Opportunistic CoMP for 5G massive MIMO Multilayer Networks

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Abstract— **In the FP7 project METIS we investigate suitable combinations of massive MIMO, joint transmission coordinated multipoint and small cells for future 5G systems. Challenging is a tight integration over small and macro layers. Straight forward is to ensure orthogonality between small and macro cell layers by allocation to different RF frequency bands like e.g. 2.6 and 3.5GHz respectively. Here within the macro layer frequency band an opportunistic tight cooperation between macro and small cell radio stations is being proposed. This requires dual band small cell radio stations operating in a traditional local area frequency band like 3.5GHz for data off loading and simultaneously - and on a need basis - at e.g. 2.6GHz as performance booster for macro UEs. First high level evaluations indicate significant spectral efficiency, capacity and coverage gains for macro cell users benefiting from higher Rx power and rank enhancement.**

***Index terms*—cooperation, massive MIMO, channel estimation, JP CoMP**

I. INTRODUCTION

Massive MIMO, small cells (SC) as well as more spectrum are probably the currently most promising technical means to boost capacity and coverage for future 5G systems. From other projects like ARTIST4G [1] it is known that macro cellular networks with inter site distances of 500m and less as well as ultra dense networks (UDN) - as defined in the FP7 project METIS [3] - suffer from strong inter cell interference (IF). Tight inter cell cooperation - and especially joint transmission coordinated multipoint (JT CoMP) - is added to overcome or even to exploit this interference.

Joint transmission has been investigated by us for homogenous networks in the EU FP7 project Artist4G leading to the so called interference mitigation framework IMF-A [1], [2]. IMF-A relies on enlarged cooperation areas formed over e.g. three sites or nine macro cells to achieve a high percentage of user centric served CoMP UEs. Interference floor shaping with the so called 'tortoise' concept defines a suitable per cell tilt adaptation and has the big advantage to decouple adjacent cooperation areas. This allows a high level optimization of the multi-layer network confined to a single cooperation area.

Tight JT CoMP cooperation over macro plus small cell layers - in 3GPP termed heterogeneous networks (HetNet) - poses new challenges due to the potentially high number of often uncoordinated placed small cells, different and potentially limited backhaul connections, different radio conditions for macro and small cell layer, etc. Macro cells are typically placed at large heights of 20 to 50m with Tx-powers of e.g. 49dBm for a 20MHz bandwidth and provide therefore large coverage. Small cells like pico stations are often located below rooftop with a significant lower Tx-power of only 23 to 30dBm so that - despite the shorter distance SC-UE between SC and user equipment (UE) - often the macro station is received with higher power than the SC.

Due to the potentially high number of SCs forming an UDN the complexity for tight cooperation might increase significantly. For example in [5] estimates of backhaul traffic resulted in extremely high fiber backhaul rates of several 10^{th} to 100^{th} of Gbit/s in a similar setup. In addition one has to consider the complexity for matrix inversions typically required for JT CoMP precoding or the effort for multi cell scheduling.

The most simple and robust HetNet solution is to allocate the macro and the SC layer to different RF carrier frequency bands (non co-channel) like 2.6 GHz for the macro and 3.5GHz for SCs.

Contrary for Co-channel deployments in 3GPP inter cell interference coordination techniques in time or frequency like ICIC, enhanced ICIC (eICIC) or further enhanced ICIC (feICIC) have been introduced allowing a fine granular coordination between macro and small cell layer and depending on load conditions [4]. Coordination means that either the macro- or small cell layer is switched off in time or frequency whenever it disturbs the other layer. In case of feICIC enhanced node Bs (eNB) are not switched off completely to ensure backward compatibility, which led to the concept of almost blank subframes (ABS) [6], i.e. subframes transmitting only common reference signals.

Is there any reason to go beyond these well proven and powerful coordination schemes, leading to the above described challenges and complications of the overall system setup? This would make sense only in case being rewarded by accordingly higher performance, especially for the precious macro layer at RF frequencies below few GHz. These lower frequency bands are very valuable for mobile network operators (MNO) due to their very good coverage and the scarcity of bandwidth compared e.g. to the mmWave bands. Furthermore the according macro sites are a precious asset for MNO as they are easily available and are typically placed at large height on top of large buildings. Contrary uncoordinated placed SCs with potentially low distance to persons face regulatory Tx-power limits of typically less than 30dBm to avoid health risks and require a new site aquisition.

From [1] two main issues could be identified upper bounding JT CoMP gains for a typical homogeneous macro cellular 4x2 MIMO 3GPP case 2 scenario. Firstly a high percentage of indoor UEs are noise instead of interference limited due to the high outdoor-to-indoor penetration loss of 20dB or more. The second issue is a limited rank of the overall channel matrix forming the cooperation areas, which is due to the relatively broad beams of four element $\lambda/2$ spaced antenna configurations often used in macro cells. As a result the pathloss and small scale fading is often highly correlated and in Artist4G the mean number of simultaneously servable UEs was limited to about 2.5 to 2.8 users per cell.

Both issues – noise and rank limitation – should benefit from small cells as well as from massive MIMO. Massive MIMO - as introduced e.g. in [7] - allows forming very narrow beams with according beamforming gains and inter beam de-correlation (= higher rank of channel matrix). Small cells may increase the SNR due to the typical low SC-UE distance with according low pathloss. In addition they might provide rank enhancement of the overall channel matrix – generated by macro and small cells - due to their distributed allocation within the cell area so that the channel correlations will be small. Accordingly first evaluations indicate significant performance gains for common JT CoMP precoding over macro plus small cell layer, but at the cost of high complexity.

To cope with the complexity dual band SC radio stations are being proposed, where conventional data offloading is done by SCs on a high RF carrier (e.g. 3.5GHz), while a selected subset of SCs support the macro layer in the e.g. 1.8, 2.1 or 2.6GHz RF band. The SCs are activating their macro layer in an opportunistic way, i.e. only if generating relevant performance gains in the macro layer.

First performance assessment of massive MIMO and interlayer cooperation will be provided in chapter II. Chapter III provides first results for opportunistic cooperation with reduced complexity, while chapter IV concludes the paper.

II. PERFORMANCE EVALUATION FOR FULL COMP

Channel Model

In the FP7 project METIS several partners work on massive MIMO, CoMP as well as small cells. For better comparability several partners agreed on some basic simulation assumptions and usage of the QUADRIGA [6] channel model as being provided by the Heinrich Hertz Institute in Berlin (HHI). QUADRIGA is an extension of the well known spatial channel model extended (SCMe) as being used in 3GPP for long time. Some of the agreed parameters and e.g. the pathloss calculation - close to 3GPP case 1 - can be found in Table **1** and details for the Quadriga channel model under [7].

General Simulation Scenario

The according multi layer simulation scenario is illustrated in Figure IV-1. 70 small cells are dropped randomly into a classical homogeneous set of 57 macro cells. The dropping area is restricted to the red central part forming one single enlarged cooperation area of three/nine macro sites/cells. To this central cooperation area interference floor shaping ('tortoise concept') is being applied, a technique to decouple adjacent cooperation areas by strong/low tilting values for outbound/inbound beams [8]. As a result for a rough first order assessment one can ignore the inter CA interference, i.e. it is sufficient to evaluate one single cooperation area. That way only nine instead of 57 cells have to be taken into account saving significant system level simulation time.

CoMP Simulation Scenario

Figure IV-2 sketches some other specific details of the overall multi-layer system setup for the here proposed OP CoMP concept. The cooperation areas consist of nine cells from three sites. The 70 small cells mentioned above are dropped randomly into the cooperation area. 16 - or alternatively 32 -

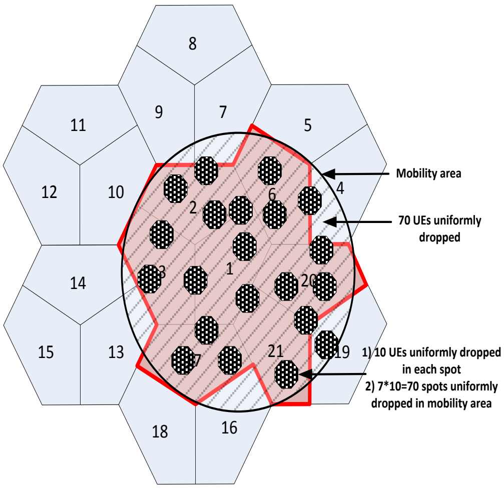

Figure IV-1: simulation scenario with randomly dropped small cells and UEs into central area of cooperation area

Parameter	Value
ISD	500 m
Minimum distance:	
macro BS-2-small cell	75 m
macro BS-2-UE	35 m
small cell-2-small cell	40 m
small cell-2-UE	10 m
Channel model	QUADRIGA
Number of taps	20
Center frequency f_c	2.6 GHz
Simulation type	Monte-Carlo
Number of samples per $\lambda/2$	4
Observed time	100 ms
Drops	300
Correlation macro-macro	0.5
Correlation macro-small cell	0
Correlation small-small cell	0
Macro BS sectors	57
Small cells per sector	10
Users per sector	average of 110

Table 1: agreed parameters for METIS massive MIMO and small cell system level simulations

standard 16-element Kathrein antennas form a linear uniform array (ULA) per each macro cell. The resulting macro cellular massive MIMO antenna arrays consist therefore of 16x16 (32x16) equal to overall 256 (512) antenna elements. The ULA transmits eight fixed narrow beams with equally spaced main lobe steering angles within each 120 degree sector. Note adaptive vertical beam steering is not included so far to keep complexity under control. The well known GoB concept has been chosen to generate fixed and predictable interference conditions avoiding the famous 'flashlight' effect. Furthermore in the context of massive MIMO it significantly reduces the number of antenna ports (AP) compared to the number of antenna elements. This is important for frequency division duplex systems (FDD), where orthogonal channel state information reference signals (CSI-RS) will be needed for channel estimation. Similarly it will limit the according CSI reporting overhead.

For a first assessment all macro and all 70 outdoor small cells forming the cooperation area are connected to a central unit (CU) over an ideal backhaul with zero latency and infinite. It is expected that 70 to 80% of UEs will be indoor users in the future. Here we assume even 100% indoor users as a worst case upper bound indicated in the figure by the local area scenarios. Indoor is here defined in a very simplistic way, just as an extra damping of 20dB for all channel components.

Channel state information (CSI) knowledge is being assumed to be available for all small as well as macro cells. Furthermore the CSI is assumed to be ideal allowing a perfect cooperation area wide zero forcing precoder at the central unit. Evaluations in [4] indicate that advanced channel prediction techniques might be able to get more or less close to 'ideal CSI' precoding performance also for real world realizations.

The small cells comprise three 120° sectors with two antennas per sector. Using sectorization for small cells adds some HW complexity, but allows controlling small cell interference effectively.

The resulting full channel matrix $\mathbf{H}_{\text{full}} \in \mathbb{C}^{90 \times 492}$ for an enlarged cooperation area consisting of 3 sites comprises the *8 virtual beams per cell x 9 cells + 70 small cells x 6 virtual beams* = 72+420=492 channel components per each of the 90UEs and is therefore very large.

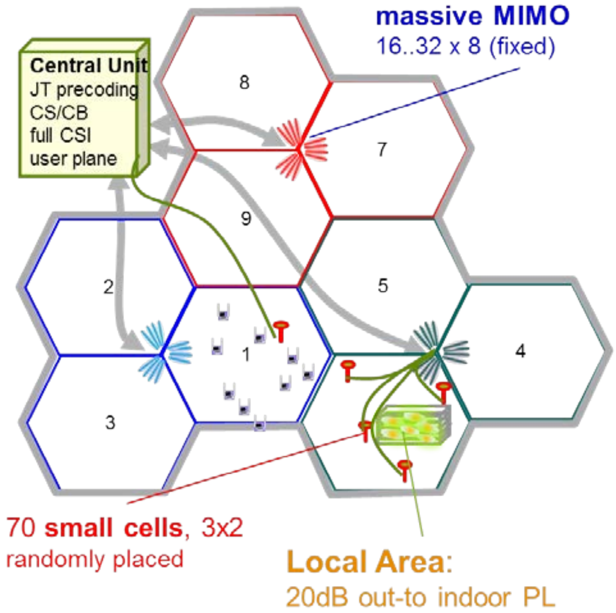

Figure IV-2: Typical multi layer and potentially multi RAT scenario for single enlarged cooperation area

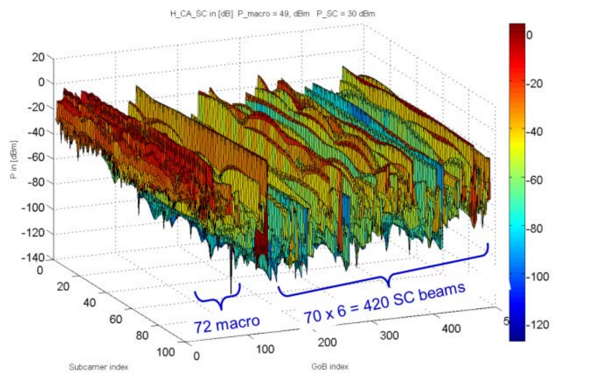

Figure IV-3: Typical Rx power over PRB index (y-axis) for multi layer channel matrix $\mathbf{H}_{\text{full}}$ with x-axis as beam index of 72 macro and 420 small cell beams.

Fortunately many of the channel components have very low Rx power as indicated by Figure IV-3, which shows $\mathbf{H}_{\text{full}}$ for one of the UEs with the first 72 beam indices for the macro and the further indices for the 420 small cells. By limiting to the relevant channel components being within a pre-defined power window of e.g. 20 dB the overall system complexity can be reduced already a lot.

It can be observed that typically the macro beams are much more frequency selective than the SC channel components. This is due to more reflections from more far off objects, while the SC-

UE links are often line of sight (LOS) or obstructed LOS (O-LOS) with according more flat channel transfer functions.

There are only few strong macro beams, which can be explained by the ‘massive MIMO’ beamforming gains focusing Tx energy to certain sub areas of the cooperation area. Ideally and asymptotically there would be even only one strong beam, but in reality NLOS links suffer from reflections and diffraction so that UEs receive typically a small set of beams.

The relative low number of relevant small cell beams can be explained by i) the strong shadowing for below rooftop placement and ii) the sectorization per SC (see above), allowing to control inter cell interference to some extent.

Massive MIMO beamforming gains

In Figure **4** signal to noise ratios have been simulated for all UEs of the macro layer either i) from a single eNB Tx antenna element to a single UE antenna or ii) including the massive MIMO beamforming gain of the GoB concept at each macro eNB, either for the 16- or 32-element ULA.

Furthermore two different titling angles of 7° and 12° have been used. It can be concluded that in this case for this cell geometry with an ISD of 500m the 12° tilt is slightly superior to 7° tilt. The SNR gain due to the massive MIMO beamforming (BF) is about 10dB. This BF gain seems to be quite similar for 16 and 32 antenna elements, indicating that we cannot assume asymptotic beamforming gains in real world scenarios. The likely reason is the well-known relatively large angle of departure (AoD) spread for macro eNBs.

Small Cell power boosting

Figure **5** enlightens another interesting aspect, which is quite related to cell range extension (CRE) applied e.g. to feICIC or relaying networks.

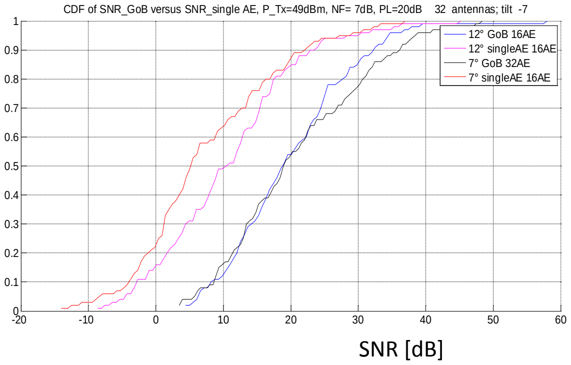

Figure 4: CDF of SNR for 90 UEs of single cooperation area for 16/32 macro antennas with 7 and 12° tilt.

Cell range extension means that UEs are handovered to small cells even so the macro eNB is still received with relatively higher power (‘early’ handover to small cell or ‘late’ handover from SC to macro cell). That way the number of UEs attached to small cells can be significantly increased ensuring a high data offloading from macro to small cells. The macro cells will be s

witched off – or in case of feICIC will transmit almost blank subframes – for subframes where small cells are active so that despite the ‘early’ or ‘late’ handover UEs experience no detrimental macro cell interference.

Figure 5 provides a histogram of the beam IDs of the strongest serving cells for all 90 UEs in a typical cooperation area as described above. In the left figure only a relatively small part of UEs is being served by small cells, while most UEs try to connect to the macro cells, which will be accordingly overloaded (multiple UEs connecting to same macro beam). The reason is the much higher eNB Tx power of 49 dBm compared to 30 dBm for SC radio stations together with the high above rooftop location of eNBs. For feICIC range extension a several dB earlier handover from macro to SCs forces UEs to be served by small cells (see above). For JT CoMP - where the macro station should never be switched off - the according here proposed alternative is to boost the Tx power of the small cells. Assuming here a very large boost factor of 10 (equal to 20dB) one can achieve a much more

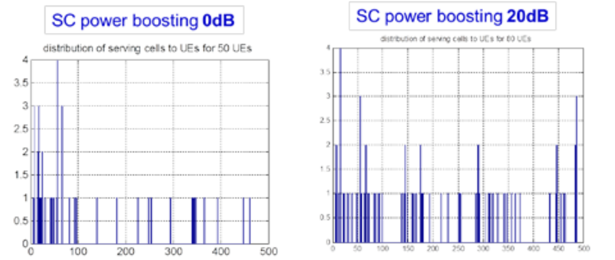

Figure 5: Serving cell indices for SC power boosting of 0dB (left) and 20 dB (right). Indices 1 to 72 are for macro and 73 to 492 for SC beams.

even allocation of serving cells to the macro and small cell layer.

At a first glance a maximum Tx-power of 30dBm and a boost factor of 20dB seems to be contradicting with respect to a regulatory Tx power limit of 30dBm, but as solution one might transmit only on an accordingly smaller part of the spectrum or only in parts of the time slots.

III. OPPORTUNISTIC COMP WITH REDUCED COMPLEXITY

In the following the performance of the above described scheme will be compared for a massive MIMO only system consisting of 72 beams per cooperation area (meaning that all small cells are being switched off), a full inter layer system including – beside the nine macro cells – all 70 SCs with six beams each and finally a system with some first reduction of complexity by activating opportunistically only parts of the small cells and only parts of the SC beams. The last scheme is termed here as OP CoMP as it opportunistically makes use of small cell beams.

As main KPI for comparison we use the so called power normalization loss (PNL), where the PNL is the sum power of all precoding weights for a zero forcing precoder relatively to the available power of all the active cells. The target is to achieve a PNL close to zero or even below zero dB as otherwise one has to reduce the Tx-power for certain UEs, leading to accordingly lower SINR for those UEs.

Figure **6** depicts the PNL over all 100 physical resource blocks (PRB) for an overall bandwidth of 18 MHz for the different schemes mentioned above. Worst is the PNL with about 6dB for the macro only plus massive MIMO case. Here it is assumed that there are 90 active simultaneously scheduled UEs, which means that with 72 beams the system is already overloaded with according further performance limits. For the blue dotted curve - which is the combination of macro plus 72 SCs - the PNL is in the order of 2 dB. Applying a boosting factor of 10 equal to 20dB to all SC channel components the PNL can be pushed below zero dB. Together with a per PRB automatic gain control this could be reduced even further to less than -4 to -6dB.

Finally the black curve is for the OP COMP scheme were only SC beams with an Rx power >-25dB below the strongest SC beam are activated and SC beams with an Rx power below 6dB are boosted by 20dB. In this special case 45 out of the 70 SCs and 89 out of 420 beams will be activated, i.e. 64% of the SCs and 21% of all beams. With this first simplification the achievable PNL is in the range of zero to 2dB.

More detailed simulation of the achievable data rate per UE indicate that spectral efficiencies of about 48bit/s/Hz/macro cell seems to be feasible, which would be in the order of an factor of 8 compared to LTE Release 10.

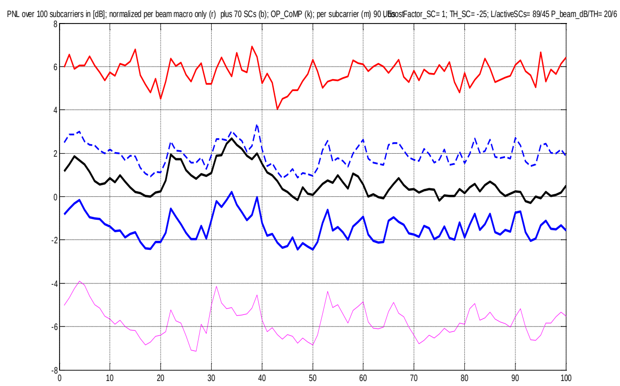

Figure 6: Power normalization loss (PNL) for macro only (red), macro + SCs (blue dotted), plus 20dB power boosting (blue), plus per PRB normalization (magenta) and for OP CoMP (black).

IV. CONCLUSIONS

A novel concept of opportunistic cooperation (OP CoMP) between macro and small cell layer - including massive MIMO at macro eNBs - has been proposed. With power boosting and activating of only 20% of all possible SC beams the concept promises a potential factor of eight higher spectral efficiency compared to LTE Rel10 with hopefully affordable complexity. Many more detailed evaluations will be required for further optimizations, but also for further verification of the promised benefits.

Note, the described framework combines many lessons learned of our previous work in Artist4G and latest METIS results. Therefore not all aspects could be covered in full detail in this paper, but more can be found in the given references.

Acknowledgment

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