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Interference Evaluation in Cellular Networks

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Abstract Interference in cellular networks is one of the most common problems in the radio access network. In fact, it is the major issue in cellular networks that affects performances and quality of service. Indeed, interference can be caused by a call on the same frequency from neighboring cell, or a call on an adjacent channel in the same or in neighboring cell. So, we can classify interference on intra-cell interference and inter-cell interference. In 4G, thanks to the use of orthogonal frequency division multiple access and single carrier frequency division multiple access as access techniques in downlink and uplink respectively, intra-cell interference is reduced compared to the inter cell one which caused by the frequency reuse one mechanism and the femto cells deployment. In this work, we will evaluate the interference in different cellular network standards from 2G to 4G.

Keywords Interference · Femto cell · Intercell interference · Performances

1 Introduction

The number of subscribers in mobile radio networks does not cease increasing every day [1]. Because of this rapid increase in demand, Telecommunications operators face a major challenge. Indeed, operators should on the one hand increase the capacity of their networks and ensure a satisfactory quality of service on the other hand. For this, since the adoption of cellular networks, these standards have not stopped evolving and this evolution has passed

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through different steps called "generations". In this context, it should be pointed out that up to now four generations are defined. The first generation, 1G was based on an analog technology with major variants advanced mobile phone system (AMPS) and total access communication system (TACS). The second generation, 2G, whose main standard is GSM, uses the frequency/time division multiple access (F/TDMA) hybrid access technique and the circuit-switched mode. The GSM standard has met with tremendous success because it makes it possible to create the need to make phone calls anywhere with the ability to send mini messages as known as short message service (SMS). It allows roaming as well. But the throughput offered by this standard is insufficient. It does not exceed 9.6 Kbit/s [2]. For this reason, the third generation of mobile networks has been defined, in particular the UMTS standard which uses the packet transmission mode and the Code Division Multiple Access (CDMA) technique. It offers high bit rates up to 2 Mbit/s [1, 2]. However, due to increasing demands on coverage and throughput, Third Generation Partnership Project (3GPP) has incorporated certain techniques into fourth generation standards such as LTE-Advanced for Satisfy this increased demand for high data rates and better quality of service. In spite of the fact that these improvements make it possible to achieve peak bit rates of up to 1 Gbit/s, the problem of interference remains a general problem in the field of telecommunications.

The rest of this paper is organized as follows. An interference analysis in cellular networks is explained in Sect. 2. Section 3 concludes our paper.

2 Interference Analysis in Cellular Networks

In mobile networks, subscribers suffer from a coverage constraint. Therefore an increase in the capacity of the network in number of cells is required. This has led the operators of the network to reuse frequency [1]. But the former is limited by the interference which constitutes a major concern for the quality of service offered to subscribers. In fact, transmitted signal is subject to many phenomena that degrade its quality. The main phenomena of this degradation are, in addition to path loss, Shadowing effects and Fading, two kinds of interference which thereafter described [3].

Intra-cell interference so called adjacent channel interference. This kind of interference is caused by imperfect receiver filters which allow nearby frequencies to leak into the pass band [4]. It is a result perturbation caused by signals transmitted on an adjacent frequencies as shown in Fig. 1 [sta] for example, signal 1 and signal 2 are transmitted on adjacent frequencies f1 and f2, so, each one causes adjacent channel interference to the other. To evaluate this interference type for considered user equipment in 2G and 3G, we are required to evaluate adjacent channel interference caused by base station and mobile station used adjacent frequencies. Interference caused by a single base station is noted I_{BS} and evaluated as Eq. (1) [5]:

$$I_{BS} = \frac{P_{BS} U_{BS}}{pl_{BS-MS}} \tag{1}$$

where P_{BS} is the adjacent channel BS transmission power, U_{BS} is the number of users served by this BS and pl_{BS-MS}, is the path loss between the adjacent channel BS and the victim mobile station MS.

However, interference caused by a single mobile station is given by Eq. (2) [5]:

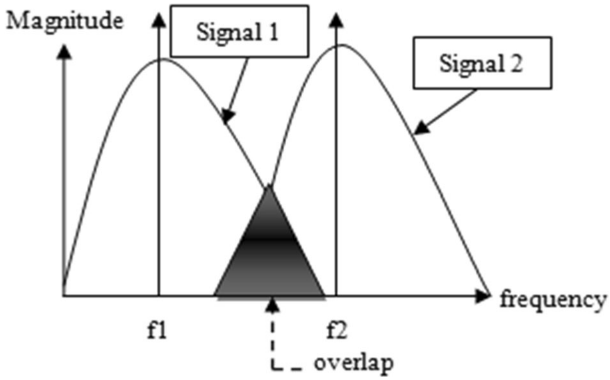


Fig. 1 Adjacent channel interference

$$I_{MS} = \frac{P_{MS}}{pl_{MS-MS}} \tag{2}$$

where P_{MS} is the adjacent channel MS transmission power and $pl_{MS–MS}$, is the path loss between the adjacent channel MS and the victim MS.

If we consider in studied network, I_{BS}, the total adjacent channel interference power caused by the total number of adjacent channel interfered base stations and I_{MS}, the total adjacent channel interference power caused by the all adjacent channel interfered mobile stations. Then, the total adjacent channel interference power (I_T) is given by Eq. (3) [5]:

$$I_T = I_{BS} + I_{MS} \tag{3}$$

The adjacent channel interference power variation is presented in Fig. 2 below when we consider only one adjacent channel interfered base station and we increase the number of active users in the cell equipped by this base station from 10 to 30.

From this figure it can be deduced that adjacent channel interference power increases if the number of active users. Figure 3 shows the variation of signal to adjacent channel interference ratio.

In LTE/LTE-A systems, orthogonal frequency division multiple access (OFDMA) and single carrier frequency division multiple access (SC-FDMA) are used in downlink and uplink respectively as multiple access techniques. This usage provides an orthogonal transmission which generally neglects intra cell or adjacent channel interference in LTE/LTE-A systems [6]. However, inter cell or co-channel interference presents a major issue in different cellular networks especially those of fourth generation. This kind of interference will be studied thereafter.

Co-channel interference is the overlap of two or more signals transmitted on the same frequency from two or more different cells as shown in Fig. 4 below [4].

In homogenous networks (2G and 3G of cellular networks), inter-cell interference was created between macro cells. In 2G systems, this problem was reduced by using the notion of cluster. Indeed, a cluster is the smallest group of cells containing the set of channels one and only once. This cluster is repeated over the entire surface to be covered. The size of this pattern can be: 3, 4, 7, 9, 12, 13… Cells that use the same carriers as a considered cell "c" are referred to as co-channel cells and cause co-channel interference to the mobiles served by the base station of cell "c". The number of co-channel cells in the first ring is

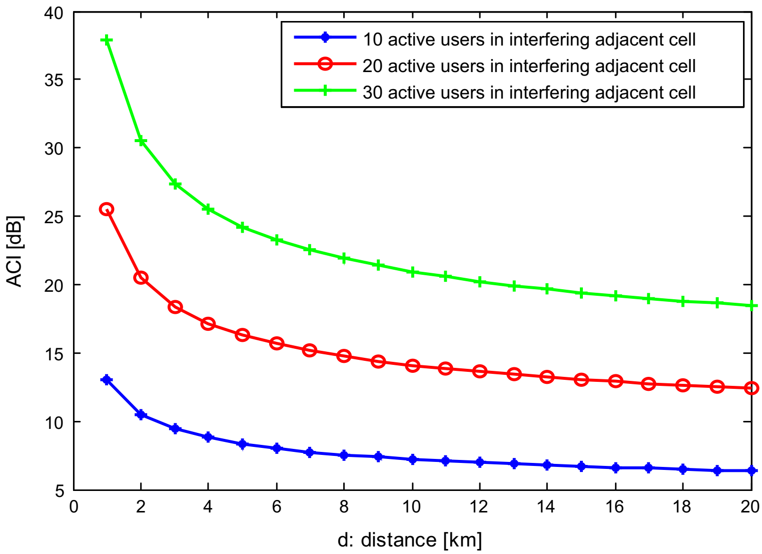


Fig. 2 Adjacent channel interference power depending on the number of active users in interfering adjacent cell

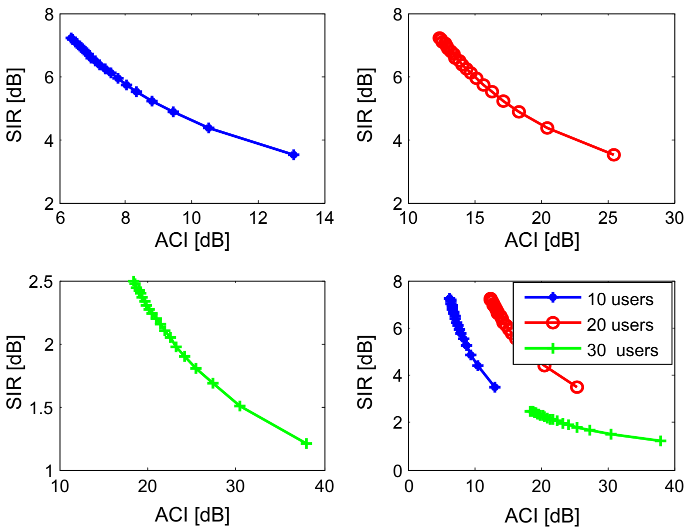


Fig. 3 Signal to adjacent channel interference ratio

always 6 regardless of the size of the cluster. A co-channel interference evaluation is done and presented thereafter for two users, the first one is close to the serving base station (in cell centre) and the second one is far from the serving base station (in edge cell).

We noted I the total of inter-cell interference. In fact I is expressed as:

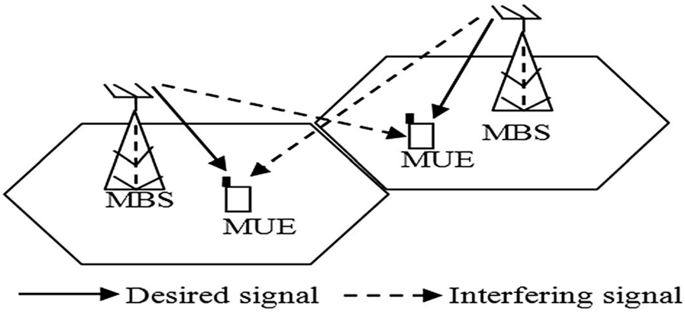


Fig. 4 Co-channel interference

$$I = \sum_{k=1}^{6} I_k \tag{4}$$

I_k is the interference caused by the kth co-channel base station. 6 is the number of co-channel base stations in the first tier.

I_k is given by [5]:

$$I_k = P_0 \left\{ \frac{d_k}{d_0} \right\}^{-\alpha} \tag{5}$$

where P_0 is the received power at reference distance d_0, α is the path loss exponent and d_k is the distance between the user and base station k. so, the signal to interference ratio is expressed:

$$\frac{S}{I} = \frac{S}{\sum_{k=1}^{6} I_k} = \frac{P_0 \left\{ \frac{R}{d_0} \right\}^{-\alpha}}{6 P_0 \left\{ \frac{d_k}{d_0} \right\}^{-\alpha}} = \frac{1}{6} \left\{ \frac{d_k}{R} \right\}^{\alpha} \tag{6}$$

where R is the cell radius.

Or, in the case where user is in the cell centre, the distance between the user and any base station k is the same can be noted *d*.

Equation (6) can be simplified as:

$$\frac{S}{I} = \frac{1}{6} \left\{ \frac{d}{R} \right\}^{\alpha} \tag{7}$$

Or, $\frac{d}{R}$ is the co-channel reuse ratio noted Q.

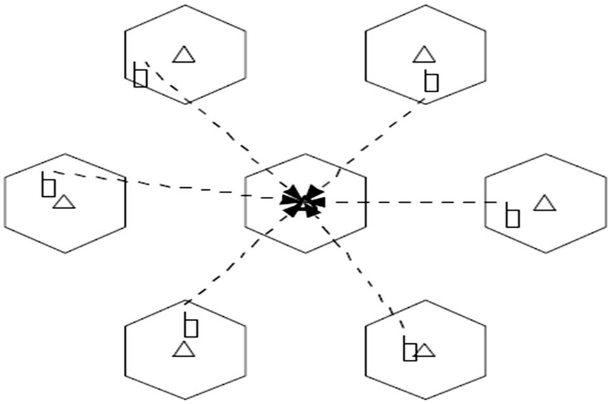
If we use Q Eq. (7) becomes:

$$\frac{S}{I} = \frac{1}{6} Q^{\alpha} \tag{8}$$

However, in case 2 where the user is far from the serving base station, the distance d_k is not the same for all base stations as shown in Fig. 5. Therefore, signal to interference ratio becomes (Fig. 6):

$$\frac{S}{I} = \frac{R^{-\alpha}}{\{2(D-R)^{-\alpha} + 2D^{-\alpha} + 2(D+R)^{-\alpha}} \tag{9}$$

Fig. 5 Case 1: user in cell centre [5]



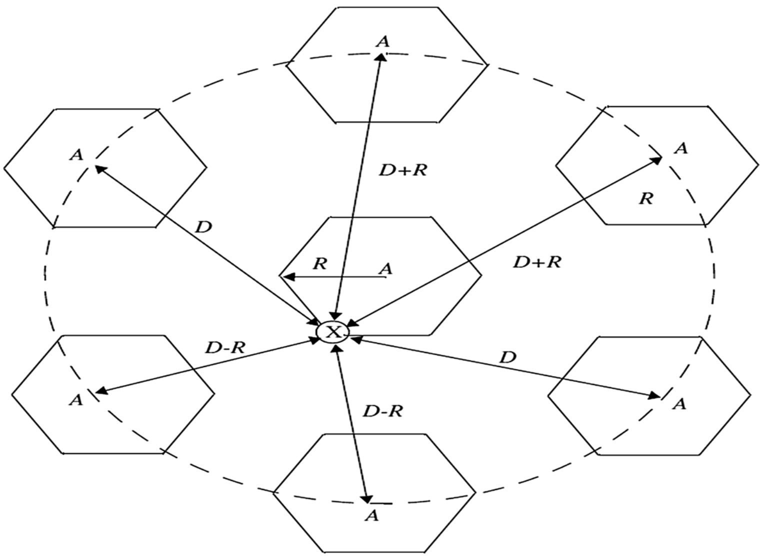


Fig. 6 Case 2: user in edge cell [5]

or

$$\frac{S}{I} = \frac{1}{\{2(Q-1)^{-\alpha} + 2Q^{-\alpha} + 2(Q+1)^{-\alpha}} \tag{10}$$

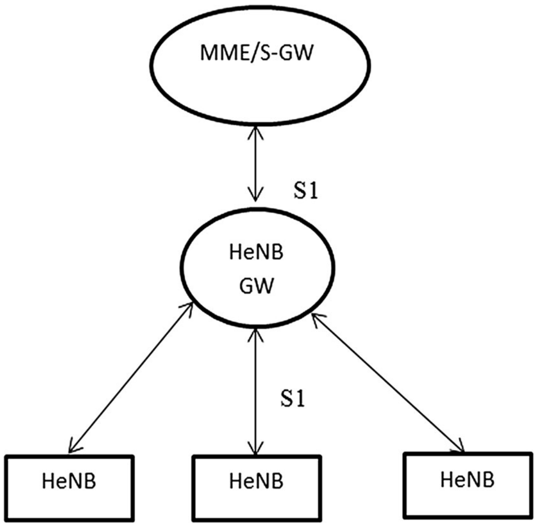
The usage of frequency reuse with factor N strictly higher than 2 in 2G of cellular networks, can reduce inter-cell interference but it has a negative effect on spectral efficiency and therefore on capacity. Indeed, only $\frac{1}{N}$ of the available spectrum is used in each cell. In 3G, thanks to CDMA technique, the reuse factor 1 can be applicated in order to increase capacity. But a 3G user suffer from a cross correlation between spreading codes.

In heterogeneous networks, such LTE-A, where small cells are integrated in the conventional macro cells in order to extend coverage and enhance performances especially in indoor area, inter-cell interference is created between macro cells, femto cells and between macro cells and femto cells. Therefore, we present firstly the femto cell concept, then inter cell interference classification will be highlighted. In fact, femto cells are also called Home base stations or Home eNode B. They are small cells having some 10 m of radius: (usually 6 m up to 50 m), inexpensive, and transmit at low power around 20 dBm. Home bases stations are meant to be placed in individual home, restaurant, company….They are usually deployed inside buildings. These nodes are connected to the core of the LTE-Advanced network system through a fixed data connection, such as ADSL, cable or fiber [7].

The architecture of a femto cell comprises 3 (three) main entities which communicate with each other [8]. The first entity forms the access point of that cell (HeNB). Indeed, the operation of the femto base station is generally similar to the macro base station, with some advanced networking added features. The second component of the system is a gateway to the femto cell named HeNB GW. This component provides aggregation and validation of signaling traffic between femto cells. It also handles authentication between these femto cells and provides security of the communication between them. A third entity, called Management System (MME/S-GW), ensures the distribution of updates of the software used by the base stations. This system is also responsible for conducting the diagnostics verification. The femto cell architecture is shown in Fig. 7.

While it is expected that femto cells bring the most gains, they present several challenges that must be resolved. First, although femto cells are designed for indoor use, they cause a lot of problems in mobility and handoff when they are very densely deployed. In fact, three benefits come from femto architecture. In a dense femto cell network, distances between the base stations are very small. This makes the handover procedure being very difficult. Secondly, femto cells are installed by consumers in their home or their business. Consequently, security emerges as a challenge that must be properly treated. In other words, the private data of a consumer circulating on the Internet access network connecting the femto cell to the cellular network must be protected against malicious users. Finally, a third advantage appears, since the femto cells coexist with cells of different sizes. They are likely to cause and suffer a lot of interference from other base stations. In particular, there are two categories of inter cell interference. An intra-level interference (co-tier), it is the

Fig. 7 Femto cell's architecture



interference between elements of the same type, that is to say interference of a macro user by neighboring macro base stations or interference of a femto user by neighboring femto base stations. It is called interference in the same layer and in our work we will calculate performances of macro user. So, co-tier interference is presented in Fig. 8 and expressed by:

$$I_{co-tier} = \sum_{M'} P_{M'} G_{m,M'} \tag{11}$$

where $P_{M'}$ is the transmit power of neighboring macro base station M'; $G_{m,M'}$ is the channel gain between macro user m and neighboring macro base station M'.

The second category of these interferences is inter-level interference (cross-tier); it is interference between elements of different types, i.e. between macro user and neighboring femto base stations or between femto user and neighboring macro base stations. It is called interference between layers, presented in Fig. 9 and in our case it is given by:

$$I_{cross-tier} = \sum_{F} P_F G_{m,F} \tag{12}$$

where P_F is the transmit power of neighboring femto base station F', $G_{m,F}$ is the channel gain between macro user m and neighboring femto base station F.

Looking to increase the performance of cellular networks by deploying femto cells, interference should be reduced especially when the cellular network is very dense. There are in fact many other challenges including technical and economic aspects [7]. But, interference's problem is the major one because we cannot suggest handover, safety or other problems causing a limited connection. This appears when a femto cell won't be able to establish a connection due to interference. For that, all interference types such those in a heterogeneous cellular network, those between the layers or others in the same layer, must necessarily be reduced.

Interference in mobile networks LTE/LTE-advanced would be analyzed based on a study of the performance of a macro user m in terms of SINR and throughput. In fact, SINR is the desired signal over the power's noise sum plus interference power from interfering macro and femto cells. The throughput is depending on the SINR. These performances are evaluated thanks to Eqs. (13) and (18) respectively [8].

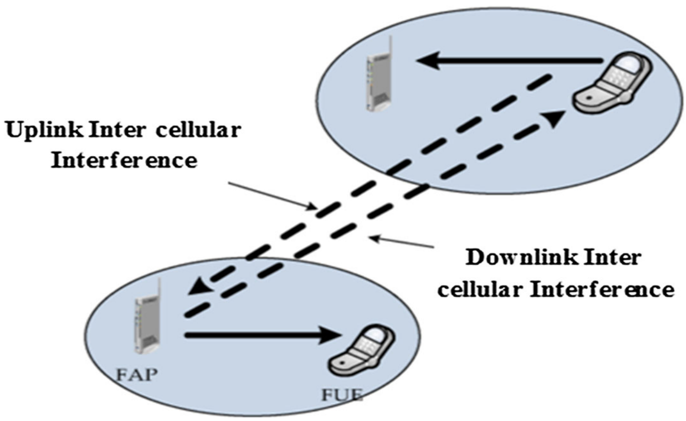


Fig. 8 Co-tier inter-cell interference

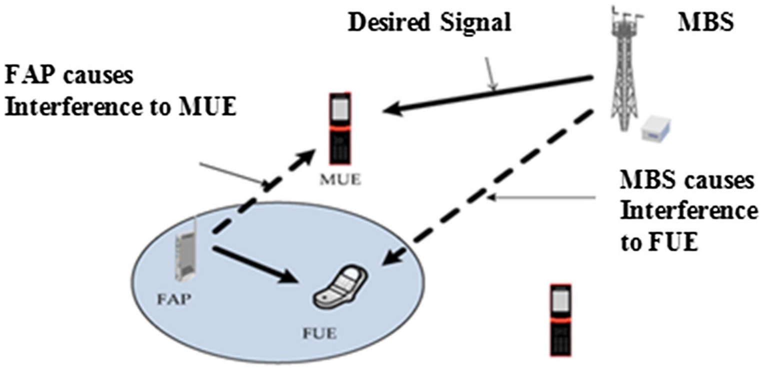


Fig. 9 Cross-tier inter-cell interference

$$SINR_m = \frac{S}{N + I} \quad (13)$$

where S is the desired signal's power, N is noise's power and I is the total interference's power. Or, S and N are expressed by Eqs. (14) and (15) respectively as [6]:

$$S = P_M G_{m,M} \quad (14)$$

where P_M is the transmit power of servant macro base station M and $G_{m,M}$ is the channel gain between the macro user m and the servant macro base station M.

$$N = N_0 \Delta_f \quad (15)$$

where N_0 presents the white noise power spectral density and Δf is the subcarrier spacing.

$$I = I_{Co-tier} + I_{Cross-tier} \quad (16)$$

$$SINR_m = \frac{P_M G_{m,M}}{N_0 \Delta_f + \sum_{M'} P_{M'} G_{m,M'} + \sum_F P_F G_{m,F}} \quad (17)$$

$$Throughput_m = W \log_2(1 + SINR_m) \quad (18)$$

where W is the available bandwidth.

Our simulation was conducted by increasing each time the number of femto cells in an urban environment with Rayleigh fading. We have also made experiments by varying the distance between the user and his servant macro cell (d = 5 m, d = 20 m and d = 50 m). The simulation parameters are summarized in the Table 1 [8]:

Table 1 Simulation parameters

Parameter	Value
Macro base station transmitted power	46 dBm
Femto base station transmitted power	20 dBm
Carrier frequency	2 GHz
Bandwidth	100 MHz
Subcarrier spacing	15 kHz

The obtained results show the effect of the number of femto cells on the SINR and throughput of a macro user. In fact, we can conclude that macro user's SINR and throughput decrease if the macro user moves away from the servant macro base station and also if we increase the number of femto cells in the macro cell. For example the SINR decreases from 10 to − 15 dB if the distance between the macro user *m* and its servant base station increased from *d* = 5 m to *d* = 50 m when we use one femto cell. Also, for a fixed distance d = 5 m e.g., if we increase the number of femto cells from 1 to 7, the SINR falls from 10 to − 5 dB as shown in Figs. 10 and 11 below.

Another simulation is made to show the importance of the femto cell deployment approach to reduce useful signal degradation. Figures below show the variation of the SINR and throughput of a macro user according to its distance from the femto base station *D*.

It can be concluded from Figs. 12 and 13, obtained for *n* = 1, where only one femto base station is deployed, that the macro user' SINR and the throughput are decreased if the

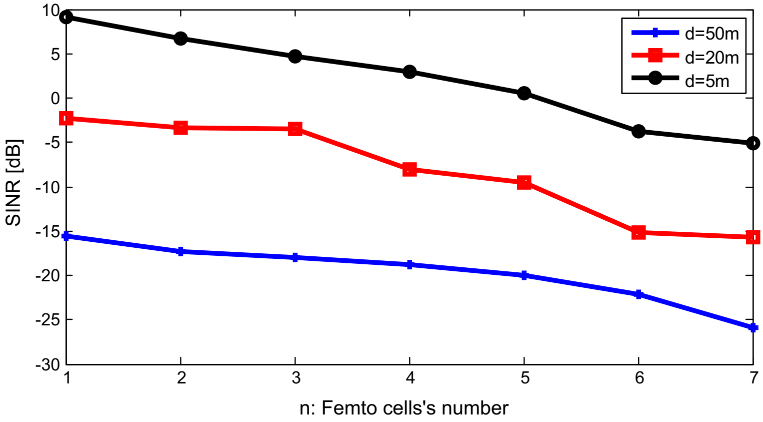


Fig. 10 SINR variation according to femto cell number

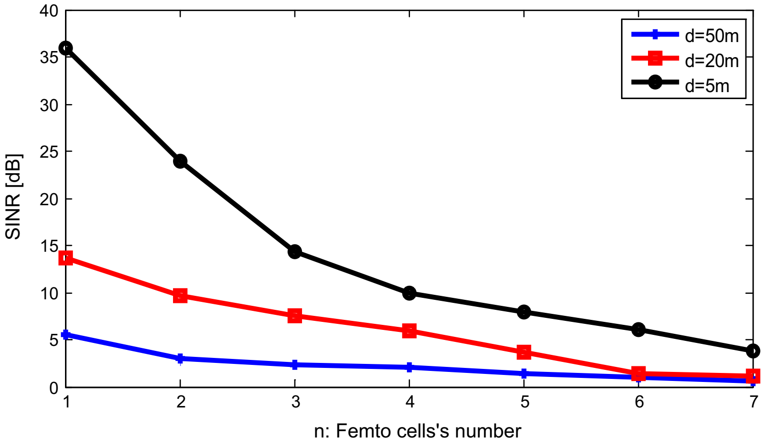


Fig. 11 Throughput variation according to femto cell number

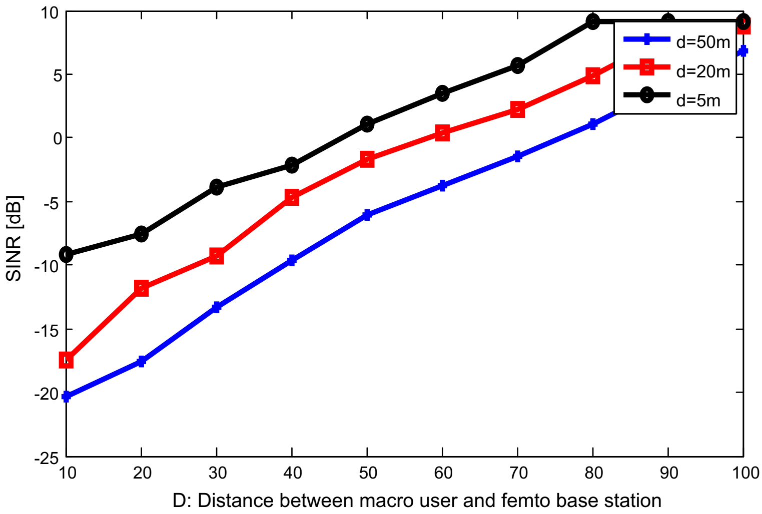


Fig. 12 SINR variation according to *D* and *d*

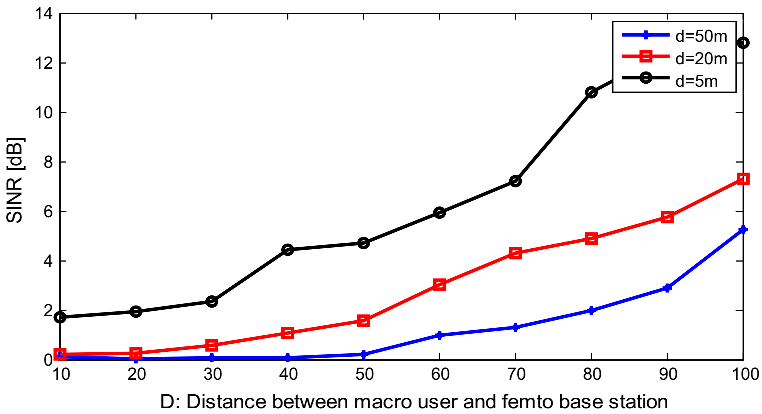


Fig. 13 Throughput variation according to *D* and *d*

macro user moves near to the interfering femto base station. Indeed, the throughput for example is increased from 13 to 2 Mbps if *D* (distance between macro user and femto base station) is varied from 100 to 10 m for a fixed distance $d = 5$ m. Interference is then reversely proportional to the distance of macro-user from the femto base station.

3 Conclusion

The problem of interference is the major issue in mobile networks. Indeed, in 2G and 3G of cellular networks, users suffer from intra and inter cell interference. In 4G, thanks to the various improvements in access techniques, the intra-cell interference kind has been surpassed. But after the notion of femto cell and heterogeneous network, 4G users suffer from inter-cell interference problem. Several techniques are proposed in the literature for the reduction of these interferences.

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