Course Project Report
Interference Management in OFDMA Femtocells

EE-764, Wireless & Mobile Communication
Prof. Abhay Karandikar | TA: Meghna Khaturia
Agrim Gupta, Varunesh Goyal, Ramanpreet Singh

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Abstract

Femto Cells are small-scale base stations deployed within a macro-scale base station's coverage area. The deployment of femto cells is motivated to enhance network coverage and capacity in select indoor areas, and act as an effective "home base station". However, interference management for femto-cells poses as a challenge since the conventional methods have deemed to be unsuitable to handle femto-cells. In this report, we present surveys for various methods evolved to deal with interference management for femtocells and a simulation for femto-cell aware scheduling scenario.

1 Introduction

Cellular networks have evolved drastically over the past decade and have nearly met to the bandwidth and data rate requirements of the population. However, seamless indoor coverage and call drops/mutes are still a challenging problem to look at. Femtocells are small scale base stations with lower transmit power than a full fledged macro cell. Deployment of femtocell near a selected indoor area can potentially solve the coverage issue in the indoor area, which makes it a good topic of interest for upcoming cellular network standards. Apart from improving the coverage in an indoor area, femtocells also help lengthen the battery life of the UEs (User Equipment) in it's coverage area, since those UE no longer needs to communicate to a far off macro cell. Femtocells also reduce the back-haul burden of the macro cell, since femtocell traffic is carried over residential broadband connections. They can also help reduce the traffic intensity at macro cell.

Femtocells can operate in three different access modes - closed access mode wherein only a set of registered UEs are allowed to access it (eg. in residential places); open access mode wherein any UE can access it (eg. in malls); and hybrid access mode in which preference is given to UEs which have subscribed to the femtocell but other UEs are also granted access (eg. in small business places).

However the above advantages come with some technical difficulties. Currently, the femto cell deployment is limited due to issues like-

- Interference management between adjacent femto cells and between femto cell and macro cell
- Convoluted handoff and mobility management
- Timing synchronisation issues between femto cells and macro cells
- Requirements of enhanced authentication to guard against potential threats like MITM [1], eavesdropping and masquerading

In the following report, we survey the methods existing in literature to deal with interference management and simulate the femto-aware spectrum arrangement scheme. The report is primarily based on "Interference Management in OFDMA Femtocell Networks: Issues and Approaches" by Saquib et al [1] and "A Novel Spectrum Arrangement Scheme for Femto Cell Deployment in LTE Macro Cells" by Wu et al [2].

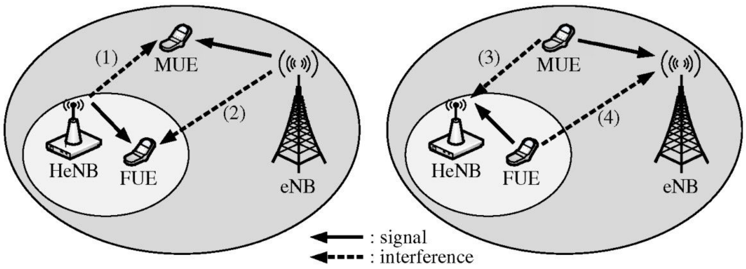
[1] Man In The Middle

2 The Problem of Interference Management in OFDMA Femtocells

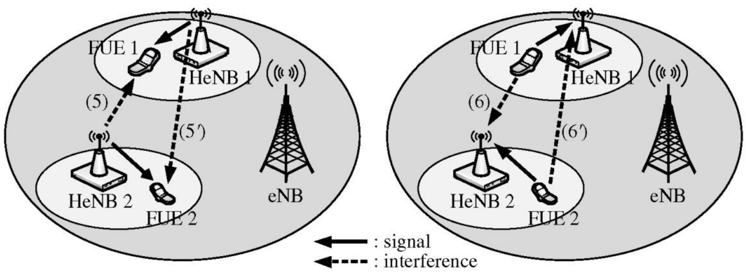
Due to scarcity of spectrum, in almost all cases there is spectrum sharing between femtocells and macro cell. The standard interference mitigation techniques used previously do not apply in case of femtocells since femtocells lie completely inside a macro cell. The problem of interference in presence of femtocells within a macro cell has been conveniently been divided into 2 types -

- **Co-tier interference**: This type of interference arises due to presence of a neighbor femto cell to a femto cell. This type of interference is thus labeled as 'co-tier interference', since this is due to interference among 2 (or more) femto cells which have similar transmit power and spectrum allocation. See Figure 1 for a pictorial representation of the same.

- **Cross-tier interference**: This type of interference arises due to spectrum sharing between macro and femto cells. Since the transmit power and spectrum allocation of the interfering units involved is not the same, this is labeled as cross-tier interference. See Figure 1 for a pictorial representation of the same.



(a) Cross-tier interference



(b) Co-teer interference

Figure 1: Co-tier and cross-tier interference [3]

Related to the problem of interference management, is the issue of **Deadzones**, which are defined as the areas where SINR goes less than a threshold, which hampers the Quality of Service (QoS) drastically. Deadzones are formed because of asymmetric level of transmission in the cell and the variability in transmit power of a femto and macro UE. As an example, macro UEs near the outskirts of a macro cell will transmit higher power, and this may cause severe interference to a femtocell Base Station (BS) located nearby and block the uplink transmission of the femtocell UEs.

It is desirable that a interference managing scheme mitigates the co-tier interference and reduce the cross-tier interference. The scheme should also be applicable to both the uplink and downlink scenarios. Due to presence of various telcos in the market, the femtocells deployed by one telco may not be cooperative with macro cell of the other telco. Hence, it may also be desired that the interferemce management scheme consider as little cooperation among the femto and macro BS as possible. Since the femtocell is an important resource to the telco, it is also desirable that the interference management scheme also serve the users in all the three modes of operation, viz. closed, open and hybrid. Lastly, the scheme should not be too complex so as to hinder the mass deployment of femto cells. However, no current scheme has been able to achieve all of the above desirabilities. In the next section, we will discuss each proposed scheme with respect to the above desirabilities, so as to form a qualitative comparison between the proposed schemes.

3 Interference Management Schemes in Literature

3.1 Femto-Aware Spectrum Arrangement Scheme

In such schemes, the macrocell base station is aware of the frequencies which the femtocell is allocating to its users. The macrocell BS can thus allot only those frequencies which aren't being used in a femtocell near a macrocell UE. There can be many ways in which the spectrum is shared between the macrocell and the femtocell in such schemes. The key takeaway here is that UEs near a femtocell (but which are under the MeNB) are assigned spectrum which doesn't overlap that of the femtocell thereby mitigating the uplink cross-tier interference and deadzone problem.

3.2 Femtocell Clustering Scheme

There is a dynamic frequency band allocation among HeNBs and MeNB, and clustering of HeNBs based on their geographical locations. A portion of the entire spectrum is shared between the MeNB and HeNBs (which depends on the number of HeNBs in a cluster) while rest is dedicated to the MeNB. This helps solve cross-tier interference. Further, HeNBs are segregated into different clusters in which each cluster uses the same sub-channels. Thus if two HeNBs are close by, they are allotted to different clusters in order to minimize co-tier interference.

3.3 Beamforming Approaches

Beamforming based approaches can reduce cross-tier interference. The MeNB selects a beam subset based on the SINR information of all channels which is feedback from the UEs. Thus if a UE reports low SINR for a particular sub-channel (indicating that there is probably some interference from a nearby femtocell), then he will be assigned some other channel. Also that particular sub-channel with low SINR will not be directed in his direction so that the femtocell UEs don't face cross-tier interference.

3.4 Collaborative Frequency Scheduling

In collaborative frequency scheduling, the HeNB does efficient spectrum sensing to figure which resource blocks are being used by a nearby macrocell UE. It also obtains the scheduling information for the macrocell UEs from the MeNB. The HeNB then utilizes only those resource blocks which are not used by nearby macrocell UEs. Being highly opportunistic and no clear part of the spectrum being dedicated for the femtocell or macrocell, there can a problem of Inter-carrier Interference in uplink due to macrocell UEs.

3.5 Power Control Approach

Power control approaches aim to check cross-tier interference by reducing transmission power of HeNBs. The HeNB adjusts its power based on either predetermined system parameters which it continuously measures or by coordinating with the MeNB. Many game theoretic models have been used to determine what would be optimal solution to such power control methods. Main advantage of a power control approach is that both MeNB and HeNBs can use entire bandwidth.

3.6 Fractional Frequency Reuse

The entire spectrum is divided into several sub-bands. The macrocell is divided into sub-areas. The sub-areas may use different sub-bands. The HeNBs sense which sub-bands have large received signal power and uses the rest of them. This results in increased SINR for the macrocell UEs as well. The partitioning of the entire spectrum into sub-bands can be made dynamic to make more efficient use of the resource.

3.7 Concise Comparison

We find that all the different approaches address the issue of cross-tier interference upto some extent. Some of the methods like clustering of femtocells and fractional frequency reuse also target co-tier interference which is of importance when we have a high density deployment of femtocells. Apart from the interference reduction which a scheme targets, there are other parameters such as whether it is applicable to both uplink and downlink, the amount of information sharing required between the MeNB and HeNBs, whether it can handle ICI, the scalability and robustness of the approach etc. which ultimately determine which one would be best suitable for a particular scenario.

4 Simulating the Femto-Aware Arrangement scheme

To understand more about the cross-tier interference problem, we tried our hands on to simulate the Femto-Aware arrangement scheme proposed by Wu et al. An brief overview of this scheme was given in Section 3.1

4.1 System Model

4.1.1 Spectrum Allocation

The scheme assumes that the spectrum is demarcated into 2 parts, the macro dedicated part and the femto-macro sharing part. The knowledge of this demarcation is assumed to be known to the macro base station.

4.1.2 Formation of Femto-Interference Pool

The macro BS identifies the UEs which are potential threat to femto uplink transmission, and notifies them to use only the macro dedicated part so that there is no co-channel interference caused at femto BS. Such UEs are said to be in "Femto-Interference Pool". Identification of such UEs is done by comparing the CQI of the reported sub-carriers by the UE. If a UE is nearby a femto cell, the CQI for subcarriers in femto-macro sharing part will be different (comparatively lower) than those subcarriers which belong to macro dedicated spectrum. Hence, if the CQI of the UE's femto-macro sharing part is lower than the CQI for the macro dedicated part by a threshold, macro BS identifies the UE to be part of the femto-interference pool.

Another consideration by the scheme here is that, by estimating the doppler frequency of the received reference signals by the macro BS, the macro BS can form a guess on the speed of the UE. If the UE's speed is higher than a set threshold, the CQI calculations above are not performed, since even if the UE is near the femto cell, it will be there just for a short period of time, and hence, the effect of co channel interference on femto uplink transmission would be just for a manageable slight amount of time.

To summarize, a UE is identified to be in the femto interference pool if and only if both it's speed is lesser than a set threshold and the CQI difference between macro dedicated and macro-femto sharing exceeds a set threshold.

A side point noted here is that by excluding the higher speed UE's actually helps the CQI thresholding as well. If the UE moves slow, the change in CQI over the adjacent sub-carriers would be slight, albeit the transition between femto-macro sharing to macro dedicated. Hence, we will get piecewise constant like CQI reporting for the subcarriers by the macro UE, which will simplify the thresholding step.

Refer Figure 2 for a pictorial representation of the Femto Interference pool scheme.

4.1.3 Considerations for the other Macro UEs and Femto BS & UE

The macro UEs not belonging to the femto-interference pool are given the full spectrum (both macro-femto sharing part and macro dedicated part) to exploit, since those UEs have not been identified as potential threats to femto uplink transmission. The scheme doesn't list down any special considerations on both Femto BS & UE apart from the spectrum demarcation assumption stated earlier. Although, by nature of the algorithm, the setting assumed for the femtocell is Closed setting. This is because the macro UEs near femto cell are informed by the macro cell to not use macro-femto sharing frequency.

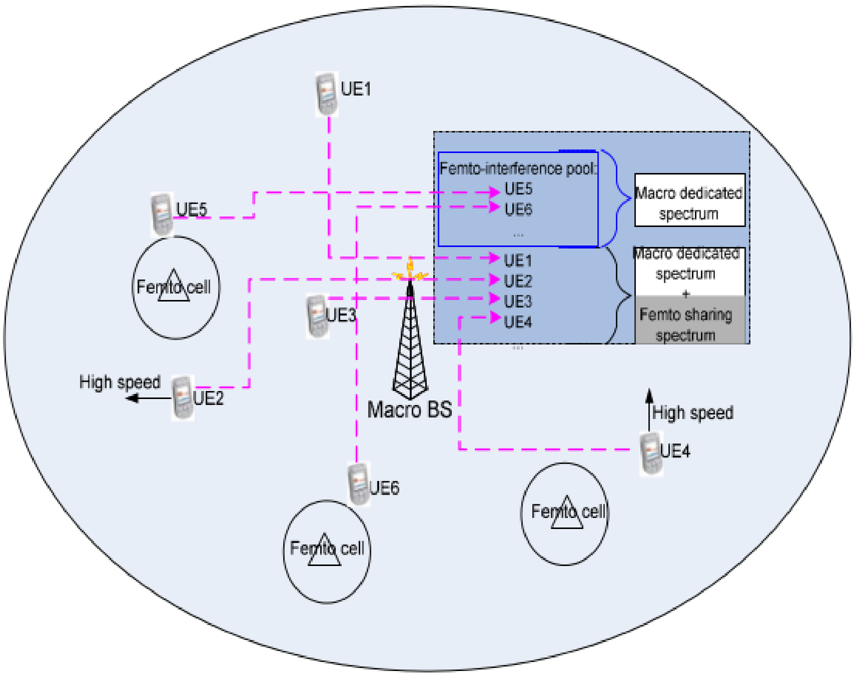


Figure 2: Pictorial Representation of femto-interference Pool [2]

4.2 Simulation Model considered and Results Obtained

The following table summarizes the system parameters considered:-

Parameter	Considerations
Femto Cell Radius	200m
Macro Cell Radius	5000m
Distance from femto cell to macro BS	1000m
Max Tx Power for macro/femto UE	25dBm/10dBm
Macro Propagation Model	$L[dB] = 128.1 + 37.6log_{10}(R)$; R is km
Indoor Propagation Model	$L[dB] = 37 + 32log_{10}(R)$; R in m
Shadow Fading	Lognormal distributed, $\sigma = 8dB$
Multipath Fading: power [dB]	EVA: [0,-1.5,-1.4,-3.6,-0.6,-9.1,-7.0,-12.0,-16.9]; EPA: [0,-1.0,-2.0,-3.0,-8.0, -17.2,-20.8]
Multipath Fading: delay [nS]	EVA: [0,30,150,310,370,710,1090,1730,2510]; EPA: [0,30,70,90,110,190,410]
Thermal Noise Density	-174 dBm/Hz
Net Macro Spectrum	2 MHz, 128 subcarriers 15.625 KHz each
Femto-Macro Sharing Spectrum	1 MHz, 64 subcarriers, 15.625 KHz each
Direction	Uplink

The simulation procedure undertaken was:-

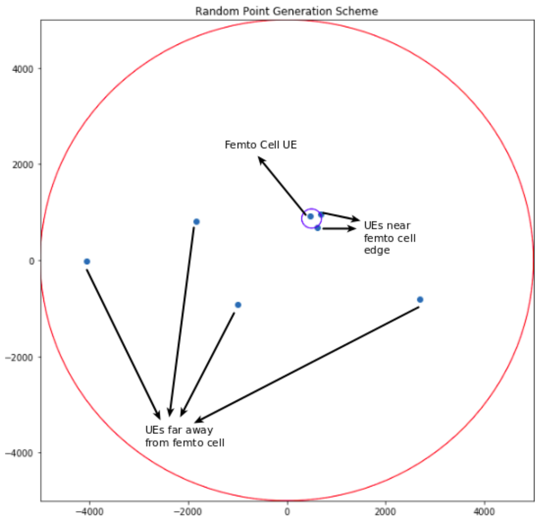
- **Generation of Random Points in the scenario**: To simulate the scenario, we generate 7 random points in the cell such that 1 of them lies in femto cell, 2 of them are slightly outside the femto cell, near the femto cell edge and 4 of them are far away from the femto cell. In the 4 UEs away from femto cells, two are assumed to be following vehicular channel model and 2 of them are assumed to have pedestrian channel model.
  The motivation behind such random generation is that at a time, the subcarriers alotted to femto UE will randomly clash with 6 other UEs in macro cell, with the assumption that 2 of them may lie near the femto cell edge. Refer to Figure 3 subfigure 1.

- **Path Loss Models**: Once the random points have been generated, the recieved powers due to these UEs at femto BS is calculated using a appropriate path loss model. For UEs outside the femto cell, say at distance d ($> R_{femto}$), for $d - R_{femto}$ the macro propagation model is considered and for R_{femto} the indoor model is considered. It is assumed that waterfilling is not being done and each subcarrier carries equal power.

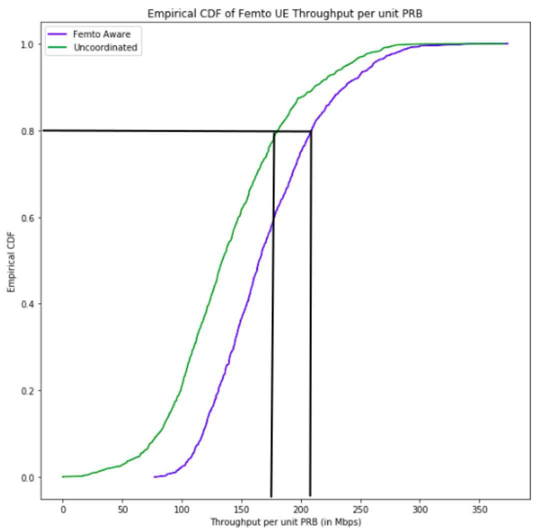
- **Fading Models**: Multipath fading model and lognormal shadow fading models are considered as in Table 1. The channel coefficients for various subcarriers across the 1 MHz (2 MHz for macro) are calculated by $c(f) = \sum_{i=1}^{n} e^{-j2\pi f \tau_i} n(p_i)$ where τ_i and p_i are delay and power coefficients associated with the model. Shadow fading is also incorporated by considering lognormal fading with std deviation 8 dB.

- **SINR calculations**: Combining both path loss and fading models, SINR can be calculated. Signal power is assumed to be the received power from Femto UE. Interference power is the summed power for the 4 UEs lying far away from Femto BS in case of femto aware scheduling and all the rest 6 UEs in case of uncoordinated scheduling.

- **CQI and throughput calculations**: CQI was calculated as $log_2(1 + SINR)$ and then using the translation of CQI to Bit Rate from Fig. 3 Table 2 [4], throughput per unit PRB was calculated.



CQI	Bit Rate, Mbit/s
1	0.95
2	1.46
3	2.35
4	3.75
5	5.47
6	7.34
7	9.21
8	11.94
9	15.02
10	17.04
11	20.73
12	24.35
13	28.23
14	31.92
15	34.66



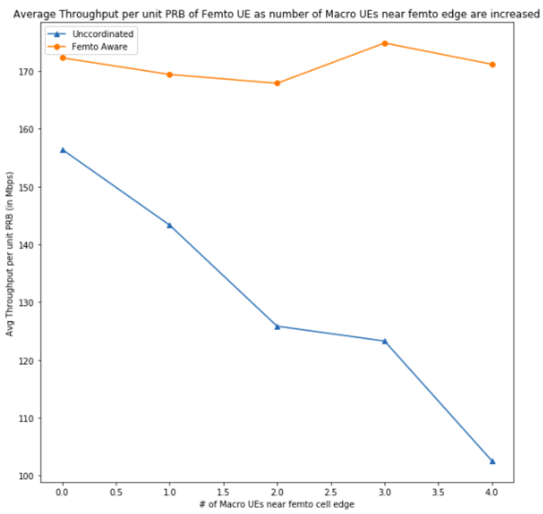


Figure 3: Subfigure 1 shows an instance of random point generation, Table 2 is the lookup table used to calculate throughput per unit PRB from CSI [4], Subfigure 3 shows the CDF for throughput per unit PRB, and Subfigure 4 shows the avg throughput per unit PRB and its behavior as number of macro cell UEs around femto cell edge increase.

The procedure was repeated for 5000 times and CDF of throughput for femto UE was plotted. Another scenario was then considered in which the number of UEs near the femto edge area were increased and average throughput over number of simulations was then obtained for both the cases again. The simulation results agree with the observations in the paper by Wu et al [2]. From Fig. 3 subplots 3 and 4, one can clearly observe that femto aware scheduling has a better throughput CDF and the throughput doesnt decrease much as number of macro UEs near femto cell edge increase.

4.3 Conclusion & Future Work Possible

- The Femto-aware scheme is a good solution towards dealing with cross-tier interference, and it solves the uplink deadzone problem as well. However, the scheme is not fair towards the UEs lying outside the femto-cell near the edge. The efficiency of those UEs is hampered since they are not able to use the macro-femto sharing part of spectrum.
- Hence, moving forward, the scheme should be hybridized with Collaborative Frequency Scheduling briefed in 3.4 so that whenever possible the macro UEs near the femto BS can use the femto BS and reap the advantages of femto BS as well.
- The scheme can also be merged with the sectorization based FFR schemes, which promise lower complexity and can be used to mitigate against the adverse situation which the proposed scheme creates for macro UEs near the femto cell edge
- Integration with clustering of adjacent femto cells method with the proposed femto aware scheme is also possible, which gives a new look towards the co-tier interference problem
- Currently, implementation wise, we have not calculated the net throughput, since we have not yet implemented a scheduling algorithm to allocate PRBs to the UEs. Hence, all the results have been given for throughput considering one PRB. The performance of the proposed scheme when there is a neighboring femto cell should also be characterized

The codes for the above are maintained in https://github.com/Agrim9/OFDMA_Femtocells

References

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