On the Design of a Radio Numerology for 5G Wide Area

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***Abstract*—A 5th Generation (5G) radio access technology is expected to cope with the relentless increase of the data traffic demand and is meant to accommodate a plethora of services with different requirements. In this paper, we elaborate on the design of the radio numerology for a 5G wide area system operating at carrier frequencies below 6 GHz. The main requirements are identified, and their inevitable conflicts are addressed. The proposed numerology options enable low latency with tolerable overhead, while maintaining a common clock with the Long Term Evolution (LTE) radio technology and robustness to hardware impairments.**

Keywords- 5G; RAT; wide area; IMT; LTE-A; frame structure; OFDM; ZT DFT-s-OFDM

I. INTRODUCTION

The International Telecommunications Union (ITU) has set challenging requirements for International Mobile Telecommunications (IMT) at 2020 and beyond [1]. Such targets include peak data rates in the order of 20 Gbps, user experienced data rates of 100 Mbps to 1 Gbps, minimum over-the-air latency of 1 ms. Current radio access technologies (RATs) such as Long Term Evolution (LTE) and Long Term Evolution- Advanced (LTE-A) [2] have backwards compatibility constraints and inner limitations which make them unsuited to fit the ITU requirements. Industry and academia are currently exploring new paradigms for a 5th Generation (5G) radio access technology, conceived as a disruptive design with respects to previous generation RATs [3]. Besides boosting the Mobile Broadband (MBB) performance, 5G is also expected to support novel communication paradigms such as Machine Type Communication (MTC), including Massive Machine Communication (MCC) with a large set of connected low cost devices and Mission Critical Communication (MCC) for high reliability services (e.g., communication autonomous driving and factory automation).

The ambitious 5G targets can be achieved by an intelligent integration of advanced technology components such as Multiple Input Multiple Output (MIMO) antenna techniques, optimized frame structure, interference suppression receivers and scalable bandwidth, e.g., from 10 MHz to at least 100 MHz.

An optimized radio numerology has a fundamental importance in the system design, since it ensures an efficient usage of the radio resources, while coping with the design requirements. In that respect, the numerology design is depending on the carrier frequency as well as the propagation characteristics of the environment, where the system is intended to operate.

In this paper, we elaborate on the numerology design for a 5G wide area concept operating on below 6 GHz licensed cellular bands, though some of the design principles can be generalized to other carrier frequencies. Our aim is to identify feasible configurations which allow to cope with the 5G requirements with a reasonable system overhead.

The paper is structured as follows. Section II introduces the radio waveforms which are considered in the numerology design. The main requirements are presented in section III, while the numerology design along with tentative proposals are presented in section IV. The open issues are addressed in section V. Finally, section VI resumes the conclusions.

II. 5G WAVEFORMS

The selection of the radio waveform has an impact on the numerology design. It is desirable that the same waveform is used in uplink and downlink; this enhances the similarity of the radio links, simplifying the system design and enabling several gain mechanisms [3]. The Orthogonal Frequency Division Multiplexing (OFDM) waveform has been adopted in the 4th generation (4G) RATs thanks to its computational effective approach of dealing with the multipath channel. On the other side, in OFDM the low complexity equalization is enabled by the usage of a Cyclic Prefix (CP), which is appended at the beginning of the time symbol and represents a pure system overhead. Further, OFDM suffers from a large Peak-to-Average Power Ratio (PAPR), poor spectral containment in case of asynchronous transmission, and sensitivity to hardware impairments such as phase noise and frequency offset. Several novel options for a 5G radio waveform have been presented in the recent literature, with the aim of overcoming the OFDM demerits. In the case of Generalized Frequency Division Multiplexing (GFDM) waveform [4], an unique CP is used for a large set of symbols, thus reducing the system overhead; further, the spectral containment is also significantly improved thanks to a pulse shaping filter applied at each frequency subcarrier. Filter Bank Multicarrier (FBMC) solutions have the promise of eliminating the CP overhead and feature an excellent spectral containment due to the usage of prototype filters [5]. Universal

Filtered Multicarrier (UFMC) acts instead as an intermediate solution between OFDM and FBMC by performing the filtering operations on a frequency block basis rather than per subcarrier [6]. All the mentioned approaches lead, however, to a significantly higher complexity than OFDM, especially in the case of MIMO transmission.

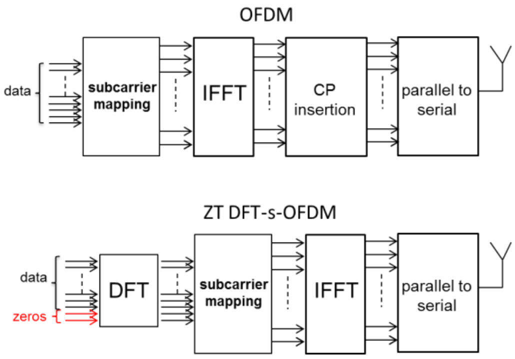

Figure 1. Signal generation in OFDM and ZT DFT-s-OFDM.

It is still under study whether the promised performance improvement of the novel options justifies their adoption as 5G waveforms. Nonetheless, some of the OFDM demerits can be easily alleviated with straightforward enhancements which do not compromise its selling points. For example, Discrete Fourier Transform – spread - OFDM (DFT-s-OFDM) modulation, emulates a traditional single carrier transmission with remarkable improvements in terms of power efficiency, and has been standardized as uplink waveform for the Long Term Evolution (LTE) RAT [2].

Recently, the novel Zero-tail Discrete Fourier Transform Spread OFDM (ZT DFT-s-OFDM) waveform has been proposed as a further enhancement of the DFT-s-OFDM waveform [7]. Fig. 1 highlights the difference between OFDM and ZT DFT-s-OFDM in the signal generation process. In ZT DFT-s-OFDM, a set of zeros is added to the vector of data symbols, which is then DFT-processed before undergoing the traditional steps of subcarrier mapping and Inverse Fast Fourier Transform (IFFT) transform. The insertion of the zero samples leads to a low power tail, referred as zero-tail (ZT), in the generated time symbol. Such ZT replaces the CP of OFDM and is part of the time symbol itself rather than being appended at its beginning. The ZT duration can be modified by varying the length of the pre-DFT set of zeros; this allows to dynamically set the overhead which is needed to cope with the delay spread of the channel rather than hard-coding it in the system numerology. Further, ZT DFT-s-OFDM features a significantly lower out-of-band emission than OFDM, thus improving the coexistence of asynchronous devices transmitting over neighbor bands. As traditional DFT-s-OFDM, ZT DFT-s-OFDM suffers, however, from noise enhancement leading to a Block Error Rate (BLER) penalty with respect to OFDM. However, the performance gap tends to vanish in case of receive diversity, especially for the case of four receive antennas. We refer to [7] for further details on the ZT DFT-s-OFDM waveform.

Given the possibility of partially overcoming some of its drawbacks while preserving its remarkable selling points, our current vision is that OFDM and its enhancements still represent the most valuable candidates for a 5G waveform. This has been further justified in [8]. In the rest of this paper, the design of a 5G wide area numerology will be presented considering OFDM and ZT DFT-s-OFDM waveforms.

III. REQUIREMENTS FOR A 5G NUMEROLOGY

The aim of this section is to introduce the main requirements for the design of a 5G numerology. As mentioned in the introduction, in this contribution we are addressing the specific case of a wide area macro system operating at carrier frequencies below 6 GHz.

A. Support of low latency.

The ITU has set an over-the-air communication latency target of 1 ms. This means, both downlink and uplink round trip times (RTTs) should not exceed 1 ms. The downlink RTT includes the time of transmitting the data payload from the base station (BS), the time for processing it at the user equipment (UE) and generating an ACK/NACK message to be fed back, and the time for the BS to decode such acknowledgement message. The uplink RTT includes the transmission of a scheduling grant from the BS, the decoding of such grant by the UE, the transmission of a payload by the UE, and the decoding of the payload by the BS [2]. Note that, in the LTE numerology, the Transmission Time Interval (TTI) duration corresponding to the transmission of a payload, is set to 1 ms, making it impossible to achieve the sub-ms latency requirement. Such short latency can be obtained instead by shortening the TTI duration to 0.2 ms or 0.25 ms. Both options leave a certain time margin for the data processing at the BS/UE. Note that such TTI duration cannot be achieved by simply parsing the LTE TTI due to the usage of 14 symbols in 1 ms, which do not downscale linearly with the proposed 0.2 ms or 0.25 ms configurations.

The usage of very short TTIs permits the achievement of extremely low latencies but has an obvious drawback in terms of higher relative overhead, from sending more frequent physical control channels with scheduling grants. Such overhead may be unnecessary for services having relaxed latency requirements, e.g., for MBB communication. In a previous contribution [9], the usage of different TTI durations (obtained as a multiple of the shortest TTI) and variable control overhead is proposed as a solution for dealing with different service requirements.

B. Low overhead for coping with time dispersion

The usage of OFDM modulation leads to the introduction of a systematic overhead given by the CP insertion, which is hardcoded in the system numerology. For instance, in LTE two different TTI structures have been defined, the first comprising of 14 OFDM symbols featuring a CP duration of around 4.76 µs each, and the second comprising of 12 OFDM symbols with a CP duration of 16.67 µs; both configurations fit the duration of 1 ms. Note that the second configuration is only used for Multimedia Broadcast Multicast Services

(MBMSs). For of the baseline configuration, the CP overhead is of 6.67%. In the light of a 5G numerology design, it is reasonable not to exceed the CP overhead of LTE.

The selection of the CP duration in LTE is obtained as a tradeoff between overhead and necessity to cope with the excess delay spread of a large set of radio channels. Nonetheless, a 4.76 µs CP duration appears excessive when considering the reported delay spread of the ITU channels, which do not exceed 1.9 µs (Urban Macro NLOS with 2 km intersite distance [10]). In [11], the impact on the spectral efficiency of different CP durations has been analyzed with link level simulations assuming different channel models, with the conclusion that a CP duration of 1 µs does not lead to a spectral efficiency degradation higher than 5-6% even for Urban Macro. Nonetheless, a safer margin for the CP may be needed in the case of transmission by multiple cells, e.g., for Cooperative MultiPoint (CoMP) transmission. Measurement campaigns carried out in Dresden and Berlin report excess delays of up to 4 µs in case of downlink multicell transmission with three cells having intersite distance of around 750 m [12]. In the case of OFDM air interface, we therefore consider both CP durations of ~2 µs and ~4 µs.

In the case of ZT DFT-s-OFDM waveform, the CP is replaced by a low power tail which is part of the time symbols itself. As a consequence, the low power tail does not need to be hardcoded in the numerology, thus simplifying the system design.

C. Common clock with LTE

Future devices are likely to support different RATs and the chip manufacturers would benefit from a system which maintains a common clock with already supported RATs. In that respect, it would be beneficial designing a 5G numerology which is based on the same reference clock as LTE. Ensuring such commonality does not necessarily require to use the same identical rate, but a frequency which can be synthetized from the same oscillator. Integer and fraction frequency synthetizer offer a simple circuital realization for synthetizing different frequencies from the same common reference [13]. For example, the 5G clock rate can be synthetized as follows:

$$5G_{rate} = LTE_{rate} \cdot \frac{a}{b} = N_{FFT} \Delta f_{LTE} \frac{a}{b} \tag{1}$$

where LTE_{rate} denotes the LTE sample rate, corresponding to the product of the Fast Fourier Transform (FTT) size N_{FFT} and the subcarrier spacing Δf_{LTE} (15 kHz), and a and b are generic integers. Equation (1) immediately translates to the following requirement for the 5G subcarrier spacing:

$$\Delta f_{5G} = \Delta f_{LTE} \frac{a}{b} \tag{2}$$

D. Similar number of resource elements as LTE

The chosen subcarrier spacing and CP duration have an impact on the number of available resource elements. In OFDM, each data symbol is directly mapped to a frequency subcarrier; a resource element corresponds then to a subcarrier symbol. In ZT DFT-s-OFDM, a resource element corresponds to a non-zero pre-DFT data symbol, with reference to Fig. 1.

In the case of LTE downlink 20 MHz configuration (with effective transmission bandwidth of 18 MHz), the resource elements correspond to 1200 frequency subcarriers per time symbols, for a total of 14 symbols per TTI. This leads to 16800 resource elements per ms. We consider a reasonable criterion maintaining at least the same number of resource elements of LTE in a 5G air interface.

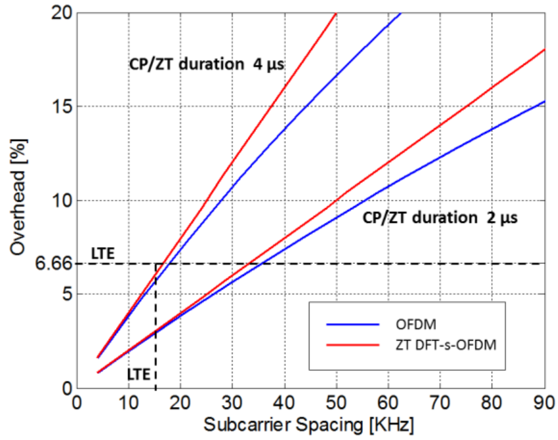

Figure 2. CP/ZT overhead as a function of the subcarrier spacing

E. Robustness to hardware impairments and high speed

Ensuring robustness to impairments such as frequency offset or phase noise is another fundamental requirement for a 5G RAT. This is further motivated by the necessity of supporting low cost devices for MTC, which may feature poor oscillators and radio frequency front-ends. Further, the phase noise is expected to have a larger impact in our 5G concept than in LTE since our 5G concept is intended to operate at higher carrier frequencies.

The usage of a sufficiently large subcarrier spacing can counteract the impact of phase noise. In [11], the optimal subcarrier spacing for a system operating at 6 GHz and 50 kmph speed was estimated to be around 60 kHz. Such estimate was derived by linearly scaling the power spectral density of a phase locked loop CMOS oscillator operating at 37.6 GHz. Nonetheless, an oscillator model for 5G has not been defined yet, since it is still unclear how the evolution of the electronic components would impact its performance. As a rule of thumb, we set as a requirement for a 5G system operating at below 6 GHz carriers to be significantly larger than the LTE one, e.g., $a \gg b$ with reference to (2). The usage of a large subcarrier spacing also improves robustness to the Doppler spread in case of high speed UEs.

Nonetheless, there is a fundamental tradeoff between subcarrier spacing and system overhead in the case of an OFDM (or ZT DFT-s-OFDM) air interface. The usage of a large subcarrier spacing leads indeed to a short time symbol duration, and therefore to a large number of symbols to be accommodated in a TTI with a given duration: this can significantly increase the overall CP overhead (or the overhead of the ZT in ZT DFT-s-OFDM). Fig. 2 depicts the CP/ZT overhead as a function of the subcarrier spacing assuming a TTI duration of 0.25 ms. The two sets of curves refer to absolute CP/ZT durations of 2 µs and 4 µs, respectively, as motivated in the previous section. In general, the overhead tends to increase faster for the ZT DFT-s-OFDM modulation, which however features the benefit of setting such overhead variable. For the case of a 4 μs CP/ZT, it is not possible to obtain significantly a larger subcarrier spacing than LTE while having lower or similar overhead; the 6.67% LTE overhead is indeed reached for a subcarrier spacing of around ~17 kHz. Achieving further robustness to the phase noise at higher carrier frequencies comes then at the expense of an overhead increase. In the case of a 2 μs CP/ZT, the overhead constraint is instead maintained for subcarrier spacing up to around ~35 kHz.

IV. NUMEROLOGY DESIGN

In this section, we propose the design of feasible numerologies for our 5G wide area concept for below 6 GHz carrier frequencies coping with the outlined requirements. We restrict here our focus to a Frequency Division Duplex (FDD) system, though some of the concepts can be generalized to a Time Division Duplex (TDD) system by including Guard Periods (GPs) in the frame design.

A. Design for OFDM

We define the numerology by setting the subcarrier spacing of 5G accordingly to (2), and numerically computing a large number of combinations by varying both a and b parameters. For each combination, the CP duration can be expressed as

$$T_{CP} = \frac{TTI_{5G} - \frac{N_{sym}}{\Delta f_{5G}}}{N_{sym}} \quad (3)$$

where N_{sym} is the number of symbols in the TTI. The CP overhead is given by $\left(N_{sym}T_{CP}\right)/T_{TTI}$, while the number of resource elements per ms is given by

$$N_{RE} = \left\lfloor \frac{B}{\Delta f_{5G}} N_{sym} \frac{TTI_{LTE}}{TTI_{5G}} \right\rfloor \quad (4)$$

where $\lfloor x \rfloor$ denotes the nearest integer lower than x , and B is the effective system bandwidth. We consider here B =18 MHz, corresponding to the LTE 20 MHz configuration.

For the case of a CP having an approximate duration of ~2 μs, it is possible to find configurations coping with all the requirements outlined in section III. In that respect, we restrict our focus to subcarrier spacing values at least double than the LTE one, i.e., $a \geq 2b$ with reference to (2), and consider a CP ranging from 1.8 μs and 2.3 μs.

Numerologies for a CP duration of approximately ~4 μs need instead to relax either the robustness to the hardware impairments or the overhead. We consider subcarrier spacing values at least as large as the LTE one, i.e., $a \geq b$ with reference to (2), and identify options which do not exceed a double overhead with respect to LTE, i.e., CP overhead lower than 13.33%. We consider here a CP ranging between 3.7 μs and 4.3 μs.

Fig. 3 displays a scatter plot of the CP overhead and subcarrier spacing combinations for the configurations identified according to the above criteria. For both TTI durations, the identified configurations are spanning a set of segments localized over different subcarrier spacing values corresponding to different number of time symbols in the TTI. Configurations for CP duration ~3.7-4.3 μs are distributed over a larger number of segments due to the more relaxed requirements. Each segment refers to the configurations obtained within the range 1.8-2.3 μs/3.7-4.3 μs for a specific number of time symbols per TTI, and spans a CP overhead increase of up to 2% for subcarrier spacing variations not larger than 300 Hz.

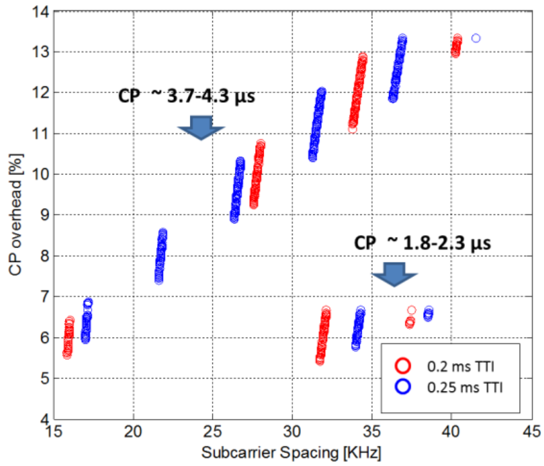

Figure 3. CP overhead for the identified configurations.

B. Design for ZT DFT-s-OFDM

In this case, the ZT duration is not hardcoded in the system numerology, since it is part of the time symbol itself rather than being appended to it. This leads to a further constraint on the selection of the a and b parameters in (2); the subcarrier spacing is indeed feasible in case $N_{sym} = \frac{a}{b}\Delta f_{5G}\, TTI_{5G}$ is an integer number. In order to ensure a fair comparison with OFDM, we consider a ZT duration equal to 2 μs and 4 μs when computing the overhead and the number of resource elements per ms. The ZT overhead is given by $\left(N_{sym}T_{ZT}\right)/T_{TTI}$, while the number of resource elements per ms is given by

$$N_{RE} = \left\lfloor B\left(\frac{1}{\Delta f_{5G}} - T_{ZT}\right) N_{sym} \frac{TTI_{LTE}}{TTI_{5G}} \right\rfloor \quad (5)$$

where T_{ZT} denotes the ZT duration. Similarly to the OFDM case, the combinations coping with the above requirements are identified.

C. Numerology examples

Table I reports the most promising examples of the identified configurations for OFDM. The LTE case is also included for the sake of comparison. The configurations for a 0.2 ms TTI duration and CP duration of around ~ 2 μs feature same (or higher) number of resource elements per ms of LTE, while having a large subcarrier spacing. In the case of CP duration of around ~4 μs, two configurations per each TTI duration are reported. Configurations I.C and I.G feature a large subcarrier spacing at the expense of a larger CP overhead. Note that a large CP overhead translates to a lower number of resource elements per ms with respect to LTE. On the contrary, configurations I.D and I.H preserve the overhead

TABLE I. NUMEROLOGY EXAMPLES FOR OFDM

Configuration	I.A	I.B	I.C	I.D	I.E	I.F	I.G	I.H	LTE
TTI duration (ms)	0.2	0.2	0.2	0.2	0.25	0.25	0.25	0.25	1
Number of symbols	7	6	6	3	9	8	7	4	14
Subcarrier spacing (kHz)	$5/2 \cdot 15 = 37.5$	$32/15 \cdot 15 = 32$	$16/7 \cdot 15 = 34.286$	$16/15 \cdot 15 = 16$	$18/7 \cdot 15 = 38.571$	$16/7 \cdot 15 = 34.286$	$19/9 \cdot 15 = 31.667$	$8/7 \cdot 15 = 17.143$	15
CP duration (µs)	1.9	2.08	4.16	4.16	1.85	2.08	4.13	4.16	4.76
CP overhead (%)	6.66	6.25	12.5	6.25	6.66	6.66	11.58	6.66	6.67
Number resource elements per ms	16800	16890	15750	16875	16812	16800	15932	16800	16800

TABLE II. NUMEROLOGY EXAMPLES FOR ZT DFT-S-OFDM

Configuration	II.A	II.B	II.C	II.D	II.E	II.F	LTE
TTI duration (ms)	0.2	0.2	0.2	0.25	0.25	0.25	1
Number of symbols	6	6	4	8	8	6	14
Subcarrier spacing (kHz)	$2 \cdot 15 = 30$	$2 \cdot 15 = 30$	$4/3 \cdot 15 = 20$	$32/15 \cdot 15 = 32$	$32/15 \cdot 15 = 32$	$24/15 \cdot 15 = 24$	15
ZT duration (µs)	2	4	4	2	4	4	4.76
CP/ZT overhead (%)	6	12	8	6.4	12.8	9.6	6.67
Number resource elements per ms	16920	15840	16560	16832	15680	16272	16800

TABLE III. NUMBER OF SUBCARRIERS AND FFT SIZE FOR CANDIDATE CONFIGURATIONS

Configuration	OFDM I.F		OFDM I.G		ZT DFT-s-OFDM II.D		ZT DFT-s-OFDM II.E		LTE	
Number of subcarriers/FFT size	10 MHz	262/ 512	10 MHz	284/ 512	10 MHz	263/ 512	10 MHz	245/ 512	10 MHz	600/ 1024
	20 MHz	525/ 1024	20 MHz	569/ 1024	20 MHz	526/ 1024	20 MHz	490/ 1024	20 MHz	1200/ 2048
	40 MHz	1050/ 2048	40 MHz	1138/ 2048	40 MHz	1052/ 2048	40 MHz	980/ 2048	40 MHz	2400/ 2x2048
	100 MHz	2625/ 4096	100 MHz	2845/ 4096	100 MHz	2630/ 4096	100 MHz	2450/ 4096	100 MHz	6000/ 5x2048

requirements at the expense of a lower robustness to hardware impairments. In case such configurations are used, phase noise estimation and correction algorithms need then to be implemented at the receiver to cope with the potential performance degradation at high carrier frequencies. Note that the configuration with the largest subcarrier spacing (I.E) also leads to the highest number of symbols per TTI.

Examples for ZT DFT-s-OFDM are reported in Table II. Recall that the ZT duration has no impact on the number of time symbols and subcarrier spacing. Configuration II.A is obtained by simply doubling the LTE subcarrier spacing, and in the case of a ZT duration of ~2 µs it leads to a larger number of resource elements per ms than LTE. Configuration II.B features the same TTI structure as II.A but a ZT duration of 4 µs is here considered, with a double overhead. Configuration II.C represents a tradeoff between the previous options. A similar behavior is visible in configurations II.D and II.E, having however a larger overhead due to the higher number of symbols. Configuration II.F is again a tradeoff between the two previous proposals.

The most promising options from Table I and Table II are reported in Table III along with the number of subcarriers and FFT size parameters. This is meant to show how our candidate numerologies support a scalable bandwidth, as targeted by 5G. For the CP ~4 µs case, we only included options having at least double subcarrier spacing than LTE; our recommendation is here to accept extra overhead but to maintain robustness to the hardware impairments. Note that in the case of ZT DFT-s-OFDM, we are here referring to *virtual* subcarriers rather than the frequency subcarriers, i.e., to the non-zero pre-DFT samples (see Fig. 1). For a 20 MHz bandwidth, all the configurations feature an FFT size of 1024, thus lower than the LTE one; this is a consequence of the larger subcarrier spacing. In LTE, transmission over larger bands (40 MHz, 100 MHz) is obtained by carrier aggregation [2]; multiple 20 MHz spectrum chunks can be then processed independently. For the identified 5G configurations, we have reported the cases of an unique FFT covering the entire spectrum. This corresponds to the case of a contiguous bandwidth allocation. Note that due to the larger subcarrier spacing, the proposed 5G numerology can achieve a 100 MHz carrier bandwidth with an FFT size of only 4096 – only twice the FFT size for an LTE 20 MHz carrier.

V. OPEN ISSUES

Current radio access technologies based on OFDM modulation have set an unique subcarrier spacing definition in their numerology. The design described above also subsumes the usage of the same subcarrier spacing for all the envisioned applications and services.

The option of relaxing the constraint of uniqueness of subcarrier spacing has been discussed in the recent 5G literature (e.g.,[14]). Using very large subcarrier spacing leads to very short time symbols and thus ultra-short TTIs and

RTTs, with obvious benefits for services targeting ultra-low latency (e.g., MCC). The corresponding large overhead, e.g., of the CP and control channels, is indeed secondary for such services. Moreover, power-limited MMC devices targeting sporadic transmissions of small data packets may also benefit from the usage of ultra-short symbols. A large subcarrier spacing leads indeed to a low number of subcarriers per time symbol. This can be shown to reduce the PAPR of the transmit signals with remarkable benefits in terms of power efficiency.

Finally, the benefits of a large subcarrier spacing at high speed are twofold: they improve the robustness to the Doppler spread as well as the quality of the channel estimation. The latter advantage is due to the fact that shorter time symbols increase the time correlation of the channel estimates in case of pilot patterns scattered between adjacent time symbols.

In that respect, traditional MBB users with low speed would benefit by the low overhead guaranteed by relatively short subcarrier spacing, while MTC and high speed users may adopt a larger subcarrier spacing to guarantee the quality of the communication at the expenses of a data rate reduction. Nevertheless, the 1 ms latency target set by the ITU copes with envisioned applications such as automation control and tactile Internet, and can be achieved by using the TTI durations of 0.2 ms and 0.25 ms, as presented above. This reduces the necessity of striving towards further shorter TTI durations.

The other mentioned benefits of the usage of different subcarrier spacing are however in our view still valid. Nonetheless, accommodating users with different subcarrier spacing sizes over adjacent bands may significantly affect their performance in case an OFDM modulation is used. This is because the different symbol duration necessarily makes such signals asynchronous, and OFDM suffers from significant out-of-band emissions in case of asynchronous transmission. In [4], the usage of GFDM is justified for improving the coexistence of asynchronous devices transmitting over neighbor bands due to the better spectral containment property of this waveform. We believe that our proposed ZT DFT-s-OFDM modulation is also a promising solution for that purpose since it improves the spectral containment with respect to OFDM [7].

Nonetheless, it is still under discussion whether the envisioned benefits of exploiting subcarrier spacing size as an extra degree of freedom justify the additional system complexity which is necessary to deal with it.

VI. Conclusions

In this paper, we have addressed the design of a radio numerology for a 5G wide area concept operating at below 6 GHz carriers. The main requirements have been identified, namely low latency and overhead, common clock with LTE, robustness to hardware impairments and similar number of resource elements as LTE. The design assumptions have been derived accordingly considering OFDM and ZT DFT-s-OFDM waveforms. For a CP/ZT of around 2 µs, numerologies coping with all the requirements have been presented. For a longer CP/ZT, we recommend to prioritize the robustness to the hardware impairments: the candidate configurations feature then a large subcarrier spacing at the expense of an overhead increase. The proposed 5G numerology only requires an FFT size of 4096 to form a 100 MHz carrier bandwidth.

Future work will address pros and cons of the usage of different subcarrier spacing sizes in the frame structure.

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