Cooperation-Multiuser Diversity Tradeoff in Wireless Cellular Networks

Zheng Wang[†], Mingyue Ji[†], Hamid R. Sadjadpour[†], J.J. Garcia-Luna-Aceves[‡]

Department of Electrical Engineering[†] and Computer Engineering[‡]
University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA
[‡] Palo Alto Research Center (PARC), 3333 Coyote Hill Road, Palo Alto, CA 94304, USA
Email:{wzgold, davidjmy, hamid, jj}@soe.ucsc.edu

***Abstract*—We introduce a new multiuser diversity scheme for interference management in cellular networks. A base station with K antennas communicates with at most K out of M mobile stations. It is proven that, if $K \ll M$, then K independent data streams can be transmitted to K mobile stations with no need for cooperative joint decoding by such stations. This result is based on a new multiuser diversity concept that allows parallel communication in the network without any cooperation among mobile stations. If the network does not have enough mobile stations, then some of the users need to jointly decode their corresponding data streams. The result suggests the existence of a tradeoff between multiuser diversity and cooperation in the downlink of cellular networks. Our interference management approach is based on a new multiuser diversity concept that achieves the capacity of dirty paper coding (DPC) asymptotically. Surprisingly, this gain is achieved without requiring full channel state information (CSI) and only K integers related to CSI are fed back from mobile stations to the base station. An additional advantage of this scheme is the fact that the encoding and decoding of signals for this distributed MIMO system is based on simple point-to-point communications.**

I. INTRODUCTION

Multiuser diversity scheme [1] was introduced as an alternative to more traditional techniques like time division multiple access (TDMA) to increase the capacity of wireless cellular networks. The main idea behind this approach is that the base station selects a mobile station (MS) that has the best channel condition by taking advantage of the time varying nature of fading channels, thus maximizing the signal-to-noise ratio (SNR). This idea was later extended to mobile wireless ad hoc networks [2] and opportunistic beamforming [3] networks.

Traditionally, fading and interference have been viewed as the two major impeding factors in increasing the capacity of wireless cellular networks. In this paper, however, we introduce a clean-slate approach to interference management that takes advantage of the fading in the channel to reduce the negative effects of interference.

We present an interference management technique for the downlink of a wireless cellular network with which D ($D \leq K$) independent data streams can be broadcasted to D out of M mobile stations with single antenna each such that these data streams do not interfere with each other. Furthermore, we demonstrate that D can be any number up to the maximum value of K, as long as M is large enough. Therefore, interference management is capable of achieving the maximum degrees of freedom as long as there is a minimum number of mobile stations in the network. Surprisingly, by fully taking advantage of fading channels in multiuser environments, the feedback requirement to transmit K independent data streams is proportional to K, and the encoding and decoding scheme is very simple and similar to that of point-to-point communications. The original multiuser diversity concept was based on searching for the best channels to use, while our approach shows that searching simultaneously for the best and worse channels can lead to significant capacity gains. This technique can asymptotically achieve the capacity of DPC when $M \rightarrow \infty$. In general, we can have D mobile stations implementing our interference management scheme, where D depends on the number of mobile stations in the network. If $D < K$, then the rest of $K - D$ mobile stations require to perform cooperative decoding in order to transmit K independent data streams. Our proposed multiuser diversity scheme provides a tradeoff between multiuser diversity and cooperation among mobile stations.

Our proposed distributed MIMO scheme does not require mobile stations to cooperate, as long as there are enough mobile stations in the network. It achieves optimal K maximum multiplexing gain in the downlink of cellular systems as long as $K \ll M$. If there are not enough mobile stations in the network, partial cooperation among them is required to achieve the maximum multiplexing gain. Therefore, there is a tradeoff between cooperation and multiuser diversity.

The remaining of this paper is organized as follows. Section II, presents an overview of related work. Section III-A introduces the model used in our analysis. Section IV introduces our interference management approach and the tradeoff analysis. Section V presents the numerical results of our analysis and we conclude the paper in Section VI.

II. RELATED WORK

Knopp and Humblet [1] derived the optimum capacity for the uplink of a wireless cellular network taking advantage of multi-user diversity. They proved that if the "best" channel (i.e., the channel with the highest SNR in the network) is selected, then all of the power should be allocated to the specific user with the "good channel" instead of using a water-filling power control technique. Tse extended this result into the broadcast case of a wireless cellular network [5]. Furthermore, Viswanath et al. [3] used a similar idea for the downlink channel and employed the so called "dumb antennas" by taking advantage of opportunistic beamforming. Grossglauser et al. [2] extended this multi-user diversity concept into mobile ad hoc networks and took advantage of the mobility of nodes to scale the network capacity.

All of the above schemes have taken advantage of multiuser diversity to combat the two major obstacles in wireless networks, namely, fading and interference.

Interference alignment [6], [7] is another technique to manage interference. The main idea in this approach is to use part of the degrees of freedom available at a node to transmit the information signal and the remaining part to transmit the interference. For example [7] considers $K \times M$ interference channels and demonstrate that the number of achievable degrees of freedom is $\frac{KM}{K+M-1}$. The drawback of interference alignment is that the system requires full knowledge of the channel state information (CSI). This condition is very difficult to implement in practice, and feedback of CSI is MK complex numbers in a $K \times M$ interference channel. The advantage of interference alignment is that there is no minimum number of users required to implement this technique.

Sharif and Hassibi introduced a new approach [4], [8] to search for the best SINR in the network. Their approach requires M complex numbers for feedback instead of complete CSI information, and achieves the same capacity of $K \log\log M$ similar to DPC. There are major differences between our approach and the design in [4], [8]. First, our approach does not require beamforming, while the techniques proposed in [4], [8] take advantage of beamforming. Second, the cooperation requirement in our technique is significantly lower than that of [4], [8], which reduces the decoding complexity significantly. Third, the feedback requirement in our scheme is proportional to the maximum of K integers while this value is proportional to M complex numbers in [4], [8]. When M grows, the feedback information in [4], [8] grows linearly, while this complexity is constant with the number of antennas at the base station in our scheme . Our approach achieves DPC capacity of $K \log\log M$ asymptotically in the presence of reduced feedback requirement.

III. Interference Management

A. Network Model

We investigate the problem of optimal transmission in the downlink of a cellular networks when the base station has independent messages for the mobile stations in the network. Clearly if the base station has only K antennas, we can transmit at most K independent data stream at any given time to K mobile stations. We assume all the mobile stations have a single antenna for communication. The channel between the base station and mobile stations $\mathbf{H}$ is a $M \times K$ matrix with elements h_{ji}, where $i \in [1, 2, \ldots, K]$ is the antenna index of the base station and $j \in [1, 2, \ldots, M]$ is the MS index. We consider block fading model where the channel coefficients are constant during coherence interval of T. Then the received signal $\mathbf{Y}^{M\times 1}$ can be expressed as

$$\mathbf{Y} = \mathbf{H}\mathbf{x} + \mathbf{n}, \tag{1}$$

where $\mathbf{x}$ is the transmit $K \times 1$ signal vector and $\mathbf{n}$ is the $M \times 1$ noise vector. The noise at each of the receive antennas is i.i.d. with $\mathcal{CN}(0, \sigma_n^2)$ distribution.

B. The scheduling protocol

During the first phase of communication, the base-station antennas sequentially transmit a pilot signal that requires K time slots. In this period, all the mobile stations listen to these known messages. After the last pilot signal is transmitted, mobile stations evaluate the SNR for each antenna. If the SNR for only one transmit antenna is greater than a pre-determined threshold SNR_{tr} and below another pre-determined threshold of INR_{tr} for the remaining $K-1$ antennas, that particular mobile station will select that particular antenna at the base station.

Given that more than one mobile station may be found with this property, in the second phase of communication, the mobile stations notify the base station that they have the required criterion to receive packets during the remaining time period of T. We will not discuss the channel access protocol required for these mobile stations to contact the base station or the case when two mobile stations have similar property for the same antenna. We assume that this will be resolved by some handshake between the mobile stations and the base station. Note that, if we choose appropriate values for SNR_{tr} and INR_{tr} such that $\text{SNR}_{tr} \gg \text{INR}_{tr}$, then the base station can simultaneously transmit different packets from its antennas to different mobile stations. The mobile stations only receive their respective packets with a strong signal and can treat the rest of the packets as noise. The value of SNR_{tr} (or INR_{tr}) can be selected as high (or low) as required for a given system, as long as M is large enough. Suppose that there are D antennas that can be matched to corresponding mobile stations with the above property. Further, we select another $K-D$ mobile stations such that they do not have the above property and require cooperation among themselves to decode the $K-D$ data streams. Note that these $K-D$ nodes operate similar to a distributed MIMO system.

In general, there is a relationship between D and number of mobile stations, M. Our approach demonstrates a tradeoff between maximum D number of users that take advantage of interference management scheme and the rest of $K-D$ users that require cooperation among themselves. Clearly, interference management decreases the encodingand decoding of such virtual MIMO system significantly at the expense of presence of large number of mobile stations. Fig. 1 demonstrates the system that is used here. Without loss of generality, we assume that the user i for $i \in [1, 2, \ldots, D]$ is assigned to antenna i in the base station. In this figure, solid line and dotted line represent a strong and weak channel between an antenna at the base station and a mobile station respectively. Note that if there is no line between the base station and mobile stations, then it means the channel is random parameter based on the channel probability distribution function.

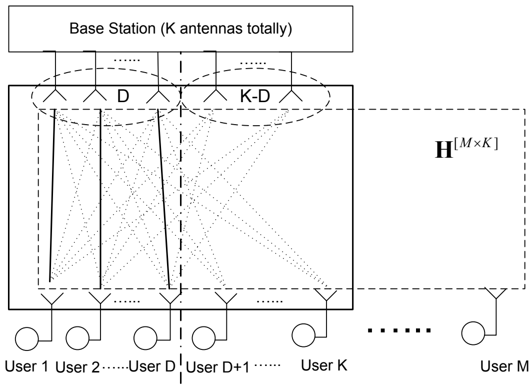

Fig. 1. Wireless cellular network model

IV. Tradeoff between Multiuser Diversity and Cooperation

A. Approximate Analysis

Let's define SNR_{ij} as the signal-to-noise ratio when antenna i at the base station is transmitting packet to mobile station j in the downlink. Further denote INR_{ij} as the interference-to-noise ratio between transmit antenna i at the base station and receiver mobile station j. The objective of interference management is to find K mobile stations out of M choices to satisfy the following criteria.

$$\begin{aligned} &\text{SNR}_{ii} \geq \text{SNR}_{tr}, 1 \leq i \leq D, \\ &\text{INR}_{ij} \leq \text{INR}_{tr}, 1 \leq i \leq D, 1 \leq j \leq K, j \neq i \\ &\text{INR}_{ij} \leq \text{INR}_{tr}, D+1 \leq i \leq K, 1 \leq j \leq D, \end{aligned} \quad (2)$$

The above condition states that each one of the D base-station antennas has a very good channel to a single mobile station and strong fading to the other $K-1$ mobile stations as shown in Fig. 1. Further, the rest of $K-D$ base-station antennas have strong fading channel to the first D mobile stations but their channel to the rest of $K-D$ mobile stations is random and their pdfs follow a Rayleigh fading distribution.

Let's define SINR_{ii} as

$$\text{SINR}_{ii} = \frac{\text{SNR}_{ii}}{\sum_{j=1, j\neq i}^{K-1} \text{INR}_{ij} + 1}, \forall i = 1, 2, \cdots, D \quad (3)$$

and SINR_{tr} as

$$\text{SINR}_{tr} = \frac{\text{SNR}_{tr}}{(K-1)\text{INR}_{tr} + 1}. \quad (4)$$

For the rest of this paper, we will concentrate on the interference management analysis. Hence, the sum rate for the first D antennas can be written as

$$\begin{aligned} R_{\text{proposed}} &= \sum_{i=1}^{D} \log\left(1 + \text{SINR}_{ii}\right) \\ &= \sum_{i=1}^{D} \log\left(1 + \frac{\text{SNR}_{ii}}{\sum_{j=1, j\neq i}^{K-1} \text{INR}_{ij} + 1}\right) \\ &\geq D \log\left(1 + \frac{\text{SNR}_{tr}}{(K-1)\text{INR}_{tr} + 1}\right) \\ &= D \log(1 + \text{SINR}_{tr}) \end{aligned} \quad (5)$$

In the following, we first prove that for any value of SINR_{tr}, there exists a minimum value of M that will satisfy Eq. (5). We will then demonstrate that this scheme achieves the optimum capacity of DPC asymptotically.

To prove the condition in Eq. (5), we assume that the channel distribution is Rayleigh fading channel. However, our approach can be extended to any time-varying channel model. Note that for a Rayleigh fading channel $\mathbf{H}$, the probability distribution function (pdf) of SNR (or INR) is given by

$$p(\text{z}) = \begin{cases} \frac{1}{\sigma} \exp\left(-\frac{z}{\sigma}\right), & z > 0 \\ 0, & z \leq 0 \end{cases} \quad (6)$$

where z is the SNR (or INR) value and $\sigma = E_{\mathbf{H}}(z)$.

Assume that event A is for any mobile station that satisfies the condition in Eq. (2), and that the channels between the base station and the mobile stations are i.i.d., then this probability can be derived as

$$\begin{aligned} P(A) &= \int_{\text{SNR}_{tr}}^{\infty} p(z)dz \left(\int_{0}^{\text{INR}_{tr}} p(z)dz\right)^{K-1}. \\ &= e^{-\frac{\text{SNR}_{tr}}{\sigma}} \left(1 - e^{-\frac{\text{INR}_{tr}}{\sigma}}\right)^{K-1}. \end{aligned} \quad (7)$$

Note that $P(A)$ is the probability of a mobile station satisfying condition in Eq. (2) for any one of the K antennas at the base station. Our objective is to maximize this probability based on network parameters. Maximizing $P(A)$ will minimize the number of required mobile stations M. Note that among all network parameters $K, D, \text{SNR}_{tr}, \text{INR}_{tr}$, and σ, the values of K, D and σ are really related to the physical properties of the network and are not design parameters. Further, the parameters SNR_{tr} and INR_{tr} can be replaced with a single parameter SINR_{tr} using Eq. (4).

Let X denote the random variable that denotes the number of mobile stations satisfying the interference management condition, i.e., each mobile station has a very strong channel with a single base-station antenna and very weak channel (deep fade) with all other base-station antennas. For any mobile station, the probability that it satisfies the interference management condition is $\binom{K}{1}P(A)$. Note that it is possible that two mobile stations satisfy interference management condition for the same base-station antenna. The probability that x mobile stations satisfy the interference management constraint is[1]

$$Pr(X=x)=\binom{M}{x}\left(\binom{K}{1}P(A)\right)^{x}\left(1-\binom{K}{1}P(A)\right)^{M-x} \quad (8)$$

Since the above probability is binomial distribution, then the expected value of x is

$$\mathbf{E}(x)=MKP(A). \quad (9)$$

It is noteworthy to mention again that the number of mobile stations that satisfy interference management condition is a random variable and D is simply the average value of this random variable.

This expected value can be approximated [2] by D, i.e., $\mathbf{E}(x)=MKP(A)\cong D$, then

$$M\cong\frac{D}{K}(P(A))^{-1}. \quad (10)$$

Note that the average value of x can be in general greater than K. However, in practice, we only need to select at most K mobile stations for communications with the base station. Note that M is proportional to inverse of $(P(A))$. Therefore, in order to minimize M, we need to minimize $(P(A))^{-1}$ such that the SINR_{tr} condition in Eq. (4) is satisfied.

$$\text{minimize} \quad (P(A))^{-1} \quad (11)$$

$$\text{subject to} \quad \text{SINR}_{tr}=\frac{\text{SNR}_{tr}}{(K-1)\text{INR}_{tr}+1} \quad (12)$$

This optimization problem can be rewritten as

$$\begin{aligned}
&\min_{Eq.(12)}\left((P(A))^{-1}\right)\\
=&\min_{Eq.(12)}\left(\frac{e^{\frac{\text{SNR}_{tr}}{\sigma}}}{\left(1-e^{-\frac{\text{INR}_{tr}}{\sigma}}\right)^{K-1}}\right)\\
\overset{(a)}{=}& e^{\frac{\text{SINR}_{tr}}{\sigma}}\min_{\text{INR}_{tr}}\left(\frac{e^{(K-1)\frac{\text{SINR}_{tr}\text{INR}_{tr}}{\sigma}}}{\left(1-e^{-\frac{\text{INR}_{tr}}{\sigma}}\right)^{K-1}}\right)\\
\overset{(b)}{\cong}& e^{\frac{\text{SINR}_{tr}}{\sigma}}\sigma^{K-1}\min_{\text{INR}_{tr}}\left(\frac{e^{(K-1)\frac{\text{SINR}_{tr}\text{INR}_{tr}}{\sigma}}}{(\text{INR}_{tr})^{K-1}}\right) \quad (13)
\end{aligned}$$

We derive the equality (a) by replacing SNR_{tr} with INR_{tr} and SINR_{tr} using Eq. (4). Since in practice a successful communication occurs when we have a predetermined minimum value for SINR, therefore we fix the value of SINR_{tr} and attempt to optimize the above equation based on INR_{tr}. The approximation in (b) is derived by assuming $\frac{\text{INR}_{tr}}{\sigma}$ is a value much smaller than 1 and the fact that $\lim_{x\to 0}(1-\exp(-x))=x$. Note that the unique characteristic of this new scheme is to take advantage of fading and clearly, under that circumstance the value of $\frac{\text{INR}_{tr}}{\sigma}$ is small.

The minimum value of $\left(\frac{e^{\frac{(K-1)\text{SINR}_{tr}}{\sigma}\text{INR}_{tr}}}{\text{INR}_{tr}^{K-1}}\right)$ can be derived by taking its first derivative with respect to INR_{tr} and making it equal to zero.

$$e^{\frac{(K-1)\text{SINR}_{tr}}{\sigma}\text{INR}_{tr}}\times\left(\frac{(K-1)\text{SINR}_{tr}}{\sigma}\text{INR}_{tr}^{K-1}-(K-1)\text{INR}_{tr}^{K-2}\right)=0 \quad (14)$$

The solution for INR^*_{tr} is

$$\text{INR}^*_{tr}=\frac{\sigma}{\text{SINR}_{tr}}. \quad (15)$$

Then the optimum value for $(P(A))^{-1}$ is given by

$$M^*=\frac{D}{K}(P^*(A))^{-1}=\frac{D}{K}e^{\frac{\text{SINR}_{tr}}{\sigma}}\left(\text{SINR}_{tr}e\right)^{K-1}. \quad (16)$$

This value is derived by replacing the optimum value of INR^*_{tr} into Eq. (13) and using the approximation (b) in this equation. σ represents the strength of fading channel and as this parameter increases or equivalently the channel experience more severe fade, then this technique is immune at higher values of INR_{tr} when SINR_{tr} is constant. The main reason is the fact that fading environment helps to combat interference. Furthermore, the optimum value for $(P^*(A))^{-1}$ demonstrates that by increasing the SINR_{tr}, the number of mobile stations required increases exponentially.

For constant values of SINR_{tr} and when $\sigma\to\infty$, then $(P(A))^{-1*}$ is

$$\lim_{\sigma\to\infty}(P(A))^{-1*}=\left(\text{SINR}_{tr}e\right)^{K-1}. \quad (17)$$

This results implies that even for very strong fading channels, there exists a minimum value of mobile stations to implement this technique.

Now we investigate the asymptotic behavior of the network(i.e. $M\to\infty$) and try to compute the maximum achievable capacity and scaling laws for this scheme. Clearly when M tends to infinity, the SINR_{tr} increases since we can select higher value for SNR_{tr} and smaller value for INR_{tr}. Under such conditions, the value of $(P(A))^{-1}$ is approximated as

$$(P(A))^{-1*}\cong e^{K-1}e^{\frac{\text{SINR}_{tr}}{\sigma}}. \quad (18)$$

Then SINR_{tr} is

$$\text{SINR}^{\max}_{tr}\cong\sigma\log\left(\frac{K}{D}\left(\frac{1}{e}\right)^{K-1}M\right). \quad (19)$$

When $D=K$, then the $\text{SINR}^{\max}_{tr}$ scales as $\log M$ so that by utilizing Eq. (5), the scaling laws of interference management scheme is

$$C=\Theta(K\log\log M). \quad (20)$$

This is exactly the same scaling laws as [4], [8] which is equivalent to the capacity of DPC! However, our scheme requires only D feedback information which is much smaller than M or $2KM$ for [4], [8] or DPC, respectively. It is worthy

[1] In this part of the paper, we derive approximate value for M and other network parameters in order to be able to compute a closed form result. Later on, exact probabilities are computed based on the fact that two mobile stations may have interference management constraint for the same base-station antenna.

[2] If we ignore the possibility that two mobile stations have the interference management constraint for the same base-station antenna.

to point out that this technique cannot achieve the optimum value of K degrees of freedom if σ is small or, equivalently, if the channel fading is not strong. This is contrary to the current belief for point-to-point communications that fading reduces the network capacity. In a multi-user environment, fading actually is very helpful! Our proposed multi-user diversity scheme also is different from the original scheme that requires the transmitter to search for the node with the best channel condition.

When $K = 1$, then our approach is similar to that of [1]. Moreover if $M \to \infty$ and $D = K$, then our scheme has the same asymptotic scaling laws capacity result as that of [4], [8]. The cost of the proposed scheme is the need for a minimum number of mobile stations, M. In most practical cellular systems, in any given frequency and time inside a cell, there is only one assigned MS while this technique suggests that we can have up to the number of base-station antennas utilizing the same spectrum at the same time with no bandwidth expansion. Clearly, this approach can increase the capacity of wireless cellular networks significantly. This gain is achieved with modest feedback requirement which is proportional to the number of transmitter antennas at the base station.

B. Exact Analysis

Our previous analysis was based on the fact that we ignore the probability that two mobile stations satisfying the interference management condition correspond to the same base-station antenna. However, our approximate analysis was useful to demonstrate the relationship between different parameters of the network. In the following section, we derive the exact analysis which does not lead to any closed form formulation.

Let's assume we have x mobile stations that satisfy the interference management condition. We know from Eq. (8) that x has a binomial distribution. We define the conditional probability of choosing y base-station antennas (or bins) that are related to all of the x mobile stations (or balls) satisfying the interference management condition and denote it as $\Pr_B(Y = y|X = x)$. This conditional probability is equal to

$$\Pr_B(Y = y|X = x) = \left(\frac{y}{K}\right)^x, \qquad y \leq K \tag{21}$$

Note that this probability includes the possibility that some of y antennas are not associated to any of x mobile stations and some correspond to more than one mobile station, i.e., some bins are empty and some bins have more than one ball in them.

Let's define $\Pr_C(Y = y|X = x)$ the probability that all of x mobile stations are associated to y base-station antennas and there is no antenna in this set that is not associated to at least one of the x mobile stations. Then, this conditional probability can be derived as

$$\Pr_C(Y = y|X = x) = \begin{cases} \Pr_B(Y = 1|X = x), & y = 1 \\ \Pr_B(Y = y|X = x) - \displaystyle\sum_{j=1}^{y-1} \binom{y}{j} & \\ (\Pr_C(Y = j|X = x)), & \\ & 1 < y \leq \min(x, K) \\ 0. & y > \min(x, K) \end{cases} \tag{22}$$

This equation is derived iteratively and in order to initialize it for $y = 1$, we utilize $\Pr_B(Y = 1|X = x)$. Since $\Pr_C(Y = y|X = x)$ represents the probability of selecting a specific combination of y antennas, the total possible choices can be derived as

$$\Pr_D(Y = y|X = x) = \binom{K}{y} \Pr_C(Y = y|X = x). \tag{23}$$

Finally, we derive the expected value of Y using law of total probability.

$$\begin{aligned} D &= \mathbf{E}(Y) = \sum_{y=1}^{K}\sum_{x=1}^{M} y\Pr_D(Y = y|X = x)\Pr(X = x) \\ &= \sum_{x=1}^{M} \mathbf{E}(Y|X)\Pr(X = x) \end{aligned} \tag{24}$$

$\mathbf{E}(Y|X)$ is defined as

$$\mathbf{E}(Y|X) = \sum_{y=1}^{K} y\Pr_D(Y|X = x)$$

and $\Pr(X = x)$ is computed from Eq. 8.

Now we like to derive the condition under which there exists $K - D$ mobile stations such that the D base-station antennas that participate in interference management, do not interfere with them. Note that we have a total of $M - D$ mobile stations and each one has D independent channels to the D base-station antennas that participate in interference management. Therefore, the probability that each one of them satisfies the above condition is $\left(\int_0^{\text{INR}_{tr}} p(z)dz\right)^D$ and for all of them, this probability is equal to $(M - D) \times \left(\int_0^{\text{INR}_{tr}} p(z)dz\right)^D \cong M \times \left(\int_0^{\text{INR}_{tr}} p(z)dz\right)^D$. It is clear that $D \leq K - 1$, then

$$\begin{aligned} M\left(\int_0^{\text{INR}_{tr}} p(z)dz\right)^D &\geq M\left(\int_0^{\text{INR}_{tr}} p(z)dz\right)^{K-1} \\ &\stackrel{a}{=} \frac{MP(A)}{\int_{\text{SNR}_{tr}}^{\infty} p(z)dz} \\ &= MP(A)e^{\frac{\text{SNR}_{tr}}{\sigma}} \\ &\stackrel{b}{\gg} K - D \end{aligned} \tag{25}$$

(a) is derived using Eq. 7 and it is easy to show that (b) is satisfied when $\text{SNR}_{tr} > \sigma \ln \frac{K^2}{D}$.

V. Numerical Results

Our simulation results are based on exact analysis of interference management technique. Fig. 2 illustrates the minimum required value for M when D varies and for $k = 3 or 5$ and $\sigma = 100$. As we can see from this result, when the SINR$_{tr}$ requirement increases, the number of mobile stations required to implement this technique increases significantly. Therefore, using capacity approaching techniques such as Turbo code or LDPC that requires very low SINR$_{tr}$ will help to implement this technique with modest number of MS users. Besides, from this figure we notice that there is a tradeoff between the total number of the mobile stations M and the number of the nodes $K - D$ needed to do cooperative communication utilizing technique such as distributed MIMO. For example when $K = 3$, the capacity of the network increases twofold with only 100 mobile stations in the network.

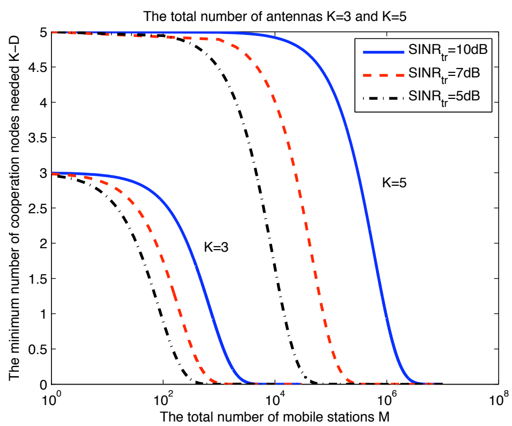

Fig. 2. Simulation results for different values of SINR

Next figure demonstrates the tradeoff between the number of mobile stations and the strength of the channel fading, $2 \leq \sigma \leq 100$. It is shown that as long as the fading channel is strong or modestly strong, the required number of mobile stations are reasonable, but when fading is weak, then this number increases significantly.

Figure 4 demonstrates the relationship between the minimum number of mobile stations required for different channel fading conditions. The result clearly shows that as the fading of the channel increases, the minimum required number for M decreases. As we mentioned it earlier, the new multiuser diversity scheme performs better when the fading strength in channel increases. Note that the original multiuser diversity concept performs better when the fading channel changes faster and that was one main reason in the gain for opportunistic beamforming technique [3].

VI. Conclusion

In this paper, we proposed an interference management technique that takes advantage of the fading in the channel to minimize the negative effect of interference in wireless cellular networks. By doing this, the system achieves the optimum

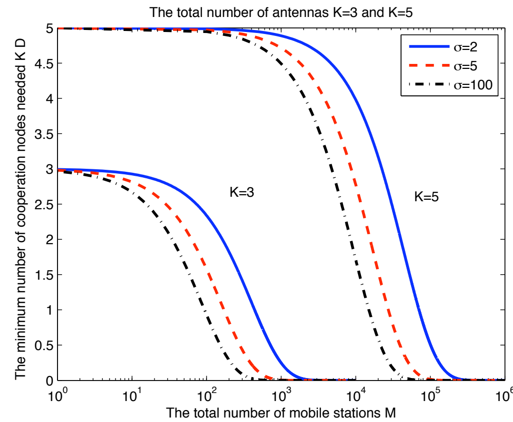

Fig. 3. Simulation results for different fading channel environments when SINR=5dB

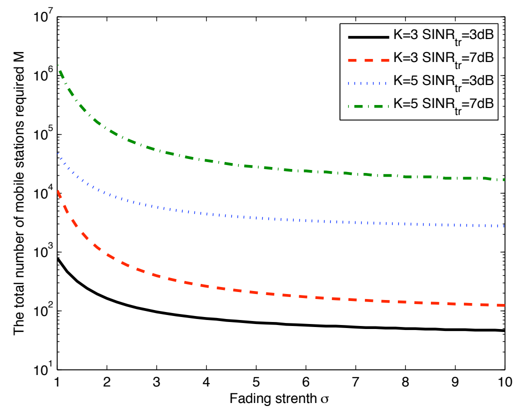

Fig. 4. Simulation results for different fading channel environments and total number of mobile stations M required

degrees of freedom when the number of mobile station M is large enough. Moreover, this technique requires approximately K integers for feedback [3] compared with MK complex numbers in [4], [8]. This technique reduces the encoding and decoding complexity for the downlink of wireless cellular networks to that of point-to-point communications, which is much simpler than proposed MIMO systems in literature. Finally, we proved that it is not necessary to perform cooperative communication in a multiuser environment, which requires significant feedback between cooperating nodes.

References

[1] R. Knopp and P. Humblet, "Information capacity and power control in single-cell multiuser communications," in *Proc. of IEEE ICC 1995*, Seattle, Washington, USA, June 18-22 1995.

[2] M. Grossglauser and D. Tse, "Mobility increases the capacity of ad hoc wireless networks," *IEEE/ACM Transactions on Networking*, vol. 10, no. 4, pp. 477–486, August 2002.

[3] Note that by proper selection of network parameters, we can assure that the number of mobile stations that satisfy interference management condition is always a small number close to K which is basically the number of feedback integers required in this technique. The mathematical proof of this claim is omitted due to page limitations.

[3] P. Viswanath, D. Tse, and R. Laroia, "Opportunistic beamforming using dumb antennas," *IEEE Transactions on Information Theory*, vol. 48, no. 6, pp. 1277–1294, June 2002.
[4] M. Sharif and B. Hassibi, "On the capacity of MIMO broadcast channels with partial side information," *IEEE Transactions on Information Theory*, vol. 51, no. 2, pp. 506–522, February 2005.
[5] D. Tse, "Optimal power allocation over parallel gaussian broadcast channels," in *Proc. of IEEE ISIT 1997*, Ulm, Germany, June 29 - July 4 1997.
[6] V. Cadambe and S. Jafar, "Interference alignment and degrees of freedom of the K-user interference channel," *IEEE Transactions on Information Theory*, vol. 54, no. 8, pp. 3425–3439, August 2008.
[7] ——, "Degrees of freedom for wireless X networks," *Submitted*, 2007.
[8] M. Sharif and B. Hassibi, "A comparison of time-sharing, DPC, and beamforming for MIMO broadcast channels with many users," *IEEE Transactions on Communications*, vol. 55, no. 1, pp. 11–15, January 2007.