An Efficient Resource Allocation Strategy in MIMO OFDMA Communication Networks

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ABSTRACT

Multi antenna orthogonal frequency division multiple access (MU-OFDMA) is one of the most promising technique for high downlink capacity in the next generation wireless systems like 3G,4G,LTE..etc . In multi cell networks , Resource allocation is distributed within each base station so in such a scenario Margin adaptive (MA) problem plays an important role , the objective of the MA problem in MIMO networks is to minimize the total transmit power with a constraint on users data rates, here we consider two cases full CSIT, and statistical CSIT. In both cases, a distributed convergence criterion for power control is determined , In the latter case power control is determined using an approximate analytical expression for outage capacity as a function of SNR and outage probability. The proposed methods avoid power divergence situations at any load and these are more efficient than the frequently used iterative water-filling technique in MIMO to solve the MA problem .

Keywords – Adaptive resource allocation, Margin adaptive problem , MIMO , OFDMA , Water-filling .

I . INTRODUCTION

As the demand for high data rate steadily increases, efficient spectrum utilization had become an critical issue in wireless communications . Orthogonal Frequency Division Multiplexing (OFDM) is regarded as one of the key promising techniques for future broadband wireless networks due to their ability to provide very high data rates in the multi-path fading environment . OFDM system divides the available broadband channel into many narrowband subchannels and in OFDM systems, only a single user can transmit on all of the subcarriers at any given time, whereas Orthogonal Frequency Division Multiple Access (OFDMA) is a multiuser version of the popular OFDM scheme which is also referred to as multiuser OFDM . Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple access technique that allows multiple users to transmit simultaneously on the different subcarriers per OFDM symbol. In this technique a subset of all subcarriers are assigned to each user by the resource allocation algorithms for efficient spectrum utilization . Multiuser diversity is achieved by adaptively adjusting subcarrier, bit and power allocation depending on channel status among users at different locations.

This paper mainly addresses Margin Adaptive (MA) resource allocation in Multiple-Input Multiple-Output (MIMO) Orthogonal Frequency Division Multiple Access (OFDMA) multi-cell networks . In a wireless network, challenges arise as the number of the users in the system increases. These challenges include dynamic subcarrier allocation, adaptive power allocation, admission control and capacity planning referred to as radio resource allocation and is the subject of this article. In MIMO, resource allocation depends on whether Channel State Information (CSI) is available at the transmitter (CSIT). We consider both the full CSIT, and the statistical CSIT cases for power control . In the latter case , an approximate analytical expression of the outage capacity is then required in order to solve the MA problem .

The paper is organized as follows section II describes MA problem for multi-cell OFDMA then the proposed resource allocation problem for full CSIT in section III and statistical CSIT in section IV then section V with performance results and finally concluded through section VI .

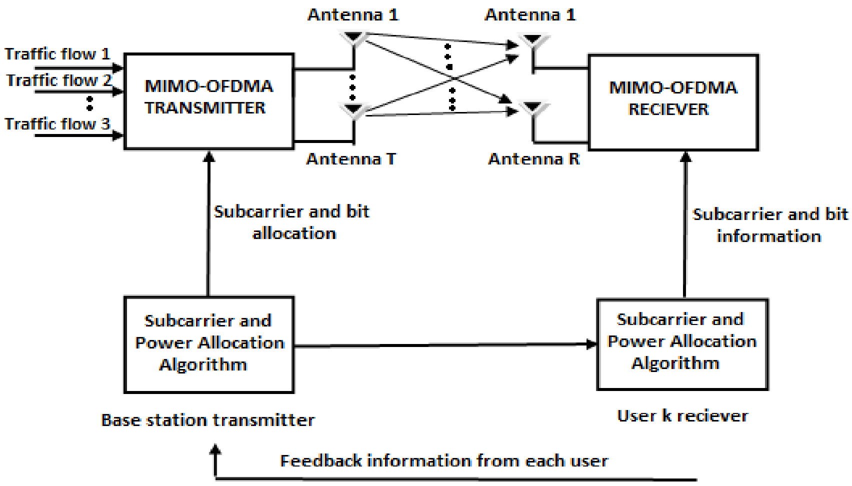

Fig 1 : Block diagram of multi user MIMO – OFDMA system

II.MARGIN ADAPTIVE PROBLEM

The Margin Adaptive resource allocation problem in multi-cell OFDMA consists in determining the subcarrier and power allocations required to achieve the target data rates for all the users of the network, while minimizing the sum power .

Let us consider a network $\mathcal{N}$comprised of N Base Stations (BSs) and base station with n_t transmit antennas , and $K_{\mathcal{N}}$ users with n_r receive antennas . So the minimum of number of transmit and receive antennas given by

$$n_{min} = min(n_t,n_r)$$

Each BS transmits over L_{SC} orthogonal subcarriers. Let b_k be the index of the serving BS of user k , and Θ_k represents the subcarrier set that has been allocated to user k by the base station b_k .Let $R_{k,\text{target}}$ is target data rate that has to be allocated for user k, and $R^l{}_k$ is the data rate of user k in subcarrier l . $P^l{}_{bk}$ is the power transmitted by BS b_k in subcarrier l. The MA optimization problem is given as

$$min_{\{P,\Theta\}} \sum_{k=1}^{K_{\mathcal{N}}} \sum_{l\in\Theta_k} P^l_{b_k}$$

The above equation is combination of several levels and it is decomposed into a set of sub-problems , firstly Subcarrier allocationand power control are performed.

In distributed networks, the original problem is also separated per each BS of the network . The MA problem is then solved iteratively in each level for each BS, with fixed inter-cell interference levels, that have been computed in the previous iteration. Finally, the per cell sum power constraint is not directly considered within power allocation, but an admission control step is added afterward to take it into account. Thus, power allocation can be decomposed over the users of the same cell.

Iterative water-filling is commonly used to solve the MA problem in a distributed way. However, power control with iterative water-filling may diverge at high load because of inter-cell interference .

Before power control Subcarrier allocation is carried out independently in each BS. Here the BS assumes equal power allocation and equal interference level on all streams and subcarriers, and uses an approximate target data rate ,,target..In our method we select subcarriers so as to maximize the power control convergence probability , by maximizing $E^l{}_k$ defined as

$$\gamma_k < \frac{g_{b_k,k}}{\sum_{\{n=1,n\neq k\}}^{N} g_{b_n,k}} \quad \forall k \in \{1,2,\dots,N\}$$

Where E_k is the upper bound on γ_k of the above equation . Initially each user is assigned the subcarrier that maximizes $E^l{}_k$

Which is followed in iterative steps until all the all users have reached approximate target data rate ,,target or when there are no subcarriers left . After each iteration, the user with current lowest approximate data rate, k^*, is identified , and it is assigned with a free subcarrier that maximizes $E^l{}_k$. Whenever a new subcarrier is allocated to a user, its approximate data rate is updated . Power control is our main concern . Thus , subcarrier allocation should have the least impact on the performances therefore to achieve this is to set the approximate target data rate $R_{k,\text{target}}$ to a higher value than the real $R_{k,\text{target}}$, so that all available subcarriers are eventually allocated in all cells. Then power control will be responsible for setting the power to zero in some subcarriers, either because they are not needed to reach the data rate objective, or because they receive too much interference.

So for power control a simple admission control process is used such that if the sum power exceeds the maximum P_{max} on a BS, the users served by this BS are ordered by descending sum transmit power value. Then the users with highest sum power are rejected, until the sum power becomes less than P_{max} .

III . FULL CSIT

This section deals with MA resource allocation for user . Subcarrier allocation has been performed prior to power allocation which has assigned l_{SC}, subcarriers to user k in sub carrier set ie., Θk. The MIMO channel in each subcarrier is used in order to increase the transmission rate.The data rate per subcarrier is given as

$$R_k^l = B_{sc} \sum_{j=1}^{n_{min}} log_2 \left(1 + \rho_k d_{k,j}^l \left((\lambda_{k,j}^l)^2\right)\right)$$

where $d^l{}_{k,j}$ is the normalized power per subcarrier l and per stream j, whereas SNR of user k corresponding to its sum power is given as

$$\rho_k = \frac{g_{b_k,k} \sum_{l \in \Theta_k} P_{b_k}^l}{N_0}$$

and $\{\lambda_{k,1}^l, \ldots\ldots, \lambda_{k,n_{min}}^l\}$ are singular values of the equivalent channel matrix . The power allocation problem at each of the iteration is given as $\sum_{l \epsilon \theta_k} p_{bk}^l$ such that

$$\sum_{l \epsilon \theta_k} R_k^l \geq R_{k,target}$$

As the data rate is an increasing function of the power, the minimum sum power is obtained when $\sum_{l \epsilon \theta_k} R_k^l \geq R_{k,target}$.

For power control we first determine the convergence criterion for power control on subcarrier l. The target data rate of user k in subcarrier l is $R^l{}_{k,target}$ then in order to obtain a distributed power control convergence criterion, the data rate objective in $P^l{}_{bk} \geq 0$ for all subcarriers set Θ_k for all users k ∈ Ωl, where Ωl represents the set of interfering users in subcarrier. Second we take pathloss and shadowing gains of interfering links . Then the data rate of user k is

$$R_k^l = B_{sc} * \sum_{j=1}^{n_{min}} log_2 \left(1 + \frac{g_{b_k,k} P^l{}_{b_k}/n_t}{N_0 + \sum_{\{n \in \Omega l, n \neq k\}}^{N} g_{b_n,k} P^l{}_{b_k}/n_t}\right)$$

$$T_k^l = \frac{n_t}{(\beta_{k,n_{min}}^l)^2} \left(\frac{I_k^l}{g_{b_k,k} P_{max}} - \frac{N_0}{g_{b_k,k} P_{max}}\right)$$

$$I_k^l = N_0 + \sum_{\{n \in \Omega l, n \neq k\}}^{N} g_{b_n,k} P^l{}_{b_k}/n_t ;$$

$$i.e., (Noise + SNR)$$

Here T_k^l provides an estimate for inter cell interference and I_k represents inter-cell interference .The transmitter assumes that inter-cell interference can be neglected if T_k^l is low i.e, if $E^l{}_k \, T_k^l < \delta$, where δ is a parameter which is set according to network conditions .The power convergence criterion for maximum data rate is given as

$$R_k^l \leq R_{k,max}^l - \varepsilon \; if \;\; E_k^l \, T_k^l \geq \delta \; \forall l \in \Theta_k$$
$$R_{k,max}^l = B_{sc} n_{min} \, log_2 (1+E_k^l)$$

When the above condition is satisfied on subcarrier l , the solution is

$$\rho_k d_{k,j}^l = \left[\eta - \frac{1}{(\lambda_{k,j}^l)^2}\right] \forall j \in \{1, .., n_{min}\}$$

Else, the solution is

$$\rho_k d_{k,j}^l = \left[\eta_l - \frac{1}{(\lambda_{k,j}^l)^2}\right] \forall j \in \{1, .., n_{min}\}$$

In the first case, η is a constant that applies to all subcarriers, and that is determined so as to fulfill the target data rate constraint. In the second case, η_l is a constant which is specific to subcarrier l, that is determined in order to fulfill the target data rate constraint on subcarrier l , $R_k^l \leq R_{k,max}^l - \varepsilon$ where ϵ is a small positive value and ρ_k denotes SNR for user k $d_{k,j}^l$ represents normalized power per subcarrier l and per stream j .

IV . STATISTICAL CSIT

Statistical CSI (or long-term CSI) means that a statistical characterization of the channel is known. This include the type of fading distribution, the average channel gain, the line-of-sight component, and the spatial correlation. As with instantaneous CSI, this information can be used for transmission optimization.

The CSI acquisition is practically limited by how fast the channel conditions are changing. In fast fading systems where channel conditions vary rapidly under the transmission of a single information symbol, only statistical CSI is reasonable. On the other hand, in slow fading systems instantaneous CSI can be estimated with reasonable accuracy and used for transmission adaptation for some time before being outdated. In practical systems, the available CSI often lies in between these two levels; instantaneous CSI with some estimation/quantization error is combined with statistical information.

In Statistical CSIT an approximate expression is obtained for outage capacity as a function of outage probability and SNR .For a MIMO system y=Hx+n.For with channel statistics known resource allocation can be carried out from the outage capacity expression

Siva Rama Krishna Kosuri , V.G.N.S.Prasad, Habibullah Khan / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 3, May-Jun 2012, pp.1254-1259

$$C = \frac{1}{2} n_{min} \log_2\left(1 + \frac{f(P_{out})}{n_{min}\, n_t}\rho\right) + \log_2\left(1 + \frac{f(P_{out})}{n_t}\rho\right)$$

Where P_{out} is the outage probability of the channel and ρ is SNR for the particular subcarrier. The data rate per subcarrier that has to be allocatedis given as

$$R_k^l = \frac{B_{sc}}{2} n_{min} \log_2\left(1 + \frac{x_k^l}{n_{min}} P_{bk}^l\right) + \log_2\left(1 + x_k^l P_{bk}^l\right)$$

$$where.,\quad x_k^l = \frac{f(P_{out})}{n_t} \frac{g_{b_{k},k}}{I_k^l}$$

Similar to the case of full CSIT , inter-cell interference estimate and power control are given respectively as

$$T_k^l = \frac{n_t}{(\beta_{k,n_{min}}^l)^2}\left(\frac{I_k^l}{g_{b_{k},k} P_{max}} - \frac{N_0}{g_{b_{k},k} P_{max}}\right)$$

$$where., I_k^l = N_0 + \sum_{\{n \in \Omega l, n \neq k\}}^{N} g_{b_{n},k}\, P^l{}_{b_k} / n_t\,;$$

$$i.e., (Noise + SNR)$$

The power control is done according to the below condition for the first equation outage capacity of statistical CSIT case

$$R_k^l \leq R_{k,max}^l - \varepsilon \; if \;\; E_k^l\, T_k^l \geq \delta \;\forall l \in \Theta_k$$

$$R_{k,max}^l = B_{sc} n_{min} \log_2(1 + E_k^l)$$

The target data rate is achieved untill outage capacity is reached by varying P_{bk}^l .

V . PERFORMANCE RESULTS

5.1 MIMO OFDMA with full CSIT

Here we had considered two scenarios where all the users have the same data rate, R_{target}=256 or 384 Kbits/s .

The following statistics are gathered for performance evaluation: the percentage of rejected users (with respect to all users served by the central cell), and the percentage of active subcarriers (with respect to L_{SC}). A user is rejected if it cannot reach its target data rate R_{target} in specified time interval . A subcarrier is active if it is allocated to a user and if the transmit power on this subcarrier is not zero.

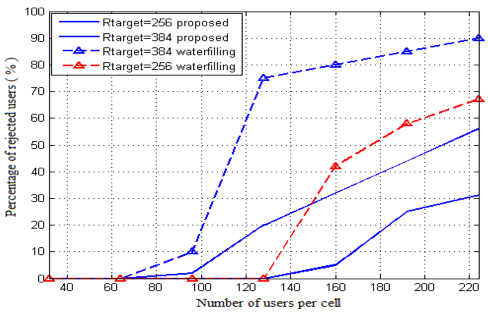

Fig. 2. Full CSIT, percentage of rejected users depending on the load.

From the above Fig 2 in both cases of target data rates of 256 kbps and 384 kbps iterative water-filling leads to an abrupt increase of the percentage of rejected users, whereas our proposed method avoids this behavior .

The percentage of active subcarriers also decreases very rapidly with iterative water-filling when power divergence occurs (Fig. 3 and Fig. 4). At low load (less than ~65 users per cell), some subcarriers are inactive because all allocated subcarriers are not necessary to achieve the target data rate, because of power control.

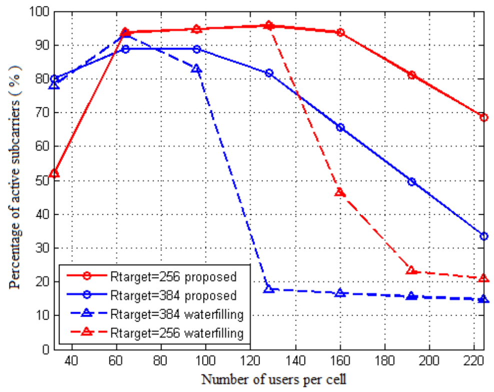

Fig. 3. Full CSIT, percentage of active subcarriers depending on the load.

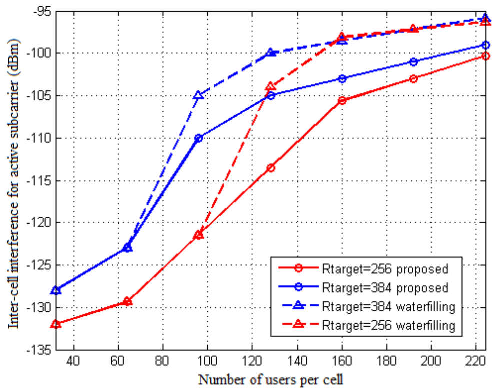

Fig. 4. Full CSIT, inter-cell interference per active subcarriers, depending on the load.

At medium load and high load compared with iterative water-filling in our proposed method, the percentage of active subcarriers decreases because of admission control, that rejects many users when their required power is too high but more efficient than the water-filling case.

Although full CSIT MIMO is approximate we cannot surely say there will not be any any power divergence situation with this criterion. However, the numerical results show that our proposed method is quite efficient compared to iterative water-filling from the graphical results obtained .

5.2 MIMO OFDMA with Statistical CSIT

In statistical CSIT network parameters and assumptions are the same as in the full CSIT case, except that *R*target = 128 kbps , here we study the influence of parameter δ on the results, when *P*out = 10^{-2} (Fig. 5). When $\delta = 10^{-3}$, criterion *E* is triggered even when inter-cell interference is insignificant, resulting in useless users rejections at low to medium load. On the contrary, when $\delta = 10^{-1}$, criterion *E* is not triggered soon enough when inter-cell interference increases, and does not prevent all power divergence situations at high load. δ should consequently result from a trade-off between these two phenomena, allowing us to trigger criterion *E* only when the channel becomes interference-limited. In the current parameters setting , this is achieved when $\delta = 10^{-2}$.

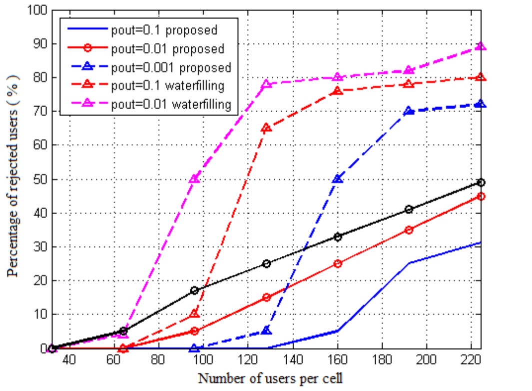

Fig. 5. Statistical CSIT, influence of δ and comparison with orthogonal allocation , pout =10^{-2}

The rejection rate obtained with users orthogonalization is also represented on Fig. 5 . Contrary to the full CSIT case, orthogonalization rejects less users than iterative waterfilling. The results obtained with $\delta = 10^{-2}$ for several values of *P*out are represented on Fig. 5 . Our proposed method is more efficient in terms of rejection rate than iterative water-filling, whatever the outage probability value. The maximum decrease in rejection rate compared to iterative water-filling is between 33 and 35% in the three cases.

The bandwidth loss has lower impact on the performances in the statistical CSIT case, because only 50% of the subcarriers are required to reach the target data rate of all users , when all subcarrier are available as shown in (Fig. 6) . The average inter-cell interference per active subcarrier is of the same order with users orthogonalization as with our proposed method, which explains why our proposed method performs better.

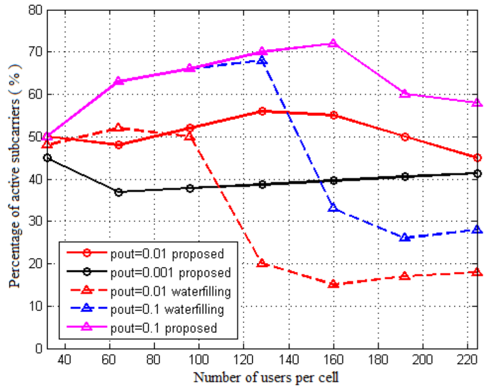

Fig. 6. Statistical CSIT, percentage of active subcarriers, depending on the load and on *P*out.

The proposed method avoids power divergence situations (see Fig. 7) which lead to many users being rejected by admission control. The rejection rate and the percentage of active subcarriers (Fig.6) are not steplike functions as in the full CSIT case, emphasizing that we are dealing with outage data rates on the statistical channel.

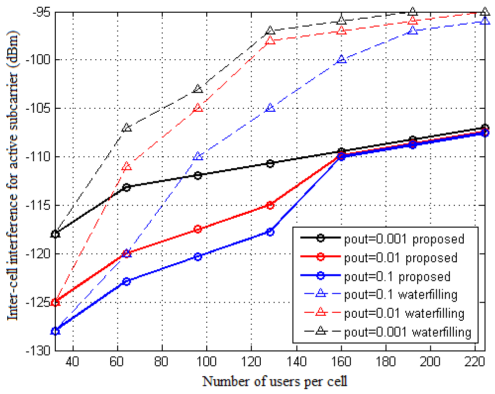

Fig. 7. Statistical CSIT, inter-cell interference per active subcarrier, depending on the load and *P*out.

VI . CONCLUSION

In this paper we have proposed a new method to solve the subcarrier allocation and power allocation problem for multi-user MIMO-OFDMA Convergence criterion has been derived for both full CSIT and statistical CSIT cases and an approximate analytical expression for outage capacity as a function of the SNR and of the outage probability has been obtained. In both cases, the proposed method avoids power divergence situations, compared to iterative water-filling, and leads to more users reaching their target data rate and hence there would be an efficient utilization of the network resources .

ACKNOWLEDGEMENTS

The authors like to express their thanks to the department of ECE and management of K L University for their continuous support and encouragement during this work.

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