Intercell Interference and Pilot Allocation in Noncooperative TDD Antenna System

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Abstract*—To be added*

Index Terms*—To be added*

I. Introduction

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II. System

A cellular system of non-cooperative L hexagonal cells, Each consisting of M central base antennas (BTS) and NU single antenna users that share the same bandwidth.

A. Hexagonal cells

Within each cell, terminals are placed randomly, uniformly distributed over the cell, with the exclusion of a central disk of radius hr. The cells are hexagonal with a radius (from center to vertex) of rc. At the center of the cell is a base station array comprising M omni-directional antennas, where in the subsequent analysis, M grows without limit

B. OFDM

OFDM symbol interval is s and the subcarrier spacing is , useful symbol duration is u = 1/, and the guard interval (duration of the cyclic prefix) is g = s u. Reciprocal of the guard interval, when measured in subcarrier spacing is called as frequency smoothness interval, smooth = 1/ (g)

C. Model and Assumptions

Orthogonal Frequency-Division Multiplexing (OFDM) is assumed to be used. Consequently, we consider a flat-fading channel model for each OFDM subcarrier. For a sub-carrier channel is denoted by gikl = ikl hikl between the i-th BTS and the k-th user of the l-th cell as shown in Fig.1. By hikl, we denote the small scale fading vectors hikl CN(0, I), and are assumed to be statistically independent across the users.

By ikl we denote the large-scale fading coefficients and are used according to the Friis equation (4d)2 where is the signal wavelength, d is the distance between the user and the BTS antenna and are assumed to be constant with respect to frequency and BTS antenna index.

A frequency block fading model is also assumed in which gikl is assumed to be constant across Nsmooth sub-carriers as a result of which each user need only send pilot in only one subcarrier for every Nsmooth sub-carriers. Hence we can say maximum number of users per cell can be Nu = K Nsmooth, where K is the number of available pilot sequences at each cell.

A time block fading model is assumed and hence the channel vector hikl stay constant during coherence block of T OFDM symbols. The channel vectors in different coherent blocks are assumed to be independent and large scale fading coefficients are assumed to be constant.

Further, reciprocity is assumed between downlink and uplink channels i.e. the ikl and hikl are equal for both directions

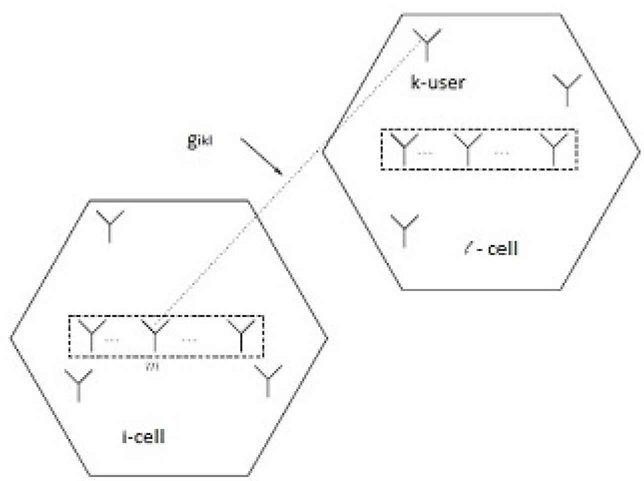

Fig. 1. Channel vector between i-th BTS and k-th user of the l-th cell

Considering a Time-Division Duplexing (TDD) Scheme, for every user, each coherence interval is organized in four phases:

- Uplink data is being sent by each user to its BTS for U symbol periods.
- Then user sends pilot sequence of length K to its BTS
- BTS then uses the pilot sequences to estimate the corresponding channel vector and then processes the data which it received in uplink phase.
- BTS then transmits downlink data to mobile units using the channel estimates as beamforming vectors for D symbol periods.
- Assuming that entire estimation process takes N OFDM symbol periods we can say that each coherence interval has the length of T = U + K + N + D.

III. Asymptotic behavior of SINR

To analyze the behavior of SINR as the number of antennas in the base station (BTS antennas) M tends to infinity and the number of users Nu remains constant which is equal to the length of the pilot sequence K.

In this scenario we are assuming a seven cell model as shown in Fig.2 with one user per cell and all are simultaneously sending pilot signals to their respective base stations.

We assume that in all cells same set of K orthogonal pilots of length K is used. The k-th user in each cell uses the same pilot sequence k = (k1, k2. kK), —kj— = 1, and as the pilots are orthogonal we have — k+ , k — = Kk,k.

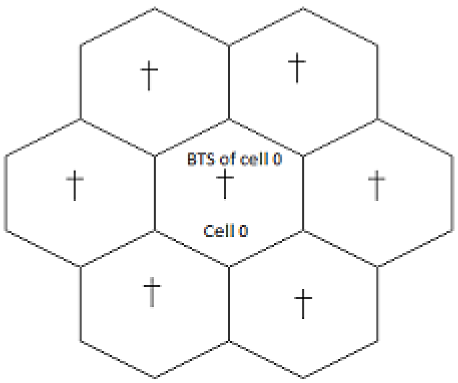

Fig. 2. 7-cell model with BTS in center and k users pe8 cell

By kl and Pkl we denote the pilot power and BTS transmit power respectively. As all pilots are transmitted, the i-th base station will receive the signal

$$y_{Bi} = \sum_{l=1}^{L}\sum_{k=1}^{K} \sqrt{\rho_{kl}\beta_{ikl}} h_{ikl}\psi_k + z_i \qquad (1)$$

where

$$z_i \in \mathcal{C}^{M \mathcal{X} K}$$

is the additive noise. All entries of z are i.i.id CN(0, 1) random variables and all gains are also scaled accordingly. The i-th base station estimates the vectors giki for users located in the same cell as: Equation (2)

$$\hat{g} = \frac{y_{Bi}\psi_{k'}^{\dagger}}{K} \qquad (2)$$

$$\hat{g} = \sqrt{\rho_{k'i}\beta_{ik'i}} h_{ik'i} + \sum_{l=1, l=i}^{L} \sqrt{\rho_{k'l}\beta_{ik'l}} h_{ik'l} + z_i' \qquad (3)$$

The BTS then forms the beamforming vector for its k-th user by normalizing the above equation and is given by:

$$w_{k'i} = \frac{\hat{g}_{ik'i}}{||\hat{g}_{ik'i}||} = \frac{\hat{g}_{ik'i}}{\alpha_{k'i}\sqrt{M}}$$

(4)

where we have $\alpha_{k'i}$ as the normalizing factor

As we can observe in equation 2, after multiplying with conjugate inverse of ψ only signals from users with same pilot sequences from different cells are getting added as other terms are cancelled out and as mentioned before $|\psi_k^{\dagger}, \psi_k| = K\delta_{k,k'}$, when k=k', all terms get added up K times as the length of pilot se-quence is K, hence that factor is normalized by dividing by K in equation 2. Hence now we have the channel estimates.

Before moving on to downlink part, a basic preliminary study for downlink simulation is being carried out in the following section to transmit the data from the base station to the user assuming that the channel is estimated using a Rayleigh channel and then also study the effects of distance of users in the cell from the base station. Fol-lowed by that we will use the above estimated channel to send the downlink data.

A generic simulator is created using C++ and IT++ library which consists of user-defined number of cells which is kept even for this particular case along with number of users per cell is set as 1. The coordinates of the users per cell as well as the base station is to be given as the input to the simulator. The purpose is to study the interference from various cells as to how can it affect the performance and what tunable factors can improve it.

Initially a randomly generated Rayleigh channel is being generated using the channel hikl (0, I). For a user in cell 0, it will face interference from other cells as well. A zero-forcing precoding is being applied and the following re-sults are obtained for the BER vs SNR curve

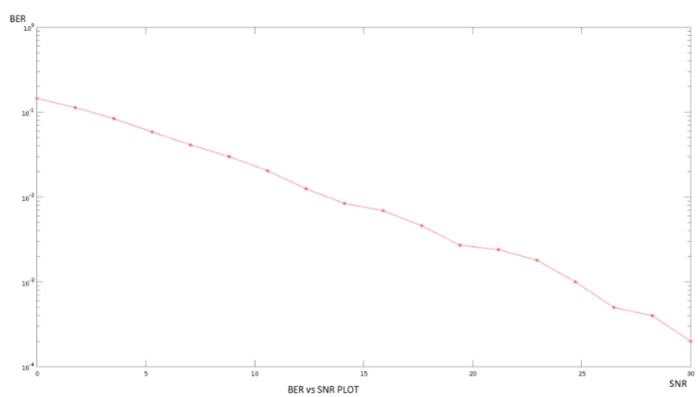

Fig. 3. BER vs SNR plot

In the above simulation the effects of distance were not taking into consideration. Hence after establishing a fair per-forming downlink Rayleigh channel for a seven cell network, the effect of distance is now being taken into consideration. By ikl we denote the large-scale fading coefficient between the i-th base station and k-th user in the l-th cell and is calculated according to the Friis equation ((4d))2 where is the signal wavelength for frequency band assumed to be 1800 Mhz, d is the distance between the corresponding user and the BTS antenna and are assumed to be constant with respect to frequency and BTS antenna index. Hence simulation is carried out to study the effect of ikl.

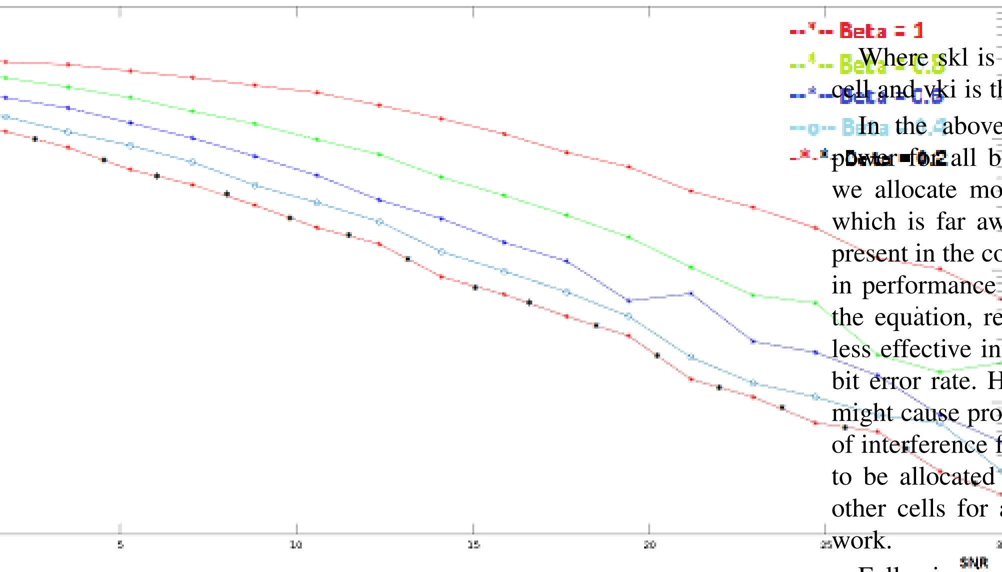

Fig. 4. BER vs SNR plot for different values of β

Hence we observe as Beta decreases we observe a de-crease in BER (Bit error rate) for range of SNR values (0 to 30dB) The observation is quite logical and as expected as we can see that the signal from other cells are multiplied by a fac-tor of beta which is inversely proportional to distance squared. As Beta is kept 0.2 it causes less interference and hence less bit error rate. As we increase the beta, the in-terference increases and if we keep a very small beta such that the signal from users in other cells can be assumed to be negligible and bit error rate will approach zero as well.

Also in terms of cellular distance results are quite intuitive as we can see when beta is large, the corresponding user is comparatively closer to the user from the cell for which we are calculating the bit error rate. As the user is close it causes more interference, assuming we have kept con-stant power for all the users. Similarly in case of very small beta, we can say that the user is very far away from the concerned user of the cell and as a result there will be less interference for that user from the far away user and hence bit error rate will be slightly better than the previ-ous one as we can observe in the plot.

Now that we have established the downlink channel, us-ing both small scale fading and large scale fading, the next task is to first estimate the channel using pilot signals as discussed earlier and then use that estimates to send the downlink signal from the BTS to the corresponding user.

A. Downlink

Once the pilot sequences are received and the channel vectors are estimated, each BTS transmit the downlink data to its respective users. The k-th user of the i-th cell receives the signal (Equation 3) :

$$y_{U_{k'i}} = \sum_{l=1}^{L}\sum_{k=1}^{K}\sqrt{P_{kl}\beta_{lk'i}}h^{\dagger}_{lk'i}w_{kl}s_{kl} + v_{k'i} \qquad (5)$$

Where skl is the signal intended to the k-th user in the l-th cell and vki is the unit variance additive white Gaussian noise. In the above equation we have assumed equal transmit power for all base station to user transmissions. However if we allocate more power to the users, lesser power to us-er which is far away in other cell and more power to the user present in the concerned cell, then we observe an improvement in performance which is quite intuitive as we can observe in the equation, reducing the power for other cells will lead to less effective interference and causing an improvement in the bit error rate. However reducing the power in other cell user might cause problem that particular user in case it is facing lot of interference from the neighboring cells. Hence power needs to be allocated after considering the location of us-ers form other cells for all the cells which is the scope of the future work.

Following is the plot for downlink signal as we acquired in Equation 3 for equal and unequal transmission power.

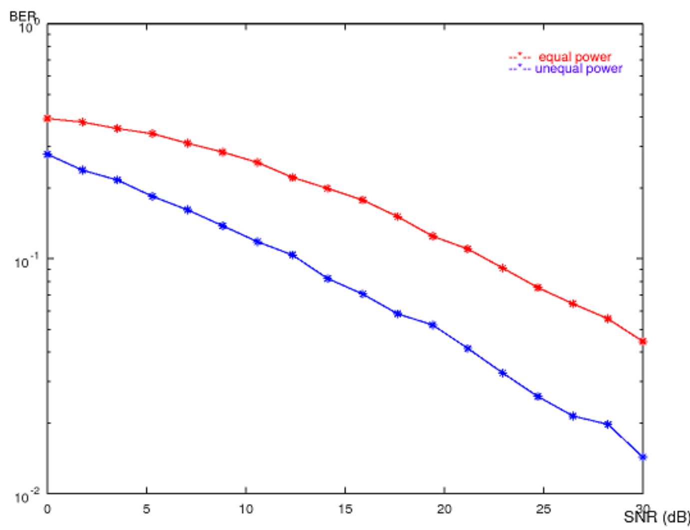

Fig. 5. BER vs SNR for downlink transmission with and equal and unequal transmit powers

As explained above, we can see in Fig.6 an improvement in BER as we allocate unequal power to different users in different cell. However as described above the effective power allocation problem is subject to further future work.

However the plot for equal power seems fairly accurate and hence now the simulator is effectively established which is capable of sending pilot signals from different users in a 7 cell network (cell numbers can be reset by the user), it estimates the channel and uses the channel estimates to send downlink signal taking into consideration the interference from other cells as well.

B. Pilot Allocation

In this section, we are considering a 2 cell network with 2 users per cell as shown in Fig.7 and the system model stays the same. As we have seen above the pilot k is same for the kth user in all cells. Hence it becomes im-portant to allocate the pilot k to the appropriate user in every cell such that the net interference is effectively minimized. So the major task is to select the user based on their coordinates to be allocated the same pilot se-quence k. In this simulation, users are located randomly inside the hexagonal cell and pilots are allocated to different users to observe changes.

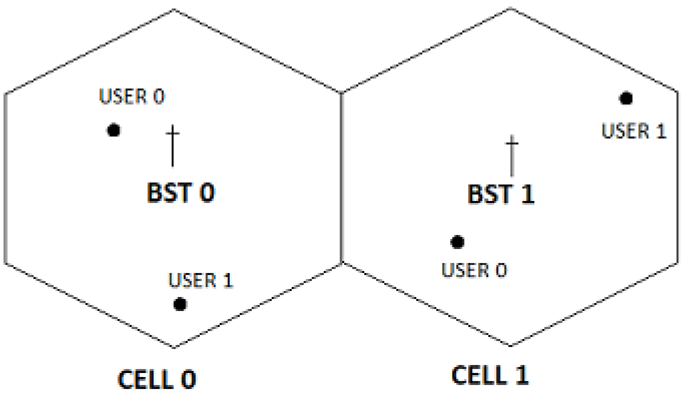

Fig. 6. Cell network with two users in each cell

Let d be the distance of user 0 in cell 0 from user 0 in cell 1. We have allocated same pilot sequences for both these users and the BTS0 is transmitting downlink data to user 0 in its cell. Hence here i = 0, k = 0 from equation 3.

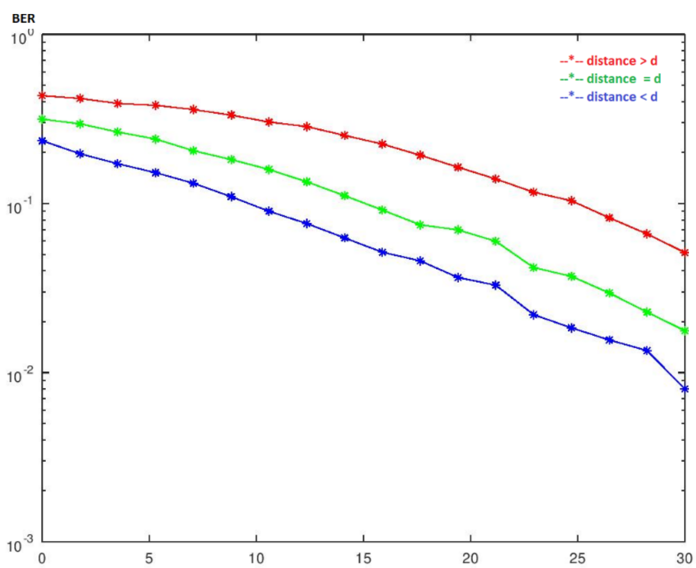

Fig. 7. BER vs SNR for a two cell network

Hence we observe that if the user from other cell which has been allocated the same pilot sequence gets nearer to the concerned cell, BER increases and performance is bad for both the cells. Hence the algorithm is to calculate the distances of all the users in other cells from the concerned the base station and the distance from all users inside the concerned cell from its base station. The user which is nearest to the base station in the concerned cell should be clubbed with the user which is nearest to the base station from other cell. It will decrease performance for that particular user, but all other users will get a fairly good performance in terms of BER which otherwise would have been good only for one user and bad for the remaining users.

Further extending the algorithm towards three users in two cells, we tried to calculate BER vs SNR for all six possible pairs to evaluate which pairing set gave the best results

**six plots to be added.

C. Downlink SINR and Achieveable Rate

The downlink SINR of the k-th user in the i-th cell is

$$\zeta_{ik'}^{D} = \frac{P_{k'i}\beta_{ik'i}^2/\alpha_{k'i}^2}{\sum_{l=1,l\neq i}^{L} P_{k'l}\beta_{lk'i}^2/\alpha_{k'l}^2} \tag{6}$$

with $\alpha_{k'l} = \sum_{j=1}^{L} \rho_{k'j}\beta_{lk'j} + 1/K$.

Note that additive noise impacts only the normalization constants $\alpha_{k'l}$. Therefore base station transmit powers P_{kl} are scalable. This allows for the use of lower power levels, resulting in a more power-efficient system.

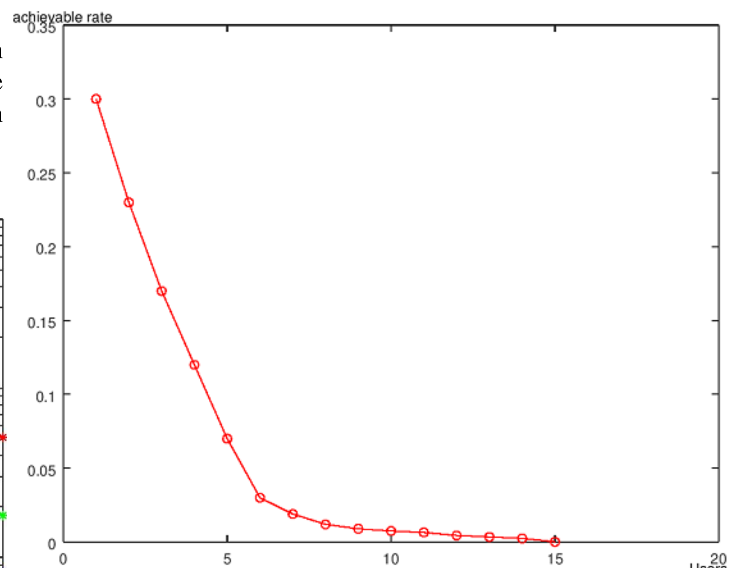

Fig. 8. Achievable rate vs number of users

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IV. Conclusion and Future Part of Project

Thus we have seen a cellular system which employs base stations equipped with large numbers of antennas for commu-nication with users in their cells. We have seen how the slow scale fading and large scale fading affects the BER as seen in BER vs SNR simulations. We have also derive expressions

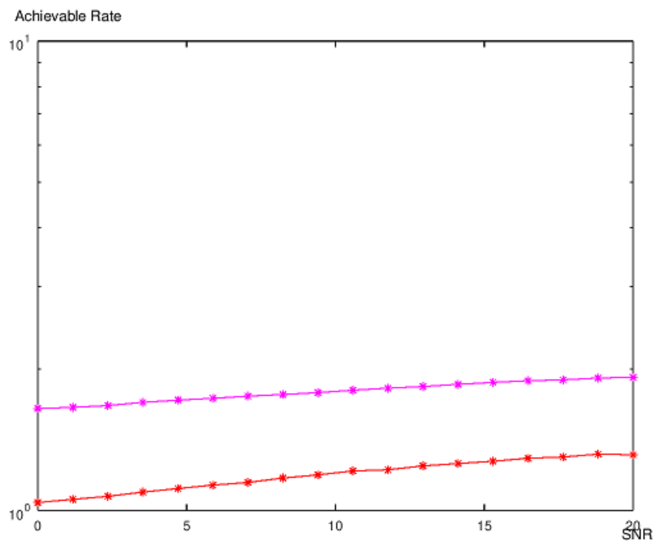

Fig. 9. Best vs worst achievable rate

for the asymptotic behavior of the SINR in the downlink of a cellular network as the number of base station antennas tends to infinity. We show that the fundamental limitation of such networks is the inter-ference present in the channel estimates computed by the base stations, due to the overlapping of non-orthogonal pilot sequences from neighboring cells. We analyze the case based on timing of pilot sequences, when all users transmit pilots to their base stations simul-taneously and performed simulations for a seven cell network to observe the BER vs SNR pattern. We then also analyzed the effect of unequal power allocation. Also we have established that the appropriate grouping of users from different cells to be allocated the same pilot se-quence plays a major role in reducing the interference and the change is a function of distance as we inferred it from the simulations carried out for a two cell network. Then, when the transmission of pilots is shifted in time from one cell to the next, avoiding overlap, it might be possible to completely cancel interference from adjacent cells, as long as the pilots do not overlap in time which is subject to further simulations and verification

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