# A Two-Tier Frequency Reuse Scheme

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***Abstract*—The race toward higher throughputs for cellular network users is getting more difficult everyday. On the one hand cellular network operators wish to increase benefits by offering new services to users, but on the other hand spare radio resource are shrinking away. The spreading of WiFi-3G dual mode devices is making this fight even harder. The new "Femtocell" technology is expected to be the rescuer of cellular network operators. This "mini" cellular base station will provide high indoor coverage and throughput to indoor users relying on regular home access connections to the internet. However the big challenge remaining is to efficiently allocate spectrum to this technology. As spectrum licenses are very expensive most operators do not hold enough to completely separate the femtocell and macrocell layers. Co-existing femtocells and macrocells lead to severe interference scenarios. We propose here a double frequency reuse scheme, which allows a femtocell to reuse the frequency already in use by adjacent sectors of the overlaying macrocell. We present three solutions: full, partial or mixed frequency reuse. Each has advantages and drawbacks, and may be more suitable than the others in some specific configurations. Thanks to our scheme we preserve the radio resource management efficiency without affecting the system performance.**

***Index Terms*—femtocell; radio resource allocation; frequency reuse; macrocell; cellular networks**

## I. Introduction

After an extraordinary success, GSM (Global System for Mobile communications) has given way to 3G (third generation), which broadens the horizon of cellular networks. Users enjoy the most advanced services, while operators are able to reap new benefits, after approaching saturation with GSM. However 3G is inherently more demanding in terms of data rates, due to the data oriented services offered. Thus even though 3G is not yet fully deployed, eyes are already looking away towards the 4G (fourth generation). Using the Orthogonal Frequency Division Multiple Access (OFDMA) modulation and access scheme, 4G will be able to offer better throughput to a larger number of users.

Meanwhile the recent development of dual-mode phones that can accommodate, in a single device, GSM, 3G and the famous Wireless Local Access Network (WLAN) technology known as WiFi (Wireless Fidelity) is a real threat to cellular network operators. 4G will never compete with a residential WiFi Access Point (AP) intended only for the user who has deployed it himself. The WiFi AP could provide the user with a signal with higher power than the one received from the macrocell, whatever technology, GSM, 3G, or 4G.

Recently, a technology intended to defy this phenomenon has been developed. It is called "residential access point", "home base station " or "femtocell". The latter name is the most used and reflects the coverage range of the base station compared to microcell or picocell which cover areas of highly populated city or airport etc. It allows a user in the vicinity of his home to connect to his cellular network directly through his own base station instead of through the overlaying macrocell. The femtocell itself is connected to the network operator through the broadband backhaul internet connection like ADSL etc., already available at the user's home. The big challenge now is how to best share radio resources between the femtocell and macrocell. For the purpose of clarity we will refer in the following to the indoor user connected through his femtocell as FUE for Femtocell User Equipment. The home base station also called simply femtocell is denoted by FAP for Femtocell Access Point. And similarly we denote MUE the macrocell user equipment and MAP the macrocell access point, also known as Base station in the cellular vocabulary. Also for simplification we suppose that the FUE and FAP are both located indoors and that the MUE and MAP are outdoors. We use the terms "femtocell" or "macrocell" simply to refer to the technology without distinction of user equipment or access point. We present in the following the several interference scenarios induced by the coexistence of several femtocells and a macrocell. Then we briefly summarize the state of the art. Our solution to cope with the severe interference is then described. Guidelines for future work are mentioned in the conclusion.

## II. Challenges

One of the main challenges with femtocell lies in radio resource management. Before we start we need to remind ourselves that this issue is less severe in the case of wireless LAN, where access points do not have to co-exist with an overlaying macrocell. Moreover the access mechanism of the WiFi technology relies on carrier sense and collision avoidance mechanism, which avoids interference. In contrast, femtocells have to take into consideration the neighboring femtocells and also the overlaying macrocells. We list four interference scenarios that could occur when a FAP serves a FUE. In fact there are also other scenarios such as femtocell to Macrocell Uplink attack etc., but they are quite similar to the ones we present in the following paragraphs.

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### A. Femtocell to Macrocell Downlink Attack[1]

Assume a MUE receiving data from its far MAP, for example, consider the MUE located at the edge of the cell covered by its MAP. Consequently the received signal at the MUE is very low due to the distance between MAP and MUE. Meanwhile a FUE very close to the MUE is receiving data from its FAP, e.g. when a pedestrian is walking along the edge of the street near the FUE home. As the FAP is likely to be close to the FUE, the downlink transmission between the FAP and the FUE will strongly disturb the ongoing downlink transmission in the macrocell. Under certain conditions it could even lead to a dropped call for the MUE.

### B. Macrocell to Femtocell uplink Attack

In this attack we assume that the MUE is transmitting to its far MAP. It requires a high transmission power so that the MAP can receive the signal over the reception power threshold. At the same time, a FUE is transmitting to its FAP. Given their location are so close, the FUE can transmit at a low power. This feature is important because it can save the battery of the FUE. Thus, the consequence is that the uplink transmission in the femtocell will be strongly interfered by the MUE.

### C. Femtocell-to-Femtocell Uplink Attack

In this scenario and also in the next one, we focus on the interference between femtocells. All the elements are located indoors. Assume FUE1 transmits to its FAP1 and that the distance between each other is maximal, for example if the user is at the opposite side of the FAP in the house, as shown in Fig. 1. At the same time, suppose that FUE2 transmits to its very close FAP2. As already mentioned, the bigger the distance between the FUE and FAP, the higher the transmission power. Consequently, in our case the transmission from FUE1 will likely interfere with the one from FUE2.

### D. Femtocell-to-Femtocell Downlink Attack

Similarly to the previous scenario, we consider here that FUE1 is receiving from its far FAP1. Meanwhile, FAP2 is transmitting to FUE2. Suppose that FAP2 is closer to FUE1 than FAP1, the transmission of FAP2 will interfere and cause a degradation of FUE1 call.

## III. State of the Art

Several methods have been suggested to cope with all or part of the problematic scenarios mentioned. In the following we separate the challenges into two parts: the co-tier interference referring to the femtocell to femtocell scenarios and the cross tier interference for the interference between femtocells and macrocells. For the cross-tier interference, two main approaches are possible [2]: Spectrum splitting or spectrum sharing. In the first approach macro and femtocells are given orthogonal frequency bands. This approach seems to be the simplest one, as no cross-tier interference is expected. The macro and femtocell tiers can be considered as totally separate networks. However a drawback is that it is not efficient. Because splitting the already allocated spectrum into two smaller ones would imply lower throughput to macrocell users which is not desirable.

[1]The term "Attack" has been derived from the term "Aggressor" used in [1]

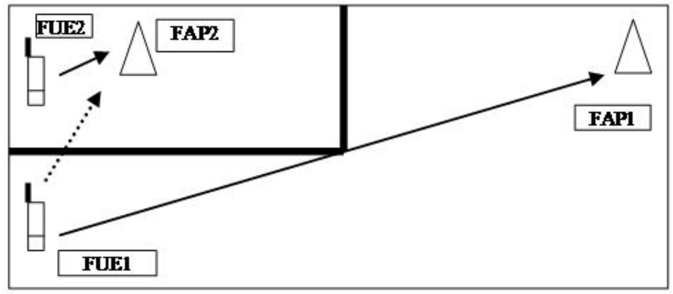


Fig. 1. Femtocell-to-Femtocell Uplink Attack

In the spectrum sharing approach the same spectrum is used by the macro and femtocell infrastructure, obviously this leads to the critical problem of co-channel interference.

In [3], a frequency assignment for femtocells is proposed. The coverage of the macrocell is split into an inner and an outer regions. If a femtocell is located in the outer region, it can reuse the channel of the overlaying macrocell. However if the femtocell is in the inner region, it must use a different channel than the overlaying macrocell. To compute where the limit must be between inner and outer region, the ILCA (Interference-limited coverage area) of a femtocell is defined. It's the area within a contour where the received power levels from the FAP and MAP are the same. If the ILCA is above a threshold, the femtocell is considered in the inner region. This frequency assignment method applies only to downlink, and [3] does not mention the femtocell frequency allocation in the inner region.

In [4], an uplink femtocell power control is proposed. It reduces the cross tier interference at the macrocell level. The study is in the context of the OFDMA WiMax system and can be also useful for LTE systems. However the power control proposed is not always realistic. In some cases, controlling the uplink transmission power of the femtocell to not disturb the macrocell, can lead to too low transmit power and the FUE could not be covered by its FAP.

Another solution proposed is to share the resource in a TDMA fashion manner on top of the CDMA [5]. Macrocell and femtocell will each transmit independently over one time slot and remain silent over other slots. This is referred to Time Hopped-CDMA (TH-CDMA). However it is in fact equivalent to splitting the resources in the time domain instead of splitting them in the frequency domain. As already said for the spectrum splitting, the loss of resource efficiency in an environment where radio resource is scarce constitutes a major drawback.

The co-tier interference challenge is overviewed in [6]. However no algorithm is mentioned and the cross-tier interference is not taken into account.

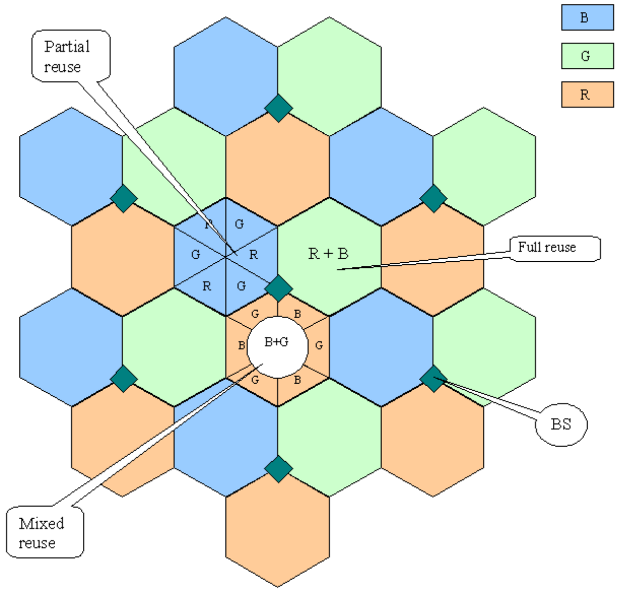


Fig. 2. Frequency reuse scheme

## IV. Double Frequency Reuse Assignment

### A. Macrocell-Femtocell Frequency Reuse

As the radio resources become scarce the spectrum sharing approach is more attractive. However as the interference mitigation problem is so challenging, spectrum splitting seems more realistic. We propose here to mix the two approaches via a frequency reuse between macrocell and femtocell. We assume that at the macrocell level we have a classical frequency reuse e.g. 3/3 frequency reuse scheme where each macrocell is split into three adjacent sectors through directional antennas. We propose a "double" frequency reuse scheme where femtocells located in a given macrocell sector will be allowed to reuse the bandwidth of the two other adjacent sectors of the same overlaying macrocell. In this way we increase spectrum efficiency and meanwhile mitigate cross-tier interferences that could occur between macrocell and femtocell users camping on the same spectrum.

Let us consider a system with an overall available bandwidth B. We split the spectrum into three equal parts, one for each of the three sectors of each MAP. This scheme is known as 1*3*3 reuse scheme also considered by the WiMax Forum. We consider here a scenario with 7 macrocells, see Fig. 2 . A three-sector clover-leaf cellular layout is used. We use 3 colors: B: Blue, R: Red and G: Green to represent the 3 parts of the split spectrum. For each sector, we allow the femtocells in it to reuse the spectrum not used by its MAP (i.e. two-thirds of the available bandwidth). We propose three kinds of reuse plans:

- Full reuse: The simplest reuse plan is full reuse over the whole area. This means that wherever the femtocell is located it can reuse whatever frequency used by the two adjacent sectors. The selection by each femtocell of a specific frequency among those spectra is detailed in section IV.B. The advantage of this reuse method is that more channels are available for femtocells, thus more flexibility to mitigate co-tier femtocell interference. The drawback of this method is that problems might occur when the FAP is close to the edge of the sector. Assume that the FAP chooses the same frequency that the adjacent macrocell sector, then it can suffer from Macrocell interference of the sector using the same spectrum in the adjacent cell in downlink, and vice versa "attack" the macrocell uplink as we explained above in Section II.
- Partial reuse: The second method to share the spectrum of the adjacent sectors between FAPs is to split each sector into equal parts (6 in our example). Then we allocate to each part, the spectrum that is not used by the nearest sector of the adjacent cell. We avoid here the problem induced by the full reuse scheme but on the other hand the pool of frequencies that can be chosen by neighboring femtocells is reduced. This can lead to severe co-tier interference in case of a dense femtocell population.
- Mixed reuse: This third method offers a tradeoff which helps in keeping the advantages of the two previous methods. We define the central region where both adjacent sectors spectra can be used as in the full reuse, and the cell boundary region where, as in partial reuse method, only the spectrum not used by the nearest sector can be used, see Fig. 2. For this method we can define the radius of the central region in a static or dynamic manner. For the dynamic radius we have to use an algorithm that computes it, based on statistics of interference of Macro-to-Femto and vice-versa. If interference decreases, e.g. because of less loaded MAP edge, then the central region can be extended.

### B. Femtocell Channel Selection

This section deals with the issue of sharing radio resources among the FAPs. At the macrocell level the resource allocation can be scheduled by some complex central algorithm. But femtocell level requires an auto-configuration mechanism. Given the high number of femtocells that will be deployed in a given area, especially in urban environments, and the lack of central coordinator a priori, channel assignment seems to be very complex. To avoid the large overhead of information transmitted to a centralized scheduler and complexity issues owing to the processing of large amounts of information, we need to carry out an auto-configuration mechanism. This issue is currently under intensive research and standardization efforts under the terms such as: Spectrum Sensing, Cognitive Radio and Self Organizing Networks. We propose here a simple approach. The FAP senses the available spectrum and selects the subchannels that are not currently being used, if there are such subchannels. Then it sends to the user the list of the subchannels and the user senses each of them for a given time and then sends a feedback through a Channel State Information (CSI) report on each subchannel. The subchannels which offer the best channel condition in terms of Signal to

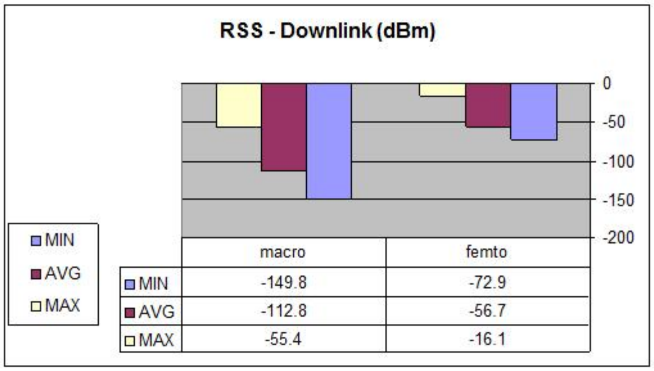


Fig. 3. RSS in Downlink with uniform distribution

Noise Ratio (SNR) is then chosen by the FAP. If no free subchannel is available, the FAP selects the least interfered subchannel, i.e. the subchannel in which the Received Signal Strength (RSS) (of the interference signals) is the lowest. This can ensure that the future transmission will not degrade the ongoing transmission. The load statistics of each subchannel can be taken into account to improve the selection since a lightly loaded subchannel could be better than a heavily loaded channel with a higher RSS. We assumed here that all the subchannels have equal bandwidth. However it might not be the case and thus channel selection may be more complex.

### *C. Some results*

We present here preliminary results retrieved with a simulator developed for the purpose of our research. The common scenario considered is 150 FAP in each sector where there is only one FUE for each FAP, 50 MUE in each sector. Transmission powers are as follows: 50 dBm for MAP, 21 dBm for FAP, 20 dBm for MUE and 18 dBm for FUE. We consider three scenario of FAP deployment: a uniform deployment where all FAP are uniformly distributed, a edge deployment where all FAP are located at the edge of the overlaying macrocell sector, and a centered deployment where the FAP are located near the MAP. Figures 3-8 show the RSS received when the FUE is connected through its FAP and when it's connected through the MAP. We notice that even when the FAP are near the MAP, the RSS received from the FAP is higher than the one received if the FUE was connected through the MAP.

## V. Conclusion

This paper presented the challenges of the new technology known as Femtocell. We developed a novel scheme for frequency assignment to the femtocell. To increase the efficiency of the network resource, we proposed to reuse the channels belonging to the neighboring sector of the overlaying macrocell. Three different reuse plans were proposed, each adapted for a specific scenario. As we saw in the state of art section, only a few works have been done, and many open issues remain. In a future work we wish to develop an optimal scheme for the sharing of spectrum between femtocells, based

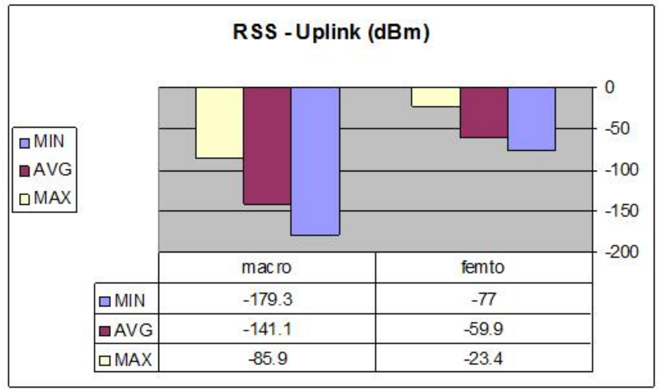


Fig. 4. RSS in Uplink with uniform distribution

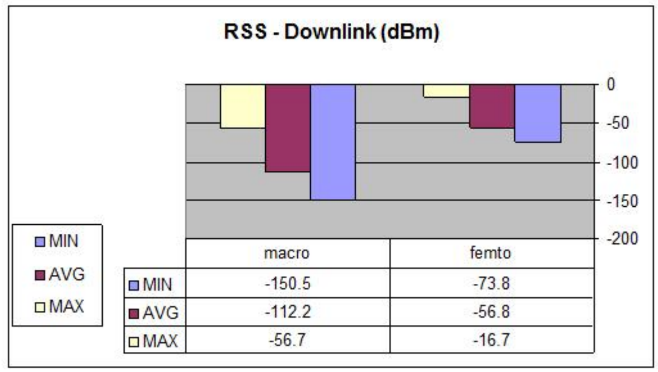


Fig. 5. RSS in Downlink with concentration at the edge

on game theory. Also it should be interesting to analyze the effect of the macrocell frequency reuse on our double frequency assignment scheme.

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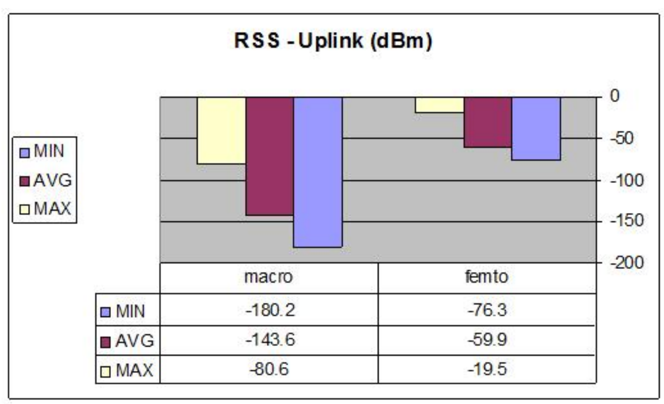
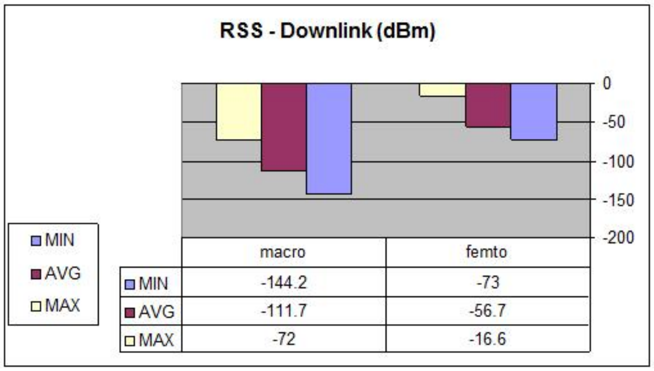
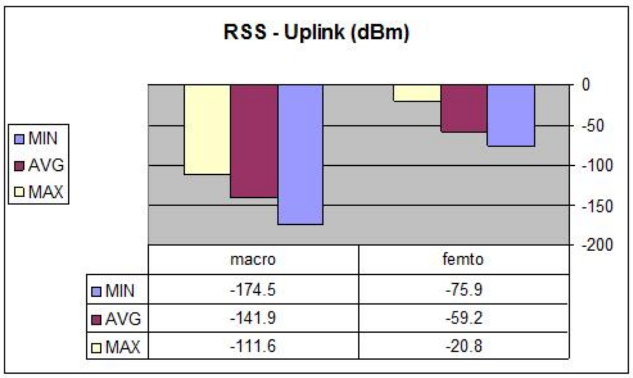



Fig. 6. RSS in Uplink with concentration at the edge




| | macro | femto |
|---|---|---|
| MIN | -144.2 | -73 |
| AVG | -111.7 | -56.7 |
| MAX | -72 | -16.6 |

Fig. 7. RSS in Downlink with concentration in the center




| | macro | femto |
|---|---|---|
| MIN | -174.5 | -75.9 |
| AVG | -141.9 | -59.2 |
| MAX | -111.6 | -20.8 |

Fig. 8. RSS in Uplink with concentration in the center

from Telecom ParisTech, and Mr. Jacques Bensimon (CEO) from Logtel are also gratefully acknowledged.

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