Threshold-Based Power Allocation Algorithms for Down-Link Switched-based Parallel Scheduling

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Abstract— In this paper, we propose threshold-based power allocation algorithms for a recently proposed down-link switched based parallel scheduling (SBS) scheme and we present their performance results via computer simulations. As its name indicates it, the system re-allocates the extracted excess signal to noise ratio (SNR) from some acceptable users to unacceptable users among the scheduled users. After the power allocation process, the unacceptable users can reach acceptable SNRs and as such the number of effective acceptable users with an acceptable SNR threshold among the scheduled users is increased without any additional down-link transmit power. Some selected numerical results, show that the proposed power allocation algorithms offer a certain improvement in average spectral efficiency (ASE) and an increase in the average number of effective acceptable users. Although the average bit error rate (BER) performance degrades especially when the average SNR is close to the SNR threshold, this average BER performance still meets the average BER requirement.

I. INTRODUCTION

Research in multiuser scheduling schemes for single user [1]–[3] and for multiple users [4], [5] has grown in recent years. Single user scheduling schemes [1]–[3] schedule only one user at a time. On the other hand, parallel scheduling schemes [4], [5] schedule multiple users at a time. The goal is to increase the average spectral efficiency (ASE) and to reduce the complexity of implementation. In [5], we proposed two new parallel multiuser scheduling schemes, namely (i) on-off based scheduling (OObS) and (ii) switched based scheduling (SBS) to reduce the complexity of implementation without a considerable performance loss in comparison with conventional selection based scheduling [4]. While the OObS scheme schedules all the users with an signal to noise ratio (SNR) above a pre-selected SNR threshold, the SBS scheme schedules only the \( K_s \) users among the \( K \) users with an acceptable SNR if there are enough acceptable users. Otherwise, the scheduler selects the best \( K_s \) users. Although the system with the SBS scheme increases the ASE and reduces the complexity of implementation, at least one user among the scheduled users may have an SNR below a pre-selected SNR threshold if there are not enough acceptable users.

In a down-link scenario, if the transmit power to the unacceptable users is increased, their SNRs increase as well and they can reach as such acceptable SNRs. However, the overall transmit power from the base station (BS) is typically limited by regulations and the level of interference to other out of cell users and devices. This limits the overall amount of power that the system can transmit. However, note that the acceptable users have SNRs above the pre-selected SNR threshold and acceptable users within the same SNR region will have the same ASE although they may have different SNRs because of the discrete nature of adaptive modulation. Therefore, if we re-allocate the excess SNR extracted from the acceptable users to the unacceptable users among the scheduled users, we can increase the number of acceptable users among the scheduled users without a considerable performance loss and without any additional down-link transmit power.

With the above motivation in mind, we propose in this paper threshold-based power allocation algorithms for SBS type of scheduling. As its name indicates it, the system re-allocates the extracted excess SNR above the threshold from the acceptable users to the unacceptable users among the scheduled users. After the power allocation process, the unacceptable users can reach acceptable SNRs and then the number of effective acceptable users (which are the users with an SNR above a pre-selected SNR threshold for scheduling after power allocation process) among the scheduled users will be increased without any additional down-link transmit power.

The remainder of this paper is organized as follows. Section II presents the system and channel models. In section III, the detailed behind the mode of operation of our proposed power allocation algorithms is provided. While section IV shows the simulation results via some selected figures, section V offers some concluding remarks.

II. SYSTEM AND CHANNEL MODELS

A. System Model

In our system model, we consider a code division multiple access (CDMA) system instead of a time division multiple access (TDMA) system because the BS needs to schedule simultaneously \( K_s \) (\( K_s = 0, 1, 2, \ldots, K \)) users among \( K \) potential users per time-slot. We assume that the multiuser signals are orthogonal and that there are no inter-cell interference and no co-interference among the users. We also assume that the schemes have a reliable feedback path between the receiver and transmitter and that they are implemented in a discrete-time fashion with a time-slot composed of a guard time period.
followed by a data transmitting time period. During the guard time period, the BS makes the necessary actions for proper power allocation after scheduling the $K_s$ users. Finally, it is assumed that the channel estimation is perfect at the receiver and that the feedback to the transmitter is performed upon request without any error.

For the scheduled users and after power allocation, a rate-adaptive $N$ multidimensional trellis coded $M$-quadrature amplitude modulation (M-QAM) modulation [6] for additive white Gaussian noise (AWGN) channels is employed to ensure amplitude modulation (M-QAM) modulation [6] for additive power allocation and sequential allocation of power to the unacceptable users from the acceptable users to the unacceptable users among users without consuming any additional down-link transmit power. For later reference, $\gamma_i$ denotes the total original number of acceptable users before this algorithm, the SNR ranking information is maintained for scheduling and for power allocation respectively. With algorithm 1, the SNR threshold for scheduling and for power allocation respectively.

$\gamma$ threshold for scheduling and for power allocation respectively. After dividing $\gamma_{req}$ by the total number of acceptable users $K_a$, the system extracts this amount, $(\gamma_{req}/K_a)$, from all the acceptable users to maintain the SNRs ranking information among the acceptable users. This yields:

i) If $(\gamma_i - \gamma_{req}) \geq \gamma_{TP}$, then we subtract $\gamma_{req}$ from $\gamma_i$ and then the modified SNR of the acceptable user is $\gamma_i = \gamma_i - \gamma_{req}, i \in \{1, 2, ..., K_a\}$.

ii) If $(\gamma_i - \gamma_{req}) < \gamma_{TP}$, then we subtract $(\gamma_i - \gamma_{TP})$ from $\gamma_i$ and then the modified SNR of the acceptable user is $\gamma_i = \gamma_i - \gamma_{TP}, i \in \{1, 2, ..., K_a\}$.

After this first step, the system adds all extracted SNRs from the acceptable users yielding $\gamma_{excess} = \sum_{i=1}^{K_a} (\gamma_i - \gamma_i^{'})$. Then the system sequentially allocates $\gamma_{excess}$ to the unacceptable users. More specifically, if $\gamma_{excess} = 0$, then all SNRs of the scheduled users are not changed after the power allocation process. If $\gamma_{excess} = \gamma_{req}$, then $\gamma_{excess}$ is sequentially allocated to all unacceptable users as much as they need to have the minimum data rate and then all the SNRs of unacceptable users, $\gamma_j (i \in \{K_a + 1, ..., K_s\})$, are equal to the SNR threshold $\gamma_{TP}$. If $\gamma_{excess} < \gamma_{req}$, then $\gamma_{excess}$ is sequentially allocated to the unacceptable users from the user with strongest SNR to the user with weakest SNR among the unacceptable users by exhausting the extracted power. More specifically, if $\gamma_{excess} \geq (\gamma_{TP} - \gamma_i)$, then the $(\gamma_{TP} - \gamma_i)$ is allocated to the unacceptable user and then $\gamma_i = \gamma_{TP}$. If $\gamma_{excess} < (\gamma_{TP} - \gamma_i)$, then the $\gamma_{excess}$ is allocated to the unacceptable user and then $\gamma_i = (\gamma_i + \gamma_{excess})$ before terminating the power allocation process. The power allocation process is continued and repeated until $\gamma_{excess} = 0$.

B. Algorithm 2

The main idea of the second algorithm is extracting only each user’s excess SNR from the acceptable users. Because acceptable users have their own SNR regions and because the extraction of each user’s excess SNR and re-allocating it to the unacceptable user, increases the number of the effective acceptable users while maintaining the ASE of the acceptable users after power allocation. After the extraction process, and like in the first algorithm, the system sequentially allocates the excess power to the unacceptable users from the strongest SNR user to the weakest SNR user among the unacceptable users. More specifically, with algorithm 2, during the guard time period, after scheduling with SBS, the system estimates the excess SNR from the acceptable users. If the $i$-th acceptable user is placed in the $j$-th SNR region, then after power allocation, the excess SNR and modified SNR of the $i$-th acceptable user among the scheduled users becomes $\gamma_{excess,i} = \gamma_i - \gamma_{TP}$ and $\gamma_i = \gamma_i^{'},$ where $i = 1, 2, ..., K_a$ and $j = 1, 2, 3, ..., N$, respectively. After the extraction process, the system adds...
all the extracted excess SNRs from the acceptable users and then allocates it to the unacceptable users like the first power allocation algorithm. If there still exits a remained excess power after power allocation process, the system allocates it to all the scheduled users equally. Note that this algorithm has less complexity in comparison with the first one.

C. Algorithm 3

The main idea of the third algorithm is that after estimating the number of effective acceptable users and comparing the excess SNR to the required SNR, the system equally allocates the total SNR of the effective acceptable users to only the effective acceptable users. After the power allocation process, all the effective acceptable users will have the same SRN and the SRNs of the remained users among the scheduled users will not be changed. This algorithm is more practical and has the lowest complexity of implementation among our proposed algorithms. More specifically, Fig. 2 illustrates the detailed mode of operation of the second power allocation algorithms. With algorithm 3, during the guard time period, the system estimates the excess SNR from the acceptable users and the required SNR from the unacceptable users and then the excess SNR and the required SNR are $\gamma_{req} = \sum_{i=K_a+1}^{K_s} (\gamma_{T,P} - \gamma_i)$ and $\gamma_{excess} = \sum_{i=K_a}^{K_s} (\gamma_i - \gamma_{T,P})$, respectively. If $\gamma_{excess} = 0$, then all the SRNs of the scheduled users are not changed after power allocation, and $\gamma_i = \gamma_i = (i = 1, 2, 3, \ldots, K_s)$. If $\gamma_{excess} \neq 0$ and $\gamma_{req} \leq \gamma_{excess}$, then all scheduled users are effective acceptable users and then they have the same SRNs $\gamma_i = \frac{\gamma_{total}}{K_s}$. If $\gamma_{excess} \neq 0$ and $\gamma_{req} > \gamma_{excess}$, then the system estimates the number of the effective acceptable users, $K_{s,eff}$, and then equally allocates the effective total SNR, $\gamma_{total,eff}$, to the effective $K_{s,eff}$ users as explained in what follows:

i) Let $K_{a,eff} = K_a - K_s$, and $K_{s,eff} = K_a + K_{a,eff}$. 

ii) Estimate the effective required SNR and the effective total SNR as the following $\gamma_{req,eff} = \sum_{i=K_{a,eff}+1}^{K_s} (\gamma_{T,P} - \gamma_i)$ and $\gamma_{total,eff} = \sum_{i=1}^{K_s} \gamma_i$, respectively.

iii) If $\gamma_{req,eff} \leq \gamma_{excess}$, then $\gamma'_i = \gamma_{total,eff} (i = 1, 2, 3, \ldots, K_{s,eff})$ and $\gamma'_i = \gamma_i (i = K_{s,eff} + 1, \ldots, K_s)$.

iv) If $\gamma_{req,eff} > \gamma_{excess}$, then $K_{a,eff} = K_{a,eff} - 1$ and $K_{s,eff} = K_a + K_{a,eff}$ and then repeat step ii).

IV. SIMULATION RESULTS

In this section, the average number of the effective acceptable users, the ASE, and the average BER with our three proposed power allocation algorithms are investigated through Monte Carlo computer simulations. In our simulation, we use the SBS scheme with $K = 20$, $K_s = 15$, the coded adaptive modulation of [6] with $N = 7$, and independent and identically distributed (i.i.d.) Rayleigh fading conditions.

Fig. 3 presents the average number of effective acceptable users with our proposed power allocation algorithms over i.i.d. Rayleigh fading conditions with $K = 20$, $K_s = 15$, and $\gamma_T = \gamma_{T,P} = 7.1$ dB. After power allocation with our proposed power allocation algorithms, as expected, the average number of effective acceptable users is increased. Also, as per our intuition, the third algorithm has a best performance among our proposed algorithms and the second algorithm has a better performance than the first algorithm.

Fig. 4 presents the ASE of SBS with our proposed power allocation algorithms over i.i.d. Rayleigh fading conditions with $K = 20$, $K_s = 15$, and $\gamma_T = \gamma_{T,P} = 7.1$ dB. Based on their mode of operation, when the average SNR is close to the SNR threshold for power allocation, algorithm 2 acts like algorithm 1 and in the region of average SNR, $\gamma$, higher than the SNR threshold, algorithm 2 acts like algorithm 3. As expected, after power allocation with algorithm 2, the ASE was increased because the acceptable users still have the same ASE and the ASE of the power allocated unacceptable users was increased. On the other hand, contrary to our original expectations, after power allocation with algorithm 1 and 3, the ASE was also increased. This can be explained by the fact that based on the statistical property of the scheduled users with SBS, at least one of acceptable users has very large SRN compared with others’ among the scheduled users and then after power allocation, most of the acceptable users can still maintain their SRN regions after power allocation. The ASE with algorithm 1 was increased only when the average SRN is close to the SNR threshold for power allocation because in the region of high $\gamma$, the required SRN is decreasing and the number of acceptable users is increasing and for that reason, most of the acceptable users can maintain their SRN regions. The ASE with algorithm 2 was increasing when $\gamma$ is slightly lower than the SNR threshold and finally approaching to the ASE prior to the application of the power allocation. Similar to algorithm 2, the ASE with algorithm 3 is also increasing when $\gamma$ is slightly lower than the SNR threshold and finally it approaches to the ASE prior to the application of power allocation.

Fig. 5 presents the average BER of SBS with our proposed power allocation algorithms over i.i.d. Rayleigh fading conditions with $K = 20$, $K_s = 15$, and $\gamma_T = \gamma_{T,P} = 7.1$ dB. After power allocation with algorithm 1, the average BER performance is degraded only when the average SRN is close to the SNR threshold for power allocation because the excess SRNs are extracted from the acceptable users. In the region of high $\gamma$, the extracted SRN from the acceptable users is decreased and then the average BER is approaching the average BER prior to the application of the power allocation. Similar to the ASE results, the average BER of algorithm 2 acts like the ASE of algorithm 2 when the average SRN is close to the SNR threshold for power allocation.

V. CONCLUSION

In this paper, we proposed threshold-based power allocation algorithms to increase the number of effective acceptable users among the scheduled users with SBS type of scheduling. The main idea is to re-allocate the extracted excess SRN
from the acceptable users to the unacceptable users. After power allocation, the unacceptable users can reach acceptable SNRs and as such the number of effective acceptable users with an acceptable SNR threshold among the scheduled users is increased without any additional power. Some selected numerical results, show that the proposed power allocation algorithms offer a certain improvement in ASE and an increase in the average number of effective acceptable users. Although the average BER performance degrades especially when the average SNR is close to the SNR threshold for power allocation, this average BER performance still meets the average BER requirement because the average BER is still below the target BER.

As on going efforts, we are looking into the average number of effective acceptable users, the statistics of output SNR, the ASE, and the average BER over i.i.d. Rayleigh fading conditions in order to analytically evaluate the performance of our proposed schemes.

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REFERENCES


Fig. 1. Flowchart of the power allocation process for algorithm 1.
Fig. 2. Flowchart of the power allocation process for algorithm 3.

\begin{align*}
\gamma'_{\text{req}} &= \sum_{i=1}^{K_s} (\gamma_{TP} - \gamma_i) \\
\gamma_{\text{access}} &= \sum_{i=1}^{K_s} (\gamma_i - \gamma_{TP}) \\
\gamma_{\text{total}} &= \sum_{i=1}^{K_s} \gamma_i
\end{align*}

\text{Yes} \quad Y_{\text{access}} = 0 \\
\text{Yes} \quad Y_{\text{req}} \leq Y_{\text{access}} \\
\gamma'_{\text{req}} = \frac{\gamma'_{\text{req}}}{K_s} \\
\gamma_{\text{access}} = \frac{\gamma_{\text{access}}}{K_s} + \frac{\gamma_{\text{access}}}{K_s}

\text{Yes} \quad \gamma_{\text{req}} \leq \gamma_{\text{access}} \\
\gamma'_{\text{req}} = \frac{\gamma'_{\text{req}}}{K_s - 1} \\
\gamma_{\text{access}} = \frac{\gamma_{\text{access}}}{K_s - 1} + \frac{\gamma_{\text{access}}}{K_s - 1}

\text{Yes} \quad \gamma_{\text{req}} \leq \gamma_{\text{access}} \\
\gamma'_{\text{req}} = \frac{\gamma'_{\text{req}}}{K_s} \\
\gamma_{\text{access}} = \frac{\gamma_{\text{access}}}{K_s + 1} + \frac{\gamma_{\text{access}}}{K_s + 1}

\text{End}

Fig. 3. Average number of effective acceptable users with SBS over i.i.d. Rayleigh fading conditions with $K = 20$, $K_s = 15$, and $\gamma_T = \gamma_T P = 7.1$ dB.

Fig. 4. ASE with SBS over i.i.d. Rayleigh fading conditions with $K = 20$, $K_s = 15$, and $\gamma_T = \gamma_T P = 7.1$ dB.

Fig. 5. Average BER with SBS over i.i.d. Rayleigh fading conditions with $K = 20$, $K_s = 15$, and $\gamma_T = \gamma_T P = 7.1$ dB.