Active Null Forming: Coordinated MIMO Transmit Precoding for Interference Mitigation in 5th Generation Networks

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***Abstract*—3gPP Long Term Evolution (LTE) Advanced and Wireless Local Area Networks (WLAN) are both striding towards the 5th generation wireless networks, with guaranteed cell edge coverage and performance. To achieve this, these networks will have unprecedented density of deployed cells, which will actively work with each other to maximize the link to all possible User Equipments (UEs). In this article, we propose a method by which individual network nodes can use additional antennae so as to transmit data to individual UEs while limiting the interference seen by other UEs on the same frequency and time-slot. Ideally, we should be able to have a dense network of nodes, all transmitting simultaneously on the same resource, without any cross-interference. We show that our proposed algorithm shows substantial performance gains over existing techniques addressing coordinated multipoint transmission between multiple transmitters and receivers.**

Keywords*—*Coordinated Multipoint; Multi-user MIMO; interference pre-cancellation

I. INTRODUCTION

The next generation of wireless networks have several challenging objectives, one of which is to meet target throughput numbers for the cell-edge, i.e., applicable to upto 99% of the UEs within the coverage area [1]. Consequently, it is anticipated that next generation wireless networks will be much denser, to improve coverage. This in turn will lead to significant cross node interference. Interference mitigation is already an active area of research in wireless networks; with the advent of newer techniques such as Inter-Cell Interference Coordination (ICIC), further enhanced as eICIC and feICIC) and Coordinated Multipoint (CoMP), there is an emphasis on inter-node coordination so as to jointly improve UE link conditions. For example, CoMP allows joint coding, where multiple nodeBs coordinate with each other so as to transmit to a single UE, further increasing the diversity (and consequently rank) of the ensemble of Multiple Input Multiple Output (MIMO) channels.

In this paper, we present an idea, first presented in [2] called Active-Null Forming (ANF), which allows network nodes to work together so as to transmit to multiple UEs in the same geographical area, while limiting cross node interference. In ANF, each network node receives feedback from multiple UEs in the neighbourhood, one of which it is transmitting data to (the target UE). It then codes the transmission in such a way that the target UE gets the intended data-stream with no interference, whereas the interference at other UEs (on the same frequency and time-slot) is minimized. The key requirement is that the network node be MIMO capable, with a large number of elements available for transmission. The method is a modification of directed feedback method of broadcast MIMO [3]. In [2], we presented a very simple initial approach to ANF, limited to two UEs and two network nodes, with a fixed template for precoding. In the current work we have extended the problem to multiple UEs and presented the solution of the precoding matrix as a constrained (not necessarily convex) optimization problem. We shall first describe how it can be used stand-alone and then jointly by a cluster of network nodes acting together.

A. *Organization of this paper*

The rest of this paper is organized as follows. In Section II we describe the problem in more detail, including the previous work done in this area. In Section III we present the ANF algorithm and introduce the underlying principle. In Section IV we formulate the interference nulling problem as an optimization problem, using the conceptual principles introduced in the previous section. Finally, in Section V, we present the simulation results for a simple network node operating on the principles of the ANF algorithm.

II. COORDINATED NODE FUNCTIONS IN DENSE HETNETS

The next generation of cellular networks will see novel deployment architectures as a means of increasing coverage, reducing cost and also, controlling energy consumption. The key developments include the widespread deployment of cloud Radio Access Networks (cRAN) with Remote Radio Heads (RRH) [4]. This approach combines centralized baseband processing in a cloud, in conjunction with a dense network of RRHs, so as to create a flexible, functionally adaptive network. It is envisioned that the network nodes (RRHs) shall be deployed densely, in overlapping coverage with each other and the network will be able to dynamically map functions to individual nodes as per demand. Already, in some current networks, we see this kind of a deployment, where there is one macro-cell with several femto-cells in its coverage region whose primary job is to off-load local traffic from the macro. This is the kind of environment where inter-node coordination functions such as CoMP are readily applicable; by multiple network nodes cooperating with each other, we can ensure that all network holes and cell-edge points are adequately serviced.

However, in such a network, management of interference (especially co-cellular interference) is a big challenge. Due to the close proximity of the network nodes, tight restrictions on frequency re-use are both inefficient and complex. Rather, the focus has been on time-sharing techniques like ICIC. Such techniques are primarily based around scheduling and not directly on interference control.

A. Multi-user MIMO, massive MIMO and remote radio-heads

Another innovation in next generation networks is the advent of widespread MIMO. Starting from basic single user MIMO, we have progressed to multi-user MIMO and CoMP. It is a fact that it is easier to add transmission elements to a network node, as compared to a user-terminal, especially a hand-held. As of now, the practical limit of antenna on a user-terminal is 2-4. With the advent of RRHs this difference shall be further increased. However, studies have shown that additional antennae don't usually lead to significant changes in throughput, since the independence of the paths are limited. This creates the challenge of using the larger number of antennae on the network node; either through time-diversity schemes (which also suffers the path independence problem), joint transmission/reception schemes of MU-MIMO, etc. This is one of the features of ANF; that it uses these additional network elements for improvement of network conditions.

B. Previous work

The application of multiuser MIMO methods to the interference coordination problem in general has been introduced in [5] [6]. Both these papers highlight the possible co-existence between the semi-static optimization brought in by standard ICIC techniques and the dynamic, frame by frame optimization achievable by CoMP techniques such as Joint Transmission (JT). However, none of these works consider adaptation of CoMP specifically for the ICIC purpose.

In the field of transmitter/precoder based interference cancellation, the previous literature that we have seen on multiple transmitter MIMO is divided into two parts. First is joint encoding with with partial interference pre-substraction and the other is in zero-forcing with block diagonalization (ZF-BD). In interference pre-subtraction our principal reference derives from the decision feedback precoding approach given in [3]. Other related work in this area has been done using trellis precoding techniques [7]. Both of these use special joint pre-coding of the transmitted vectors so as to cancel out interference, taking into account the different channel matrices. Caire and Shamai [8] consider the problem in the context of a single transmitter and multiple single-antenna receivers with full knowledge of the entire channel matrix on both sides and show that for two users, the sum-rate approaches the optimal theoretical Dirty Paper Coding (DPC) output. While their work is based on single antenna receivers, the idea of ordering the two users such that the first user is interference free, but the second user has to deal with the first is introduced by them.

Techniques for ZF-BD for multi-user transmission is given in [9] [10] and others. The basic SVD technique for extracting precoding matrices orthogonal to other users are given in [9]. Zhang [11] describes a cooperative algorithm for zero-forcing transmission with per network node power constraints. Zukang Shen and his co-authors [12] extend this to show that a significant part of the Marton's upper bound can be achieved using the analytically feasible BD approach.

ZF-BD is part of a more generic problem in optimal MIMO MAC precoding matrix design introduced in [13] and further discussed in, for example, [14] and others. These are global cooperative methods that require network nodes to jointly compute the precoding matrices for all nodes simultaneously (typically they involve solutions that require the manipulation of the term $\sum_{k,k\neq i}^{K} \log\left(H_k Q_k H_k^*\right)$. In [15], the authors provide a framework for comparing the relative capacities of the Multiple Access Channel with cooperative precoding and the interference presubtraction approach and conclude that the two cover each other. In more recent work [16] describes a method of optimal linear precoding called 'Soft Interference Nulling' (we found the paper after we had already coined our own term, so any similarity is coincidence), which is also a global technique. In SIN, clusters of base-stations transmit a data stream to a single UE using a jointly constructed set of linear precoding matrices.

C. Our contribution

In this paper, we propose a new method for multi-user MIMO operation, which we call Active Null Forming. Our solution is designed for the multi-transmitter, multiple receiver MuMIMO case; specifically where the number of antennae per transmitter is larger than the number of antennae per receiver. In this sense, it is different from existing algorithms.

The crucial difference in our approach is the use of additional network elements; we propose to use them *explicitly* for modifying the transmitted signal so as to actively cancel interference (as opposed to the passive means suggested in ICIC). As far as we are aware, this approach in general has not been addressed in pre-existing work. Our algorithm is particularly suited to use in next generation mobile networks that are expected to use distributed antenna systems (DAS) [17] [18] liberally to improve signal penetration and diversity, since there will be likely a large number of elements available to each network node.

Technically, our approach is derived from broadcast MIMO; however, by the very nature of our method, it is easy to scale it a number of transmitters. We will show our algorithm achieves results close to cooperative precoding without requiring a global optimization, due to the very nature of the approach; each node can independently compute their own precoding matrices. A second issue that we consider is the power diversion problem; when we do optimal precoding for interference mitigation, we are, to an extent sacrificing the immediate needs of the network node for some global objectives. In this case, this comes to power; in a power constrained network node, we need to decide how much power should be diverted for the purpose of interference mitigation at the cost of SINR for the primary signal. Both these issues are addressed in our paper, as we shall see.

Our algorithm is hence an alternative to the ZFBD algorithm and its variants. In general, ZFBD requires the target UEs to have orthogonal channel matrices [19], i.e., $H_i Q_j H_i^* \equiv \delta_{ij}$ and scheduling algorithms have to take this into account. Our algorithm is not dependent on this condition, which gives it additional flexibility, especially when the number of UEs is relative small, i.e., the $K \to \infty$ condition is not met.

III. ACTIVE NULL-FORMING - THE GENERAL FRAMEWORK

A. Problem Context

The Figure 1a shows the deployment of the proposed approach. We see a small cluster of inter-connected and coordinated network nodes servicing a group of UEs. Each node is assumed to have full state information of the channel to all UEs (in TDD systems, this is easy, but in FDD systems this will require additional signaling and coordination between network nodes for pilot transmission). There is a central coordination and scheduling function, which, for each transmission time slot determines the subset of UEs $\mathfrak{S}$ to be transmitted to and the mapping from nodes to UEs, i.e., for a given UE u to be transmitted to, which node N_u is going to transmit to it. For a given node, the UE to which it has to transmit data to at a particular instant is called the *target UE*. The other active UEs (which are going to receive transmissions from any of the other network nodes) are called *co-resident UEs*. This is shown in Figure 1b.

Each node then computes a precoding matrix as per the ANF algorithm (Section IV). The objective of ANF is to simultaneously transmit the intended signal to the target UE, while minimizing the signal received by the co-resident UEs as much as possible. We achieve this by using the additional transmission elements and a specifically computed precoding matrix to create 'nulls' at the receiver, conceptually similar to the null-forming done in beamforming systems. The core of the algorithm is a specially selected structure for the precoding matrix as given in Sub-Section III-D. Due to this structure, the precoding matrix is guaranteed to make the transmission to the target UE completely free from the rest of the signal (as is achieved in interference subtracting broadcast MIMO). Figure 1b shows ANF in some detail, from the context of a single network node. Note that all the UEs don't need to have the same number of receive antenna and the sum of receive antennae for the UEs may be less than, equal to or greater than the sum of transmit antennae N_t for the network node; the only restriction is that the receive antennae for the target UE must be less than the number of transmit antenna N_t.

B. Conventions and naming

The terminology used in this paper is as per conventional norms. Lowercase variables z, w, etc. refer to vectors, whereas uppercase variables V, W are complex matrices. $\mathfrak{M}_{a\ x\ b}$ is the set of matrices with a rows and b columns, $a < b$ having a eigen-values. If w is a vector, w^* refers to its conjugate form, i.e., each element is replaced by its conjugate and w^T is its transpose. If X is a matrix, $X_{a,b}$ refers to the element in its ath row and bth column, X^* is its complex adjoint (Hermitian) form and $\|X\|_P$ refers to the Frobenius Norm $\|X\|_P = \sum_{i,j} X_{i,j} X_{i,j}^*$. The vector norm is the square norm $\|w\| = \langle w, w^* \rangle$, unless otherwise specified. A matrix may be partitioned columnwise into two matrices, in which case it is designated as $W = [W_i \ W_j]$.

C. Realization at each transmitter

In this section, we discuss the implementation at each network node. We consider a single OFDM network node, with N_t transmit antennae with several UEs in its immediate range. As mentioned above, at each time interval, each node receives channel state information implicitly (through uplink reference signals in TDD mode) or explicitly (feedback on a shared PUSCH in FDD mode). One of the UEs is selected as the target for transmitting data to by a centralized scheduler (which makes this selection for each network node jointly). The network node then uses the CSI of the other UEs to code the transmission in such a way so as to minimize interference for all the others. In our problem, the ith UE has an antenna count of $N_i < N_t$. We designate the number of antenna available to the target UE as N_r and the total number of antennae for all the other UEs as $N_u = \sum_i N_i - N_r$. The channel matrix between the network node and the ith UE is given as $H_i \in \mathfrak{M}_{N_i\ x\ N_t}$.

Each channel matrix H_i has a singular value decomposition $\mathbb{U}_i \Sigma_i \mathbb{V}_i^*$, where $\mathbb{U}_i, \mathbb{V}_i$ are orthonormal column matrices and Σ_i is a diagonal matrix. Since H_i is a matrix with more rows than columns, the SVD actually looks like

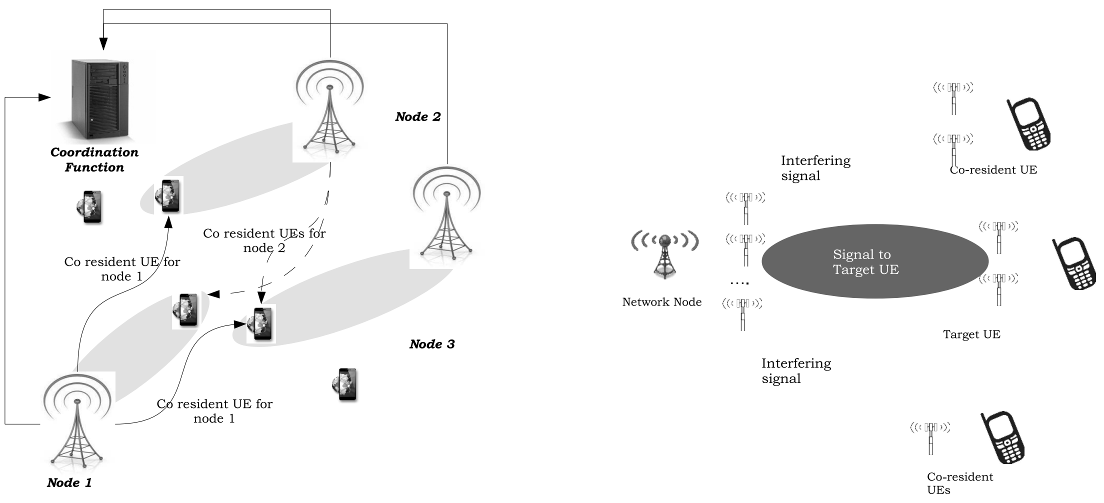
$$H_i = \mathbb{U}_i \begin{bmatrix} \Sigma_i & 0 \end{bmatrix} \begin{bmatrix} V_i & \tilde{V}_i \end{bmatrix}^* \tag{1}$$

D. Structure of the precoding matrix

The transmitting network node uses a precoding matrix of the form

$$\begin{aligned} \Phi F &= \begin{bmatrix} V_r & W \end{bmatrix} \begin{bmatrix} I & -D \\ 0 & I \end{bmatrix} \\ &= \begin{bmatrix} V_r & W - V_r D \end{bmatrix} \end{aligned} \tag{2}$$

Φ is a diagonal power loading matrix, which is used to scale the matrix F to meet the power constraint (see Section III-E). We note that V_r is the sub-matrix of $\mathbb{V}_i$ corresponding to the non-null eigenvalues. W is the 'null forming' matrix and is the key to interference minimization, as we shall show in Sub-Section III-F. The matrix D is given by $D = V_r^* W$; this is dictated by the target UE interference nulling requirement. The precoding matrix F is then applied on a transmit vector $\begin{bmatrix} z & \tilde{z} \end{bmatrix}^T$, where z is the vector



(a). ANF - deployment diagram (b). ANF: Single Node Case

Figure 1. ANF deployment in the network

of N_r symbols (post-modulation) to be transmitted to the target UE. The vector $\tilde{z}$ of size $N_t - N_r$ is also statistically independent and derived from z

We first show that the precoding matrix as shown in (2) will ensure that the signal received at the target UE is free of any effect of the precoding for the other UEs (specifically the interference minimization term W). The received vector on the target UE is given by (3). We ignore the power loading matrix Φ temporarily, since it only has an amplifying effect.

$$y_{tgt} = H_r F \left[\begin{array}{cc} z & \tilde{z} \end{array} \right]^T \tag{3}$$

$$= \mathbb{U}_r \left[\begin{array}{cc} \Sigma_r & 0 \end{array} \right] \left[\begin{array}{c} V_r^* \\ \tilde{V}_r^* \end{array} \right] \left[\begin{array}{cc} V_r & W \end{array} \right] \left[\begin{array}{cc} I & -D \\ 0 & I \end{array} \right] \left[\begin{array}{c} z \\ \tilde{z} \end{array} \right]$$

$$= \mathbb{U}_r \Sigma_r \left[\begin{array}{cc} I & V_r^* W \end{array} \right] [\left[\begin{array}{cc} I & -D \\ 0 & I \end{array} \right] \left[\begin{array}{c} z \\ \tilde{z} \end{array} \right]$$

$$= \mathbb{U}_r \Sigma_r \left[\begin{array}{cc} z & \left(V_r^* W - D \right) \tilde{z} \end{array} \right] \tag{4}$$

By taking $D = V_r^* W$, we ensure that the signal received by the target UE is of the form $\mathbb{U}_i \Sigma_i z$, which can then be decoded using a standard MMSE equalizer [20]. We note that the vector $\tilde{z}$ has no impact on y_{tgt} whatsoever.

E. Obeying the power constraint

Given that the transmission vector $\left[\begin{array}{cc} z & \tilde{z} \end{array} \right]$ has a constant modulus, we have to designthe precoding matrix F given in (2) so as to obey the power constraint that $\text{Tr}\left(FF^*\right) \leq P$. It is easy to see that the power term $\text{Tr}\left(FF^*\right)$ can be written in a simplified form as in (5), using cyclic permutations

$$\text{Tr} \left(\left[\begin{array}{cc} V_r & W \end{array} \right] \left[\begin{array}{cc} I & -D \\ 0 & I \end{array} \right] \left[\begin{array}{cc} I & 0 \\ -D^* & I \end{array} \right] \left[\begin{array}{c} V_r^* \\ W^* \end{array} \right] \right)$$

$$= \text{Tr} \left(\left[\begin{array}{c} V_r^* \\ W^* \end{array} \right] \left[\begin{array}{cc} V_r & W \end{array} \right] \left[\begin{array}{cc} I & -D \\ 0 & I \end{array} \right] \left[\begin{array}{cc} I & 0 \\ -D^* & I \end{array} \right] \right)$$

$$= \text{Tr} \left(I + W^* W - D^* D \right) \tag{5}$$

We note that since W and V_r are not square matrices $W^*W - D^*D$ do not automatically cancel out.

In order to achieve equality with a given overall power constraint P, it is normal to add a diagonal power loading matrix $\Phi = \left[\vec{\phi_1} \ \vec{\phi_2} \right]$ consisting of real amplification factors so that $\text{Tr}\left(\Phi F F^* \Phi^*\right) = \text{tr}\left(\Phi^2 F F^*\right) = P$. Taking the expression from (5) and putting it into the form above, we get

$$\text{Tr}\left(\Phi^2 F F^*\right) = \text{Tr}\left(\vec{\phi_1}^2 + \vec{\phi_2}^2 \left(W^* W - D^* D \right) \right) = P \tag{6}$$

Clearly, the Signal strength as seen by the target UE is a function of $\vec{\phi_1}^2$, whereas $P - \text{Tr}\left(\vec{\phi_2}^2 \left(W W^* - D D^* \right) \right)$ is the power diverted for the purpose of ANF. We would like to choose W so as to bring $\vec{\phi_1}^2$ as high as possible. This in turn means minimizing $\text{Tr}\left(W^* W - D^* D\right) = \| \left(I - V_c\right) W \|_{FP}$.

F. Interference minimization

We now consider the interference to the co-resident UEs due to the combined effect of V_r and W. The task of the transmitter is to choose W of size $N_t \ * \ N_u$, so as to minimize the energy as received by the co-resident UEs, with channel matrices H_i. Since the transmitter is power constrained, we have to limit the overall energy expended in transmission. Let the combined matrix corresponding to the individual channel responses for all the antennae on be given as

$$X = \left[\begin{array}{cccccc} H_1 & H_2 & \ldots & H_{r-1} & H_{r+1} & \ldots \end{array} \right]^T \tag{7}$$

where, as previously mentioned H_r is the channel matrix for the targetted UE. We note that X is a $N_u \ x \ N_t$ sized matrix.

The interference vector ιreceived by a co-resident UE with a $N_u x N_t$ channel matrix X is given by (8). We note that the choice of $\tilde{z}$ is not particularly important, other than meeting the constant modulus approach. Rather, it must be selected based on other criteria, such as maintaining PAPR across the transmission sequence. Hence, $\tilde{z}$ must be a known vector of symbols chosen from the same constellation as z, with the same statistical properties.

$$\begin{aligned} \iota(W) &= X\Phi \begin{bmatrix} V_r & W - V_r D \end{bmatrix} \begin{bmatrix} z \\ \tilde{z} \end{bmatrix} \\ &= X \begin{bmatrix} V & W - V_r D \end{bmatrix} \begin{bmatrix} \vec{\phi_1} z \\ \vec{\phi_2} \tilde{z} \end{bmatrix} \\ &= X V_r \vec{\phi_1} z + X\left(W - V_r D\right) \vec{\phi_2} \tilde{z} \end{aligned} \quad (8)$$

We can expand and rewrite $W - V_r\left(V^* W\right)$ in the form of $(I - V_c)W$, where I is the identity matrix and V_c is a $N_t \ x \ N_t$ matrix given by

$$V_c[i,j] = \sum_k V_r[i,k] V_r[j,k]^* \quad (9)$$

We substitute this back into (8) to get

$$\iota(W, \tilde{z}) = X V_r \vec{\phi_1} z + X\left(I - V_c\right) W \vec{\phi_2} \tilde{z} \quad (10)$$

IV. CONSTRAINED INTERFERENCE MINIMIZATION

Minimizing the interference directly can be written as minimizing $\|I(W)\|$ where I is given in (10) The most direct way to do this is to make $\|\iota(W)\|$ is 0. From (10), this leads to selecting W, ϕ such that $W = (I - V_c)^{-1} V_r$ and adjusting ϕ_1, ϕ_2 suitably. However, it can easily be seen that $(I - V_c)$ is ill-conditioned, having $N_t - N_r$ eigenvalues near zero, so it cannot be directly inverted. This may also be true for X and $X(I - V_c)$. Also, as noted in Section III-E, we have to balance the interference with power constraints as well.

In the simplest approach, we jointly minimize both $\iota(w) = \|I(W)\|_2$ as well as $\|F\|_P$. Φ can then be scaled so as to maximize the transmit power of entire transmission, subject to the power constraint given in (6).

We note that the expression for $\iota(w)$ is equivalent to minimizing the norm of the vector sum $X V_r z + X\left(I - V_c\right) W \tilde{z}$. In general, we can solve equations of this nature iteratively by doing a linear search around the existing gradient. Since z will change for every sub-carrier, we need to eliminate the dependence on it. Hence, we choose an orthogonal transformation $\tilde{z} = Mz$, where M is an orthonormal matrix. As is usual in convex optimization problems, we replace the constraint by a log-barrier function with a multiplier μ, which can be iteratively adjusted for each optimization step to ensure that the power bound is met.

$$\begin{aligned} \text{Minimize} \quad & \|X V_r + X\left(I - V_c\right) W M\| \\ \text{subject to} \quad & \|(I - V_c) W\|_{FP} \leq P_m \\ \equiv \text{Minimize} \quad & \|X V_r + X\left(I - V_c\right) W M\| \\ - \quad & \mu \log\left(P_m - \|(I - V_c) W\|_{FP}\right) \end{aligned} \quad (11)$$

The gradient of an expression of the nature $\|Y + H.W.M\|$ where Y, W, H, M are matrices of the appropriate dimensions can be computed by noting that

$$\frac{\partial \text{Tr}\left[A X^* B\right]}{\partial X} = BA, \quad \frac{\partial \text{Tr}\left[A X B\right]}{\partial X} = A^* B^*$$

We can expand Y as

$$\begin{aligned} \|Y \quad + \quad & HWM\| = \text{Tr}\left(Y + HWM\right)\left(Y + HWM\right)^* \\ = \quad & \text{Tr}(YY^*) + \text{Tr}\left(Y(HWM)^*\right) \\ + \quad & \text{Tr}\left(Y^* HWM\right) + \text{Tr}\left(HWM(HWM)^*\right) \end{aligned}$$

Substituting, we get

$$\Rightarrow \frac{\partial \|Y + HWM\|}{\partial W} = 2H^* Y M^* + 2H^* M M^* W^* H^*$$

Similarly, the derivative of the log-barrier term becomes

$$dW_2 = -\frac{\left(W^*(I - V_c)^*(I - V_c)\right)}{P_m - \|(I - V_c)W\|_{FP}}$$

The optimization procedure hence consists of the following steps. We start with the knowledge of X and V_r. For W we do the following steps

1) Start with $W = 0$, which is a feasible starting point.
2) Compute the corresponding matrix $D = V_r^* W$ and the interference vector $\iota(W)$
3) Compute the gradient matrix $dW = \frac{\partial|\iota(W)|}{\partial W} + \mu dW_2$
4) Find the maximal linear step size γ, such that $W \leftarrow W + \gamma dW$ improves the interference without violating the power constraint.
5) if $\gamma >$ minimum step size, go to 2, else terminate
6) Set ϕ accordingingly.

It is clear that the outcome of this operation depends on the relative orthogonality of $X^* V_r$. We define the normalized metric

$$\gamma = \frac{\text{Tr}(X^* V_r)}{\text{Tr}\left(X^* X\right)}$$

If $\gamma \longrightarrow 0$, the effectiveness of interference cancellation will correspondingly go up.

V. NETWORK WIDE PERFORMANCE - THEORETICAL ANALYSIS

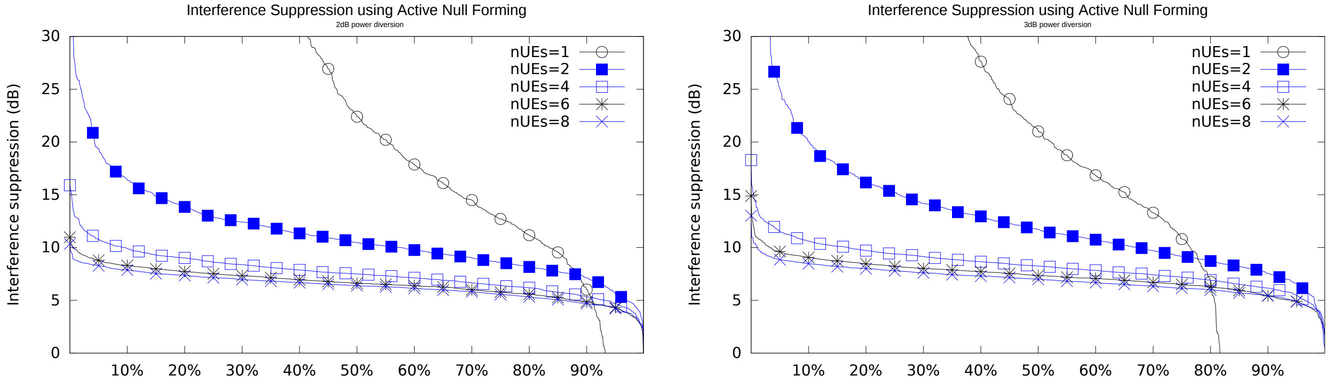
We now consider the performance of the ANF in a network wide environment and present the simulation results.

We simulate a single network node transmitting to one target UE with 2 receive antennae $N_r = 2$. The transmitter has 4 antennae $N_t = 4$, with the remaining two antennae dedicated to ANF. The overall maximum power available to be diverted to the cause of ANF is an optimization variable η. Each co-resident UE is modelled as a single antenna receiver with statistically independent channel matrix, known to the network node. The output metric γ is the ratio of the interference energy received at the coresident UEs divided by the interference energy if there had been no ANF, i.e., $W = 0$.

$$\eta = \frac{P_m}{P_t} \quad (12)$$

$$\gamma = \frac{\|\iota(W^{opt})\|}{\|\iota(0)\|} \quad (13)$$

The results for $\eta = 2dB$ and $\eta = 3dB$ are given in Figure 2a and 2b, respectively. It can be seen that for a single coresident UE, 80% of the cases the interference suppression



(a). Case 1: 2dB pwr diversion

(b). Case 2: 3dB pwr diversion

Figure 2. Simulation Results

is better than 10dB and in the top 50% it is better than 20dB. The cases where a single coresident UE cannot be improved is where its channel matrix is very close that of the target UE As the number of UEs increase, the maximum improvement drops; however, as we can see, even in the case of 8 co-resident UEs, we get a 10dB interference suppression by diverting 2-3dB of power for the ANF purpose.

VI. CONCLUSION

In this paper, we have demonstrated a novel technique for utilization of multi-user and distributed antennae equipment in the network by directed interference cancellation. Our algorithm demonstrates large improvements in SINR and consequently resource utilization for 1,2 4 and 8 UEs. In the future, we shall explore more complicated network scenarios and feedback conditions

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