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Abstract:

In this work different 3G-LTE DL scheduling strategies have been implemented and compared in terms of cell capacity, UEs throughput and SINR distributions. Fixed reuse schemes considering both, reuse 1 and 3 strategies, soft frequency reuse with different transmitted power levels and, finally, reuse partitioning with different partitions and power levels, have been tested in a synthetic regular scenario. The work is the first step oriented to a more ambitious purpose consisting in the implementation of some simple rules for frequency/power scheduling that would be automatically changed depending on the system load, both in a centralized and in a distributed environment.

1. Theoretical analysis

The signal to noise ratio measured by UE i, on RBG n is given by the well known expression below, being σ^2 the UE received thermal noise at RBG *n*, $\hat{i}$ the serving eNB for user *i*, L_{ib} the attenuation between UE i and eNB b, P_{bn}, the power transmitted by eNB b in RBG n, B the number of eNBs in the scenario and M_b the number of users served by eNB b.

$$SINR_{in} = \frac{P_{\hat{i}n} / L_{i\hat{i}}}{\sigma^2 + \sum_{\substack{b=1 \\ b\neq\hat{i}}}^{B} \left(\sum_{m=1}^{M_b} y_{mn} \cdot P_{bn} / L_{ib} \right)}$$

Through this expression the variable y_{mn} {1: if RBG n is assigned to UE m, 0: if not} is one of the outputs of the system.

Associated to the SINR value, the UE will obtain a given combination of modulation and coding, and therefore a given capacity (expressed in bits/s). To compare the behavior of different strategies two approximations can be used:

- Using Shannon capacity formula which gives an upper bound on the capacity values [1]
- Using a simulator of the LTE physical layer to obtain more accurate values. In this paper the figures from [2] have been used.

Assuming that we can consider three different values for the $SINR_{in}$:

- The realistic value with real interference level ($SINR_{in,real}$) and
- The ideal value with no interference ($SINR_{in,ideal}$).
- The worst value assuming that all the eNB use the all the resources simultaneously ($SINR_{in,worst}$)

All these values will have their corresponding capacities $C_{in,real}$, $C_{in,ideal}$ and $C_{in.worst}$ respectively. The best scheduling algorithm will be the one that guarantees a minimum value for the capacity loss, being expressed as the difference between the optimum ideal value and the realistic value ($C_{in,loss}$=$C_{in,ideal}$-$C_{in,real}$). In terms of a scenario with different cells, the best scheduling for cell b is the one that achieves the maximum possible capacity for the maximum number of UEs in the cell, while simultaneously minimizing the capacity loss over the rest of cells of the scenario. In several publications this study is performed considering only one UE per cell with an infinite buffer and changing the UEs position at each snapshot, doing around 10.000 simulations. This simplifies considerably the calculations, but poses the limitation that a single SINR per cell is obtained at each snapshot (for example if in one snapshot the SINR is low, this means that this is equivalent to have all cell edge UEs in this cell, which is not the usual case, etc.). Instead of doing this analysis, we have considered several UEs per cell, randomly distributed, so we can have simultaneously cell edge UEs and internal UEs (those with high SINR).

Then the scheduling rules are quite simple:

- Obtain the $SINR_{in,worst}$ for all the UEs in the scenario. According to this value classify the UEs in internal or cell edge UEs (necessary for some of the algorithms to be tested).
- Sort randomly the order of the cells to be analyzed (to prevent from starting always with the same cell).
- For each cell, start assigning one RBG per UE, starting with the UE with highest SINR. After each assignment recalculate the real $SINR_{in,real}$ and consequently the AMC (modulation order and code rate) to adapt to the real scheduling.
- If after assigning one RBG to each UEs, there are still free RBGs, start again with the UEs with higher $SINR_{in,real}$
- Proceed with the second cell following the same steps and recalculating the SINR and the AMC parameters for each UE in the scenario, after assigning a new RBG.
- After finishing store the parameters that are important in terms of statistics (UEs throughput in bits/s, cell efficiency in bits/s/Hz, SINR values, etc.) and start again with a new distribution of UEs in the scenario.

It can be seen through the previous steps that the results are focused not in terms of deciding which is the best scheduling strategy from in UE per UE basis, but to obtain the final parameters that allow a comparison between the different strategies to assign frequency band/power levels to the different cells.

The scheduling strategies analyzed in this work can be implemented in a complete distributed system, with no coordination, because it has been decided previously (at system level, when designing the network) which are the bands and the power levels associated to each cell and subband. So the eNB only have to choose which is the best RBG (and the number of RBGs) for a given UE based on UE quality indicators. Some extra degree of freedom could be easily implemented at the eNBs giving them the faculty to decide the reduction in the transmitted power to be applied to the different subbands. Finally, a completely adaptive system can be implemented at the eNBs where the scenario could dynamically evolve from a reuse 1 strategy (with very low traffic) to different partitions and powers as traffic increases. This has not yet been tested in this work, but will be one of the next simulations to perform, as soon as the simulator is adapted to inlcude dynamic and realistic traffic models.

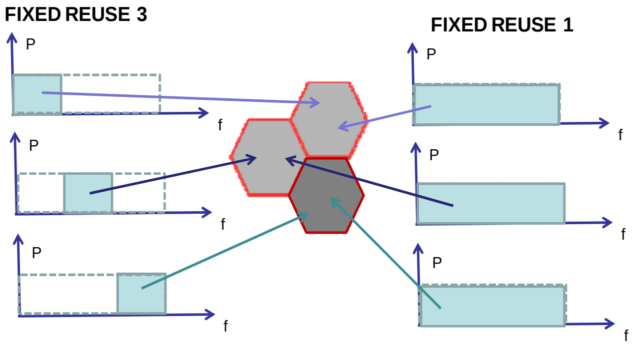
Finally as all the algorithms tested here combine frecuency with power scheduling, to compare algorithms' performance, it is convinient to define an utility factor that combines both parameters.

$$Utility = \frac{1}{N_{RBG} \cdot P_{T,max}} \cdot \sum_{i=1}^{N_{RBG}} P_{t,i} = \frac{P_{T,tot}}{N_{RBG} \cdot P_{T,max}} = \frac{P_{T,tot}}{P_{T,tot,max}}$$

Being N_{RBG} the total number of RBGs in the system (25 for B=20 MHz), $P_{T,tot}$ the total power transmitted for the global bandwidth B, and $P_{T,max}$ the maximum transmitted power per RBG. $P_{T,tot,max}=N_{RBG} \cdot P_{T,max}$ (46 dBm is considered as the maximum total transmitted power for a 20 MHz bandwidth) [3]

Fixed reuse

Reuse 1 and 3 have been considered in this analysis, considering fixed the power transmitted per RBG ($P_{T,max}$) The improvement in SINR due to the interference reduction will not be directly traduced in a similar capacity increase, due to the bandwidth reduction (from B to B/3). So reuse 3 will basically benefit to cell edge UEs, because their SINR increase will be traduced in a higher throughput for these UEs, but with a global cell capacity loss.



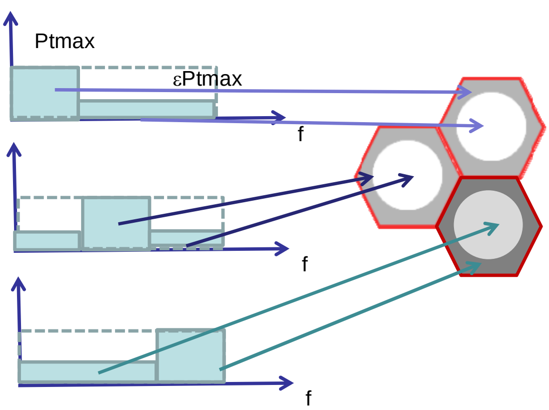
Reuse 1 is a good option for scenarios with low traffic while reuse 3 is better for high load scenarios. Reuse 1 in high load scenarios will cause a lot of interferences, and therefore low SINR and low throughput. If the throughput per UE is not reduced (because the service cannot accept it), then errors will occur, forcing retransmissions and causing anyway a throughput reduction.

Figure 1: Fixed reuse schemes R1 and R3

Soft frequency reuse

Using this scheduling technique means that each cell priories one third of the band (transmitting with power equal to $P_{t,max}$ for each RBG) but can also use the rest of RBG if necessary but with a lower transmitted power ($\varepsilon P_{T,max}$) being ε lower than 1. A variable ε can be considered to better adapt to different load conditions while controlling the interference levels, this is for low traffic we can use ε close to one (if ε=1 then fixed reuse 1 is implemented), while for high load conditions ε can be close to zero (if ε=0 then fixed reuse 3 is implemented).

This power division is similar to dividing the cell in two parts, because naturally we will assign the best subband (the one with $P_{T,max}$) to cell edge UEs to reduce their interference levels, allowing a good cell edge throughput. Then the two thirds with lower power will be associated to internal UEs, those close to the eNB so having less interference and requiring less power to achieve a good throughput.



The thresholds of SINR are used to decide whether a UE has to be considered a cell edge UE or not. They are obtained by considering the SINR value for the worst case (assuming that all the eNB are using all the RBG simultaneously and with the same transmitted power). Threshold values are the same than in [4]. A better way to classify UEs is the one described in [4] according not only on their SINR but also on the EESIR and CQI parameters. This has not yet been introduced in the algorithms.

Figure 2: Soft frequency reuse scheme with cell edge and internal areas

The utility function can be expressed as:

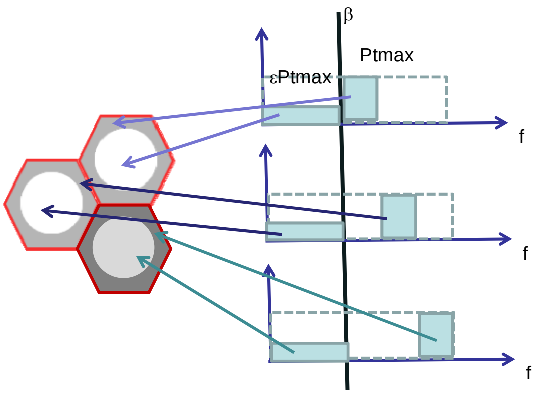
$$Utility = \frac{1}{N_{RBG} \cdot P_{T,max}} \cdot \left[\frac{N_{RBG}}{3} \cdot P_{T,max} + \frac{2 \cdot N_{RBG}}{3} \cdot \varepsilon \cdot P_{T,max} \right] = \frac{1+2\varepsilon}{3}$$

This scheduling scheme requires the introduction of some initial coordination or the stablishment of some priorities, to decide that, for example, cell A has the first third of the RBGs as her prioritary assignment, while cells B and C the second and third respectively. If this priorities are initially fixed by the designer, a cell will use only one third of the bandwidth causing no interferences over the others under low traffic condition. Furthermore, the threshold traffic or load levels, when it’s advisable that the system has changes the mode (the value of ε) , have to be obtained by simulation.

This is a simple scheme to be tested, being probably one of its drawbacks the fact it is more oriented to reduce the interference level instead of maximizing the overall cell throughput. The algorithm assigns the low transmitted power level RBGs (then reducing the potential SINR) to the users close to the base station that could have experienced the maximum throughput.

Reuse partitioning

This is a technique that has been proved to be effective for interference reduction in second generation mobile communication systems. The idea for LTE deployment is quite similar and consists in dividing the total bandwidth in two parts:



- In one subband a fixed reuse 3 is implemented, with maximum transmitted power $P_{T,max}$, so each cell has only permission to use one third of this subband in a coordinated way with the surrounding cells.
- In the other subband a fixed reuse 3 is used considering also a reduction in the transmitted power $\varepsilon P_{T,max}$.

So there are two parameters to control, one associated to the transmitted power level (ε), and the other related with the bandwidth subdivision (β).

Figure 3: Reuse partitioning scheme

The utility funciont is given by

$$Utility = \frac{1}{NRBGs \cdot P_{T,max}} \cdot \left[\beta \cdot NRGBs \cdot \varepsilon \cdot P_{T,max} + \frac{(1-\beta)\cdot NRBGs}{3} \cdot P_{T,max}\right] = \frac{\beta \cdot (3\varepsilon - 1)}{3}$$

2. Scenario parameters:

Simulation parameters are summarized in tables I and II, being most of them extracted from the 3GPP specifications. SINR and capacity statistics have been obtained by averaging only the result from the central cells (those surrounded completely by other cells). A static network has been considered averaging 1000 snapshots with 900 randomly allocated users (around 15 users per cell). Traffic models have not yet been considered, so in this analysis users have infinite buffers.

Parameter	Value
Carrier frequency	2 GHz
Transmission Bandwidth	20 MHz
Sub-carrier spacing	15 kHz
OFDM PHY parameters	CP of 4.69 µs 7 modulation symbols/sub-frame (2 for control)
FFT size	2048
Number of useful sub-carriers	1200
OFDM symbol duration	71.43 µs
Number of sub-carriers per PRB	12
Number of PRBs/RBGs	108/27
Number of PRBs per RBG	4
Sub-frame duration	0.5 ms

TTI length	1 ms
Number of OFDM symbols per TTI	14 (4 for control)
Frame duration	10 ms
Superframe duration	600 ms
Transmission mode	Localized
Power Delay Profile	EPA channel model Pedestrian speed 3 km/h

Table 1: Scenario parameters

Parameter	Value
Channel Coding	Turbo code basic rate 1/3
Code block sizes	40-120 bits
Rate Matching and H-ARQ	According to [9] (release 8). Max 4 IR transmissions.
AMC formats	QPSK: 1/3, 1/2, 2/3, 4/5 16QAM: 1/2 , 2/3, 4/5 64QAM: 2/3, 4/5
Channel estimation	Ideal
Antenna scheme	SISO/MIMO
Cell radius	500 m
Path loss expression	31.5+35log(d[m]) [dB]
Shadowing fading standard deviation	8 dB
Number of active UEs per cell (infinite buffer per user)	15 (900 UEs in the scenario)
Number of cells	21 trisectorial cells
Maximum transmitted power	49 dBm

Table 2: Link level parameters

3. Comparison between systems

The parameters that should be analyzed and compared for the different strategies are the SINR histograms, the cdf of the average cell throughput and the utility function, changing the power levels and band partition, through a variation of ε and β.

With this, a complete set of different scheduling strategies commonly referenced in the literature [5][6], will be analyzed and compared in detail.

Figure 4 represents the SINR cdf for fixed reuse 1 (R1) and reuse 3 (R3) strategies. As is expected R3 shows higher SINR values (at 5th percentile the difference is around 10 dB). This improvement in quality, and consequently in the throughput per RBG, only compensates the reduction in bandwidth per cell (from B to B/3) being the cdf of the average capacity per cell slightly worse than for R1 system. So, even considering that R3 improves the capacity of UEs at the cell edge, reducing their interference level, it is slightly worse in terms of overall cell capacity. This can be observed in Figure 5 where the cdf of the cell throughput (in bits/s/Hz) is represented. For this reason there is a narrow variation in terms of capacity. In the rest of the paper the capacity will be represented in terms of the cdf of the UEs throughput expressed in bits/s.

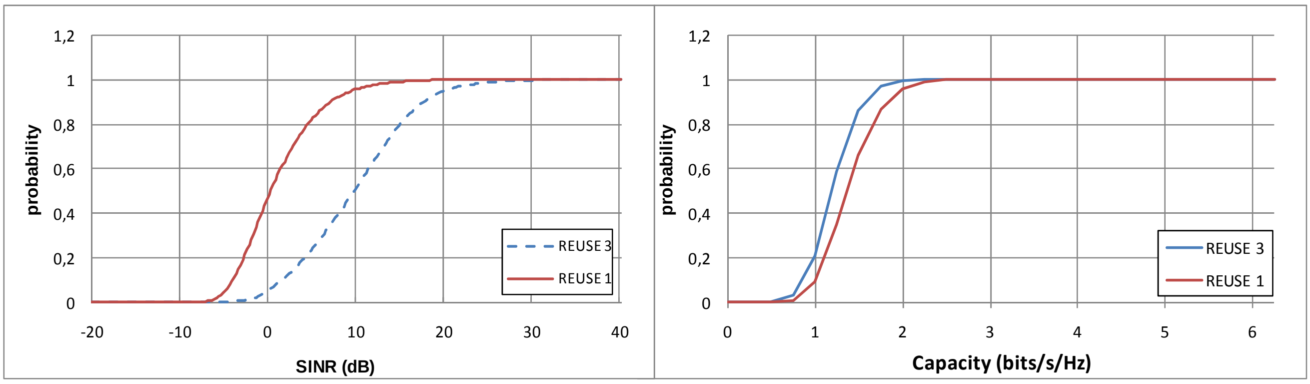
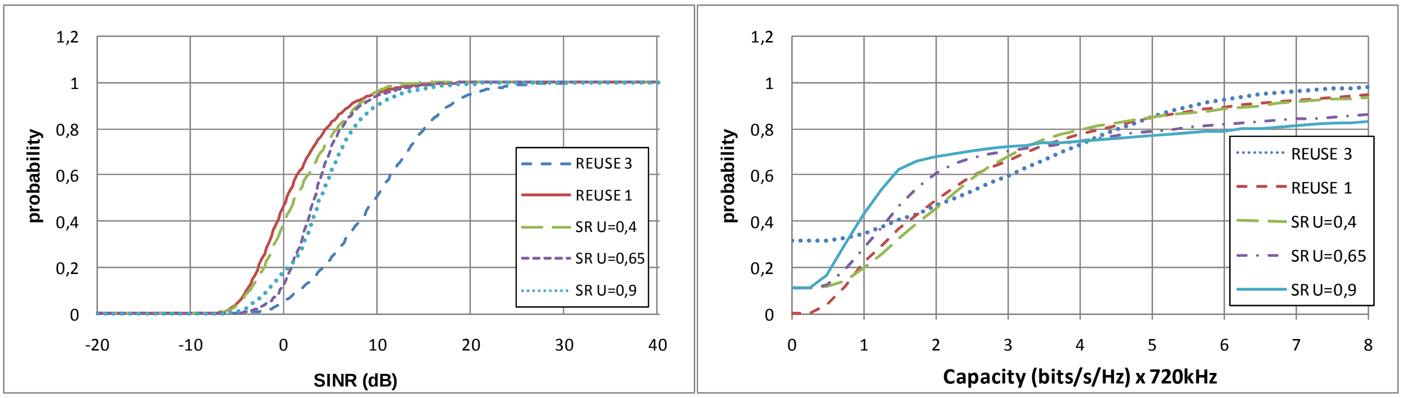


Figure 4 and 5: cdf of the SINR and the cell average throughput for fixed reuse schemes R1 and R3

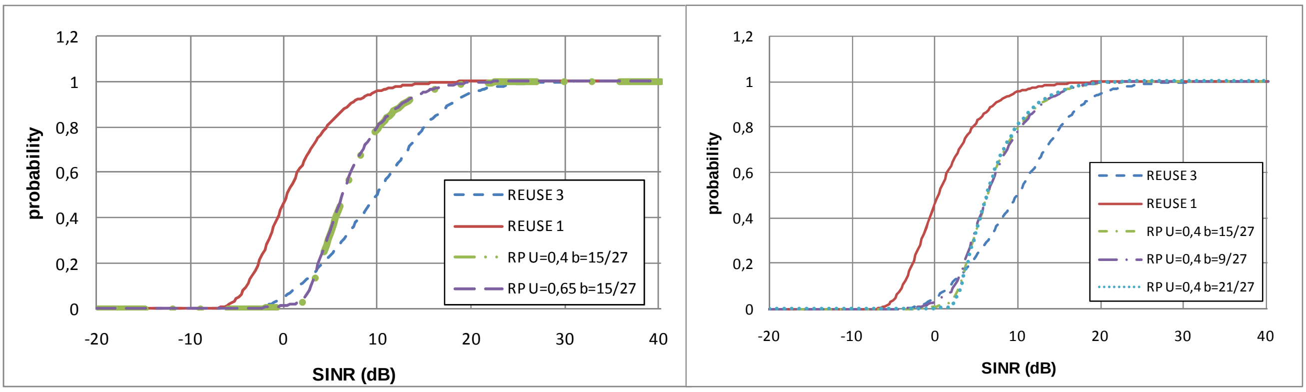
Figure 6 represents the SINR cdf for three different soft frequency reuse schemes (with different utility factors, this is with different ε values). As a reference, the cdfs for fixed reuse R1 and R3 have been also represented. It can be seen that the three statistics are in between both figures, being closer to R1 patterns. This is due to the fact that UEs transmitting the low level $\varepsilon P_{T,max}$ (those close to the eNB) will have a low SINR and consequently a low capacity. So this strategy is worse in terms of SINR distribution compared with fixed R3. What is significant is that SR U=0.4 (Soft Frequency Reuse with utility factor equal to 0.4, this is with ε=0.1) is quasi identical to R1. It is important to notice that SR is a technique not oriented to improve the SINR, but only to improve the throughput of the cell edge UEs.



Figures 6 and 7: cdf of the SINR and UEs throughput for different Soft Frequency Reuse Schemes (ε=0.1, 0.475 and 0.85)

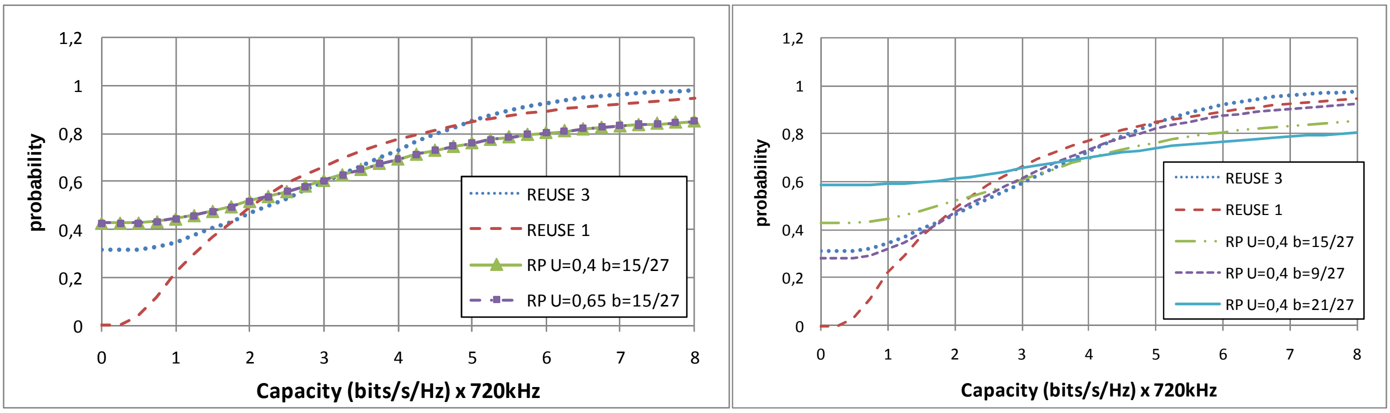
In Figure 7 the cdf of the UEs throughput has been represented (horizontal axis has been normalized by the RBG bandwidth, so axis values have to be multiplied by 720 KHz to obtain bits/s). The three cases analyzed correspond to ε=0.1, 0.475 and 0.85. Utility 0.9 means ε=0.85 being this case close to R1 and R3 from the 4th percentile to the 10th percentile. From the 8th percentile to the 10th percentile ε=0.1, 0.475 offer better performance (able to achieve higher capacity than the other systems). This is due to the fact that while reserving one third of the band quite free from interference for the cell-edge UEs, they are able to simultaneously serve internal UEs with a relatively high power and therefore with high throughput. It can be also appreciated that except in the R1 scheduling, the other strategies have the first percentile with really low throughput or even with UEs that cannot be attended, being the worst case R3. Also the value of around 3rd percentile where R3 has a throughput zero is due to the fact that 15 UEs per cell are considered, and there are only 27/3 RBGs to be assigned so one third of the UEs will not be served.

In figures 8 and 9 the performances in terms of SINR distribution are represented giving R1 and R3 curves as a reference. In figure 8 half of the band is a R1 with low transmitted power, while the other half is with a fixed reuse 3 and with maximum transmitted power. The only parameter that changes is the utility value (this is, the low power level). Both figures show the same performance and are identical, so the power level here is not important. It can be seen that low SINR values disappear and a narrow cdf is obtained (variation between 3 and 20 dB) while in the R1 the variation is between -8 dB and 15 dB. The 1st percentile shows a difference of around 10 dB in SINR and this difference is reduced being of around 5 dB at the 8th percentile. Also for low SINR the values are better than for R3 scheduling (they cross at the 1st percentile). Changing the band division as is done in Figure 9, show the same performances, except that for low SINR there are slightly differences between the values, being the 9/27 division (a low subband for the low power level) the worst one (the one that is closer to R3 behavior).



Figures 8 and 9: cdf of the SINR varying Utility maintaining constant β, and with fixed Utility but changing β

When comparing both parameters in terms of capacity it can be seen againt that there is no influence on the transmitted power level (Figure 10) because both curves are identical, but in any case this scheduling schemes experiences a clear advantage compared with fixed R1 system from the 5th percentile, and are better than R3 from the 6th percentile. Below the 4th percentile the throughput is zero, meaning that this scheduling strategy has not been combined with a proportional fair scheduling, as has been already mentioned in the theoretical analysis. Finally in figure 11 it can be appreciated that if β is equal to 9/27 (remember that βB_{tot} is the part of the spectrum associated to the low transmitted power $\varepsilon P_{T,max}$) the results are similar to fixed R3, while for 21/27 most part of the spectrum is for low transmitted power, leaving few RBGs for the reuse 3 strategy (and of this RBGs only one third can be used because the other two thirds are for the other cells). So many external UEs would not be served, increasing considerable the percentile of UEs with throughput zero. So there β has a great impact on the UEs throughput and should be carefully adjusted.



Figures 10 and 11: cdf of the UE throughput Utility maintaining a constant β, and with fixed Utility but changing β

4. Conclusions and further work

Through the comparison between all the tested algorithms and scheduling strategies, it is difficult to choose which one is better, or which one should be used depending on traffic load and measured interference levels. This is due to the fact that only static snapshots have been done so far, and that no real traffic has been simulated, so each UE is able to use all the bandwidth assigned to the cell (each UE has associated an infinite buffer). Moreover, depending on the bandwidth subdivision some cell regions have not enough resources to guarantee a minimum UE throughput, so there are UEs that will not be served. This causes a high dispersion in the cdf curve.

In terms of SINR distribution R3 is the one showing the best performance, while R1 is the worst. Soft Reuse and Frequency Partitioning strategies are in between both, being in general Soft Reuse closer to R1 and Frequency Partitioning a bit closer to R3.

In terms of capacity, not all the results are easy to justify and require a more detailed analysis. Maintaining a static scenario is interesting to obtain separate statistics for the internal and external UEs to see whether the different strategies favor one or other type. This is difficult to be answered by looking to the cell capacity or to the cell throughputs.

After this the next step will be the implementation of a dynamic simulator to be able to test the influence of time variations, finite buffers, traffic models and multipath variation.

Acknowledgment

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