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MULTIUSER SCHEDULING ALGORITHMS FOR MAXIMIZING THE THROUGHPUT ON THE DOWNLINK OF A MULTIUSER LTE

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Abstract
In this paper Scheduling user transmission on the downlink of a LTE cellular communication system is addressed. Here we see that Maximum rate algorithm is the one that does not consider fairness among users. Multiuser scheduler with proportional fairness (PF) provides a superior fairness performance with a modest loss in throughput, as long as the user average SINRs are fairly uniform. Suboptimal PF scheduler has much lower complexity but then throughput degradation.

Introduction
We have 2 scheduling algorithms [3]:
1. Maximum-rate scheduler: it is simpler to implement.
2. Proportional- rate scheduler: improve fairness among users.

In this paper we basically examine some scheduling schemes, ideally focusing on how the physical resource blocks are assigned.

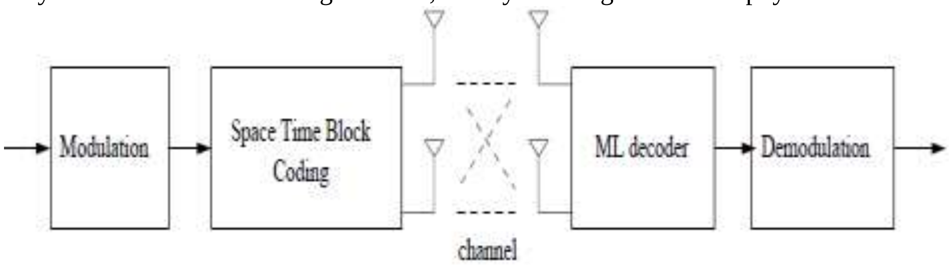

Fig. 1 MIMO system

Section II deals with the System model, Section III deals with various scheduling algorithms, Section IV deals with the numerical results and discussions and Section V deals with the conclusion part respectively.

System model
The modulation scheme used is basically OFDM [1]. In order to reduce signalling overhead, subcarriers are grouped into resource blocks RBs. The scheduler allocates resources to users in quanta of 2 consecutive RB, where 2 consecutive RB is equal to 1 scheduling block (SB)and Each RB is equal to 12 adjacent subcarriers with an inter subcarrier spacing of 15 kHz, the SB has a duration of 1 ms. It consists of Nsb is equal to 12 to 14 OFDM symbols where L=total number of subcarriers.

Ld (v) $\leq$ L= number of data-carrying subcarriers for symbol v, where v= 1. 2, …., Nsb.

$$r_j = \frac{R_j^{(c)} \log_2(M_j)}{T_s N_{sb}} \sum_{v=1}^{N_{sb}} L_d\,(v)$$

Where, $R_j^{(c)}$ = code rate associated with MCS, M_j= constellation size of the MCS,T_s= OFDM symbol duration, r_j = bit rate that corresponds to a single SB, U= no of simultaneous users, Ntot= total no of SB that are available during each TTI, ⍰i is a subset of Ntot SBs whose channel quality index (CQI) values are to be reported back by user i, Ni denotes the size of ⍰i and determines the feedback overhead ie. Ni highest SB, CQI values are feedback. $q_{i,max}$ $(x_{i,n})$is the index of highest-rate MCS that can be supported by user i for the n-th SB at CQI value $x_{i,n}$.

Assumptions: MCS rate $R_j^{(c)} \log_2(M_j)$ increases monotonically with j and the rate of MCS 1 =0. SB whose CQI values are not reported back are assigned MCS=1

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The Constraint in LTE downlink scheduling: all SBs allocated to a given user in any given scheduling period need to use same MCS. If MCS j is to be used for user i, then only certain SBs are assigned to user. Eg: if Ni=4

$$1 \leq q_{i.max}(x_{i,2}) < q_{i.max}(x_{i,1}) < q_{i.max}(x_{i,3}) < q_{i.max}(x_{i,5}) \leq J$$

Then if MCS j=$q_{i.max}(x_{i,3})$ is used, only SBn=3 and 5 can be allocated to user i since only these SBs have good enough channel qualities to support an MCS index of $q_{i.max}(x_{i,3})$ or higher. Selecting SB n=1 or 2 with MCS j=$q_{i.max}(x_{i,3})$ will result in unacceptably high error rates for these SB. Whereas, j= $q_{i.max}(x_{i,2})$ here all 4 SB can be selected at the cost of a lower bit rate for SB 1, 3, and 5. Thus, there is an optimal value of j which maximizes the total bit rate for user i.

Scheduling algorithms

1. Single user optimization
2. Multiuser sequential suboptimal scheduling
3. Joint optimization

Single user optimization

Main aim is to determine MCS rate index j* and set of SBs to be allocated to user i so as to maximize the assigned bit rate Ri in the given set of channel qualities.

Here, b_i= MCS vector for user i

$$b_{i,j} = \begin{cases} 0, \textit{if user i is not assigned MCS j} \\ 1, \textit{if user i is assigned MCS j} \end{cases}$$

Optimal b_i, that maximizes the total bit rate for user i , is obtained by solving Problem (P1).

Where,

$$P1 = \max_{b_i} \sum_{n \epsilon N_i} \sum_{j=1}^{q_{i,max}(x_{i,n})} b_{i,j}\, r_j$$

The above equation allows the selected bit rate for SB n to be less than what $x_{i,n}$ can potentially support, as may be the case if user i is assigned more than one SB during a TTI.

Here, $c_j^i = \sum_{n=1}^{N_i} r_{n,j}^i$

And MCS rate index $j^* = \arg \max_{1 \leq j \leq Q_{max}(i)} c_j^i$

Multiuser sequential suboptimal scheduling

It consists of 2 stages:

STAGE 1: The scheduler determines the set of maximum rate indices, one for each SB for user i at time t. Users are then ranked according to their priority index values

Index values φ_i,i=1,2,….,U

Where U= number of users

$$\varphi_i = \begin{cases} g\left(Q_{i,max}^t(N_i)\right)/R_i * (t) \quad \textit{PF Scheduling} \\ g\left(Q_{i,max}^t(N_i)\right) \quad \textit{Max} - \textit{Rate Scheduling} \end{cases}$$

Where

Average bit rate upto time t-1, $R_i * (t) = (1 - \alpha) R_i * (t-1) + \alpha R_i(t-1)$ where $R_i(t)$= bit rate assigned to user i at time t. The term g(.) is a function which returns the highest bit rate that user i can support based on $Q_{i,max}^t(N_i)$.

STAGE 2: ϴ(j)= function which maps the ordered user index j back to original user index i. In this stage basically, allocation of resources is done in a sequential fashion, one user at a time according to the following user order ϴ(1), ϴ(2),….

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Thus, starting with user Θ(1) and initial set of SBs corresponding to - complete set of available SBs, MCS index and set of SBs are determined in same way as that of single user optimization. The remaining SBs, are then made available to user Θ(2). The resource allocation process continues until all SBs have been assigned.

Joint optimization

In this algorithm we consider the joint optimization of allocation of BSs and MCSs among all users. It can be formulated as P2 = $\max_{A,B} \sum_{i=1}^{U} \sum_{n\epsilon N_i} a_{i,n} \sum_{j=1}^{q_{i,max}(x_{i,n}(t))} b_{i,j} \left(\frac{r_j}{\varphi_i(t)}\right)$

A= { $a_{i,n}$,i = 1,…., U}

B= { $b_{i,j}$, i= 1,…., U}

Problem with P2 is nonlinear due to the product $a_{i,n}\, b_{i,j}$

The term $\varphi_i(t)$ is given as:

$$\varphi_i(t) = \begin{cases} R_i(t) * & PF\ Scheduling \\ 1 & Max-Rate\ Scheduling \end{cases}$$

$a_{i,n}$ = binary decision variable with value

1= if SB n is assigned to user i

0= if SB n is not assigned to user i

Solution to the above problem P2 is obtained using optimization techniques such as *Branch-and-Bound.*

To overcome this difficulty P2 is transformed into an equivalent linear problem P2′ by introducing an auxiliary variable $t_{n,i,j}$= $a_{i,n}\, b_{i,j}$**as**

$$\max_{A,B,T} \sum_{i=1}^{U} \sum_{n\epsilon N_i} \sum_{j=1}^{q_{i,max}(x_{i,n}(t))} t_{n,i,j} \left(\frac{r_j}{\varphi_i(t)}\right)$$

Problem P2′ is then solved using standard integer linear programming techniques.

Numerical results & discussions

1. We assumeNtot =12 SBs per TTI
2. L=12 subcarriers per SB
3. fading amplitude for each subcarrier of any user follows Nagakami-m model with a fading figure m=1.
4. SINRs for all subcarriers of any user are correlated and identically distributed and RB follow localized configuration. The SINR of given subcarrier is assumed to be independent (for the purpose of comparing long-term fairness of Max-Rate and PF schedulers) and constant at every scheduling period.
5. Modulation and coding scheme consists of QPSK ½, QPSK ¾ , 16- QAM ½, 16- QAM ¾, 64- QAM ¾.
6. L1/L2 control channels are mapped to first OFDM symbol within each subframe where each subframe has 8 reference symbols.
7. Feedback method used= Exponential Effective SINR Mapping (EESM)

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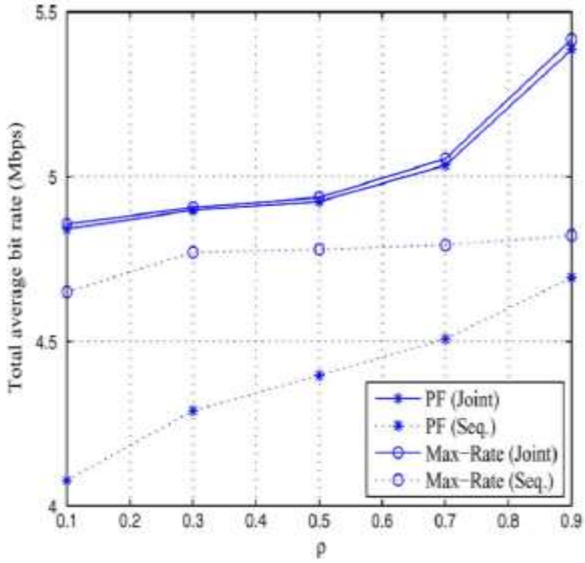

Fig. 2 Avg total bit rate as a function of ρ for three users with avg SINR of 14, 15, 16 dB

Above figure demonstrates that bit rates for all schedulers increase with ρ, reason being that: The motivation behind EESM is to map a set of subcarrier SINRs, to a single effective SINR (Γ*) in such a way that the block error probability (BLEP) can be well approximated by that at Γ* in additive white Gaussian noise (AWGN). The value of Γ* tends to be skewed towards the weaker subcarriers in order to maintain an acceptable BLEP. At a low value of ρ, subcarriers with large SINRs are not effectively utilized, leading to a relatively poor performance. It can also be seen that the bit rate for the jointly optimal PF scheduler is almost as good as that for the jointly optimal Max-Rate scheduler. In comparison, the bit rates for the sequential Max-Rate and PF schedulers are about 5% and 10% lower.

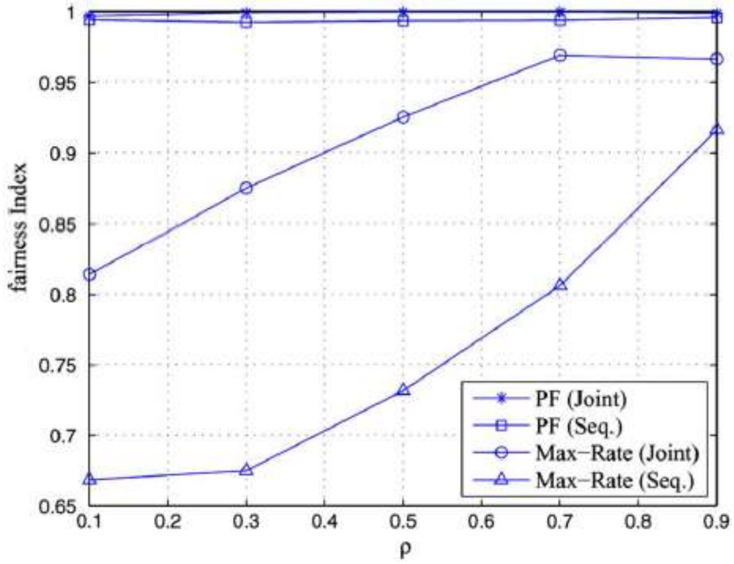

Fig. 3 Fairness index as a function of ρ for three users with avg SINR of 14, 15, 16 dB

On x-axis we have ρ and y axis corresponds to fairness index in the above figure. We infer that fairness index ή is significantly higher for PF (joint) and PF(seq) [7] than for Max-rate(joint) and Max-rate (seq), showing that the PF schedulers are quite effective in promoting fairness among users.

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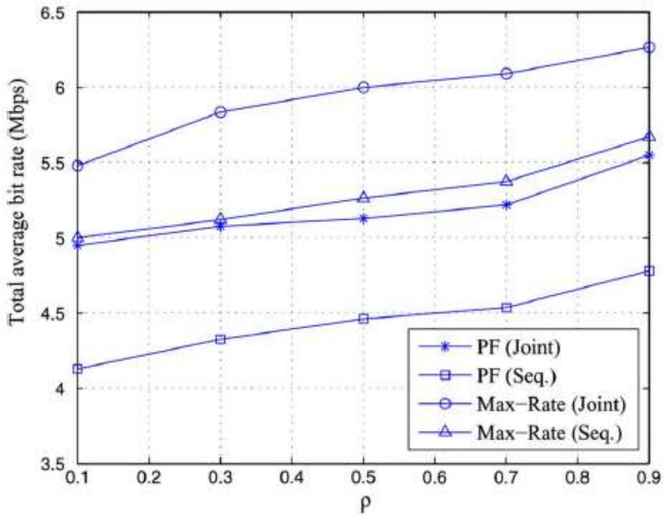

Fig. 4 Avg total bit rate as a function of ρ for three users with avg SINR of 10, 15, 20 dB

On the horizontal axis we plot ρ and vertical axis corresponds to the Total avg bit rate taken in Mbps. Here the variation among user average SINRs is larger than above two figures. This fig shows that there is now larger gap between bit rates for jointly optimal PF and Max-Rate schedulers' reason being that, due to increased effort needed to maintain fairness.

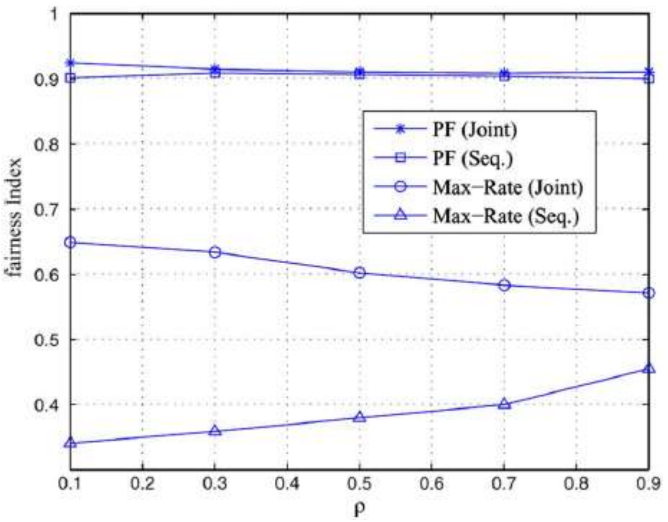

Fig. 5 Fairness index as a function of ρ for three users with avg SINR of 10, 15, 20 dB

On the horizontal axis we plot ρ and vertical axis corresponds to the fairness index. This fig shows that two PF schedulers provide significantly better user fairness than Max-rate schedulers.

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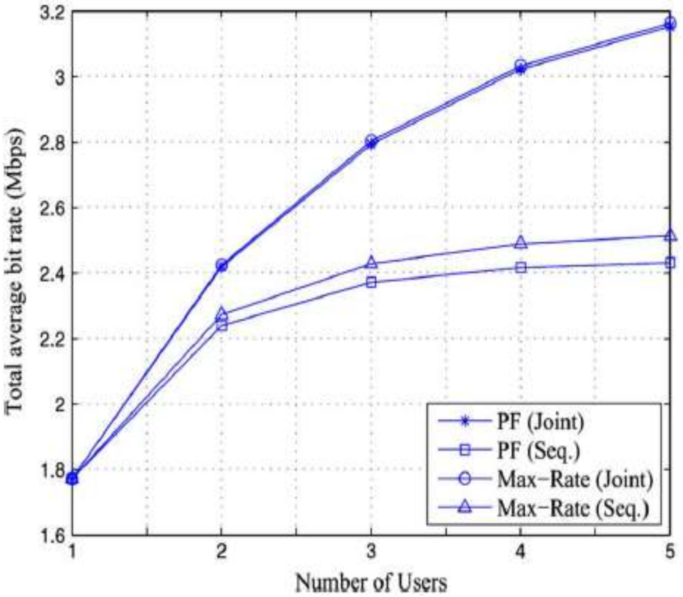

Fig. 6 Avg total bit rate as a function of number of users with ρ= 0.9 and with avg SINR of 7dB for all users

The average total bit rate is plotted as a function of the number of users with an average SINR of 7 dB for all users. We infer that jointly optimized Max-rate and PF schedulers provide similar performances.

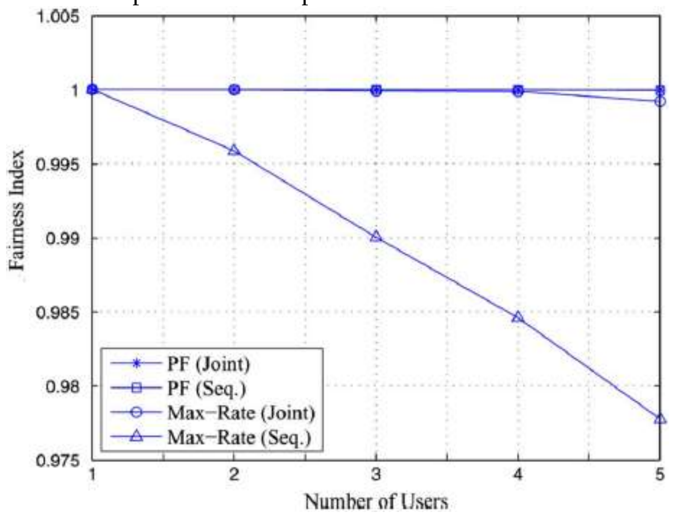

Fig. 7 Fairness index as a function of number of users with ρ= 0.9 and with avg SINR of 7dB for all users

The fairness index is plotted as a function of the number of users with an average SINR of 7 dB for all users. We infer that sequential PF scheduler has slightly lower throughput than Max-rate scheduler but a higher fairness index.

Conclusion

PF scheduler is effective in reducing variations in user bit rates with little average bit rate degradation relative to max-rate scheduler as long as user average SINRs are fairly uniform.

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