Enhanced Interference Management Technique for Multi-Cell Multi-Antenna System

Simon E. Uguru, Victor E. Idigo, Obinna S. Oguejiofor, Naveed Nawaz

***Abstract*—**As the deployment of the Fifth Generation (5G) mobile communication networks take shape all over the world, achieving spectral efficiency, energy efficiency, and dealing with interference are among the greatest challenges encountered so far. The aim of this study is to mitigate inter-cell interference (ICI) in a multi-cell multi-antenna system while maximizing the spectral efficiency of the system. In this study, a system model was devised that showed a miniature representation of a multi-cell multi-antenna system. Based on this system model, a convex optimization problem was formulated to maximize the spectral efficiency of the system while mitigating the ICI. This optimization problem was solved using CVX, which is a modeling system for constructing and solving discipline convex programs. The solutions to the optimization problem are sub-optimal coordinated beamformers. These coordinated beamformers direct each data to the served user equipments (UEs) in each cell without interference during downlink transmission, thereby maximizing the system-wide spectral efficiency.

***Keywords*—**Coordinated beamforming, convex optimization, inter-cell interference, multi-antenna, multi-cell, spectral efficiency.

I. Introduction

INTERFERENCE can be simply defined in wireless communication as an unwanted signal that corrupts the desired signal, thereby reducing the quality of the desired signal. They operate in the same frequency band and share similar structure/characteristics, hence difficult to eliminate. In contrast, interference can be distinguished from thermal noise in its physical and statistical features, because thermal noise is normally distributed, whereas interference has the same structure as the desired signal. It is good to note that interferences are desired signals in other cells and for other user equipments (UEs) also. Many interference management techniques have been proposed for the multi-cell system, however, while these interference management techniques improve performance, some do sacrifice the aggregate spectral efficiency (SE) of the system in order to solve the problem of ICI. Some notable interference management techniques that sacrifice the SE of the system include: Frequency-domain inter-cell interference coordination (ICIC) [1] which was proposed to address ICI by coordinating the use of frequencies among cells. Enhanced inter-cell interference coordination (eICIC) schemes have been developed and specified in LTE-Advanced releases 10 and 11, enhanced frequency domain and time-domain ICIC [2] are performed through carrier aggregation (CA) [3] which is supported by LTE-Advanced (3GPP Release 10) and can be used to avoid ICI interference in the downlink. In a conventional multi-cell system using single antenna technology, electromagnetic waves are radiated omnidirectionally. By utilizing fixed frequency reuse patterns and single cell processing (SCP), neighboring cells will be protected from ICI. This frequency allocation scheme to each cell and UEs are usually computed and evaluated during the radio planning process and only long-term readjustment is performed during the operation of the network. However, this approach is statically done and involves a lot of frequency planning to enable successful implementation rollout.

This work is focused on maximizing the system-wide spectral efficiency of a multi-cell multi-antenna system such that UEs in the cell edge of the cells will not experience a loss in throughput due to much ICI received from neighboring BSs. In this regard, enhanced interference management technique that is antenna based will be devised, couple with cooperation among BSs, to deal with ICI that has the capability to limit the achievable system-wide system efficiency for multi-cell multi-antenna systems.

The rest of this paper is organized as follows. In Section 2, related works to this study were reviewed. In Section 3, the method used to actualize the results is presented. Simulation results and discussions are provided in section 4 and the conclusion is given in the last section.

Notation: $(\cdot)^H$is the transpose conjugate operation, $(\cdot)^T$is the transpose operation, $\|\cdot\|_2$is the Euclidean norm of a vector, $|\cdot|$ is the magnitude of a complex variable, $\mathbb{R}^{\boldsymbol{n}}$denotes the set of real n-vectors. $\mathbb{C}$ denotes the set of complex numbers, while $\mathbb{C}^n$ denotes the set of complex n-vectors. Uppercase boldface letters are used to represent matrices while lower-case boldface for vectors.

II. Literature Review

Interference is a limiting factor to the performance of the multi-cell multi-antenna systems and if not properly managed will deteriorate the achievable system-wide throughput. Different techniques have been proposed in different research works to proffer solutions to the interference problem. Multi-cell processing (MCP) has become evident as one of the

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efficient ways to control interference as well as enhance the SE of the system. In this regard, many authors have proposed a lot of techniques on how the ICI will be managed in multi-cell systems. In what follows, a review of some of the relevant works is hereby presented.

Authors in [4] proposed a type of multi-cell cooperation, where the BSs only exchange control-level signals. They require some form of joint allocation of available resources to orthogonalize UE transmission in neighboring cells by allocating frequency bands and/or timing cycles. This is the type of cooperation used by inter-cell interference coordination (ICIC), while these techniques may yield higher sum-rates than static transmission algorithm, they did not utilize all the available frequency and time resources, hence, cannot realize the significant performance gain that is obtainable using MCP.

Authors in [5]-[7] proposed coordinated beamforming (CB), which is a type of MCP reported in LTE-Advanced (3GPP Release 10). In CB, each BS serves its UE with data but share channel state information (CSI) and selects transmit strategies jointly with all other cooperating base stations. This will bring about a fair balance between realizing the gains for using MCP and ensuring a moderate load on the backhaul links. The shared CSI can be used by each BS to design individual beamformers or precoders for single-stream and multi-stream transmission to its served UEs respectively. Authors in [8] proposed joint transmission (JT), which is also a type of MCP, however when compared with CB, CB has been shown to be a practical and feasible approach for mitigating interference in the downlink of multi-cell systems. From a practical perspective, JT has limitations because it requires global CSI knowledge and data sharing among all cooperating BSs, which puts huge demands on the feedback links and backhaul networks. Tight synchronization is a very important factor JT needs to become practically feasible.

In [9], the authors proposed the use of enhanced inter-cell interference coordination (eICIC), which is an interference control technology defined in 3GPP release 10, it is an advanced version of ICIC, previously defined in 3GPP release 8, evolved to support heterogeneous Network (HetNet) environment. To prevent ICI, eICIC allows cell-edge UEs to use different time ranges (subframes) in neighboring cells.

Having reviewed some notable and relevant literature, it can easily be seen that most of the reviewed work roughly solves the ICI problem through the techniques they proposed. However, most of these techniques did not maximize the system-wide spectral efficiency of the system. This study differs from the study in [4] because the access scheme they adopt is orthogonal frequency division multiple access (OFDMA) in each cell, while this study adopts space division multiple access (SDMA) in each cell and cooperation among neighboring cells which insinuate universal frequency reuse for all cells.

eICIC proposed by authors in [9], can improve performance only when the cell-edge UEs are operating under different time ranges (subframes). This differs from the method utilized in this study because, all BS can transmit signals simultaneously in the same frequency/time resource, the ICI to the cell edge UEs are coordinated through the cooperation of the BSs and handled through precoders jointly designed by the BSs.

Authors in [6], in their seminal work in CB, proposed the use of the Lagrange multiplier method as a technique for designing coordinated beamformers for multi-cell multi-antenna systems. In this study, optimization problem was formulated with the aim of selecting an optimal coordinated beamformer that will maximize the system-wide spectral efficiency while controlling the accompanying ICI. This proposed technique differs from the one proposed in the seminal work because the aim in that work is to select the coordinated beamformer that will minimize the total transmitted power in the system while controlling the accompanying ICI.

III. Methodology

A. System Model

The downlink of a Multi-Cell Multi-Antenna System is considered as shown in Fig. 1. It consists of K_t cells, all cells in the system use the same carrier frequency. The set of base stations (BSs) in this system is denoted by $\mathcal{M} = \{1, \ldots, K_t\}$. The jth BS is denoted BS_j which can be any of the BSs in the system model, and is assumed to have N antennas with which it communicates with K UEs per cell (with at least one active UE per cell) which is also assumed to have a single antenna. The set of UEs served by BS_j is denoted by $\mathcal{S}_j \subset \{1, \ldots, K_r\}$, where K_r denotes the total number of UEs in the system, also the kth UE is denoted UE_k. The complex-baseband received data signal at UE_k is $y_k \in \mathbb{C}$ and given by

$$y_k = \sum_{j=1}^{K_t} \sqrt{g_{j,k}} \left(\boldsymbol{h}_{j,k}^{s}\right)^H \boldsymbol{x_j} + n_k \,. \tag{1}$$

where $\sqrt{g_{j,k}}$ is the large-scale path loss from BS_j to UE_k. Also $\boldsymbol{h}_{j,k}^{s} \in \mathbb{C}^{N\times 1}$ is the small scale (fading) channel vector from BS_j to UE_k. Furthermore, $n_k \in \mathbb{C}$ is the additive noise from the surroundings and is modeled as circularly symmetric complex Gaussian, distributed as $n_k \sim \mathcal{CN}(0, \delta^2)$, where δ^2 is the variance of the noise. $\boldsymbol{x_j} \in \mathbb{C}^{N\times 1}$ is the transmit signal vector from BS_j. To enable spatial separation of data symbols s_k from BS_j to UE $\{k: k \in \mathcal{S}_j\}$, the transmitted signal vector is represented as a linear function of the symbols in the form

$$\boldsymbol{x_j} = \boldsymbol{w}_{j,k} s_k \qquad \forall_j. \tag{2}$$

where $\boldsymbol{w}_{j,k} \in \mathbb{C}^{N\times 1}$ corresponds to the transmit beamformers from BS_j for each symbol meant for UE_k. Furthermore, s_k is assumed to be uncorrelated and therefore, normalized to unit power, $s_k \sim \mathcal{CN}(0,1)$. Assuming BS_l is the serving BS of UE_k, the signal-to-noise-and-interference-ratio (SINR) at UE_k is given by

$$SINR_k = \frac{\left|\boldsymbol{h}_{l,k}^{H} \boldsymbol{w}_{l,k}\right|^2}{\delta^2 + \sum_{j\neq l}^{K_t} \left|\boldsymbol{h}_{j,k}^{H} \boldsymbol{w}_{n}\right|^2} \,. \tag{3}$$

where $\boldsymbol{h}_{j,k} \triangleq \sqrt{g_{j,k}}\boldsymbol{h}_{j,k}^{s}$, the term in the numerator of (3) is the desired received signal power, while the first and second terms in the denominator of (3) are the noise power and the received inter-cell interference (ICI) respectively. Therefore the achievable data rate for UE_k is given by

$$r_k(\{\boldsymbol{w}_{l,k}\}) = \log_2(1 + SINR_k) \quad \forall l, k \ . \tag{4}$$

where $\{\boldsymbol{w}_{l,k}\}\, \forall l, k$ denotes the set of beamforming vectors in the system. From (4) it is easily to claim that the achievable data of the system is a function of the beamforming vectors, which can be expressed in a more detailed form as

$$r_k(\{\boldsymbol{w}_{l,k}\}) = \log_2\left(1 + \frac{\left|\boldsymbol{h}_{l,k}^{H}\boldsymbol{w}_{l,k}\right|^2}{\delta^2 + \sum_{j\neq l}^{K_t}\left|\boldsymbol{h}_{j,k}^{H}\boldsymbol{w}_{j,n}\right|^2}\right). \tag{5}$$

B. Problem Formulation: Optimization Problem

In this subsection, the goal is to maximize the weighted sum-rate achievable in the system, while fulfilling power, quality of service (QoS) and interference constraints respectively. The QoS constraint will enable UEs in the cell edge area of the macrocells to achieve at least the minimum performance level as planned by the mobile operator, while the interference constraint (IC) is needed to shape interfering transmissions from each cell so that their powers will not exceed a given threshold. To achieve this goal, the transmit beamforming vectors for each cell in the system must be coordinated in such a way that only the best beamforming vectors that satisfied the optimization constraints will be selected in order to maximize the sum-rate of the system. Having said that, the optimization problem is therefore formulated as

$$\begin{aligned} &\underset{\{\boldsymbol{w}_{l,k}\}}{\text{maximize}} \quad \sum_{k=1}^{K_r} u_k\, r_k \\ &\text{Subject to} \quad C1\colon SINR_k \geq \gamma_k \qquad \forall k, \\ &C2\colon \left\|\boldsymbol{w}_{l,k}\right\|_2^2 \leq P \qquad \forall l \in \mathcal{M}\,, \\ &C3\colon \boldsymbol{w}_{j,n}^{H}\boldsymbol{R}_{j,k}\boldsymbol{w}_{j,n} \leq \tau_k \qquad \forall j, k. \end{aligned} \tag{6}$$

where the utility function represents the weighted sum-rate of the multi-cell multi-antenna system with the positive factor u_k denoting the distinctive weight assigned to each UE, chosen to reflect different levels of concern about the individual channel gains. Also, the constraints ($C1 \sim C3$) represent the desired QoS constraint, with γ_k denoting the QoS threshold for UE_k; the Macro base station (MBS) transmit power constraint, with P limiting the MBS transmit power and interference power constraint (i.e, interference generated from other non-serving BSs to UE_k) respectively. $\boldsymbol{R}_{j,k} \triangleq \boldsymbol{h}_{j,k}\boldsymbol{h}_{j,k}^{H}$ is a positive semidefinite (PSD) matrix $(\boldsymbol{R}_{j,k} \geq \boldsymbol{0})$, where $\boldsymbol{h}_{j,k}$ is the channel vector from other interfering BSs to UE_k and τ_k is the non-negative threshold which controls the allowable level of interference at UE_k.

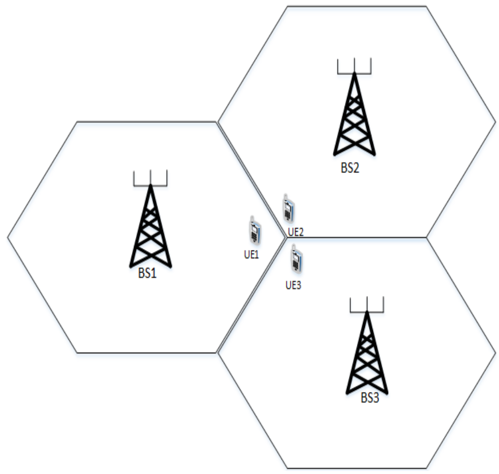

Fig. 1 System model of a multi-cell multi-antenna system

Maximizing the weighted sum-rate of the system under some given constraints as expressed in ($C1 \sim C3$) is generally regarded as a non-convex non-polynomial *(NP)* hard problem because efficient algorithms that can solve it in polynomial time are difficult to find. However, this difficult problem can be solved by branch and bound ($B\&B$) algorithms [10], [11] which are computer algorithms that are not efficient but run in exponential time and can give global solutions. To pinpoint the actual cause of non-convexity of the optimization problem of (6), let's analyze each function that made up the optimization. First, the utility function in (6) is a concave function that can be maximized, though it depends on the SINRs of the UEs in the system. Second, the power constraint in $C2$ together with the interference power constraint function in $C3$ are all convex functions. The SINR constraint function in $C1$ is a non-convex function of the beamforming vectors $\{\boldsymbol{w}_{l,k}\}$, because it cannot be classified as a semi-definite constraint or second-order cone constraint. The constraint $SINR_k \geq \gamma_k$ can be expressed as

$$\frac{1}{\gamma_k}\left|\boldsymbol{h}_{l,k}^{H}\boldsymbol{w}_{l,k}\right|^2 \geq \sum_{j\neq l}^{K_t}\left|\boldsymbol{h}_{j,k}^{H}\boldsymbol{w}_{j,n}\right|^2 + \delta^2. \tag{7}$$

And in order to extract the hidden convexity of the SINR constraints, $SINR_k \geq \gamma_k$, a trick was adopted from [12], which makes (7) equivalent to

$$\frac{1}{\sqrt{\gamma_k}}\Re\left(\boldsymbol{h}_{l,k}^{H}\boldsymbol{w}_{l,k}\right) \geq \sqrt{\sum_{j\neq l}^{K_t}\left|\boldsymbol{h}_{j,k}^{H}\boldsymbol{w}_{j,n}\right|^2 + \delta^2}. \tag{8}$$

where $\Re(\cdot)$ denotes the real part, also, the γ_k value at each UE needs to be fixed and these values are assumed to be known a priori but can be computed as $\gamma_k \triangleq 2^{r_k} - 1$ obtainable from (4). Therefore, the SINR constraint can now be classified as a second-order cone constraint, which is a convex type constraint.

This work is interested in finding approximate solutions to the optimization problems that are feasible in practice for large scale problems, consequently, the non-convex optimization problem is readily solved using a convex heuristic approach.

C. Convex Heuristic Reformulation

To solve a non-convex problem, convex heuristics are easily adopted by researchers because of their efficiency. However, it produces a suboptimal solution to the original non-convex optimization problem. To reformulate (6) into a convex heuristic optimization problem, (8) needs to be used as the new SINR constraint $C1$, also, the γ_k value at each UE must be fixed. Having said that, the convex heuristic reformulation is therefore obtained as

$$\begin{aligned} &\underset{\{\boldsymbol{w}_{l,k}\}}{\text{minimize}} \quad -\sum_{k=1}^{K_r} u_k\, r_k(\{\boldsymbol{w}_{l,k}\}) \\ &\text{subj. to } C1: \left(\Re\left(\boldsymbol{h}_{l,k}^H \boldsymbol{w}_{l,k}\right)\right)^2 \geq \gamma_k \left(\sum_{j\neq l}^{K_t} \left|\boldsymbol{h}_{j,k}^H \boldsymbol{w}_{j,n}\right|^2 + \delta^2\right), \\ &\qquad C2: \left\|\boldsymbol{w}_{l,k}\right\|_2^2 \leq P \qquad \forall l \in \mathcal{M}, \\ &\qquad C3: \boldsymbol{w}_{j,n}^H \boldsymbol{R}_{j,k} \boldsymbol{w}_{j,n} \leq \tau_k \forall j,k. \end{aligned} \tag{9}$$

What makes (9) a convex optimization problem is that all the functions involve in this optimization are convex functions. The utility function is a convex function of the beamforming vectors, while all the constraint functions are as well convex. The implication of this is that (9) can now be solved in polynomial time using numerical algorithms such as interior-point methods. In this work, the solution to the optimization problem (9), is obtained through the use of CVX (a package for specifying and solving convex programs). CVX [13] is a modeling system for constructing and solving disciplined convex programs. It is implemented in MatLab, effectively turning MatLab into an optimization modeling language.

IV. Simulation Results and Discussion

A. Simulation Setting

This study considered a simple multi-cell multi-antenna system simulation setting. It was assumed that the UEs in this system are uniformly distributed and are located at the cell edge of the macrocells such that each MBS served UE will receive significant inter-cell interference (ICI). The UE served by each MBS is located at 240m from the serving MBS. Other simulation parameters are as follows: the transmit power of the MBS is 43dBm, while the receiver noise power is -75dBm. The large-Scale path loss model of the macro cell is

$l(dB) = 128.1 + 37.6 \log\left(\frac{d_{l,k}}{10^3}\right)$, where $d_{l,k}$ is the distance between BS_l and UE_k. The small scale fading channel vectors $\boldsymbol{h}_{j,k}^s$ are generated as uncorrelated Rayleigh fading distribution while the large-scale pathloss is generated in linear scale as

$$l = g_{l,k} = \frac{\psi}{d_{l,k}^n}\ . \tag{10}$$

where ψ is the constant which represent loss at a particular reference distance and n denote the pathloss exponent and in this study is regarded as 3.76. The weights $u_k \geq 0$ which is a parameter in the utility function is obtained through uniform distribution, it is assumed that $\sum_{k=1}^{K_r} u_k = 1$.

The fixed system parameters or setting which is used in this study are N=3 and $K_r = 3$. These settings will be used except otherwise indicated.

In Fig. 2, the average sum-rate achievable in the system is showcased as a function of SNR. It compares the average sum-rate achieved in the system using the proposed method, the optimal method (branch and bound), Inter-cell Interference coordination (ICIC) method and no cooperation method which is regarded as SCP method

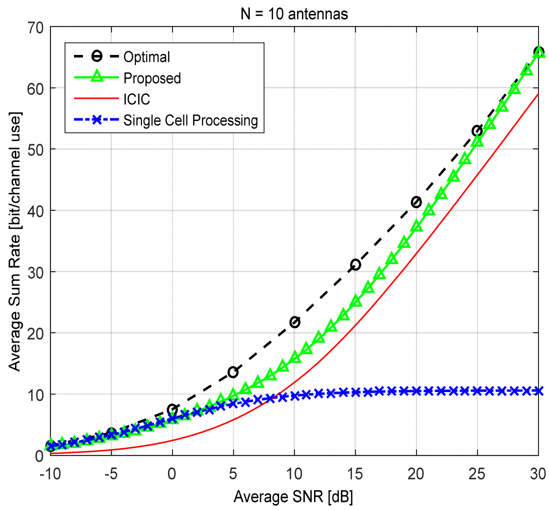

Fig. 2 Average sum rate as a function of SNR for different schemes

From the figure, one can see that the optimal method, the proposed method, and the ICIC method outperformed the method based on single-cell processing because the frequency reuse pattern used by the SCP method is replaced by cooperation among base stations. And all cooperating base stations are simultaneously using the same frequency resource in order to maximize the system-wide spectral efficiency. It is important to note that the optimal method, the proposed method, and the ICIC method are different forms of MCP. Where the channel state information between the BSs and UEs are shared among the cooperating BSs in order to design beamformers that will enable accurate transmission of data to their serving UEs to mitigate ICI. SCP is the least performing method because the BSs only consider the channel to its served UE while designing the beamformers without cooperation with other BSs in the system. Furthermore, it regards any out-of-cell interference in the system as part of the background noise.

In Fig. 3, it is showcased that the performance of the proposed method improve as $N = 12, K_r = 9$. It is an indication that the proposed method though suboptimal, however, is asymptotically optimal as N and K_r increases. Note, that it can also be deduced from Fig. 3 that the system-wide spectral efficiency increases almost linearly with the number of transmit antennas if the receiver (UEs) knows the channel and their individual antennas are as many in number as the total transmit antenna present in the system.

In the optimal method (Branch & Bound method), it is well known that in practice, the computational complexity grows exponentially in order t^n, where n is the problem size input size) and t is just a constraint. In Fig. 4, a simple scenario is used to show how different input size configurations give rise to the varying order of complexity for the proposed method and the optimal method.

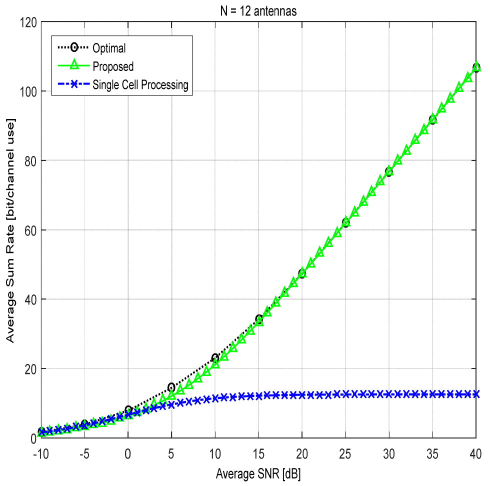

Fig. 3 Average Sum-rate achievable at different SNR for $N = 12, K_r = 9$

The number of variables, $v_a = NK_r$, where N and K_r have already been used to denote the number of antennas and the total number of UEs in the system. When $K_r = 3\ UEs$, $N = 4$ transmit antennas and $m = 4$ constraints (power and interference constraints), the order of complexity for the proposed method is roughly 1000 seconds while that of the optimal method is 20,000 seconds.

The proposed method computational complexity is polynomial in the number of UEs, transmit antennas, power, and interference constraints while that of the optimal method has worst-case complexity that increases exponentially with the number of UEs. This study cannot recommend that the optimal method should be used for $K_r \geq 6\ UEs$, hence should not be used for large scale real-time application but can be used for small scale application and for off-line benchmarking.

V. Conclusion

This work has shown an enhanced way of managing inter-cell interference as well as maximizing the system-wide spectral efficiency. Through the results achieved, this work can boast of having provided a more efficient method that can mitigate inter-cell interference as well as maximizing the system-wide spectral efficiency. The present classical methods using single-cell processing were shown to be inferior to the proposed method because they still utilized different frequency patterns in adjacent cells to curb ICI, also they utilized only the CSI of their served UE to design beamformers that will help in the precise transmission of data to their served UEs. However, since universal frequency reuse is now adopted for the future generation networks, in this context, the single-cell processing method will suffer from inter-cell interference and that was what the results obtained showed.

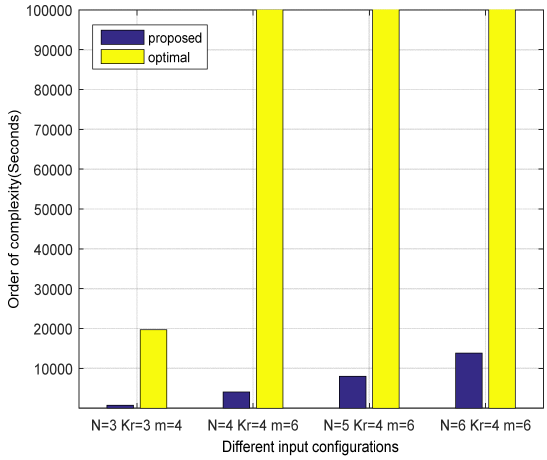

Fig. 4 Order of complexity as a function of the input size configurations

The optimal method has a slightly better performance than the proposed method but that method cannot be used in large scale application because of its huge computation complexity as was shown in the results.

References

[1] R1-104968 (2015), "Summary of the Description of Candidate eICIC Solutions", available at http://www.3gpp.org/DynaReport/TDocExMtg--R1-62--28032.htm.

[2] Kamel M. I. and Elsayed K. M., "Performance Evaluation of a Coordinated Time-Domain eICIC Framework Based on ABSF in Heterogeneous LTE-Advanced Networks", Proc. IEEE Global Telecommun. Conf., pp. 5326-5331, 2012.

[3] Simsek M., Bennis M. and Czylwik A., "Dynamic Inter-Cell Interference Coordination in Hetnets: A Reinforcement Learning Approach", Proc. IEEE Global Commun. Conf., pp. 5446-5450, 2012.

[4] M. Yassin et al, "A novel dynamic inter-cell interference coordination technique for LTE networks," in proceedings of IEEE personal, indoor, and mobile Radio communications (PIMRC), 1380—1385, 2017.

[5] W. Li, T. Chang, C. Lin, and C. Chi, "Coordinated beamforming for multiuser miso interference channel under rate outage constraints," IEEE Trans. Signal Process., vol. 61, no. 5, pp. 1087–1103, 2015.

[6] H. Dahrouj and W. Yu, "Coordinated beamforming for the multicell multiantenna wireless system," IEEE Trans. Wireless Commun., vol. 9, no. 5, 2010.

[7] O. S. Oguejiofor, L. Zhang," Heuristic Coordinated Beamforming for Heterogeneous Cellular Network," in *proc. IEEE 83rd Veh. Tech. Conf.*, Nanjing, China, May 2016, pp. 1-5.

[8] S. Chen, T. Zhao and H. Chen, "Performance analysis of downlink coordinated multipoint joint transmission in ultra-dene networks," IEEE Networks, vol. 31, no. 5, pp. 106-114, 2017.

[9] Simsek M., Bennis M. and Czylwik A., "Dynamic Inter-Cell Interference Coordination in Hetnets: A Reinforcement Learning Approach", Proc. IEEE Global Commun. Conf., pp. 5446-5450, 2012.

[10] S. K. Joshi, P. C. Weeraddana, M. Codreanu, and M. Latva-Aho, "Weighted sum-rate maximization for miso downlink cellular networks via branch and bound," IEEE Trans. Signal Process., vol. 60, no. 4, pp. 2090–2095, 2012.

[11] O. Oguejiofor, L. Zhang," Global Optimization of Weighted Sum-Rate for Downlink Heterogeneous Cellular Networks," in *proc. 23rd Int. Conf. on Telecommun.* Thessaloniki, Greece, May 2016, pp. 1-6.

[12] E. Bjornson, "Optimal Resource Allocation for Multicell," Foundations & Trends in Communications & Information Theory, vol. 9, no.2-3, pp. 115, 2018.

[13] Grant, M., Boyd, S., Ye, Y.: 'CVX: MatLab Software for discipline convex programming version 2.1'. Available at http://cvxr.com/cvx, accessed January 2019.

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