5GNOW: Intermediate Frame Structure and Transceiver Concepts

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***Abstract*—This paper reports intermediate transceiver and frame structure concepts and corresponding results from the European FP7 research project 5GNOW. The core is the *unified frame structure concept* which supports an integrated 5G air interface, capable of dealing both with broadband data services and small packet services within the same band. It is essential for this concept to introduce waveforms which are more robust than OFDM, e.g., with respect to time-frequency misalignment. Encouraging candidate waveform technologies are presented and discussed with respective results. This goes along with the corresponding multiple access technologies using multi-layered signals and advanced multi-user receivers. In addition we introduce new (compressive) random access strategies to enable "*one shot transmission*" with greatly reduced control signaling particularly for sporadic traffic *by orders of magnitude*. Finally, we comment on the recent results on the 5GNOW networking interface. The intermediate results of 5GNOW lay the ground for the standardization path towards a new 5G air interface beyond LTE-A.**

Keywords—5G, waveforms, new air interface,unified frame structure, OFDM, FBMC, UFMC, GFDM, non-orthogonal, asynchronous

I. INTRODUCTION

The advent of the *Internet of Things* (IoT) and its integration with high rate bit pipes for the content-driven Internet (fast video download, 3D video streaming etc.) imposes new, virtually contradicting requirements on next generation wireless air interfaces. While the former demands supporting a scalable (large) number of nodes (3GPP: >30k nodes per cell) under the premises of low cost and life time (>10 years) with particular traffic characteristics, e.g. sporadic transmissions; the latter demands *Gigabit wireless connectivity*. In addition, application visions like the *Tactile Internet* postulate the support of very low latencies (<1ms). The main paradigm of the European FP7 5GNOW project is that the underlying design principles–synchronicity and orthogonality–of the PHY layer of today's LTE-A radio access network constitute a major obstacle for such envisioned service architecture [1].

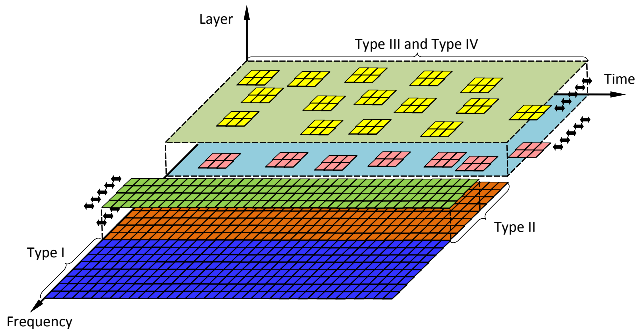

Fig. 1. Unified Frame Structure

This paper provides a summary of intermediate 5GNOW results, leading to the intermediate 5GNOW transceiver and frame structure concept, which is able to address the wide range of application scenarios in future wireless systems. The main focus of 5GNOW work lies in the classical frequency ranges below 6 GHz, but the concepts derived may be well applicable to higher frequency ranges as well.

II. 5GNOW UNIFIED FRAME STRUCTURE

Fig. 1 depicts the *unified frame structure concept* [1], aiming at handling the very heterogeneous service and device classes within one wireless access frame structure. Here, colors represent time-frequency resource elements of different traffic types and different classes of synchronicity. Radio resource control can adjust the assigned bandwidth semi-statically based on the respective service loads. The third dimension in this Unified Frame Structure is the usage of multiple superimposed signal layers (see section III.A for more details). High-volume broadband traffic (Type I), typically human-initiated, will operate as in LTE-A with synchronicity, whenever possible, using scheduled access. At cell edges, with Coordinated Multi-Point (CoMP) transmission and reception, it is not always possible to establish synchronicity to all cells, so the system has to operate with relaxed synchronicity requirements (Type II traffic). For sporadic small packet services, as occurring in Machine-Type Communication (MTC), the general relaxation of time-frequency alignment reduces signaling overhead and battery consumption (Type III traffic). Multiple signal layers may superimpose, which is handled by advanced multi-user / multi-cell receivers. For low-end sensor devices, it may be helpful to spread the transmission over a longer time and to allow completely asynchronous transmission (Type IV) traffic. The unified frame concept shall be main part of the standardization processes to be initiated in the future.

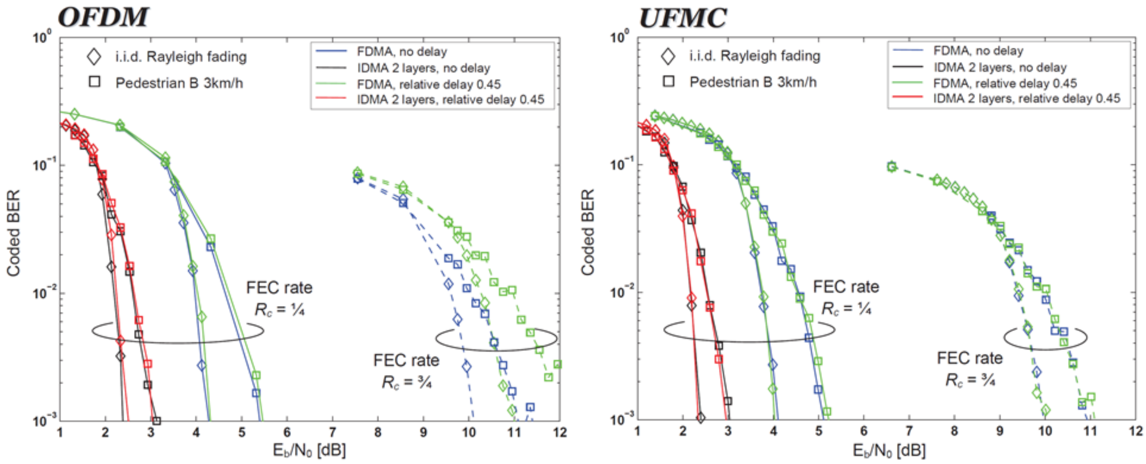

Fig. 2. Uplink OFDM vs UFMC using either FDMA or IDMA multiple access.

In that context, an example multiple access schemes are defined as follows:

a) Dynamic, channel adaptive resource scheduling for traffic Type I using standard resource scheduling mechanisms.

b) Semi-static/persistent scheduling for traffic Type II. From MAC point of view it is necessary to decide on the amount of resources allocated for this type of traffic, since schedulers will not adapt to specific parts of the frequency (may also be used for high speed terminals).

c) *One shot transmission* (low amount of data and pilots) with contention-like based approaches for random access (Type III and IV) enabling payload transmission in physical layer random access channel [2].

Notably, traffic types II and III rely on open-loop synchronization. The device listens to the downlink and synchronizes itself coarsely, based on synchronization channel and/or reference symbols, similar to 4G systems. Furthermore, the devices may apply some autonomously derived timing advance which we call *Autonomous Timing Advance* (ATA) [3] relevant particularly for MTC in 5GNOW.

III. 5GNOW Waveform and Multiple Accesss Approaches

The widely adopted OFDM waveform, used in 4G systems has high spectral side lobe levels, due to rectangular symbol shapes in time. This results in a high sensitivity to time-frequency misalignment. However, for the unified frame structure concept which includes high spectral and temporal fragmentation, new waveform candidates for the simultaneous operation of synchronous and asynchronous traffic in the same frequency band are required. This leads to a much more flexible and scalable air interface, being able to support the very heterogeneous requirements of next generation systems.

A. UFMC with multiple signal layers

The usage of multiple signal layers is part of the unified frame structure concept as it occurs at least in “collision” situations of contention-based access. Furthermore it is required to achieve the capacity of the multiple access channel [4], e.g., in the two-user rate region. In 3G systems, multiple signal layers could be supported by separation via code (CDMA). In beyond 3G systems, with the addition of MIMO, multiple signal layers were used in the spatial domain. A natural generalization of code and spatial layers, tailored to modern multi-user receiver strategies, is to separate multiple layers via coding and layer-specific interleavers. This concept is called Interleave Division Multiple Access (IDMA) [5]. This multi-layering approach can now be used in conjunction with multi-carrier waveforms in order to benefit further [4].

The drawbacks of classic cyclic prefix (CP-) OFDM w.r.t. spectral properties have already been discussed before. A recent alternative, very close to OFDM, has been designed and investigated within 5GNOW: Universal Filtered Multicarrier (UFMC), which is also known as UF-OFDM, as it can be parameterized to OFDM. In contrast to Filter Bank Multicarrier (FBMC) (see below) that uses a *per-subcarrier filter*, UFMC filters *bundles of subcarriers*, shortening the filter length. This is motivated by the observation that temporal and spectral asynchronicities occur between bundles of subcarriers (as e.g. uplink allocations are carried out block-wise, i.e. physical resource blocks (PRB) in LTE terminology) while in between them the transmission remains orthogonal. In short-burst communication scenarios, e.g. required in applications with low latency and/or small packets, the advantages of UFMC over CP-OFDM and FBMC were shown in [6]. Due to its improved spectral properties over CP-OFDM, UFMC offers an increased robustness against sources of inter-carrier interference, like carrier frequency offset. Those advantages were demonstrated in an uplink CoMP joint multi-cell reception scenario [7]. Due to QAM-modulation and closed relationship with CP-OFDM, UFMC allows straightforward usage of all known MIMO techniques without notable addition of complexity. Further optimization of UFMC filters for different ranges of carrier frequency offsets can be made, where first results and optimization approaches are discussed in [8]. Interestingly, UFMC goes beyond classical Gabor signaling scheme due to block operation and different possible block filter characteristics. First indications discuss UFMC as an extension of Gabor signaling: An interpretation, roughly speaking, as a hierarchical concatenation of an inner Gabor scheme (the subcarriers inside each subband) and an outer Gabor scheme (the filters of the subbands) is for further studies.

5GNOW [9] has investigated combinations of the UFMC waveform with different multiple access strategies, namely FDMA and IDMA. As a benchmark, the same multiple access approaches are combined with the CP-OFDM waveform [4]. The comparison is made in a setting with relaxed synchronicity requirements. According to Fig. 2, with low-rate forward error correction (FEC) codes, IDMA is strongly outperforming FDMA. (Higher code rates in the range of R_C=3/4 are outside of typical IDMA working points and thus are not plotted for better lucidity.) In order to compare the schemes under the same maximum throughput conditions, two 16-QAM FDMA users occupy each half the allocation size as the two superimposed IDMA layers using QPSK. For higher values of Eb/N0, the benefits of UFMC get more visible (e.g. comparing the green curves with squares), especially in an asynchronous setting [3]. The combination of UFMC with both multiple access schemes is always better than pure CP-OFDM, and we see that the strengths of UFMC and IDMA are complementing each other well over different ranges of SINR.

B. *GFDM*

Generalized Frequency Division Multiplexing (GFDM) [10] is a new multicarrier modulation scheme with OFDM and SC-FDE being corner cases of a more general concept. The GFDM signal is based on a block structure of *KM* total data symbols $d_{\mathrm{k,m}}$ from a constellation mapping such as QAM, which are divided into *K* subcarriers and *M* subsymbols. Each subcarrier is shaped with a subcarrier filter $g_{k,m}[n]$ that is constructed by circularly shifting a prototype pulse $g[n]$ in both the time and the frequency dimension as

$$g_{k,m}[n] = g[(n.mK)\mathrm{mod}MK]\exp\left(j2\pi\frac{k}{K}n\right), \tag{1}$$

where *m* and *k* are the subsymbols and the subcarrier indexes, respectively. The transmission signal is generated by summing all waveforms weighted by the data symbol $d_{k,m}$. GFDM turns into OFDM when using M=1, while SC-FDE modulation is achieved with K=1. In the general case of M>1 and K>1, the circular definition of $g_{k,m}[n]$ eliminates convolution tails when applying the subcarrier filter. This cyclic structure requires adding only one CP for *M* subsymbols in GFDM, while every symbol has a CP in OFDM. Hence, CP-GFDM has a higher spectral efficiency than CP-OFDM. Moreover, the pulse shaping of the GFDM subcarriers guarantees well localized spectral properties with steep edges and shoulders that can achieve up to -65dBc attenuation [11]. Lastly, the very flexible block structure of the GFDM signal *makes this modulation scheme a good candidate for a low latency PHY*. The fact that subsymbols with duration in the order of 10 μs can be transmitted with a single CP for the entire block and then be detected independently on the receiver side is a big advantage over OFDM. In addition to that, subcarriers in GFDM have an *M* times higher spectrum resolution than OFDM, because each subsymbol contributes with one sample. Consequently, when increasing the number of subsymbols while reducing their duration it is still possible to equalize the channel, even if it is frequency selective per subcarrier. Such a configuration is not possible with OFDM.

On the receiver side, assuming that the channel is time-invariant during the duration of the GFDM block and that the channel delay profile is shorter than the CP, the estimated data symbols can be retrieved from the equalized received sequence $r[n]$ by matching with the receiver impulse response $\gamma_{k,m}[n]$ for the *m*th subsymbol and *k*th subcarrier. If $g[n]$ is identified as a discrete Gabor prototype window where the data symbols $d_{\mathrm{k,m}}$ are the Gabor expansion coefficients, then, clearly, the GFDM signal is a *critically sampled Gabor expansion* [12] so that $\gamma[n]$ is the corresponding dual window to $g[n]$ (with the same time-frequency cyclic shift structure) and the received filters represent the Gabor transform of the equalized received sequence. One important practical application of this theory is the computation of the prototype receiver filter. Since $\gamma[n]$ is the dual to $g[n]$, the prototype receiver filter can be obtained by

$$\gamma[n,k] = ((Z^{-1})^{(K,M)})\left(\frac{1}{K(Z^{(K,M)}g)^{*}[n,k]}\right), \tag{2}$$

where

$$\left(Z^{(K,M)}g\right)[n,k] = \sum_{l=0}^{M-1} g\left(\frac{n}{K}+l\right)e^{-j2\pi\frac{kl}{M}} \tag{3}$$

is the Discrete Zak Transform (DZT) of a periodic sequence $g[n]$ and $(Z^{-1})^{(K,M)}$ is the inverse DZT. From (2) and (3), it is clear that the evaluation of the receiver filters does not require a large computation based on all possible waveforms, but the computationally efficient DZT transform pair can provide the prototype receiver filter only based on the transmit prototype filter.

The consequence of pulse shaping the GFDM subcarriers without offset QAM modulation or orthogonal pulses is that the data symbols within a GFDM block interfere with each other. While the zero-forcing receiver is an efficient tool to avoid this self-interference, it bears the drawback of noise enhancement. Due to the discrete Gabor setting this noise enhancement heavily depends on the system parameters: while the Balian-Low theorem prohibits efficient operation it can be shown that for the discrete setting here in certain cases the Balian-Low theorem can be circumvented at least to avoid sampling the DZT at zeros [12]. Moreover, to avoid amplifying the noise in the reception process, a Matched Filter (MF) receiver can be used to maximize the SNR for the individual subcarriers, in combination with a subsequent Successive Interference Cancellation (SIC) stage to remove the non-orthogonal parts in the signal, before detection. In GFDM, SIC is particularly effective, because each subcarrier is well localized in frequency domain and only immediate neighbors interfere with each other. Results have shown that MF-SIC can effectively remove self-interference at the cost of a reasonable computational complexity [13].

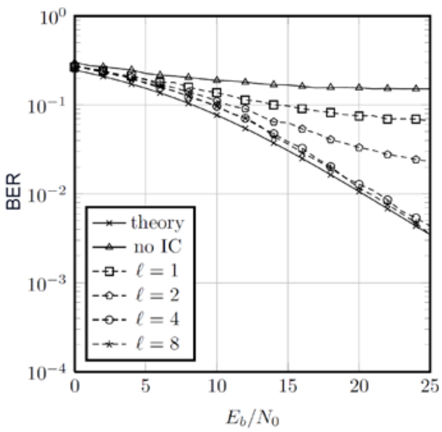

Fig. 3. BER performance of MF-SIC GFDM receiver considering different number of iterations (with parameters M=5, K=128, $g[n]$ is a raised cossine pulse with roll-off of 0.4, 64-QAM and Rayleigh multipath channel with exponential decaying profile between 0 dB and -10 dB).

Fig. 3 shows the Bit Error Rate (BER) performance of the MF-SIC receiver for different number of iterations (ℓ). The BER performance of the MF-SIC receiver approaches the theoretical lower bound as the number of iterations increase, which means that GFDM can practically achieve the same performance than OFDM in mobile communication channels.

C. *FBMC for asynchronous multiple access and fragmented spectrum*

FBMC is a multicarrier modulation technique that is experiencing renewed interest [14], due to a significant increase in the processing capacity of electronic equipment. The prototype filter of FBMC can be designed with great flexibility: subcarrier filters can be built with arbitrarily low secondary lobes, making FBMC a good candidate for asynchronous multiple access and/or fragmented spectrum communications. Classical implementation of FBMC receivers thanks to polyphase networks [14] is suitable to multiuser reception. However, synchronization, channel estimation and equalization have then to be carried out in the time domain, at the cost of a high complexity. To cope with this issue, frequency-spreading FBMC is considered [15]: at the expense of a larger FFT size, all the above mentioned processes may be efficiently done in the frequency domain with low complexity and relaxed synchronizations constraints.

The scenario under consideration hereafter is fragmented spectrum access in the context of asynchronous uplink multi-user transmissions [16]. In particular, below we consider a set of three users, where the user of interest is located in between the other users in frequency. The UEs are considered unsynchronized. We assume LTE-like parameters, the intercarrier spacing is set to 15 kHz, the cell coverage is assumed to be 5 km. We depict in Fig. 4 the SINR measured at the output of the equalizer for OFDM and FBMC waveforms. No guard carrier is inserted between the edges of each user spectrum band (24 carriers per user). The SINR has been computed for each carrier location and for each timing offset from 0 to 256 samples ($16.67\mu s$). For OFDM, thermal noise dominates the SINR when the timing offset is lower than the duration of the guard interval. In that case, the received signal is not affected by interference. However, as soon as the timing offset is larger than the guard interval, SINR is dominated by the interference. This clearly illustrates that the interference level is more important on the edges of the spectrum, when the OFDM signal is not synchronized within the guard interval of its adjacent signal. This is due to the sinc frequency shape of the OFDM waveform. For FBMC, the center of the spectrum is always dominated by thermal noise, while interference at the edges of the carrier is preponderant, whatever the timing offset. This is a direct consequence of the properties of the prototype filter which has been designed to minimize out of band interference. Interference affects the edges of the spectrum because the orthogonality of OQAM modulation is not preserved between asynchronous adjacent users. These results underline the benefit of FBMC over OFDM in this scenario.

Further simulations in above mentioned scenario show that, for 16-QAM modulation, FBMC gives a significantly better capacity, particularly in the range of 10 to 20 dB of SNR. Due to the better frequency localization, only the carriers located at the border of the user spectrum are affected by interference. For 64-QAM, the FBMC waveform clearly outperforms the

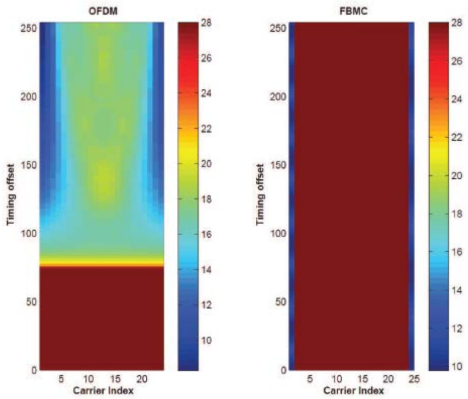

Fig. 4. SINR in dB as a function of carrier index and timing offset for OFDM and FBMC waveforms.

OFDM waveform. Interference dominates the SINR in the OFDM case and consequently for a given capacity of 5 bits/s/carrier, the SNR loss compared to FBMC is around 5dB.

IV. 5GNOW Random Access Strategies: One Shot transmission

Sporadic traffic due to MTC will dramatically increase in the 5G market and, obviously, cannot be handled with the bulky 4G random access procedures. Two major challenges must be addressed: 1) unprecedented number of devices asynchronously access the network over a limited resource and 2) the same resource carries control signaling and payload [17]. Dimensioning the channel according to classical theory results in a severe waste of resources which even worse does not scale towards the requirements of the IoT. On the other hand, since typically user activity, channel profiles and message sizes are compressible within a very large receive space, sparse signal processing methodology is a natural framework to tackle the sporadic traffic. One of the main ideas is a common control channel to enable "one shot" transmission.

A. *Compressive Random Access*

To explain the overall idea we start by considering first a generic single–user system model. Let $p \in \mathbb{C}^n$ be a pilot (preamble) sequence which is unknown but from a given set $\mathcal{P} \subset \mathbb{C}^n$ and $x \in \mathbb{C}^n$ be an unknown (coded) data vector. Both are transmitted simultaneously and use potentially the same resource. We set $\mathbb{E}\frac{1}{n}\|p\|_{l_2}^2 = \alpha$, and $\mathbb{E}\frac{1}{n}\|x\|_{l_2}^2 = 1 - \alpha$. Hence, the control signalling fraction of the power is α and, due to the random nature of x we have $\mathbb{E}\frac{1}{n}\|p + x\|_{l_2}^2 = 1$, i.e. the total transmit power is unity. Note that in typical systems n is large, say n=24576 as in LTE/LTE-A with 20 Mhz bandwidth and $\mathcal{P}$ represents the Frank-Zadoff-Chu sequence set and no data is transmitted. The primary goal at the receiver is to estimate the data vector x from the observations y whereby also the vector h of channel coefficients is unknown. A possible strategy is to estimate separately first the channel coefficients $\tilde{h} = Q_h(y|x \in X)$, under certain assumptions on the data x. A simple approach here is for example to treat the data as noise. In a second phase then the data $\tilde{x} = Q_x(y|\tilde{h})$ conditioned onto $\tilde{h}$ has to be estimated. Obviously, this procedure can then be iterated with or without data decoding. While for a classical receiver this procedure results in a huge interference for the channel estimation, a non-standard receiver can make use of the reduced dimensionality of the problem beyond the classical Shannon setting: 1) The communication in random access is sporadic so that out of the total set only an unknown small subset of users are actually active. Alternatively, we can assert certain probabilities to each node. 2) We assume to have a–priori support knowledge on h, i.e. $supp(h) \subseteq \mathrm{T}$ with T denotes, e.g., a subset of $[0, \ldots, T_{cp}]$ where T_{cp} represents the cyclic prefix of LTE-A (i.e. T_{cp}=8192). Moreover, we assume "sparsity" of channel profile with only six relevant paths and supp(h) < 300 (corresponding to a 1.5 km cell).

A key is the *illumination and partial Fourier sampling concepts* from [18] with the limitation to a relatively small observation frequency window, i.e. frequency indices in the set $\mathfrak{B}$ of cardinality $m = |\mathfrak{B}|$ so that the data noise floor is effectively suppressed. Let us denote with $P_B: \mathbb{C}^n \to \mathbb{C}^m$ the corresponding projection matrix. It is known that fixed Fourier windowing has several drawbacks. To introduce certain randomization we consider pointwise multipliers $\xi \in \mathbb{C}^n$ in time domain and we denote the corresponding $n \times n$ diagonal matrix as $M_\xi := diag(\xi)$. Summarizing, the $m \times n$ sampling matrix $\Phi = P_B W M_\xi$ will be considered. The $m \times n$ matrix $P_B \cdot circ(\hat{\xi})$, is usually called partial circulant matrix and it can be shown that it is applied to $\hat{h}$ (instead of h) so that $\hat{h}$ is actually sparse in the inverse Fourier domain. Preferable for sparse channel vectors h (in whatever domain) is the l_1–penalized least square method or quite efficient greedy methods like CoSAMP with precise guarantees in reconstruction performance [18].

Performance results are depicted in Fig. 5, where we show symbol error rates (SER) over the pilot-to-data power ratio α. Recall the extremely challenging scenario of only 839 subcarriers in the measurement window versus almost 24k data payload subcarriers. Moreover, in Fig. 6, we show the false detection probability P_{FD} over the missed detection probability P_{MD}. We observe that, although the algorithms do not yet capture the full potential of the idea, reasonable data detection performance can be achieved by varying α, cf. [18]. In the 4G LTE-A standard a minimum $P_{FD} = 10^{-3}$ is required for any number of receive antennas, for all frame structures and for any channel bandwidth. For certain SNRs a minimum $P_{MD} = 10^{-2}$ is required. It can be observed from the simulations that the requirements can be achieved. Actually, compared to LTE-A where the control signalling can be up to 2000% [1] of a single resource element the control overhead is in the CS setting down to 5% (let alone the huge increase in latency)! Additionally, we have equipped the transmitter with the capability of sending information in "one shot".

V. 5GNOW NETWORKING INTERFACES

The original approach of 3GPP to CoMP mechanisms required huge additional overhead, e.g. backhaul message sharing, eNB synchronization, feedback of CSI and exchange of control information among CoMP cooperating nodes. Practical realizations of initial CoMP algorithms showed very low gains far away from theoretical limits [2].

3GPP Release 12 dual connectivity with lean carrier and CoMP serve as framework for multi-cell / HetNet scenarios in which 5GNOW concepts may be implemented. These two features could be enhanced / complemented by such features as

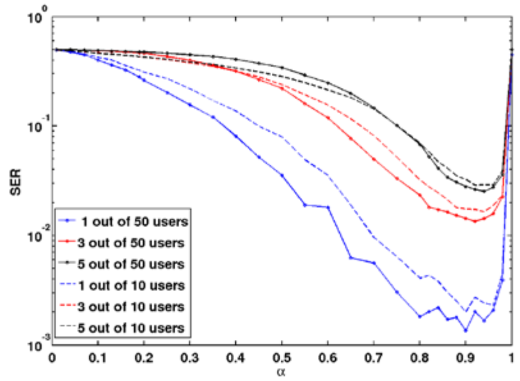

Fig. 5. Avg. BPSK SER in 5G "one-shot" random access (in 20MHz LTE-A setting) at SNR=20dB. Out of n=24576 dimensions, m=839 are used for CS.

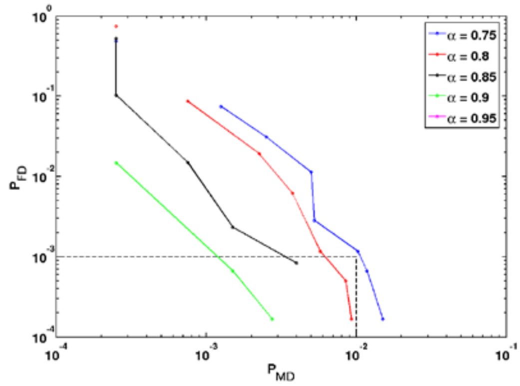

Fig. 6. P_{FD} over P_{MD} for the 5G "one-shot" random access with varying detection thresholds. The box illustrates the LTE feasible region.

the unified frame structure and the robustness framework presented in [1][2] to overcome current limitations and to be utilized within the current 3GPP considerations for non-ideally backhauled scenarios. It is dedicated for CoMP/MU-MIMO processing, including delay insensitivity (or low sensitivity to backhaul delay) and limited feedback approach. Merging of mentioned 3GPP and 5GNOW ideas sets the intermediate HetNet concepts for the 5GNOW project.

Classical analyses of orthogonal waveforms in literature reveals a scaling of the throughput degradation in the number of feedback bits in the order of $2^{-b(p)/(N_T-1)}$ where p and $b = b(p)$ denote the SNR and feedback budget per user and resource block (in bits/channel use) as a function of SNR, respectively. Very recent studies indicate that these results are fragile and that, in fact, the tradeoffs actually behave very differently in more practical regimes. In [19,20] it is shown that for any finite SNR point p and for any scaling in b the per-node capacity degradation is actually in the order of $2^{-b/(2(N_T-1))}$, which actually doubles the required number of bits! On the other hand in [19, 20] a robust feedback method is developed that actually achieves the lower bound, providing a huge net throughput gain. Secondly as 3GPP opens up for new carrier concepts starting from introduction of non-backward compatible Rel. 12 lean carrier for downlink, 5GNOW ideas may fit in the next releases of 3GPP standards e.g. for providing vision for enhanced uplink. This can also be extended to dual connectivity (aka "Phantom Cell"). A potential improvement may include the use of 5GNOW's waveforms provided within a form of unified frame structure, possibly utilized in the HetNet scenario to serve as a supporting cell / resources, while still using legacy LTE carrier for signaling. In [21] the robustness of FBMC was assessed in downlink CoMP scenarios with respect to standard compliant feedback links and MAC related asynchronicities such as outdated channel state information, considering also different user velocities. Previous work [22] showed that FBMC has a better packet error rate performance compared to OFDM, leading to improved performance in system level simulations.

VI. 5GNOW Impact on 5G Standardization

LTE and its evolution LTE-A are standardized via the 3rd generation partnership project (3GPP) [23]. The foreseen diversification of the service and device-class mix of future telecommunications and the related expansion of the requirement space [1] require a revolutionary step. This step from 4G to 5G, anticipated in the 5GNOW project goals, implies a backward compatibility drop. New waveforms and the usage of the unified frame structure with a mixture of synchronous and asynchronous traffic are a major building block for supporting those goals. Those new signal formats require standardization, as they need to be known on both ends of the link. The 5GNOW project assesses the advantages gained when using the new 5GNOW technologies and thus will generate technical findings which guide the decisions on this generation change. The wireless industry as a whole has to build up consensus on the technology candidates for 5G standardization. For this purpose, 5GNOW is in close contact to the European METIS research project [24], in order to spread 5GNOW outcomes on a broad basis into the industry and research community. The encouraging results, 5GNOW and METIS have achieved so far, lay the ground for the arising 5G infrastructure PPP projects [25]. Those projects, based on generated 5GNOW know-how, guided by METIS system concepts, will then be able to directly work towards pre-standardization. 3GPP release 14, starting in 2016 could be a first platform for creating a study item focused on a new air interface.

VII. Conclusion

This paper has presented the 5GNOW transceiver and frame structure approaches together with intermediate performance results. The intermediate results of 5GNOW lay the ground for the design of a new 5G air interface beyond LTE-A, which suits the diverse needs of future applications.

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