

# Inter-Cell Interference Coordination for LTE-A

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## Summary

Multi-layer heterogeneous network layout including small cell base stations are considered to be the key to further enhancements of the spectral efficiency achieved in mobile communication networks. It has been recognized that inter-cell interference has become the limiting factor when trying to achieve not only high average user satisfaction, but a high degree of satisfaction for as many users as possible. Therefore, inter-cell interference coordination (ICIC) lies in the focus of researchers defining next generation mobile communication standards, such as LTE-A.

Building upon [1], this paper provides an overview over the background calling for ICIC in heterogeneous LTE-A networks. It outlines techniques standardized in Rel. 10 of LTE-A, discusses them showing their benefits and limitations by means of system-level simulations and motivates the importance of self optimizing network (SON) procedures for ICIC in LTE-A.

## Introduction

In 3GPP work on LTE Advanced is ongoing. Release 10 of the standard already introduces significant technological enhancements to meet the ambitious requirements set forth by 3GPP in [2].

Besides features to boost overall peak data rates like carrier aggregation or higher-order spatial multiplexing for uplink and downlink, enhancement of *inter-cell interference*

*coordination (ICIC)* has moved into the focus of intensive research and standardization. The reason is that 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 (SINR) ratio [3], [4] is feasible. Significant increases in spectral efficiency can therefore only be achieved by improving the SINR through reduction / avoidance of the interference.

The basic goal of ICIC in practice 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.

The remainder of this paper is organized as follows: Starting with a brief recapitulation of severe inter-cell interference scenarios in multi-layer heterogeneous networks, range expansion and its deficiencies in terms of ICIC, this paper gives an overview over ICIC methods considered in the standardization of Release 10 of LTE Advanced. At this, we focus on *heterogeneous networks (HetNet)* with outdoor *pico eNodeBs (PeNB)* using range expansion and briefly discuss the scenario of *Home eNodeBs (HeNB)* with *closed subscriber groups (CSG)* noting that here many of the problems—and hence the corresponding solutions—apply in a dual manner.

**Scenarios of severe Inter-Cell Interference**

Recently, the topic of multi-layer heterogeneous networks<sup>1</sup> (HetNet) has been discussed extensively for application in LTE and LTE-Advanced, cf. e.g. [1] for a review. The idea is to build up the network of not only a single type of eNodeB (homogeneous network), but to deploy eNodeBs with different capabilities, most importantly different Tx-power classes. These eNodeBs are commonly referred to as *macro eNodeBs (MeNB)*, *pico eNodeBs (PeNB)* and *femto/home eNodeBs (HeNB)* and meant for basic outdoor, outdoor hot-zone and indoor/enterprise coverage, respectively.

The concept of HetNets supported by SON procedures offers great opportunities to enable large scale, low cost deployment of small base stations below roof top to boost user experience at hotspots or to improve network coverage. The traffic offloading effect (or cell-splitting gain) can be leveraged by cell range expansion for PeNBs that lets a larger number of users connect to the small cells. On the other hand, HetNets is introducing new challenges regarding inter-cell interference coordination and load balancing as well as user mobility in idle and active mode.

Heterogeneous network layouts introduce basically two predominant inter-cell interference scenarios. One is the macro-pico scenario with *cell range expansion (CRE)* depicted in Figure 1 the other is the macro-femto scenario with *closed subscriber groups (CSG)* depicted in Figure 2. For more details on these cf. [1].

The two interference scenarios are dual in many ways, i.e. severe interference situations occurring for UEs served by the PeNB and the possible remedies in the macro-pico scenario are

<sup>1</sup> In the following, we will just briefly refer to this as "heterogeneous networks" or "HetNets", while other aspects of HetNets such as multi-RAT HetNets are not considered in this paper.

very similar to those that can occur for UEs served by the MeNB in the macro-femto scenario. We will therefore in the following concentrate on the more important macro-pico scenario and merely point out that the procedures to alleviate the interference there can often be applied in a dual manner in the macro-femto scenario.

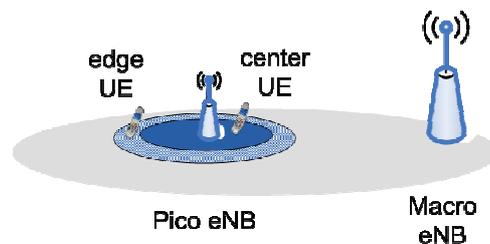


Figure 1: Macro-Pico scenario

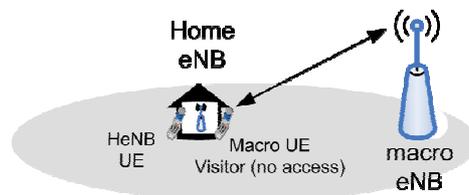
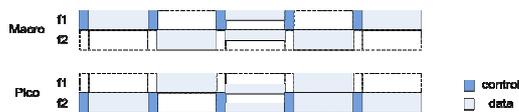


Figure 2: Macro-Femto scenario

**ICIC Methods for LTE Advanced**

The main problem of the Rel.-8/9 ICIC methods (cf. e.g. [1]) is that they are limited to data channels. Therefore, the standard does not provide sufficient protection for the downlink control channels in the two above-mentioned severe interference scenarios. Furthermore range expansion has to be limited to small offsets between cells, to keep control channel errors at a reasonable level.

For Rel.-10 3GPP therefore devised two new approaches to avoid heavy inter-cell interference on both data and control channels of the downlink. One is based on carrier aggregation with cross-carrier scheduling, the other is based on time-domain multiplexing (TDM) using so-called *almost blank subframes (ABS)*. Both are described and discussed in the following.



**Figure 3: Illustration of carrier-aggregation based ICIC**

**ICIC based on Carrier Aggregation:** Carrier Aggregation is one of the most important features of LTE Advanced. Unlike LTE, it enables an LTE-A UE to connect to several carriers simultaneously. It not only allows resource allocation across carriers, it also allows scheduler based fast switching between carriers without time consuming handover. A simple principle in a HetNet scenario is to partition the available spectrum into e.g. two separate component carriers and assign the *primary component carriers (PCC)* to different network layers as illustrated in Figure 3. The primary component carrier is the cell that provides the control information to the UEs, whereas control in the figure only illustrates the PDCCH, PCFICH, PHICH at the beginning of a subframe. By assigning this to different frequencies, interference on control channels like PDCCH, PCFICH, PHICH and also BCH or RACH between network layers can be avoided. By means of so-called cross-carrier scheduling, each network layer can still schedule UEs on other CCs called *secondary component carriers (SCC)* (see the second subframe in figure 3).

This way various interference mitigation schemes in frequency, time or space can be applied. A promising approach of spatial ICIC is where the macro layer uses only the PCC frequency, while the pico layer schedules its UEs served in CRE mode on its PCC and its cell-center UEs on its SCC, i.e. the macro layer's PCC (see fourth subframe in figure 3). Inter-cell interference can thus be kept to a minimum. Similarly the MeNBs might serve UEs in very favorable positions with reduced Tx power on their SCCs.

Carrier Aggregation with cross carrier scheduling as well as the supported frequency bands are UE capability from Rel.-10 onwards. A Rel.-8/9 UE can still be served by the different network layers, but cannot make use of such cross carrier scheduling.

**Time Domain Multiplexing ICIC:** In this alternative approach transmissions from eNodeBs inflicting severe interference onto others are periodically muted for entire subframes, so that the victim eNodeBs have a chance to serve their UEs suffering from severe interference from the aggressor eNodeB in these subframes. This muting is not complete, as certain signals

- Common reference symbols (unless configured as MBSFN subframe)
- Primary and secondary synchronization signals (PSS and SSS)
- Physical broadcast channel (PBCH)
- SIB-1 and paging with their associated PDCCH

have to be transmitted even in otherwise muted subframes e.g. to avoid radio link failure or for reasons of backwards compatibility. Collisions of subframe muting with PSS, SSS, SIB-1 and paging should be minimized. Hence muting in subframes #0, #1, #5 and #9 should be avoided as far as possible. Subframes thus muted are referred to as almost blank subframes (ABS).

TDM muting patterns are configured semi-statically and signaled between eNBs over the X2 interface. Signaling is done by means of bit maps of length 40, i.e. spanning over four frames, for FDD and two to seven for TDD. Hence, they can be in principle configured freely by the network. It is expedient to not statically fix such patterns, but to have a *self-optimizing networks (SON)* function optimizing the muting pattern according to some target criterion (e.g. load balancing) taking into account the above constraints on subframes that should be avoided.

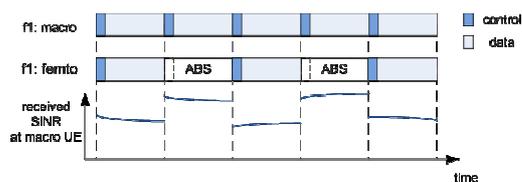


Figure 4: Illustration of TDM ICIC

As illustrated in Figure 4, TDM ICIC will cause strong interference variations between subframes. These can be exploited to better serve strongly interfered UEs, but must be considered in all UEs doing measurements, link adaptation etc.

In victim cells, UEs are categorized into two groups,

- UEs that are exposed to severe interference from another cell using TDM muting and that should hence rather be scheduled in subframes muted in the corresponding aggressor cell. In the macro-pico scenario, these are cell-edge pico UEs, in the macro-femto scenario, these are macro UEs in the vicinity of the HeNB.
- UEs that are rather indifferent to the interference from an eNB using TDM muting. In the macro-pico scenario, these are UEs located near the PeNB, in the macro-femto scenario, these are macro UEs far away from any HeNB.

Based on Rel.-10 standardization eNBs can restrict channel measurements done by their UEs to freely configurable patterns. With this, the above categorization can be done by means of selective channel quality feedback for subframes that are muted / not muted in the aggressor cell. UEs of the first group would then typically provide CSI feedback and be scheduled during subframes muted in the aggressor cell, whereas the others would be—for reasons of fairness—rather be restricted to the un-muted subframes. The exact categorization of UEs should of course also depend on other factors, like fairness and quality of service requirements.

It is worth pointing out that the restriction of the subframes in which CQI measurements are taken is crucial for efficient channel-aware scheduling. Rel.-8/9 UEs exposed to severe TDM-ICIC like interference will experience quite poor performance if their CQI measurements span over both muted and unmuted subframes in the aggressor cell.

Interference from CSI and common reference symbols sent out by the aggressor eNB is another limiting factor for the benefits of TDM ICIC [5]. In order to avoid this, resource element (RE) muting in the victim cell is required. That is, rather than trying to cope with heavy interference on a subset of the REs used for PDSCH transmissions, these are left unused at the expense of a slightly increased code rate. Thus, the performance degradation due to CSI-RS and CRS in ABS is negligible.

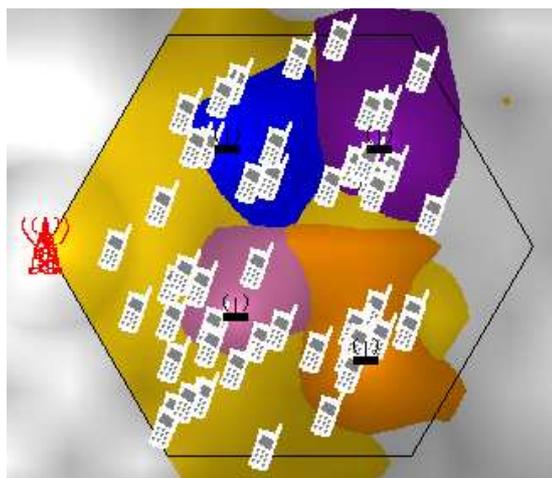


Figure 5: Illustration of simulated scenario (random sample)

### Simulation Results

In the following, we present some simulation results to illustrate the effect of cell-range expansion and TDM ICIC. We simulated a scenario with 4 PeNBs and 50 UEs per macro cell area, where 5 UEs were dropped randomly in the

vicinity of each PeNB, while the remaining 30 UEs were distributed uniformly over the entire macro-cell area. Figure 5 shows one random drop. The colors of the background indicate the coverage areas of the different eNBs, here assuming a CRE bias of 10dB. The brightness indicates the magnitude of the RSRP from the serving cell. Gray areas are served by other MeNBs or their associated PeNBs.

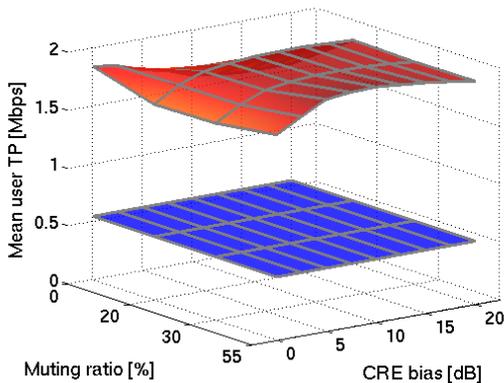


Figure 6: Mean user throughput

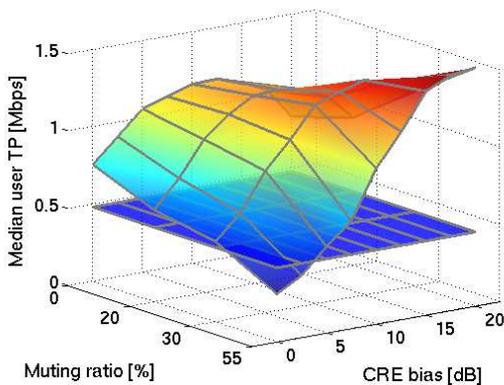


Figure 7: Median user throughput

Results for the achieved DL user TP with different CRE biases and TDM ICIC muting ratios are depicted in Figures 6 - 8 in terms of mean, median and 5%-ile, respectively. The horizontal plane in each figure represents the respective

performance in a homogeneous macro-only scenario. In addition, Figure 9 shows the CDFs of the user throughput for a number of selected scenarios.

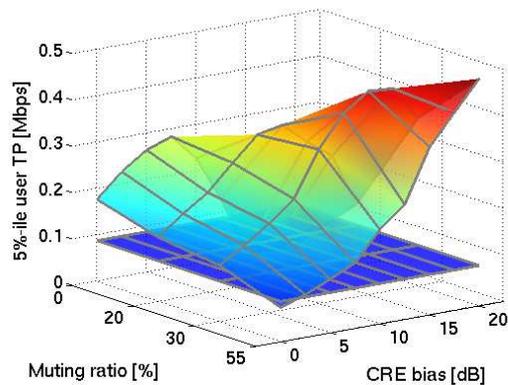


Figure 8: 5%-ile user throughput

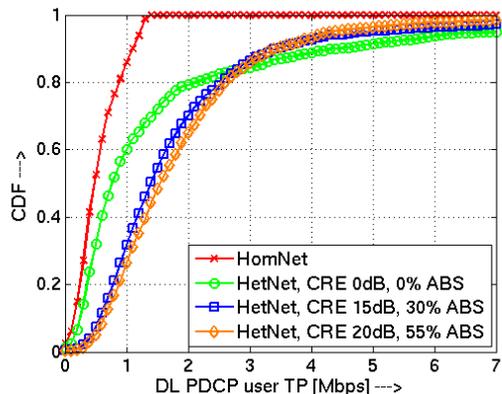


Figure 9: CDFs of user throughput for some specific configurations

Numerous conclusions can be drawn from these results:

- The introduction of PeNBs increases the mean user TP significantly, even without CRE and TDM ICIC. This gain is however only based on a very small number of UEs being served by PeNBs with very high data rates, as can be seen from the

fact that median and 5%-ile TP are only increased slightly.

- Increasing the range of the pico cells without TDM ICIC does not improve the mean user throughput in this scenario. Only 5%-ile and median throughput is increased due to PeNBs that happen to be located near the cell edge or in coverage holes of the MeNB.<sup>2</sup>
- The combination of CRE and TDM ICIC is very beneficial. Best performance is achieved with CRE biases as large as 15dB-20dB and ABS ratios of 30%-55%. Especially fairness is improved as can be seen from the 5%-ile plot. The crucial point for TDM ICIC to be effective in the macro-pico scenario is to have a sufficiently large number of PeNBs per MeNB to compensate for the reduction of resources available to the MeNB.

Note that these results were obtained using a fixed categorization of the UEs served by the PeNBs: If the RSRP from the MeNB was higher than that from the serving PeNB, the UE was served during ABS subframes only, otherwise during non-ABS subframes. This strict partitioning at times leads to the situation that a PeNB schedules all of its UEs only during ABS subframes, leaving the non-ABS subframes entirely vacant. An adaptive categorization taking into account the particular load situations in the macro and the pico cell can in many cases further improve system performance. The same is true for the adaptation of the CRE bias and also—though less trivially—the selection of the muting pattern depending on the current situation in the macro-cell area as a whole.

## Conclusions

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- 2 Note that degradation of PDCCH reliability or channel estimation in extreme interference situations are not taken into account here. This makes results for CRE without TDM ICIC overly optimistic.

In this paper we have briefly summarized ICIC methodologies in Rel.-10 of LTE-A, namely in frequency domain based on carrier aggregation in combination with cross-carrier scheduling and in time domain using the concept of almost blank subframes. For the latter case, we provided some system-level simulation results illustrating the great potential of TDM ICIC to improve not only peak data rates but also fairness. Furthermore, we pointed out, that scenario-dependent automatic configuration of TDM ICIC is very likely to further boost to system performance.

## References

- [1] V. Pauli, J. Naranjo, E. Seidel, Heterogenous LTE Networks and Inter-cell Interference Coordination; 2010
- [2] 3GPP, Requirements for further Advancements for E-UTRAN (LTE Advanced), 2011
- [3] C. E. Shannon, A Mathematical Theory of Communication, 1948
- [4] I. E. Telatar, Capacity of Multi-Antenna Gaussian Channels, 1999
- [5] ZTE, Discussion of CRS Interference and CSI Measurement in Macro-Pico Deployment, 2010

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### System Level Simulation Services

Nomor Research has developed a comprehensive simulation environment supporting various standards such as LTE, LTE Advanced and HSPA and offers related services to support research, development and standardisation.

The simulator can be used on project basis or in customized simulation campaigns. The performance of the system level simulator has been calibrated to simulation results obtained in standardisation.

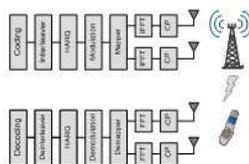
Features of the dynamic multi-cell, multi-user system level simulator include:

- macro-cell and HetNet deployments (pico-, femto-cell, relay nodes)
- flexible base station and user configurations and drop models
- different transmitter and receiver chains incl. MIMO, ZF, MMSE
- channel modeling with slow/fast fading, pathloss, full user mobility
- intra- and intercell interference modeling for OFDMA, SC-FDMA and WCDMA
- 2D and 3D antenna pattern and multi-antenna beam forming
- Extensive metrics and KPIs: capacity, throughput, spectral efficiency, user QoS etc

Research on advanced algorithms include, but are not limited to:

- advanced features as link adaptation, HARQ, power control, measurements
- scheduling and resource allocation algorithms considering channel and buffer status, QoS etc.
- inter-cell interference coordination, avoidance and cancellation
- Single user-, multi-user MIMO with open and closed loop feedback
- Cooperative multi-point transmission and reception
- functions for self-organising and self-optimizing networks (e.g. load balancing, mobility optimization, tilt optimisation, range extension, power saving etc.)

#### Link Level



#### System Level



#### Protocol Level

