Evolution Game Theoretic Optimization of Realistic Cooperative Networks using Power Control with Imperfect Feedback

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***Abstract*—Distributed spatial diversity systems, such as multi-relay and multi-user networks, have drawn significant attention from the research community. However, their feasibility in a practical environment remains an open concern. Most notably, how to optimize cooperation between multiple users with individual interests and how practical systems issues can erode diversity gains. Whilst existing information theoretical analysis may yield insightful bounds, they provide an inadequate solution for optimal power allocation in realistic systems due to the mutual information saturation of non-Gaussian inputs. In our work, we use feasible modulation and error correction codes to implement a system and demonstrate how multiple users cannot only improve their performance through cooperation, but also optimize their performance through power allocation with imperfect feedback. We do so, by considering an evolution game theoretic (EGT) approach, whereby the status-quo between users change with each decision.**

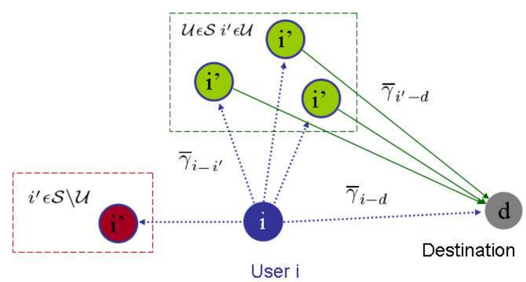

Fig. 1. Multiple users in cooperation, observed from a user i's perspective. Other users (i') are potential partners (set $\mathcal{S}$), of which some can cooperate (subset $\mathcal{U}$) and others cannot (subset $\mathcal{S} \setminus \{\mathcal{U}\}$).

I. Introduction

Cooperative communication has many aspects, and chiefly amongst them are: diversity techniques, relaying protocols and optimization. In order to achieve full diversity amongst available paths, two commonly used techniques are Distributed-Space-Time-Codes (DSTCs) [1] and Maximum-Ratio-Combining (MRC) [2]. DSTCs can achieve the same diversity order as MRC, whilst potentially offering significant spectral efficiency savings when the number of transmit nodes is large. However, DSTCs face feasibility challenges concerning synchronization and coordination. Whilst these challenges have been partially addressed, the sensitivity to orthogonality errors can cause unacceptable performance degradation [3]. In order to relay the same transmission through different independently faded paths, two popular protocols are often considered, i.e., Amplify-and-Forward, and Decode-and-Forward. Furthermore, forward-error-correction (FEC) codes can also be included to improve performance. In literature, information theoretic and symbol error rate characterization are well defined for MRC receivers [2] [4]. It has also been shown in [5] that power allocation solutions cannot assume Gaussian inputs due to the saturation of realistic modulation constellations. Optimization of such networks has been performed mostly for relay networks, where multiple relays unselfishly assist a single user in transmission. Such optimization include partner selection [6][7] and power control [8]. Relay network optimization is significantly different to that of cooperative networks, where each user must optimize power allocation between transmitting its own data and relaying that of others. What remains unclear is how multiple users should optimally allocate their resources in a realistic cooperative network. The open challenges are: how will competing users settle on cooperation, and how to optimize such a network given channel state information (CSI) estimation errors? To consider these problems, we first construct a system model consisting of multiple users in cooperation as shown in Fig. 1. We then characterize the system's performance before investigating the aspects of user behaviour, partner selection, optimization and channel state feedback.

II. System Setup

A. System Model

We consider M single-antenna users, randomly distributed and connected by channels which experience reciprocal quasi-static Rayleigh fading and are impaired by

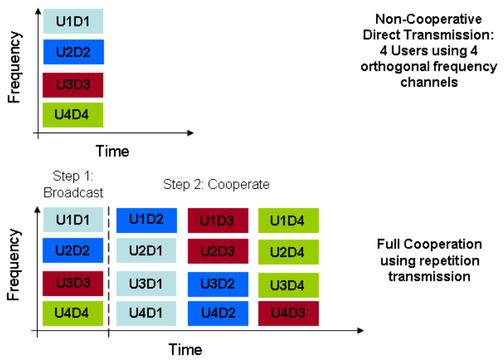

Fig. 2. Non-Cooperative, and Repetition Cooperative Transmission Stages for $M = 4$ Users. $U1D2$ means User 1 is transmitting User 2's data through cooperation.

Additive White Gaussian Noise (AWGN). Such a channel model is most appropriate for transmissions dominated by non-line-of-sight (NLOS) propagation paths. Each cooperation cycle will experience a constant fading gain, and spatial diversity is achieved through MRC at the common destination. In Fig. 2, we show the frequency-time utilization of Non-Cooperative (Direct) Transmission and Repetition Cooperative Transmission. When in cooperation, the first transmission step for every user is used to broadcast their own data to the common destination and to each other. In the remaining steps, they relay each other's data in cooperation and in the case of unsuccessful cooperation, they simply retransmit their own data. We also consider two commonly used forward-error-correction (FEC) codes, namely: Block codes and Convolution codes. We note that No-Cooperation utilizes a fraction of $\frac{1}{M}$ and Repetition Diversity utilizes a fraction of $\frac{1}{M^2}$ the degrees of freedom inside a channel. Therefore, for a fairer transmit power comparison, we shall compensate the No-Cooperation case with the use of M times greater transmit power. We note that alternatively a fair rate comparison can also be made by having different modulation and coding schemes, as shown in our previous work [9].

B. Definitions

For a system of M users, a particular user i can have m other partners at any particular fading instance, where $0 \leq m \leq M-1$. Each other partner is denoted as user i' where $i', i' \neq i$. In a Decode-and-Forward protocol, the chance of cooperation is based on the inter-user channel condition and the FEC code ($\mathbf{C}$) utilized. We define the instantaneous channel signal to noise ratio (SNR) as $\gamma = |h|^2 \frac{E}{N_0}$, where E is the transmit energy, $|h|$ is the magnitude of the complex fading coefficient h, and N_0 is the average additive white Gaussian noise (AWGN) power spectral density. We define $\overline{\gamma}_{i-d}$ as the average SNR of the uplink channel between node i and destination d, and $\overline{\gamma}_{i-i'}$ as the average SNR of the interuser channel between nodes i and i'. Referring to Fig. 1, we define a powerset $\mathcal{S}$, which contains all the valid subsets of $0 \leq m \leq M-1$ potential cooperation partners. The subset $\mathcal{U}$ is a part of $\mathcal{S}$, that contains all the partners which can provide cooperation. Hence, $\mathcal{S}\setminus\{\mathcal{U}\}$ contains all the remaining nodes that cannot assist the considered user i.

C. Characterization

In our previous work [10], we found the exact frame-error-rate (FER) expression for Decode-and-Forward (DF) user, in a cooperative system with arbitrary (asymmetrical) channels. For user i, its FER is:

$$\begin{aligned} p^{\text{DF}}_{f_{\text{Fading,C}}} &= \prod_{i'=1,i'\neq i}^{M-1} (1-\wp^{B}_{i-i'}) \int_0^\infty p^{\text{Direct}}_{f_{\text{AWGN,C}}} \frac{1}{\psi\overline{\gamma}_{i-d}} e^{-\frac{\gamma}{\psi\overline{\gamma}_{i-d}}} \mathrm{d}\gamma \\ &+ \sum_{m=1}^{M-1} \sum_{\mathcal{U}\epsilon\mathcal{S}} \prod_{i'\epsilon\mathcal{U}} \wp^{B}_{i-i'} \prod_{i'\epsilon\mathcal{S}\setminus\mathcal{U}} (1-\wp^{B}_{i-i'}) \\ &\int_0^\infty p^{\text{Direct}}_{f_{\text{AWGN,C}}} \sum_{i=1}^{m} \prod_{i'=1,i'\neq i}^{m} \frac{e^{-\frac{\gamma}{\omega\overline{\gamma}_{i-d}}}}{\omega\overline{\gamma}_{i-d}-\overline{\gamma}_{i'-d}} \mathrm{d}\gamma, \end{aligned} \tag{1}$$

where ω and ψ are power allocation factors to allow fair comparison between different user behaviour scenarios (B), that we shall explain in section III and for now we assume $\omega = 1$, $\psi = M-m$ and $B = 1$. We define $\wp_{i-i'}$ as the chance of cooperation between user i and i':

$$\begin{aligned} \wp_{i-i'} &= 1 - p^{\text{Direct}}_{f_{\text{Fading,C}}} \\ &= 1 - \int_0^\infty p^{\text{Direct}}_{f_{\text{AWGN,C}}} \frac{1}{\overline{\gamma}_{i-d}} e^{-\frac{\gamma}{\overline{\gamma}_{i-d}}} \mathrm{d}\gamma. \end{aligned} \tag{2}$$

The term $p^{\text{Direct}}_{f_{\text{AWGN,C}}}$ is the FER for Non-Cooperative (Direct) transmission in an AWGN channel utilizing FEC code $\mathbf{C}$. Previously, we have considered DF systems utilizing Block Codes [11] and Turbo Codes [10]. For the purpose of this paper we shall be considering channel codes, whose performance in AWGN channels can be characterized by an SNR threshold (T), i.e., convolution and turbo codes [12]. In [10], we substitute the chance of cooperation (2) into the FER expression (1) and the user i's frame error rate (FER) was found to be:

$$\begin{aligned} p^{\text{DF}}_{f_{\text{Fading,C}(T)}} &= \prod_{i'=1,i'\neq i}^{M-1} (1-e^{-\frac{T}{\overline{\gamma}_{i-i'}}})(1-e^{-\frac{T}{(M-m)\overline{\gamma}_{i-d}}}) \\ &+ \sum_{m=1}^{M-1} \sum_{\mathcal{U}\epsilon\mathcal{S}} \prod_{i'\epsilon\mathcal{U}} e^{-\frac{T}{\overline{\gamma}_{i-i'}}} \prod_{i'\epsilon\mathcal{S}\setminus\mathcal{U}} (1-e^{-\frac{T}{\overline{\gamma}_{i-i'}}}) \\ &\sum_{i=0}^{m} \prod_{i'=1,i'\neq i}^{m} \frac{\overline{\gamma}_{i-d}}{\overline{\gamma}_{i-d}-\overline{\gamma}_{i'-d}} (1-e^{-\frac{T}{\overline{\gamma}_{i-d}}}). \end{aligned} \tag{3}$$

Expression 3 considers users who are willing to cooperate if possible. In the following section, we investigate a practical system with M users, where each user is only willing to cooperate if certain conditions are satisfied.

III. Game Theory

A. User Behaviour

Thus far, most previous literature investigates cooperation between nodes who are willing to cooperate. We call this *unselfish cooperation* (UsC). In our previous work [11], we investigated the impact of *mutually selfish cooperation* (MsC). In MsC, we define cooperation to exist when it is both possible and reciprocal, otherwise there will be *no cooperation* (NC). It was concluded that MsC significantly reduces the performance and renders optimization less effective. We also considered the impact of users deceiving other users by not cooperating despite promising to, which we called *leeching cooperation* (LC). The *exploited user* (EX) experiences a significantly reduced performance. Our previous work established that the aggregate long-term performance of all users is higher in unselfish cooperation, consequently we now consider the dynamics of the cooperative behaviour problem.

B. System Setup

In this work, we extend our investigation concerning user behaviour this time using Evolutionary Game Theoretic (EGT) analysis. In EGT, the game theory's model is updated based upon previous experience. We consider a system of M users, each user i has a set of strategies $\mathcal{A}_i$ available, compromising of the aforementioned behaviour strategies. A user's behaviour strategy is consistent within one cooperation cycle (a quasi-static fading block). We introduce a penalty factor X, which is the number of cooperation cycles that a Leecher (LC) is locked out of cooperation by the other users. When denied the opportunity to cooperate, a Leecher node has only one behaviour strategy available: no cooperation (NC).

Let us assume that user i chooses behaviour strategy a_i from the available strategy set $\mathcal{A}_i$. Given that other users observe a set of behaviour strategies, the user knows what the ideal performance outcome is. However, since strategies are decided independently, each user is uncertain what performance outcome to expect until some knowledge is acquired about the game theory trade-off. A user i acquires this knowledge by recording the performance of previous attempts at strategy a_i. We define user i's utility U_i as a function of the ideal error rate expression given in (1) for behaviour a_i, in addition to previous experience of the error rate performance based on other users' strategies:

$$U_i(a_i) = p^{\text{DF}}_{f_{\text{Fading},\mathbf{C}(T)}}(a_i) + \sum_{j=1}^{n} e^{\text{DF}}_{\text{Fading},\mathbf{C}(T)}(j, a_i, \mathcal{A}_{i'}), \quad (4)$$

where the previously measured frame error ($e^{\text{DF}}_{\text{Fading},\mathbf{C}(T)}(j, a_i, \mathcal{A}_{i'})$) is averaged over all previous n transmission frames using strategy a_i, subject to other users' strategy set $\mathcal{A}_{i'}$. Referring to the error rate expression (1) for different user behaviors, the variables B, ψ and ω are as follows:

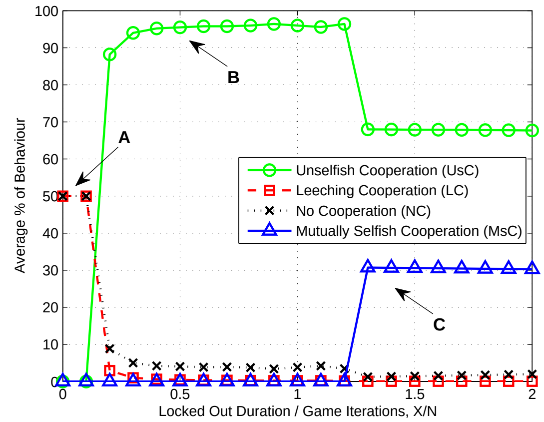

Fig. 3. Evolution Game Theory simulation results on Average Chance of a Behaviour mode against the Lock-out duration X. Uplink SNR of 10dB averaged between asymmetrical values, and Interuser SNR of 20dB averaged, for $M = 6$ users and $N = 5000$ evolution cycles. We have used a turbo code with generator polynomials $(1, 5/7, 5/7)$ in octal form, a threshold of $T = -4.4$dB, and an input frame size of 256.

- Unselfish - UsC ($B = 1$ $\omega = 1$ $\psi = M - m$)
- Mutually Selfish - MsC ($B = 2$ $\omega = 1$ $\psi = M - m$)
- No Cooperation - NC ($B = \infty$, $\psi = M$)
- Leeching User - LC (UsC, $B = 1$) or (MsC, $B = 2$) and $\omega = M$ $\psi = M$
- User Being Leeched - EX ($B = \infty$, $\psi = M - m$).

As new users enter a network with no prior performance experience, the utility function (error rate) have the following relationship for most channel conditions: $U^{EX} > U^{NC} > U^{MsC} > U^{UsC} > U^{LC}$. Therefore, from an individual user's perspective, there is a constant evaluation of whether to trust other users with Unselfish Cooperation (UsC), or exploiting other users (LC) and risk suffering the consequences of no cooperation (NC) for X cycles. The stability criterion for this dynamic trade-off is represented as the Nash Equilibrium, which occurs when a behaviour exists so that no unilateral deviation to a new behaviour ($a_i^{'}$) by any single user is profitable. This notion is formally represented by the following expression:

$$U_i(\mathbf{a}) = U_i(a_i, \mathbf{a}^{i'}) \leq U_i(a_i^{'}, \mathbf{a}^{i'}), \quad (5)$$

and this applies to all users. Since the utility function U_i is the error rate, lower values represent a better utility and corresponding behaviour.

C. Results and Analysis

We examine the effect of the normalized lock out period, X/N (cooperation cycles) has on the user behaviour dynamics in an evolutionary game theory setup. The parameter N affects the duration a user has to learn about the various evolutionary game theoretic possibilities, and we found $N = 5000$ to adequately describe the possible outcomes. Based on this, we present the simulation results shown in Fig.3 for the aforementioned user behaviour scenarios. Here we consider half of the users in the network are new and without experience of the game, and the rest have experience of the game. For a no lock out duration $\frac{X}{N} = 0\%$, the experienced users will not attempt to leech (LC), because they have experience of the fact that if all users leech, it will simply have the poor performance owing to no-cooperation (NC). Therefore, the experienced users will attempt cooperation, but this fails due to the new users leeching behaviour. The experienced users update their own learning model to account for this fact, and this results in mixture of leeching (LC) and no-cooperation (NC) behaviour (Point **A** in Fig.3). For low lock out duration ratios $\frac{X}{N} = 0.2\%$ (corresponding to 10 frames), leeching is significantly reduced. This leads to cooperative behaviour, that is dominated by Unselfish Cooperation (UsC) (Point **B**). As we further increase the lock out duration penalty, the likelihood of Leecher (LC) behaviour falls to near zero and the performance trade-off between Mutually Selfish Cooperation (MsC) and Unselfish Cooperation (UsC) becomes dominant (Point **C**). This trade-off reflects the dilemma that when an asymmetry in cooperation behaviour exists between users, the user that adopts MsC experiences the benefits of the user that adopts UsC, whilst the UsC user suffers a performance loss. Yet, if both users adopt the MsC strategy, the performance is below the scenario of all users adopting the UsC strategy. Learning from this trade-off becomes the dominant effect in the evolutionary learning experience. What we can conclude from our findings is that a stable equilibrium is difficult to establish for any behaviour strategy. In Unselfish Cooperation, the users are aware of the potential performance degradation of Leeching and Mutually Cooperating users. In No Cooperation, the users are aware of the potential performance gains of any other strategy. Hence, what we have found is that for a small lock out duration penalty $X > 4$ cycles, there can be a high chance of cooperation (95%), which is dominated by the optimal performance behaviour, i.e., Unselfish Cooperation (UsC). This is similar to the conclusion reached by other game theoretic approaches such as those by [13]. Therefore, we shall proceed to optimize the performance of unselfish users by power allocation and evaluate the solution's resilience to feedback delays and errors.

IV. Realistic Optimization

A. Partner Selection

We have so far considered cooperation without any penalties. In a realistic system, factors such as synchronization, channel-state-information (CSI) feedback delay, and user behaviour can potentially erode that capacity. Whilst modeling such penalties and their precise effects are important, the analysis can also be complex, as shown in [14]. We consider the Decode-and-Forward (DF) protocol, due to the fact that the Amplify-and-Forward (AF) protocol's performance is highly susceptible to instantaneous channel estimation errors [15]. The challenge of partner selection is more difficult due to uncertain cooperation. In our previous work [10], we used a method similar to that proposed by [6] and [7], where partnerships are selected based on minimizing the harmonic mean of the SNRs. First we define the harmonic mean of user i's channels with respect to a partner i': $S_{i-i'} = \frac{2}{\frac{1}{\overline{\gamma}_{i-i'}} + \frac{1}{\overline{\gamma}_{i'-d}}}$. We then minimize the difference between the average harmonic mean of all partnerships, thus creating partnerships of similar channel quality. This can be seen as a modified and long term version of the instantaneous relay selection criterion used in [6]. After partner selection, the partnerships of $M = 2$ users each have their own individual FER, and the system FER is the sum of all partnership FERs. Whilst we cannot prove what the optimal partnership size is for a given set of channel conditions, we have chosen $M = 2$ to demonstrate optimization through power allocation and effect of channel feedback issues. Therefore, for a specific partnership, we can use the previous FER function (3) for $M = 2$ users, and we will now look at applying a power constraint and optimizing power allocation.

B. Power Allocation

Given that we have now selected one partner for each user, we have effectively reduced a M sized network to $M/2$ pairs of 2 user cooperation. For the schemes to be fair and comparable to each other, we add a power constraint whereby the amount of power available to each user is fixed (i.e., unity per block):

$$\mathrm{P}_{\mathrm{B}_i} + \mathrm{P}_{\mathrm{C}_i} = 1, \tag{6}$$

where $\mathrm{P}_{\mathrm{B}_i}$ is the power allocation factor for step 1 and $\mathrm{P}_{\mathrm{C}_i}$ is for step 2 of a cooperation cycle. As shown in [10], we first utilize a brute force search approach, which searches along all valid FER possibilities, subject to the power constraint. This may be seen as a optimal solution for our error rate minimization approach. In order for a deterministic power optimization to produce unique solutions which provide the lowest system FER, we must ensure the objective system FER equation and the power constraint equation are both convex. To do so, we examine the second-order partial derivatives of the FER and constraint functions. When the derivatives are formed into a square matrix, it is known as the Hessian matrix. The Hessian is used to show whether the functions are semi-definite positive; or in other words: convex. In our previous work [10], we showed that it is indeed convex. Therefore, using Lagrangian multipliers (Lagrangian Λ), we found the minimum FER under the power constraint:

$$\mathrm{P}_{\mathrm{B}_i} = \frac{\left(\frac{\overline{\gamma}_{i-i'} + \overline{\gamma}_{i-d}}{\overline{\gamma}_{i-i'} + \overline{\gamma}_{i'-d}}\right)^{\frac{1}{3}}}{1 + \left(\frac{\overline{\gamma}_{i-i'} + \overline{\gamma}_{i-d}}{\overline{\gamma}_{i-i'} + \overline{\gamma}_{i'-d}}\right)^{\frac{1}{3}}}. \tag{7}$$

From (7), we can see that a symmetric system ($\overline{\gamma}_{i-d} = \overline{\gamma}_{i'-d}$) would reduce the scheme to equal power allocation.

V. CHANNEL FEEDBACK: ERRORS AND DELAYS

So far, the power allocation solutions have relied on an accurate average CSI feedback in all channels ($\overline{\gamma}$). Currently the receiver averages the perfect channel state estimates over a period of N blocks, where N is sufficiently large to yield an accurate description of the average channel state information (CSI). The CSI is then fed back to the transmit nodes via full duplex channels. We now consider how estimation errors in the average CSI can affect the performance gains achieved through adaptive power allocation. Furthermore, we consider the ideal case of instantaneous feedback, the gains that can be achieved with utilizing that, and how a delay in feedback can erode such gains.

A. Erroneous CSI

In the first part of Fig. 4, we show the 3 fading blocks, each a cooperation cycle with M transmission stages. The first stage is the broadcast stage (labeled B), and the remaining $M-1$ stages are for cooperation or retransmission. The average CSI is fed back from the receiver to each transmitting user. The average CSI is defined as the instantaneous CSI over N fading blocks, and for large values of N, the average CSI can be accurately estimated, despite the errors in the instantaneous CSI. We now introduce scenarios, where the CSI is corrupted by errors made during the estimation process that is not fully eliminated through averaging. Conventionally this estimation error is assumed to be independent complex Gaussian distributed [16]. We define the estimated channel gain $|h'|$ as:

$$|h'| = |h| + |\Delta h|, \tag{8}$$

where $|\Delta h|$ is the independent complex Gaussian error, which is zero mean and has a variance σ^2_{CSI}. We define the CSI error as a percentage, given by: $\frac{|\Delta h|}{|h|} \times 100\%$. In general, the pilot channel SNR $\overline{\gamma}_{\text{Pilot}}$ is not equal to the data channel SNR $\overline{\gamma}$, as the pilot channel is transmitted at a different power. We run simulations whereby we insert this estimation noise into our deterministic power allocation solution for a M user system. In Fig. 5, we plot the following scenarios: Equal Power Allocation (circles); and Power Allocation with the original clean average CSI (squares), 5% (crosses) and 10% (stars) noisy average CSI. The simulation results are shown using symbols and theory using lines. We can see that by introducing what is equivalent to a 5% estimation error to the average CSI estimation, the performance of power allocation is degraded, but it is still an improvement over equal power allocation. A tolerance of 10% can be accepted before the performance degrades to equal power allocation or worse.

B. Delayed CSI

We also consider the case where we feed back the instantaneous CSI of a fading block (one fading block is one cooperation cycle which contains M transmission stages). Hence, power allocation is adapted based on each fading

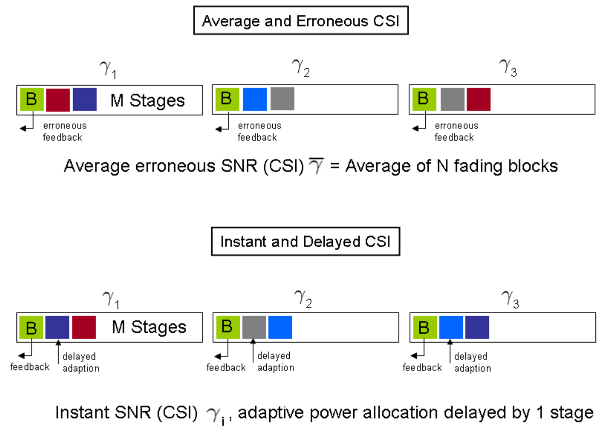

Fig. 4. Cooperation transmission cycles with Average-Erroneous and Instant-Delayed CSI feedback

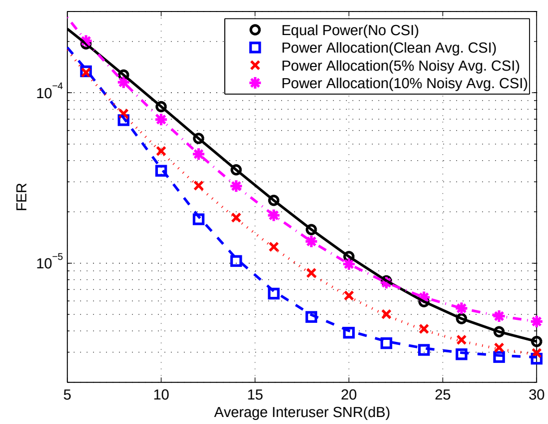

Fig. 5. DF system with Turbo Codes for 4 Users: Effect of CSI on the system FER with 25dB interuser channel and 5 and 10 per cent CSI estimation error. Symbols indicate simulation results, and lines indicate approximate theoretical expressions.

block as opposed to the average CSI of N fading blocks. In the second part of Fig. 4, we show the 3 fading blocks, each is a cooperation cycle with M transmission stages. The ideal scenario is for the destination to observe if a significant change in CSI occurs on receiving every stage of transmission, via a constant power pilot channel. Therefore, in such a scenario, the earliest form of meaningful adaptive power control takes place after a delay. Either way we assume that the first transmission stage out of M stages, cannot benefit from adaptive power allocation and will be transmitted at equal power ($\frac{1}{M}$). In order for power allocation based on instantaneous CSI to be effective, M must be high (i.e., it must be for a large number of cooperating users). The complexity of such a problem (large M) makes the deterministic approaches too complex and we run simulations on a system whereby we numerically search for optimal power allocation solutions based on perfect and delayed and non-delayed instantaneously CSI. In Fig. 6,

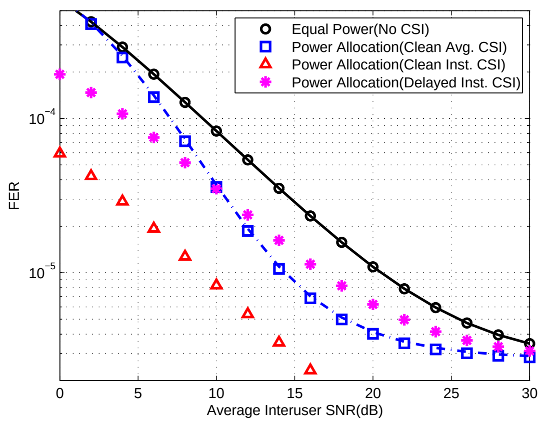

Fig. 6. DF system with Turbo Codes for 4 Users: Effect of CSI on the system FER with 25dB interuser channel and 1 transmission stage delay. Symbols indicate simulation results, and lines indicate approximate theoretical expressions.

we observe that the ideal instantaneous CSI feedback, i.e., no errors and instant feedback (triangles), can improve performance significantly compared to both equal power (circles) and power allocation based on average CSI without errors (squares). However, a delay of one transmission stage (stars) for $M = 4$ users can reduce performance to that of a power allocation solution which relies on average CSI. This is because the first transmission stage is used for channel discovery as shown in Fig. 4 and adaptive power allocation begins at the second transmission stage, by when an sub-optimal amount power has already been consumed. We can conclude that a similar observation can be made for other sized networks, but the performance will be better for networks with a high number of cooperating partners $M > 2$.

VI. Conclusion

Most existing work has succeeded in analyzing and optimizing cooperation for systems with unselfish nodes and no competing interests, often using information theoretic analysis. In our work, we utilize practical modulation and coding schemes which have been shown to yield more reliable optimization solutions in [5]. We use an evolutionary game theoretic (EGT) approach to find the dynamics of various user behaviors and how cooperation can be established. We found that given a small lock-out period (10 frames) for leeching users, cooperation can be established with high certainty (95%). Furthermore, we use partner selection and develop power allocation strategies between the selected partners and produce matching numerical and theoretical solutions. We then analyzed the effect that CSI delay and estimation errors have upon our solutions. We found how an average CSI estimation error in excess of 10% can reduce the effectiveness of our solution to that of equal power allocation, which requires no CSI. Furthermore, it was found that whilst an idealized power allocation solution that relies on instantaneous CSI can yield large performance gains, a delay of one transmission stage can reduce these gains to that of our solution that relies upon the use of average CSI. Therefore, we conclude that a realistic cooperative communication system needs to first utilize a suitable performance metric to encourage cooperation. Then, partner selection can be performed to reduce operational complexity. After which, power allocation based on the average of estimated channel gains can be used to improve performance in most SNR regimes.

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