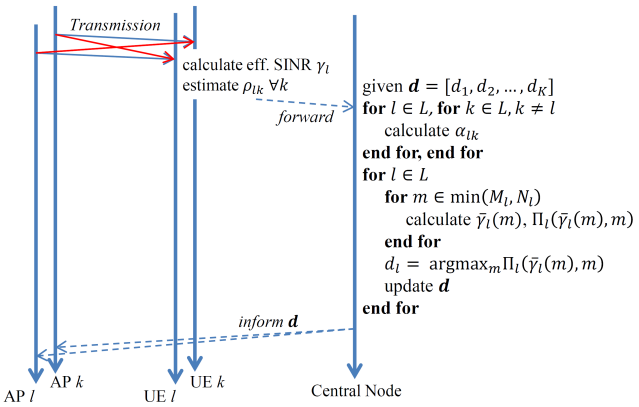

Fig. 1. Message flow diagram of the proposed centralized interference-aware rank adaptation algorithm.

At each rank update interval, each UE forwards the effective SINR, measured as outlined in Section III-B1, along with the interference power measurements from the interfering APs to the central node. The mean path loss can be estimated at each receiver, for instance, from the orthogonal reference sequences transmitted by neighbour nodes [15]. Path loss measurements below a certain threshold are excluded from the reporting since they will have negligible impact for most scenarios.

Given the mean path loss measurements and the available information about the transmission rank, the central node can calculate the interference prices $\alpha_{lk} \forall l, k$ using Eq. (9). The estimated mean post-MMSE SINR $\bar{\gamma}_l(d_l)$ for a candidate transmission rank d_l at a given receiver l can then be calculated using Eq. (6). Note that, the updated transmission from the current rank adaptation cycle is considered as the transmission ranks of users $1, 2, \ldots, l-1$ when calculating $\bar{\gamma}_l(d_l)$ for user l. On the other hand, the transmission rank of the previous RA cycle is considered for the yet-to-be-updated users $l+1, \ldots, K$.

The effective utility measure at user l can thereafter be evaluated for each candidate rank $d_l \in \{1, 2, \ldots, \min(M_l, N_l)\}$. Finally, the candidate rank that maximizes the effective utility is selected as the transmission rank $d_l^\star$ of user l. The proposed centralized algorithm only requires the mean path loss values ρ_{lk} and the received effective SINR γ_l as inputs to the central node. The other parameters, namely the ranks d_l and the interference prices

α_{lk}) of the interfering users are obtained from information readily available at the central node. This is in contrast to the complete channel matrix information required for an ICM based rank adaptation approach, such as those presented in [2], [3].

IV. Numerical Results

Performance results for the proposed algorithms, obtained through Monte Carlo simulations, are presented in this Section. All results are presented in the form of system sum rate in bps/Hz. The presented results consider 4×4 MIMO configuration. A full buffer traffic model is considered for all links. The path loss between any pair of interfering links are chosen randomly from an uniform distribution, the range and support of which is varied to represent different densities of the interfering network. The presented simulation results are averaged over at least 1000 sample runs to ensure statistical reliability. During each snapshot, the path loss, shadowing and location of devices remain fixed. However these parameters change independently from one snapshot to another.

A. Impact of Network Interference Density

The sum network spectral efficiency curves for the proposed algorithms under different interference conditions with 6 cells are presented in Figures 2 and 3. Each figure represents a particular interference density scenario. The ideally attainable maximum sum rate obtained through brute force (BF) search across the all possible rank combinations is also shown for comparison. Alongside, the performance obtained with a fixed rank 2, and the conventional non victim aware (non-VA) rank adaptation algorithm are presented as benchmark results.

Observing the performance trends in Figures 2 and 3, the centralized RA algorithm is found to perform close to the optimum performance. This highlights the fact that the method to estimate the SINR as employed in the proposed RA algorithm, and the interference price as an effective interference control mechanism, are in fact useful in providing a good estimate of the performance of the MMSE receiver. In practice, the BF search optimum performance can only be achieved in the presence of a near-infinite capacity instantaneous feedback link between each user and the central node as it entails centrally available non-causal global CSI. The nominal sum rate gap with the optimum performance can partially be attributed to the fact that the parameters, such as the interference price, are calculated based on the previous transmission time interval parameters, and the approximation involved in estimating the effective interference measure.

A significant performance benefit can be observed through introducing the interference awareness framework, which helps to estimate the impact of the interference on other co-existing users, as can be deduced from the performance gap between the interference aware and the non-VA algorithm. On a closer observation, at low SNRs where the system is *power limited*, the *interference price* and *effective interference* calculation methods of the centralized algorithm allow for better exploitation of the spatial gain vs. interference rejection tradeoff, resulting in close-to-optimum performance. On the other hand, the dynamics of the spatial gain-vs.-interference rejection tradeoff are left unexplored when transmitting with a fixed rank as illustrated by the relatively good performance of the fixed rank curves at low SNR values, but not at higher SNR values.

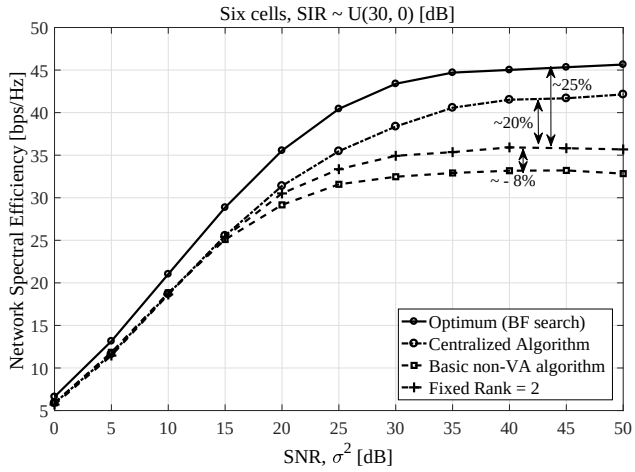

Fig. 2. Network spectral efficiency in bps/Hz across 6 users for the proposed interference aware RA algorithms with the SIR $\sim \mathcal{U}(30, 0)$ [dB] representing a dense network.

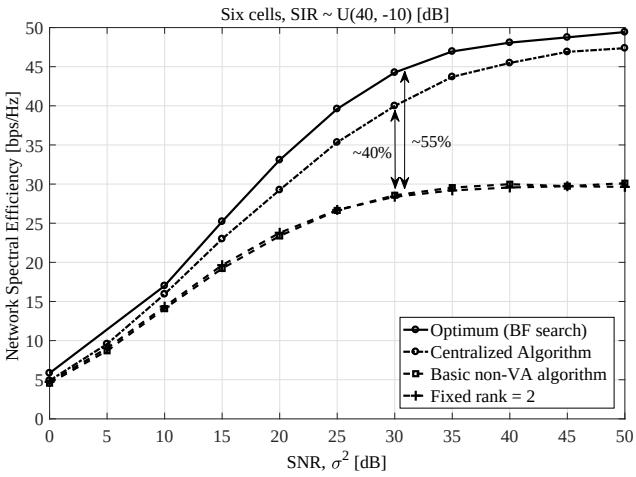

Fig. 3. Network spectral efficiency in bps/Hz across 6 users for the proposed interference aware RA algorithms with the SIR $\sim \mathcal{U}(40, -10)$ [dB] representing a sparse network where the interferer can at times be stronger than the desired signal.

B. Impact of Network Size

Next, we investigate the impact of the number of cells in the network in Fig. 4. The SNR of the desired link is fixed at 30 dB, while the interference link strengths are randomly chosen to ensure that the signal to interference ratios (SIR) are follow the uniform distribution $\mathcal{U}(40, -10)$[dB]. The

uniform distribution with a wide range is chosen to model the large interference fluctuation considered in this work. Physically, such a set up can be seen as sparse network where the interferer can at times be stronger than the desired signal, for example due to a closed user group configuration.

The interference increase with increasing number of active cells, resulting in a decline in the mean rate per cell. For all the considered network sizes, the proposed centralized algorithm performs close to the optimum performance found through BF search. Furthermore, the centralized algorithm converges to the optimum performance with increasing number of cells. With increasing network size, the inter-user interference becomes the dominant performance limiting factor, and hence the proposed algorithm basically converges to transmitting with rank one. However, this is not the case with the non-VA algorithm as it does not consider the increased inter-cell interference when making the rank decision.

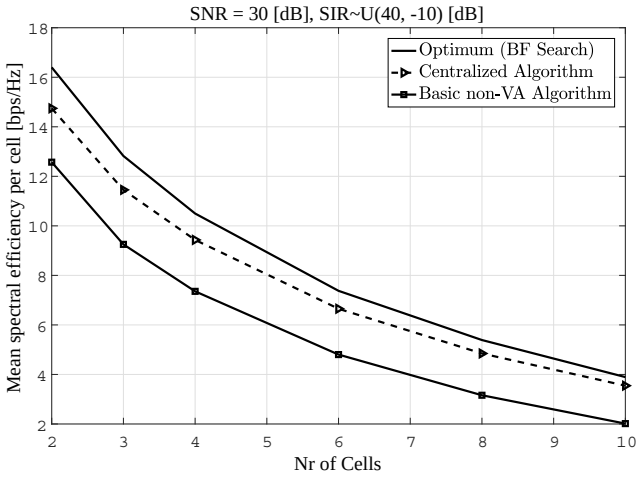

Fig. 4. Network spectral efficiency per cell with different number of cells for the different proposed algorithms.

V. Conclusion

We have introduced a novel and practical *'interference-aware'* rank adaptation algorithm for a 5G system employing the MMSE receiver. The proposed algorithm uses tools from random matrix theory to evaluate the mean post-MMSE SINR, which is one of the parameters used to estimate the achievable rate for each rank combination. Alongside, the concepts of *interference pricing* as a control mechanism, and *effective utility* as an interference-aware measure of the sum throughput are introduced to better reflect the dynamics of the interference-throughput interaction, and to account for the impact of the generated interference on the throughput performance at the interfered receivers.

The selected rank is expected to maximize the sum network throughput. The performance of the proposed centralized algorithm in terms of the system-wide sum throughput are evaluated in details. The proposed algorithm is found to perform close to the maximum achievable performance obtained through an exhaustive search algorithm for a wide range of network size, while incurring much lower complexity; thus making it suitable for practical implementation in 5G systems. As part of the future work, we plan to incorporate the different 5G service classes and the concept of multi-connectivity into the proposed inter-cell rank coordination framework.

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