A Cooperation Framework for LTE Femtocells’ Efficient Integration in Cellular Infrastructures Based on Femto Relay Concept

Nikolaos Nomikos, Prodromos Makris, Dimitrios N. Skoutas, Demosthenes Vouyioukas and Charalabos Skianis
Department of Information & Communication Systems Engineering
University of the Aegean, Greece
Karlovassi, Samos Island, GR83200
{nnomikos, pmakris, d.skoutas, dvouyiou, cskianis}@aegean.gr

Abstract— The fast emerging technology of femtocells, by utilizing existing IP infrastructures, is promising to improve critical performance indicators of cellular networks, such as coverage and capacity, with minimum cost. However, the placement of femtocells can be completely unrelated to the structure of the cellular network, raising thus interference management challenges. In order to reduce interference at the forward link of femtocells caused by the macrocell Base Station (BS) and to improve the Signal-to-Interference plus Noise ratio (SINR) of macrocell users located in the vicinity of femtocells, we propose a Cooperation Framework for LTE Femtocells’ Efficient Integration (COF-FEI) in cellular infrastructures. COF-FEI introduces a novel merging of relaying and femtocells (i.e. femto-relays) and sets the base for an efficient cooperation between macro BS and femtocells through wireless links. As confirmed through simulations results, COF-FEI is able improve the overall Quality of Service provided to the macro and femto end users.

Index Terms - HetNet; Femtocell; Relaying; Inter-Cell Interference; QoS

I. INTRODUCTION

Heterogeneous Network (HetNet) deployments, as they are introduced by the LTE-Advanced group, are expected to be realized in the near future giving thus effective ways to cope with the continuously increasing traffic volume. HetNet concepts mainly deal with problems such as dynamically leveraging the existing cellular network topology and increasing the proximity between the access network and the end users [1]. In order to reduce the distance between transmitter and receiver a HetNet combines macrocells with low-power nodes, such as picocells, femtocells and relays. Speaking in technical terms, all the above considerations can be realized only if HetNet environments follow some basic context-aware mobile and wireless networking principles such as those discussed in [2]. More specifically, the more accurate and up-to-date context information is acquired, exchanged and evaluated by all HetNet entities’, the better decision making procedures will take place regarding the connectivity options of mobile terminals from an overall HetNet environment perspective.

Femtocells, while they are able to enhance the coverage and capacity of a cellular network with minimum cost by utilizing existing IP infrastructures, their unstructured placement may also cause major interference-related problems [3]. However, we argue that if the femtocell operation is assisted by relays then the signal transmissions to/from the macrocell can be moved closer to the User Equipment (UE). As a result, transmitting with better channel conditions leads to transmission power reduction in both uplink and downlink and thus intercell interference (ICI) between the macrocell and the femtocells can be reduced. Consequently, femtocell technology if fully exploited, can lead to improvements in interference reduction and data rate means, not only for the femto-users but also for nearby macro-users.

In this work, aiming to reduce the ICI at the downlink of femtocells which are located within a macrocell, we propose a novel merging of relaying and femtocells (i.e. femto relays). Subsequently, a Cooperation Framework for LTE Femtocells’ Efficient Integration (COF-FEI) in cellular infrastructures based on femto relays is also proposed. COF-FEI takes advantage of the exchanged context information about underutilized femtocells in order to serve macro UEs in their vicinity. However, as the femtocells’ IP backhaul may be utilized by users connected through Ethernet or Wi-Fi interfaces [4], we suggest that the traffic destined to the nearby macro UE should be directly relayed through a wireless link, from the macro BS to the femtocell, as is the case of typical relaying.

More specifically, the macro UE receives messages from the nearby femtocells denoting their availability to serve as relays. Estimating the SINR of all the available links, including the direct link to the macro BS, the most suitable path for each macro UE can be opportunistically selected. To summarize, the main contributions of our work are:

a) Exploitation of unplanned or partially planned femtocell deployment, in order to mitigate ICI at the downlink for both femto and macro users, through transmit power reduction and improved SINR.
b) Since there are no wired transmissions assumed for macro-users’ traffic, we avoid to put more burden to the already constrained femtocell backhaul link. Macro users are served only through the wireless relay link when a two-hop transmission is selected.

c) Data rate improvements can also be achieved for the macro-users through the opportunistic path selection process which always offers the best possible transmission quality to the macro UE at the forward link.

The structure of the paper is as follows: In Section II, the related work is studied in order to guide the interested reader in the area of heterogeneous cellular networks. The assumed system model is described in detail in Section III. The proposed COF-FEI scheme is presented in Section IV, and in Section V we evaluate the performance of the proposed scheme through simulation results. Finally, in Section VI conclusions are drawn and future directions are discussed.

II. RELATED WORK

In recent years, there is an increased interest in providing access to macro UEs through nearby femtocells. There is a number of works investigating this case and the resulting benefits. The authors in [5] study the advantages and disadvantages of adopting an open or closed access policy in a macrocell-femtocell topology. They conclude that in the uplink of OFDMA/TDMA networks an adaptive policy based on user density should be adopted, while in CDMA networks the employment of an open access policy benefits both femtocell and macro UEs.

In [6] an outage analysis of a network employing femtocells that relay soft information of outdoor users to the macro BS is performed. The authors conclude that the proposed scheme is able to improve the network’s performance if an open-access policy is adopted. The papers [7], [8] and [9] suggest an open-access policy by underutilized femtocells aiming to serve macro UEs in the uplink. In order to achieve this, an increase in the coverage area of the femtocells is proposed through multi-hop transmissions with the help of femto UEs. For relaying the macro UE’s traffic towards the macrocell, the wired connection of the femtocell is used. Numerical results show improved power efficiency and data rate for the macro UEs and load balancing for the macrocell.

Moreover, Tyrell et al. [10], present use cases where evolved femtocells can be employed, as well as the technical requirements for their deployment. Various types of femtocells are suggested to serve in different scenarios including indoor femtocells and outdoor relaying femtocells. Finally, in [11], the authors describe a scheme where femtocells are able to decode the received control message of the macro BS. By decoding this message, information about scheduled macro UEs can be extracted and afterwards an adjustment of femtocells’ transmission takes place. As a result, macrocell-femtocell interference is avoided and as an extra mitigation technique, interference cancellation is employed at the femtocells.

We can therefore conclude from the above, that there is a definite need for cooperation between macro and femto base stations. In most cases, femtocells should be operated in open or hybrid mode as this can significantly improve the overall performance of the HetNet. However, to the best of our knowledge, none of the works in the field considers a wireless relay link between the macro BS and the Femtocell Access Points (FAPs) and, even more, a femtocell equipped with a relay module. Thus, in the following we study this concept and at the same time we provide the framework for the efficient cooperation of macro BS and femto-relays.

III. SYSTEM MODEL

We consider a single cell in an urban environment, where the macro BS is located in the center. Within the area of the cell a number of femtocells are also deployed. We also assume that the femtocells are able to communicate with the macro BS through a wireless relay link. To enhance the benefits of wireless connectivity, some femtocells may be equipped with outdoor donor antennas to support this relay link. The macrocell’s users are moving in the cell and in random instances they may be within a femtocell’s coverage area.

In the downlink, when the macro BS is transmitting, the users served by femtocells (i.e. femto UEs) may experience increased interference if the signal from the macro BS is strong. In addition, when the femtocells are serving their users, macro UEs in the vicinity of the femtocells are interfered in the reception of the macrocell BS’s downlink transmissions.

This setup is illustrated on Figure 1, where the interference signals towards the femto UEs and macro UEs are highlighted, as this is our main focus in this work. We assume only pathloss and log-normal shadowing effects in our system. Following the technical specifications of [12], the pathloss of the direct link between the macro BS and a macro UE, is given by:

\[
PL(R)_{BS-UE} = 131.1 + 42.8 \log_{10}(R) \tag{1}
\]
where $R$ is the distance in kilometers between the transmitter and the receiver. In (1) we take under consideration the Non-Line-Of-Sight (NLOS) case, which in an urban setting of UEs, maintains, most of the time, NLOS connectivity with the macro BS.

For the two-hop transmission the pathloss of the macro BS-femto BS link, in the case that an outdoor antenna is used, is given by [12]:

$$PL(R)_{BS-fBS} = 100.7 + 23.5 \log_{10}(R)$$

(2)

In this case we assume Line-Of-Sight (LOS) conditions, as the outdoor antenna will be on the rooftop and directed towards the macro BS.

In the case of no outdoor antenna, the link is assumed to be NLOS and the pathloss is calculated by [12]:

$$PL(R)_{BS-fBS} = 131.1 + 42.8 \log_{10}(R)$$

(3)

In the link between the cooperating femto BS and the macro UE, NLOS conditions will be dominant, as the access antennas of the femtocells will be located inside buildings. As a result, the pathloss will be [12]:

$$PL(R)_{fBS-UE} = 128.1 + 37.6 \log_{10}(R)$$

(4)

IV. THE PROPOSED COF-FEI SCHEME

From the previous description we can easily conclude, that the macro-femtocell interference is one of the main degrading factors in the assumed HetNet topology described in Figure 1. Our goal is twofold: on one hand by reducing the power level of the macro BS’s transmissions, to reduce the interference to the femto UEs. On the other hand, by providing the macro UEs with better links through open-access underutilized femtocells, their SINR will be enhanced, thus protecting them from interference by other femtocells that are currently serving their UEs. In order to alleviate these problems, we propose a novel scheme as described below.

A. Identifying Femtocells Availability

More specifically, when a macro UE is in the vicinity of one or more femtocells that are available to cooperate, messages (i.e. context information) are transmitted from the latter to denote this event. Through this context information being exchanged, the macro UE is also informed about the conditions of the links between the macro BS and the femtocell as well as between the femtocell and macro UE. After receiving this information, the macro UE should decide on whether or not a two-hop transmission would result in a better SINR than a direct transmission from the macro BS. Finally, this decision is sent to the macro BS in order to relay the traffic destined to the macro UE through the cooperating proximate femtocell and consequently the latter activates its relay module in order to be able to act according to the femto-relay concept proposed in this paper.

B. Link Selection Algorithm

The Link Selection Algorithm (LSA) employs an opportunistic selection criterion [13], which is based on the SINR of each hop. LSA is performed at the macro UE in order to define the most efficient link:

```
FOR j=1:M macro UEs
    FOR i=1:N available femtocells
        SINR_{best,i} = \max \min (SINR_{BS,i}, SINR_{fBS,i})
        IF SINR_{best,i} > SINR_{BS-j}
            Route the f^{th} macro UE’s traffic through a two hop link
        ELSE
            Route the f^{th} macro UE’s traffic through a one-hop link
    END
END
```

Fig. 2 Link Selection Algorithm

Thus, the path with the best end-to-end transmission quality towards the macro UE is selected and thus optimal results in power reduction and data rate improvements can be achieved.

C. Macro BS Transmission Power Reduction

It is evident that during system operation the link selection algorithm offers to the macro UE a transmission path that, in many cases, is better when compared to the direct link. In such cases, it is possible to lower the transmission power of the macro BS and at the same time to keep the SINR at the same, or better, level compared to the direct link. In other words, we can keep the end-to-end capacity over a specific data rate threshold with lower transmission power. Consequently, that would result in less interference towards femto UEs. On the other hand, in a dense femtocell deployment, macro UEs having weak links towards the macro BS due to fading or cell-edge location, could be effectively served through their neighboring FAPs.

V. SIMULATION RESULTS

In order to study the efficiency of our scheme, a simulation setup was developed in MATLAB and two simulation scenarios are considered. The details of the designated simulations parameters are shown in Table I, where the values for shadowing and transmit SNR are taken from [12].

A. Power Reduction -Increasing the percentage of available femtocells

For the first simulation scenario, we evaluate the ability of COF-FEI to reduce the transmission power of the macro BS. As we study the downlink, power reduction can be achieved if the users experiencing bad links towards the macro BS are offered better two-hop links through nearby femtocells.
Thus, we assume a cell consisting of a varying number of cooperating femtocells and a single service with target data rate of 20MBps. We set a target data rate in order to quantify the power reduction achieved by our scheme for the corresponding SINR value [14].

We also consider a semi-planned deployment where apart from femtocell installation in houses, planned installation in office buildings and campuses could take place. Consequently, we assume that some FAPs are properly deployed by ICT specialists and equipped with outdoor antennas. The percentage of outdoor antennas is considered fixed at 50%.

The results are illustrated in Figure 3. We can see that as the percentage of available femtocells increases, more paths are offered to macro UEs, and thus the required transmission power is reduced. The power reduction reaches a saturation point at 90% where any further increase of the number of available femtocells cannot offer a better transmission path to the macro UE.

### B. Power Reduction - Increasing the percentage of femtocells with outdoor donor antennas

In the next simulation scenario, we change the percentage of the outdoor donor antennas in order to study power reduction for the whole range of unplanned femtocell to fully planned femtocell deployments. We keep the percentage of femtocell cooperation fixed to 30% and 40% which is a reasonable cooperation degree. The results are shown in Figure 4. We observe that the power reduces in an almost linear fashion as the number of outdoor antennas increases.

In this case, the percentage of the cell covered by the femtocells is stable and the ratio of macro UEs served by them does not vary, as is the case for the simulation involving the increasing percentage of cooperating femtocells. In the case of 40% cooperation, the corresponding curve has a higher slope indicating a greater range of improvement compared to the 30% one. For low percentages, the first-hop is the bottleneck of the end-to-end transmission in many cases, while for high percentages the NLOS second-hop is the main cause of degraded channel conditions. Furthermore, the effect of the proposed scheme on the data rate of the macro UEs is examined.

### C. Data rate improvement

Assuming the same simulation scenarios as in Sections V.A and V.B, Figures 5 and 6 illustrate the improvement of data rate over the case of no femtocell cooperation when the COF-FEI scheme is employed, for variable percentage of cooperating femtocells. In these scenarios, no target data rate is set and our main goal is to select the best path for each macro UE based on the achieved SINR, in order to maximize the end-to-end capacity. These simulations demonstrate a behavior similar to the corresponding comparisons for the power reduction. In Figure 5, we realize that the data rate improvement for percentages above 70% isn’t as notable as for lower percentages. As shown previously, while more femtocells become available, more macro UE tend to associate

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**Table I Simulation Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Macrocell radius (m)</td>
<td>500</td>
</tr>
<tr>
<td>Femtocell radius (m)</td>
<td>50</td>
</tr>
<tr>
<td>Number of femtocells</td>
<td>0-100</td>
</tr>
<tr>
<td>Number of macro UEs</td>
<td>25</td>
</tr>
<tr>
<td>Modulation</td>
<td>BS-fBS link: Adaptive modulation (QPSK, 16 QAM) BS-UE link: Adaptive modulation (QPSK, 16 QAM)</td>
</tr>
<tr>
<td>Shadowing std macro BS-UE (dB)</td>
<td>10</td>
</tr>
<tr>
<td>Shadowing std femto BS-UE (dB)</td>
<td>10</td>
</tr>
<tr>
<td>Shadowing std macro BS-femto BS (dB)</td>
<td>6</td>
</tr>
<tr>
<td>macro BS transmit SNR (dBm)</td>
<td>46</td>
</tr>
<tr>
<td>femto BS transmit SNR (dBm)</td>
<td>23</td>
</tr>
<tr>
<td>Penetration loss (dB)</td>
<td>20</td>
</tr>
<tr>
<td>Results</td>
<td>Power reduction, macro UE data rate</td>
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</tbody>
</table>
with them and for these values femtocell-macro UE association saturates. Finally, in Figure 6 we investigate the relation of increasing the percentage of equipping the available femtocells with outdoor antennas. We observe again, that for the 40% cooperation case, the slope of the curve is higher and the range of data rate improvement is greater.

VI. CONCLUSION

This paper elaborates on aspects of the recently introduced communication paradigm of HetNets currently being investigated as a study item in 3GPP LTE-Advanced releases. More specifically, a cooperation framework for LTE femtocells’ efficient integration in cellular infrastructures (i.e. COF-FEI) is proposed in order to mitigate inter-cell interference among heterogeneous cells. COF-FEI aims to: a) reduce the average transmission power of macro BS incurring less interference to femto UEs and b) provide macro UEs with better-quality links through hybrid-access underutilized FAPs, enhancing thus their SINR and protecting them from interference by other FAPs that are currently serving their own UEs. Numerical results verify the effectiveness of COF-FEI scheme in terms of macro BS transmission power reduction and UEs data rate improvements. Conclusively, COF-FEI’s main novelty lies in the fact that enhancing FAPs with wireless relaying capabilities can lead to promising results in ICI mitigation and resource utilization in HetNet environments.

Regarding our related future work considerations, we plan to extend COF-FEI concepts applicability to larger-scale HetNet environments investigating its flexibility to various diversifiable network deployment scenarios. Furthermore, a power control mechanism will be developed to take advantage of the power reduction achieved by our scheme. In addition, we aim to prove that operating femtocells as relays can improve HetNet’s overall RRM objectives by extending the overall virtual backhaul link capacity in small cell areas, where excessive traffic is monitored at specific time intervals and that optimal exploitation of context information among all HetNet entities can be the cornerstone of proposed architectural solutions.

REFERENCES