The Gain of a Targeted Introduction of OSG Femtocells into a LTE Macro Network

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Abstract—**Previous studies have indicated that the drawback of a heterogeneous network deployment is that the required number of new sites to fulfill a desired coverage and capacity requirement becomes considerably larger compared to a densified macro deployment. Therefore, the scope of this study is to investigate if a more targeted introduction of femtocells, under the assumption of a non-uniform user traffic, could help to reduce the required number of new femto sites. The enhanced femto deployments evaluated in this paper are aiming to offload initially the users with the worst macro coverage and/or the users generating most of the traffic. The obtained results show that an approach, which deploys femto eNodeBs initially within the traffic-heavy apartments provides considerable gains compared to a random deployment, or a deployment looking only at the macro cell coverage. The best results are achieved, when the approach based on the user traffic is combined with the coverage-based approach.**

Keywords-LTE; femtocell; heterogeneous networks

I. Introduction

The traffic in the mobile networks is expected to grow very rapidly in the coming years [1][2]. This traffic growth is caused both by the evolution of the mobile terminals (an increasing penetration of smart phones, tablets and mobile computers) and by the increased use of more traffic-heavy services, such as video, web access and peer-to-peer. It is also expected that the wider introduction of various cloud-based services and machine-to-machine communication will accelerate the traffic growth even further. In order to be able to serve the increased traffic, all three possible ways to increase the network capacity will have to be utilized: increased spectrum, improved spectral efficiency and network densification [3][4].

The downlink and uplink performance of a number of different network densification alternatives (densified macro, heterogeneous micro, heterogeneous pico and heterogeneous OSG femto) was compared in [5] and [6]. The results in both papers indicated clearly that the drawback of a heterogeneous network deployment is that the required number of new sites becomes considerably larger compared to a densified macro deployment. One reason for this was the fact that the low-power cells had difficulties in providing sufficiently large coverage areas and hence, the level of traffic offloading.

As demonstrated for example in [7], the coverage area of a low-power cell depends on the received downlink signal strength of the overlaying co-channel macro cell. Therefore, the coverage areas, as well as the probability of offloading the most power-limited users, can be increased by deploying the low-power cells within the areas with the worst macro cell coverage. Perhaps an even greater performance improvement can be achieved by taking into account the fact that quite often a small number of users consume a large part of the total traffic [2]. If the locations of the low-power sites are selected so that most of the traffic generated by the “traffic-heavy” users can be offloaded, a relatively small number of low-power cells would be sufficient to result in considerable performance gains.

The scope of this paper is to evaluate the LTE downlink performance of a heterogeneous open access (OSG) femto deployment with both a non-uniform user traffic and a number of different approaches for the selection of the femto apartments. Even though it might not be realistic to assume that a real femto deployment is able to fully target on the users with the worst macro coverage and/or high traffic, the results on this study can provide an estimate of the performance potential of such ideal deployments.

Furthermore, a deployment utilizing open access femto eNodeBs is assumed since it is expected to reflect the maximum capacity potential of the heterogeneous femto deployments. Assuming a CSG, or a hybrid mode operation would result in a lower level of traffic offloading and/or worse user performance and overall network capacity [8].

The structure of the paper is the following: First, in chapter II, the main models and assumptions are introduced. Chapter III presents evaluation results and discusses the downlink performance of the different OSG femto deployment alternatives. Finally, some concluding remarks are provided in chapter IV.

II. Models and Assumptions

The downlink evaluations in this paper are based on the models and assumptions introduced already in [5]. Therefore, only the changes made into the traffic distribution and the femto deployment are discussed in this chapter.

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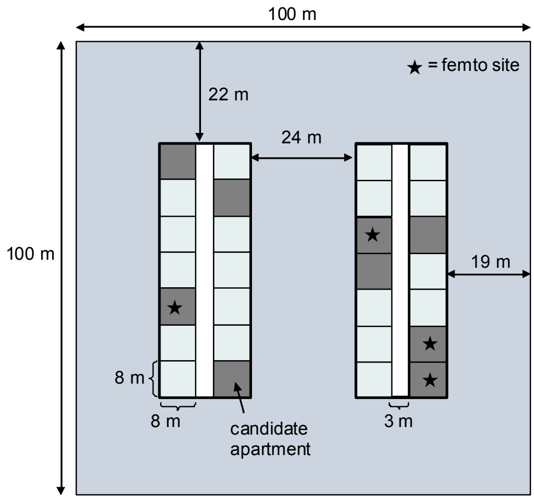

Fig. 1. Layout of a *traffic cluster bin*. Both buildings have five floors. The locations of the femto base stations are indicated by the stars.

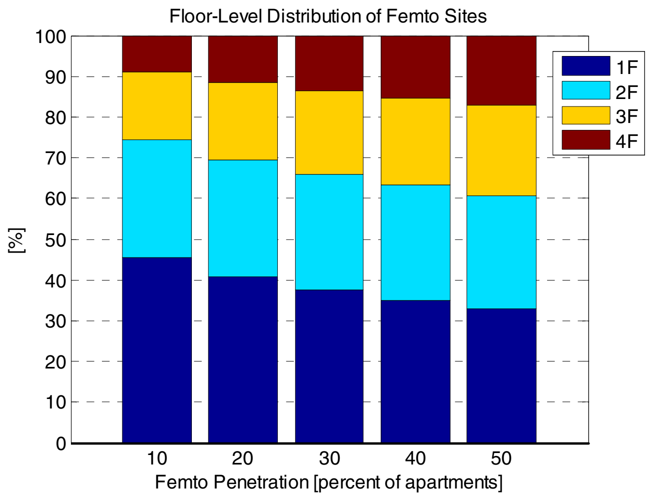

Fig. 2. Floor-level distribution of the femto sites as a function of the femto penetration, assuming a coverage-based selection of femto apartments.

A. Non-Uniform User Traffic

In [5], each residential candidate apartment, as highlighted in Fig. 1, had an equal probability of including an active user and each active user was assumed to generate an equal amount of traffic into the system. Furthermore, the total traffic was divided into three different groups based on the locations of the active users: residential indoor traffic (64% of the total traffic, users located on the 1st, 2nd, 3rd and 4th floor), non-residential indoor traffic (16%, users located on the ground floor) and in-vehicle traffic (20%). Ignoring any visiting residential users, the traffic distribution could be interpreted also so that a subscriber consumes 64% of the traffic at home, 16% within non-residential indoor locations and 20% inside vehicles.

The assumption of a uniform traffic distribution does not necessarily reflect the reality, where the amount of monthly traffic can have large variations between the subscribers. Therefore, a model for “traffic-heavy” users is introduced in this paper. The model is based on two fundamental assumptions: a) 20% of the subscribers generate approximately 80% of the total traffic, and b) the distribution of the total traffic between the residential, non-residential and in-vehicle locations is kept intact. By doing so, only the distribution of the residential traffic needs to be modified. In practice the assumption that 20% of the subscribers generate approximately 80% of the total traffic means that approximately 50% of the total traffic is generated within 20% of the candidate apartments (the so called *traffic-heavy apartments*), while 14% of the total traffic is generated within the remaining 80% of the candidate apartments. The traffic-heavy apartments are selected randomly for each snapshot, assuming a uniform distribution.

B. Selection of Femto Apartments

The second new aspect discussed in this paper is a targeted deployment of OSG femto eNodeBs. A random deployment of femto eNodeBs was assumed in [5], i.e. the femto apartments were selected randomly from the group of the residential candidate apartments. Instead of a random deployment, one could think of somewhat more advanced approaches, where the femto eNodeBs are deployed to improve the coverage and/or to offload as much of the traffic as possible. The performance of four different femto deployment alternatives is investigated in this paper:

- Random deployment (RND).
- Deployment based on the macro cell signal strength, starting from the apartments with the worst macro coverage (COV)
- Deployment focusing on the traffic-heavy apartments, assuming a random selection of apartments (HVYR)
- Deployment focusing on the traffic-heavy apartments, starting from the ones with the worst macro coverage (HVYC)

The approach taking the macro cell coverage into account has two advantages. Firstly, the traffic offloading is targeted towards the users that have the worst macro coverage, which are quite often also the most expensive users from the overall macro cell performance point of view. Secondly, the femto eNodeBs are deployed within areas with a weak macro cell, which leads to increased sizes of the femto cells. As a result of the floor height gain, the apartments with the worst macro cell coverage can be to a large extent found on the lower floors. This is verified in Fig. 2, which presents the floor-level distribution of the femto sites as a function of the assumed femto penetration. For example, if the femto penetration is assumed to be equal to 10%, approximately 46% of the deployed femto sites are located on the 1st floor, and only 9% on the 4th floor. As the level of femto penetration increases, the floor-level distribution of the femto sites becomes more uniform. The downside of the coverage-based femto deployment is that the femto site density becomes smaller on the upper floors, which can be expected to result in a reduced traffic offloading and a worse user performance.

In case of the deployments focusing on the traffic-heavy apartments, the femto eNodeBs are deployed first within the

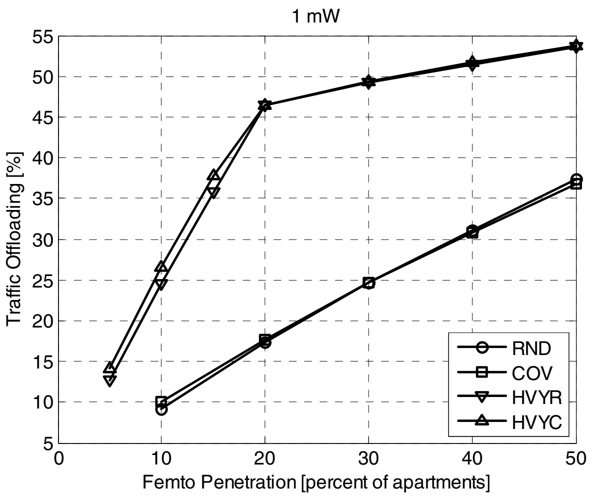

Fig. 3. Observed traffic offloading as a function of the femto penetration for the evaluated femto deployments. Maximum femto eNodeB output power equal to 1 mW is assumed.

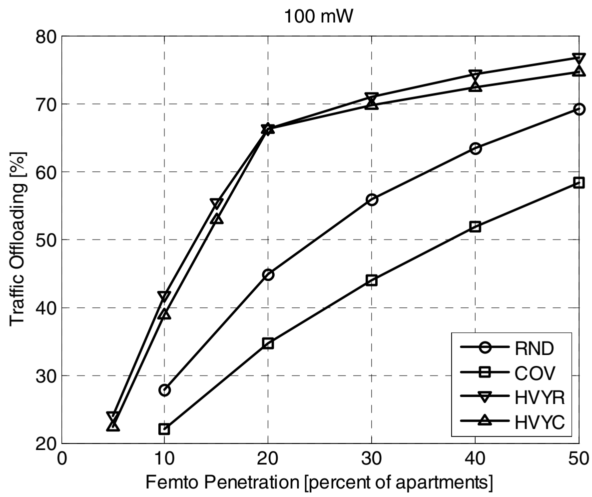

Fig. 4. Observed traffic offloading as a function of the femto penetration for the evaluated femto deployments. Maximum femto eNodeB output power equal to 100 mW is assumed.

traffic-heavy apartments, and only after that within the other candidate apartments. These kind of approaches maximize the amount of traffic offloaded from the macro layer with the minimum amount of femto eNodeBs. In case of HVYR, a random selection of femto apartments, first from the group of traffic-heavy, and then from the group of traffic-light candidate apartments is assumed. In case of HVYC, the femto apartments are selected based on the macro cell coverage.

III. Evaluation Results

In this chapter the downlink performance is evaluated for a heterogeneous LTE network consisting of a homogeneous macro cell layer with inter-site distance equal to 500 meters, and a heterogeneous OSG femto cell layer. The femto eNodeBs, with an output power equal to either 1 mW or 100 mW, are assumed to be operating on the same 20 MHz carrier as the overlaying macro eNodeBs with an output power equal to 40 W per sector. A more detailed list of simulation parameters can be found in [5].

A. Impact on Traffic Offloading

The evaluation of the heterogeneous OSG femto deployment is initiated by investigating the impact of the different femto deployment alternatives on the overall traffic offloading. The results for the traffic offloading as a function of the femto penetration are presented in Fig. 3 and Fig. 4 for maximum femto eNodeB output power equal to 1 mW and 100 mW, respectively. Femto penetration up to 50% of the candidate apartments is assumed in this study. However, it is quite easy to understand that the performance of the different femto selection alternatives will converge when the femto penetration approaches 100%.

As indicated by the results, the coverage-based femto deployment does not seem to increase the overall traffic offloading compared to the random selection of femto apartments. In fact, the traffic offloading is reduced if a high femto eNodeB output power is assumed. The main reason for this is the fact that the OSG femto cells can offload users also outside the actual femto apartment. Therefore, an approach which spreads the femto cells more uniformly between the different floors and buildings can provide a better overall traffic offloading compared to a more clustered deployment of femto cells. The coverage-based deployment increases the traffic offloading of the users on the ground floor and on the 1st floor, at least for a low femto eNodeB output power. At the same time, the offloading of the in-vehicle users, as well as the users on the upper floors becomes worse.

The approaches focusing on the traffic-heavy apartments result in a considerably increased level of traffic offloading. As mentioned, the evaluations assume that 50% of the total traffic is generated in 20% of the candidate apartments. In case of a 20% femto penetration all these traffic-heavy apartments include a femto eNodeB, which together with the fact that the OSG femto coverage area can extend beyond the walls of the apartment, can result in an overall traffic offloading well over 50%. Taking the scenario with femto eNodeB output power equal to 100 mW as an example, a deployment where all traffic-heavy apartments include a femto eNodeB results in an overall traffic offloading equal to 66%, which consists of 87% of the residential users, 38% of the ground floor users and 23% of the in-vehicle users.

The difference between HVYR and HVYC seems to be quite small, which means that the major part of the traffic offloading gains are achieved by focusing initially on the traffic-heavy apartments. However, the order in which the traffic-heavy apartments are selected is less important.

B. Impact on User Performance

This section evaluates the average user performance for different user locations and with the different femto eNodeB deployment options. The evaluations assume that 30% of the candidate apartments have a femto eNodeB with output power equal to 100 mW, and that the offered area traffic is equal to 100 GB/h/km^2.

Results for the user performance within the different locations (in-vehicle, ground floor, residential, 1st floor, 4th

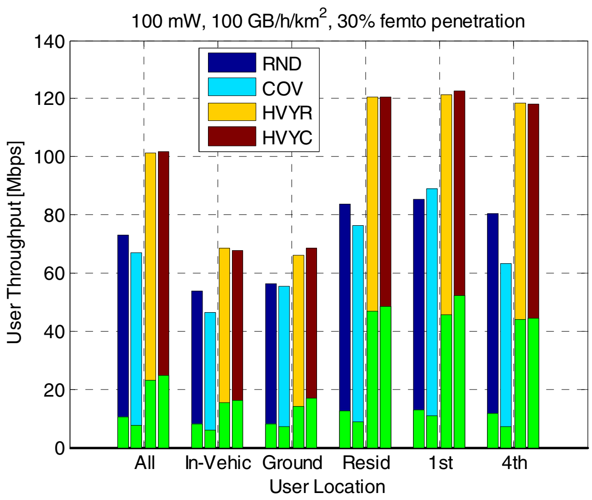

Fig. 5. Observed user performance for different user locations. Offered traffic equal to 100 GB/h/km^2, femto eNodeB output power equal to 100 mW and a femto penetration equal to 30% of the apartments are assumed.

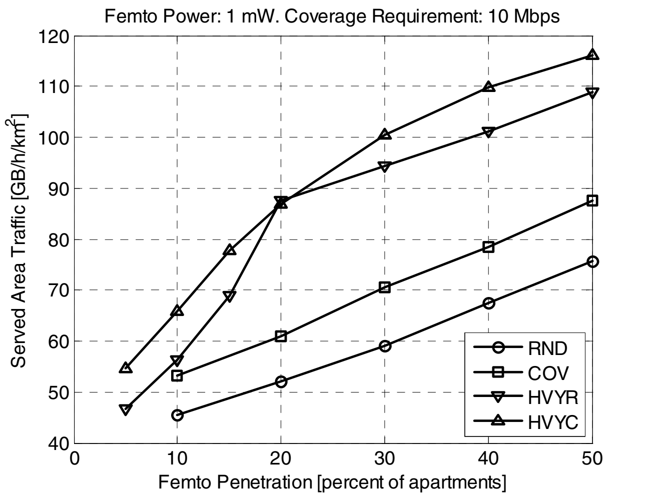

Fig. 6. Served area traffic as a function of the femto penetration for the different femto deployment alternatives. Femto eNodeB output power equal to 1 mW and coverage requirement equal to 10 Mbps are assumed.

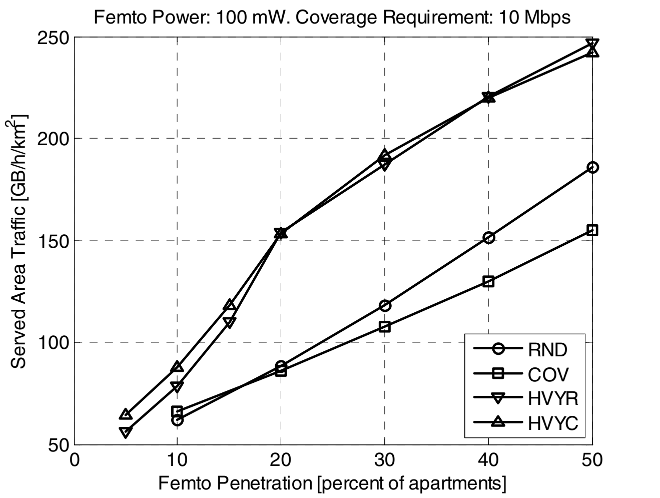

Fig. 7. Served area traffic as a function of the femto penetration for the different femto deployment alternatives. Femto eNodeB output power equal to 100 mW and coverage requirement equal to 10 Mbps are assumed.

floor) are presented in Fig. 5. The multi-colored bars indicate the average user throughput, while the throughput of the worst 5th percentile of the users is indicated by the green bars.

Results for the random selection of femto apartments (RND) demonstrate the same findings as in [5]: a) heterogeneous femto deployment results in better indoor than in-vehicle user performance, b) the user performance is reduced as a function of the floor level, and c) the performance of the non-residential indoor users (located on the ground floor) is clearly worse than the performance of the residential indoor users.

The coverage-based deployment (COV) is found to result in a reduced level of traffic offloading for all the evaluated user locations. Furthermore, COV seems to result in a worse average performance for all users, except the ones located on the 1st floor. There, the gain of offloading the users with the worst macro coverage is able to outweigh the loss of a reduced number of offloaded users.

The approaches based on the user traffic (HVYR and HVYC) result in a considerably increased offloading of the residential traffic, which is also clearly reflected in the results in Fig. 5. Since the traffic-heavy apartments are assumed to be uniformly distributed, the changes in the offloading of the non-residential in-vehicle and ground floor users are not remarkable. However, even the non-residential users can enjoy the benefit of an increased overall offloading of the macro cell users, resulting in a reduced inter-cell interference and increased amount of resources in the time domain, which both contribute to an improved user throughput.

C. Impact on Network Capacity

The results for the served area traffic as a function of the femto penetration are presented in Fig. 6 and Fig. 7 for maximum femto eNodeB output power equal to 1 mW and 100 mW, respectively. As can be seen, the coverage-based femto deployment results in a clear capacity gain when the femto eNodeB output power is low. However, in case of a high femto eNodeB output power, a capacity loss is observed instead unless the level of femto penetration is less than 16%. The obtained results are a combination of two things: a) reduced overall traffic offloading, and b) increased offloading of the users with the largest path losses towards the serving macro eNodeBs. The reduced overall traffic offloading is expected to result in a worse system performance for scenarios that are mostly capacity-limited (low coverage requirement, high femto eNodeB output power, high femto penetration), whereas the approach aiming to offload the users with the worst macro cell coverage is expected to benefit mostly the scenarios that are power-limited (high coverage requirement, low femto eNodeB output power, low femto penetration).

The approaches focusing initially on the traffic-heavy users seem to clearly outperform both COV and RND, which is a direct result of the greatly increased level of traffic offloading from the macro to the femto cell layer. Furthermore, from the system capacity point of view, HVYC seems to have an advantage over HVYR, even though the differences in the

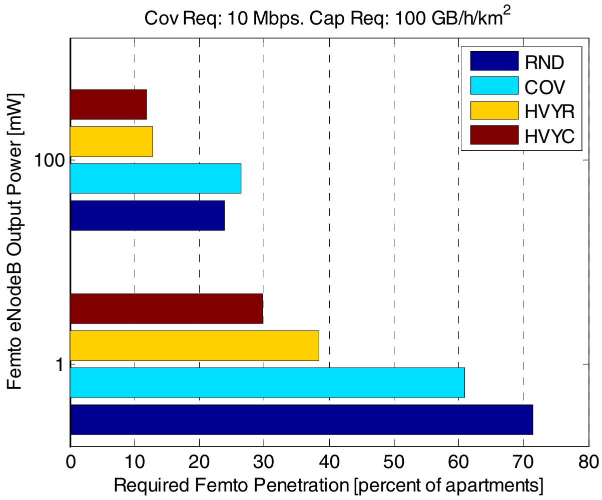

Fig. 8. Required femto penetration for the different femto deployment alternatives to fulfill both a coverage requirement of 10 Mbps and a capacity requirement of 100 GB/h/km^2.

observed traffic offloading are quite small. Similar to the difference between COV and RND, the capacity gains are larger for the deployment with a low femto eNodeB output power. This is due to the fact that the system is more power-limited, and will therefore benefit more from the offloading of the users with the worst macro cell coverage.

D. *Impact on Network Dimensioning*

The previous sections have demonstrated how the targeted deployment of OSG femto eNodeBs will improve both the user performance and the overall system capacity. This section will demonstrate how the observed capacity improvement will affect the number of femto eNodeBs required to fulfill the desired coverage and capacity requirement.

Fig. 8 presents the results for the required femto penetration in order to fulfill both the coverage requirement of 10 Mbps and the capacity requirement of 100 GB/h/km^2. The results follow quite well the capacity gains observed in Fig. 6 and Fig. 7. Hence, targeting the OSG femto eNodeB deployment towards the apartments with the worst macro coverage and/or the highest traffic will in most of the cases result in a lower requirement on the femto penetration. More specifically, the coverage-based deployment of OSG femto eNodeBs will result in a 15% lower number of femto sites than the random deployment, when the femto eNodeB output power is low (1 mW). However, when the femto eNodeB output power is high (100 mW), the required number of femto eNodeBs becomes 11% higher as a result of the coverage-based deployment.

One can also see how the traffic-based deployment is beneficial for both the low and the high femto eNodeB output power. In case of the low output power, the required number of femto eNodeBs becomes 46% (HVYR) or 58% (HVYC) smaller than in case of the random femto deployment. Similarly, in case of the high output power, the required number of femto eNodeBs becomes 46% or 50% smaller for the HVYR and HVYC deployments, respectively. Hence, as a summary, the approach combining both the traffic and the coverage-based deployment seems to be the most efficient from the required femto eNodeB density point of view.

Even though the required femto penetration in Fig. 8 appears to be quite low, at least for the HVYC with a high femto eNodeB output power (12% of the candidate apartments), it still corresponds to a density of approximately 161 femto sites/km^2, or an average of 11.6 femto sites per macro cell. As a comparison, if the same network performance is achieved by densifying the macro cell layer, or by deploying micro sites with 1 W output power into the traffic clusters, the required density of new sites becomes equal to 4.2 macro sites/km^2 or 30.3 micro sites/km^2 [5].

IV. Conclusions

This paper has evaluated the LTE downlink performance with different approaches to deploy femto eNodeBs, under the assumption of a non-uniform distribution of the user traffic. The obtained results show that an approach, which deploys femto eNodeBs initially within the traffic-heavy apartments provides considerable gains compared to a random deployment, or a deployment looking only at the macro cell coverage. The best results are achieved, when the approach based on the user traffic is combined with the coverage-based approach.

Based on the results shown in this paper the targeted, and ideal, femto introduction is able to provide a 50-60% reduction in the required number of new sites compared to a random deployment. However, the required number of new femto sites becomes still considerably larger than the required number of new macro or micro sites to reach the same system performance.

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