Analysis of Macro-Fem to Cellular Performance in Long-Term Evolution under Various Transmit Power and Scheduling Schemes

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Abstract—Mobile networks use femtocells as low-power nodes to improve indoor coverage and thus achieve a high network capacity. In this paper, we focus on a combination of macrocells and femtocells in Long-Term Evolution (LTE) networks. In order to achieve a high LTE network performance, we investigate the influence of power allocated to Evolved Node B (eNodeB) and Home eNodeB (HeNodeB). Using the Round-Robin scheduling, while decreasing the eNodeB's transmit power and increasing the HeNodeB's transmit power, improves the user's throughput significantly. We further demonstrate, by simulations, that applying other scheduling algorithms under the low eNodeB transmit power and high eNodeB transmit power results in a significantly increased performance in the LTE network.

Index Terms—Scheduling, transmit power, HetNet, LTE, resource block.

I. INTRODUCTION

Wireless data traffic has exponentially increased in recent years. Driven by many factors like the new generation of devices (smartphones, netbooks, tablets, etc.), highly bandwidth-demanding applications, users' attitude to be always connected to social networks, and other applications, the capacity demand increases much faster than the spectral efficiency improvement [1]. As a result, growth in the mobile data traffic will exponentially increase in the next few years.

Heterogeneous mobile networks are the solution for improving systems' capacity as well as effectively enhancing network coverage [2–6]. Moving from macrocentric cellular deployment to small-cell deployment seems to be the only sensible way to generate a 10 or 1000% increase in capacity in the network.

It is estimated that, in cellular networks, two out of three of the calls and over 90% of the data services occur indoors [7]. Hence, it is extremely important for mobile network operators to provide good indoor coverage for not only voice, but also video and high-speed data services, which are becoming increasingly important. So, a very powerful property of heterogeneous networks is, on the one hand, the offloading of the congested macrotraffic and, on the other hand, the improvement of the performance of the majority of mobile communications that are generated indoors. Improvement in performance means high-data-rate, high-capacity, always-on, and always-connected-to-the-best-network user experience [8, 9].

Recently, researchers have carried out some studies concerning the problem of power control in heterogeneous networks [10, 11]. A fully distributed power control algorithm which adapts the pilot power of the femto base station in a heterogeneous network to improve the coverage is explained by the authors of [12, 13]. A different approach that shows an improvement in terms of the capacity of heterogeneous networks by optimizing the transmit power in the uplink under a low signal-to-interference (SIR) regime has been presented by the authors of [14].

Scheduling of resources and interference mitigation are among the key issues in macro/femtocell deployment. A joint uplink and downlink scheduling based on channel state information was proposed in [15]. In contrast, in [16], the authors proposed a method that considers fairness to solve the user's resource allocation problem without considering the interference mitigation problem that occurs because of the difference in the transmit power between macrocells and femtocells in a macro/femto cellular scenario.

Even though a significant number of mobile network operators around the world have already deployed the Long-Term Evolution (LTE) network, they still have difficulties mitigating interference while using the appropriate scheduling algorithm. A distributed resource allocation scheme employing scheduling algorithms in uplink Orthogonal Frequency Division Multiple Access (OFDMA) systems was proposed by the authors of [17]. Proportional Fair Scheduling, which reduces the feedback signaling while keeping the user's throughput, was implemented in [18].

In order to offer an appropriate solution to the mobile network operators, we analyzed three different scenarios of macro- and femtocells in LTE networks using an LTE system-level simulator [19, 20]. This LTE system-level simulator calculates the postequalization signal-to-interference-plus-noise ratio (SINR) per subcarrier [21, 22]. Referring to [23], it is possible to evaluate the performance of the downlink shared channel of LTE Single-Input, Single-Output (SISO) and Multiple-Input, Multiple-Output (MIMO) systems.

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The aim of this paper is to evaluate network performance considering interference mitigation and radio resources scheduling. We used the Empirical Cumulative Distribution Function (ECDF) to evaluate the network's performance in terms of the average user's throughput and the user's wideband SINR. In the first and second scenarios, we used the Round-Robin scheduling algorithm [24] and analyzed the network's performance when the macro base station (eNodeB) and femto base station (HeNodeB) transmit power varies. In the third scenario, we analyzed the network's performance when four scheduling algorithms were applied under the condition of minimized interference: Round-Robin, Best CQI [25], Proportional Fair Sun [26], and Max Throughput [27]. A comparison in terms of the average throughput, fairness index, and mean resource block (RB) occupancy was performed.

II. System Model

In this section, we present a macro/femto cellular system model. This model consists of a cluster containing seven macrocells with a homogenous distribution of femtocells within macrocells. We use sectorized macrocells where in each sector there were four femtocells.

The network model is shown in Fig. 1, where all of the considered users are pedestrians, moving at a speed of 5 km/h. The femto users are considered as a Closed Space Group [28] so that the interference between macro and femto users is avoided.

In the SISO case, the SINR for a mobile user is given as in [23]

$$\boldsymbol{SINR} = \frac{P_{tx}}{\frac{1}{|h_0|^2}\sigma^2 + \sum_{l=1}^{N_{int}} \frac{|h_l|^2}{|h_0|^2} P_{tx,l}}, \quad (1)$$

where $\frac{1}{|h_0|^2}$ and $\frac{|h_l|^2}{|h_0|^2}$ are the noise and interference parameters. In Eq. (1), the macroscopic path loss between eNodeB and user equipment (UE) and between HeNodeB and UE is modeled by two components: propagation loss due to distance and antenna gain.

We use the path-loss model for urban areas [29] as expressed by the following equation:

$$\boldsymbol{L = 40(1 - 4 \times 10^{-3} \times Dhb) \times \log_{10}(R) - 18 \times \log_{10}(Dhb) + 21 \times \log_{10}(f) + 80dB} \quad (2)$$

where R is the distance between the base station and the UE in kilometers, f is the carrier frequency in MHz, and Dhb is the base station's antenna height in meters, measured from the average rooftop level.

Considering a carrier frequency of 2,014 MHz and a base station antenna height of 15 m above the average rooftop level in Eq. (2), we have the following formula for the propagation model:

$$\boldsymbol{L = 127.68 + 37.6 \log_{10}(R)}. \quad (3)$$

After the propagation model (L) is calculated from Eq. (3), log-normal distributed shadowing (LogF) with a standard deviation of 10 dB is added to it. A shadowing correlation factor of 0.5 for the shadowing between sites (whether an aggressive or a victim system) and a factor of 1 between sectors of the same site is used.

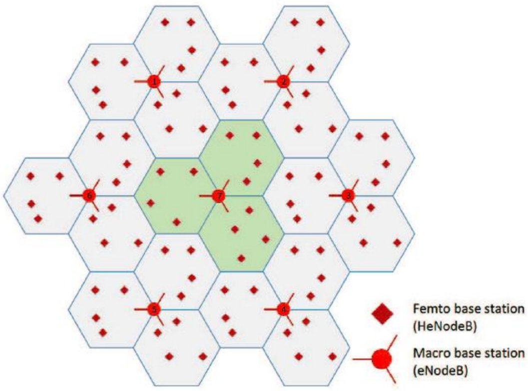

Fig. 1. Distribution of eNodeB and UE in LTE macro/femto deployment.

The path loss is given by the following equation:

$$\boldsymbol{Pathloss_{macro} = L + LogF}. \quad (4)$$

The standard 2D radiation pattern G in Eq. (4), for each sector in a three-sector cell site, dependent on the azimuth angle θ, is given by the following expression:

$$\boldsymbol{G(\theta) = -min\left[12\left(\frac{\theta}{\theta_{3dB}}, A_m\right)\right]}, \quad (5)$$

where θ_{3dB} is the 3 dB beam width that corresponds to 65 ° and A_m = 20 dB is the maximum attenuation. The antenna gain is 15 dBi.

III. Simulation Results

TABLE I: Simulation parameters.

Parameter	Value
Carrier frequency	2.14 GHz
Transmission bandwidth	20 MHz
Number of transmit antennas (*n*Tx)	1
Number of receive antennas (*n*Rx)	1
Transmit mode	CLSM
Macroscopic path loss, urban	TS 36.942
Channel model	Winner+
Shadow fading	Claussen
Number of eNodeB rings	1
Number of femtocells per cell	4
Number of users per eNodeB	15
Number of users per HeNodeB	3
User speed	5 km/h
Antenna type	Kathrein antenna with a 15 dBi gain

In this section, we evaluate the possible deployment scenario of LTE heterogeneous networks using the Vienna LTE system-level simulator. In such network, we evaluate different transmit power and scheduling schemes.

Some of the simulation parameters are defined as follows. The maximum transmit power recommended by [30] for a 10–20 MHz carrier is 46/49 dBm, whereas we consider the range of power level for femtocells between

50 and 200 mW. For macrocell base stations, we consider the range of power level between 10 and 40 W using a 20 MHz carrier.

The other network simulation parameters are shown in Table I.

A. The Effect of HeNodeB Transmit Power on Macro/Femto Deployment Using Round-Robin Scheduling

In this subsection, we evaluate the impact of the femtocell transmit power in an LTE network using the Round-Robin scheduling algorithm. We also analyze the network performance of macro/femtocell topology, using constant eNodeB transmit power and variational HeNodeB transmit power.

We used the simulation parameters given in Table I and the LTE system-level simulator to provide the simulation results based on ECDF calculation. The ECDF of the average user's throughput is shown in Fig. 2.

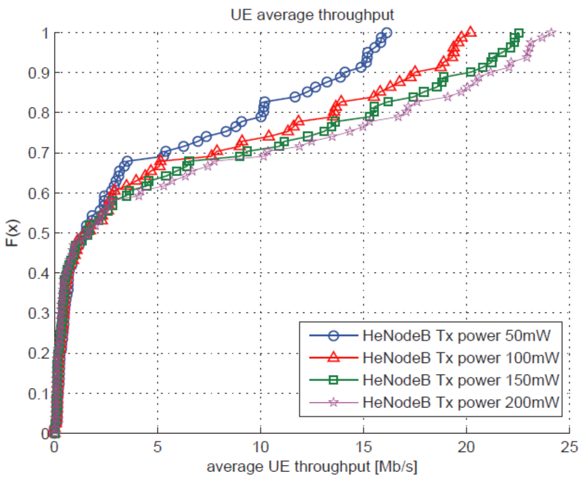

Fig. 2. ECDF of the average UE throughput for variable HeNodeB Tx power.

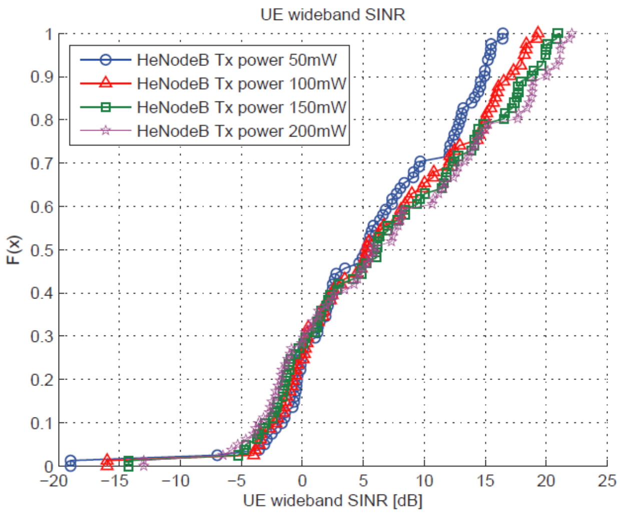

Fig. 3. ECDF of the wideband SINR for variable HeNodeB Tx power.

The simulation results shown in Fig. 2 indicate that the increase in the HeNodeB transmit power has no impact on the user's throughput until the value of 3 Mbps. In this case, the eNodeB transmit power is set to a constant value of 46 dBm. One can see that a higher throughput is achieved for a higher transmit power of HeNodeB, in this case for 200 mW. The increase of the user's throughput shown in Fig. 2, even when the HeNodeB transmit power is increased, occurs as a result of the low-power operation of HeNodeB compared to eNodeB, which results in a low interference. The ECDF of users versus wideband SINR is shown in Fig. 3.

Similar to the results shown in Fig. 2, the simulation results shown in Fig. 3 indicate higher values of users' wideband SINR for higher HeNodeB transmit power.

B. LTE User Throughput under Different Scheduling Algorithms

In this subsection, we show by simulations the positive impact of HeNodeB on the user's throughput in a macro/femto cellular scenario that employs the Round-Robin scheduling algorithm.

In order to compare the influences of different scheduling algorithms on LTE users' throughput, we used the simulation parameters in Table I in the LTE system-level simulation. The transmit power for HeNodeB was set to 20 dBm and that for eNodeB was set to 46 dBm. In this scenario, we compared four scheduling algorithms: Round-Robin, Best CQI, Proportional Fair Sun, and Max Throughput. The performance evaluation of the mentioned scheduling algorithms in terms of the user's average throughput, fairness index, and mean RB occupancy is given in Table II.

TABLE II: RESULTS FOR DIFFERENT SCHEDULERS.

Scheduler	Results		
	Avg. throughput	Fairness index	Mean RB occupancy
Round-Robin	5.61 Mbps	0.398	90.93%
Best CQI	9.74 Mbps	0.372	98.76%
Prop. Fair Sun	7.88 Mbps	0.435	93.88%
Max Throughput	9.72 Mbps	0.366	97.98%

For average throughput comparison, the best performance schedulers are Best CQI and Max Throughput, which offer the highest throughput rate. Round-Robin offers the lowest throughput because this algorithm does not consider channel conditions. No big difference was found between Best CQI and Max Throughput; these two algorithms are quite similar in terms of throughput, fairness index, and mean RB occupancy. The Proportional Fair Sun algorithm has the highest fairness index of 0.435, meaning that 43.55% of the users are served with a fair share of resources, whereas for the rest of the users, the sharing of resources is unfair.

In Fig. 4, the ECDF of the average user's throughput is shown.

From the simulation results shown in Fig. 4, one concludes that, with Best CQI and Max Throughput, a higher UE average throughput can be achieved compared to Round-Robin and Proportional Fair Sun.

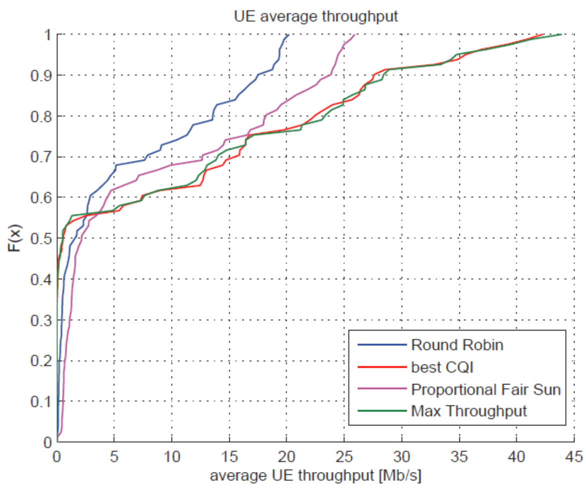

Fig. 4. ECDF of the average UE throughput for different schedulers.

IV. Conclusions

In this paper, we evaluated the performance of LTE networks in a macro/femtocell scenario using an LTE system-level simulation. From the simulation results, we noticed that when the eNodeB transmit power is reduced, the system's performance improves in terms of average user's throughput and wideband SINR. By contrast, if the HeNodeB transmit power is increased, the system's performance will be improved for the same scenario. Furthermore, we investigated the impact of scheduling algorithms and found that the decision of mobile network operators to use the scheduling algorithm in LTE and LTE-Advanced networks is a tradeoff between average throughput and fairness index of resource sharing. If the radio resources are not scarce, then the best schedulers will be Max Throughput and Best CQI, which offer the highest throughput. If the radio resources are to be shared in a fair manner with the users, then the best scheduler will be Proportional Fair Sun, but the average throughput will not be as high as for Best CQI.

As future work, we plan to compare the simulation results with real data from LTE operators.

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