Power Control in Wireless Interference Networks with Limited Feedback

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***Abstract*—This paper addresses a power control problem in a wireless time-varying K-user interference network. Each transmitter intends to communicate to its desired receiver at a fixed rate. Quantized channel gains are globally available through limited feedback signals. To eliminate multi-user interference, *interference alignment* scheme is performed based on the imperfect channel knowledge. The communication quality is affected by the channel quantization errors and interference leakage. We propose a power control algorithm, aiming to guarantee successful transmissions of each user while minimizing the transmission power of the network. Our results show that even with limited number of feedback bits, by performing power control the considered interference alignment scheme can outperform the conventional time-division-multiple-access scheme.**

I. Introduction

Design of the efficient transmission schemes for wireless interference networks has attracted much research interest. A K-user interference network refers to a wireless network consisting of K transmitter-receiver pairs. Since all the users share the same radio resources, the reception at each receiver may potentially be interfered by unintended signals. Conventional interference management strategies (e.g. time-division-multiple-access, TDMA) tend to orthogonalize each user pair's operation. This requirement leads to the fact that at each receiver's signal space different interference signals are orthogonal to the desired signals and also orthogonal to each other. The interference is avoided at the cost of low spectral efficiency. Thus, it was believed that the performance of the interference networks is limited by interference. However, the elegant *interference alignment* concept [1], [2] reveals that with proper transmit signalling design, different interference signals can in fact be aligned together, leaving maximally half of the signal space at each receiver to its desired signals. Each user may achieve half of the interference-free transmission rate no matter how many interferers exist. Therefore, interference networks may not be interference-limited in nature.

To perform interference alignment, in general the global channel state information (CSI) is required to be perfectly known at all the transmitters and the receivers. However, acquiring such perfect global CSI is a challenging problem in practice, especially for time-varying channel environments. A more feasible assumption can be that each terminal obtains only the quantized version of the channel gains through feedback signals broadcasted by different receivers. It has been shown that when the number of feedback bits is sufficiently large, the aforementioned good performance can still be achieved [3], [4], [5]. However, the bandwidth of the feedback channels is limited in practice so that the terminals may not be able to attain sufficiently accurate CSI. It has been shown that even with limited feedback, if proper rate adaptation is performed the interference alignment scheme can still outperform TDMA, in terms of sum throughput [6].

In the finite-SNR region, the transmitters may exploit the available CSI not only to eliminate the multi-user interference, but also to adapt their transmission strategies to fulfil certain service requirements. For instance, in a class of systems considered in [6] given that the transmission powers are fixed a maximum sum throughput is always desired. Thus, rate adaptation is performed among the transmitters. However, in this paper we focus on a different type of the systems where it is required to guarantee that each transmitter successfully communicates with corresponding receiver at a pre-agreed fixed rate [7]. Therefore, it is required to properly control the powers. Certain power control techniques are proposed in [8], [9] and [10] for the systems which treat the interference as noise while decoding. For the systems with multiple antennas at the terminals these are extended to joint beamforming and power control in [11], [12] and [13].

Specifically, we consider a time-varying K-user interference channel. Each transmitter intends to communicate with its desired receiver at a fixed rate and can obtain quantized channel gains through limited feedback signals from all the receivers. We apply the interference alignment scheme based on the imperfect channel knowledge to partially eliminate the multi-user interference. We propose a power control algorithm, aiming to guarantee successful transmissions of each user while minimizing the total transmission power of the network. Our results show that even with only a small number of feedback bits, with proper power control the average total power requirement of applying the interference alignment scheme can be lower than that of applying the TDMA scheme. Thus, the advantage of performing power control while managing interference through the *interference alignment* can be clearly seen over the *interference orthogonalization*.

II. System Model

We consider a single-antenna K-user interference network represented in Fig. 1. Each transmitter has independent messages for its dedicated receiver. All the users share the medium and simultaneously transmit. We assume discrete-time, *block-fading* (each block contains n channel uses) channels. The

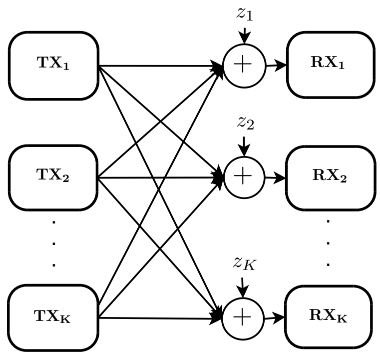

Fig. 1. System model

channel gains remain constant over each block, but change independently across different blocks. We consider transmission over a large number of blocks. At any block index a, the transmitter k ($k \in \{1, 2, ..., K\}$) chooses its message independently and uniformly from a set of size 2^{nR_k} where R_k is the code rate which is fixed for all channel realizations. It encodes its message to a unit-power codeword $\mathbf{x}_k^a$ of length n. The channel output at the receiver k is given by:

$$\mathbf{y}_k^a = \sqrt{p_k} h_{kk}^a \mathbf{x}_k^a + \sum_{l=1, l\neq k}^{K} \sqrt{p_l} h_{kl}^a \mathbf{x}_l^a + \mathbf{z}_k^a, \ k = 1, 2, \cdots, K \quad (1)$$

where h_{kl}^a is the channel gain between the transmitter l and the receiver k, drawn independently from a complex Gaussian distribution, i.e. $h_{kl}^a \sim \mathcal{CN}(0, 1)$, p_k is the transmission power of the transmitter k and $\mathbf{z}_k^a \sim \mathcal{CN}(0, 1)$ is the noise. h_{kk}^a denotes the *desired channel* gain and the first term on the right hand side (RHS) of equation (1) is the desired signal of the receiver k, while h_{kl}^a for $l \neq k$ denotes the *interference channel* gain and the second term on the RHS of equation (1) is the multi-user interference experienced by the receiver k. At the beginning of each block, each receiver estimates the incoming channel gains based on the training sequences broadcasted by each transmitter (this estimation is assumed to be perfect). Next, it quantizes the channel gains and broadcasts the corresponding indices to all the other terminals using error-free feedback channels. There are two quantizers at each receiver with possibly different resolutions regarding the desired and the interference channels. More specifically, each receiver uses $2N_I$ bits to quantize its desired channel gain. In addition, it uses $2N_{II}$ bits to quantize each interference channel gain. Therefore, each receiver totally broadcasts $N_f = 2N_I + 2(K-1)N_{II}$ bits to all the other terminals. Each terminal reconstructs the quantized channel gains from the received feedback signal and tries to accordingly compute its required transmission power. At the next block, since all the channels change independently, this process is conducted again.

A. Channel Gain Quantization

To gain an insight on the performance of applying interference alignment with limited feedback, we consider using a uniform quantization scheme to quantize the channels. It can be conjectured that using certain more sophisticated quantization schemes [14] may lead to even better performance.

We deploy a two-dimensional vector quantizer to quantize each complex-valued channel gain. The complex plane from distance h_{min} up to distance h_{max} from the the real and the imaginary axes, is divided into multiple equal-size ($\Delta \times \Delta$) square regions. Each region is called a *quantization cell* and Δ is termed the *quantization step size*. For example, a $2N$-bit quantizer has $2^N \times 2^N$ quantization cells and the corresponding quantization step size is $\Delta = \frac{h_{\text{max}} - h_{\text{min}}}{2^{N-1}}$. To quantize the interference channel gains we set h_{min} equal to zero and to quantize the direct channel gains we choose this parameter according to the power constraint that will be mentioned in the next section. The quantizer maps the channel coefficients within a quantization cell to the quantized value which is the mid-point of the corresponding cell. For channel realization h_{kl}^a, we represent this quantization process as follows:

$$\hat{h}_{kl}^a = Q(h_{kl}^a), \quad \forall k, l \in \{1, 2, ..., K\} \quad (2)$$

where $\hat{h}_{kl}^a$ is the quantized channel gain. The associated quantization error is denoted as δ_{kl}^a (i.e. $\delta_{kl}^a = \hat{h}_{kl}^a - h_{kl}^a$). If $|\text{Re}(h_{kk}^a)| < h_{\text{min}}$ or $|\text{Im}(h_{kk}^a) < h_{\text{min}}$ then $\hat{h}_{kk}^a = 0$. Since we assume each receiver uses $2N_I$ bits to quantize its desired channel gains and uses $2N_{II}$ bits to quantize each interference channel gain, the quantization step sizes for the desired and the interference channel gains are $\Delta_I = \frac{h_{\text{max}} - h_{\text{min}}}{2^{N_I - 1}}$ and $\Delta_{II} = \frac{h_{\text{max}}}{2^{N_{II} - 1}}$, respectively. As a result, the magnitude of both the real and the imaginary parts of the quantization error for the desired (interference) channel gain is bounded by $\frac{\Delta_I}{2}$ ($\frac{\Delta_{II}}{2}$).

B. Transmission Scheme

We first provide the definition of the *complement channels*.

Definition 1: The channels at the block indices a and b are called *complement* if the following conditions are satisfied:

$$\hat{h}_{ii}^a = \hat{h}_{ii}^b \ , \ \hat{h}_{ij}^a = -\hat{h}_{ij}^b \ ; \ \forall i, j \in \{1, ..., K\} \ , \ i \neq j. \quad (3)$$

Assume m and m_p are the block indices of a pair of complement channels. Similar to the ergodic interference alignment scheme proposed in [3] we require each transmitter to send the same codeword during these two blocks (i.e. $\mathbf{x}_k^m = \mathbf{x}_k^{m_p}$, $\forall k \in \{1, ..., K\}$). Each receiver adds its received signals in these two blocks (i.e. $\overline{\mathbf{y}}_k^m = \mathbf{y}_k^m + \mathbf{y}_k^{m_p}$) and tries to decode its desired codeword. Therefore, according to the system model in (1) the equivalent received signal at the receiver k is:

$$\begin{aligned} \overline{\mathbf{y}}_k^m &= \sqrt{p_k} \left(2\hat{h}_{kk}^m + \delta_{kk}^m + \delta_{kk}^{m_p} \right) \mathbf{x}_k^m \\ &\quad + \sum_{l=1, l\neq k}^{K} \sqrt{p_l} \left(\delta_{kl}^m + \delta_{kl}^{m_p} \right) \mathbf{x}_l^m + \overline{\mathbf{z}}_k^m. \end{aligned} \quad (4)$$

The first term on the RHS of (4) is the desired signal, we call the second term the *residual interference*, and $\overline{\mathbf{z}}_k^m = \mathbf{z}_k^m + \mathbf{z}_k^{m_p}$ is the equivalent noise. Clearly, part of the interference is eliminated because of the complementarity of the quantized channel gains. However, due to the quantization errors certain amount of the residual interference remains at the receivers.

If the quantization resolution asymptotically goes to infinity, the power of the residual interference approaches zero and the transmitter k can achieve the rate $R_k = \frac{1}{2}\log\left(1+2|h_{kk}^m|^2 p_k\right)$ if the codeword length n is sufficiently large and the code is capacity achieving [3]. In this case, to guarantee successful transmission at fixed rate R_k, the transmitter k should transmit with power $p_k(h_{kk}^m) = \frac{(2^{2R_k}-1)}{2|h_{kk}^m|^2}$. This power control can be done at each transmitter independent of the others.

It has been proved in [3] that for the channels with a symmetric distribution (e.g. zero mean complex Gaussian), the probability of finding the complement channel for any channel realization increases as the number of the transmitted blocks increases. Therefore, with sufficiently large number of the blocks for any of the block indices almost surely we can find another block index such that the channels are complement. Each receiver is able to decode its message after some delay (the delay can be reduced by sacrificing the achievable rate as mentioned in [15]).

To guarantee successful transmission at a fixed rate, each of the transmitters is required to choose its power according to the current channel gains. Therefore, if the quantization has infinite precision, the average required power for the transmitter k is $\mathrm{E}[p_k(h_{kk})] = \mathrm{E}[\frac{(2^{2R_k}-1)}{2|h_{kk}|^2}]$. This is substantially lower than the required power of the conventional orthogonal transmission schemes such as TDMA which is $\mathrm{E}[p_k(h_{kk})] = \mathrm{E}[\frac{(2^{KR_k}-1)}{K|h_{kk}|^2}]$ (The average required power for the TDMA would increase as the number of the users increases). However, with limited resolution quantizers the quantization errors lead to a certain amount of the interference leakage. The power control strategy for the different users is interrelated and thus is challenging. In what follows, we propose a power control algorithm which aims to guarantee the successful transmissions with the minimum transmission power.

III. Rate Constrained Power Control

In this section, we first present the rate constrained power control problem for the considered network. Next, we propose an iterative power control algorithm as a solution of this problem.

A. Rate Constrained Power Control Problem

Assume that the channels with block indices m and m_p are complement. We require each transmitter to repeat the same codeword over the blocks m and m_p. According to the input-output relation (4), the signal-to-interference-plus-noise ratio (SINR) of the equivalent received signal of the receiver k ($k \in \{1,2,...,K\}$) can be expressed as follows:

$$\mathrm{SINR}_{\overline{\mathbf{y}}_k^m} = \frac{\left|2\hat{h}_{kk}^m + \delta_{kk}^m + \delta_{kk}^{m_p}\right|^2 p_k}{2+\sum_{l=1,l\neq k}^K \left|\delta_{kl}^m + \delta_{kl}^{m_p}\right|^2 p_l}, \quad (5)$$

This SINR value is random and it depends on the quantization errors which are unknown to the transmitters. This value can be lower bounded as $\mathrm{SINR}_{\overline{\mathbf{y}}_k^m} \geq \mathrm{SINR}_{\overline{\mathbf{y}}_k^m}^{\min}$, where $\mathrm{SINR}_{\overline{\mathbf{y}}_k^m}^{\min}$ can be calculated at the transmitters as follows:

$$\mathrm{SINR}_{\overline{\mathbf{y}}_k^m}^{\min} = \frac{\left(4\left|\hat{h}_{kk}^m\right|^2 + \Delta_I^2 - 4\Delta_I\left(\left|\mathrm{Re}(\hat{h}_{kk})\right| + \left|\mathrm{Im}(\hat{h}_{kk})\right|\right)\right)p_k}{2+2\Delta_{II}^2\sum_{l=1,l\neq k}^K p_l}. \quad (6)$$

Therefore, the mutual information between the transmitter-receiver pair k is $\frac{1}{2}\log_2\left(1+\mathrm{SINR}_{\overline{\mathbf{y}}_k^m}\right)$ and it can be lower bounded by $\frac{1}{2}\log_2\left(1+\mathrm{SINR}_{\overline{\mathbf{y}}_k^m}^{\min}\right)$. In order to guarantee successful transmission at rate R_k, the following condition should be satisfied:

$$\frac{1}{2}\log_2\left(1+\mathrm{SINR}_{\overline{\mathbf{y}}_k^m}\right) \geq R_k. \quad (7)$$

Clearly, if the transmitters compute their transmission powers such that meet the following condition, we can guarantee the condition (7):

$$\frac{1}{2}\log_2\left(1+\mathrm{SINR}_{\overline{\mathbf{y}}_k^m}^{\min}\right) \geq R_k. \quad (8)$$

According to (6), the condition (8) can be re-written as power constraint $p_k \geq I_k(\mathbf{p})$, where

$$I_k(\mathbf{p}) = \frac{(2^{2R_k}-1)(2+2\Delta_{II}^2\sum_{l=1,l\neq k}^K p_l)}{4\left|\hat{h}_{kk}^m\right|^2 + 2\Delta_I^2 - 4\Delta_I\left(\left|\mathrm{Re}(\hat{h}_{kk})\right| + \left|\mathrm{Im}(\hat{h}_{kk})\right|\right)} \quad (9)$$

and $\mathbf{p} = [p_1 \ \cdots \ p_K]^T$. Thus the rate constraints for all the users can be described by a vector inequality:

$$\mathbf{p} \succ \mathbf{I}(\mathbf{p}), \quad (10)$$

where the operator $\succ$ denotes element-wise strict inequalities. $\mathbf{I}(\mathbf{p}) = [I_1(\mathbf{p}) \ \cdots \ I_K(\mathbf{p})]^T$, where $I_k(\mathbf{p})$ is defined in (9). The power vector $\mathbf{p}$ is a *feasible solution* of the power control problem if it satisfies (10) and the function $\mathbf{I}(\mathbf{p})$ is *feasible* if (10) has at least one feasible solution. Consequently, the power control problem can be formulated as follows:

$$\min_{\text{st. } \mathbf{p}\succeq\mathbf{I}(\mathbf{p})} \sum_{l=1}^K p_l. \quad (11)$$

In the next part, we propose a solution for this problem.

B. Iterative Power Control

In this part, first we present an iterative power control algorithm to solve the problem (11). Next, we study the convergence of the proposed algorithm.

1) Iterative Power Control Algorithm: The iterative power control procedure is shown in Algorithm 1. In each iteration of the algorithm, the transmitter k ($k \in \{1,2,...,K\}$) computes the function I_k given by (9) according to $\hat{h}_{kk}^m$ and the total transmission power of the other transmitters in the network for the previous iteration (this power can also be computed by the transmitter k based on the quantized channel gains $\hat{h}_{ll}^m$, $\forall l \neq k$). Next, it updates its transmission power following Algorithm 1. If $\hat{h}_{kk}^m = 0$, the link quality of the user k is poor. To guarantee successful transmission, the transmitter has to transmit with a very large power, which may also introduce strong interference to the others. Thus, we require this user

Algorithm 1 Iterative power control for interference alignment

Initialize: $p_1(0), ..., p_K(0)$, max_{itr}
for $t = 1 : max_{\text{itr}}$ **do**
  for $k = 1 : K$ **do**
    if $\hat{h}_{kk}^m = 0$ **then**
      Transmitter k does not transmit and $p_k(t) = 0$.
    end if
    Transmitter k computes function I_k:
    $I_k(\mathbf{p}(t-1)) = \frac{(2^{2R_k}-1)(2+2\Delta_{II}^2 \sum_{l=1,l\neq k}^K p_l(t-1))}{4\left|\hat{h}_{kk}^m\right|^2+2\Delta_I^2-4\Delta_I\left(\left|\text{Re}(\hat{h}_{kk}^m)\right|+\left|\text{Im}(\hat{h}_{kk}^m)\right|\right)}$
    Transmitter k updates its transmission power:
$$p_k(t) = I_k(\mathbf{p}(t-1))$$
  end for
end for
if p_k did not converge **then**
  Feasible solution does not exist. Stop transmission of the transmitter k in blocks m and m_p. Exclude transmitter k from the set of active transmitters in the current block and repeat the algorithm among the remained users.
end if

to stop its transmission to save energy and protect other users which in fact leads to a rate loss. The probability of this event is $(1-2Q(h_{\text{min}}))^2$, where $Q(x)$ is the Q-function.

This algorithm, converges to the optimum solution if there is at least one feasible power vector which satisfies the constraint of the problem (11). If there is no such feasible power vector, the transmitter whose power does not converge to the optimum solution would be shut down and be excluded from the list of the active transmitters. The optimization procedure repeats until feasible solutions are found.

2) Convergence of the Algorithm: To provide the convergence proof of the proposed algorithm, we need to define a family of functions and a corresponding iterative algorithm. The definitions are consistent with reference [10].

Definition 2: $\mathbf{I}(\mathbf{p})$ is called *standard interference function* if for all vectors $\mathbf{p}, \mathbf{p}' \succeq 0$, it satisfies following conditions:

$$\begin{aligned} &1) \quad \text{Positivity}: \quad \mathbf{I}(\mathbf{p}) \succ 0 \\ &2) \quad \text{Monotonicity}: \quad \mathbf{I}(\mathbf{p}) \succeq \mathbf{I}(\mathbf{p}'),\ (\forall \mathbf{p} \succeq \mathbf{p}') \\ &3) \quad \text{Scalability}: \quad \alpha\mathbf{I}(\mathbf{p}) \succ \mathbf{I}(\alpha\mathbf{p}),\ (\forall \alpha > 1). \end{aligned} \tag{12}$$

Definition 3: If $\mathbf{I}(\mathbf{p})$ is a standard function, *standard power control* algorithm is defined as:

$$\mathbf{p}(t) = \mathbf{I}(\mathbf{p}(t-1)). \tag{13}$$

For any initial vector $\mathbf{p}(0)$, the standard power control algorithm (13) generates a sequence of vectors $\mathbf{p}(1), ..., \mathbf{p}(t)$.

Theorem 1: If the problem (11) is feasible, for any initial power vector $\mathbf{p}(0)$ Algorithm 1 converges to a unique fixed point $\mathbf{p}^*$ which is the optimum solution of the problem (11).

Proof: First we show that function $\mathbf{I}(\mathbf{p})$ given in (9) is a standard interference function. For this purpose we show that this function satisfies the conditions given in (12). For simplicity of the presentation, we re-write

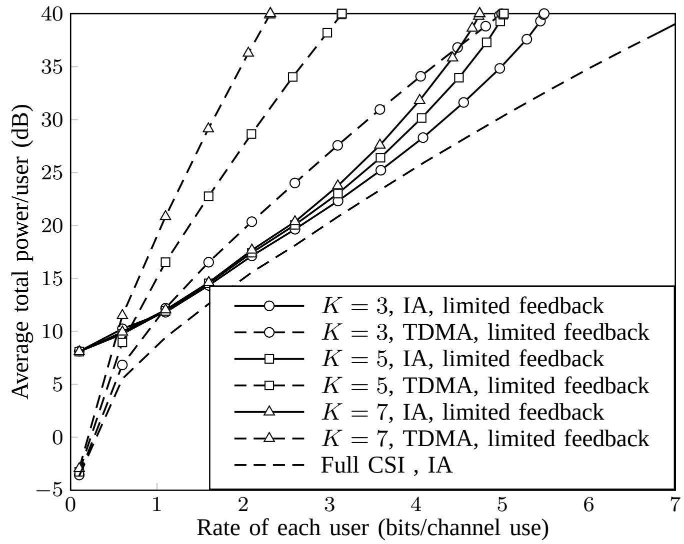

Fig. 2. Average total power per user vs. rate of each user in a K-user interference networks ($N_I = N_{II} = 8$).

$I_k(\mathbf{p})$ as $I_k(\mathbf{p}) = L(1 + \Delta_{II}^2 \sum_{l=1,l\neq k}^K p_l)$, where $L = \frac{(2^{2R_k}-1)}{2\left|\hat{h}_{kk}^m\right|^2+\Delta_I^2-2\Delta_I\left(\left|\text{Re}(\hat{h}_{kk})\right|+\left|\text{Im}(\hat{h}_{kk})\right|\right)} > 0$ is a constant.

1) $I_k(\mathbf{p}) = L(1 + \Delta_{II}^2 \sum_{l=1,l\neq k}^K p_l) \geq L > 0$ and the positivity condition is satisfied.
2) If $\mathbf{p} \succeq \mathbf{p}'$, then $(1+\Delta_{II}^2 \sum_{l=1,l\neq k}^K p_l) \geq (1+\Delta_{II}^2 \sum_{l=1,l\neq k}^K p_l')$ and since $L > 0$ we have $I_k(\mathbf{p}) \geq I_k(\mathbf{p}')$. Thus, the monotonicity condition is satisfied.
3) If $\alpha > 1$, then

$$I_k(\alpha\mathbf{p}) = L(1+\alpha\Delta_{II}^2 \sum_{l=1,l\neq k}^K p_l) < \alpha L(1+\Delta_{II}^2 \sum_{l=1,l\neq k}^K p_l) = \alpha I_k(\mathbf{p}).$$

Therefore, the scalability condition is satisfied.

These conditions are satisfied for all the users and we can conclude that the function $\mathbf{I}(\mathbf{p})$ given in (9) is a standard function. Therefore, according to the Theorem 2 in [10] for any initial power vector $\mathbf{p}(0)$ the standard power control algorithm (13) converges to a unique fixed point $\mathbf{p}^*$. The Lemma 1 in [10] implies this fixed point corresponds to the solution with minimum required transmission power. ■

IV. Numerical Evaluation

In this section we numerically evaluate the performance of the power control algorithm for the wireless interference networks when quantized CSI are available at the transmitters. For the TDMA scheme, we assume user scheduling is fixed and the channel inversion is performed according to the weakest channel corresponding to the quantized channel gain. In all the simulations, we consider truncated channels where the weak direct channels fall in the region bounded by distance h_{min} from the real and imaginary axes are excluded where this parameter is chosen according to the power constraint. For the quantization of the Gaussian distributed channels, since almost all channel realizations fall in the region bounded by $h_{\text{max}} = 4\sigma$ [16] we set $h_{\text{max}} = 4$.

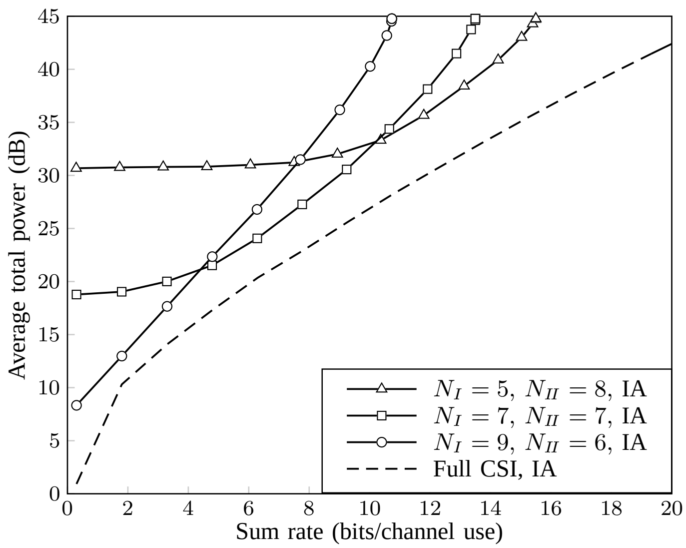

Fig. 3. Feedback bits trade-off in a 3-user network ($N_f = 21$).

Fig. 2 shows the average required power per user, as a function of the rate of each user for different number of users in the network ($N_I = N_{II} = 8$). The performance of the TDMA scheme (with the same number of feedback bits) and the interference alignment scheme with full CSI are also shown for comparison. As we increase the number of users, the required transmission power at a given rate does not change for the interference alignment scheme with full CSI. But, it considerably increases for the TDMA scheme, especially in the high rate region. For the interference alignment scheme with limited feedback, increasing the number of users does not significantly increase the required power at the low-rate region. However, if the transmission rate is high, the power is increased notably when the number of users increases. This is because at higher rates, the performance is affected more severely by the residual interference. It can be seen from the figure that even with limited feedback, applying the interference alignment scheme with proper power control outperforms the TDMA in the intermediate rate region by requiring less power for the fixed-rate transmission.

Fig. 3 shows the trade-off between allocating feedback bits to the quantizer of the desired channel and that of the interference channels. In this example, the total number of the feedback bits is $N_f = 21$. We can see that in the low-rate region, allocating more bits to the desired channel is preferred while in the high-rate region, it is more efficient to allocate more bits for the quantization of the interference channels. This is because when the desired transmission rate is low, the network is working in the noise-limited region and it is better to more precisely control the powers. However, in the high- rate region the users should transmit with large powers to guarantee successful transmission. Thus, the network is interference-limited and it is preferred to more accurately perform interference alignment rather than power control. This result coincides with the trade-off observed in [6].

V. CONCLUSION

In this paper we have studied a time-vary interference network in which the transmitters perform both interference alignment and power control based on the quantized CSI, obtained through limited feedbacks from the receivers. We have proposed an iterative power control algorithm for such a network, which aims to guarantee successful transmission of each user at a fixed rate with minimum total transmission power. The proposed algorithm converges to the optimum solution whenever the problem has a solution. Through simulation results, we have shown that the proposed scheme can require lower transmission powers than the TDMA scheme in a certain rate region. Thus, the advantages of performing power control for the wireless interference networks where the interference alignment based on the imperfect CSI is applied is explicitly seen.

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