Improving energy efficiency in cellular networks using multicell cooperation

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Abstract—The main objective of this work was to study the impact of Coordinated Multipoint’s (CoMP) technique Joint Transmission (JT) in Long Term Evolution (LTE) networks, concerning both capacity and fairness. Two models were developed and implemented in an existing LTE simulator. One of the models makes the decision on which UEs use JT while the other does the scheduling of the radio resources. The impact of both this technique and these models were studied and the input parameters that guarantee the highest gain in fairness and the lowest loss in throughput were estimated. A reference scenario was simulated that consists in the same LTE network but not using the technique JT. Using JT, the best result obtained compared to the reference scenario was a gain of 11.4% in fairness and a loss of 6% in throughput. Higher gains in fairness were achieved but at the cost of higher losses in throughput.

Index Terms—LTE, CoMP, JT, Fairness, Throughput.

I. INTRODUCTION

In 2014, mobile networks have shown a huge increment in capacity [1]. It is mandatory for mobile operators, and technologies, to keep up with the market’s demand. Given the lack of radio spectrum available, the main ways to do this are by: increasing spectral efficiency, same frequency reuse in all cells, and decreasing the coverage area of cells.

LTE Release 11 [2] specified CoMP technique. CoMP uses cooperation among adjacent cells or sectors to increase system capacity and/or coverage mainly by decreasing the inter-cell interference. This technique can be used in LTE-Advance (LTE-A) networks. CoMP has techniques for both downlink and uplink. The cooperation groups of cells using CoMP are called clusters.

The available techniques for DL are Joint Processing (JP) and Coordinated Scheduling/Beamforming (CS/CB). JP divides into two techniques: JT and Dynamic Point Selection (DPS). JT consists on sending data from more than one transmission point to an User Equipment (UE), using the same radio resource. It’s guaranteed that interference will be lower using JT since the highest sources of interference before will be now sending data to the UE instead. On the other hand, DPS sends data from the transmission point that has the highest quality of signal at a given time. While doing so, it is possible to mute the main sources of interference. Both JT and DPS can be used at the same time. Using CS/CB, the transmission is done from only one point but the scheduling and beamforming is coordinated by the cluster. As in DPS, muting can be used to minimize interference.

Two techniques are available for UL: Joint Reception (JR) and CS/CB. On JR, data is received by multiple points in order to increase signal quality. On CS/CB the scheduling is done by the cluster but the data is only received by one point.

In order to study the impact of JT in a LTE-A network, this technique was implemented in an existing LTE simulator, LTE Downlink System Level Simulator v1.7 r1119 [3]. Three conditions were created to decide which UEs use JT and two schedulers were developed. Multiple scenarios were simulated to find out which input parameters get the best results, taking into account fairness and throughput.

II. SIMULATOR

The simulator LTE Downlink System Level Simulator v1.7 r1119 [3] used on this work was developed by Institute of Communications and Radio-Frequency Engineering of Vienna University of Technology. It runs on Matlab and its flowchart is illustrated on Figure 1.

Fig. 1: LTE Downlink System Level Simulator v1.7 r1119’s flowchart [3].

It starts by reading and storing the input parameters that define...
the simulation and are not changed throughout the same. On
the second block, the simulator loads an available scenario,
which can be defined by the user and stored on a file to simplify changing from scenario to scenario. The network is then created by the simulator according to the input parameters and the scenario chosen.
Apart from the number of eNodeBs (eNBs), it is also required which of those will form the region of interest (ROI). The performance of the network will only be calculated for those eNBs, as the others will only act as sources of interference. The number of UEs is specified per sector, and they can be static or mobile.
The radiation pattern of the eNB’s antennas is modulated in 3D [4]. This model has as input parameters: height of eNB and UE, mechanical/electrical downtilt, type of the antenna and bandwidth.
The models implemented in the simulator to calculate the free space pathloss are described in [5]. In this work, model TS36942 for urban scenarios is used. Concerning the shadow fading, for each eNB it’s generated a lognormal-distributed 2D space-correlated shadow fading map [6]. The input parameters for this model are: map resolution, number of neighbours the algorithm takes into account when space-correlating the shadow-fading maps, mean and standard deviation of the log-normal distribution, and inter-site shadow fading correlation. The correlation between the sectors in a site is fixed to 1, meaning that for a given point in the map and a given eNB, the three sectors of that eNB have the same value of shadow fading.
It is then generated the macroscopic pathloss maps for each sector. To generate these maps, it is taken into account radiation pattern, free space pathloss and shadow fading. It is now possible, given a point in the map, to know which sector has the lowest macroscopic pathloss value.
Fast fading is then calculated using the model Wireless World Initiative New Radio (WINNER II) [7]. This model takes into account the number of antennas both in the receiver and transmitter, system’s bandwidth, UE’s speed, fading’s correlation over time and the duration in seconds.
Before the main loop, UEs are attached to sectors based on the macroscopic pathloss maps. The model that decides which UEs will use JT was implemented at this stage, and it’s described in Section III.
The first function in the loop consists on calculating Signal to Interference plus Noise Ratio (SINR) and Channel Quality Indicator (CQI), as well as Rank Indication (RI) and Precoding Matrix Indicator (PMI) if they are required, depending on the transmission mode being used. In this work there is no delay between the feedback and the transmission. SNR to CQI mapping used by the simulator is represented in [5].
After eNBs receive the feedback from the UEs, the scheduling of the radio resources is done. The schedulers available are described in [5]. It’s at this stage that the schedulers presented in Section IV are implemented. The metric fairness is calculated in this simulator according to [8]. Data is then sent to the UEs using Transport Blocks (TBs). In the end of the simulation, results are printed on the screen and in a file. A more detailed approach on the simulator and its models is available in [9].

III. USE OF JOINT TRANSMISSION

The first model has the purpose of deciding which UEs will use JT, and was implemented in the block “Network Creation” in Figure 1. Each UE using JT can be connected to 2 or 3 sectors, depending on the input parameters. Concerning cluster formation, four different types of cooperation were defined. They are static throughout all simulations and are described in [9].
As in the simulator without changes, UEs are firstly connected to the sector that presents the lowest value of macroscopic pathloss. This sector is called the main sector.
Three conditions were created to decide whether or not a UE will use JT. These conditions use three new variables: relation between the radius as of it is considered edge of a cell and the radius of a cell (\(R_{\text{min}}\)), maximum value of macroscopic pathloss to the main sector that justifies looking for another sector (\(PL_{\text{max}}\)), and the maximum difference between the macroscopic pathloss value of the main sector to the side sectors (\(\Delta PL_{\text{max}}\)). The first conditions says that a given UE looks for a better sector if it’s located in the edge of the cell, if its distance to the main eNB is higher than \(R_{\text{min}}\). After fulfilling either condition 1 or 2, UEs look for a secondary sector. UEs only connect to this secondary sector if it fulfills condition 3, meaning that its macroscopic pathloss value must be lower than the value of the main sector plus the variable \(\Delta PL_{\text{max}}\). If it’s possible to connect to a third sector, considering the input parameters, this third sector needs only to fulfill condition 3.

IV. SCHEDULERS

The scheduling of RBs was changed in order to synchronize UEs using JT in all sectors. If a given UE is using JT, he must have the same RBs in all the sectors that are serving him at a given TTI. This is done right after the main scheduling, in block “Scheduler”, Figure 1. Two schedulers were developed: scheduler 1 and scheduler 2. Either one or the other is executed after one of the default simulator’s scheduler. Scheduler 1 is executed for every UE belonging to the ROI, while scheduler 2 for every sector in the ROI.

A. Scheduler 1

Figure 2 shows the flowchart of scheduler 1.
In the first place, scheduler 1 calculates for a given UE their positions in the RBG for his sectors. Positions are calculated under the form of a vector, and each UE will have a vector for each sector he is connected to. Each position of the vector indicates a RB that the UE has in the current TTI, in the corresponding sector. Then the scheduler starts a loop where at each iteration it deals with a position of the 2/3 sectors. In turns, one of the values of one vector is taken as the reference, and the scheduler tries to change the other(s) vector(s) to that value. The swap is done if: that RB is not allocated yet, or the UE for which it belongs is not using JT, or the identifier (ID)
Get RB’s positions

Change RB

Last RB?

Clean isolated RBs

No

Fig. 2: Flowchart of scheduler 1, executed for every UE in the ROI.

The first block is executed to every sector, while the remaining 3 blocks are executed to sectors of the RDI. Each block is executed to every sector and only then it advances to the next block. In the first block, UEs using JT are taken out of every RBG and replaced by normal UEs. Then every RB belonging to the part of the RBG dedicated to JT are freed.

In the second block, each sector allocates one RB to each UE using JT that has that sector as his main. This allocation is only possible if the RB is still free in the side sectors. This way, each UE using JT will have access to at least one RB before RBGs start to fill. In the third block, the remaining RBs are allocated to UEs using JT. Each sector uses a priority vector in which its first position has the UE with the lowest number of RBs, and the last position the UE with the highest number of RBs. To avoid the possibility of a UE having too many RBs, the following condition was created:

\[
N_{RB} > \frac{N_{RB}/RBG}{N_{UEs}} + C_d
\]  

where:
- \(N_{RB}\): UE’s number of RBs;
- \(N_{RB}/RBG\): total number of RBs in each RBG;
- \(N_{UEs}\): number of UEs connected to the sector;
- \(C_d\): equality constant.

If an UE has too many RBs, he is taken out of the priority vector and loses the possibility of having more RBs allocated to him. The value of \(C_d\) is an input parameter. In the last block, RBs unoccupied are allocated to normal UEs.

V. ANALYSIS OF RESULTS

The system simulated was a LTE network consisting on 2 rings of tri-sectorized eNBs. The first ring is the ROI. Most of the input parameters are constant throughout all simulations, and are displayed in Table I.

A more detailed description of the input parameters used is in [9].

The models implemented were simulated in order to estimate their input parameters that get the best results, taking into account throughput and fairness. Each parameter was simulated and optimized separately, one at a time. Every scenario was compared to a reference scenario, which can be consulted in [9]. In this scenario it’s not used JT.

A. Macroscopic Pathloss Difference

The first parameter to be analysed was \(\Delta P_{L_{max}}[dB]\), concerning condition 3. Table II shows the parameters used. Parameter \(R_{min}\) equals to 0 and \(P_{L_{max}}\) equals to \(\infty\) means that every UE will fulfil condition 1 and 2. \(RBG_{JT}\) defines the percentage of the RBG that will be dedicated to UEs using JT. If it’s equal to 0, scheduler 1 will be used instead. \(Cluster_{CoMP}\) defines the cooperation clusters used: 1 for all the network being one cluster, 2 for groups of 2 eNBs, 3 for groups of 3 eNBs, and 4 for intra-eNB cooperation only. \(eNB_{max}\) defines the maximum number of sectors a UE can be connected to. Figure 4 shows the fairness and throughput obtained. When \(\Delta P_{L_{max}}\) is equal to 12 dB, 58.7% of UEs
TABLE I: Constant input parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency [GHz]</td>
<td>2.6</td>
</tr>
<tr>
<td>Bandwidth [MHz]</td>
<td>20</td>
</tr>
<tr>
<td>Minimum Coupling Loss [dB]</td>
<td>70</td>
</tr>
<tr>
<td>eNB Number of Transmitter Antennas</td>
<td>2</td>
</tr>
<tr>
<td>Transmission Mode</td>
<td>4</td>
</tr>
<tr>
<td>Transmission Power [W]</td>
<td>46</td>
</tr>
<tr>
<td>Site Altitude [m]</td>
<td>20</td>
</tr>
<tr>
<td>Scheduler</td>
<td>Round Robin</td>
</tr>
<tr>
<td>UE Number of Receiver Antennas</td>
<td>2</td>
</tr>
<tr>
<td>Receiver Height [m]</td>
<td>1.5</td>
</tr>
<tr>
<td>Receiver Noise Figure [dB]</td>
<td>9</td>
</tr>
<tr>
<td>Thermal Noise Density [dBm/Hz]</td>
<td>-174</td>
</tr>
<tr>
<td>Pathloss Model</td>
<td>TS36942</td>
</tr>
<tr>
<td>Environment</td>
<td>Urban</td>
</tr>
<tr>
<td>Slow Fading Model</td>
<td>Claussen</td>
</tr>
<tr>
<td>Map Resolution [m/pixel]</td>
<td>5</td>
</tr>
<tr>
<td>Mean</td>
<td>0</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>8</td>
</tr>
<tr>
<td>Inter-eNB Correlation</td>
<td>0.5</td>
</tr>
<tr>
<td>Fast Fading Model</td>
<td>Winner+</td>
</tr>
<tr>
<td>Correlation Over Time</td>
<td>Yes</td>
</tr>
</tbody>
</table>

TABLE II: Input parameters used to assess parameter $\Delta PL_{max}$.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Transmission</td>
<td>1</td>
</tr>
<tr>
<td>$R_{min}$</td>
<td>0</td>
</tr>
<tr>
<td>$PL_{max}$ [dB]</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$\Delta PL_{max}$ [dB]</td>
<td>[3; 6; 9; 12]</td>
</tr>
<tr>
<td>$RBG_{JT}$</td>
<td>0</td>
</tr>
<tr>
<td>$PL_{max}$ [dB]</td>
<td>75, 85, 95, 105</td>
</tr>
</tbody>
</table>

The number of UEs using JT is lower than in the first scenario, which means that UEs use JT even when their radius is lower than 0.25. UEs connected to 2 sectors can occur throughout the cell, while UEs connected to 3 occur mostly for a $R_{min}$ higher than 0.7. Neither one of these values of $R_{min}$ presented better results than the first scenario, so condition 1 will be discarded.

C. Maximum Macroscopic Pathloss

The values used in this scenario for variable $PL_{max}$ are: 75, 85, 95, 105. Results are shown in Figure 6.

The number of UEs using JT when $PL_{max}$ is equal to 75 dB is practically the same when condition 3 is not applied. Concerning UEs connected to 2 sectors, 80.4% of these have a $PL_{max}$ between 85 dB and 105 dB, while 65.1% of UEs connected to 3 sectors have a $PL_{max}$ between 95 dB and 105 dB. To a $PL_{max}$ of 75 dB, this scenario is similar to the one where $\Delta PL_{max}$ was assessed, since the number of UEs use JT and the fairness increases in 22.2% and throughput decreases 32.8%. For a $\Delta PL_{max}$ equal to 3 dB, 19.7% of UEs use JT and fairness has a gain of 11.6% and throughput has a loss of 8.7%. When the number of UEs using JT increases, throughput decreases since these UEs are costly to the system given the fact that they use more RBs than normal UEs. The gain in power is not high enough to make up for this, especially if the difference in macroscopic pathloss for the main sector is high. On the other hand, if it’s low, the fairness can increase substantially considering the loss in throughput. The value for $\Delta PL_{max}$ used in the remaining simulations was 3 dB.

B. Minimum Radius Edge

Every simulation will use the values in Table II with $\Delta PL_{max}$ equals to 3 dB. This scenario will assess parameter $R_{min}$ with the following values: 0.5, 0.7, 0.9. Figure 5 shows the fairness and throughput obtained.

Fig. 5: Fairness and mean throughput per sector for multiple values of $R_{min}$.
using JT is roughly the same. The first value obtained the best results, as the fairness kept on decreasing and the throughput only increased to the last value. Condition 3 is then discarded.

D. Maximum Number of Sectors

The two values tested for variable $eNB_{max}$ were: 2, 3. Results can be seen in Figure 7.

Throughput per group of UE is higher when $eNB_{max}$ is equal to 2 given the fact that there are more RBs available. Fairness is practically the same in the 2 cases, but throughput has a loss of 1.34 Mbit/s when $eNB_{max}$ is 3. Even though a $eNB_{max}$ equal to 2 gets the best results, this variable will be 3 in the remaining simulations in order to get a better understanding on how UEs connected to 3 sectors are affected.

E. CoMP Clusters

The values used for variable $Cluster_{CoMP}$ are: 1, 2, 3, and 4. Figure 8 shows the results for this scenario.

The number of UEs connected to 2 sector decreases 50\%.

F. Scheduler 2

In the last scenario, scheduler 2 is assessed with the values: 0.3, 0.4, 0.5. Figure 9 shows the results for this scenario.

Scheduler 2 allows UEs connected to 3 sectors to more easily obtain RBs. If $RBG_{JT}$ is too high, every UE not using JT will have access to a small number of RBs. This is a problem specially for UEs in the edge of the cell that were not able to connect to a second sector.

VI. CONCLUSION

The main objective of this work was to study the impact of JT in LTE networks. Altogether, 3 conditions on the use of JT and 2 schedulers were implemented and simulated. Condition 1 and 2 proved to have no beneficial improvement in the results. Condition 3, $\Delta PL_{max}$, proved to be enough to decide on which UEs to use JT. The best results were obtained when variable $eNB_{max}$ was equal to 2, with a gain in fairness of 11.4 \% to a throughput loss of 6 \%. UEs connected to 3 sectors are too expensive to the network.

REFERENCES