CHAPTER 4

MULTI-THRESHOLD-BASED CHANNEL-AWARE SCHEDULING

4.1 INTRODUCTION

Multi-user multi-input multi-output (MU-MIMO) system has been eventually used in fourth generation wireless networks either to achieve diversity gain or multiplexing gain. Many recent scheduling schemes address the threshold-based scheduling for resource allocation wherein resources are not utilized properly. In this chapter, a new multi-threshold based channel aware scheduling to improve the resource utilization compared to threshold-based scheduling is described. This new multi-threshold-based channel-aware scheduling (MTCAS) is aimed at improving the resource utilization without compromising fairness.

Multi-Threshold-based channel-aware scheduler (MTCAS) probes all active user SNR’s and computes multiple threshold regions such as $\text{SNR}_H$, $\text{SNR}_M$ and $\text{SNR}_L$ which is based on Equation 4.1.

\[
\begin{align*}
\text{SNR}_L &< \frac{\text{max (SNR)}}{3}, \\
\frac{\text{max (SNR)}}{3} &\leq \text{SNR}_M < 2 \times \frac{\text{max (SNR)}}{3}, \\
2 \times \frac{\text{max (SNR)}}{3} &\leq \text{SNR}_H
\end{align*}
\] (4.1)
This scheduler allocates resource based on user’s channel quality (i.e. SNR). The scheduler allocates resources to all the users whose SNR is $\geq \text{SNR}_H$ until resource is available. If there is any remaining resource, then the scheduler allocates them to the next threshold region users whose SNR is $\geq \text{SNR}_M$. This scheduler considers the second threshold region to improve the resource utilization. Among this two threshold region, this scheduler first schedule $\text{SNR}_H$ region users to improve the BER performance and then it schedules the $\text{SNR}_M$ region users to improve the resource utilization.

### 4.2 MTCAS FLOW DIAGRAM

The scheduling flow diagram of MTCAS is shown in Figure 4.1. The base station probes all users CSI. Then the base station scheduler computes three equal channel quality regions which are based on maximum value of the user SNR. The scheduler first schedules the user those who come under $\text{SNR}_H$ region based on first come first serve (FCFS) and then it schedules the $\text{SNR}_M$ region user.

Let $x = \{x_1, x_2, x_3, \ldots, x_N\}$ be the active users at time slot $t_k$ and Let $x' = \{x'_1, x'_2, x'_3, \ldots, x'_p\}$ be the users whose SNR $\geq \text{SNR}_H$ and $x'' = \{x''_1, x''_2, x''_3, \ldots, x''_q\}$ be the users who come under $\text{SNR}_M$ region.
Figure 4.1 Flow diagram of MTCAS
The resource granted user is given in Equation 4.2.

\[
G_k = \begin{cases} 
  x_1, x_2, x_3, \ldots, x_L & \text{if } p \geq L \\
  x_1, x_2, x_3, \ldots, x_p, x_1, x_2, x_3, \ldots, x_q & \text{if } p < L \& (p + q) \leq L \\
  x_1, x_2, x_3, \ldots, x_p, x_1, x_2 \ldots, x_q & \text{if } p < L, (p + q) \geq L \& (p + s) = L 
\end{cases}
\] (4.2)

where \( p \) is the number of scheduled user in SNR_H region

\( q \) is the number of scheduled user in SNR_M region

MTCAS resource allocation flow diagram is shown in Figure 4.2.

The resource allocation process allocates resource to the scheduled user. The resource allocator allocates all resources if the number of scheduled user is greater than the available resource. Otherwise it allocates required resources to all scheduled users.

![Figure 4.2 MTCAS resource allocation](image-url)
This scheduler considers the user who comes under two threshold regions for performance improvement and proper resource utilization. If the resources are unutilized after resource allocation, it remains unutilized during that particular time slot. But the chance of unutilized resource wastage is very less, since MTCAS considers more than one threshold region for resource allocation.

4.3 SIMULATION RESULTS OF MTCAS

The system is modeled using one base station, ‘N’ number of active users and ‘L’ number of resources (pair of antenna) available at base station. The BS receives users’ SNR and their demand data rate. The performance of scheduling is simulated under each user has 2 antenna and demand 2 antenna resources from the base station. In 2x2 MU-MIMO systems the user data are transmitted via Rayleigh channel after Alamouti - Space Time Block Coding (STBC). MTCAS simulation parameters are shown in Table 4.1. For this simulation, the users’ SNR value is preferred at random between 1db and 25db.

Table 4.1 MTCAS simulation parameters for MIMO-STBC system with different L

<table>
<thead>
<tr>
<th>System</th>
<th>MIMO-STBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Transmit antenna</td>
<td>2 for each user</td>
</tr>
<tr>
<td>Number of Receive antenna</td>
<td>2 for each user</td>
</tr>
<tr>
<td>Channel</td>
<td>Rayleigh flat fading</td>
</tr>
<tr>
<td>Noise</td>
<td>AWGN</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>Total Number of active users N</td>
<td>25</td>
</tr>
<tr>
<td>Number of resource L varied</td>
<td>4,6,10</td>
</tr>
</tbody>
</table>
BER performance of 2X2 MU-MIMO system with MTCAS scheduler with different number of resource is shown in Figures 4.3, 4.4 and 4.5.

Figure 4.3 shows that the MTCAS performed better than OTFS when the number of users is greater than three times of resource available. This is because when the number of user increases, there will be a chance of scheduling better channel quality user. And it is found there is degradation in average BER performance when the number of user is less than three times of the number of available resource. This is because MTCAS considers two threshold region user, hence, it schedules the users even if their channel quality comes under second threshold region. Therefore, resource utilization is improved as compared to OTFS but at the cost of degradation in BER performance. This scheduler achieves 28% BER improvement when N=15, and 83% improvement when N=20 compared to OTFS.

Figure 4.3  Comparison of average BER performance of 2X2 MTCAS with other schedulers when resource L=4
Also it is observed that MTCAS almost gives similar performance compared to normalized priority scheduling but MTCAS fairness is enhanced compared to NPS due to MTCAS treating the users fairly who come under multiple threshold regions.

Figure 4.4 shows that the performance of MTCAS is close to OTFS and it is improved when the number of users exceeds thrice over the number of resources. Since OTFS threshold is based on best and worst user average and optimization factor, there will be less chance to schedule the multi-user equal to number of resource available, resulting in improved level of performance but less resource utilization.

Figure 4.4  Comparison of average BER performance of 2X2 MTCAS with other schedulers when resource L=6
Simulation result of BER values of various schedulers along with MTCAS with L=6 is shown in Table 4.2. It is clear from Table 4.2 that MTCAS performs well compared to NPS. Also it is observed that MTCAS performs well compared to OTFS when the number of resource is equal to 30% of active users. But, when the number of available resource L is 60 percent and 80 percent, Table 4.2 shows that OTFS outperforms MTCAS. In resource constrained environment (i.e. L=30% or less), MTCAS outperforms other scheduler performance.

Table 4.2 Simulation results of BER values of MTCAS with different schedulers when L=6

<table>
<thead>
<tr>
<th>Resource</th>
<th>Scheduler</th>
<th>FS</th>
<th>NPS</th>
<th>OTFS</th>
<th>MTCAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>L=30%</td>
<td></td>
<td>10^{-2}</td>
<td>8×10^{-4}</td>
<td>2×10^{-4}</td>
<td>10^{-4}</td>
</tr>
<tr>
<td>L=60%</td>
<td></td>
<td>10^{-2}</td>
<td>7×10^{-3}</td>
<td>8×10^{-5}</td>
<td>3×10^{-4}</td>
</tr>
<tr>
<td>L=80%</td>
<td></td>
<td>10^{-2}</td>
<td>9×10^{-3}</td>
<td>8×10^{-5}</td>
<td>2×10^{-4}</td>
</tr>
</tbody>
</table>

The BER performance of MTCAS with other scheduling when L=9 is shown in Figure 4.5. MTCAS performance is superior to NPS but inferior compared to OTFS. When the available resource is more, OTFS may schedule less number of users compared to MTCAS. Hence, OTFS resource utilization is less compared to MTCAS. But MTCAS achieves better resource utilization at the cost of small degradation in BER performance when the number of user exceeds more than thrice the number of users.
Figure 4.5 Comparison of average BER performance of 2X2 MTCAS with other schedulers when resource L=9

Simulation result of BER values of various schedulers along with MTCAS when L=9 is shown in Table 4.3. From Table 4.3, it is observed that MTCAS performs well compared to OTFS when L=40%. But, when the number of available resource L is 60 percent and 80 percent, OTFS outperforms MTCAS. In resource constrained environment (i.e. L=40% or less), MTCAS outperforms other scheduler performance.

Table 4.3 Simulation results of BER values of MTCAS with different schedulers when L=9

<table>
<thead>
<tr>
<th>Scheduler Resource</th>
<th>FS</th>
<th>NPS</th>
<th>OTFS</th>
<th>MTCAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>L=40%</td>
<td>10^{-3}</td>
<td>2×10^{-5}</td>
<td>10^{-5}</td>
<td>8×10^{-6}</td>
</tr>
<tr>
<td>L=60%</td>
<td>10^{-3}</td>
<td>9×10^{-4}</td>
<td>10^{-5}</td>
<td>2×10^{-4}</td>
</tr>
<tr>
<td>L=80%</td>
<td>10^{-3}</td>
<td>10^{-3}</td>
<td>9×10^{-6}</td>
<td>4×10^{-4}</td>
</tr>
</tbody>
</table>
The packet delivery ratio (PDR) of MTCAS is shown in Figures 4.6 to 4.8. Simulation results are compared with OTFS. The PDR performance of MTCAS scheme is found improved as compared to the OTFS scheme when the number of users exceeds three times of the number of resource available. Also it is observed that when the number of users is less than three times the number of resource, the PDR performance of OTFS is better than MTCAS but at the cost of less resource utilization.

Figure 4.6 Comparison of average PDR performance of 2X2 MTCAS with OTFS when resource L=4
Figure 4.7  Comparison of average PDR performance of 2X2 MTCAS with OTFS when resource L=6

Figure 4.8  Comparison of average PDR performance of 2X2 MTCAS with OTFS with resource L=9
Resource utilization of MTCAS is shown in Figure 4.9 and it is found that MTCAS resource utilization is improved as compared to OTFS. When the number of active user is twice over available resource, all scheduler utilize the entire available resource. But under resource constrained environment MTCAS utilizes the resource in improved manner than OTFS. That is when the number of users is less than two times of available resource, MTCAS resource utilization is improved compared to OTFS. When N=13 along with L=9, MTCAS resource utilization is 89% but OTFS resource utilization is 77%. MTCAS achieves 12% improvement in resource utilization at this point.

![Comparison of MTCAS Resource Utilization with other Schedulers](image)

**Figure 4.9** Comparison of resource utilization of 2X2 MTCAS with FS, NPS & OTFS when L=9

Order of MTCAS served user index (with a number of active users N=16) is shown in Table 4.4. FS maintains full fairness since it serves the user in FCFS basis. NPS does not maintain full fairness but give better BER performance. In OTFS, the users are served on FCFS basis provided the
user’s channel strength is greater than or equal to required optimized threshold value. In MTCAS, first the SNR_{H} region users are served in FCFS basis. Then SNR_{M} region users are served in FCFS basis to maintain fairness.

**Table 4.4 MTCAS served user index with FS, NPS and OTFS**

<table>
<thead>
<tr>
<th></th>
<th>Scheduled User Index when N=16</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS</td>
<td>1 2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td>NPS</td>
<td>1 10 12 14 13 7 6 2 3</td>
</tr>
<tr>
<td>OTFS</td>
<td>1 2 3 5 6 7 10 12 13</td>
</tr>
<tr>
<td>MTCAS</td>
<td>1 10 12 13 14 2 3 5 6</td>
</tr>
</tbody>
</table>

**4.4 SUMMARY**

This chapter has described MTCAS scheme for average BER performance improvement and proper resource utilization in MU-MIMO system. The MTCAS performance is based on user’s channel quality. BER performances of this scheme with BPSK modulations in flat Rayleigh fading channel was studied and compared with other scheduling schemes such as FS, NPS and OTFS. From the simulation results it was found that MTCAS outperforms other scheduling schemes in BER and PDR performance when the number of users greater than three times of number of available resource. Also it is observed that the resource utilization of this scheduler found improved compared to OTFS. MTCAS achieves 12% improvement in resource utilization as compared to OTFS. This scheme provides a network BER of about $8 \times 10^{-5}$ when $L= 6$ and $N=23$. But this scheme provides a network average BER of about $2 \times 10^{-4}$ when $L= 6$ and $N=8$. Hence, under resource constrained environment MTCAS outperforms other scheduler.
In other cases, this scheduler link level performance is slightly degraded with improved resource utilization. Multiple user parameters like user channel strength, user demand rate may be considered while scheduling for link level performance improvement without affecting resource utilization and fairness. In the next chapter, a new multi-parameter-based user scheduling is described for system performance improvement.