Adaptive SINR Threshold Allocation for Joint Power Control and Beamforming Over Wireless Networks

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Abstract— **Cochannel interference is one of the main impairments that degrade the performance of a wireless link. Power control and antenna beamforming are two approaches for improving the performance in wireless networks by appropriately controlling the cochannel interference. Joint optimal beamforming and power control scheme has been considered in previous work. It has been shown that the scheme can reduce the total transmitted power and increase the maximum number of allowable users or maximum achievable Signal-to-Interference-Noise-Ratio (SINR) in wireless networks. However previous scheme only works well in low SINR situation. In higher SINR situation, the total transmitted power is much higher than necessary. When required SINR is higher than a specific value, there are no feasible solutions for power allocation. This problem is caused by the assumption that every mobile user has fixed and the same SINR requirement (threshold). In this paper, we introduce a novel adaptive SINR threshold allocation scheme with joint power control and antenna beamforming that can overcome the problems and work in the real wireless communication conditions. From simulation results, we can see that our scheme reduce 60 percent of overall transmitted power and increase working area of joint power control and beamforming by 4 dB.**

Keywords— **Power control, Antenna Beamforming, Mobile Communication, Interface Suppression.**

I. Introduction

The capacity of a cellular system is limited by the cochannel interference (CCI). CCI is due to interference caused by users sharing the same channel. Adaptive beamforming schemes have been widely used to reduce CCI in both receiver and transmitter. The link capacities are improved by adjusting the beam pattern such that the effective signal to interference and noise ratio (SINR) is optimally increased. Deploying antenna arrays are only practical in the baste station nowadays. In receive diversity, the beamformer places nulls at the directions of interference, while the gain at the direction of the desired transmitter is maintained constant. In transmit diversity, the beampattern of each antenna array can be adjusted to minimize the introduced interference to undesired receivers. Transmit diversity and receiver beamforming are substantially different. Receiver beamforming can be implemented independently and locally at each base station, without affecting the performance of other link. While transmit beamforming at each transmitter will change the interference to all the other receivers. As a result, transmit beamforming has to be done jointly in the entire network. Feedback channels have to be used to send downlink channel responses. However, in time division duplex (TDD) sytems where uplink and downlink channel are reciprocal, the uplink channel information can be used for the downlink.

In [1] and [2], transmit beamforming and power control are combined for cellular wireless communication system. Each user SINR is maintain above some thresholds. The optimal beamforming and allocation schemes are obtained by adaptive algorithms. In [3] and [4], Per-User-Per-Weight (PUPW) beamforming scheme is introduced for DS-CDMA system. The channel capacity is analyzed by comparing the outage probability. In [5], Quality of Service (QoS) is introduced for wireless multimedia network. Algorithms are proposed to efficiently add new users to network and tune up the users' QoS. All the previous works suffer the same problem: the schemes only work in low SINR areas. When target SINR is higher than some point, the overall needed transmitted power grows very fast until there is no feasible solution, i.e. not matter how large the transmitted power is, the receivers' SINR still can not reach the required SINR.

In this paper, we consider a novel scheme for power control and beamforming. Instead of assigning every user the same SINR threshold, we find out that if some users can sacrifice their performance a little bit, the other users will have a lot of gains in power and the working area is extended to higher SINR areas. We find the gradient of overall transmitted power. We develop an adaptive algorithm to find the optimal way to reduce the overall power while keeping the average SINR as high as possible. In simulation, we set practical restriction on SINR allocation. We can find out that our schemes reduce 60% of overall transmitted power and increase working area by 4 dB.

The organization of paper is as follows: In Section II, we will present system model of a network with multipath fading channels and discuss the optimal criteria for power allocation and beamforming. In section III, we will describe our algorithms of adaptive SINR threshold allocation with joint power allocation and beamforming. A suboptimal algorithms is also introduced. In Section IV, we will evaluate the performance of our algorithms by using simulation study. In Section V, we will have summery and conclusion.

II. System and Channel Model

Consider M cochannel links that may exist in distinct cell as in TDMA or FDMA networks. Assume coherent detection is possible. Antenna arrays with P elements are used only at base station. We assume that the multipath

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propagation delay is less than one symbol period. For uplink case, the signal at the output vector of the i^{th} base station array can be expressed as:

$$\mathbf{x}_i(t) = \sum_{m=1}^{M} \sqrt{\rho_{mi} G_{mi} \alpha_{mi} P_m} \mathbf{a}_{mi} g_m(t - \tau_{mi}^l) s_m(t) + \mathbf{n}_i(t) \quad (1)$$

Where M is the number of users that share the same channel. L is the maximum number of multipath. ρ_{mi} is the log-normal shadow fading from m^{th} user to i^{th} base station. G_{mi} is path loss. α_{mi}^l is the fading loss for l_{th} path. P_m is the m^{th} user's transmitted power. $\mathbf{a}_{mi} = [a_{mi}^1(\theta_l), \ldots, a_{mi}^P(\theta_l)]^T$ is the i^{th} base station array response to the signal coming from m^{th} mobile at direction θ_l. $g_m(t)$ is the shaping function. τ_{mi}^l is the multipath delay for l^{th} multipath. $s_m(t)$ is the message symbol. $\mathbf{n}_i(t)$ is the $P \times 1$ thermal noise vector. Define the response of fading, array and shaping function from the m^{th} mobile to the p^{th} element of i^{th} base station as:

$$h_{mi}^p = \sum_{l=1}^{L} \sqrt{\alpha_{mi}^l} a_{mi}^p(\theta_l) r_{mi}^{pl} \quad (2)$$

Where r_{mi}^{pl} includes the effect of the transmitter and receiver filter and $g_m(t)$. The vector form is $\mathbf{h}_{mi} = [h_{mi}^1, \ldots, h_{mi}^P]^T$. Then we can express the sampled received signal vector as:

$$\mathbf{x}_i(k) = \sum_{m=1}^{M} \mathbf{h}_{mi} \sqrt{P_m \rho_{mi} G_{mi}} s_m(k) + \mathbf{n}_i(k) \quad (3)$$

Where $\mathbf{n}_i(k)$ is the sampled thermal noise vector.

With adaptive beamforming, the output of the combiner at the i^{th} receiver is written as $\mathbf{w}_i^H \mathbf{x}_i$, where $\mathbf{w}_i$ is the beamforming weight vector. The aim is to adjust the weight vector to achieve maximum SINR at the output of the combiner. If the uplink channel response from the desired user is know, The minimum variance distortion response (MVDR) solution to this problem can be achieved by minimizing the total interference at the output of beamformer while the gain for the desired user is kept constant.

$$\begin{array}{c} \min_{\{\mathbf{w}_i\}i=1,\ldots,M} \|\mathbf{w}_i^H \mathbf{x}_i\|^2 \\ \text{subject to } \|\mathbf{w}_i^H \mathbf{h}_{ii}\|^2 = 1, \ i = 1, \ldots, M \end{array} \quad (4)$$

Define correlation matrix as $\Phi_i = E[\mathbf{x}_i \mathbf{x}_i^H(k)]$. Optimal weight vector is given by:

$$\hat{\mathbf{w}}_i = \frac{\Phi_i^{-1} \mathbf{h}_{ii}}{\mathbf{h}_{ii}^H \Phi_i^{-1} \mathbf{h}_{ii}} \quad (5)$$

If the channel response is not available, we use a training sequence, which is correlated with the desired signal. The weight vector is obtained by minimizing the mean square error between the beamformer output and the training sequence, denoted by d_i. The minimum mean square error (MMSE) problem is:

$$\hat{\mathbf{w}}_i = \arg\min_{\mathbf{W}_i} E\{\|d_i - \mathbf{w}_i^H \mathbf{x}_i\|^2\}$$

For simplicity, the training sequence is considered to be a copy of the singal of interest. Then the solution is given by Wiener-Hopf solution.

$$\mathbf{w}_i = \sqrt{P_i} \Phi_i^{-1} \mathbf{h}_{ii}(0) \quad (6)$$

Assuming the transmitted signals from different sources are uncorrelated and zero mean, and the additive noise is spatially and temporally white. We can write the power at the output of beamformer as:

$$\begin{aligned} \Psi_i &= E[\|\mathbf{w}_i^H \mathbf{x}_i\|^2] \\ &= P_i \rho_{ii} G_{ii} + \textstyle\sum_{m \neq i} P_m \rho_{mi} G_{mi} \|\mathbf{w}_i^H \mathbf{h}_{mi}\|^2 + \mathbf{w}_i^H N_i \mathbf{w}_i \end{aligned}$$

The effective SINR at the beamformer output for i^{th} user can be expressed as:

$$\Gamma_i = \frac{P_i \rho_{ii} G_{ii}}{\sum_{m \neq i} P_m \rho_{mi} G_{mi} \|\mathbf{w}_i^H \mathbf{h}_{mi}\|^2 + \mathbf{w}_i^H N_i \mathbf{w}_i} \quad (7)$$

The purpose of power control is to select the transmitting power of each mobile user so as to have $\Gamma_i \geq \gamma_i$ for $i = 1, \ldots, M$, while minimizing the overall power used by all mobile users. Here γ_i is the target SINR threshold to maintain the required link quality. Given that path gains and powers are non-negative, the matrix version of the problem statement for the power control is now given by:

$$\begin{array}{c} \min \sum_{i=1}^{M} P_i \\ \text{subject to } (I - DF)\mathbf{P} \geq \mathbf{u} \end{array} \quad (8)$$

where $\mathbf{u} = [u_1, \ldots, u_M]^T$, $u_i = \gamma_i \mathbf{w}_i^H N_i \mathbf{w}_i / \rho_{ii} G_{ii}$, $\mathbf{P} = [P_1, \ldots, P_M]^T$, $D = diag\{\gamma_1, \ldots, \gamma_M\}$ and

$$[F_{ij}] = \begin{cases} 0 & \text{if } j = i, \\ \frac{\rho_{ji} G_{ji} \|\mathbf{w}_i^H \mathbf{h}_{ji}\|^2}{\rho_{ii} G_{ii}} & \text{if } j \neq i \end{cases}$$

If the spectral radius [6] of DF is inside the unit circle, i.e. the maximum eigenvalue of DF is inside unit circle, the system has feasible solutions and the optimum power vector for the constrained problem is $\hat{\mathbf{P}} = (I - DF)^{-1}\mathbf{u}$. However this is a NP hard problem. In the next section, we use adaptive algorithms to modify γ_i. The overall performance and complexity can be improved a lot.

In downlink case, the beamforming will affect all users in the system. The deduction of system model is similar to uplink situation. The signal at the i^{th} mobile receiver can be expressed as:

$$\begin{array}{l} \tilde{\mathbf{y}}_i(t) = \sum_{m=1}^{M} \sum_{l=1}^{L} \mathbf{w}_m^H \mathbf{a}_{im}(\theta_l) \sqrt{\rho_{im} G_{im} \alpha_{im} \tilde{P}_m} \\ \cdot g_{im}(t - \tau_{im}^l) \tilde{s}_m(t) + \tilde{n}_i(t) \end{array} \quad (9)$$

The response of fading, array and shaping function is

$$\tilde{\mathbf{h}}_{im} = \sum_{l=1}^{L} \mathbf{a}_{im}(\theta_l) \sqrt{\alpha_{im}^l} r_{im}^l \quad (10)$$

Then the sampled received signal vector is given by:

$$\tilde{y}_i(k) = \sum_{m=1}^{M} \mathbf{w}_m^H \tilde{\mathbf{h}}_{im} \sqrt{\tilde{P}_m \rho_{im} G_{im}} \tilde{s}_m(k) + \tilde{n}_i(k) \quad (11)$$

The SINR at the mobile receiver can be expressed as:

$$\tilde{\Gamma}_i = \frac{\tilde{P}_i \rho_{ii} G_{ii} \|\mathbf{w}_i^H \tilde{\mathbf{h}}_{ii}\|^2}{\sum_{m \neq i} \tilde{P}_m \rho_{im} G_{im} \|\mathbf{w}_m^H \tilde{\mathbf{h}}_{im}\|^2 + \tilde{N}_i} \tag{12}$$

If we have constraint that $\|\mathbf{w}_i\|^2 = 1, \forall i$, i.e. there is no gain in beamforming. The optimal problem becomes:

$$\begin{array}{c} \min \sum_{i=1}^{M} \tilde{P}_i \\ \text{subject to } (I - D\tilde{F}^T)\tilde{\mathbf{P}} \geq \mathbf{u} \end{array} \tag{13}$$

where $\tilde{\mathbf{u}} = [\tilde{u}_1, \ldots, \tilde{u}_M]^T$, $\tilde{u}_i = \gamma_i \tilde{N}_i / \rho_{ii} G_{ii} \|\mathbf{w}_i^H \tilde{\mathbf{h}}_{ii}\|^2$, $\tilde{\mathbf{P}} = [\tilde{P}_1, \ldots, \tilde{P}_M]^T$, $D = diag\{\gamma_1, \ldots, \gamma_M\}$ and

$$[\tilde{F}_{ij}] = \begin{cases} 0 & \text{if } j = i, \\ \frac{\rho_{ij} G_{ij} \|\mathbf{w}_j^H \tilde{\mathbf{h}}_{ij}\|^2}{\rho_{ii} G_{ii} \|\mathbf{w}_i^H \tilde{\mathbf{h}}_{ii}\|^2} & \text{if } j \neq i \end{cases}$$

The optimal solution is $\hat{\mathbf{P}} = (I - D\tilde{F}^T)^{-1}\tilde{\mathbf{u}}$.

III. Adaptive Threshold Allocation with Joint Power Control and Beamforming

The solution of the optimum power vector in the previous section suffers problems. It works perfect in low SINR areas. When the target SINR thresholds become large enough, the overall transmitted power increases too fast. If the target SINR thresholds are larger than specific points, there are no feasible solutions, i.e. receiver cannot get enough SINR level not matter how large the transmitted powers are. The underlying reason for the problem is that the target SINR thresholds are fixed and the same for all mobile users, which is not optimal. In this paper, we assume users can accept SINR thresholds within a range from $\gamma_{\min}$ to $\gamma_{\max}$. We will develop some adaptive algorithms to find the optimal target SINR allocation. It is shown simulation that overall transmitted power is dramatically reduced and the working areas are extended to higher SINR areas.

We will discuss uplink case first. We prove that the overall transmitted power $P_{sum} = \sum P_i$ is a convex and increasing function of $\gamma_1 ... \gamma_M$.

Proof: If $(DF) \in R^{M \times M}$ and $\|DF\|^2 < 1$, then $Q = [I - DF]^{-1} = \sum_{k=0}^{\infty} (DF)^k$. Since $D = diag(\gamma_1, \ldots, \gamma_M)$ and $F_{ij} > 0, \forall i, j$, every component in Q is a function of $(\gamma_i)^k, k = 1 \ldots \infty, i = 1 \ldots M$ with non-negative coefficient. In vector $\mathbf{u}$, all u_i have the non-negative coefficients as well. So $P_{sum} = \sum_{i=1}^{M} P_i = Q^{-1}\mathbf{u}$ is also a function of $(\gamma_i)^k$ with non-negative coefficients. The only situation that the coefficients are zeros is that the antenna beamforming puts a null in the desired mobile user. This will hardly happen in practical condition. Since $\gamma_i > 0, \forall i$, P_{sum} is a convex and increasing function of γ_i.

Since $\|DF\|^2 < 1$, then $P = [I - DF]^{-1}\mathbf{u} = \sum_{k=0}^{\infty} (DF)^k \mathbf{u} \approx (I + DF)\mathbf{u}$. We have

$$\begin{array}{l} P_{sum} = \sum_{k=1}^{M} \frac{\mathbf{w}_k^H N_k \mathbf{w}_k \gamma_k}{G_{kk} \rho_{kk}} + \\ \sum_{k=1}^{M} \sum_{n=1, n \neq i}^{M} \frac{\mathbf{w}_n^H N_n \mathbf{w}_n G_{kn} \rho_{kn} \|\mathbf{w}_k^H \mathbf{h}_{kn}\|^2 \gamma_n \gamma_k}{G_{nn} G_{kk} \rho_{nn} \rho_{kk}} \end{array} \tag{14}$$

Then the gradient $\mathbf{g}_i$ for P_{sum} is given as:

$$\begin{array}{l} g_i = \frac{\partial P_{sum}}{\partial \gamma_i} \approx \sum_{n=1\ n \neq i}^{M} \Big(\frac{\mathbf{w}_n^H N_n \mathbf{w}_n G_{in} \rho_{in} \|\mathbf{w}_i^H \mathbf{h}_{in}\|^2 \gamma_n}{G_{ii} G_{nn} \rho_{ii} \rho_{nn}} \\ + \frac{\mathbf{w}_i^H N_i \mathbf{w}_i G_{ni} \rho_{ni} \|\mathbf{w}_n^H \mathbf{h}_{ni}\|^2 \gamma_n}{G_{ii} G_{nn} \rho_{ii} \rho_{nn}} \Big) + \frac{\mathbf{w}_i^H N_i \mathbf{w}_i}{G_{ii} \rho_{ii}} \end{array} \tag{15}$$

Since we have proved that P_{sum} is a convex and increasing function and we have the gradient, we can construct an adaptive algorithm to find the optimal target SINR threshold allocation scheme. Before that, we have a practical assumption: Average target SINR threshold is the same as before, but each mobile user can work with SINR thresholds from $\gamma_{\text{ave}} - \Delta\gamma$ to $\gamma_{\text{ave}} + \Delta\gamma$. The matrix version of the power control is now given by:

$$\begin{array}{c} \min_{\{\gamma_i\} i=1,\ldots,M} \sum_{i=1}^{M} P_i \\ \text{subject to } \begin{cases} (I - DF)\mathbf{P} \geq \mathbf{u}, \\ \frac{1}{M} \sum_{i=1}^{M} \gamma_i = \gamma_{\text{ave}} = \text{const.}, \\ \gamma_{\text{ave}} - \Delta\gamma \leq \gamma_i \leq \gamma_{\text{ave}} + \Delta\gamma. \end{cases} \end{array} \tag{16}$$

Since P_{sum} is a convex function of $\{\gamma_1 \ldots \gamma_M\}$, we have

$$\begin{array}{l} P_{sum}(\lambda\gamma_1 + (1-\lambda)\gamma_1^{'}, \ldots, \lambda\gamma_M + (1-\lambda)\gamma_M^{'}) \\ \leq \lambda P_{sum}(\gamma_1, \ldots, \gamma_M) + (1-\lambda) P_{sum}(\gamma_1^{'}, \ldots, \gamma_M^{'}) \\ \forall \gamma_i, \forall \gamma_i^{'}, \forall 0 \leq \lambda \leq 1 \end{array}$$

We have the constrain $\gamma_M = const. - \sum_{i=1}^{M-1} \gamma_i$ and $\gamma_M^{'} = const. - \sum_{i=1}^{M-1} \gamma_i^{'}$. The above formular still hold for all $\gamma_i, \gamma_i^{'}, i = 1 \ldots M-1$. So P_{sum} is still a convex function under the constraint of $\gamma_{\text{ave}} = \text{const.}$.

In order to develop the adaptive algorithm for this practical assumption, we need to modify the gradient such that $\sum_{i=1}^{M} \gamma_i = const.$ holds along the modified gradient $\mathbf{q} = [q_1 \ldots q_M]$. $\mathbf{q}$ is a projection of $\mathbf{g} = [g_1 \ldots g_M]$ on plane $1/M \sum_{i=1}^{M} \gamma_i = const.$, where $q_m = -\sum_{i=1}^{M-1} q_i$ and

$$\begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_{M-1} \end{bmatrix} = \frac{1}{M} \begin{bmatrix} M-1 & -1 & \ldots & -1 \\ -1 & M-1 & \ldots & -1 \\ \vdots & \vdots & \ddots & \vdots \\ -1 & -1 & \ldots & M-1 \end{bmatrix} \begin{bmatrix} g_1 - g_M \\ g_2 - g_M \\ \vdots \\ g_{M-1} - g_M \end{bmatrix}$$

Proof: By definition of projection, vector $\mathbf{q}$ satisfies equation $\|\mathbf{g} - \mathbf{q}\|^2 = \min_{\forall \mathbf{x} \in plane} \|\mathbf{g} - \mathbf{x}\|^2$. We only need to mimimize the right hand side to get the optimal vector, i.e. the projection $\mathbf{q}$. Write

$$\begin{array}{l} f(x_1, \ldots, x_{M-1}) = \|\mathbf{g} - \mathbf{x}\|^2 \\ = \sum_{i=1}^{M-1} (x_i - g_i)^2 + (-\sum_{i=1}^{M-1} x_i - g_M)^2 \end{array}$$

Take derivatives with respect to each of arguments and set the derivatives to zeros. We have equations:

$$\begin{array}{c} x_1 - g_1 + (\sum_{i=1}^{M-1} x_i + g_M) = 0 \\ \vdots \\ x_{M-1} - g_{M-1} + (\sum_{i=1}^{M-1} x_i + g_M) = 0 \end{array}$$

Write above equations in matrix form and use the fact $1/M \sum_{i=1}^{M} \gamma_i = const.$ (set constant to zero). We can get the optimal projection $\mathbf{q}$.

The adaptive iterative algorithm to find the best target SINR threshold allocation under this constraint is given by:

Adaptive Algorithm A

Initial:

$$\gamma_1 = \gamma_2 = \ldots = \gamma_M = \gamma_{ave}$$
$$P_1 = P_2 = \ldots = P_M = any \ \ positive \ \ const.$$

Iteration:

- Beamforming: $\mathbf{w}_i = \arg\max_{\mathbf{w}} \Gamma_i$
- Power Allocation Update:

$$D[n] = \mathrm{diag}(\gamma_1, \gamma_2 ... \gamma_M);$$

$$\mathbf{u}[n]_i = \frac{\gamma_i N_i}{G_{ii}};$$

$$\mathbf{P}[n+1] = D[n]F[n]\mathbf{P}[n] + \mathbf{u}[n].$$

- Adaptive Threshold Allocation

$$\mathbf{g} = \nabla P_{sum};$$

$$\mathbf{q} = \mathrm{projection}(\mathbf{g});$$

do {
$\gamma_i = \gamma_i - \mu.\mathbf{q}_i \ \forall i;$
if $(\gamma_i > \gamma_{\max}) \ \ \gamma_i = \gamma_{\max};$.
if $(\gamma_i < \gamma_{\min}) \ \ \gamma_i = \gamma_{\min}.$}
while (γ_i *not stable*)

Where μ is a small constant.

Now we will discuss downlink case. The gradience $\tilde{\mathbf{g}}$ is given by:

$$\tilde{g}_i = \frac{\partial_{\tilde{P}_{sum}}}{\partial \gamma_i} \approx \sum_{n=1 \ n \neq i}^{M} \Big(\frac{\tilde{N}_n G_{ni} \rho_{ni} \|\mathbf{w}_n^H \mathbf{h}_{ni}\|^2 \gamma_n}{G_{ii} G_{nn} \rho_{ii} \rho_{nn} \|\mathbf{w}_n^H h_{nn}\|^2} + \frac{\tilde{N}_i G_{in} \rho_{in} \|\mathbf{w}_i^H \mathbf{h}_{in}\|^2 \gamma_n}{G_{ii} G_{nn} \rho_{ii} \rho_{nn} \|\mathbf{w}_i^H h_{ii}\|^2} \Big) + \frac{\tilde{N}_i}{G_{ii} \rho_{ii} \|\mathbf{w}_i^H h_{ii}\|^2} \quad (17)$$

If the downlink channel responses are known. we can use the method of virtual uplink for beamforming and power control. First we construct a virtual network whose channel responses are similar to that of the downlink. Then we find the receiver diversity vectors at the base stations of the virtual uplink. At each iteration, we use the same combining vector for the downlink.

Adaptive Algorithm B

Initial:

$$\gamma_1 = \gamma_2 = \ldots = \gamma_M = \gamma_{ave}$$
$$\tilde{P}_1 = \tilde{P}_2 = \ldots = \tilde{P}_M = any \ \ positive \ \ const.$$

Iteration:

- Beamforming for Virtual Uplink:

$$\mathbf{w}_i = \arg\max_{\mathbf{w}} \tilde{\Gamma}_i$$

- Uplink Power Update:

$$\mathbf{P}[n+1] = D[n]F[n]\mathbf{P}[n] + \mathbf{u}[n].$$

- Adaptive Threshold Allocation

$$\tilde{\mathbf{g}} = \nabla \tilde{P}_{sum};$$

$$\tilde{\mathbf{q}} = \mathrm{projection}(\tilde{\mathbf{g}});$$

do {
$\gamma_i = \gamma_i - \mu.\tilde{\mathbf{q}}_i \ \forall i;$
if $(\gamma_i > \gamma_{\max}) \ \ \gamma_i = \gamma_{\max};$.
if $(\gamma_i < \gamma_{\min}) \ \ \gamma_i = \gamma_{\min}.$}
while (γ_i *not stable*)

- Downlink Power Update:

$$\tilde{\mathbf{P}}[n+1] = D[n]F^T[n]\tilde{\mathbf{P}}[n] + \mathbf{u}[n].$$

If the uplink and downlink are reciprocal, we can use uplink channel response as downlink response. However in the case of FDD, Algorithm B requires the full knowledge of the channel and array responses for the entire network. This requires channel measurements at the mobile and a feedback mechanism to send the information to the base station. Moreover, base stations should transfer the measured channel responses to the other base stations which requires a lot of wireline communication bandwidth. We need simplified and practical algorithm [7] [8].

First in order to calculated the transmit diversity weight vectors, we can only use the channel response to the closest cochannel users. In order to update the transmitted power, downlink SINR is calculated in each mobile. Knowing its previous transmitted power and the target SINR, the mobile will use feedback channel to update the transmitted power in the base station. i.e. the downlink power iteration can be implemented using only local downlink measurements at mobile.

Adaptive Algorithm C

- Beamforming at each base station:

$$\mathbf{w}_i = \arg\max_{\mathbf{w}} \|\mathbf{w}^H \mathbf{h}_{ii}\|^2$$

- Power Allocation:

$$\tilde{\mathbf{P}} = [I - DF^T]^{-1}\mathbf{u}.$$

- Adaptive Threshold Allocation

The same as Algorithm B

IV. Simulation Results

In order to evaluate the performance of our algorthms, a network with hexagonal cells and a cluster size of one is simulated as illustrated in Fig. 1. The base stations are placed at the center of the cell. Two adjacent base stations don't share the same channels. In each cell, one user is placed randomly with a uniform distribution. The path loss is proportional to r^{-2}, where r is the distance between the mobile and base station. For each link, 3-dB log-normal shadow fading are considered. In the simulation, we consider three multipath with equal power Rayleigh fading.

There is negligible delay spread between different paths. The angle of arrival for each path is uniform random variable in $[0, 2\pi]$. Each base station has four element antenna arrays. Raised cosine function is used as the pulse shaping function. We select $\Delta\gamma = 5dB$.

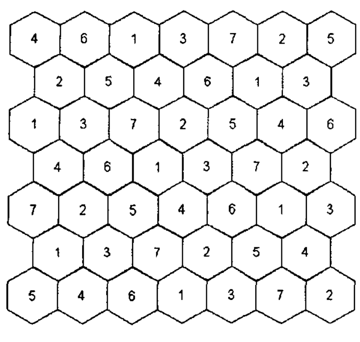

Fig. 1. Simulation system setup

The total transmitted power in uplink as a function of the average target SINR is shown in Fig. 2. We compare performance of four schemes. The solid curve (NbNa) shows the case where neither beamforming nor adaptive SINR threshold allocation is used. The dashed curve (BNa) shows the case where only beamforming is used. The dashdot curve (NbA) shows the case where only adaptive SINR threshold allocation is used. The dotted curve (BA) shows the case where both beamforming and adaptive SINR threshold allocation are used. The simulation results show that by using our algorithms, we can significantly reduce the total transmitted power by 60% in the uplink. Moreover we extend maximum achievable SINR about 4 dB and the system can work in a practical SINR range.

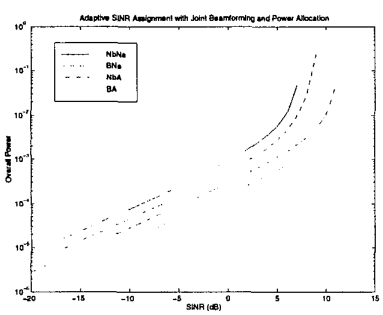

Fig. 2. Total uplink power as a function of average target SINR

The total transmitted power in downlink as a function of the average target SINR is shown in Fig. 3. We compare performance of four schemes. The dotted curve shows the case where adaptive SINR threshold allocation is not used in Algorithm B. The solid curve shows the case where adaptive SINR threshold allocation is not used in Algorithm C. The dashed curve shows the case where adaptive SINR threshold allocation is used in Alogirthm B. The dash-dot curve shows the case where adaptive SINR threshold allocation is used in Alogirthm C. From the curves, we can see the Algorithm C has almost the same performance as Algorithm B, while Algorithm C requires much lower system complexity than Algorithm B. The adaptive SINR threshold allocation can significantly improve the performance.

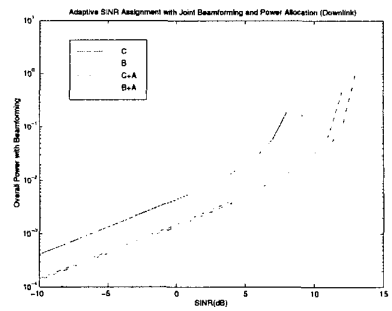

Fig. 3. Total downlink power as a function of average target SINR

V. Conclusions

In summery, we propose three novel adaptive algorithms for SINR threshold allocation with joint beamforming and power control. In uplink, Algorithm A reduce 60% of the total transmitted power of mobile users, which is very critical in terms of battery life in mobile sets. In downlink, our algorithms significantly save overall transmitted power by base stations, which in turn will increase the capacity of wireless networks significantly. Moreover, the feasible working areas are extended 4dB to higher SINR areas which can be used in practical wireless communication networks. We also introduce a sub-optimal algorithm with much lower complexity and good performance.

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