Inter Cell Interference Coordination techniques in HETNETS

Almost Blank Sub-Frames approach

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ABSTRACT

The increasing popularity of connected devices and the augmentation of users’ number are boosting the mobile broadband traffic, which has grown exponentially during the last years. Also customers’ expectations are on the rise, users have come to expect a consistent, high-quality and seamless mobile broadband experience everywhere. To meet these expectations, the capacity and the coverage of the current networks need to be improved to deliver high data throughput with very low latency. Since spectrum has become a scarce resource nowadays, new ways have to be found to improve the network performance. The key options to achieve this target include improving and densifying the existing macro layer and complementing the macro layer with low power nodes; that is to say, deploying heterogeneous networks.

The concept of heterogeneous networks has recently attracted considerable interest as a way to optimize the performance of the network, particularly for unequal user or traffic distribution situations. A heterogeneous network is composed of multiple radio access technologies, architectures, transmission solutions, and base stations of varying transmission power that can interoperate, thus creating a multilayer structure. Due to the different operating modes of the nodes, some of them work in open access mode but others work in closed access mode, and the unbalanced transmission power of the different base stations of the network, select the appropriate server station can be challenging for the users equipments. A wrong cell selection process can lead to the under-utilization of low power nodes; so that, range extension technique is proposed to allow more users to be attached to low power nodes.

Manage the interferences caused by the macro station to the low power nodes and vice versa is one of the biggest challenges in the deployment of heterogeneous networks. Enhanced Inter Cell Interference Coordination (eICIC) schemes have been proposed to deal with this problem. These approaches can be divided into time domain techniques, such as Almost Blank Sub-frames (ABS), and frequency domain techniques. Their implementation relays in the use of some basic characteristics of the radio access technology used in the network.
This project is structured as follows: in Section 1 the concept of heterogeneous networks is defined, deepening in to the factors that have led to their apparition. Different techniques to address the major technical challenges of heterogeneous deployments are described in Section 2. In Section 3, the main techniques to deal with intra-frequency interference are introduced. Finally, one of the methods described in the previous section, the time domain technique, is explained in detail in Section 4.

Objectives

The main goal of this project is to have a deeper understanding about the novel concept of heterogeneous networks, comprehending the reasons that have led to the need of them as well as the different approaches to implement them and the technical challenges involved in these sorts of deployments.

Another objective is to make a thorough analysis of the inter cell interference coordination time domain technique, called almost blank sub-frames, in the case when macro stations and femto nodes coexist in the same geographical area, examining carefully different works done in this field.
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1. **SECTION 1: MOBILE SYSTEM EVOLUTION**

1.1 **TRAFFIC EXPLOSION**

In recent years, mobile broadband traffic has grown exponentially, exceeding voice, thanks to the new generation of mobile terminals, such as smartphones, tablets and laptops, and to the new services and capabilities they offer. Mobile users have also increased and, with them, the number of connections. Furthermore, cellular operators have in general reported non-uniform traffic distributions in their networks, stating that for instance 50% of the total traffic volume is carried on only 30% of the macrosites. Exact percentages of course vary from network to network [1]. The required capacity has augmented faster than progress in spectral efficiency. In addition, the service is migrating from a voice-centralized model to a data-centralized model. Subscribers use connected devices not only to access the Internet, but also to access applications and cloud-based services, including video and other bandwidth-intensive content. As a result of these trends, overall mobile data traffic is expected to grow tenfold by 2016 [2].

![Figure 1: Key facts](image)

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2016</th>
<th>CAGR 2011-2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile subscriptions (million)</td>
<td>6,100</td>
<td>8,400</td>
<td>6%</td>
</tr>
<tr>
<td>Mobile PC/tablet subscriptions (million)</td>
<td>180</td>
<td>550</td>
<td>25%</td>
</tr>
<tr>
<td>Smartphone subscriptions (million)</td>
<td>810</td>
<td>2,600</td>
<td>25%</td>
</tr>
<tr>
<td>High-traffic smartphone subscriptions (million)</td>
<td>450</td>
<td>2,100</td>
<td>35%</td>
</tr>
<tr>
<td>Monthly traffic per high-traffic smartphone (MB/month)</td>
<td>300</td>
<td>800</td>
<td>20%</td>
</tr>
<tr>
<td>Monthly traffic per mobile PC (MB/month)</td>
<td>1,900</td>
<td>6,500</td>
<td>25%</td>
</tr>
<tr>
<td>Total monthly mobile PC traffic (PetaByte/month)</td>
<td>310</td>
<td>2,500</td>
<td>50%</td>
</tr>
<tr>
<td>Total monthly mobile traffic including voice (PetaByte/month)</td>
<td>530</td>
<td>4,600</td>
<td>55%</td>
</tr>
</tbody>
</table>

| Traffic ratio: per mobile PC compared to per high-traffic smartphone | 6     | 8     |
| Subscriptions ratio: high-traffic smartphones compared to PCs and tablets | 2.5   | 4     |
| Increase in total data traffic 2011-2016 (multiple) | 10    |
| Increase in high-traffic smartphone subscriptions 2011-2016 (multiple) | 5     |

---

1 PetaByte $= 10^{15}$ B
Users’ expectations for mobile broadband are growing parallel to traffic and, increasingly, users expect a robust, high-quality and seamless service. Further, more and more, customers are operating inside offices and buildings, where about 70 percent of today’s data traffic is generated and where coverage represents a major problem for mobile operators. Meet the demand for mobile broadband is specially challenging in certain scenarios; such as:

- Large outdoor hotspots with high traffic demand and a dense macro network, implying high interference. E.g., town squares and commercial streets.
- Large, isolated indoor hotspots, which may be difficult to reach from an outdoor macro network. E.g., businesses and hotels
- Large indoor hotspots, where mobility demands and interference are high. E.g., shopping centers, airports and subway stations.
- Localized, indoor hotspots or minor coverage holes, which represent a challenge of implementation and cost to conventional cellular networks. E.g., small offices and restaurants.

In order to meet the growing demand for mobile broadband and users’ expectations, it is necessary improve data performance overall and at cell edges, and, to achieve this, more resources are needed and also new ways of acquiring, deploying, managing and optimizing these resources. Broadband services providers use a variety of technologies in order to meet customers’ expectations; namely, improve the existing network, densify current macro cells and, the most important one, add small cells to improve coverage, capacity and power signal when necessary.

## 1.2 Approaches to Meet Increasing Demand

Traditionally, the design adopted for the implementation of wireless cellular networks is a homogenous approach. A homogeneous cellular system is a network of base stations in a planned layout and a collection of user terminals, in which all the base stations have similar transmit power levels, antenna patterns, receiver noise floors, and similar backhaul connectivity to the (packet) data network [3]. In these kind of networks, the locations of the macro stations has to be carefully planned and the settings of each station should be properly configured in order to maximize the coverage and control the interference between adjacent stations.
As the traffic demand grows dramatically, spectral efficiency in point-to-point wireless networks is reaching its theoretical limit and the capacity of the current network is not enough. Therefore, it is necessary to find solutions; that is to say, improve network capacity, to maintain uniform user experience and, thereby, customers satisfied. There are several approaches that can be taken to meet traffic and data rate demands. On a high level, the key options to expand network capacity include improving and densifying the macro layer and complementing the macro layer with low power nodes, thereby creating a heterogeneous network.

![Enhancements on existing site grid](image)

![Densify with additional macro sites](image)

![Densify with complementary “pico” sites](image)

Figure 2: Key options to expand network capacity [4]

Improving the existing network consists in enhancing current macro cells. So that it is necessary provide them with more spectrum, advanced antennas with increased order of diversity, and advanced baseband processing capacity within and between nodes. Although the improvement achieved could not be enough at some point, increasing capacity and data rates in this way is an attractive solution as it avoids installing new sites. Due to large attenuation between terminals and the base station caused by the distance and the radio propagation, the received power is relatively low. That is known as power limitation and is the cause of limited data rates.

Densifying the macro network consists in reducing the coverage area of each cell and increasing the total number of macro-cell sites; that is, adding cells strategically located. As a result, the traffic per square meter can be increased and the distance between the base station and the terminal will be shorter, implying an improvement in achievable data rates.
The densification, if the number of macro stations is low, keeps the number of sites relatively low while network performance becomes less sensitive to traffic location; all this, without severely increasing the interference between cells. However, in deployments already presenting high density of macro stations, the densification of the network may be limited by a high inter-cell interference and, in dense urban areas, site acquisition for macro base stations with towers is quite difficult.

Although these two strategies, improve and densify, may slightly enhance the capacity of the network, nowadays wireless cellular systems have evolved to the point where an isolated system, with just one macro base station, achieves near optimal performance. Consequently, future gains of wireless networks will be obtained from a more flexible and advanced deployment model, which will allow improving broadband user experience everywhere and in a cost effective way. This new deployment model is based on densifying the current network with complementary low power nodes; that is to say, adding small cells to create a heterogeneous network (HETNET).

HETNETS involve the use of different types of radio technology and employ low power nodes working together with the current macro cells; that is to say, they may coexist in the same geographical area sharing the same spectrum, so it is not necessary that they provide full area coverage. For this reason, while the location of the macro stations is generally carefully planned, the low power nodes are typically deployed in a relatively unplanned manner. Usually, the main aim of low power nodes is to eliminate coverage holes in the macro network, improve capacity in hot-spots and improve cell edge throughput; that is why, the location chosen for their deployment is based on the knowledge of coverage issues and traffic density in the network.

Figure 3: HETNET architecture – low power node 1 is used capacity improvement in a hot-spot, low power node-2 and low power node-3 are used for improving edge throughput
Deploying low power nodes can be challenging, as performance depends on close proximity to where traffic is generated and, due to their reduced coverage range, a lot of them may be needed. Nevertheless, owing to their lower transmit power and smaller physical size, low power stations can offer flexible site acquisitions. Furthermore, HETNETS allow improving spectral efficiency per unit area and offer very high capacity and data rates in areas covered by the low power nodes. Therefore, it is an attractive solution in scenarios where users are highly clustered.

1.2.1 NETWORK ELEMENTS

Elements that compose a HETNET can be divided into two main groups. On one hand, macro stations, which are conventional operator installed base stations (BSs) that provide open public access and wide area coverage typically on the order of a few tens of kilometers. Their transmit power varies between 5 W and 40 W, serving thousands of customers and using a dedicated backhaul. On the other hand, low power nodes, which are characterized by their short range coverage, but a high throughput. According to the kind of low power node used, different types of small cell can be conformed:

- Picocells: Conformed by low power operator installed stations with the same access features as macro BS. They are usually deployed in indoor public areas, such as shopping centers or train stations, for coverage improvement. They can serve more than 32 users within a radio range of 200 meters or less. Their typical transmit power ranges from 250 mW to approximately 2W. Picocells are widely deployed.

- Femtocells: Conformed by low cost low power user deployed access points. They are usually deployed in consumer and enterprise indoor environments, serving from 4 up to 32 active users within a range in the order of 10 meters. Typically, their transmit power is 100 mW or less. They can provide open access, but they are typically operated in a closed mode, meaning that only certain users that are part of a closed subscriber group (CSG) are allowed to connect to such node. Femtocells are the widest deployed kind of small cells.
• Microcells: They are usually deployed in outdoor urban areas that are capacity constrained, but may be also useful in rural areas, where population is concentrated in a limited area. They have a coverage area of less than 2 kilometers and their typical transmit power is the same as picocells. Microcells are also widely deployed.

• Metrocells: They are deployed in outdoor urban areas that are capacity constrained, as microcells. Their typical range is of 200 meters or less and their transmit power ranges from 250 mW to approximately 2W. Metrocells are the kind of small cells less deployed because they are the newest ones; they are expected to expand significantly during 2014 and 2015.

For the network to be efficient, each low power node has to have the ability to interact with all the layers of the network and has to perform tasks as the handoff, the management of interferences and authentication. [6] [7].

The next figure shows the prediction of the global number of small cells for 2016. It is important to note the leading role played by femto cells in HETNETS deployments.

![Figure 4: Heterogeneous network – types of low power nodes [5]](image)

![Figure 5: Global small cell deployment forecast, by category [7]](image)
In order to find the right combination between the three approaches discussed - improve, densify and add small cells- to meet future capacity and coverage demands, it will be necessary to consider the nature of the existing network, the availability of backhaul and spectrum, estimated traffic volumes and required data rates, as well as some technical and economic considerations.
2. **SECTION 2: HETEROGENEOUS NETWORKS TECHNOQUES**

As stated in the previous section, HETNETS, that is to say, the mix of different types of radio technology and the use of macro cells with low power nodes working together, provide important improvements in terms of increased data rates and cell coverage. It should be emphasized that HETNETS can be deployed with the existing technologies (e.g. HSPA, LTE Release 8, 9, 10, ...) and without standards changes, although them will enable further range expansion, concept that will be further explained below. In this section, the main technical challenges for HETNETS deployment will be discussed as well as server selection and coordination between cells strategies when the radio access technology used is LTE, which is the most used in HETNETS.

In conventional single layer networks, in other words, homogeneous networks, each mobile terminal connects to the node from which the downlink (DL) signal strength is the strongest, while the undesired signals from the other base stations are treated as interference. Although this gives the optimum server selection methodology for these networks, it is not the best strategy for HETNETS since this principle can lead to sub-optimal performance. Therefore, resources coordination between base stations and server selection strategies, as well as advanced techniques for efficient interference management, are very important issues in HETNETS, needed in order to achieve gains in throughput and user-experience.

### 2.1 CELL SELECTION

A terminal, before being able to receive or transmit data, must perform certain steps, such as searching the possible cells to which it can be connected, selecting the suitable one and deriving some system information.

![Cell selection diagram](image)

**Figure 6: Initial access**
The cell search procedure that a User Equipment (UE) wishing to access the LTE system follows includes a series of synchronization stages by which the UE determines time and frequency parameters that are necessary to demodulate DL signals, to transmit with correct timing and to acquire some critical system parameters. There are three synchronization requirements in LTE: symbol timing acquisition, carrier frequency synchronization, and sampling clock synchronization. There are two cell search procedures in LTE, one for initial synchronization and another for detecting neighbor cells in preparation for handover. In both cases, the UE uses two special signals broadcast on each cell: Primary Synchronization Sequence (PSS) and Secondary Synchronization Sequence (SSS). The detection of these signals allows the UE to complete time and frequency synchronization and to acquire useful system parameters such as cell identity, cyclic prefix length, and access mode (FDD/TDD). Once UE knows the physical cell id (PCI) for a given cell, it also knows the location of cell reference signals that are used in channel estimation, cell selection / reselection and handover procedures.

In homogeneous deployments, where all the cells transmit on similar power levels, the cell selection process is based on the comparison of the Reference Signal Received Power\(^2\) (RSRP) and the Reference Signal Received Quality (RSRQ) of downlink signaling transmitted from neighboring cells. That is to say, each UE selects its serving cell ID according to the cell from which the largest RSRP is provided [8]:

\[
\text{Cell ID}^\text{\text{\emph{serving}}} = \arg\max_i \{\text{RSRP}_i\}
\]

\(^2\)RSRP is defined as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth [9].
Following this principle, the cell which provides larger RSRP will be selected as the serving cell. As a consequence of the large disparity between the transmit power level of macro and low power stations, DL coverage of low power nodes is much smaller than that of macro stations and, that is why, conventional cell selection method cannot be applied in HETNETS. Therefore, the assignment of user equipments (UEs) to appropriate server stations becomes a non-trivial task. For the uplink (UL), the strength of the received signal depends only on the terminal transmit power which is the same either to the low power node or to the macro station, hence the UL coverage of all the stations is similar.

In HETNETS, follow the server selection strategy explained before, that is to say, the one based on DL received signal strength, causes an inefficient use of low power nodes in different ways. On one hand, most users’ terminals will be connected towards macro stations, based on the signal strength. While the available resources of the small cells would not be fully exploited; in other words, lower power stations may be underutilized, thus defeating the purpose of deploying these low power nodes, macro stations may not have enough resources to efficiently serve all UEs connected towards them. On the other hand, this strategy can lead to an area surrounding the low power node where the macro base station would be selected, although the path loss could be lower towards the low power node. Furthermore, disparity between the UL and the DL coverage can also create discordances in each handover boundary, making the cell selection process much more difficult in HETNETS than in homogeneous networks, where DL and UL handover boundaries are more closely matched.

Therefore, to deal with these problems, it will be beneficial to develop a new cell selection scheme based on expand the coverage of low power nodes in order to maximize cell splitting gains, reduce UL interference and balance the load between macro and low power stations.
2.2 RANGE EXPANSION

In order to expand the coverage of low power nodes, it is possible to increase their transmission power; in that way, the cell size of low power nodes will be extended. However, this strategy affects the cost and size of the node, so it is not a desirable option. Another approach to increase low power’s DL coverage footprint is the one known as range expansion. In this proposal, the decision of where is the cell border is based on the path loss. This technique consist in adding an offset to the received DL signal strength in the conventional cell selection mechanism, the one explained before; as a consequence, the cell border level chosen will be the addition of the RSRP and the offset. For the macro cell, $bias = 0 \text{dB}$ will be chosen and for the low power node $bias > 0$.

$$Cell\ ID_{\text{serving}} = \underset{i}{\text{argmax}} \{\text{RSRP}_i + bias_i\}$$
Range expansion allows more users to be associated with low power stations, enabling a more equitable distribution of resources by offloading traffic from the macro station. This fact is especially beneficial in situations where users are clustered around a low power node. The advantages of this technique are:

- **Enhanced UL data rates**: taking into account UL path loss when associating terminals with a low power node and significantly mitigating cross-tier interference.
- **Increased capacity**: transmission resources can be reused by receiving DL traffic from the low power node even if the received signal strength from the macro is higher.
- **Improved robustness**: sensitivity to ideal placement in a traffic hotspot can be reduced by enlarging the coverage area of a low power node.

A heterogeneous deployment, with a modest range expansion somewhere in the region of 3-4dB, is already possible in LTE Release 8. The benefits gained from range expansion are highly dependent on the individual scenario and are at the expense of reducing the DL signal quality of those users in the expanded region; so that, in many cases, modest range expansion is best. Nevertheless, 3rd Generation Partnership Project (3GPP) has recently discussed the applicability of excessive range expansion with cell selection offsets up to 9dB [10]. These deployments are particularly problematic. As terminals in the range expansion zone may experience very low DL signal to interference ratio, interferences may kill DL control signaling, which is essential for the low power node to control transmission activity. It is important to emphasize that it is the DL interference at UEs associated with the low power node that needs additional protection from the macro; the UL interference at the low power station can be mitigated using the same power control principle than in a macro-only network. In order to allow more expansion and, with that, more uptake area for low power nodes and a higher total throughput, DL control signaling must be protected, that is why, enhanced inter-cell interference coordination (eICIC) techniques are so important. In summary, a tradeoff between offloading and interference from the macro station is required.

**2.2.1 RELATED WORKS**

In [8] a simulation for compare the two cell selection strategies described, the conventional one, based only in RSRP, and the one based in biased RSRP (range expansion), is realized verifying the most important advantages and disadvantages of the range expansion
technique described previously. In this papers, different bias values ($bias_i = 5 / 10 / 20$ dB) are adopted. Results are summarized in the next figure:

![Figure 9: Simulation results - a) The spectral efficiency gain compare to conventional cell selection scheme. b) UE association statistics [8]](image)

As it can be seen in figure 8 b, the simulation results demonstrate that using biased RSRP selection ends in more UEs being served by the small cells. The greater the bias, more users are associated with the low power node. In figure 8 a, it is evidenced that there is only a minor improvement on whole cell efficiency (first column), only about 1.02% for 5 dB bias. Whole cell efficiency even gets worse than when using conventional cell selection scheme when using high bias values. This is because the high interference that UEs served by small cells experience from macro cell. Therefore, this scheme might be adopted with some interference management methods, which will be explained through the next section. Looking at the second and third column of figure 8 a, it is possible to see that both the 5% tile cell spectral efficiency and the median cell spectral efficiency increase for both 5dB and 10 dB bias values, but they decrease at large bias values. This implies that if the bias value used is appropriate, cell-edge cell spectral efficiency and median cell spectral efficiency could be effectively improved by adopting biased cell selection scheme.
2.2.2 Another Technical Challenges

Because of the reduction of the DL signal quality, users on the edge of the low power node cell will suffer higher DL interference, which negatively affects backhaul capacity, needed in order to connect the small cells to the core network, internet and other services. Although backhaul network design will be a major issue in HETNETS because of the complex topology of the various types of coexisting cells, this project is not focused on this point.

Besides backhaul, another important technical challenge to consider is the handover. Handovers are essential in order to provide a seamless uniform service when users move in or out of the cell coverage. Furthermore, handovers are efficient for traffic load balancing, by shifting users at the border of adjacent/overlapping cells from the more congested cells to the less congested ones [11]. Typically, a handover is done when receive signal strength of the target cell exceeds the one of the source cell. This is still true for a bias value of 0 dB. However, if a higher bias value is chosen for the target cell (i.e. the pico cell) the handover takes place earlier, namely when the received signal strength of the target cell plus the bias value exceeds the received signal strength of the source cell [12].

![Figure 10: Pico cell embedded in a macro cell](image)

In brief, range expansion is not only effective for optimizing the use of resources in the system, but also for reducing the frequency of handovers, hence improving system throughput and user experience. Despite these benefits this feature presents a challenge to interference management for HETNETS, but the deployment of appropriate Inter-Cell Interference Coordination (ICIC) algorithms can further boost system performance.
2.3 HETEROGENEOUS DEPLOYMENTS

There are two different approaches to heterogeneous deployment both of which provide support for excessive range expansion. On one hand, the resource partitioning in frequency or time domain, and on the other hand the shared cells, also known as soft-cells schemes or multi-sector cells. The next figure shows the three heterogeneous deployments - the basic one, the resources partitioning and the shared cells- and summarizes their main characteristics, which will be explained more detailed below.

![Figure 11: Tools discussed in 3GPP [4]](image)

2.3.1 RESOURCE PARTITIONING

Through resource coordination among base stations, DL interference caused by high power macro base stations to the user terminals served by low power base stations can be mitigated. This is the concept on which eICIC techniques are based. Therefore, it will be slightly introduced here and, through the next section, it will be explained in more detail.

To enable resource coordination among base stations, two different sets of resources may be allocated for the two classes of nodes; namely high power and low power base stations. The resources can be time domain (slots or sub-frames) in a synchronous system or frequency domain (groups of sub-carriers). The resource partitioning deployment consists in restricting macro cell transmissions from using the same time-frequency resources as low power nodes in order to protect the control signaling from the low power nodes.
In the frequency domain, DL control signals from the macro and low power nodes are placed in separate carriers. Due to that fact, and assuming that transmissions from low power nodes are time synchronized with the overlying macro, the control signaling in the range expansion zone will not be expose to major interference from the macro node because it would be placed in another frequency. Through the use of carrier aggregation, data transmissions can still benefit from the full bandwidth of both carriers.

In the time domain, DL control signals from the low power node are protected by reducing macro transmission activity in certain sub-frames. The low power node is provided with data about the protected sub-frames and can use this information when scheduling users who are in the range expansion zone.

In both, frequency and time domain partitioning schemes, low power nodes create new cells, with individual cells identities that differ from the macro cell identity. As a consequence, each low power node transmits unique system information and synchronization signals; that is to say, each of these cells has separate broadcast channel (BCH), cell-specific reference signal (CRS), PSS and SSS.

![Figure 12: Resource partitioning](image)

In both, frequency and time domain partitioning schemes, low power nodes create new cells, with individual cells identities that differ from the macro cell identity. As a consequence, each low power node transmits unique system information and synchronization signals; that is to say, each of these cells has separate broadcast channel (BCH), cell-specific reference signal (CRS), PSS and SSS.
2.3.2 Shared Cells

In the shared cells approach, low power nodes and the macro station do not create new cells; therefore, they are all part of the same cell. This fact leads to a cell with a unique cell identity and synchronization signals but with more than one transmission points. As a result, different types of information can come from different sites, or in other words, different transmission point, which are transparent to the UE. So coordination between low power nodes and the macro station is one of the most important issues in this approach.

![Soft-cell scheme](image)

Figure 13: Soft-cell scheme [10]

This technique has some important benefits in front of the resource partitioning technique. Since there is only one cell formed by low power nodes and the macro site, the deployment is easier because careful cell planning is not needed. Given that low power nodes can turn off their transmissions when they are not necessary, it is possible to say that the technique is energetically efficient. The soft cell scheme also allows an efficient use of the spectrum as there is no problem with CRS interference. In addition to these advantages, due to the fact that transmission nodes are transparent to UE, soft cells can provide greater mobility robustness than deployments with separate cells. Traditional handover procedure is not required when moving between macro and low power nodes, so the probability of dropped connections is lower.
3. SECTION 3: INTER-CELL INTERFERENCE MANAGEMENT

Nowadays, the evolution of the physical layer has reached a level, where operation very close to information theoretic bounds on achievable spectral efficiency for a given signal to interference and noise ratio (SINR) is feasible [14]. For this reason, improving the SINR by reducing or, even better, avoiding the inter-cell interference is the only way to achieve significant increases in spectral efficiency. Therefore, researchers are focusing on inter-cell interference coordination (ICIC) when defining next generation mobile communication standards, such as LTE-Advanced (LTE-A).

3.1 BACKGROUND

For the DL, LTE uses orthogonal frequency division multiple access (OFDMA), which is a combination of orthogonal frequency division multiplexing (OFDM) and time division multiple access (TDMA), unlike for the UL that Single-carrier frequency-division multiple access (SC-FDMA) is used. DL and UL transmissions are organized into frames of 10 ms, each one divided into 10 sub-frames. Each sub-frame divides into 2 slots of 0.5 ms. Each slot consist in 6 or 7 OFDM symbols, depending on which kind of cyclic prefix is used, normal or extended. In the time domain, a slot is exactly one Resource Block long.

![Figure 14: LTE generic frame structure](image)
OFDMA identifies different subscribers in the same cell by different time and subcarriers. To maximize spectrum efficiency, LTE is designed for a frequency reuse of 1, or in other words, uses intra-frequency networking, meaning that every base station uses the whole system bandwidth for transmission. Since all neighbor cells are using same frequency channels, there is no frequency planning among cells to deal with interference issues. Hence, LTE macro cell deployments experience heavy interference at the boundaries of the cells [15].

There is a high probability that different subscribers in the neighboring cells, especially those at the cell edge, receive two or more signals of the same frequency at the same time. If these co-frequency signals from various cells are very strong, subscribers may suffer high interference and the quality of their communication is affected, leading in to eventually low throughput or call drops. Careful consideration need to be implemented on the control channel mitigating the inter-cell interference, as the UE could consider the radio link as failed in case of severe interference resulting in service outage due to the unreliable control channels.
Due to co-frequency signals, HETNETS require some sort of interference mitigation, since low power cells and macro cells are overlapping in many scenarios. Besides intra-frequency interference, there are some other factors inherent to HETNETS that generate interference, such as the unplanned deployment of low power nodes or the power difference between nodes. ICIC and eICIC schemes are used to improve the performance degradation caused due to these situations.

### 3.2 Inter-cell Interference Coordination

ICIC was introduced in 3GPP Release 8 as an optional method to solve inter-cell intra-frequency interference. The main idea of ICIC is to divide each cell into two sections, the cell center and the cell edge, and then allocate different subcarriers to users in different locations. Theoretically, it is impossible for subscribers at the edge of two neighboring cells to use the same frequency, and, in that way, the possibility of interference between two neighboring cells is reduced.

ICIC methods allow achieving a slight system performance boost by managing the system bandwidth and transmit power. However, the frequency-domain ICIC schemes introduced in Release 8 and 9 were mainly designed for macro-only scenarios and only provide improvements for the physical data channels, while failing to offer protection for physical control channels carrying critical information for achieving good system performance.

The basic idea on which the ICIC schemes rely is to divide the whole available resources into two groups, one for serve the cell-edge users and the other for the cell-center users. According to the type of resource scheduling, ICIC techniques can be classified into hard frequency reuse, fractional frequency reuse and soft frequency reuse. The transmission power of each portion of the spectrum is also controlled to prevent cell edges and neighboring cells from being affected.
3.2.1 HARD FREQUENCY REUSE

In this ICIC scheme neighboring nodes use different sets of resource blocks throughout the cell at given time; that is why, two neighbor stations will not use same resource assignments for their UEs. This is achieved dividing the sub-carriers into 3, 4 or 7 disjoint sets, depending on the number of neighboring cells. These sets of subcarriers are assigned to an individual node, in such a way that neighboring cells don’t use the same set of frequencies. This method minimizes significantly the interference at the cell edge, improving greatly cell edge SINR. The disadvantage is that the spectrum efficiency drops by a factor equal to the reuse factor, leading to reduced performance of the entire cell, since full resources blocks are not being utilized. This approach can be considered the opposite extreme to the conventional frequency planning with frequency reuse of 1.

![Figure 17: Hard frequency reuse [15]](image)

3.2.2 FRACTIONAL FREQUENCY REUSE

This ICIC scheme is based on dividing the spectrum into two parts, each of which will have different frequency reuse and transmission power. One section is a common frequency band used in all the cells; in other words, this portion of the spectrum has a frequency reuse of 1. Nodes would assign this fully-reused frequency portion, which has low power level, only to UEs located in the center of the cell. The other part of the spectrum, which has high power level, is divided among the different nodes of the network, as in hard frequency reuse scheme. This portion of spectrum is assigned to the cell-edge UEs. In that way, two neighbor cells cannot assign the same set of resource blocks to their cell-edge subscribers at given time. This scheme is particularly useful for ICIC in the uplink.
3.2.3 Soft Frequency Reuse

The last ICIC scheme is probably the preferred one. In this method all nodes in a network transmit in the whole system bandwidth, but using different power schemes; that is to say, with a non-uniform power spectrum. The spectrum is divided into two regions, one with high power transmissions, which resources are allocated to the cell-center UEs, and the other one with low power transmissions, which resources are assigned to cell-edge users. The specific set of resources used in the edge of a cell cannot be used by neighboring cells, but center users have availability of all resource blocks in all the cells. The spectrum dedicated for the cell edge may also be used in the central region if it is not being used at the cell edge. This ICIC scheme allows achieving improved SINR levels for cell-edge UEs while keeping suitable SINR levels for cell-center users. This method is particularly useful for ICIC in the DL.
3.2.4 RELATED WORKS

Some simulations comparing the different schemes of frequency reuse discussed before can be found in [15]. In this paper, they compare the three ICIC techniques described with the case of no frequency planning among cells, that is to say, the case of frequency reuse of 1.

As was already known, their simulation confirm that reuse factor 1 deployment maximizes the cell capacity, since all users can benefit from all the bandwidth, but fails to guarantee the cell edge throughput. The soft frequency reuse, allocating more power to the cell edge users, and less to the cell center users, has smaller capacity than reuse factor 1, but it enhances the cell edge throughput. Although fractional frequency reuse and hard frequency reuse schemes have better transmission quality than soft frequency reuse, they show smaller cell capacity. So that, they conclude that the soft frequency reuse scheme is a good candidate to enhance the cell edge throughput, without sacrificing the average cell throughput.

3.3 ENHANCED INTER-CELL INTERFERENCE COORDINATION

ICIC methods specified in release 8 and release 9 of 3GPP may not be effective in the case of HETNETS, because, as it was said before, they were mainly designed for macro-only scenarios. The basic goal of ICIC is the provision of a more homogeneous service to users located in different regions of the network, i.e. mostly to promote the cell-edge performance. This aspect has gained even more importance with the introduction of multi-layer heterogeneous networks [13]. With the deployment of low power nodes, that is to say, with the implementation of HETNETS, more cells with intra-frequency interference are introduced into the existing network and, not only that but also their coverage areas are overlapped, as a consequence, interference between cells is more difficult to control.

According to the type of low power node, there are two mainly inter-cell interference scenarios in HETNETS deployments, but, in both of them, the way that severe interferences affect and the possible remedies are very similar. These scenarios are:

- The macro-pico scenario with cell range expansion: UEs served by the pico cell may be affected by large interference, specially these ones located in the range expansion zone, as a result of increasing the pico cell radio range in order to offload greater numbers of users from the macro cell on to pico cells.
The macro-femto scenario with CSG: UEs served by the macro station may experience large interference when they move close to a femto node operating in closed access mode, this is also known as macro cell coverage hole. This is because, although the femto node offers better signal quality, UEs are not allowed to connect due to the fact that the femto node is operating in closed access mode.

To cope with intra-frequency interference problems in HETNET, eICIC techniques have been developed in Release 10 of 3GPP (LTE-A). These procedures can reduce inter-cell interference not only on traffic channels, as ICIC schemes, but also on control channels of the DL. These techniques can be classified under two main categories: frequency domain and time domain solutions. Both of them will be briefly explained below, but through the next section the time domain technique will be deeply examined.
3.3.1 FREQUENCY DOMAIN TECHNIQUES

The main frequency domain method for interference cancelation is based on carrier aggregation (CA), which is one of the most important features of LTE-A (3GPP Release 10). CA enables UEs to be connected to several carriers simultaneously. Besides that, a terminal supporting CA can be configured by higher layer signaling to enable cross-carrier scheduling on certain component carriers. This implies that a terminal receiving a DL assignment on one component carrier (CC) may receive associated data on another CC; in other words, a node can schedule its control information on a CC and its data information on another CC. One of the main motivations for introducing cross-carrier scheduling was to enhance operations in HETNETS in a multi-carrier deployment. [11]

The basic idea of this eICIC technique avoid co-channel interference on DL is to create a protected CC for reliable reception of DL physical signals, system information and control channels at victim layers but where data can be received on any configured DL CC via cross-carrier scheduling. So that, the available spectrum is divided into two or more separate CCs.

There are two categories of CC:

- Primary component carrier (PCC): It is the main carrier in any group. There will be a primary DL carrier and an associated UL primary component carrier for transmitting control signaling.
- Secondary component carrier (SCC): It is generally used for data transmission. There may be one or more SCC.

By assigning the PPC and the SCC to different network layers; that to say, different cells, at a given time, interference on control channels between network layers can be avoided.

![Figure 22: Cross-carrier scheduling](image-url)
In the case of the figure above, the macro layer schedules its control information on $f_1$, and can schedule its users on both $f_1$ and $f_2$. Interference on control and data is avoided by scheduling control and data information for different layers on different component carriers, as it can be seen in figure. Although data information of UEs served by the low power node located in the center of the cell can be scheduled on the same carrier as the UEs served by the macro cell, because the interference from the macro layer on UEs in the center of the small cell can be tolerated, UEs in the range expansion zone must be scheduled in the other carrier where the macro UEs are not scheduled.

This frequency-domain partitioning technique is a natural choice to support heterogeneous deployments for operators who already rely on CA to exploit fragmented spectrum, but it is only supported by release 10 terminals and onwards, so this feature cannot be used by release 8 and 9 terminals.

### 3.3.2 Time Domain Technique

When the sub-frames of the macro station and low power nodes are aligned, their control and data channels overlap with each other. The basic idea with time domain eICIC in order to coordinate inter-cell interference and protect control channels is that an aggressor layer creates protected sub-frames for a victim layer by reducing its transmission activity in certain sub-frames. Whereby, transmissions of the victim users are scheduled in time domain resources where the interference from other nodes is mitigated. The concept relies on accurate time and phase synchronization on sub-frame resolution between all base station nodes within the same geographical area. This approach involves periodically muting the transmissions of entire sub-frames from nodes that cause harmful interference onto others; in this way, nodes affected by high interferences can serve their subscribers in these sub-frames.

In the case of a macro-pico scenario, users served by the low power node who are located in the range expansion zone observe large DL interference from the macro cell. In order to protect the DL control signaling from the low power node, macro transmission activity is reduced in certain sub-frames, which are called almost blank sub-frame (ABS) and range expanded pico cell users are scheduled within sub-frames that overlap with the ABSs of the macro cell. The low power node is provided with data about the set of protected sub-frames over the X2 interface, which connects the macro cell with low power nodes [10]. Therefore,
low power users are categorized into 2 groups: Users in the range extension area, who suffer from a high level of interference and are only served during the ABS, and users that are located closer to the low power node, so they are not heavily affected by the interference from the macro, and can be served by any sub-frame whether ABS or non-ABS.

In a macro-femto scenario, the situation is very similar, but, in this case, ABS are used at low power nodes in order to mitigate the interference in control channels of users served by the macro stations; in other words, on this occasion, the transmission activity that is muted is of the femto nodes. Macro cells users in the vicinity of a small cell can be scheduled within the sub-frames overlapping with the ABSs of the femto nodes, which significantly mitigate cross-tier interference [11].

![Illustration of ABSs used in different scenarios](image)

For backward compatibility, certain signals must be transmitted in all DL sub-frames even if they should be muted. Therefore, an ABS is characterized by minimum transmission, but not completely null; that is why these sub-frames are called almost blank. No control or data signals are transmitted in ABSs, only reference signals are sent, namely:

- Common reference signals (CRS)
- Primary and secondary synchronization signals (PSS and SSS)
- Physical broadcast channel (PBCH)
- System Information Block-1 (SIB-1) and paging with their associated physical downlink control channel (PDCCH)
The main argument for implementing time domain partitioning is to enable support for excessive range expansion for those operators that do not want to rely on CA.

ABS technique in the case of macro-femto scenarios will be further explained through the next section. The explanation is focused on the scenario where macro stations and femto nodes coexist in the same geographical area, because as it was said previously, femto cells are the sort of small cells most deployed in HETNETS implementations.
4. SECTION 4: ALMOST BLANK SUB-FRAMES PROCEDURE

Through this section it will be further explained how the time domain eICIC technique ABS works for mitigating interferences in macro-femto scenarios. As it was explained previously, when an UE served by the macro station is in close proximity to a femto cell working in closed mode, it suffers from strong interference in the DL.

![Figure 24: Macro-femto interference scenario](image)

Therefore, the criterion to determine when a femto node must transmit ABSs is based on the value of the SINR of the UE. Based on technical documentation in 3GPP standardization, typical values of target SINR for DL control channels transmission are -6 dB or -4 dB [16] so that, if the SINR falls below this level, the UE cannot receive either control or data channels.

To implement the procedure of transmitting ABS, first of all, the macro station needs to know which UEs are suffering high interferences from femto nodes. Once victim UEs are identified, the macro station has to communicate the femto nodes that are causing interference that they should launch ABS transmission mode. The SINR level at the victim UEs should be track to determine when the UE is out of risk and, then, the macro station must notifies the femto node to deactivate ABS transmissions. Coordination between both the macro station and its served UEs and the macro station and the femto nodes is indispensable during all the process. The next scheme synthesizes the procedure described:
If a SINR level below the threshold is detected in a macro UE; that is to say, this UE is affected by high interference from a close femto node, the ABS procedure must be initiated. The ABS transmission should be stopped when the UE affected by high interference moves away from the femto node, which was causing the interference; in other words, when the SINR level in the UE rises above the threshold. Therefore, the macro base station must track continuously all the UEs it serves. In order to do that, the macro stations tracks the Channel Quality Indication (CQI) report message of all the UEs it serves. This report message is an important element of LTE that contains information sent from a UE to his serving node to indicate a suitable DL transmission data rate. It is important to note that the larger the CQI value, the channel quality is better. Coordination between the macro station and its served UEs is essential to perform the tracking procedure.

4.1 Track Macro UEs and Victims Detection

In LTE, CQI is a 4-bit integer, there are 15 different values ranging from 1 to 15, and is based on the observed SINR. The 3GPP specification does not state how CQI should be generated; the only requirement it must satisfy is that the block error rate (BLER) with CQI feedback from UE must be under 10%. The CQI estimation process takes into account the UE capability such as the number of antennas and the type of receiver used for detection. The CQI
reported values are used by the macro station for DL scheduling and link adaptation\(^3\), which are important features of LTE. How often and when the UE feeds back CQI is controlled by the macro station.

The CQI can be periodic or aperiodic. The aperiodic CQI is carried by Physical Uplink Shared Channel (PUSCH) and it is only sent when it is asked to by the macro station. On the other hand, the periodic feedback is usually carried by the Physical Uplink Control Channel (PUCCH). However, if the UE is scheduled in the UL, the reported CQI moves to the Physical Uplink Shared Channel (PUSCH). This is because a UE cannot transmit on both PUCCH and PUSCH simultaneously and, unlike the PUSCH, the PUCCH is limited in capacity. Periodic CQI feedbacks are sent periodically to the macro station; the period between 2 consecutive CQI reports is communicated by the macro station to the UE at the start of the CQI reporting process. If both of them are needed, periodic and aperiodic reports, only the aperiodic is sent.

The granularity of CQI report can be divided into three levels: UE selected sub-band, higher layer configured sub-band and wideband CQI report. In Sub-band level feedback, the UE reports CQI for each sub-band. On the other hand, in Wideband feedback, the UE reports one wideband CQI value for the whole system bandwidth. Since no information about the frequency domain behavior of the channel is included, wideband CQI report cannot be utilized in frequency domain packet scheduling [18] [19].

### 4.2 Identify Aggressors Femto Nodes

Once the victim UEs have been detected, the macro station needs to identify which femto nodes are located near each macro UE and generating strong interference in its DL. These nodes will be called aggressors femto nodes. Coordination between the macro station and its served UEs is indispensable because victims UEs are the responsible of reporting the aggressors femto nodes to the macro station.

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\(^3\) Link adaptation techniques are employed to make the most of instantaneous channel quality. In essence, link adaptation adapts the selection of modulation and channel coding schemes to current channel conditions. This in turn determines the data rate or error probabilities of each link [17].
Each victim UE reports its measurements for the received signal power from adjacent femto nodes to its serving macro station, which analyzes these reports. In order to do that, the RSRP measurement report control message is sent from a victim UE to its serving macro station. The macro station defines triggering conditions under which UEs can send their reports. The RSRP measurement report message contains a list of neighboring cells of the UE specifying the measured RSRP for each of them. The RSRP from each one of the listed cells represents the interference level seen by the victim macro UE from this femto node. The measurement report includes the first 8 cells sorted in descending order depending on their RSRP values; that is to say, the femto node with the highest interference level comes first. For determinate the RSRP measured from a specific femto node, its cell specific reference signals shall be used. If the UE can reliably detect cell specific reference signals from other neighboring antennas, it may use also these signals in addition with the ones of the specific femto node to determine the RSRP \[20\]. The RSRP measurement report is the same as regular scanning reports used for handover.

According to this information, the macro station identifies and selects the femto nodes with higher level of interference and triggers these femto nodes to activate the ABS mode, until the SINR level, that is to say, the CQI value reported, of the victim UE raises to a certain target SINR.

### 4.3 Activation Of ABS Mode

Once the macro station knows which femto nodes are generating high interferences on the victims UEs, the ABS transmission mode in these femto nodes must be activated. In this process, coordination between the macro station and the femto nodes of the network is essential. The macro station not only has to notify the femto nodes selected as aggressors that they must operate in ABS mode, but also must specify which ABS pattern should be followed.

\[20\] Reference signals are transmitted during the first and fifth OFDM symbols of each slot when the short cyclic prefix is used and during the first and fourth OFDM symbols when the long cyclic prefix is used [21].
The macro station decides which ABS pattern will be used taking into account some parameters such as the number of victim UEs, the level of interference at the victim UEs, their locations in the cell and their requested services, or in other words, their input load. It is also important to consider the impact that the selected pattern will have on the performance of the aggressors femto nodes, since the throughput of the femto cells selected to operate in the ABS mode will be degraded due to the blanked sub-frames.

4.3.1 ABS PATTERNS

The ABS pattern specifies which sub-frames in a given frame will be scheduled as ABS. This information is exchanged between the macro station and the aggressors femto nodes via bitmap patterns. Upon receiving the bitmap pattern, either via customized operation administration and maintenance or via X2 interface, the femto node starts ABS transmission. So that, the macro station can schedule data for its victim UEs on sub-frames that overlap with the aggressor ABS transmissions. In order to enable this, time-domain ICIC requires time-synchronized transmissions between base stations at least at the sub-frame boundaries.

ABS sub-frame patterns can be constructed by configuring so-called multicast/broadcast over single-frequency sub-frames (MBSF) or by not scheduling unicast traffic (or by reducing transmit powers) in certain sub-frames.

There is a set of available ABS patterns for FDD and TDD deployments. The blanking rate \( \leq \frac{2}{8} \) (for FDD) and \( \leq \frac{2}{10} \) (for TDD), and the patterns shall apply from sub-frame 0. These patterns are defined by 3GPP [22] and are illustrated below:

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5 MBSF are sent to all the users in a cell (broadcast) or to a given set of users in a cell (multicast) using a subset of the available radio resources. Information about the set of sub-frames that are configured as MBSF sub-frames in a cell is provided as part of the system information.
• FDD patterns:

(1/8, 1, ABS) [10000000, ... ]

PDCCH

PDSCH

1 sub-frame (1 ms)

1 frame (10 ms)

non-ABS – femto UEs and cell-center macro UEs are scheduled in these sub-frames (cell-edge macro UEs not allowed to be scheduled here because they are affected by strong interference)

ABS – cell-edge macro UEs are scheduled in these sub-frames (no interference because the femto node does not transmit control or data signals in these sub-frames, only reference signals)

(2/8, 2, ABS) [11000000, ... ]

(3/20, 1, MBSF) [1000010000 1000000000 ]

• TDD patterns:

(1/10,1) [0000000001, ... ]

(2/10,2) [0000011000 0000011000 ]

(2/10,1, MBSF) [0000100001 0000100001 ]

6 Physical channel transmitted in the DL. PDCCH carries between others the DL allocation information, UL allocation grants for the terminal.

7 Physical channel transmitted in the DL. PDSCH is used for layer 1 transport data transmission. Supported modulation formats on the PDSCH are QPSK, 16QAM and 64QAM.
Other candidate patterns for consideration if the group is ok with the work load:

- FDD patterns:

(3/8,1,ABS)  [11100000, ... ]

The throughput of the femto cell operating in the ABS mode will be degraded since it can only schedule its UEs in the non-ABS. Obviously, the higher the blanking rate, major is the degradation. The macro station should give to victims UEs higher priority to be scheduled during the ABS and prohibits their scheduling during non-ABS. At the beginning of each sub-frame, the scheduler selects all flows that can be scheduled and decides which scheduling algorithm will be assigned to each flow. The scheduler is concerned mainly with throughput, latency and fairness. There are different scheduler algorithms pre-defined, each of them giving preference to any one of the mentioned concerns depending upon the user's needs and objectives. The scheduler algorithm selected (i.e. the method by which data flows are given access to system resources) for the DL at the macro station is a very important decision. The use of ABS patterns naturally results in dramatic variations in the interference level experienced by macro UEs, and this represents a major challenge for the macro station to conduct accurate link adaptation during the scheduling process.

### 4.4 Tracking of SINR during ABS Transmission

In order to know when the femto node can finish transmitting ABS; that is to say, when the UE is no longer affected by high interference, the macro station has to analyze the RSRP reports as well as the CQI feedback from its served UEs during all the time that femto nodes are working in the ABS mode. The target SINR level for each victim macro UE is based on its location from the macro station where typically the cell center UEs target SINR is higher than that of the cell edge macro UEs. For decide if the UE is no longer affected by strong interference only non-ABS have to be taken into account because during ABS the level of the SINR at the victim UE will considerable improve.
4.5 Deactivation of ABS Mode

When the SINR level of the victim UE rises to the target SINR level during the non-ABS; that is to say, when a victim UE reports a CQI feedback above the CQI threshold, the macro station has to trigger the femto node, which was causing interference in the UE, to deactivate the ABS transmissions. This procedure is symmetrical as the described for activating the ABS mode.

4.6 Related Works

Several researches have been done and different methods have been proposed in order to improve the ABS time domain technique described before. How these approaches presented can improve ABS technique will be explained below, so as to comprehend in which principles the improvements proposed are based and to analyze the results achieved, specifying which problems they solve.

4.6.1 Instantaneous Radio-Channel Quality

An intrinsic characteristic of radio communication is that the instantaneous radio channel quality varies in time, space, and frequency. This includes relatively rapid variations due to multipath propagation. Consequently, degradation in the SINR of a given UE could be instantaneous and not lasting for a long time. In this situation, the given macro UE should not be considered as a victim even if it presents a SINR below the threshold at a given time.

In [23], in order to avoid committing such mistake, the authors propose that the tracking procedure of UEs should be during a certain period. To decide the appropriate period, the authors have into account the fact that some services supported by LTE, such as VoIP, are considered to be in outage if it cannot receive control data for a time interval of 200 ms, and, therefore, they set the tracking period to 50 ms. Once a UE reports a CQI value equivalent to the set SINR threshold, the macro station starts the tracking procedure that will be executed during the time predefined. The reported CQI for a given time is filtered following the equation: $CQI_f[n] = \alpha \cdot CQI[n] + (1-\alpha) \cdot CQI_f[n-1]$, where $CQI_f[n]$ and $CQI_f[n-1]$ are the filtered CQI values at time instants $n$ and $n-1$, $CQI[n]$ is the reported CQI at time instant $n$ and $\alpha$ is the filter...
Inter cell interference coordination techniques in HETNETS
Almost Blank Sub-frames approach

4.6.2 SINR Estimation

Victim macro UEs experience strong interference in the sub-frames preceding the ABS. However, due to the ABS activation, this interference level is highly mitigated during the ABS, and hence the reported CQI feedback just before an ABS is misleading. Scheduling decisions are strictly related to the channel quality experienced by each macro UE, and therefore, with the CQI feedback. Since the reported CQI feedback just before an ABS should not be used for the calculation of the scheduling metric during ABSF periods, in [23] a strategy to estimate the SINR level during an ABS is proposed, based on the reported CQI feedbacks from previous ABS instants.

The measured SINR level for the previous ABS is considered as the expected SINR level for the next ABS. In order to consider the behavior of the process that governs the change of SINR level during ABS, and the abrupt variations that may occur, a Kalman filter\(^8\) is used to estimate the SINR level during an ABS based on the reported SINR level, via CQI feedbacks, for the past ABS.

The discrete Kalman filter converges rapidly to the exact measurements with 2 or 3 iterations at most, as it can be seen in the figure below. Therefore, it is a good procedure to estimate the SINR of a given victim macro UE during ABS from previous CQI feedbacks for ABS.

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\(^8\) The Kalman filter is a set of mathematical equations that provides an efficient computational (recursive) means to estimate the state of a process, in a way that minimizes the mean of the squared error. The filter is very powerful in several aspects: it supports estimations of past, present, and even future states, and it can do so even when the precise nature of the modeled system is unknown [24].
4.6.3 Throughput Degradation in Femto Cells

In order to reduce the throughput degradation in femto cells due to the use of ABS, a novel approach, called ABS offsetting, is proposed in [25]. The aim of this is proposal is to reduce the blanking rate at the femto cells while preserving the required optimal blanking rate at the macro cell. The main idea in this paper is that there is no need to force the entire aggressor femto nodes in the macro cell area, may be several of them affecting different UEs, to operate in the ABS mode with the same pattern required by the macro cell. Therefore, each aggressor femto node will be configured to operate in ABS mode with a certain blanking rate, and it will not start blanking at sub-frame 0 as defined in [22], but will start blanking at an offset.

To achieve this, the system resources are partitioned in two stages. Firstly, all the macro UEs are divided into two groups, normal UEs and victim UEs, and the resources are divided between them, that is, the optimal and fair blanking rate is specified. Secondly, victim macro UEs are divided into groups according which femto node is causing strong interference; in other words, all victim UEs affected by the same femto node are put together. System resources are partitioned again between the different groups of victim macro UEs; in other words, each coalition is assigned a part of the ABS amount, achieving a reduction of the blanking rate associated to each group. It is important to note that there may be a resource partition that is shared partially or completely between two coalitions. To guarantee that the effective blanking rate seen by the macro cell is the optimal and fair blanking rate decided in the first stage, each reduced blanking pattern will be associated with an offset. The ABS
pattern selection problem in both the first and the second stage of resources partition is solved modeling the system as a Nash bargaining problem.

The throughput of femto cells triggered to operate in ABS mode decreases the higher blanking rate, because it is relative to the amount of blanked sub-frames. Therefore, using reduced blanking rates, aggressor femto nodes throughput is not so degraded as if it had to follow the optimal rate specified by the macro.

In conclusion, the ABSF offsetting highly compensate the decrease in the aggressor femto nodes throughput, and it gives higher throughput to the femto UEs in ABS-mode triggered femto cells without affecting the throughput of the macro cell UEs, both normal UEs and victim UEs.
Figure 29: Aggregate throughput of the femto cells [25]
CONCLUSIONS

In this project a deeply research about heterogeneous networks has been done with a special focus on the inter-frequency interference cancelation time-domain technique called Almost Blank Sub-frames.

As a matter of fact, mobile broadband traffic is increasing and, with it, also users’ expectations for higher data rates. Deploying heterogeneous networks is a convenient means to meet increasing traffic demands and performance expectations, because it enables for substantial gains in the capacity and performance of wireless systems.

The range expansion technique allows a better load balancing over the different network layers, increasing the capacity and robustness of the network. However, it is limited by inter-cell interference. Femto nodes working in closed access mode also produce high interferences to users that cannot connect to them. Therefore, coordination between differents cells in the networks and interference management is essential to achieve an effective heterogeneous network deployment.

The various eICIC techniques explained through the project enable the improvement of the performance degradation caused due to the inter frequency interference. But, despite the great advances that are being made in the field of eICIC techniques, they fail to completely cancel the interference in the control channels, so that network performance is always degraded.

Future researches should be focused on implementing the soft-cell scheme, concept described at the end of Section 2. This approach is based on the fact that the low power nodes do not create a new cell different of the macro cell. Thereby, the problem that the transmission cannot be carried out owing to the fact that reception of control channels is not reliable is eliminated, because reference signals are the same for low power nodes and for the macro station.
TERMS AND ABBREVIATIONS

2G - second generation
3G - third generation
3GPP - 3rd Generation Partnership Project
4G - fourth generation
BCH - broadcast channel
BLER - block error rate
BS - base station
CA - Carrier Aggregation
CAGR - Compound Annual Growth Rate
CBW - Cell Border Window
CC - component carriers
CDMA - code division multiple access
CRS - cell-specific reference signal
CSG - closed subscriber group
DL – Downlink
DM-RSs - demodulation-specific reference signals
eICIC - Enhanced Intercell Interference Coordination
FDD - Frequency-division duplexing
FDM - frequency division multiplexing
GSM - Global System for Mobile
HETNETS - Heterogeneous Networks
ICIC - Inter-Cell Interference Coordination
ISI - intersymbol interference
LTE - Long Term Evolution
LTE-A - Long Term Evolution Advanced
OFDM - Orthogonal Frequency Division Multiplexing
PCI - physical cell id
PDCCH - physical downlink control channel
PSS - primary synchronization signal
RRUs - Remote Radio Units
RSRP - Reference signal received power
Inter cell interference coordination techniques in HETNETS
Almost Blank Sub-frames approach

SC-FDMA - Single-carrier frequency-division multiple access
SIB-1 - System Information Block-1
SINR - Signal to Interference and Noise Ratio
SSS - secondary synchronization signal
TD-SCDMA - Time Division Synchronous Code Division Multiple Access
TDD - Time-division duplexing
UE - User Equipment
UL - Uplink
UMTS - Universal Mobile Telecommunications System
WCDMA - Wideband Code Division Multiple Access
WiMAX - Worldwide Interoperability for Microwave Access
REFERENCES


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