Flexible 5G below 6GHz mobile broadband radio air interface

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***Abstract*—In November 2015 the latest world radio conference took place and as a result the below 6 GHz RF bands have become more important for 5G in the foreseeable future. In the 5GPPP project Fantastic5G options for higher spectral efficiency based on massive MIMO, joint transmission cooperative multi point and interference mitigation are being investigated. Most of these concepts have been already developed in previous projects like Artist4G or METIS, but now it is important to integrate these into a flexible framework supporting a rudimentary phase I as well as a future proof phase II system. Interference mitigation might become the main differentiator to LTE and the inevitable enablers will be shortly highlighted. According to current results the novel 5G system has the potential to increase spectral efficiency by roughly a factor of ten compared to a 4x2 LTE system, thereby significantly outperforming also latest LTE results for full dimension MIMO.**

Keywords—5G, massive MIMO, CoMP, flexible framework

I. Introduction

According to the last World Radiocommunication Conference 2015 (WRC-15) in November 2015 [1] all newly allocated radio frequency (RF) bands will be below 6GHz, while for the cm- as well as mmWave bands so far no frequencies have been agreed on. For the upcoming WRC19 it has been agreed to study/consider bands from 24 GHz to 86 GHz. This means for the time being the below 6GHz frequency range has to support the expected 5G traffic grow for time- as well as frequency division duplex (TDD / FDD) systems due to the mix of paired and unpaired bands.

The 5GPPP project Fantastic5G has defined the five core services *mobile broadband* (MBB), *massive machine communication* (MMC), *mission critical communication* (MCC), *broadcast/multicast services* (BMS) and *vehicle-to-vehicle or to-infrastructure* (V2X) [2]. Similar requirements can be found in [3][4].

For MBB the primary key performance indicators (KPIs) are data throughput per area, latency, coverage and mobility. The KPI 'data throughput per area' seems to be the most challenging given the expected trends for a future 5G system of 1000x higher data volumes and 10-100 times higher end user data rates for downlink transmission (see e.g. [3][4]).

As LTE is the result of a long lasting evolution and optimization process and typically integrates upcoming new trends - like for example full dimension MIMO – there is often the question '*how might a new 5G radio system excel LTE evolution, especially in the light of the limits given by physics?*.

According to current understanding it seems that the main differentiator for a new 5G system might be a significantly more powerful interference mitigation framework compared to what is considered in LTE and as for example explained in [6] or [7]. This framework combines a number of techniques like massive MIMO, interference floor shaping, small cells and its according enablers. Exactly these enablers - like a support of joint transmission CoMP from the scratch together with the required changes in the channel state information (CSI) feedback channel - might motivate to go for a new air interface. Eventually the combination of massive MIMO and interference mitigation might be rewarded by a factor of ten higher spectral efficieny compared to a 4x2 MIMO cellular network.

There are some other prerequisites for implementation of the interference mitigation framework like fast and high capacity interconnection between cooperating sites, a central unit with high processing power, high end user equipments (UEs) supporting most advanced interference rejection algorithms or feedback schemes. Generally these enablers will be available in various degrees and - more importantly - during the introduction phase of 5G probably only to a limited extent. Due to the need for a fast introduction of 5G 3GPP has already started to discuss a phased approach, withoud deciding on any details yet. Here we will assume two phases, with phase I providing a basic and phase II the full set of features. This requires a certain type of flexibility – beside adaptation to different use cases [5] –, which allows to adapt to available mobile network operator (MNO) assets like backbone infrastructure, macro and small cell sites, antenna configurations, UE capabilities serving the limited and advanced setups of phase I as well as of phase II.

Focus of the paper will be on a short recapitulation of the interference mitigation framework in combination with the grid of beam concept, the introduction of a flexible CSI feedback scheme based on reporting on

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relevant channel components and of relevant taps as well as currently considered concepts to get as close as possible to stellar phase II performance despite a limited set of phase I features.

II. FUTURE PROOF 5G RADIO SYSTEM

Before designing a flexible air interface it is important to have a certain understanding how the future radio system might potentially look alike. Therefore, first, let's have a look at the future proof 5G phase II concept. As nothing has been specified for such a futere 5G system yet, the below described concepts reflect our opinion.

For below 6GHz techniques like massive MIMO or network assisted interference cancelation (NAIC) have been already identified as main pillars for the evolution of LTE. One main target for a novel 5G air interface is to solve on top of it the challenging interference conditions in cellular radio networks from the scratch. In previous FP7 projects like Artist4G or METIS I a more fundamental interference mitigation framework has been derived, where joint transmission cooperative multipoint (JT CoMP) is one of its main features. Together with JT CoMP a set of supporting enablers has been developed, which finally might mark 5G as the first "*interference free*" or "*interference exploiting*" radio system.

In the following the performance of a single macro cell equipped with a massive MIMO array will be analyzed providing a first estimate of potential 5G performance under the assumption of perfect IF handling and ideal channel state information (CSI).

GRID OF BEAM CONCEPT – SINGLE CELL

Massive MIMO [8] in the sense of a high number of antenna elements placed at available macro sites is one of the core elements of a future 5G system. It provides either high beamforming gains with according high Rx-sided signal to noise ratios (SINRs) for few devices or high rank as pre-requisite for multi user (MU) MIMO over high number of devices.

Error! Reference source not found. illustrates the grid of beam (GoB) concept, which seems to be the most promising way of converting high dimensional physical antenna arrays into a limited set of orthogonal Tx-beams. For example an antenna array with 16 rows and 32 columns each with two polarizations equals 1024 antenna elements, which might be reduced to 32 beams, i.e. eight azimuth and two elevation beams per polarization. This GoB is generated from fixed wideband uniform beamforming vectors $\mathbf{v}$ of size $\mathbb{C}^{512x1}$ being combined into the GoB precoding matrix $\mathbf{V} = [\mathbf{v}_1 \ldots \mathbf{v}_{32}]$.

Assuming for 5G in the longer run UEs equipped with eight Rx antennas each UE sees the channel matrix $\mathbf{H}^{8x32}$, which would result for explicit feedback in the reporting of 256 channel components. To reduce that number we form 32 effective channel components including the UE beamformer $\mathbf{g}_k$ of size $\mathbb{C}^{8x1}$, which might be an interference rejection combining (IRC), NAICs or other beamformer [9].

A suitable rank adaptation allows for different modes like single- or multi-stream per UE. Note, here the numbers of eight UE antennas and 32 beams is just an example, which might be adapted depending on the scenario or other criteria.

Different to codebook based PMI feedback as known from LTE, here explicit feedback per effective channel component is being proposed. That way the eNB has full CSI knowledge, allowing the calculation of the optimum MU MIMO precoder matrix $\mathbf{W}$ of size $\mathbb{C}^{32xK}$, where K is the number of served UEs. The overall system can be described as $\mathbf{y} = \mathbf{G\,H\,V\,W\,x} + \mathbf{G\,n}$, with $\mathbf{G}$ as $\mathbb{C}^{Kx8}$ matrix of Rx filters, $\mathbf{x}$ being the $\mathbb{C}^{Kx1}$ vector of user data, $\mathbf{y}$ the $\mathbb{C}^{Kx1}$ vector of Rx-signals after spatial filtering and $\mathbf{n}$ being the circular symmetric complex Gaussian noise vector.

This setup has been evaluated for a single cell for the urban macro scenario with inter site distance[1] (ISD) of 500m and a RF frequency of 2.6 GHz, achieving average aggregated user throughputs of >50 bit/s/Hz for K=10 to 16 active full buffer users. This is about a factor of ten compared to the 3 bit/s/Hz of net througthput of a LTE 4x2 MIMO system [10].

Under the assumption of a perfect IF mitigation scheme - providing similar to single cell performance - 5G has the potential to provide outstanding spectral efficiency.

One should note these simulations are supported by latest real world massive MIMO or network MIMO demonstrators in different context, where similar performance could be achieved for single cell standalone systems [11].

The main next question is 'is it really possible to get close to a perfect inter cell interference mitigation'?

INTERFERENCE MITIGATION FRAMEWORK – CELLULAR NETWORK

In latest research starting from Artist4G, METIS and now Fantastic5G a very powerful IF mitigation framework could be derived [6][7]. Challenging for

[1] Note, the meaning of the ISD is here more related to the size of the cell as only one cell active

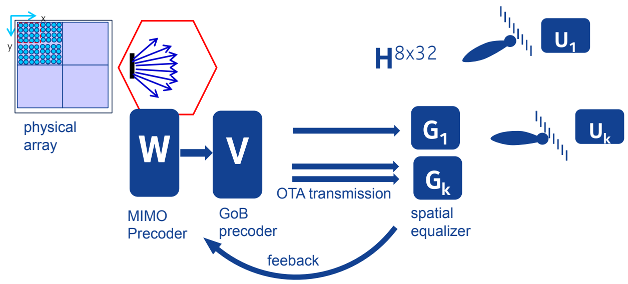

Figure 1: Basic GoB concept converting a high dimensional physical antenna array into a limited set of beams

such a framework are especially the high number of interfering channel components. For that reason there is no single means to overcome all these interferers, but instead one has to combine different schemes like IRC processing at UE side, massive MIMO to limit interference into other areas as far as possible, JT CoMP over enlarged cooperation areas like e.g. over 3 adjacent sites (= nine cells for three-sector sites) and even more advanced schemes like virtual beamforming or artificial mutual coupling [12].

While the last ideas are quite novel and need more evaluation, for example interference floor shaping based on the so called tortoise concept has been investigated in the meantime by different research groups [13]. It combines the so called cover shift concept – grouping JT CoMP users into the center of cooperation areas – with optimized tilt values for beams directing in- or outbound of a cooperation area. That way inter cooperation interference can be on average < -20dB, i.e., is for 64QAM close to an optimum interference free system. Figure 2 illustrates the benefit of interference floor shaping for the user geometry, which on average is being increased from <5dB to almost 20dB.

Note, this tortoise concept relies inherently on JT CoMP as the strong interference due to low antenna tilting for beams directing into the center of the cooperation areas has to be converted into useful signals.

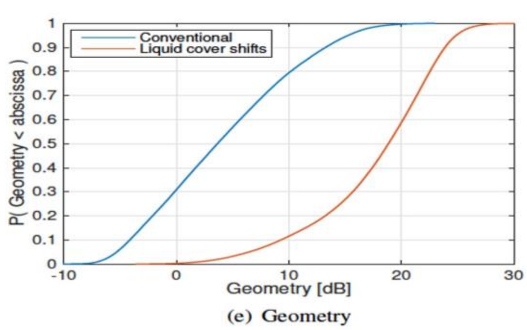

Figure 2: Geometry without (blue) and with interference floor shaping (red)

III. Main Enablers

So far we have seen that single cell performance using massive MIMO might provides a factor of ten higher performance over LTE 4x2 MIMO systems. Interference floor shaping can almost perfectly decouple inter cooperation area interference and JT CoMP finally exploits strong intra cooperation area interference.

As JT CoMP is well known to be sensitive to many impairments like CSI inaccuracies -, e.g., due to channel outdating -, frequency offsets between cooperating radio stations, capacity and latency for back- or front-hauling etc. 5G needs some basic enablers to make JT CoMP happen.

The trend to cloud based RANs based on fiber networks providing inter eNB connections with latencies in the millisecond (ms) range are already quite helpful. The cloud is for example the quite natural place for the central unit doing the common scheduling and precoding per cooperation area.

Another important enabler is reporting of accurate and explicit CSI per channel component in combination with channel prediction to allow for accurate MU MIMO precoding with minimum inter stream interference. See [14] to learn how channel prediction will help to support higher user mobility and the final conclusion in METIS that channel prediction is the main enabler for JT CoMP. This has implications to the standardization of the CSI feedback, which cannot longer rely on the codebook concept from LTE.

State of the art Wiener or Kalman filtering for CSI prediction is already quite useful, but more recent research promises much larger prediction horizons, more accurate predictions and ways to minimize the overhead for CSI reporting. There seems to be even a break point where explicit reporting of relevant channel components might provide higher performance with lower overhead compared to current LTE PMI feedback.

Note, for channel estimation the preferred concept are coded CSI reference signals [15], which combine accurate estimation of high number of channel components with low overhead for reference signals.

IV. Flexible Framework

Bridging phase I and II requires a flexible framework adapting to the different needs of the low and high end solutions.

Phase I has to be implementable quite soon with accordingly more limited capabilities like no inter site JT CoMP or lower number of antenna elements. In Fantstic5G research is about adequate replacements like more advanced UE receivers, more flexible and adaptive antenna tilting or even more advanced techniques like virtual beamforming with or without artificial mutual coupling. This will be investigated also with respect to the required inter site control channel signals. Phase II has to be future proof and a novel 5G system has to bridge both phases and should be flexible enough to support both phases with a few parameter adaptations and ideally without generating performance limitations for phase II or undue overhead for phase I.

REPORTING ON RELEVANT CHANNEL COMPONENTS AND TAPS

According to Section II0 the GoB concept relies on explicit reporting of CSI per channel component (CC). Per cell and UE this would be for the given example 32 CCs per cell, 96 CCs per site of three cells and 288 CCs per cooperation area consisting of three sites. For accurate reporting CSI feedback will be needed every 5 to 10 ms with accordingly exploding reporting overhead assuming moderate velocities of less than 30 km/h. One characteristic of the cellular radio channel is that most of the channel components will be received by UEs with very low power and there will be only a limited set of *relevant channel components* above a certain power threshold (TH) with respect to the strongest CC. With typical thresholds like TH=20 or 25 dB the number of relevant CCs will be in the range of ten to some tens of CCs. The CCs not being reported by the UEs will be set to zero at the eNB so that the overall channel matrix for calculation of the precoding matrix **W** will be sparse. The effect on the precoding performance has been evaluated for example in [16] and for the interference mitigation framework as described in Section II. It was found that for an average JT-CoMP precoding error due to unreported channel components of less than -20dB the reporting threshold should be set close to 25dB.

Massive MIMO, and even more important UE sided beamforming, do not only affect the number of relevant CCs, but also the number of multi path components (MPC) defining the frequency selectivity of the relevant CCs. By strong beamforming – for example relying on virtual beamforming [12] - the number of MPCs can be reduced significantly, which eventually affects the number of relevant taps of the channel impulse response (CIR) of the relevant CCs. Similar to [17][1] in Fantastic5G the reporting of relevant taps per relevant CCs has been identified as a very promising option, as it compresses the feedback per channel component to the relevant information really affecting the final precoding performance. An iterative approach for estimation of the relevant taps can be found in [18].

In addition this solution is very flexible. For example in phase I it allows to report the CIR for a single physical resource block (PRB) or small group of PRBs with accordingly a very low number of relevant taps or even only a single tap. In that case the reporting falls back more or less to that of LTE alike reporting per PRB or PRB group. At the other end it will allow in phase II accurate reporting of wideband radio CSI including channel prediction by reporting more relevant taps.

For illustration of the concept Figure 3 depicts the typical time domain channel impulse response (CIR) evolution over time for one single relevant channel component. It depicts the CIR(t,τ) at different discret time instances t_i and with τ as the delay of the multi path components (MPC). It is assumed that the UE estimates the CIR based on equidistant CSI RSs in the frequency domain channel transfer function (CTF) so that the CIR is known after an IFFT as well for equidistant discret τ values τ_j only. Generally each tap will be the superposition of a set of unobservable MPCs, resulting in a tap evolution over time with respect to its phase and amplitude. As already mentioned above, taps falling below a certain power threshold will be set to zero in the following and the remaining ones are called the relvant taps.

This is a first step of data compression by deleting irrelevance having only minimal effect on the eNB precoder performance. This close to the physical radio channel representation seems to be best suited to support flexible reporting modes. For example selecting a subband like one or multiple PRBs in the frequency domain CTF is essentially a rectangular filtering operation, simulatanouesly reducing the number of relvant taps of the CIR. Eventually the CIR might be reduced to a single tap corresponding to a single complex value per PRB or PRB group. In 5G this value might be reported with a certain vector quantization, while for LTE it would be used to calculate the best codebook entry or PMI value.

For 5G the next interesting mode would be to report all relevant taps of the unfiltered CIR allowing the eNB to reconstruct the full wideband radio channel, or at least a large frequency subband of the channel. Assume there are only very few, e.g., only five relevant taps, a full 100 to 400 MHz radio channel might be characterized just by five taps times ,e.g., seven quantisation bits or overall only 35 bits. Much less than would be needed for narrowband PMI reporting for 500 to 2000 PRBs, if one linearly upscales 100 PRB in LTE for 20 MHz bandwidth up to 400 MHz.

So far reporting has been per time instant t_i without any prediction so that CSI outdating will degrade precoding performance. In a next variant the UE might perform an internal channel prediction and reports the relevant taps for a future predefined time instant.

In the most future proof variant the UE reports even the evolution of relvant taps so that the eNB can reconstruct the evolution of the radio channel over time. Many other modes are feasible, like for example certain tracking solutions, if considered to be useful.

This concept thas the benefit to be neutral against specific implementation options, i.e., the channel estimation or prediction algorithms leading to the relevant taps does not have to be specified and are fully vendor specific, thereby following an important 3GPP principle.

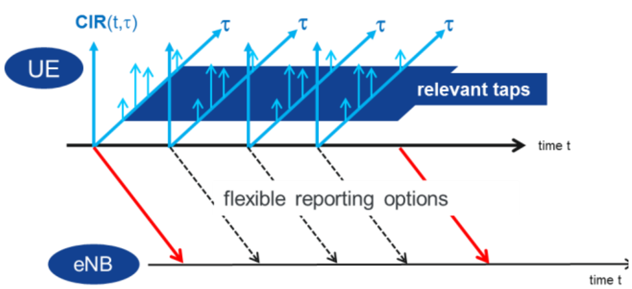

Figure 3: Relevant taps as basis for flexible reporting options

V. CONCLUSION

According to our current understanding the main differentiator of 5G versus LTE evolution seems to be a powerful interference mitigation framework making 5G the first '*interference free*' or better '*interference exploiting*' cellular radio system. In this framework JT CoMP plays one prominent role and given the history in LTE it seems that neither JT CoMP as such nor the inevitable enablers like reporting on relevant channel components and taps as well as channel prediction have a real chance to be included into LTE in the foreseeable future. Starting from the scratch and putting all required means together seems to be the right way to benefit from the lessons learned from latest research projects like Artist4G or METIS and now from Fantastic5G.

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