# Impact of MAC Scheduling algorithms on throughput, in a multi-UE scenario

## Introduction

Base stations (eNBs) generally deal with multiple mobile stations UEs, some of which require larger bandwidths than others and some of which have better connections (signal quality) than others. In ideal circumstances the base station has plenty of resources (e.g., bandwidth) and each UE gets the resources it needs. However, usually resources are limited, and the base station needs some way of fairly allocating the resources between the UEs.

Consider the downlink of a single eNB 4G cellular system. SeveralUEs are receiving data from ongoing transfers, for example, TCP controlled file downloads. Assuming that the bottleneck on the transfer path for these connections is this eNB to UE wireless access, the downlink per-UE queues in the eNB will be nonempty. At the beginning of each downlink slot (TTI) the eNB scheduler has to decide which of the UEs’ waiting data to transmit in that slot.

At each eNB the MAC scheduler decides the PRB allocation, per carrier, per TTI (slot), in the PDSCH (DL) and in the PUSCH (UL). Control packets such as the buffer status report (BSR) and UL assignment, are assumed to be sent out of band. The resources for transmission of these control packets are part of Overhead as defined in 3.9.21 5G manual.

### Round Robin Scheduler

It divides the available PRBs among the active flows, i.e., those logical channels which have a non-empty RLC queue. The MCS for each user is calculated according to the received CQIs.

### Proportional Fair Scheduler

For data transfers, an important performance measure is long term throughput in bits/second, say, where is the number of UEs. One approach to designing a scheduler is to evaluate the goodness of the throughput vector by a network utility, which is the sum of individual user utilities. The utility (or, usefulness) of a throughput to a user, increases with increasing throughput, but for large throughputs, increasing throughput further gives diminishing increase in usefulness. This property is modeled as a nondecreasing concave function of throughput. A common measure of utility is the log function, i.e., for the throughput vector the utility of throughput to user is measured as . The network utility is, then, given as

A Proportional Fair (PF) scheduler works by scheduling users in slots so that the utility of their long-term throughputs is maximized. In the 4G setting, the scheduling decisions at the beginning of a TTI are based on the physical rates that each UE can get in each Resource Block (RB). If we are given statistical models of these rates, then a nonlinear optimization problem can be formulated and solved to obtain the schedule. This is not a practical approach, however, and a learning algorithm is desired, which, based on slot-by-slot CSI measurements, takes scheduling decisions, which lead to PF optimal throughputs.

The Proportional Fair Scheduler is such a learning scheduler, that uses the throughputs that users are expected to get in the next slot, and the average throughputs they have each obtained up to this slot, to decide which UEs to schedule in the next slot. The practical PF scheme, described below, is based on information such as a presently available data rate for each user in each RB in the next slot (obtained by CSI measurements), and an average data rate over an immediately prior predetermined interval for each user.

**Implementation**

Since NetSim uses a flat fading model, in each slot, each UE achieves the same MCS in every RB in that slot. In other words, different UEs achieve, possibly, different MCSs, but a single UE has the same MCS across all RBs in a slot. Under this assumption, it is optimal to schedule the same UE in every RB in that slot. Since the channel condition can stochastically vary from slot to slot, the MCSs that the UEs achieve will vary from slot to slot. Under this assumption, the following algorithm is Proportional Fair optimal.

Let denote generic users and let be the slot index. A resource block index is required given the flat fading assumption. Let be the MCS seen by user at time (slot) . The channel CQI (derived from the data channel SINR) is used by the adaptive modulation and coding (AMC) module to determine the MCS. We denote by the TB size in bits for a given MCS, , and a given number of physical resource blocks (PRBs), . The achievable rate in bit/s for user in slot is defined as

where is the TTI, i.e., slot duration. At the start of each slot , the user index - selected by the scheduler - to which required PRBs (per that user’s demand) is assigned at time is determined as

This selection is carried out by the scheduler till all PRBs in slot are allocated. In the above expression, is the past throughput performance perceived by the user and is defined as

where is the time constant (in units of slots) of the exponential moving average. NetSim uses , and is the actual throughput achieved by the user in the subframe . If is the number of PRBs allocated to user , we finally get

The value of can be changed by the user by editing the NetSim’s source code; it cannot be changed via the GUI. The PF scheduler thus selects a user having the maximum among values obtained by dividing a present possible data rate by an average data rate during a predetermined interval at every scheduling time point.

### Max Throughput Scheduler

The Max Throughput (MT) scheduler aims to maximize the overall throughput of the Base station (eNB or eNB). It allocates each PRBs to the user that can achieve the maximum achievable rate in the current TTI. The highest achievable rate is calculated by wideband MCS, that is derived from the CQI which in-turn is computed from the SINR. The scheduler allocates the required PRBs to this UE in the current TTI (slot). The calculation of achievable rate similar to what is explained in PF scheduler.

We denote as the TB size in bits for a given MCS, and a given number of physical resource blocks (PRBs), . The achievable rate in bit/s for user at slot is defined as

where is the TTI i.e., slot duration. At the start of each slot , the user index - selected by the scheduler - to which required PRBs (per that user’s demand) is assigned at time is determined as

While MT can maximize cell throughput, it cannot provide fairness to the UEs that experience poor channel condition.

When there are several UEs having the same achievable rate, NetSim implements RR scheduling amongst these UEs that have the same achievable rate.

## Procedure:

1. Use the following download Link to download a compressed zip folder which contains workspace [GitHub link](https://codeload.github.com/NetSim-TETCOS/Communication-Lab_BITS-Goa/zip/refs/heads/main)
2. Extract the zip folder.
3. The extracted project folder consists of a NetSim workspace file (4G\_advanced\_experiments\_with\_NetSim.netsimexp).
4. Go to NetSim Home window, go to Your Work and click on Import.

A screenshot of a computer

Description automatically generated

Fig 1: Your Work Page of Netsim.

1. In the Import Workspace Window, browse and select downloaded. netsimexp file from the extracted directory. Click on create a new workspace option and browse to select a path in your system where you want to set up the workspace folder.
2. Choose a suitable name for the workspace of your choice. Click Import

A screenshot of a computer

Description automatically generated

Fig 2: Creating a new Workspace.

1. The Imported Project workspace will automatically be set as the current workspace.
2. The list of experiments is now loaded onto the selected workspace.

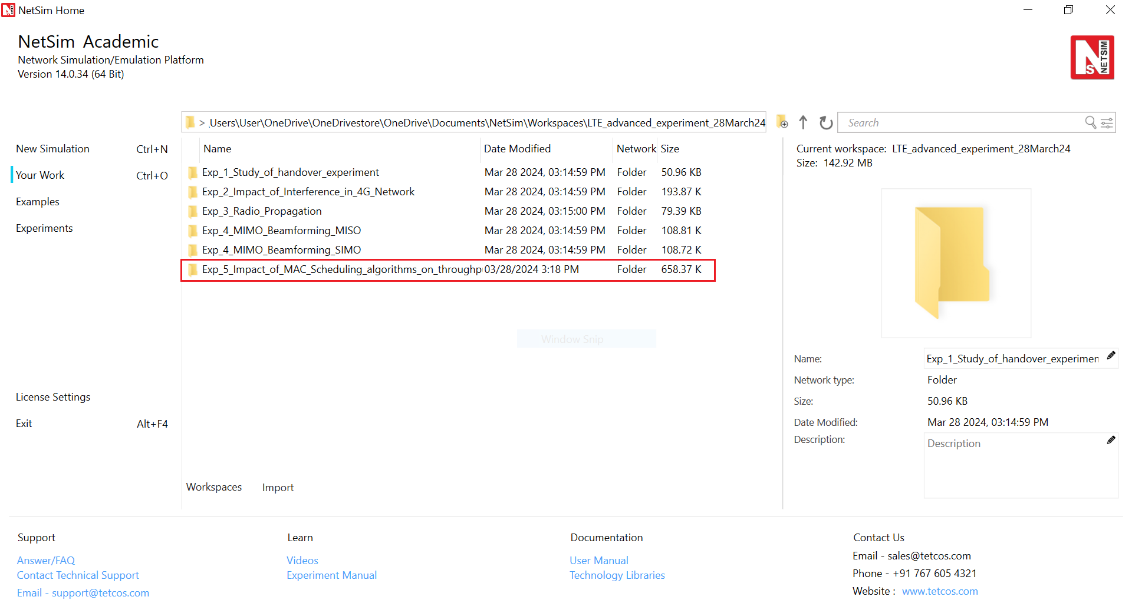


Fig 3: NetSim Your Work Window with the experiment folders inside the workspace

## Part I: Multi UE throughput with UEs at different distances and channel is not time varying.

In this example we understand how the scheduling algorithm affects the UDP download throughput of a multi-user (UE) system where the UEs are at different distances from the eNB.

The following network diagram illustrates what the NetSim UI displays when you open this example configuration file.

A diagram of a graph

Description automatically generated

Fig 4: Network set up for studying the Scheduling example.

**Configuring the scheduling algorithm, and parameter settings in example config files**

1. Set grid length as 6000m from Environment setting.
2. Set distance as follows.
3. eNB\_4 to UE\_5 = 1500m
4. eNB\_4 to UE\_6 = 2000m, and
5. eNB\_4 to UE\_7 = 2500m
6. Go to eNB properties à Interface (LTE), set the following properties as shown below table**.** In the first sample the scheduling type is set to Round Robin, in the second to Proportional fair, and in the third to Max throughput.

|  |  |
| --- | --- |
| Properties | |
| Data Link Layer Properties | |
| Scheduling Type | Varies: Proportional Fair, Max throughput, Round Robin |
| Physical Layer Properties | |
| CA Type | SINGLE\_BAND |
| CA Configuration | BAND33 |
| CC1 | |
| Numerology | 0 |
| Channel Bandwidth | 20 MHz |
| Outdoor Scenario | URBAN\_MACRO |
| LOS NLOS Selection | USER\_DEFINED |
| LOS Probability | 1 |
| Pathloss Model | 3GPPTR38.901-7.4.1 |
| Shadow Fading Model | None |
| Fading and Beamforming | NO\_FADING\_MIMO\_UNIT\_GAIN |

Table 1: eNB >Interface (LTE) >Data Link layer properties

1. Set Tx Antenna Count as 1 and Rx Antenna Count as 1 in eNB properties.
2. Set Tx Antenna Count as 1 and Rx Antenna Count as 1 in all the UEs.
3. Go to Application properties and set the following properties as shown below table.

|  |  |  |  |
| --- | --- | --- | --- |
| Application Properties | | | |
|  | **Application 1** | **Application 2** | **Application 3** |
| Application Type | CBR | CBR | CBR |
| Source ID | 3 | 3 | 3 |
| Destination ID | 5 | 6 | 7 |
| QoS | UGS | UGS | UGS |
| Transport Protocol | UDP | UDP | UDP |
| Packet Size | 1460Bytes | 1460Bytes | 1460Bytes |
| Inter-arrival time | 116.8μs | 116.8μs | 116.8μs |

Table 2: Application properties

1. Run Simulation for 1.5s and note down throughput value in the results window in each sample. Recall that each sample has a different scheduling algorithm configured.

**Results and discussions**

The results with all the three UEs simultaneously downloading data is as given below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Throughput (Mbps) | | | | |
| Scheduling | **Application 1** | **Application 2** | **Application 3** | **Aggregate** |
| Round Robin | 17.55 | 11.69 | 8.18 | 37.42 |
| Proportional Fair | 17.55 | 11.69 | 8.18 | 37.42 |
| Max Throughput | 52.66 | 0 | 0 | 52.66 |

Table 3: UDP download throughputs for different scheduling algorithms when all three 3 UEs simultaneously downloading data.

Next, consider a scenario with only one of the UEs seeing DL traffic (we don’t provide inbuilt configuration file for this, and since it is a simple exercise for a user) First, run for the UE at 1500m, then for UE at 2000m and finally for UE at 2500m. This gives the maximum achievable throughput per node since the eNB resources (bandwidth) is not shared between 3 UEs and is fully dedicated to just one UE. The results are below.

|  |  |  |  |
| --- | --- | --- | --- |
| Distance from eNB (m) | Application ID | Throughput (Mbps) | Remarks |
| 1500 | 1 | 52.66 | UE 1 alone has full buffer DL traffic |
| 2000 | 2 | 35.10 | UE 2 alone has full buffer DL traffic |
| 2500 | 3 | 24.56 | UE 3 alone has full buffer DL traffic |

Table 4: UE throughputs if they were run standalone (without the other UEs downloading data)

The PHY rate is decided per the received SNR. Therefore, a UE closer to the eNB will get a higher date rate than a UE further away. In this example the distances from the eNB are such that UE12\_Distance > UE11\_Distance > UE10\_Distance.

In Round Robin PRBs are allocated equally among all three nodes. However, throughputs are in the order UE10\_Distance > UE11\_Distance > UE12\_Distance because of their distances from the eNB. The individual throughputs seen by each of the UEs is exactly of the throughput as shown in Table 4.The PF scheduler results will match that of the RR scheduler since the channel is not time varying. In Max throughput scheduling the PRBs are allocated such that the system gets the maximum download throughput. The nearest UE will get all the resources and its throughput will be times the throughput of the UE which got the max throughout in RR.

## Part II: Multi UEs at different distances with a time varying channel

Configuring the scheduling algorithm, and parameter settings will remain the same for the case below.

**Changes in the eNB properties are as follows.**

1. Go to eNB properties à Interface (LTE), set the following properties as shown below. In the first sample the scheduling type is set to Round Robin, in the second to Proportional fair, and in the third to Max throughput.

|  |  |
| --- | --- |
| Properties | |
| Data Link Layer Properties | |
| Scheduling Type | Varies: Proportional Fair, Max throughput, Round Robin |
| Physical Layer Properties | |
| CA Type | SINGLE\_BAND |
| CA Configuration | BAND33 |
| CC1 | |
| Numerology | 0 |
| Channel Bandwidth | 20 MHz |
| Outdoor Scenario | URBAN\_MACRO |
| LOS NLOS Selection | USER\_DEFINED |
| LOS Probability | 1 |
| Pathloss Model | 3GPPTR38.901-7.4.1 |
| Shadow Fading Model | None |
| Fading and Beamforming | RAYLIEGH\_WITH\_EIGEN\_BEAMFORMING |

Table 5: eNB >Interface (LTE) >Data Link layer properties

1. Run Simulation for 1.5s and note down throughput value in the results window in each sample.

**Results and discussions**

The results with all the three UEs simultaneously downloading data are as given below

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Throughput (Mbps) | | | | |
| Scheduling | **Application 1** | **Application 2** | **Application 3** | **Aggregate** |
| Round Robin | 13.76 | 9.92 | 7.19 | 30.87 |
| Proportional Fair | 16.35 | 12.06 | 9.01 | 37.42 |
| Max Throughput | 34.38 | 7.75 | 2.76 | 44.89 |

Table 6: UDP download throughputs for different scheduling algorithms when all three 3 UEs simultaneously downloading data with time varying channel.

A difference in the performance of the RR and PF schedulers can be seen when the channel is time varying (of the order of the coherence time which is 10ms). To induce time varying randomness in the channel we enable fading and beamforming. Thus, after every 10ms, NetSim draws an i.e. fading random variable, as the additional loss. Under these conditions, the RR scheduler would allot resources to the UEs in a round robin fashion, whereas the PF scheduler would give preference to the UE which sees the best channel (highest SINR). The reason why the RR scheduler yields lower throughputs than the PF scheduler is that the RR scheduler is not “opportunistic,” i.e., it does not take advantage of the knowledge that a UE has a good channel in the next slot and continues to serve the UEs cyclically. The results are shown in Table 6; observe how this is different from Table 3 where the channel is not time varying.