Amelioration of LTE's Network (4G) Performance by Interference Reducing Mechanism

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Abstract
The proliferation of mobile communication systems is growing rapidly in terms of subscriber numbers, and users are expressing increased expectations for better quality of service and extended coverage with robust signals, particularly in areas where coverage is inadequate.The HetNet concept integrates small coverage cells, called femtocells, with existing macrocells. These extra layers of cells introduce interference that affects user equipment in neighboring macrocells (MUE) and femtocells (FUE), degrading network performance. The strategy proposed in this paper aims to mitigate the impact of interference on users by optimizing the signal-to-noise ratio (SINR) received by FUEs and MUEs. The proposed strategy utilizes a utility function that enables each user to select which interfering signals to cancel, thereby optimizing the cancellation rate for each interfering signal and the overall cancellation ratios. This approach serves to reduce implementation complexity while maximizing SINR, QoS, and throughput.To assess the effectiveness of the strategy, a system-level LTE simulator was adapted and validated to support HetNet's LTE network configuration. The HetNet LTE simulator is employed to assess the performance of the HetNet LTE network and to support it with various system-level simulations.These demonstrate that overall network performance and user experience, as measured by total throughput and received signal-to-noise ratio, respectively, are significantly improved.The effectiveness of the new mechanism is evident in its ability to produce throughput gains of up to 200% compared to a homogeneous LTE network without IC (interference cancellation). Our study shows that interference cancellation increases the throughput of an LTE HetNet network by 48% for each additional femtocell base station.

Keywords:
HetNet LTE ; Femto cell ; HeNB ; eNB ; Interference DL..

1. Introduction

The telecommunications industry has recently undergone a substantial increase in mobile internet traffic, a trend that is projected to continue in the coming years. According to a study conducted by Cisco, mobile data traffic is estimated to grow at an annual rate of approximately 55% from 2020 to 2030, reaching 607 exabytes (EB) in 2025 and 5,016 EB in 2030 [1]. This projected growth is evidenced by the substantial increase in mobile data consumption, as demonstrated in Figure 1.

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Fig. 1 Mobile data traffic.

The last decade has seen a radical transformation in the use of cellular networks, driven by the advent of 4G technology (LTE/LTE-A). Networks of previous generations (3G), initially designed for voice and data transport with low and average speeds, are struggling to keep up with the surge in multimedia data traffic. They are ill-equipped to meet the stringent quality service (QoS) requirements. To address these needs, 4G networks have adopted heterogeneous networks (HetNets), which introduce a new level of heterogeneity by introducing small cells (Fig. 2). These cells have low-emission power, contributing to a network composed of multiple layers that overlap, ensuring a comprehensive coverage.

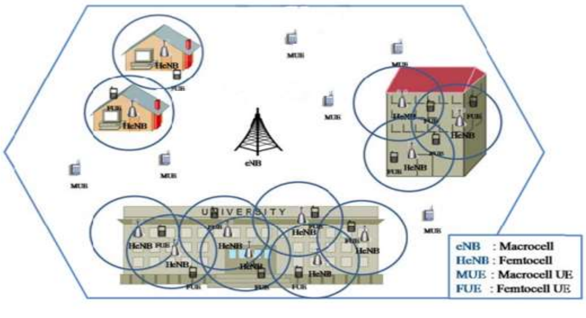
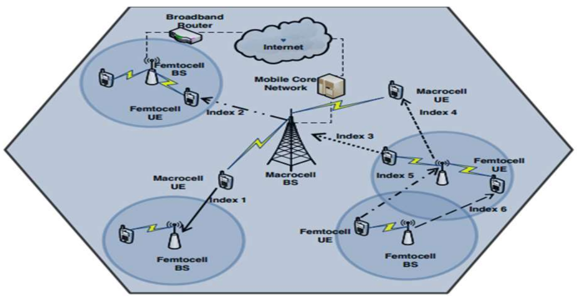


Fig.2 *Example of architecture of a HetNet network*

In addition to the enhancement of radios' covers in indoor environments, small cells facilitate the augmentation of system capacity through the optimization of spectrum utilization and the restriction of user access to the network. A direct consequence of this cellular intensification is the interference generated between different cells of various layers when they reuse the same frequency. Consequently, the identification of effective solutions for the management or mitigation of interference represents a significant challenge.

One the most efficient techniques to ameliorate the cover and increase the debit in the wireless networks is to reduce the size of the cells (for example: fraction of the cell) and the range of transmission [3]. Therefore, the concept of femto cells deployment in the macro cells has recently draw the growing interest of the industry. Various technic challenges towards quantity of femto cells have been tackled in the recent literature. The management of interferences between the close femto cells and between the femto cells and the macro cell, and the admission control are considered as the major challenges in the HetNet networks because the femto cells share the same spectrum of frequency with the macro cells[4, 5]. Generally, two types of interferences occur in HetNet network. The different types of interferences are presented in the following **Fig.3.**



Index	Aggressor	Victim	Interference Type	Transmission Mode	Symbol
1	Macrocell UE	Femtocell BS	Cross-tier	Uplink	———→
2	Macrocell BS	Femtocell UE	Cross-tier	Downlink	–··–··→
3	Femtocell UE	Macrocell BS	Cross-tier	Uplink	··········→
4	Femtocell BS	Macrocell UE	Cross-tier	Downlink	---------→
5	Femtocell UE	Femtocell BS	Co-tier	Uplink	-·-·-·→
6	Femtocell BS	Femtocell UE	Co-tier	Downlink	– – – →

Fig.3 *Scenarios of interference in the HetNet network of type OFDMA*

In the following section, we will present a review of the various approaches to mitigating interferences at two levels in the HetNet network of OFDMA type. These approaches will include the transmission rising link and/or lowering, as well as the interferences co-tier and/or cross-tier.

Subsequently, we will present the different approaches to interference mitigation.

- **The techniques < femto-aware Spectrum arrangement >**

The techniques < femto-aware Spectrum arrangement> to avoid cross-tier interference in rising direction between the macro basis station and the FBSs (Femto Base Stations).

- **The technique of gathering femto cells.**

To reduce the interference, this technique uses the combination between a dynamic allocation of the wave band of the frequency between the FBSs (***Femto Base Station***) and the MBSs (***Macro Base Station***), and the regrouping of the FBSs according to their geographic sites.

- **The approach of the power control:**

The methods of power control to reduce the cross-tier interferences are generally concentrated on power reduction of FBSs transmission. These techniques are benefits by the fact the MBSs (***Macro Base Station)*** and the FBSs (***Femto Base Station***) can use all the whole band with the interference coordination.

- **The fractioned frequency reuse (FFR) and resources sharing**

The basic mechanism of this method divides the spectrum of frequencies in several sub-bands. Next, each sub-band is attributed differently to each macro cell or of macro cell sub-zone. Since the resource for MBS (***Macro Base Station)*** and FBS (***Femto Base Station***) is not overlapped, the interference between MBS and FBS can be mitigating.

- **Cognitive approach:** The radio cognitive approach is based on spectrum direction distributed. It can be used for interference mitigation in femto networks.
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Whence a qualitative comparison between the different interferences management approaches is presented in **Table 1** as follow:

Technics	Mode of transmission	Cooperation between the BSs	Acces mode	Complexity	Efficacity	Type of interference
Femto-aware Spectrum arrangement	UL	Required	Closed	Moderated	weak	Cross-tier
Gathering of Femtos cells	DL	Required	Closed	Moderated	Moderated	Co-tier and Cross-tier
Collaborative structuring of frequence	DL et UL	Non required	Closed	Moderated	increased	Cross-tier and between canals
Approch power control	DL	Non required	Open and fermé	Moderated	increased	Cross-tier
FFR and sharing of ressources	DL	Required	Open and Closed	Moderated	Moderated	Cross-tier
Cognitive Approach	DL	Non required	Open, Closed and hybrid	Weak	increased	Cross-tier and Co-tier

Where; DL= downlink, UL= uplink, BS= base station.

2. Research Methodology.

The layer of femto cells is integrated into the existing LTE network to solve the limit capacity issues of the network, so that to offer a better quality of service to users (**Figure 2**). We presented two major contributions that consists firstly to evaluate all the impact of femto cells upon the LTE homogeneous network performance and we propose our mechanism of interference reductions in HetNet LTE networks via simulations tools.

2.1 Performances of HetNet network.

2.1.1 Simulation scenarios and Parameters

The LTE HetNet scenario being studied consists of 7 macrocells arranged in a hexagonal pattern to provide optimal and uniform coverage. The macrocells are spaced at a distance of 500 meters, ensuring precision and reliability. Each macrocell is divided into three sectors and uses sector antennas as specified by 3GPP TS 36.942. The maximum transmission power for each antenna is set at 43 dBm. The purpose of this scenario is to evaluate the impact of femtocells on LTE performance within this homogeneous network. A total of 175 users, with 25 users per macrocell, are simulated in the scenario. These users are constantly moving at a speed of 30 km/h and change their position at each Transmission Time Interval (TTI).

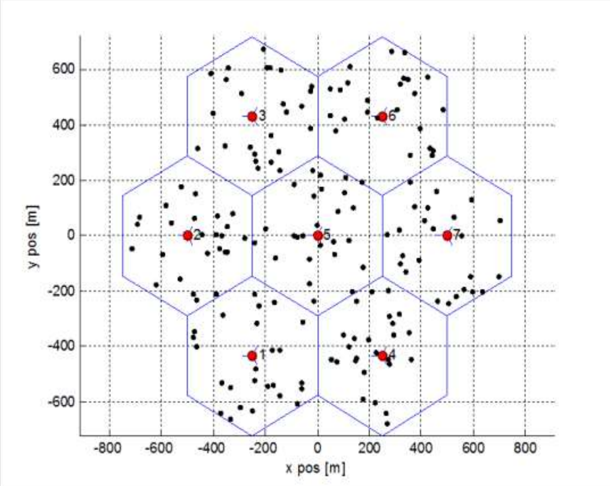

Figure 4: *Schema of initial network (reference scenario).*

The reference scenario (**figure 4**) is a LTE homogeneous network composed only of macro cells. In fact, we assimilate a femto cell to a circular cover of ray equal to 20 m, insured through an omnidirectional antenna of power of maximal transmission equal to 20 dBm. We rise progressively, in each scenario, the number of each femto cell introduced in the network. Initially, we strongly fasten a user to each femto cell introduced. The speed of moving of femto's user is set at 3 Km/h. During simulation, each user tips up to the cell assuring him a better signal. The following **Table 2** summarize the parameters of simulation.

Table 2: *Parameters of simulation*

Parameters	**Macro Cells**	**Femto Cells**
Frequency of system	2 GHz	
Band of frequency	5 MHz (shared)	
Schéma of cells	Hexagonal interval of 7 cells, 3 sectors per cell.	Circular cell, 1 sector per cell.
Size of cells	250 m	20 m
Antenna gain modal	TS 36.942	Omnidirectional
Antenna gain maximal	15 dBi	0 dBi
Maximal power transmission	43 dBm	20 dBm
Factor of receptor noise	9 dB	9 dB
Level of thermic noise	-174 dBm/Hz	-174 dBm/Hz
Modal of pathloss	Cost 231 urban macro	Indoor hotspot
Initial users numbers	25 UEs	1 forced user
User 's speed	30 Km/h	3 Km/h
Scheduler	Proportional Fair	
Simulation time in TTIs	1000	

Yet, in the dense environments deploying a great number of femto cells [8, 9, 10], the antenna problem appears and provokes the damage of the network performances (**Figure3**). Consequently, we propose in the following part a mechanism of reduction that allows to remediate to this problem.

2.2 Mechanism of reduction of interference in a HetNet LTE network and evaluation.

Our mechanism aims to select optimally the interferent signals to mitigate in order to minimize the impact of the interference upon the quality of the signal provided to a user and thus ameliorate the performance of the system.

2.2.1 Basic principle

The interference mitigating technics suggested consists to select the interferente signals to mitigate, as well as to determine their rate of mitigating [11, 12, 13]. The analytic database of this technique aims to quieten the interferent's signals according to the rates between 0 and 1, also called coefficients of mitigating. These coefficients of mitigating, marked $\mathbf{a}_{\mathbf{u,j,r}}$ (j ∈ J_u), reduice the values of these interferents' powers receives, and then minimize the term $\sum_{\mathbf{j}\in \mathbf{J_u}} \mathbf{P}_{\mathbf{u,j,r}}$(***sums of interferents' powers***). Consequently, the SINR(***Signal to Interference plus Noise Ratio)*** received resulting after the procedure of mitigating, called SINR post-IC, is expressed as follow:

$$\gamma_{u,r} = \frac{P_{u,i(u),r}}{\sum_{j\epsilon J_u} a_{u,j,r} \times P_{u,j,r} + \sigma_{u,r}} \quad \textbf{(1)}$$

Where $\boldsymbol{\sigma}_{\mathbf{u,r}}$ is the Gaussien power of noise received by the user **u**. $\mathbf{P}_{\mathbf{u,i(u),r}}$ is the power received in the RBr from the cell **i(u)** to which it's fastened, $\mathbf{P}_{\mathbf{u,j,r}}$ indicates the power received from the close interference cell **j** $\in \mathbf{J_u}$ **.**

In this mechanism, we look for to propose an optiomal solution that allows to calculate the optimal values of the coefficients $\mathbf{a}_{\mathbf{u,j,r}}$ **(j∈Ju)** using the concept of fonction of usefulness.

In fact, the fonctions of usefulness have been largely adopted by the algorithms of power control as well as the approaches of allocation of radios' resources[14, 15,16]. A little more, some solutions of alignment of interference focus in their concept on these functions. However, to the better of our knowledgement, this concept hasn't been used yet by the techniques of mitigating of the interference DL in the HetNet's network. A little more, the maximization of the usefulness function to the user to select clearly the interferent signals received to quieten and determine optimally the rate of mitigating for each interferent signal[17, 18. 19].

Therefore, we define for each user u ∈ L a function of definite usefulness (2) marked $\mathbf{U}_{\mathbf{net,u}}$ that he looks for to maximize. The standart expression of this function for a base station in the cellular network is comped of a usefulness function marked $\mathbf{U_u}$ that represents a degree of satisfaction of the customer, and a cost function $\mathbf{C_u}$ that represent the incured cost as well as to reach this level of satisfaction. The expression of the definite utility function $\mathbf{U}_{\mathbf{net,u}}$ is presented then by the following expression:

$$\mathbf{U}_{net,u}(\gamma_u) = \mathbf{U}_u(\gamma_u) - \mathbf{C}_u(\gamma_u) \quad \textbf{(2)}$$

It should be noted that the cost function is introduced to represent the computational costs generated by the precise cancellation process, characterized by low implementation errors. Therefore, it is used to design an efficient and feasible cancellation strategy. For each user, the same cost function is used, defined as follows: $\mathbf{C}_u(\gamma_u) = \boldsymbol{\beta\gamma_u}$ **(3)**

where $\boldsymbol{\beta}$ is the cost parameter to be determined.

In order to calculate the values of the coefficients $\mathbf{a}_{\mathbf{u,j,r}}$ (j ∈ J_u), it is necessary to calculate the optimal post-IC SINR, denoted$\hat{\boldsymbol{\gamma}}_{\mathbf{u}}$, which maximizes the net utility function$\mathbf{U}_{\mathbf{net,u}}$. To do so, we derive equation **(2)** with respect to the variable$\boldsymbol{\gamma}_{\mathbf{u}}$, also using expression **(3)**. The optimal post-IC SINR $\hat{\boldsymbol{\gamma}}_{\mathbf{u}}$ will therefore be expressed as follows:

$$\frac{dU_{net,u}(\gamma_u)}{d\gamma_u} = U'_u(\hat{\gamma}_u) - \beta = 0 \quad <=> \quad \hat{\gamma}_u = U'^{-1}_u(\beta)$$
(4)

Substituting equation **(1)** with the optimal SINR expression **(4)** yields the following condition:

$$\sum_{j\in J_u} a_{u,j,r} \times P_{u,j,r} = \frac{P_{u,i(u),r}}{U'^{-1}_u(\beta)} - \sigma_{u,r} \quad (5)$$

Consequently, we can express the coefficient $a_{u,j,r}$ (j ∈ J_u), as follows:

$$a_{u,j,r} = \frac{1}{J_u P_{u,j,r}} \left[\frac{P_{u,i(u),r}}{U'^{-1}_u(\beta)} - \sigma_{u,r}\right] \quad (6)$$

where j_u represents the number of interfering cells [j_u= card(Ju)].

Using this expression of the coefficients $a_{u,j,r}$ (j ∈ J_u, we succeed in reducing the interference received by the user u ∈ L to a level that guarantees optimal SINR.

However, when calculating the coefficients, we distinguish between two types of users: MUE and FUE.

2.2.2 Utility function and mitigating coefficients of MUE(*Macro cell user*).

For each user MUE, we define a utility function that represent's that degree of satisfaction of the user in terms of quality of service. Analytically, we define for user MUE u∈L_m his function of usefulness marked $U_{m,u}$ as follow[20]:

$$U_{m,u}(\gamma_u) = \frac{1}{1+exp(-\alpha_m \gamma_u)} \quad (4)$$

where L_m represents the whole macro users and α_m a parameter that controls the slope of the usefulness function. It's to notice that a high SINR γ_u can be reached if the derivative of the usefulness function $U'_{u,m}$ becomes more flat.

This comes back to take the less small values of parameter α_m. However, the usefulness function has been used to optimized the value of the power of transmission for each user[21, 22, 23]. In our work we adopt the similar form of utility function in the aim to determine on the optimal manner the values of the coefficients of mitigating of different interferent signals received, and then select properly the interferent signals to qieten. Consequently, the maximization of the definite utility function of each user allows to optimize his SINR post-IC received.

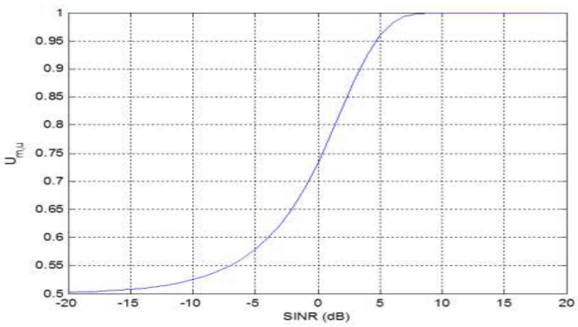

Figure 5: *The representative curve of the function $U_{m,u}$ (α_m = 1).*

The representative curve of the usefulness function $U_{m,u}$ capture then represents the quality of service offered to the user. As the figure above represents, it's clear, maximizing the usefulness, the user is more and more satisfied by the service of quality offered.Yet, the value of the cost of the function C_u increases maximizing the usefulness function $U_{m,u}$.

2.2.3 Utility function and mitigating coefficients of FUE(*Femto cell user*).

In a similar way to MUE, we define for each user FUE, u ∈L_f its usefulness function $U_{f,u}$ at the following form:

$$U_{f,u}(\gamma_u) = W\log(1+\gamma_u) \quad (5)$$

where $U_{f,u}$ the capture usefulness function represents the capacity of shannon for this user FUE. **W** represents the broad band of system. We draw in the following figure the representive curve of this function.

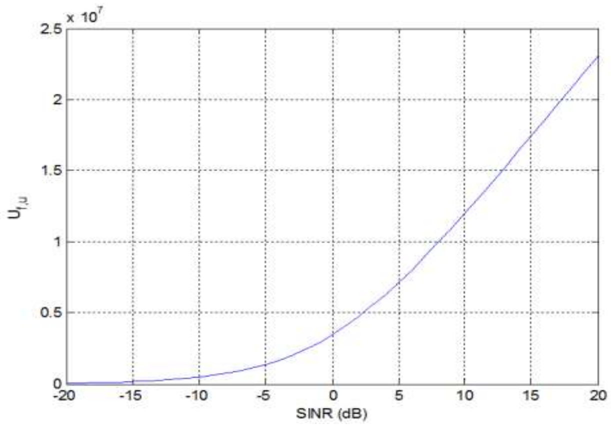

Figure 6: *Representative curve of the function $U_{f,u}$ (W = 5 MHz).*

In a nutshell, the principle basis of this technique is to calculate on the optimal manner the values of the coefficients $\mathbf{a_{u,j,r}}$ **(j∈$\mathbf{J_u}$),** that leads to an optimization of SINR received according to this algorithm:

For each TTI
For each RBr
1-each user UϵL meseares $P_{u,i(u),r}$,$P_{u,j,r}$ for jϵJ_u et $\sigma_{u,r}$
2-if the user is MUE
-He calculates the coefficients $a_{u,j,r}$ (jϵJ_u) .
- if $a_{u,j,r} > A_u$ then $a_{u,j,r} = 1$
- $a_{u,j,r} = \max (A_l, a_{u,j,r})$
- He calculates the SNIR received $\boldsymbol{\gamma_{u,r}}$(M)
3- if the user is FUE
-He calculates the coefficients $a_{u,j,r}$ (j∈ J_u).
-if $a_{u,j,r} > A_u$ the $a_{u,j,r} = 1$
- $a_{u,j,r} = \max(A_l, a_{u,j,r})$
- He calculates the SINR received $\boldsymbol{\gamma_{u,r}}$(F)
End
End

Where, TTI = transmission Time Interval; RB = Resource Block ;
M= Macro ; F= Femto.

3. Result and discussion

3.1 Cells debits layers of the HetNet LTE network.

During a simulation, we have stored the total debit of the layer of macro cells, and the layer of femto cells. Then we have calculated the total debit all the HetNet network for different scenarios of deployment of femto cells. The results are presented in the following **figure 7**:

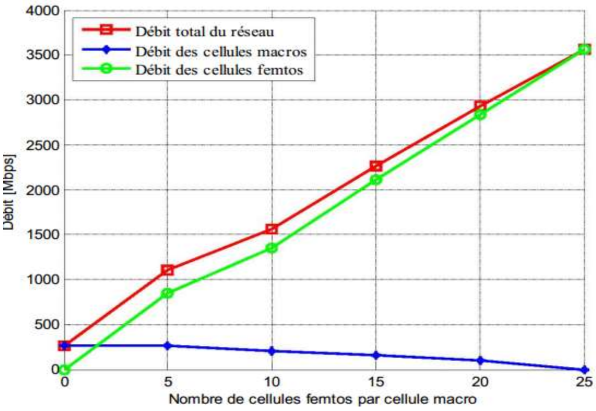

Figure 7: *Cell layers' debits of HetNet LTE network.*

The obtained results (***Figure 7)*** effectively confirm the performance of the HetNet LTE network discussed before. In fact, the debit of the network increases by rising the number of femto cells in the network. Furthermore, the total debit of macro cells diminishes since users move more and more towards the close femto cells which offer them a better cover and quality of signal. Then the total debit of femto cells increase, what ameliorates the performance of the network. In the following **figure 8**, we have drawn the profit comparing to the reference scenario that deploys only a layer of macro cells.

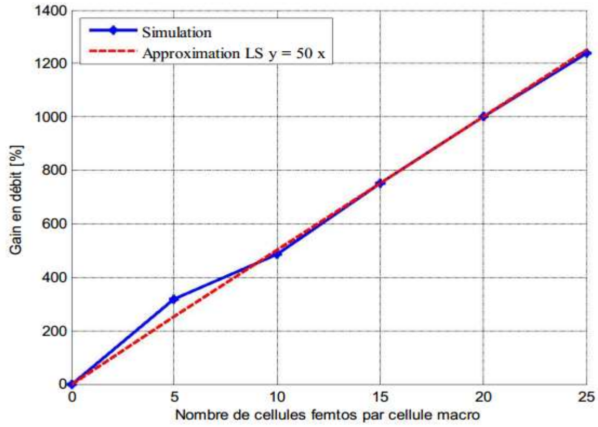

Figure 8: *Debit gain of HetNet LTE network compared to homogeneous LTE.*

We notice well through graphs (**figure 8**) that the debit gain of the network is proportional to the deployment of femto cells in the network. Furthermore, the femto cells introduced offer to the users a better cover and the debits overtaking those offered by macro cells of LTE homogeneous network. For that, the concept of femto cell promise to satisfy the demands of the IMT-Advanced system.

3.2 Performance of the mitigating technics of the DL interference proposed.

We have implemented the technics in our LTE-Sim simulator to the level of the system in order to analyse the performance of the DL mitigating interference proposed and study its impact upon the performance of HetNet LTE network. Then we have considered different scenarios of simulation deploying different numbers of femtos cells in the network.
So we have used the parameters of simulation in this listed table 3:

Table 3: *Parameters of simulation.*

Parameters	Macro Cell	Femto Cell
Parameter of the strategy	$\alpha_m = 4.5\ \beta_m$	W = 5MHz ; $\beta_f = 10^4$[54]

We compare the performance of the suggested technics to those of the algorithm of power control (DL-PC) of 3GPP [24, 25, 26] to present the quality of our work better . In fact, the algorithm aims to control and to reduce the DL interference in a LTE HetNet network by reducing the power transmission of the femto cells to a level including between the minimal transmission power $\mathbf{P_{min}}$ and the maximal transmission power $\mathbf{P_{max}}$. The values of both powers $\mathbf{P_{min}}$ and $\mathbf{P_{max}}$ are fixed at 10dBm and 20dBm. After the implementation of dynamic algorithm of the DL power control, we draw its curve of profit in debit and we compare it with those obtained without mitigating of interference, then with the corresponding curve to the DL-IC technics suggested . The results are presented in the following **figure 9:**

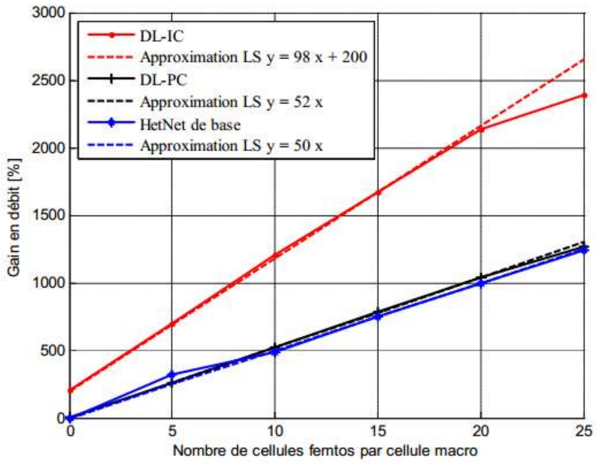

Figure 9: *Total debit of network for algorithm DL-PC and the strategy DL-IC proposed (βm = 10−3).*

It is clear that observing the **figure 9**, the performance of the strategy proposed is largely more important[27, 28, 29] than the DL-PC algorithm. In fact, the latter presents only a slight amelioration of gain in debit of the network compared to the reference scenario of the basic HetNet deploying neither power control nor the interference mitigating.

4. Conclusion.

This study, based on the HetNet LTE network and approved by the 3GPP group, examines the benefits of this technology. We first present the significance of HetNet networks thanks to femtocells, which are distinguished by throughput gains and improved network capacity. This advance overcomes the capacity limitations of homogeneous LTE networks and solves network capacity constraints, while addressing areas of poor coverage by integrating femtocells into the homogeneous LTE system. However, the implementation of multiple small cells generates interference that degrades quality of service and makes interference management more complex. Our approach, based on the utility function, aims to optimize interference management in a HetNet network, demonstrating that maximizing this function enables the user to identify and cancel interference in a targeted manner, while optimizing the cancellation rate for each interfering signal received.

Simulations have demonstrated the effectiveness of this approach, which significantly reduces the impact of interference while optimizing the performance of the HetNet LTE network, without increasing the complexity of its implementation. The throughput gains achieved by this mechanism can reach 200% compared to a homogeneous LTE network without interference reduction, and 48% per additional femto cell compared to a basic LTE HetNet network without interference cancellation. Our work was carried out in a simulation environment, however to perfect our idea we hope to have the opportunity to apply it in mobile telecommunications networks even if this should be the subject of other studies with the help of 4G network suppliers.

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