LTE-A HetNets using Carrier Aggregation

Eiko Seidel, Chief Technical Officer
NoMoR Research GmbH, Munich, Germany
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Summary

LTE-Advanced standardisation in Release 10 was completed in early 2011 and commercial network deployments using first Release 10 features are likely to be announced later this year. One of the most attractive features of LTE-A is Carrier Aggregation, where a user equipment (UE) might be scheduled across multiple carriers. Besides this, Heterogeneous Networks (HetNet) using small cells gained a lot of interest recently due to their potential to increase network capacity. This white paper provides some insight into how LTE-A HetNets with or without a centralized architecture might be deployed today and in the future, in particular in combination with Carrier Aggregation.

Introduction Heterogeneous Networks

Small cells are seen as the second phase in LTE/LTE-A network deployments once macro cell coverage is provided. Initially such small cells will improve the available capacity in high load cells locally or at hotspots, or will be used for coverage extension in certain scenarios. The simplest deployment will be to use a dedicated carrier for the small cell layer. This will avoid interfering with the existing macro-cell network and avoids tight coordination or synchronisation.

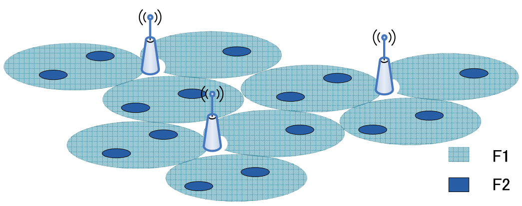

Figure 1: LTE-A HetNet using a Dedicated Carrier

On the other hand there are some drawbacks, since multiple frequency bands are required, which might not be used most efficiently. Moreover, mobility between the frequencies will require time and terminal power consuming inter-frequency handover.

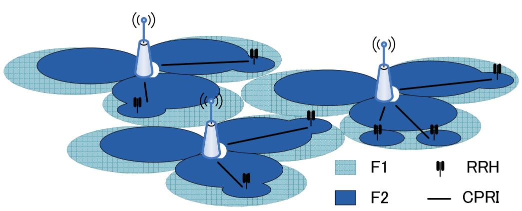

Figure 2: LTE-A HetNet using Co-Channel Deployment

If macro and small cell layer would use the same spectrum (Figure 2**Fehler! Verweisquelle konnte nicht gefunden werden.**), higher spectral efficiency would be possible. Nevertheless it will be very challenging to limit inter-cell interference and to provide mobility between the cells using the same frequency.

Tight interworking between the macro and the small cell layer will become essential. In practice this might only work with centralized processing. Such architecture will make use of Remote Radio Heads (RRH) that are connected via a Common Public Radio Interface (CPRI). Recently NTT DoCoMo announced the development of next generation base stations utilizing an advanced Centralized Radio Access Network architecture [2].

HetNets using Carrier Aggregation

Once such a centralized architecture, using multiple bands, is available, it will be natural to extend the base stations to use Carrier Aggregation of LTE-A Release 10. In CA multiple up- or down-link LTE carriers in contiguous or non-contiguous frequency bands can be bundled (Figure 3).

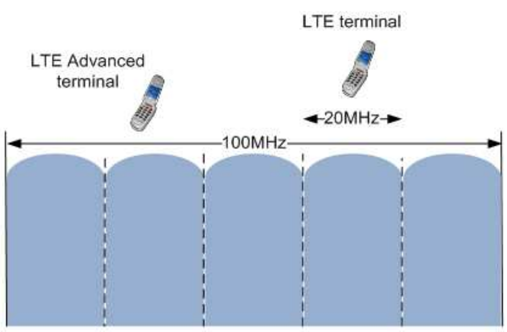

Figure 3: Carrier Aggregation

In a previous 3GPP newsletter [1] we introduced the general technology of Carrier Aggregation. Usually small cell base stations are designed as low cost base stations and the number of supported bands might be limited by this complexity constraint. Initially CA will only be used to aggregate carriers of the same site, but a centralized architecture also allows multi-site Carrier Aggregation (CA). LTE-A Release 11 introduced the support of multi-site CA by supporting multiple uplink Timing Advance enhanced uplink power control for Heterogeneous Networks (HetNet) (Figure 4). In this case the macro base station with full coverage could serve as Primary Cell (PCell) providing system information, RRC control signalling and bandwidth limited data transmission, while the small base station would serve local high data rate requirements. This CA technique will also be beneficial when macro- and pico-cells are using dedicated carriers. Fast selection of small cells would be beneficial even for moving users as long as the proximity of the user within the small cell coverage can be detected.

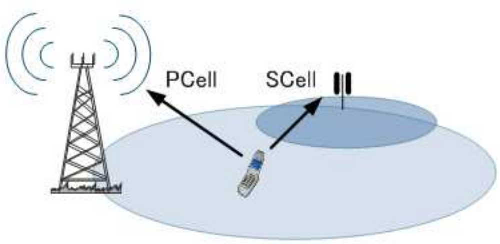

Figure 4: LTE-A HetNet Multi-site Carrier Aggregation

Nevertheless there are also drawbacks of this functionality. First of all tight coordination is assumed between macro/pico layers, requiring a centralized architecture. Furthermore Carrier Aggregation capable terminals supporting Multiple Timing Advance are required. This will basically require two transmitters in the terminal which is a big step in implementation complexity. At least initially, terminals having such functionality will be in a minority. Later on, it might go hand in hand with the introduction of uplink LTE-A spatial multiplexing.

An alternative deployment, not necessarily based on a centralized architecture, will be described in the following. Macro cell and the pico cells might operate with own control signalling on both frequency layers. Such deployment will require advanced interference management. Since Rel. 8 Inter-cell Interference Coordination (ICIC) is limited to the PDSCH data region, new solutions are required to protect the control channels e.g. Physical Downlink Control Channel – PDCCH.

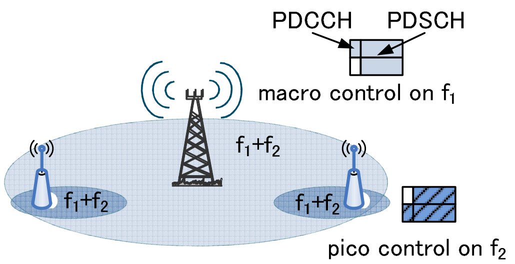

Figure 5: LTE-A HetNet using CA in a Co-channel Deployment Scenario

Macro and pico cell will allocate different frequency layers for their respective Primary Cell and Secondary Cells (SCell). The SCells might not transmit any data or may transmit data with lower power to avoid interfering with the PCell of the other layer (Figure 6).

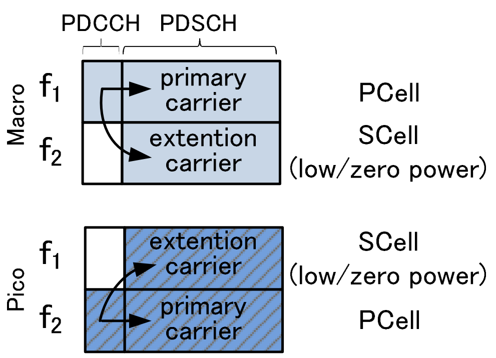

Figure 6: LTE-A HetNet using CA with Cross Carrier Scheduling for PDCCH Protection

Depending on the implementation of the Radio Resource Management and scheduling algorithm, UEs close to the base station can be scheduled with low power SCell allocations, while cell edge users are allocated using the PCell, less affected by interference. Power variations of the SCell to a single UE can only be semi-static, since the power difference to the reference symbols needs to be known by the UE (signalled on slow basis by RRC in LTE) for amplitude modulation.

For full protection of the control region, PDCCH Cross Carrier Scheduling from the Pcell can be used. If the Scell's PDCCH is not used at all, interference on the PCell's PDCCH is minimized. Spectrum efficiency can be increased, because all frequencies are available at macro and pico cell.

Such Frequency Domain Interference Coordination has some benefits compared to a Time Domain Interference Coordination in a co-channel deployment using Almost Blank Subframes (Rel. 11 Enhanced Inter-cell Interference Coordination - eICIC) [7]. Although at least a certain penetration of Carrier Aggregation capable UEs is required, Rel. 8/9 legacy terminals are always supported on the PCell without performance degradation. On the other side, in a HetNet using eICIC with large cell range expansion offsets, Rel. 8/9 UEs might experience performance degradation since ABS subframes are not supported. Alternatively the cell individual offset could also consider the differences in UE capabilities. Overall the level of complexity for network integration, to support user mobility, the signalling and measurement overhead is likely to be higher in a co-channel deployment using eICIC. Therefore the natural HetNet choice at least for operators having fragmented spectrum and planning to introduce Carrier Aggregation is the Frequency Domain Multiplexing as shown in Figure 5.

One issue of this approach is that eventually the macro cell might run out of PDCCH resources due to its use of cross carrier scheduling. PCell and SCell resource allocations have to be signalled separately, potentially doubling the load on the downlink control channel. On top of this, additional PDCCH capacity could be required to support future Multi-User MIMO, where resources are allocated to multiple UEs in the spatial domain. This problem has already been identified in 3GPP standardisation. Release 11 introduces a new downlink control channel concept called Enhanced Physical Downlink Control Channel (ePDCCH).

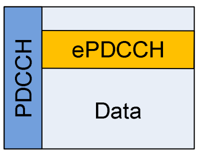

Figure 7: Enhanced Physical Downlink Control Channel

The ePDCCH as shown in Figure 7 is a new downlink control channel reusing Physical Resource Blocks formerly used for PDSCH transmission. This concept provides various benefits.

Besides the general increase of control channel flexibility, ePDCCH also nicely supports the HetNet scenario as described before. As shown in Figure 8, the ePDCCH could provide downlink control signalling resources within each SCell without the use of cross carrier scheduling and without interfering with the PDCCH of the other layer's PCell.

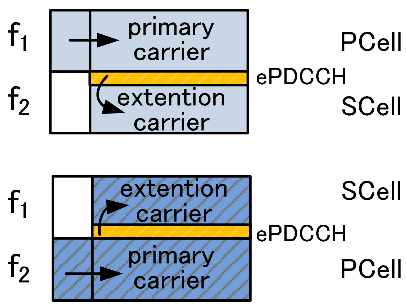

Figure 8: LTE-A HetNet using CA and an Enhanced PDCCH Control Channel

The reliability of the ePDCCH could be increased in case frequency domain interference coordination is applied between sites. In that case SCell's ePDCCH resource blocks are not scheduled in the other layer's PCell. Figure 9 illustrates this principle that can be applied in case ePDCCH performance is interference limited.

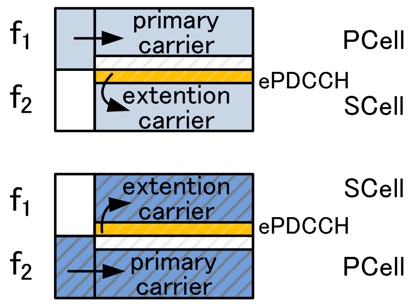

Figure 9: LTE-A HetNet using CA and ePDCCH with Interference Coordination

This would once again require interactions between macro and pico cells or at least required the configuration of scheduler restrictions via Operations And Maintenance (OAM). The ePDCCH is not the focus of this white paper, but other benefits shall be mentioned here. They include the use of dedicated pilot symbols that would allow user specific beam forming and improved link adaptation. ePDCCH can also co-exist with legacy terminals that will be scheduled in other resource blocks.

Future HetNets using Carrier Aggregation

3GPP RAN currently studies dense small cell deployment using non ideal backhaul that does not rely on a centralized architecture [4]. This will naturally reduce the applicability of multi-site Carrier Aggregation as well as Coordinated Multi-point Transmission (CoMP) which rely on an ideal (very large bandwidth, very low latency) backhaul of a centralized architecture. Still, a separation of the control plane could be provided by terminating the

RRC layer 3 signalling in a central node [5]. This would improve the mobility robustness of such HetNets and would thus also improve the offloading capabilities. User plane latency and backhaul requirements could be reduced by local user plane breakout directly at the small cells in case this is actually supported by the respective backhaul technology.

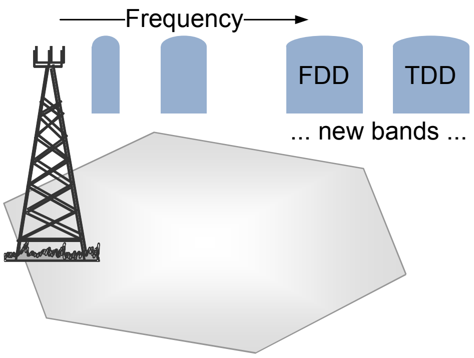

Figure 10: Increase of Available Bands and Band Combinations for Carrier Aggregation

Today's baseline implementation of Carrier Aggregation is limited two downlink carriers and a single uplink carrier. The number of supported bands and available band combinations on the market will grow over time. Future small cells might support new frequency bands for instance for carrier frequencies of 3.5 or 5 GHz, where more spectrum might become available in the future. Over the years to come we might eventually see an aggregation of up to 5 carriers fulfilling the 4G requirements promised a long time ago.

The joint aggregation of FDD and TDD spectrum could become a key element for such an evolution. It is proposed by key companies and is currently under discussion in 3GPP RAN [8]. Already in Rel.11 the option to aggregate two TDD carriers with different uplink / downlink subframe configuration was introduced. In such a TDD configuration the UE is required to transmit and receive in parallel in some subframes, highlighted red in Figure 11. As consequence such a system becomes very similar to an FDD system, causing the differences between these two duplexing schemes to vanish in the long term.

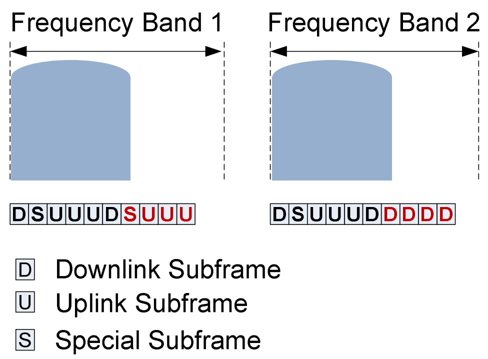

Figure 11: TDD Carrier Aggregation with Different Subframe Configuration

The combination of FDD and TDD spectrum will become more and more attractive to operators. The capability of TDD to adjust the uplink / downlink subframe ratio to the actual traffic needs is another benefit that can be exploited.

For HetNets using TDD, the small cells might be deployed in clusters. Such clusters might be isolated from each other, allowing to adjust the uplink / downlinking frame structure dynamically depending on the local traffic needs. Such scheme is sometimes referred to as "dynamic TDD".

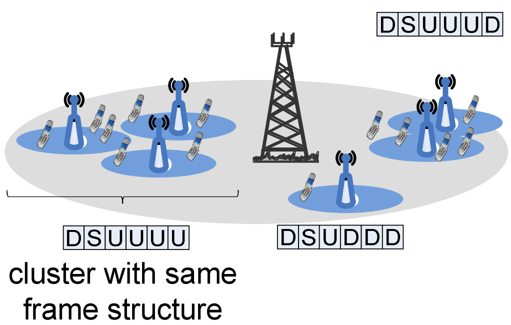

Figure 12: HetNets using Dynamic TDD

Depending on the deployment scenario and market requirements there will be room for radio access networks with and without centralized processing. The preferred backhaul solution will be an important factor for the architecture of choice as well. As shown in Figure 13 small cell solutions with different architectures and backhaul solutions might even co-exist in the same geographical area. Small cell layers might be added based on traffic needs. Major train stations are well-known examples where small cell deployments are essential to serve the traffic needs.

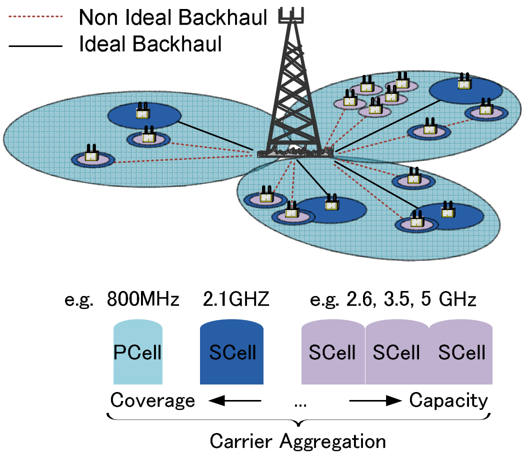

Figure 13: Future HetNets using Carrier Aggregation with ideal and non-ideal backhaul

The support of new high frequency bands will be limited to new terminals and therefore such carrier will inherently be non-backwards compatible. Thus, already today, major modifications of the LTE/LTE-A design are being discussed as part of a Work Item called New Carrier Type and the Small Cell Study Item. The New Carrier Type work item aims at an ultra-lean carrier with no system information and a minimum use of Common Reference Symbols. Such symbols became partly redundant in LTE-A. Coherent demodulation in LTE-A will be based on dedicated demodulation reference symbols (DM-RS) and link adaptation is based on Channel State Information Reference Symbols (CSI-RS). In the small cell work item, on the other side, techniques to increase spectral efficiency for small cells are studied e.g. use of 256 QAM modulation. Also procedures to enhance small cell operation are considered, amongst others small cell discovery procedures, enhanced inter-frequency measurements or interference coordination. In RAN2 even a modification of the architecture for future HetNets is currently studied considering the expected gain versus the additional complexity introduced in the system.

References

[1] NOMOR 3GPP Newsletter, "LTE-A Carrier Aggregation Enhancements", Eiko Seidel, August 2012

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[3] 3GPP TR 36.819, "Coordinated multi-point operation for LTE physical layer aspects", Release 11

[4] 3GPP RP-122005, "Study Item: Small Cells Physical Layer issues"

[5] 3GPP R2-130416, "Small cell challenges and benefits of dual connectivity", Ericsson

[6] S.Parkvall, E.Dahlman et.al. "The Soft-Cell Approach: Heterogeneous Network Deployments in LTE"

[7] NOMOR 3GPP Newsletter, "Inter-Cell Interference Coordination for LTE-A", Volker Pauli, Eiko Seidel, September 2011

[8] 3GPP RP-130391, TSG RAN Meeting #59, LTE Carrier Aggregation between TDD and FDD, TeliaSonera, Orange, Telefonica, Deutsche Telekom, Vienna, Austria, 26 February - 1 March, 2013

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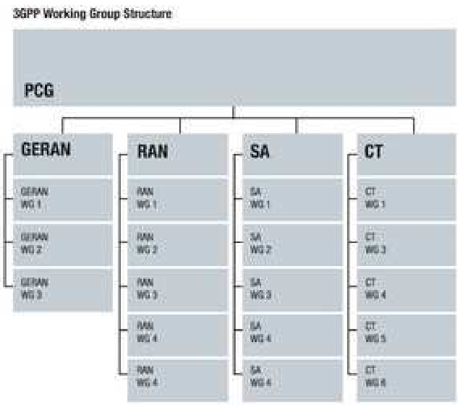

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