

# Large-Scale MIMO versus Network MIMO for Multicell Interference Mitigation

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**Abstract**—This paper compares two distinct downlink multicell interference mitigation techniques for wireless cellular networks: large-scale (LS) multiple-input multiple-output (MIMO) and network MIMO. The considered cellular network operates in a time-division duplex (TDD) fashion and includes non-overlapping cooperating clusters, where each cluster comprises  $B$  base-stations (BSs), each equipped with multiple antennas, and schedules multiple single-antenna users. In the LS-MIMO system, each BS is equipped with  $BM$  antennas, serving its  $K$  scheduled users using zero-forcing (ZF) beamforming, while sacrificing its excess number of spatial degrees of freedom (DoF) using interference coordination to prevent causing interference to the other  $K(B-1)$  users within the cooperating cluster. In the network MIMO system, although each BS is equipped with  $M$  antennas, the intra-cluster interference cancellation is enabled by data and channel state information sharing across the cooperating BSs and joint downlink transmission to  $BK$  users via ZF beamforming. Accounting for uplink-downlink channel reciprocity provided by TDD and invoking the orthogonality principle of ZF beamforming, respectively, the channel acquisition overhead in each cluster and the number of spatial DoF per user are identical in both systems. Therefore, it is not obvious whether one system is superior to the other from the performance point of view. Building upon the channel distribution functions in the two systems and adopting tools from stochastic orders, this paper shows that in fact an LS-MIMO system provides considerably better performance than a network MIMO system. Thus, given the likely lower cost of adding excess number of antennas, LS-MIMO could be a preferred multicell coordination approach for interference mitigation.

## I. INTRODUCTION

Multicell cooperation is considered as an efficient means to minimize or even completely eliminate interference, thereby providing capacity enhancement for future wireless cellular networks [1]. This paper compares the performance gains of two important multicell interference mitigation schemes: large-scale (LS) multiple-input multiple-output (MIMO), and network MIMO. In an LS-MIMO system, a large number of antennas at each base-station (BS) enables it to not only serve its scheduled users, but also to choose its downlink beam directions using interference coordination (IC) [1] to null out interference to other users in the cooperating cluster.

In a network MIMO system, each BS is equipped with a smaller number of antennas, but interference cancellation is realized by significant data and channel state information (CSI) sharing across the cooperating BSs over the backhaul links and joint downlink transmission to the scheduled users. The main objective of this paper is to illustrate that interference mitigation through employing an excess number of antennas

at each cell-site in conjunction with IC outperforms the cooperation gains of a network MIMO system.

Both IC and network MIMO systems have been extensively discussed in the literature. For example, beamforming and power adaptation methods for IC have been proposed [2], [3]. In addition, tools from stochastic geometry have been employed to investigate different performance metrics under IC by taking random BS positions into account [4], [5]. On a separate track, practical system designs have been proposed for network MIMO systems considering limited backhaul capacity [6], and coordination amongst a small set of BSs [7]. Despite the numerous proposed algorithms and analytic investigations of the two interference management schemes, their performance comparison is only available in special scenarios, e.g., a two-cell cellular network [8].

In contrast to the aforementioned works, the core emphasis of this paper is on performing an analytic comparison between the two coordination strategies. In order to carry out a concrete comparison, we consider the downlink of a time division duplex (TDD) cellular network where each cluster comprises  $B$  cooperating BSs, and compare the following two systems:

- An LS-MIMO system where each BS is equipped with  $BM$  transmit antennas, serves its  $K$  scheduled users using zero-forcing (ZF) beamforming with  $K \leq M$ , while adopting IC to choose its beam directions so as to not interfere with the other  $K(B-1)$  users in its cluster;
- A network MIMO system where each BS is equipped with  $M$  transmit antennas and schedules  $K$  users with  $K \leq M$ , and the total of  $BK$  scheduled users are jointly served using ZF beamforming.

Despite the different infrastructure requirements, however, accounting for the orthogonality principle of ZF beamforming, both systems provide the same number of spatial degrees of freedom (DoF) per user, i.e.,  $\zeta = B(M-K) + 1$ . Further, since the two systems serve the same number of users during each given time-slot, their channel estimation overhead, through uplink training is the same [9]. Given these identical aspects and the fact that both systems are capable of completely eliminating intra-cluster interference, it is not obvious whether one system outperforms the other from the performance point of view. However, using the channel distribution functions and by adopting tools from stochastic orders, this paper illustrates that an LS-MIMO system with a larger number of transmit antennas outperforms

a comparable network MIMO system under a general class of utility functions. The main implication of this paper is that given the likely lower cost of adding excess number of antenna elements at each cell-site versus joint data processing and establishing backhaul links across the cooperating BSs [7], LS-MIMO could be the preferred multicell coordination approach for interference cancellation in wireless networks.

## II. SYSTEM AND RECEIVED SIGNAL MODELS

### A. System Model

Consider a downlink of a TDD cellular network where non-overlapping cooperating clusters of size  $B$  are formed, each BS is equipped with multiple antennas, and schedules  $K$  users from within its cell area. BSs concurrently transmit over the shared spectrum, and their available transmit power is constrained to  $P_T$ . We assume that the available transmit power of each cluster  $BP_T$  is equally distributed across the  $K_c = BK$  selected users. The channel vector from BS  $m$  in cluster  $j$  to user  $i$  in cluster  $l$  is defined as  $\sqrt{\beta_{ilmj}}\mathbf{h}_{ilmj}$ , where  $\mathbf{h}_{ilmj}$  denotes the small-scale Rayleigh channel fading and has independent and identically distributed (i.i.d.)  $\mathcal{CN}(0, 1)$  elements. Here,  $\beta_{ilmj} = r_{ilmj}^{-\alpha}$  denotes the path-loss component,  $r_{ilmj}$  is the distance between BS  $m$  in cluster  $j$  and user  $i$  in cluster  $l$ , and  $\alpha$  is the path-loss exponent. Since channel estimation overhead does not influence the system comparison of this paper, perfect channel estimation is assumed.<sup>1</sup>

For analytical tractability, we impose the following assumptions. First, linear ZF beamforming is used to spatially distinguish multiple users. Although not optimal in general, ZF beamforming does not involve prohibitive computational complexity [10]. Second, we assume that clusters are subject to a sum-power constraint. Further, round-robin scheduling is adopted in this paper. As a result, both systems select the same set of  $K_c$  users during each given time-slot in each individual cluster. The ZF beams designed in each cluster are not, in general, orthogonal. However, in order to characterize the inter-cluster interference distribution functions, similar to other related works [11]–[13], the ZF beams are assumed to be orthogonal in this paper. A cellular network as presented here is denoted as  $(B, N_t, K_c)$ , where  $N_t$  is the number of transmit antennas per BS.

The remainder of this section presents the received signal models and signal-to-interference-plus-noise ratio (SINR) of user  $i$  in cluster  $l$  under both coordination strategies.

### B. Received Signal Model under LS-MIMO

First, we consider a  $(B, BM, K_c)$  LS-MIMO system. BS  $b$  is assumed to have knowledge of its corresponding channel matrix  $\mathbf{G}_{bl} = [\mathbf{g}_{1bl}, \dots, \mathbf{g}_{K_cbl}] \in \mathcal{C}^{BM \times K_c}$  with  $\mathbf{g}_{ibl} = \sqrt{\beta_{ibl}}\mathbf{h}_{ibl}$ . In order to serve its  $K$  scheduled users, while

<sup>1</sup>The available CSI at each BS requires to be shared across the cooperating BSs through backhaul links in a network MIMO system. The conclusion of this paper holds true even without accounting for this signaling overhead.

nulling out its interference on other users within the cooperating cluster, BS  $b$  computes its  $K$  downlink ZF beams as

$$\mathbf{W}_{bl} = \left[ \mathbf{G}_{bl} (\mathbf{G}_{bl}^H \mathbf{G}_{bl})^{-1} \right]_{1:K} = [\mathbf{w}_{1bl}, \dots, \mathbf{w}_{Kbl}]$$

where  $[\cdot]_{1:K}$  selects the  $K$  columns associated with the  $K$  users scheduled by BS  $b$ , the beam vector assigned to user  $i$  is denoted by  $\mathbf{w}_{ibl} \in \mathcal{C}^{BM}$  and satisfies the zero-forcing orthogonality condition, i.e.,  $\mathbf{w}_{ibl} \perp \text{span}\{\mathbf{g}_{klbl}\}_{k \neq i}$ . Each beam is normalized to ensure equal power assignment across the  $K$  beams, i.e.,  $\|\mathbf{w}_{ibl}\| = 1$ . Moreover, we define  $\mathbf{f}_{ilmj} = \sqrt{\beta_{ilmj}}\mathbf{h}_{ilmj}$  as the interference channel between BS  $m$  in cluster  $j$  and user  $i$  in cluster  $l$ . Therefore, the SINR of user  $i$  under the LS-MIMO system is given by

$$\gamma_{ibl}^{\text{LSM}} = \frac{\rho |\mathbf{g}_{ibl}^H \mathbf{w}_{ibl}|^2}{\sum_{j \neq l} \sum_{m=1}^B \sum_{k=1}^K \rho |\mathbf{f}_{ilmj}^H \mathbf{w}_{kmj}|^2 + 1} \quad (1)$$

where  $\rho = \frac{P_T}{KN_o}$  indicates the signal-to-noise ratio (SNR) of each user and  $N_o$  is the noise power.

### C. Received Signal Model under network MIMO

In a  $(B, M, K_c)$  network MIMO system, the cooperating BSs in cluster  $l$  have the knowledge of the composite channel matrix  $\mathbf{G}_l = [\mathbf{g}_{1l}, \dots, \mathbf{g}_{K_cl}] \in \mathcal{C}^{BM \times K_c}$ , where  $\mathbf{g}_{il} = [\mathbf{g}_{i1l}^T, \dots, \mathbf{g}_{iBl}^T]^T \in \mathcal{C}^{BM}$  indicates the collective channel vector between the  $B$  serving BSs and user  $i$ . Therefore, the downlink ZF beams are jointly designed as a pseudo-inverse of the channel matrix, where  $\mathbf{w}_{il}$  denotes the beam vector assigned to user  $i$  normalized such that  $\|\mathbf{w}_{il}\| = 1$ . Let  $\mathbf{f}_{ilj} = [\mathbf{g}_{i1j}^T, \dots, \mathbf{g}_{iBj}^T]^T$  represent the collective interference channel from the BSs in cluster  $j$  to user  $i$  in cluster  $l$ . Therefore, the SINR of user  $i$  under the network MIMO system is expressed as

$$\gamma_{il}^{\text{NM}} = \frac{\rho |\mathbf{g}_{il}^H \mathbf{w}_{il}|^2}{\sum_{j \neq l} \sum_{k=1}^{K_c} \rho |\mathbf{f}_{ilj}^H \mathbf{w}_{kj}|^2 + 1} \quad (2)$$

*Remark 1:* As it is evident from (1) and (2), the SINR expressions involve the power of the inner products between the channel vectors and ZF beams. Hence, as the first step toward performance comparison between the two systems, the next section presents the distribution functions of both the signal power and the interference power caused by transmission of a single beam in an interfering cluster under both coordination strategies.

## III. SIGNAL AND INTERFERENCE POWER DISTRIBUTIONS

When channel vectors only consist of i.i.d. components, adopting ZF beamforming leads to tractable characterization of the signal and interference power distributions [14]. While the channel vectors are composed of i.i.d. components in an LS-MIMO system, each composite channel vector is subject to different path-loss coefficients in a network MIMO system. Therefore, obtaining distribution functions in a network MIMO system is challenging. Moreover, the interference signals produced by different BSs in an LS-MIMO system

experience different path-loss coefficients. As a result, the exact distribution of the aggregate interference power at each user location is not tractable. To address these issues, we employ an approximation based on the following lemma from [11].

*Lemma 1 (Sum of Gamma Distributions):* Let  $\{X_i\}_{i=1}^m$  be a set of  $m$  independent random variables such that  $X_i \sim \Gamma(k_i, \theta_i)$ . Then,  $Y = \sum_i X_i$  has the same first and second order statistics as a Gamma random variable with the shape and scale parameters given as

$$k = \frac{(\sum_i k_i \theta_i)^2}{\sum_i k_i \theta_i^2} \text{ and } \theta = \frac{\sum_i k_i \theta_i^2}{\sum_i k_i \theta_i}. \quad (3)$$

*Approximation 1:* Using Lemma 1, the sum of  $m$  non-identically distributed Gamma random variables can be approximated as a Gamma random variable with the effective shape and scale parameters as presented in (3).

#### A. Distribution Functions under LS-MIMO

In an LS-MIMO system, both the intended channel  $\mathbf{g}_{ilbl}$  and the interference channel  $\mathbf{f}_{ilmj}$  vectors consist of i.i.d. entries; they are random isotropic vectors in a  $BM$ -dimensional vector space. Therefore, by invoking the orthogonality principle of ZF beamforming, it follows that the effective signal power is the power of a  $BM$ -dimensional isotropic vector  $\mathbf{g}_{ilbl}$  projected onto a  $BM - K_c + 1$  dimensional ZF beamforming subspace [14]. Hence

$$|\mathbf{g}_{ilbl}^H \mathbf{w}_{ibl}|^2 \sim \Gamma(BM - K_c + 1, \beta_{ilbl}). \quad (4)$$

Further, to obtain the distribution function associated with the interference power produced by transmitting  $\mathbf{w}_{kmj}$  on user  $i$ , we note that designing  $\mathbf{w}_{kmj}$  is independent of  $\mathbf{f}_{ilmj}$ . As a result,  $|\mathbf{f}_{ilmj}^H \mathbf{w}_{kmj}|^2$  is the power of a random isotropic vector  $\mathbf{f}_{ilmj}$  projected onto a 1-dimensional beamforming space [14], and is distributed as

$$|\mathbf{f}_{ilmj}^H \mathbf{w}_{kmj}|^2 \sim \Gamma(1, \beta_{ilmj}). \quad (5)$$

#### B. Distribution Functions under Network MIMO

In a network MIMO system, the intended channel power  $\|\mathbf{g}_{il}\|^2 = \sum_b \|\mathbf{g}_{ilbl}\|^2$  and each interference channel power  $\|\mathbf{f}_{ilj}\|^2 = \sum_m \|\mathbf{f}_{ilmj}\|^2$  are the sum of  $B$  independent, but non-identically distributed, Gamma random variables. Adopting Approximation 1, it follows that  $\|\mathbf{g}_{il}\|^2 \sim \Gamma(k_{il}, \theta_{il})$  and  $\|\mathbf{f}_{ilj}\|^2 \sim \Gamma(k_{ij}, \theta_{ij})$  wherein

$$k_{il} = M \frac{(\sum_{b=1}^B \beta_{ilbl})^2}{\sum_{b=1}^B \beta_{ilbl}^2} \text{ and } \theta_{il} = \frac{\sum_{b=1}^B \beta_{ilbl}^2}{\sum_{b=1}^B \beta_{ilbl}} \quad (6)$$

$$k_{ij} = M \frac{(\sum_{m=1}^B \beta_{ilmj})^2}{\sum_{m=1}^B \beta_{ilmj}^2} \text{ and } \theta_{ij} = \frac{\sum_{m=1}^B \beta_{ilmj}^2}{\sum_{m=1}^B \beta_{ilmj}}. \quad (7)$$

*Approximation 2:* Using the approach proposed in [13], the approximate distribution functions presented in (6) and (7) can further be assumed to be associated with the power of  $BM$ -dimensional isotropic random vectors distributed as

$\mathbf{g}_{il} \sim \mathcal{CN}(\mathbf{0}, \theta_{il} \mathbf{I}_{BM})$  and  $\mathbf{f}_{ilj} \sim \mathcal{CN}(\mathbf{0}, \theta_{ij} \mathbf{I}_{BM})$  where *each spatial dimension* contributes, respectively,  $k_{il}/BM$  and  $k_{ij}/BM$  to the shape parameter of the corresponding power distribution functions.

Therefore, noting that the ZF beam associated with each user lies within a  $BM - K_c + 1$  dimensional space and the fact that the ZF beam design in each cluster is independent of the inter-cluster interference channels, one concludes that

$$|\mathbf{g}_{il}^H \mathbf{w}_{il}|^2 \sim \Gamma\left(\frac{k_{il}(BM - K_c + 1)}{BM}, \theta_{il}\right) \quad (8)$$

$$|\mathbf{f}_{ilj}^H \mathbf{w}_{kj}|^2 \sim \Gamma\left(\frac{k_{ij}}{BM}, \theta_{ij}\right). \quad (9)$$

The subsequent section uses the presented distribution functions to investigate the statistical relations of the signal and aggregate interference powers at each user location under the two systems.

## IV. STOCHASTIC ORDERING AND PERFORMANCE COMPARISON

The distribution functions presented in the preceding section are dependent on the BS locations across the network. This section therefore considers a fixed BS deployment and separately investigates the statistical relations of the signal powers and aggregate interference powers at any chosen user location under both systems. Then, tools from stochastic orders enable us to combine these results, obtain the SINR first-order dominance, and carry out a concrete comparative performance analysis of the two interference mitigation schemes. First, we define the stochastic dominance in the first-order sense as follows.

*Definition 1 ([15]):* A random variable  $X_1$  is said to be first-order stochastically dominated by a random variable  $X_2$  denoted by  $X_2 \geq_{st} X_1$  if and only if for any  $x$ , the complementary cumulative distribution function (CCDF) associated with  $X_2$  is not smaller than that of the  $X_1$ , i.e.

$$\mathbb{P}\{X_2 \geq x\} \geq \mathbb{P}\{X_1 \geq x\}, \forall x.$$

Considering the distribution functions in (4) and (8), the following theorem establishes the first-order dominance of the signal powers at each user location under the two systems.

*Theorem 1:* Under Approximations 1 and 2, the signal power at each user location under a  $(B, BM, K_c)$  LS-MIMO system first-order stochastically dominates the signal power of the same user in a  $(B, M, K_c)$  network MIMO system.

*Proof:* Without loss of generality, we show the correctness of this result for user  $i$  in cluster  $l$  by separately examining the shape and scale parameters of the signal power distribution functions as presented in (4) and (8). First, from (6), we note that  $k_{il} \leq BM$  with equality when user  $i$  is equidistant from its serving BSs. Therefore, it follows that

$$\frac{k_{il}(BM - K_c + 1)}{BM} \leq BM - K_c + 1$$

where the left-hand side and the right-hand side of the inequality denote, respectively, the shape parameter associated with

the signal power distribution in the network MIMO and LS-MIMO systems. Further, noting that each user is served by its closest BS in an LS-MIMO system and using the scale parameter in (6), it can be shown that  $\theta_{il} \leq \beta_{ibl}$  where the left-hand side and the right-hand side of the inequality correspond, respectively, to the scale parameter of the signal power distribution in the network MIMO and LS-MIMO systems. As a result, both the shape and scale parameters of the signal power distribution are greater in an LS-MIMO system as compared to a network MIMO system. Given that the CCDF of Gamma distribution is increasing in its parameters, this completes the proof. ■

*Remark 2:* Theorem 1 implies that receiving the intended signal from only the closest BS is preferred over multiple scattered BSs. In particular, unlike an LS-MIMO system where all the serving antennas are located at the closest BS, in the network MIMO system, many of them are further away. Therefore, the disparity in the distances between the set of serving BSs and a user introduces a penalty in terms of received signal power in a network MIMO system.

Next, the following theorem establishes the equivalence, in distribution, of the aggregate interference powers at any user location.

*Theorem 2:* Under Approximations 1 and 2, the aggregate inter-cluster interference powers seen by each user are equal in distribution under a  $(B, BM, K_c)$  LS-MIMO and a  $(B, M, K_c)$  network MIMO systems.

*Proof:* Given that the interference signals initiated from different cooperating clusters are statistically independent, we only consider the aggregate interference power from cluster  $j$  seen by user  $i$  in cluster  $l$  in both systems.

The aggregate interference power created by cluster  $j$  in an LS-MIMO system is given by

$$I_{ibl}^j = \sum_{m=1}^B \sum_{k=1}^K |\mathbf{f}_{ilmj}^H \mathbf{w}_{kmj}|^2 \quad (10)$$

where the  $m^{\text{th}}$  term (the inner sum in (10)) denotes the interference power from BS  $m$  in cluster  $j$ . In this paper, we assume that the  $K$  ZF beams designed by each BS are orthogonal. Therefore, the interference power imposed by BS  $m$  in cluster  $j$  is equivalent to a summation of  $K$  independent Gamma random variables, which using (5), is distributed as  $\Gamma(K, \beta_{ilmj})$ . Moreover, the ZF beams designed at each BS are only dependent on the small-scale channel fading between the BS and the users in its cluster. Further the small-scale channel fading is independent across the BSs. Therefore, the summation in (10) is a sum of  $B$  independent Gamma random variables. Hence, using Approximation 1, we have

$$I_{ibl}^j \sim \Gamma \left( K \frac{\left( \sum_{m=1}^B \beta_{ilmj} \right)^2}{\sum_{m=1}^B \beta_{ilmj}^2}, \frac{\sum_{m=1}^B \beta_{ilmj}^2}{\sum_{m=1}^B \beta_{ilmj}} \right). \quad (11)$$

By regarding the interfering beams initiated from each cluster as orthogonal vectors, the total interference power produced by cluster  $j$  in a network MIMO system is a summation of

$K_c$  independent Gamma random variables wherein each term is distributed as in (9). Since the  $K_c$  terms are identically distributed, it is easy to observe that the aggregate interference power produced by cluster  $j$  is distributed as (11). Therefore, one concludes that the inter-cluster interference power at any given user location is equivalent, in distribution, under the two systems. ■

Based on the previous results, the following theorem presents the SINR stochastic dominance under the two systems.

*Theorem 3:* Under Approximations 1 and 2, the SINR of any user under a  $(B, BM, K_c)$  LS-MIMO system first-order stochastically dominates the SINR of the same user under a  $(B, M, K_c)$  network MIMO system.

*Proof:* We again evaluate the achievable SINR of user  $i$  in cluster  $l$  in the LS-MIMO and the network MIMO systems as given, respectively, in (1) and (2).

Based on Theorem 2, the aggregate interference power seen at user  $i$  in cluster  $l$  under the LS-MIMO system  $I_{ibl}^{\text{LSM}}$  and network MIMO system  $I_{il}^{\text{NM}}$  are equal in distribution. For convenience, let  $\bar{\gamma} \stackrel{d}{=} (\rho I_{ibl}^{\text{LSM}} + 1) / \rho \stackrel{d}{=} (\rho I_{il}^{\text{NM}} + 1) / \rho$  and  $p_{\bar{\gamma}}(\cdot)$  denote the common distribution of these two random variables. Further, let  $X_{ibl} = |\mathbf{g}_{ibl}^H \mathbf{w}_{ibl}|^2$  and  $Y_{il} = |\mathbf{g}_{il}^H \mathbf{w}_{il}|^2$ . Therefore

$$\begin{aligned} \mathbb{P} \{ \gamma_{ibl}^{\text{LSM}} \geq \gamma_0 \} &= \mathbb{P} \left\{ X_{ibl} \geq \gamma_0 \frac{(\rho I_{ibl}^{\text{LSM}} + 1)}{\rho} \right\} \\ &= \int_0^\infty \mathbb{P} \{ X_{ibl} \geq \gamma_0 \bar{\gamma} | \bar{\gamma} \} p_{\bar{\gamma}}(\bar{\gamma}) d\bar{\gamma} \\ &\geq \int_0^\infty \mathbb{P} \{ Y_{il} \geq \gamma_0 \bar{\gamma} | \bar{\gamma} \} p_{\bar{\gamma}}(\bar{\gamma}) d\bar{\gamma} = \mathbb{P} \{ \gamma_{il}^{\text{NM}} \geq \gamma_0 \} \end{aligned}$$

where the inequality follows from Theorem 1. Since this result holds for every choice of  $\gamma_0$ , it implies that  $\gamma_{ibl}^{\text{LSM}} \geq_{st} \gamma_{il}^{\text{NM}}$ . ■

The SINR stochastic dominance can be used to compare the performance of the two interference mitigation schemes under utility functions which are non-decreasing in SINR. Before presenting the final result of this paper, the following lemma presents the stochastic ordering of the functionals of random variables.

*Lemma 2 ([15]):* For any non-decreasing function  $g$ , if  $X \geq_{st} Y$ , then  $g(X) \geq_{st} g(Y)$ .

*Theorem 4:* Under Approximations 1 and 2, for any utility function that is non-decreasing in SINR, each user experiences a better quality of service (averaged over small-scale fading) in a  $(B, BM, K_c)$  LS-MIMO system than in a  $(B, M, K_c)$  network MIMO system.

*Proof:* Let  $U_{il}$  denote the non-decreasing utility function of user  $i$  in cluster  $l$ . Using Theorem 3 and Lemma 2, it follows that  $\mathbb{P}(U_{il}(\gamma_{ibl}^{\text{LSM}}) > t) \geq \mathbb{P}(U_{il}(\gamma_{il}^{\text{NM}}) > t)$  for any  $t$ . Then, given that  $\mathbb{E}[X] = \int_{t>0} \mathbb{P}(X > t) dt$  for any non-negative random variable  $X$ , taking the integral with respect to  $t$  from both sides of the above inequality, it turns out that  $\mathbb{E}_{\mathbf{h}}[U_{il}(\gamma_{ibl}^{\text{LSM}})] \geq \mathbb{E}_{\mathbf{h}}[U_{il}(\gamma_{il}^{\text{NM}})]$ . Hence, the proof is complete. ■

TABLE I  
SYSTEM PARAMETERS

Number of clusters	$C = 9$
Number of cooperating BSs per cluster	$B = 4$
Number of scheduled users per cell	$K = 5$
Total bandwidth	$W = 20$ MHz
BS Max available power	43 dBm
Cluster side length	$L = 1000$ m
Path-loss exponent	$\alpha = 3.5$
Background noise	$N_o = -174$ dBm/Hz

It is worth highlighting that Theorem 4 holds true for some of the key performance metrics in wireless networks, e.g., user ergodic rate when  $U_{il}(\gamma_{il}) = \log_2(1 + \gamma_{il})$  and  $\gamma_{il}$  is the SINR of user  $i$ .

## V. NUMERICAL VALIDATION

We consider a cellular network comprises  $C = 9$  clusters formed using non-overlapping square lattice of side length  $L = 1000$  meters. Each cluster has  $B = 4$  cooperating BSs with inter-BS distance of 500 meters. Each BS is equipped with multiple antennas and chooses  $K = 5$  single-antenna users from within its cell area using round-robin scheduling scheme. Therefore, regardless of the cooperation method employed in each cluster, the same set of users are selected to be served in both systems during each given time-slot. The system parameters are listed in Table I.

Figure 1 plots the cumulative distribution function of the achievable downlink rates in the center cluster when the results are averaged over both user locations and small-scale channel fading. In the network MIMO system, BSs are equipped with  $M = 5, 6, 7$  transmit antennas which, respectively, correspond to spatial DoF of  $\zeta = 1, 5, 9$  per user (Recall that  $\zeta = B(M - K) + 1$ ). To provide the same number of spatial DoF per user in the LS-MIMO system, BSs accommodate a larger number of antennas each, i.e.,  $BM = 20, 24, 28$ , accordingly. As shown in this figure, the LS-MIMO network provides about 55% rate improvement for the 10<sup>th</sup> percentile users as compared to the network MIMO system for different choices of  $\zeta$ . Further, it is noticeable that even the LS-MIMO system with  $\zeta = 5$  significantly outperforms the network MIMO system with  $\zeta = 9$ .

## VI. CONCLUSION

This paper compares two important classes of multicell coordination schemes, namely, LS-MIMO and network MIMO. Both systems considered in this paper are capable of completely eliminating intra-cluster interference, providing the same number of spatial DoF per user, and are subject to identical channel estimation overhead. Using the channel distribution functions and adopting tools from stochastic orders, we show that each given user experiences a better quality of service in an LS-MIMO system. Numerical simulations reveal that considerable improvement in the downlink user rate can be realized under an LS-MIMO system as compared to a network MIMO system.

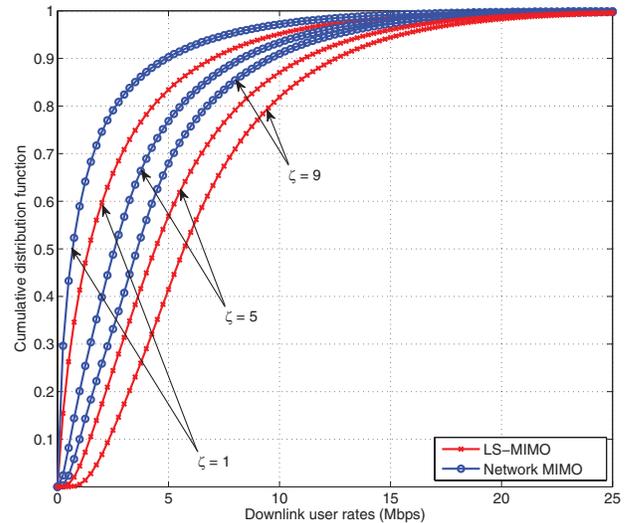


Fig. 1. CDF of the downlink rates under the LS-MIMO and network MIMO systems with various choices of the number of spatial DoF per user.

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