LTE multi-cellular system in urban environment: inter-cell interference Impact on the Downlink radio transmission

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Abstract- The fourth-generation networks based on OFDMA (3GPP LTE) (3rd Generation Partnership Project Long Term Evolution) offer high bit rate and takes into account in their mechanisms the simplicity and efficiency of the radio transmission. But with the volume of traffic constantly increasing, especially in high density population environments, the reuse of bandwidth is the only effective way to increase the capacity in LTE system.
The conventional approach to improve the spectrum efficiency is to reuse the same frequency band in multiple geographic areas or cells. However, inter-cell interference (ICI) will inevitably disadvantageous, when the mobile stations or users in adjacent cells share the same spectrum. High mobility makes the situation worse. The SINR at the Cell-edge may be so poor that even the most robust control channel PDCCH cannot function properly. This is one of the major problems limiting the performance of LTE (Long Term Evolution).
This work studies the impact of inter-cell interference on the downlink LTE radio systems in multi-cellular urban environment that meets the specifications of the 3GPP, and deals with the challenge to optimize the SINR in real networks that can be far from the idealistic model of the 3GPP.

Keywords – LTE, LTE Advanced, inter-cell interference, multi-cellular urban environment

I. INTRODUCTION

The increase of mobile broadband users and the emergence of mobile services that require a permanent connection to internet network like social networks (Facebook, Twitter ...) or gaming networks, require improved transmission quality, higher bit rate and enhanced capacity.

Long Term Evolution (LTE), which is developed by 3GPP, brings the cellular communication to the fourth generation (4G). The objectives of LTE are to obtain significantly lower end-to-end latency, higher user data rates, improved system capacity and coverage, and lower cost of operation. But with the volume of traffic constantly increasing, especially in high density population environments the reuse of bandwidth is the only effective way to increase the capacity in LTE system. In this case inter-cell interference (ICI) will inevitably disadvantageous, when the mobile stations or users in adjacent cells share the same spectrum. High mobility makes the situation worse. The SINR at the Cell-edge is so poor that even the most robust control channel PDCCH cannot function properly. [1]

The performance of the LTE network is estimated by the simulation results according to the model of the 3GPP. [2] In test's networks, the simulation performance seem very promising, but after large-scale deployment the actual performance can be worse than expected especially with high population density areas. In this context our work focuses on the impact of inter-cell interference on the performance of Down Link LTE transmission in multi cellular urban environment in terms of user distribution and speed with the respect of 3GPP simulation model requirements.

This paper is structured as follows: After a brief overview of the characteristics and performance of LTE system according to the 3GPP model in part 2, Part 3 will give an outline of the problem of inter-cell interference in LTE Downlink. In part 4 will be presented assumptions, simulation Models in urban areas, and numerical results with their analysis. Finally Part 5 will be dedicated to a general conclusion and the challenge to optimize the SINR in downlink transmission.

II. LTE SYSTEM CHARACTERISTICS AND PERFORMANCE ACCORDING TO THE 3GPP MODEL

LTE system is designed to provide high peak data rate, low latency and to improve capacity and coverage, the system allow the use of multiple antenna and easy integration with existing systems such as WCDMA, HSUPA, CDMA2000, etc..

The 4G LTE-Advanced should ensure backward compatibility and interworking with LTE Release 8 in the sense that it can be deployed in the spectrum already occupied by LTE with no impact on the terminals.Table1 lists the basic requirements of LTE and LTE-Advanced technology. [3]

Table -1 Main requirement of LTE and LTE-Advanced

	LTE		**LTE-Advanced**	
	Downlink	**Uplink**	**Downlink**	**Uplink**
Peak spectrum usage efficiency (b/s/Hz)	**>5**	**>2.5**	**30**	**15**
Average spectrum usage efficiency (b/s/cell)	**1.6-2.1**	**0.66-1.0**	**2.4-3.7**	**1.2-2.0**
Cell-edge spectrum usage efficiency (b/s/user)	**0.04-0.06**	**0.02-0.03**	**0.07-0.12**	**0.04-0.07**
Operating bandwidth (MHz)	**1.4-20**		**Up to 100**	
User plane delay (unidirectional) (ms)	**<5**		**<5**	
Connection setup Delay (ms)	**<100**		**<50**	

The LTE network performance is estimated by the simulation testing results. Figure 1 show the 3GPP model used to simulate the performance of the LTE system.

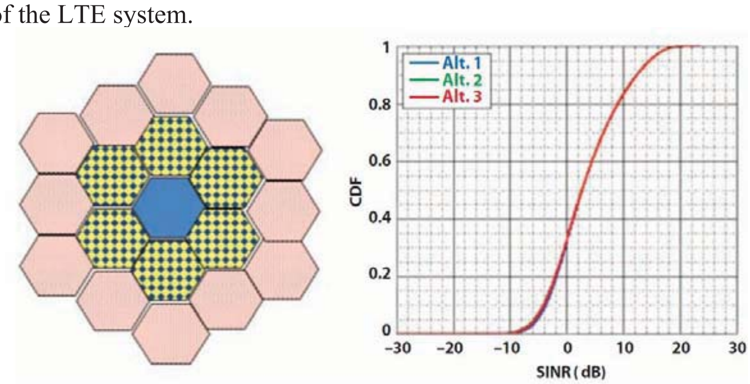


Figure 1. The 3GPP Model used to simulate the performance of LTE system [4].

According to the 3GPP model, the SINR values are rarely below - 8dB. The 3GPP urban test network model contains only 19 hexagonal base stations with OMNI single antennas with uniform population density and mobility less than 30 km/h, the few neighboring cells do not sufficiently contribute to the cell interference even if they are fully charged. Some people believe that interference outside the cell is not important if it comes from cells that are physically far from the central cell. This is not always true in the case of urban areas where cells are close and mobility speed can actually go up to 60 km/h. The next part of this study will discuss the problem of inter-cell interference in down link LTE.

III. THE PROBLEM OF INTER-CELL INTERFERENCE IN DOWN LINK L.T.E

The impact of interference on the achievable data rate for a given user can be expressed analytically. If user k is experiencing no interference, then its achievable rate in an RB (Resource Block) m of sub frame f can be expressed as [5]:

$$D_{k,no-interference} = \frac{B}{M}\log\left[1+\frac{P^f(m,f)\left|H_k^f(m,f)\right|^2}{N_0}\right]$$

Where: M is the number of resources allocated in the band B, and $H_k^s(m,f)$ the gain of the channel of the cell s that serves the user k, P (m, f) is the transmission power of the cell s and N0 is the noise power.

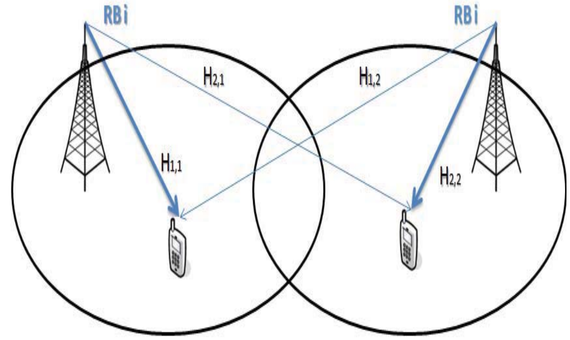


Figure 2. Example of inter-cell interference with two cells

If the neighboring cells to the cell s emit, then it is likely that the same resources are used, and hence the achievable rate for user k is reduced to [5]:

$$D_{k,with\ interference} = \frac{B}{M} log\left[1 + \frac{P^s(m,f)\,|H_k^s(m,f)|^2}{N_0 + \sum_{i \neq s} P^i(m,f)\,|H_k^i(m,f)|^2}\right]$$

With $\sum_{i \neq s} P^i(m,f)\,|H_k^i(m,f)|^2$ the sum of the interference and the index i represents the interfering cells.

The loss of throughput due to interference experienced by user k is [5]:

$$D_{k,perte} = D_{k,no-interference} - D_{k,with\ interference}$$

$$D_{k,perte} = \frac{B}{M} log\left[\frac{1+SNR}{1+\left[\frac{1}{SNR} + \frac{\sum_{i \neq s} P^i(m,f)\,|H_k^i(m,f)|^2}{P^s(m,f)\,|H_k^s(m,f)|^2}\right]^{-1}}\right]$$

With $SNR = \frac{P^s(m,f)\,|H_k^s(m,f)|^2}{N_0}$ is the signal to noise ratio at the receiver input, and $\gamma = \frac{\sum_{i \neq s} P^i(m,f)\,|H_k^i(m,f)|^2}{P^s(m,f)\,|H_k^s(m,f)|^2} = \frac{P_{interference}}{P_{user\ k}}$

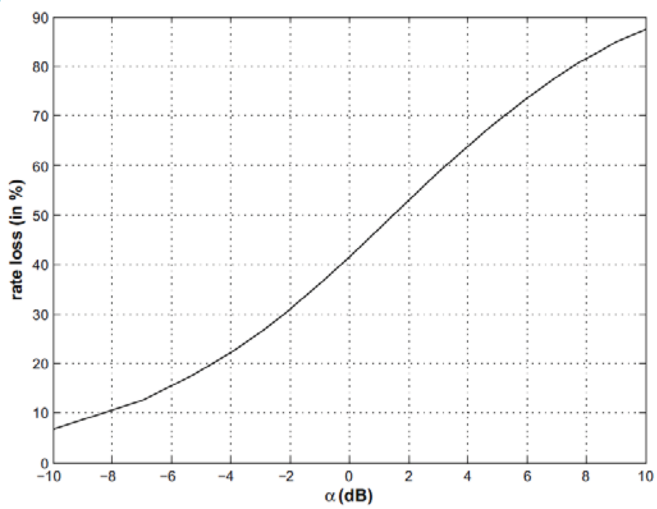


Figure 3. The rate loss for the user k due to the variation of the coefficient $\alpha = 10\log_{10}(\gamma)$ at SNR = 0 dB

In the LTE broadband (reuse factor is 1), the data rate of loss at the Inner-cell will be greater than 8% and less than 40% and in the cell-edge, it is greater than 40% and 90%. This is unacceptable in a system that must ensure high throughput.

In the next part of this paper we will introduce our contribution. It comes to expand simulation models and results to study the impact of inter cell interference on LTE Downlink radio transmission in urban area.

IV. LTE SIMULATION MODELS AND RESULTS FOR DOWNLINK RADIO TRANSMISSION IN URBAN AREA

a- Simulation Models and assumptions:

Simulation Models and assumptions are aligned with the 3GPP recommendations for urban area. Table 3 contains the main parameters of the simulation models. The evaluation method is based on multi-cellular time dynamic simulations.

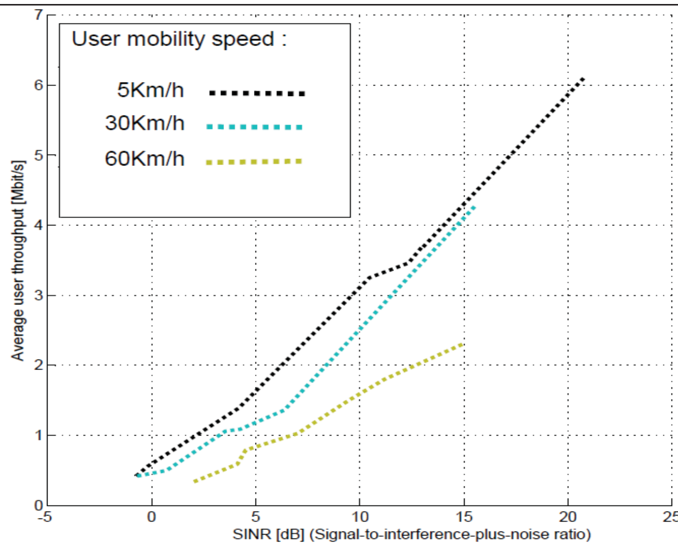
Table -3 Main parameters of the simulation models

Simulation Models	**Model A**	**Model B**	**Model C**
Geometry and number of cells	**Regular hexagonal grid, 19 Cell**	**Regular hexagonal grid, 19 Site With 3 Sector (Cell) by Site**	**Regular hexagonal grid, 19 Site With 3 Sector (Cell) by Site and 1 indoor Femto-cell by Sector[6]**
Settings	**Values**		
Traffic model	**Full buffer**	**Full buffer**	**Full buffer**
Inter cell distance	**500 m**	**500 m**	**500 m**
Radius of the indoor Femto-cell	**Femto-cell note used**		**20m**
Central frequency	**2.14Ghz**		
Used band	**20Mhz by Cell**	**20Mhz by Sector**	**20Mhzby Sector and 20Mhz by indoor Femto-cell**
Path loss Model (Urban area)	**TS36942, Recommended by TS 36.942, sub clause 4.5 [7]**		
Downlink transmission Feedback Channel	**Each 3 T.T.I (Transmission Time Interval)**		
Micro scale fading (between E-node B and attached users)	**Winner II Channel model [Reference channel model vr1.1] [8]**		
Number of users	**10User by Cell**	**10 User by Sector (Cell)**	**10 User by Sector (Cell) and 10 user by indoor Femto-Cell**
Users distribution	**Normal distribution**		
Users speed	**(5km/h -30km/h - 60km/h) and (5km/h in indoor Femto-Cell)**		
Base station power	**46 dBm (B.S does not emit when there's no attached user) (0.1 Watt Femto-cell power)**		
The transmitting antenna configuration	**Omnidirectional antenna Antenna Gain = 0dB**	**Kathrein 742212 [8] 8 degree of Electrical tilt**	
Transmission mode	**C.L.S.M (Closed Loop Spatial Multiplexing) n.TX =2 and n.RX =1**		
Scheduler	**Round Robin**		
Receiver type	**Zero Forcing**		

b- Simulation Results:

	Figure 4. Average user downlink throughput in Center cell according to the variation of SINR at different user mobility speed (5 km/h, 30km/h and 60km/h).	Table -4 Downlink LTE user experience in Center cell according to model A

Model A



User mobility speed (Km/h)	Average spectral efficiency [Bit/cu]
5 Km/h	1.58 Bit/cu
30 Km/h	1.24 Bit/cu
60 Km/h	0.96 Bit/cu

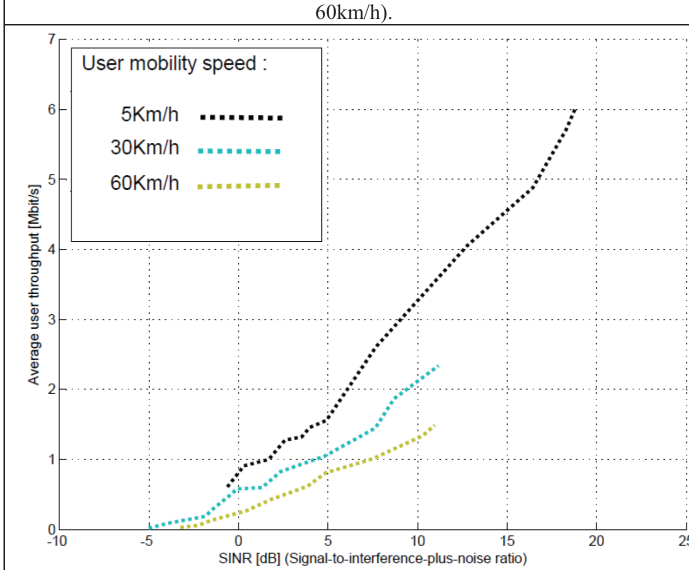
User mobility speed (Km/h)	(peak/average/edge) user throughput [Mbit/s]
5 Km/h	8.42/2.61/0.64
30 Km/h	8.2/2.02/0.36
60 Km/h	5.19/1.59/0.35

MIN SINR	MAX SINR
-0.69 dB	21.94 dB

Figure 5. Average user downlink throughput in Center Site according to the variation of SINR at different user mobility speed (5 km/h, 30km/h and 60km/h).

Table -5 Downlink LTE user experience in Center site according to model B

Model B



User mobility speed (Km/h)	Average spectral efficiency [Bit/cu]
5 Km/h	1.45 Bit/cu
30 Km/h	0.6 Bit/cu
60 Km/h	0.38 Bit/cu

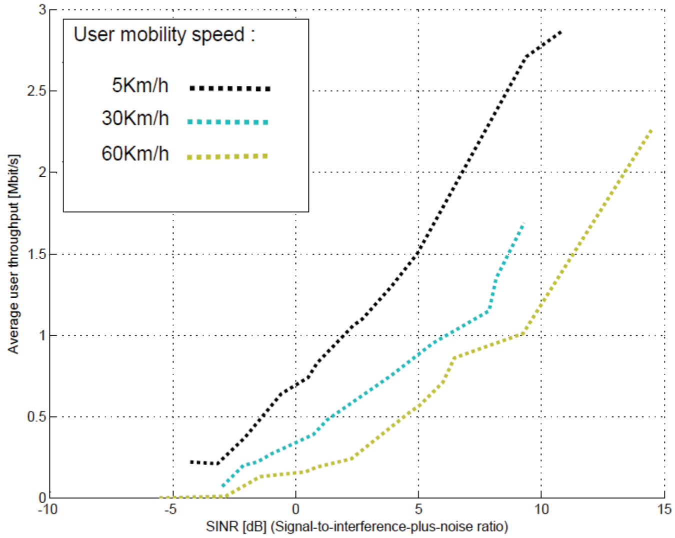
User mobility speed (Km/h)	(peak/average/edge) user throughput [Mbit/s]
5 Km/h	6.78/2.42/0.39
30 Km/h	2.28/0.96/0.09
60 Km/h	1.5/0.57/0.05

MIN SINR	MAX SINR
-5.02 dB	18.78 dB

Mode l C

Figure 6. Average user downlink throughput in Center Site according to the variation of SINR at different user mobility speed (5 km/h, 30km/h and 60km/h).

Table -6 Downlink LTE user experience in Center site according to model C



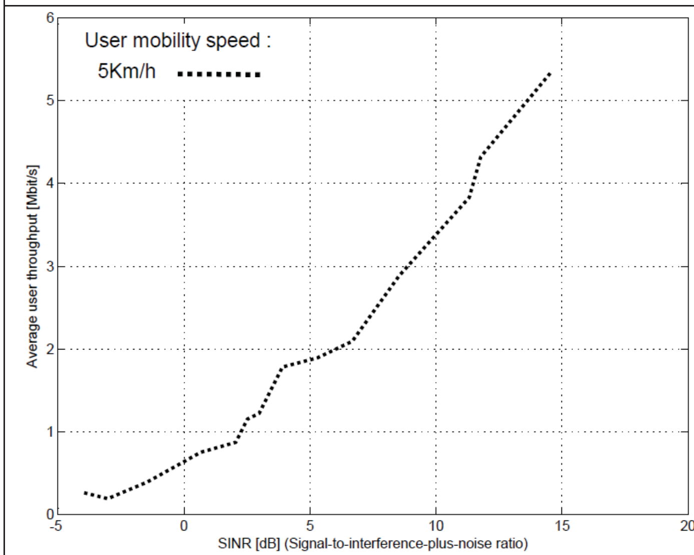
User mobility speed (Km/h)	Average spectral efficiency [Bit/cu]
5 Km/h	0.77 Bit/cu
30 Km/h	0.45 Bit/cu
60 Km/h	0.37 Bit/cu

User mobility speed (Km/h)	(peak/average/edge) user throughput [Mbit/s]
5 Km/h	2.87/1.25/0.21
30 Km/h	2.45/0.7/0.1
60 Km/h	1.74/0.56/0.01

MIN SINR	MAX SINR
-5.54dB	14.89dB

Figure 7. Average user downlink through put in Center Site Femto-Cell according to the variation of SINR at 5 km/h user mobility speed.

Table -7 Downlink LTE user experience in Center Site Femto-Cell according to model C



User mobility speed (Km/h)	Average spectral efficiency [Bit/cu]
5 Km/h	1.11 Bit/cu

User mobility speed (Km/h)	(peak/average/edge) user throughput [Mbit/s]
5 Km/h	5.35/1.84/0.26

MIN SINR	MAX SINR
-3.96dB	14.56dB

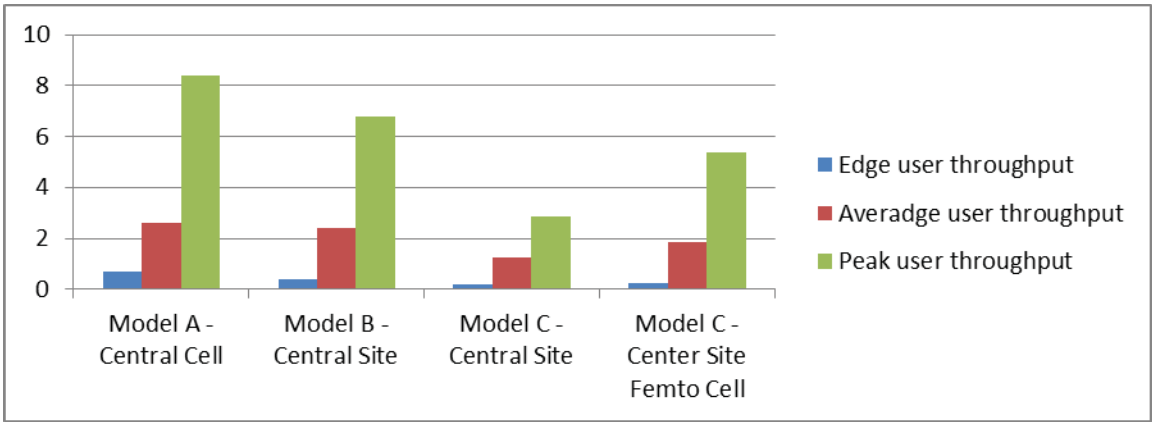


Figure 8. Downlink Peak, average, edge user throughput (Mb/s) according to the simulation models (A, B, C and C Center Site Femto-Cell).

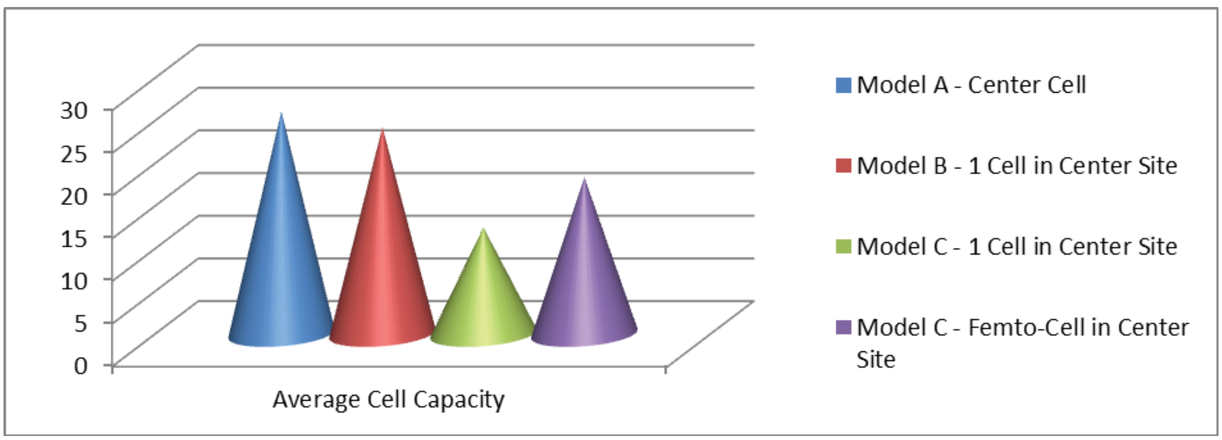


Figure 9. Downlink average Cell Capacity (Mb/s) according to the simulation models (A, B, C and C Center Site Femto-Cell).

c- Simulation analysis:

i. SINR and Mobility impact on user downlink throughput:

From Tables 4, 5 and 6 it is clear that user mobility speed impacts their downlink transmission. For model A: the average throughput losses value taking as reference 5 km/h mobility speed is 22.60% for mobility speed 30 km/h and can go up to 39.08% for mobility 60 km/h. For model B: the average throughput losses value taking as reference 5 km/h mobility speed is 60.33% for mobility speed 30 km/h and can go up to 76.44% for mobility 60 km/h. For model C the addition of indoor Femto-cells promotes Downlink QoS of users inside Femto-cell but adds additional interference to the cell, also the cell adds additional interference to the indoor Femto-cell (see table 6 for cell and table 7 for Femto-cell).

From Figure 4, 5 and 6 we can also conclude that low SINR (SINR <= 0 dB) deteriorate considerably the downlink throughput of users with mobility speed higher or equal to 30 km/h. Also Figure 8 allow to deduce the critical impact of interference on Cell edge users, the interference can be very high in a way that the edge user throughput in the best case not exceed 0.64 Mb/s, which greatly degrade the user experience in cell border.

ii. SINR impact on Cell capacity :

Figures 8 and 9 summarize the impact of interference on LTE multi-cellular system in an urban environment. Model A notes a loss of 73.92% of the total cell capacity due to interference, in Model B which can support (30 user per site (10 per cell)) the impact of interference reaches 75.78% loss of the cell capacity, In model C the addition of indoor Femto-cell improves the experience of users inside the Femto-cells but adds additional interference to the system which reduces the ability of the cell to 81.63% loss compared to the Total, the interference also affects Femto-cells and reduces their capacity to 87.51% loss of the total capacity of the Femto-cell.

Based on these analyzes, it is really necessary to consider the impact of inter cell interference, the 3GPP model underestimates the impact of inter cell interference especially in border cell, the segmentation solution and reuse patterns may allow an increase in the number of served user, but it will not solve the problem of interference that can degrade considerably the downlink user experience, which is unacceptable for LTE and LTE Advanced system, which have to ensure high data rates and low latency.

V. CONCLUSION

We show through simulation results that the impact of inter cell interference should not be under estimated, especially with high population density areas. Recent solutions for interference reduction in LTE, LTE advanced are based on the bandwidth distribution and power transmission management techniques such as S.F.R (Soft Frequency Reuse) and P.F.R (partial frequency reuse), these techniques can reduce the impact of interference but does not provide a radical solution, because these techniques reduce the usable capacity of the cell and also not consider or give a little improvement to the cell edge user experience. The SINR optimization in LTE, LTE advanced networks must take essentially into account an overview of cells distribution and capacity, indeed it cannot be possible only with the existence of the communication interfaces between neighboring cells (X2 interface) and the collaboration in power management and resource sharing, with this vision we give a proposal for a new optimization technique based on a distributed architecture in our article named " LTE – INTER-CELL INTERFERENCE MANAGEMENT TO IMPROVE THE QUALITY RECEPTION IN DOWNLINK RADIO RESOURCES LINKS " [9], this technique may improve the downlink user experience in inner cell and also in cell edge.

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