THE INTERNATIONAL JOURNAL OF
SCIENCE & TECHNOLEDGE

Enhanced Inter-cell Interference in LTE-Advanced: Heterogeneous Networks

Abhijeet R. Pathak
Student, Department of Electronics and Telecommunications, Mumbai University, Maharashtra, India

Abstract:
Third Generation Partnership Project (3GPP) has continuously been working on improving cellular experience for users. The latest developments in the cellular standards of the Fourth Generation has been towards providing better throughput, higher data rate, improved and efficient service through signal modulations and coding schemes. One of their core improvements is the introduction of heterogeneous networks. Heterogeneous networks (Hetnets) are a combination of macro cells and small cell networks that consist of picocells, femtocells, relay nodes and radio remote head. The introduction of small cells has led to co-channel interference between the multi-layer networks. New proposals have been suggested to mitigate interference between femto-macrocells and pico-macrocells, by blanking orthogonal frequency division multiplexing (OFDM) symbols or time shifting the same. Resource assignment is then done based on the amount of interference Experienced by the users.

Keywords: *4G mobile communication, femtocells, Hetnets, LTE, picocells.*

1. Introduction

With the proliferation of the wireless traffic in recent years hitting the one billion wireless subscribers mark and the number to be tripled over the next five years, the tremendously fast increase in demand has become a serious concern for the industry. The number of mobiles will exceed the population of the earth by the end of 2014, whereas the number of mobile-connected devices will surpass 10 billion by 2018[1]. This growth is due to the invention of advanced wireless devices, like smartphones, tablets, mobile TV, machine to machine communications and the increase in their demand. Proposals to improve network efficiency have been given on various fronts viz-a-viz allocation of resources on various frequency spectrums, carrier aggregation, Multiple-input-Multiple-output (MIMO) and heterogeneous networks.

HetNets have been very efficient in providing network densification along with high spectrum efficiency. Being a cost effective deployment, it gathers demand both from the vendors end as well as the customers end. However, it introduces new interference problems that affect the overall network. Various coordination schemes have been proposed to mitigate interference. This paper highlights some of those coordination schemes currently being used.

The remainder of this paper follows as described: II explains the HetNet architecture and its specifications. III introduces the sources of interference that macrocells and small cells encounter. IV provides details on interference coordination between macrocell and femtocells and the techniques used. V provides details on picocell and macrocell interference coordination and scheduling strategies for their specific users. VI concludes the paper with a look into future enhancements.

2. Heterogeneous Networks

A HetNet is one of the key methods of efficient radio spectrum allocation. It is a multi-layer network infrastructure that consists of base stations (BS) having different functionalities depending upon the requirements of the area it is deployed in. Apart from the traditional Marco enhanced Node-B's (M-eNB), the HetNet architecture consists of various low power nodes (LPN) like the relay nodes, picocell, femtocells and remote radio head. The architecture is shown in Figure 1. As is shown in the figure, the M-eNB is connected to all the LPNs – picocell, femtocell and relay node [2]. The victim users shown are the ones that experience co-channel interference. The Macro users (MUE) are serviced by the M-eNB. The picocells work on the same access strategy as the M-eNB, only with a lower footprint, and thus have fewer users comparatively. The picocells are usually located at places where there is poor signal quality and where there are holes in the macrocell's network. The femtocell, as shown in figure 1, is used for providing indoor coverage where the M-eNB signal is weak. All of these nodes have different power ceilings and backhauls to support them. The macro cell typically transmits up to a few kilometers with a maximum transmit power of 46 dBm, while being supported by an S1 interface for backhaul. The picocell, is a low power open access BS that cover only up to 300 m with a power of 23-30 dBm. The Femto cell is the LPN that provides coverage only to indoor locations and hence does not need coverage beyond 50 m and a maximum power of 23 dBm. These however, work on the IP backhaul and thus need good internet connectivity to support the network [3].

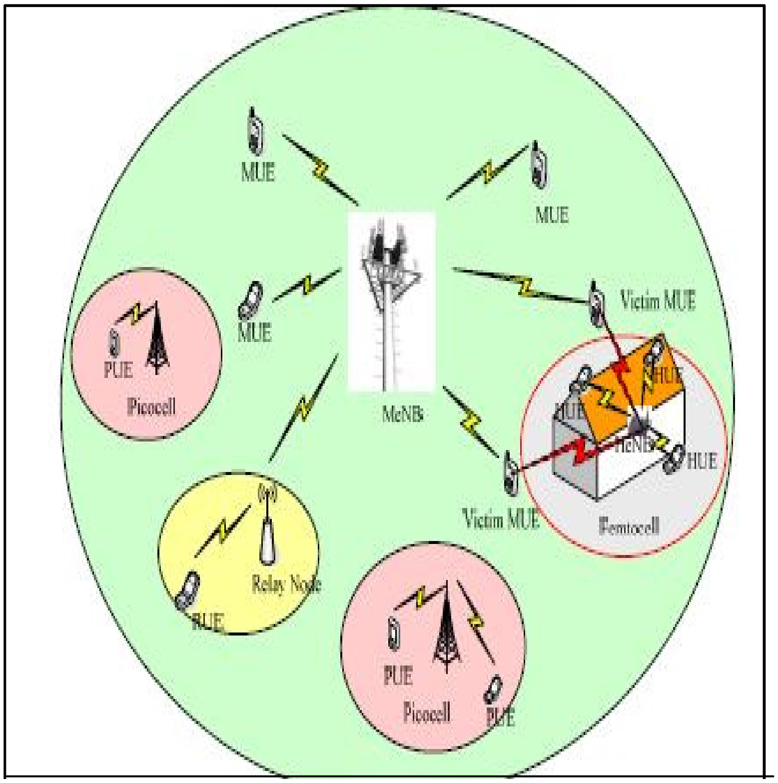

Figure 1: Heterogenous network in LTE-Advance [2]

Some of these multi-tier base stations are placed with proper planning in the network (picocells, relay nodes), whereas some of them are placed in an unplanned manner by the users (femtocells). Apart from filling the holes in the coverage areas, these deployments even help relax the traffic load on the macro BS by offloading the traffic onto their own respective networks as they work in the same frequency bands. Since they are deployed in the same band as the M-eNB, they create substantial interference [3]. To tackle these issues, 3GPP has standardized interference coordination techniques. This paper provides a brief analysis on tackling the issues using enhanced inter-cell interference coordination (eICIC).

3. Sources of Interference

With the deployment of HetNets, many issues arise that affect the throughput of the macro and microcells. This happens due to the following reasons:

Deployment of H-eNBs: H-eNBs are deployed in homes and offices in an unplanned manner by the users. Due to lack of centralized control on the location and operations of the femtocells, no optimization can be performed to improve network performance [4].

Accessibility for users: The femtocells are usually deployed in the same bandwidth as the macro cells. However, access can either be open to all users to handover to the better signal quality providing eNB, or it can be a closed group access (CSG), where only registered users can be allowed to handover to the femtocell [5]. This creates the possibility of cross-tier interference, resulting from the leakage of the signal from the indoor location, to and from the access-denied victim users (figure 1) that are denied access to the femtocell network. When the victim users transmit in the uplink at a high power, it creates interference for the femtocells that receive signals from its subscribers at a lower power level. Similarly, during downlink, the femtocell might have a stronger signal for the victim MUE which is expected to receive the signal from the distant M-eNB [3].

Transmission power of the eNBs: The M-eNBs are known to transmit at 46 dBm, whereas all the LPNs transmit at a much lower power level. This creates an uneven balancing of the load when the LPNs work in open access mode. The macro cell will almost always transmit a higher power level signal to the users as compared to picocells, relay nodes or femtocells. Users would always pick a transmitted signal that has better quality and this would lead to over-loading of the macrocells, leading to under-utilization of the picocells. Even in the downlink, the MUE would transmit at much higher power level as compared to the users associated with the picocell. This would jam the picocell users as they would be transmitting signals at a much lower power level [3].

Cell Range expansion: The received power level and hence the range of the picocell can be increased by adding a bias value to increase the cell coverage area and making the LPN more attractive for users. This helps offload more traffic from the M-eNB onto the picocell [8]. However, this is at the expense of the picocell receiving even a below 0dB SINR signal, which is too corrupted to be decoded [3].

4. eICIC between M-eNBs and Femto Cells (Home-eNBs)

In most cases, the coverage of the M-eNB is poor for indoor areas like homes or offices. To provide coverage at these places, femtocells are deployed. Being cost effective and an efficient technique of co-channel deployment, they have become very popular in recent times. Having a small coverage area, the channels can be reused more often, improving spectral efficiency. These H-eNBs are working with a backhaul connection provided by the broadband connection available at homes or offices via co-axial cables or optical fibers. As mentioned earlier, they can work either in open access mode or CSG mode while occupying the same frequency as the M-eNBs. The CSG mode is where a lot of signal interference is observed with respect to the MUEs in the vicinity of the H-eNB [5].

The most important channel that carries control and resource allocation information is the Physical Downlink Control Channel (PDCCH) [6]. They can be configured to occupy up to the first 3 OFDM symbols and are broadcasted over the entire coverage area. Signals from H-eNBs are the major cause of interference, especially when the H-eNBs serve as a CSG. The interference can be reduced to a great extent by blanking the OFDM symbols, while keeping backward compatibility with the legacy 3GPP Release 8 or 9 technologies [2].

The process first starts by detecting the victim Macro user equipment (MUEs). There are two ways of detecting the victim user. One of them is by the H-eNBs detecting the victim MUEs with the uplink (UL) Reference Signals (RSs) that are terminal specific. These can be distinguished from the users associated with H-eNBs by their UL signal information. The H-eNB can then report the victim MUE to the M-eNB. Another way to identify the victim MUE, experiencing interference from the H-eNB, is by triggered transmission of interference report sent by the victim MUEs to the M-eNB [2].

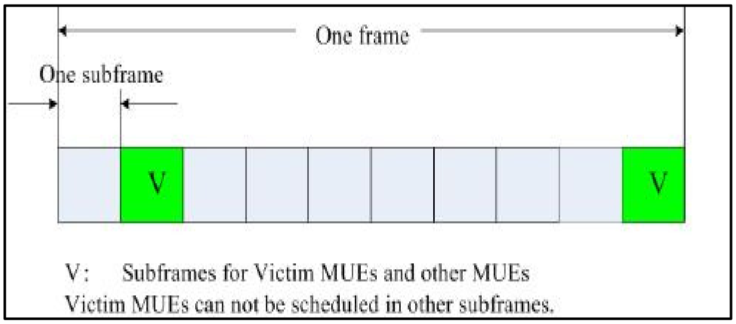

Figure 2: Allocation of downlink subframes based on interference detection [2]

Once the M-eNB receives the information about the victim MUEs, it then starts the process of allocating resources separately to the victim users. Two subframes are reserved for the interference experiencing MUEs, whilst other users can be allocated any of the remaining subframes as shown in Figure 2. For the MeNB the PDCCH can occupy the first 3 symbols entirely, whereas the HeNB restricts itself to allocating the PDCCH to the 1st symbol only, as shown in figure 3. This reduces the spectral efficiency of the H-eNBs as the other two symbols are left blank, but greatly reduces the cross-tier interference arising between the two different base stations [2].

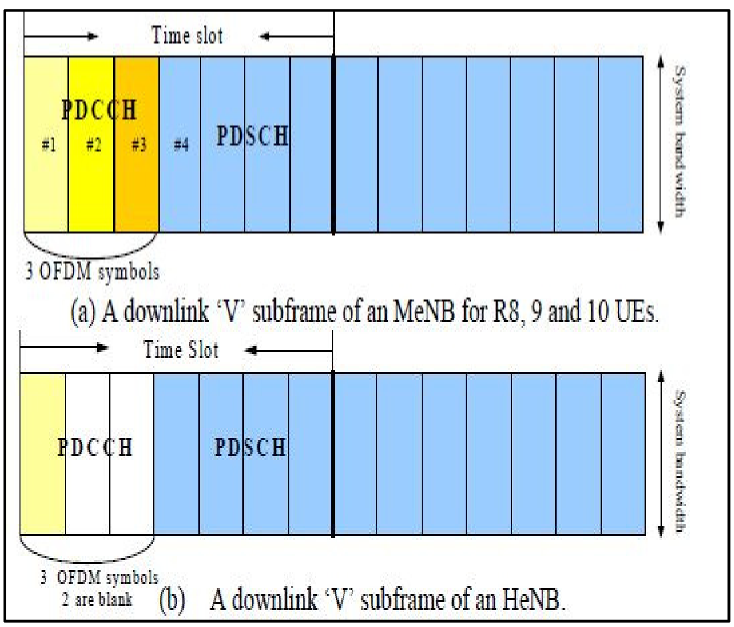

Figure 3: Blanking of 2 OFDM symbols in H-eNB to reduce interference [2]

Another time domain method of interference mitigation can be achieved by shifting the OFDM symbols of the subframe of the H-eNB so as to eradicate symbol alignment with the OFDM symbol of the M-eNB as shown in figure 4 [7]. As symbols are shifted, the PDCCH of the two eNBs are no longer aligned with each other. Instead, the control channel of one eNB is aligned with the physical shared channel of the interfering eNB. This would help prevent loss of control information in either of the networks. To mitigate the interference of the control channel with the now time shifted shared channel, the shared symbol can either be transmitted as a blanked symbol or it can be muted to allow the transmission of control channel information. However, for legacy devices, eradicating the shared channel becomes an issue as users have no way of knowing where the muted or blanked symbols are in the frame. This leads to the degradation of throughput, especially when high order modulation and coding techniques are used [3].

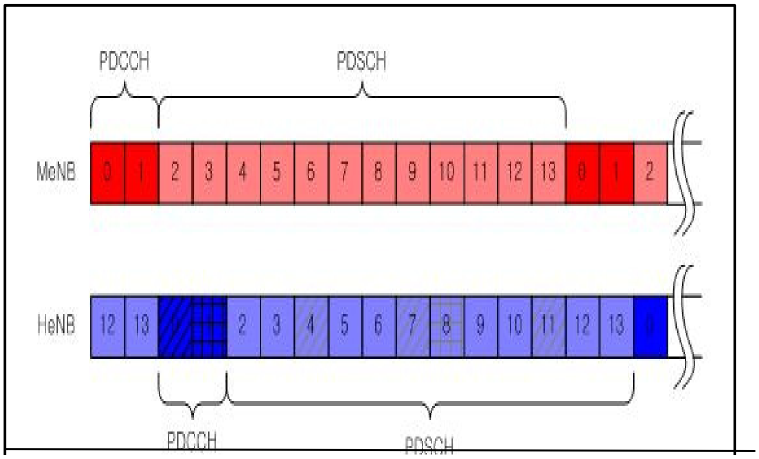

Figure 4: Example Representing a 2 OFDM symbol shift [7]

5. eICIC between M-eNBs and PicoCells

For heavily crowded places in the footprint of the macro cell, picocells are installed to ease up the user traffic load over the M-eNB. As compared to the Macro BS, these BSs are transmitting at 1W with a lower gain, thus leading to a smaller coverage area. As is the case for femto cells, picocells are mostly deployed in a co-channel allocation along with the macro cell. The same resource that is allocated to the number of users in the macrocell is allocated to fewer number of picocell users. This causes unfairness in the spectrum allocation. To reduce unfairness, we introduce the concept of cell biasing [8]. By adding a bias value to the signal received at the picocell, we increase the number of users that can associate themselves with picocell. This leads to expansion of the footprint of the small cell network, helping reduce the load further from the macro cell. However, due to the addition of bias value, a device at the border of the extended pico range would hand over to the picocell, even if the macro cell is providing a better signal quality. This would degrade the throughput for the user directly and give below acceptable levels of SINR for the signal. Also, the strong signal from the macrocell would create strong interference for picocell users [3] [8].

To combat this, enhanced interference coordination is used to schedule resource allocation as shown in figure 5. The picocell network is divided into two areas: cell inner mobile and extended cell edge users. The cell edge users have been associated with the picocell due to the bias value added [8].

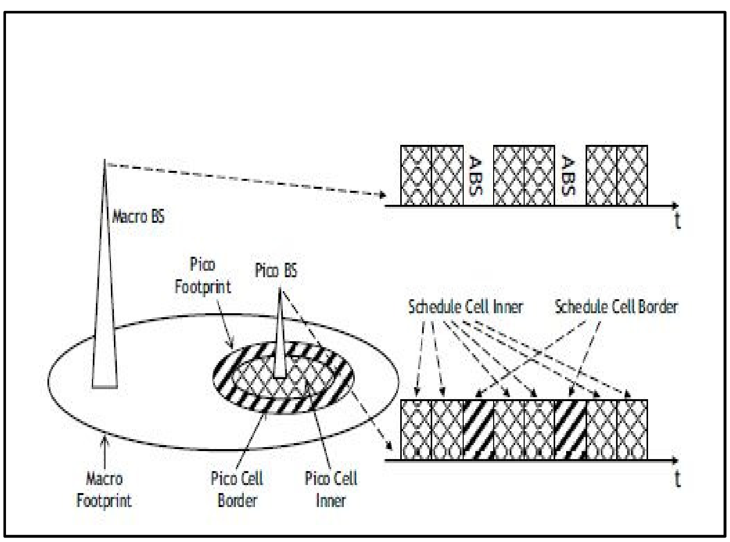

Figure 5: Macro-pico architecture with the eICIC timing diagram [8]

The M-eNB blanks certain subframes to reduce the interference caused for the picocells. The subframes blanked by M-eNBs can carry certain control information like scheduling information, pilots, synchronization channel and broadcast channel to provide backward compatibility to the Rel. 8, 9 users. These Almost Blank subframes (ABS) are used by the picocells to schedule only those devices that exist near the edge of the coverage area, whereas the other users are allocated on the remaining subframes. This mitigates interference

caused for the edge users greatly, as the power allotted to the ABS by the M-eNB is negligible, which helps improve the SINR of the signal received by the picocell [3] [8].
The Scheduler has two ways to schedule the resources for the picocell users:
Strict Scheduling: The scheduler assigns the ABS to the border cell users, whereas the users close to the center of the cell are assigned resources in the remaining subframes. The Cell border window (CBW) decides if the user is a cell border user or a cell inner user. If CBW is greater than the difference between the signal strength of the source BS and interfering BS, then the device is a cell border user. If the CBW is lower than the difference, then the device is an inner cell user. The users only measure the channel quality indicator (CQI) of the subframe (blanked/ non-blanked) for the scheduling group they belong to, and send it to the scheduler. Based on this categorization, the allocation of ABS for cell border users and the remaining subframes for cell inner users can be carried out [8].
Dynamic Scheduling: This method assigns resources on a priority basis. Every user within a picocell reports the CQI to the pico BS. The pico BS calculates the worst CQI sent by the user and assigns them the ABS, whereas the others are assigned the remaining resources.
The advantage of strict scheduler is that at a time, a user has to send either the ABS CQI feedback or the non-blanked feedback. The main drawback is the lack of resource utilization for the cell that doesn't have many users. The advantage of Dynamic Scheduling is that all resources are utilized irrespective of the number of users. The main drawback is that users have to send double the CQI measurements for both ABS and non-blanked subframes. Simulations have shown that for a loaded network the strict scheduling works on par with dynamic scheduling. Whereas for a network that doesn't have many users, the dynamic scheduling outperforms the strict scheduler in terms of resource allocation [8].

6. Conclusion

The techniques for suppressing cross-tier interference in a multi-tier heterogeneous network in LTE-Advance scenario have been explained. The main sources of interference which leads to the main topic of eICIC have also been highlighted.
Interference between macrocell and femtocell has also been explained followed by methods to eradicate or suppress interference. The blanking of the OFDM symbol and OFDM symbol shift are proposed as efficient methods for femto-macrocell interference mitigation. The pico-macrocell interference, occurring due to the cell bias theory, is a serious concern for the efficiency of Heterogeneous networks. Steps on mitigating interference, followed by scheduling strategies to allocate resources have been indicated. eICIC has laid the foundation for future developments in Heterogeneous networks. HetNets, being the most emphasized topic in today's wireless technological world, needs far better improvements than are available in Rel. 10. Hence, Further-enhanced Interference coordination control is being discussed in 3GPP Rel.11 that deals with detecting the first two interfering sources, along with enhanced dynamic scheduling strategy implementation for a much better HetNet deployment.

7. References

i. Cisco White paper, "Cisco Visual Networking Index: Global Mobile Data Traffic ForecastUpdate",Internet:http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/s827/white_paper_c11-520862.pdf, [February 5th, 2014]
ii. Shaoyi Xu; Jing Han; Tao Chen, "Enhanced Inter-Cell Interference Coordination in Heterogeneous Networks for LTE-Advanced," Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th , vol., no., pp.1,5, 6-9 May 2012
iii. Lopez-Perez, D.; Guvenc, I.; de la Roche, G.; Kountouris, M.; Quek, T.Q.S.; Jie Zhang, "Enhanced intercell interference coordination challenges in heterogeneous networks," Wireless Communications, IEEE , vol.18, no.3, pp.22,30, June 2011
iv. Lopez-Perez, D.; Valcarce, A.; de la Roche, G.; Jie Zhang, "OFDMA femtocells: A roadmap on interference avoidance," Communications Magazine, IEEE , vol.47, no.9, pp.41,48,September2009
v. Zahir, T.; Arshad, K.; Nakata, A.; Moessner, K., "Interference Management in Femtocells," Communications Surveys & Tutorials, IEEE, vol.15, no.1, pp.293, 31, First Quarter 2013
vi. S. Sesia, I. Toufik, and M. Baker, The UMTS Long Term Evolution：From Theory to Practice, Wiley, 2009
vii. R1-104661, Comparison of Time-Domain eICIC Solutions, 3GPP Std., Madrid, Spain, Aug. 2010
viii. Weber, A.; Stanze, O., "Scheduling strategies for HetNets using eICIC," Communications (ICC), 2012 IEEE International Conference on, vol., no., pp.6787,6791, 10-15 June 2012