Picocell positioning in an LTE network

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Abstract—As a way to increase the capacity of the mobile communications network, the service provider usually chooses to place more macrocells in the areas in which there is a big intensity of data traffic. This approach has, as a disadvantage, an elevated cost of implementation. In the LTE (Long Term Evolution) project it is proposed the placement of smaller cells with smaller coverage and a lower implementation cost, called picocells. The work here presented aimed to study the way in which the picocells are placed in the system in order to optimize the results of its introduction. The various scenarios of picocell placement simulated were analysed through the measuring of the SINR (Signal to Noise and Interference Ratio) value and the values of the throughputs of the network users. It is shown that the result of the introduction of picocells in the network greatly depends on the positions in which these are placed, but by following some rules there can be a positive outcome.

Index Terms—LTE, Picocells, Positioning, Interference

I. INTRODUCTION

In response to the rising demand in broadband mobile data services, in March 2008, ITU-R (International Telecommunications Union – Radiocommunication Sector) defined the specification set IMT-A (International Mobile Telecommunications – Advanced)[1]. This document aims to standardize the main characteristics of a new generation communications system — 4G.

One of the candidate technologies to this specification is LTE (3GPP Long Term Evolution), defined in 3GPP Releases 8 through 10. Although this technology doesn’t quite reach the requirements for a 4G network, its evolution, LTE-A (3GPP Long Term Evolution – Advanced) does.

These technologies are capable of meeting the requirements of a 4G system but the current macrocell network architecture limits its performance. The alternative, supported by LTE, is the introduction of pico and femtocells. These new types of cells are small and cost efficient equipments, ideal for placement in Hotspots. In the case the equipment is placed indoors, it is called a femtocell, in the case it’s placed outdoors, it is a picocell in which this paper is focused.

In 2012, 4G data connections accounted for 14% of worldwide data traffic. It is predicted that this value will increase to 45% by 2017. Furthermore, the traffic downloaded through Wi-fi devices or femtocells amounts to 33% of the mobile data traffic of 2012[2]. These statistics predict a big increase in data traffic and in small cell usage.

The introduction of this new type of cell inside the existing macrocell network, leads to increased inter-cell interference and therefore their positioning must be studied in order to improve system performance instead of deteriorating it.

The remaining of this paper is structured as follows. In section I some background information regarding the included technologies is provided. Section II describes the simulator and some of the system models used. The results of the simulations are presented in section III and in section IV some conclusions and future work are discussed.

II. BACKGROUND

LTE is a part of the 3GPP Release 8 specifications, frozen in December 2008[3]. Its main characteristics are the use of OFDMA (Orthogonal Frequency Division Multiple Access) in downlink connections and SC-FDMA (Single Carrier – Frequency Division Multiple Access) in uplink, as well as MIMO (Multiple Input Multiple Output) schemes.

OFDMA consists on the division of electromagnetic spectrum in several orthogonal sub-carriers. The orthogonality between the sub-carriers grants the elimination of ICI (Inter-Carrier Interference) and because they are placed very close to each other, a high spectral efficiency is achieved. LTE supports bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz for use with OFDMA. Another type of interference, ISI (Inter-Symbol Interference), is eliminated through the use of a guard interval called Cyclic Prefix between two consecutive symbols in the time domain, allowing information to be correctly retrieved even with symbol superposition. In LTE, OFDMA is used in conjunction with TDMA (Time Division Multiple Access) transforming the time and frequency dimensions in a grid of Resource Blocks which can then be assigned to individual users for a big flexibility in bandwidth allocation.

The disadvantage of OFDMA is its requirement for very linear and expensive amplifiers making it impractical for usage in the UE (User Equipment) and therefore only used in downlink. For uplink, SC-FDMA is used because it allows for a simpler implementation. SC-FDMA allocates bigger frequency “slices” to each user without making use of the same high spectral efficiency techniques employed by OFDMA.

MIMO schemes use multiple antennas for improving the quality of the connection. The 8 Transmission Modes implemented can offer more robust data link (with less errors), increase the maximum throughput or the ability to use beamforming techniques. LTE supports MIMO schemes up to 4x4.

The main improvement of LTE-A is the introduction of carrier aggregation. Allowing for as much as 5 LTE carriers...
to be aggregated, LTE-A has a maximum bandwidth of 100 MHz. The chosen carriers can belong to the same frequency band — being contiguous or not — or be from different bands altogether. LTE-A also allows for higher order MIMO (8x8).

A. Picocells

The most common way of improving signal quality in a certain area is to place more base stations in that area. Because macro-eNodeBs are expensive to install, the concept of small cells emerged. These consist of less expensive equipment with smaller coverage area, optimal for placement in hotspots. There are different types of small cells: femtocells are intended for indoor placement and have a lower transmit power than that of a picocell, which is intended for outdoor usage. Different access policies can also be used: Open Access applies mostly to situations where the service provider placed the cell in a hotspot and all users can connect to it; Close Access policy is used when the cell belongs to a user that wants all of the cell’s capacity for himself.

In the cases here presented, outdoor picocells with open access policies were considered for the purpose of offloading users from the surrounding macrocells.

To aid in the offloading, a technique of extending the picocells’ sectors without increasing their transmit power is also tested. This technique is called CRE (Cell Range Extension) and works by influencing the UE’s decision on which cell to connect to by attributing a bias value to the picocells — described by (1).

\[
\text{CellID}_{\text{serving}} = \arg \max_i \{ RSPR_i + \text{bias}_i \} \tag{1}
\]

where \( \text{CellID}_{\text{serving}} \) is the identifier for the cell that will serve the UE in question, \( RSPR_i \) (Reference Signal Receiving Power) is the emitting power measured by the UE for each cell \( i \) through the LTE reference signals and \( \text{bias}_i \) is the bias value attributed to each cell \( i \). This way, a picocell that provides a lower reference signal to the UE — because of the distance between them and the higher signals from nearby macrocells — can still serve that UE if the bias value is high enough.

The goal is then to study the effects of picocell placement in an LTE network, and also the effects of CRE in such cases.

III. SIMULATOR AND SYSTEM MODELS

A. Simulator

All of the simulations were performed using the “LTE Downlink System Level Simulator” (v1.6r885) developed by Vienna University of Technology which is based on MATLAB. The flowchart in figure 1 summarizes the operations of a group of simulations.

The error and tolerance decision point was added to the simulator for use in cases where statistical average results are required. Because the average results tend to converge in a final result as the number of individual simulations increase, this comparison was added to stop the simulator when the difference between the average result before and after the current individual simulation is bellow a pre-defined tolerance, ensuring that the error of the result is bellow that tolerance value. The results chosen to be a part of this decision are the average throughput per UE, the average throughput per picocell UE and the cell edge throughput (5th percentile of UEs’ throughputs) with tolerances equal to 0.1 Mb/s.

B. Models and parameters

Table I describes the parameters used in simulation. The UE distributions “Distribution A” and “Distribution B” are now explained in more detail.
Fig. 2. Picocell positions inside the macrocell

1) **UE Distribution A:** This distribution is the recommended by 3GPP in TR 36.814 in table A.2.1.1.2-4 [10]. It uses a constant number of UEs per picocell calculated previously. For the cases simulated, the total number of UEs utilized is \( N_{UE} = 30 \), which leads to a number of UEs per picocell, \( N_{UE,pico} = 2 \). This distribution has the disadvantage of impeding the simulation of the CRE technique explained above. By having a constant number of UEs per picocell, the range and coverage of such cell doesn’t affect the offloading of macrocells.

2) **UE Distribution B:** In this distribution, the UEs are placed randomly through the map and are free to connect to whichever cell offers them the best coverage. Because of this randomness, if the picocells’ range is extended they are more likely to serve more UEs and therefore better offload macrocells. The number of UEs placed in the simulation is equal to the previous case, \( N_{UE} = 30 \).

In both these distributions, UEs are only placed in cells close to the center of the map in order to prevent outcasts located in the far regions of the map from influencing the outcome of the simulation.

**IV. RESULTS**

A. **One Picocell**

Firstly, scenarios with just one picocell were simulated. The location of this picocell was varied from one scenario to another with distances ranging from 75 metres from the macro-eNodeB until 250 metres and with angles from the macrocell’s antenna main beam of 0° up to 60°. As demonstrated in figure 2.

Fig. 3. Map average SINR

Fig. 4. Picocell average SINR

For each different position, the average SINR (Signal to Noise and Interference Ratio) of the map is calculated as well as the average SINR of the picocells’ sectors to provide an indication of service quality. These values are represented in figures 3 and 4. No UEs were simulated and no fading was considered either.

The colour scheme used in these figures represents the value of SINR calculated. Colder colours (blue) represent low values of SINR and hotter colours (red) represent high values of SINR. Black dots represent cases in which the interference caused by the macrocell was so intense that the pico-eNodeB didn’t create a new cell. Analysing the figures, it is possible to observe that when the picocell is placed very near the centre of the macrocell or very close to the main beam of the macrocell’s antenna, no new sector is created due to interference. On the other hand, placing the picocell further away from the centre of the macrocell and far from the beam leads to higher SINR values, both to the total map and to the picocell.

B. **Two Picocells**

After the scenarios with one picocell, attention goes to the simulation of scenarios with two picocells. These cases are similar to the previous ones with the difference being that instead of placing one picocell in each of the described positions, we place two picocells 40 metres apart, centred around the previously defined position. The same SINR values are calculated — map average SINR and picocell average SINR — and, as before, no UEs are simulated and no fading considered. The results of these simulations are described in...
As before, colder colours indicate lower SINR values and hotter colours, higher. Similarly to the previous case, with one picocell, positioning the new cells away from the centre of the macrocell and far from the antenna’s beam results in the best outcome. In these areas, the signal from the macrocell is low, causing less interference to the picocells and therefore allowing them to offer a higher quality service than before. On the reverse case, if the picocells are placed too close to a high interference area, such as the centre of the macrocell or near its antenna’s beam, they can only offer a limited service due to the interference suffered, or no service altogether if their SINR isn’t high enough to produce a new sector (black dots in the figures).

C. Various picocells using UE Distribution A

In the scenarios tested here, various picocells were placed and the simulations were performed using UE Distribution A described in section III-B. Two areas for placing the picocells were defined:

1) $75 \text{ m} < d < 140 \text{ m}$

2) $d > 140 \text{ m}$

where $d$ represents the distance between the placed pico-eNodeB and the macro-eNodeB (center of macrocell). The number of picocells placed per each macrocell sector and the CRE bias value were also varied according to the values described in table I.

Firstly, we study the results without the use of CRE bias values. Figure 7 represents the variation of the average throughput per UE and figure 8 represents the average throughput per picocell UE.

Analysing the results from these figures, we can quickly conclude that the distance the centre of the macrocell, $d$, is an important factor for the system performance. When the picocells are placed in the furthest areas from the centre of the macrocell, the attained results are greatly improved, both for general UE throughput and picocell UE throughput. As for the number of picocells per sector, when this value increases, so does the general UE throughput meaning that, for the service provider, the optimal set-up would be to place the maximum number of picocells possible, preferably in the outskirts of the macrocell. The picocell UE throughput seems to have an
optimal point of 4 picocells per sector when in the distant area, allowing picocell users to have the best performance. However, if the picocells are placed in the area closest to the macro-eNodeB, these results are greatly reduced due to the interference caused by the macrocell’s proximity.

The 5th percentile of UE throughput is represented in figure 9. This value allows for the analysis of the fairness of the network, by representing the 5% worst served users. As can be seen in the figure, the introduction of picocells improved the fairness of the network and the 5th percentile throughput increases with the number of picocells placed. Regarding the distance of placement of the picocells, this factor doesn’t seem to have a big effect over the 5th percentile throughput.

As we introduce the CRE bias value to these scenarios it is possible to conclude that the fixed number of UEs per picocell determined by UE Distribution A doesn’t allow for testing this technique. The extended sectors resulting from the use of a bias value don’t offload the macrocell because they have a fixed number of UEs. Therefore, this analysis was made using the UE Distribution B described in section III-B2 and the results are presented in the following section IV-D.

D. Various picocells using UE Distribution B

These simulations are similar to those in the previous section IV-C but using the random UE distribution described in III-B2. For the cases presented before, the results found with this new UE distribution confirm the conclusions already attained, therefore the CRE technique is now introduced and analysed. To achieve these results, the number of picocells per sector is now fixed at 6, and the bias value of CRE is varied. In figures 10 and 11 are represented the average UE throughput and the average picocell UE throughput, respectively.

Analysing the first figure, we observe that the usage of high CRE bias values improves the general system performance since average UE throughput increases. The picocells are increasingly offloading the macrocells through the usage of CRE, improving system performance overall. From the provider’s point of view, using high CRE bias values increases the total traffic in the network, therefore increasing the profit of the provider.

In figure 11 we verify that the use of CRE decreases the throughputs of UEs connected to the picocells. Because the UE’s decision at the time of choosing a cell to connect is influenced by the bias value, some UEs are served by picocells which provide them with lower performances than the macrocells which would serve them in case the CRE technique wasn’t used. Therefore, if the purpose of the picocell is to provide great service to users located in the area of the picocell, the optimal set-up is without making use of the CRE technique (biasCRE = 0 dB).

Figure 12 describes the variation of the 5th percentile throughput with CRE bias value. It is possible to observe that the introduction of the CRE technique worsens the service quality for cell-edge UEs. This means that for providing good service to all users, a low CRE bias value is preferred.

V. CONCLUSION

Picocells are introduced with the purpose of increasing the system’s capacity. As more are placed in the network, the better the performance provided by the system. The newly placed picocells offload users from macrocells therefore allowing the system’s resources to be better distributed.
The positioning of picocells is important to reduce interference. By placing them away from the macrocell’s antenna beam and in the outskirts of the cell, better results are attained.

Extending the picocells coverage area using the CRE technique has a good effect in the system’s overall throughput. This means that increasing the bias value also increases the offload to the picocells, better distributing the resources. However, a trade-off is required: increasing the bias value increases system performance but decreases the picocells’ performance and lowers 5th percentile throughput. Therefore, if the operator aims to achieve the highest amount of traffic in the network, high CRE bias is advised; if picocells’ high performance is required, then a low bias value must be chosen; and to provide similar system performance to all users in the network, a low bias value must also be chosen.

For future work, similar scenarios using indoor femtocells instead of outdoor picocells should be studied. These scenarios have an added difficulty of implementation which is the introduction of Penetration Losses to the system’s model.

REFERENCES


