5G New Radio and LTE Uplink Coexistence

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***Abstract*—By the introduction of the fifth generation (5G) mobile communication networks and its physical layer entitled as new radio (NR), the question of link performance in coexistence scenario between the 5G NR and fourth generation (4G) mobile communication networks based on long term evolution (LTE) has been raised. In this paper, we evaluate the uplink (UL) performance of 5G NR and LTE links operating within a common channel. The need for subcarrier shift in 5G NR UL similar to LTE UL is addressed and analyzed, and the effect of guard band (GB) in frequency domain between 5G NR and LTE is studied. It is shown that with a single physical resource block GB no subcarrier shifting is required in 5G NR, as long as the power control accuracy is sufficient, in which case LTE performance is unaffected. From the 5G NR performance point of view no GB is required.**

***Keywords*—5G NR, coexistence, link performance, LTE, PHY layer, power control**

I. Introduction

As the first non-standalone (NSA) standard of the fifth generation (5G) mobile communication system and its physical layer, denoted as new radio (NR), has been approved by 3GPP [1], the question of coexistence between 5G NR and current long term evolution (LTE) networks arises. It is clear that to accelerate 5G NR rollout, several operators wish to accommodate 5G NR connectivity to existing LTE channels, especially in sub-6 GHz carrier frequencies. In Fig. 1, this concept is illustrated.

The co-existence scenario considered in this article is within a 20 MHz LTE channel, as shown in Fig. 1. It is assumed that a certain amount of LTE physical uplink (UL) shared channel (PUSCH) physical resource blocks (PRBs) are disabled to make room for the 5G NR system. Now the inter-system-interference is between 5G NR signal and LTE PUSCH. The 5G NR signal is considered to contain OFDM based PUSCH and short physical uplink control channel (PUCCH) [1]. In our view, this corresponds to the most difficult interference scenario in 5G NR and LTE UL coexistence. If the 20 MHz LTE channel channel would be divided into two 10 MHz channels, for both systems, then LTE PUCCH would act as an robust channel (or as a guard band) between the two systems reducing the inter-system-interference between 5G NR and LTE PUSCH. Furthermore, if the LTE system locates a narrow band Internet-of-Things (NB-IoT) system, also known as LTE Cat NB [2] next to the 5G NR system, it can also act as a robust channel between the 5G NR and LTE PUSCH. The NB-IoT devices use robust coding

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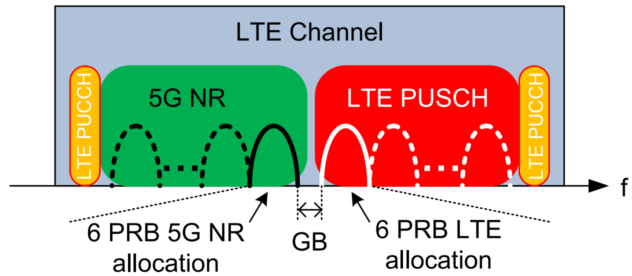


Fig. 1: Illustration of the channel sharing between 5G NR and LTE.

and modulation schemes together with repetition for extended coverage operation [3] which allows them improved tolerance towards the inter-system interference. To even further reduce the inter-system-interference between PUSCH channels, 5G NR can assign a long PUCCH [1] to the channel edges which would have similar effect as LTE PUCCH.

The most important question to address is whether 5G NR UL requires similar subcarrier (SC) shift as is used in LTE UL. In LTE, the UL SCs are shifted by 7.5 kHz with respect to downlink (DL) SC raster, or half a SC spacing (SCS), to align the DC component to lie between SCs [4]. In addition, the question of how much guard band (GB) is required between different systems to allow operation without significant degradation on the link performance is addressed in this work. In this paper, we will show that from the LTE system perspective a single physical resource block (PRB) is sufficient GB and that 5G NR does not require GB, especially if enhanced waveform processing is assumed in the receiver (Rx). The possible inter-system single-PRB guard band (GB) has a minor effect on the aggregated throughput of the two systems and it is a small price to pay in order to allow refarming existing LTE channels to simultaenously provide 5G NR UL coverage. This allows operators to speed up the rollout of 5G NR based services without limiting the support for the elder LTE devices. Furthermore, we evaluate the effect of the power control loop accuracy on the coexistence link performance and show that with sufficient power control error (PCE) accuracy no SC raster alignment is required between 5G NR and LTE UL.

The novelty of this paper is in providing the first co-existence results for 5G NR and LTE UL and in providing reasonable design parameters for sharing UL channel access between 5G NR and LTE systems. Both are aspects and results that have not been reported earlier in the existing literature. The rest of the article is organized as follows. In Section II, the evaluated systems' parameterizations are given and assumptions behind the selected parameters are discussed. In addition, the different coexistence scenarios are defined.

Then, in Section III, the LTE system performance in different coexistence scenarios is analyzed and evaluated, followed by 5G NR system performance analysis in different coexistence scenarios in Section IV. Finally, in Section V the conclusions are drawn.

II. System Parameterizations and Coexistence Scenario Descriptions

A. 5G NR and LTE System Parameterizations

A recent technical report describing 5G NR [5] states that the baseline assumption for the waveform for below 40 GHz communications is CP-OFDM and that the transmitter (Tx) processing has to be transparent to the receiver (Rx). It is also defined that user equipment (UE) has to support DFT-s-OFDM for coverage limited UL service. The work and analysis on this article concentrates on CP-OFDM based UL for 5G NR [1]. For 5G NR, where time domain duplexing is assumed to be the dominant duplexing scheme, it is preferable to use multicarrier waveform in both UL and DL [6]. Among other things, it simplifies the UL and DL transceiver design, allows improved interference cancellation schemes, and aligns the control channel and reference symbol designs in UL and DL. For LTE, the UL is based on DFT-s-OFDM [7].

Due to the enhancements in the physical layer design of 5G NR combined with hardware improvements, we assume that 5G NR UL is dedicated for high throughput UEs and LTE is used for low-to-medium throughput UEs and coverage limited UEs. We focus in our evaluations on a concrete example where 5G NR and LTE systems both have six PRB wide allocations at their virtual channel edges. The six PRB allocation is selected as a reference modeling the average UE allocation size in UL as it has been typically assumed for LTE UE UL requirements [4] and in 3GPP RAN1 and RAN4 evaluations (e.g. [8]).

The baseline physical layer definition and numerology follow the one defined for LTE operating in a 10 MHz channel while 5G NR can also adopt 30 kHz SCS (instead of 15 kHz), as defined in Table I. The performance is evaluated in TDL-C channels [9] with 300 ns and 1000 ns RMS delay spreads for 5G NR and LTE, respectively. Because the 5G NR network is assumed to support high throughput users, their pathloss and thus the channel delay spread can be assumed to be lower than for cell edge users served by the LTE network. In TDL-C channels the root-mean-squared (RMS) delay spread is defined by a scaling factor indicated in the name. The main link performance evaluation parameters are given in Table I.

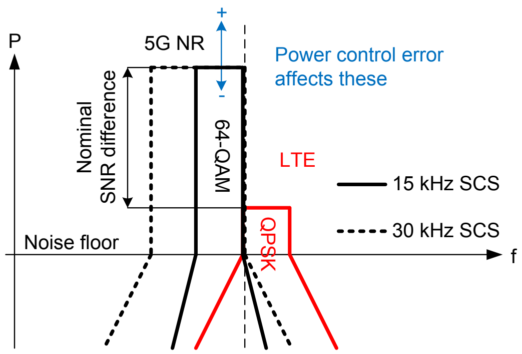
For the LTE based UL system, we assume that the UE Tx uses windowed overlap-and-add (WOLA) based signal processing. WOLA is a well known, low complexity technique to reduce OOB emissions of CP-OFDM or DFT-s-OFDM signals [11]. The window slope length defines the length of the rising or falling slope. The total window length in Tx is $N_{win,Tx} = N_{FFT} + N_{CP} + N_{ws}$ and preceding symbols overlap by N_{ws} samples. The LTE Rx is assumed to implement a channel filter designed to attenuate interference only outside LTE channel, thus not being able to suppress the interference leakage from the virtual 5G NR channel within the LTE channel. The LTE UL link performance is evaluated by assuming either 15 kHz SCS or 30 kHz SCS for the 5G NR interfering signal. The 30 kHz SCS case is seen as an important scenario to reduce the latency of the 5G NR radio interface compared to the LTE in sub-6 GHz communications. For example, in [12] it was demonstrated that with 30 kHz SCS it is possible to achieve 1 ms layer 1 and layer 2 latency with high probability.

TABLE I: Physical layer parameterization

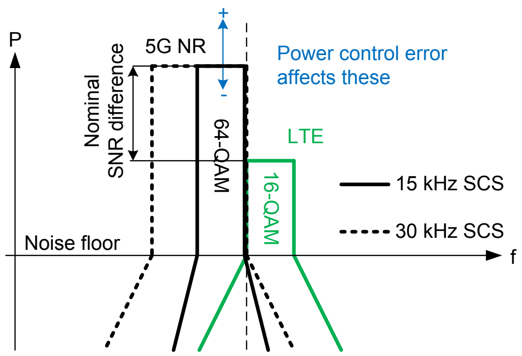
Parameter	Value
Carrier frequency	2 GHz
Channel bandwidth	20 MHz
Channel model [9]	TDL-C 300 ns (64-QAM) TDL-C 1000 ns (QPSK / 16-QAM)
UE mobility	3 km/h
Modulation	64-QAM (5G NR) QPSK/16-QAM (LTE)
Channel code [7]	turbo code
Coding rate R	$1/2$ (LTE), $3/4$ (NR)
FFT size	1024 / 512 (NR only)
CP length (N_{CP})	72 / 36 (NR only)
Guard period	72
Subcarrier spacing	15 kHz / 30 kHz (NR only)
SCs per PRB	12
OFDM symbols per subframe	14 / 28 (NR only)
Allocation granularity	6 PRBs
LTE Tx and Rx Configuration	
Tx Waveform processing	WOLA-based DFT-s-OFDM
Window slope length (N_{WS})	$N_{\text{CP}}/8$
Rx Waveform processing	Channel filtered DFT-s-OFDM
NR Tx and Rx Configuration	
Tx Waveform processing	WOLA-based CP-OFDM + channel filter
Window slope length (N_{WS})	$N_{\text{CP}}/8$
Rx Waveform processing	Channel filtered CP-OFDM or FC-F-OFDM
5G NR Rx with FC-F-OFDM [10]	
Transition band width (N_{TBW})	2 FFT bins
Minimum stopband attenuation (A_s)	10 dB

In the assumed 5G NR UL Tx waveform processing, the new aspect is to combine channel filtering with WOLA to allow better spectral containment at the virtual channel edges and to allow usage of different peak-to-average power (PAPR) reduction methods required to improve the Tx power amplifier (PA) efficiency with CP-OFDM based waveforms. On the Rx side, two different options are evaluated: either using a similar channel filter as with LTE or using an advanced waveform processing technique entitled as fast convolution based subband filtered CP-OFDM (FC-F-OFDM) [10]. FC-F-OFDM is an efficient and flexible subband filtering scheme that allows computationally efficient implementation of steep subband or channel filters. The filter design is based on optimized frequency domain windows allowing to balance the required minimum stopband attenuation, transition band width, and EVM performance. For the frequency domain window used in the performance evaluations the minimum stopband attenuation is $A_s = 10$ dB and the transition band width is 2 FFT bins (30 kHz) [10].

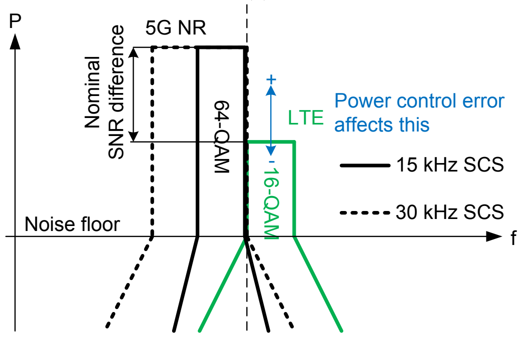
All the results presented assume ideal channel knowledge in the Rx and each simulated subframe contains only data symbols. A constant CP length is assumed for simplicity. For the UL a polynomial PA model of order nine was used [13]. This particular PA model was selected because it is used also by 3GPP and is publicly available. The maximum power reduction (MPR) values used for different modulations in LTE system follow the LTE specification [4], and correspond to



(a)



(b)



(c)

Fig. 2: Evaluated coexistence scenarios. In (a) QPSK modulated and in (b) 16-QAM modulated LTE signal is interfered by the 5G NR signal and in (c) the 5G NR signal is interfered by the 16-QAM modulated LTE signal.

0 dB for QPSK modulation and 1 dB for 16-QAM modulation. For the 5G NR using CP-OFDM based UL a MPR value of 3 dB is used for 64-QAM to achieve LTE EVM target with the 3GPP polynomial PA model.

B. Coexistence Scenarios

In Fig. 2, the different evaluated coexistence scenarios are illustrated. In all evaluated scenarios time synchronization between 5G NR and LTE systems is assumed and the 5G NR can operate using either 15 kHz or 30 kHz SCS. As the allocation size is 6 PRBs, the allocation width in Hz is doubled by the doubling of the SCS as indicated by the dashed line in Fig. 2.

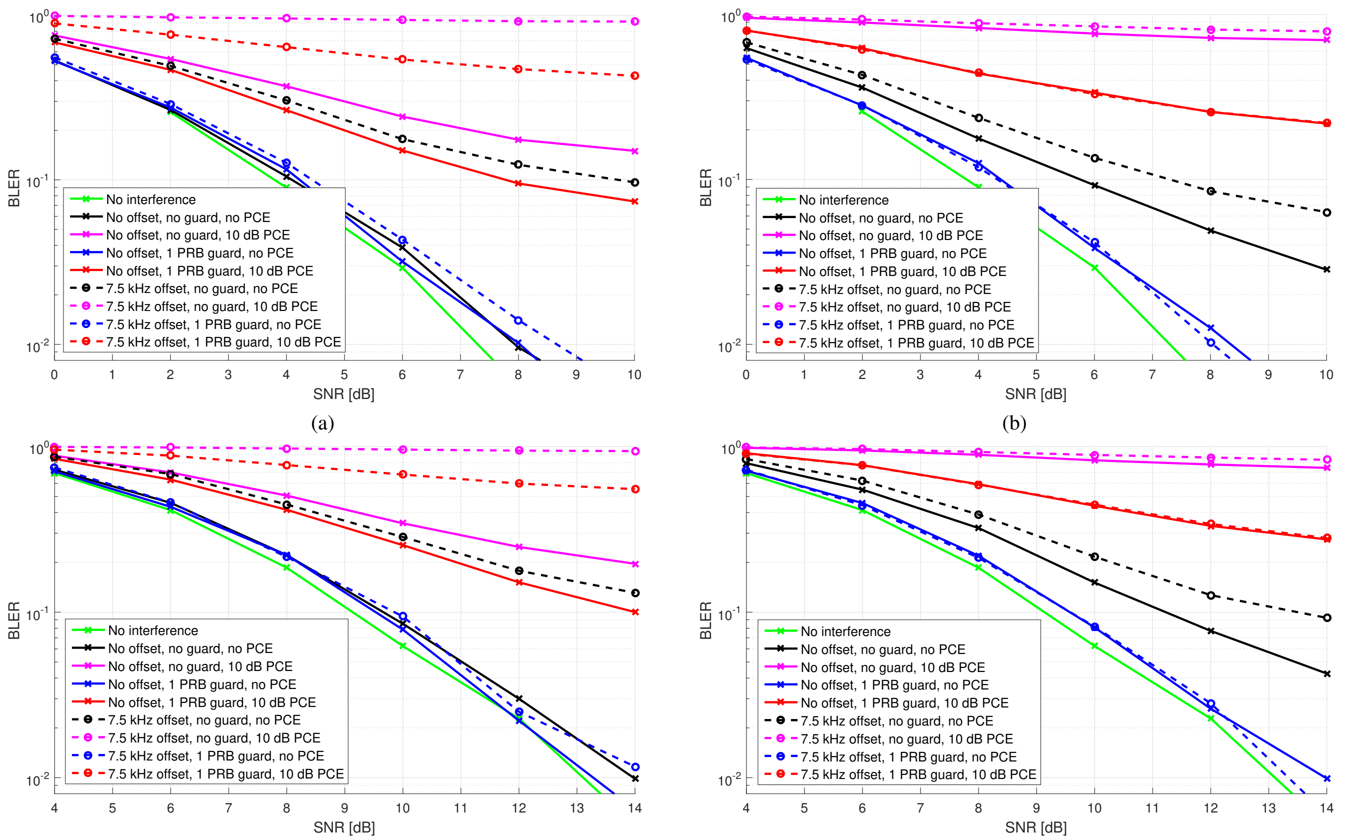
In Fig. 2 (a) and (b), the 5G NR link is considered as interference and LTE UL link performance with either (a) QPSK or (b) 16-QAM modulation is evaluated. In the Rx, the relative difference in the average power of the received signals is defined by the signal-to-noise-ratio (SNR) required by each modulation and coding scheme to achieve block error rate (BLER) target of 10% in the interference free scenario which can be observed from Figures 3 and 4. For clarity, they are restated here and are $\mathrm{SNR} = 4$ dB for QPSK and $R = 1/2$, $\mathrm{SNR} = 9$ dB for 16-QAM and $R = 1/2$, and $\mathrm{SNR} = 18$ dB for 64-QAM and $R = 3/4$. From these we can define the nominal power difference levels (see Fig. 2) without power control error (PCE), which can be considered as the target value for the power control loop of each system. In the performance evaluations PCE is introduced, which allows the interfering signal average power to increase from the target value. PCE values up to 10 dB are evaluated, because the LTE specification [4][Section 6.3.5] states that the absolute power tolerance can deviate even up to 12 dB in specific scenarios. In Fig. 2 (c) the scenarios where 5G NR is the victim and LTE system acts as an aggressor are shown. In these cases the interfering LTE signal is always assumed to use 16-QAM modulation and the PCE increases the power of the LTE signal.

In all evaluated scenarios also the effect of GB is addressed. The GB corresponds to one PRB with 15 kHz SCS (180 kHz), if used. Furthermore, the effect of aligning the 5G NR SC raster with LTE UL SC raster is evaluated. In LTE, the UL SC raster is shifted by 7.5 kHz with respect to the DL SC raster [4]. In 5G NR, such a shift has not been decided because both UL and DL use CP-OFDM as baseline waveform and is now a system parameter indicated in SIB1 [14]. In our evaluations, the 7.5 kHz offset decreases the distance between 5G NR and LTE signals, therefore modeling the worst case scenario. This explains why in Figures 3 (b) and (d) the performance is degraded when 5G NR signal with SCS 30 kHz has a 7.5 kHz offset.

III. LTE Performance in Coexistence Scenarios

In this section, the achievable LTE link performance in the presence of 5G NR interferer is evaluated by using state-of-the-art fully 3GPP standardization compliant radio link simulator. In Figures 3 (a)-(b), the results for QPSK modulated LTE signal are shown with 5G NR interferer using (a) 15 kHz SCS or (b) 30 kHz SCS. From Fig. 3 (a), we can observe that shifting the 5G NR SC raster by 7.5 kHz to align them with LTE SCs, corresponding to ”No offset” results, no GB is required if the PCE is 0 dB. If the 5G NR and LTE SC rasters are not aligned, which corresponds to the ”7.5 kHz offset” results, there is only a 0.2 dB SNR loss at the target level of 10% BLER if one PRB GB is used. Without a GB, there is a clear degradation in the performance due to the completely lost orthogonality between 5G NR and LTE signals.

Important to note is that both schemes, aligned and non-aligned SC rasters, suffer from poor power control loop performance which is seen as the clear degradation in performance results with 10 dB PCE. Thus, the SC raster alignment doesn’t help in this case if 5G NR power control loop is of the same quality as (or worse than) in LTE. This is primarily because of the PA induced interference falling at the neighboring PRB in Rx, despite the transmitter is conforming with the emission requirements. It should also be noted that the PCEs



(a) (b) (c) (d)

Fig. 3: LTE link performance with QPSK modulation and $R = 1/2$ given in (a)-(b) and with 16-QAM modulation and $R = 1/2$ (c)-(d). In (a),(c), the link performance is shown with 15 kHz SCS 5G NR interferer and in (b),(d), with 30 kHz SCS 5G NR interferer. PCE refers to power control error, as further elaborated in text.

TABLE II: LTE link SNR loss assuming a 15 kHz SCS 5G NR interferer in coexistence scenario when compared to interference free performance at 10% BLER target. The results are given for QPSK and 16-QAM modulation in the format of ”QPSK loss, 16-QAM loss”.

SNR loss [dB]	Aligned SC grid		7.5 kHz offset	
PCE	0 PRB GB	1 PRB GB	0 PRB GB	1 PRB GB
0 dB	0.3, 0.5	0.4, 0.4	5.9, -	0.7, 0.7
1 dB	0.6, 0.6	0.3, 0.5	-, -	0.8, 0.9
2 dB	0.5, 0.7	0.4, 0.5	-, -	0.9, 1.0
3 dB	0.7, 0.9	0.6, 0.4	-, -	1.5, 1.4
4 dB	0.8, 0.9	0.6, 0.7	-, -	1.7, 2.0
5 dB	1.1, 1.3	0.8, 1.1	-, -	2.5, 3.4
6 dB	1.7, 1.9	1.0, 1.3	-, -	3.6, -
7 dB	2.3, 2.5	1.4, 1.6	-, -	-, -
8 dB	3.4, 4.0	2.2, 2.2	-, -	-, -
9 dB	5.6, -	2.9, 3.2	-, -	-, -
10 dB	-, -	4.0, -	-, -	-, -

take place within each system and therefore different UEs experience degraded link performance because of PCEs. Thus, this phenomenon is not only between systems but also within a system and therefore more accurate power control loop allows to improve the physical layer throughput and reliability.

From Fig. 3 (b), we can observe that because the use of different SCS in 5G NR destroys the orthogonality between the two systems, there is basically no difference between aligned or non-aligned SC rasters. Also, it is observed that using a one PRB GB allows the LTE system to achieve a link performance very close to the ideal interference free link performance. Hence in such LTE/NR coexistence scenarios where NR network is adopting 30 kHz SCS, a single PRB guard-band is required to keep the LTE UL performance unaffected even when the LTE system is adopting robust QPSK modulation.

TABLE III: LTE link SNR loss assuming a 30 kHz SCS 5G NR interferer in coexistence scenario when compared to interference free performance at 10% BLER target. The results are given for QPSK and 16-QAM modulation in the format of ”QPSK loss, 16-QAM loss”.

SNR loss [dB]	Aligned SC grid		7.5 kHz offset	
PCE	0 PRB GB	1 PRB GB	0 PRB GB	1 PRB GB
0 dB	2.0, 2.1	0.6, 0.4	3.5, 4.4	0.5, 0.5
1 dB	2.6, 3.1	0.7, 0.7	-, -	0.6, 0.7
2 dB	3.9, 4.4	0.8, 0.9	-, -	0.7, 0.8
3 dB	6.0, -	1.0, 1.2	-, -	0.9, 1.1
4 dB	-, -	1.2, 1.4	-, -	1.3, 1.4
5 dB	-, -	1.6, 1.7	-, -	1.7, 1.9
6 dB	-, -	2.1, 2.6	-, -	2.3, 2.6
7 dB	-, -	3.4, 3.8	-, -	3.3, 3.8
8 dB	-, -	5.4, -	-, -	5.4, -

In Figures 3 (c)-(d), the LTE link performance with UL signal using 16-QAM modulation is evaluated with 5G NR interferer using either (c) 15 kHz SCS or (d) 30 kHz SCS. With 16-QAM modulation the results are basically the same

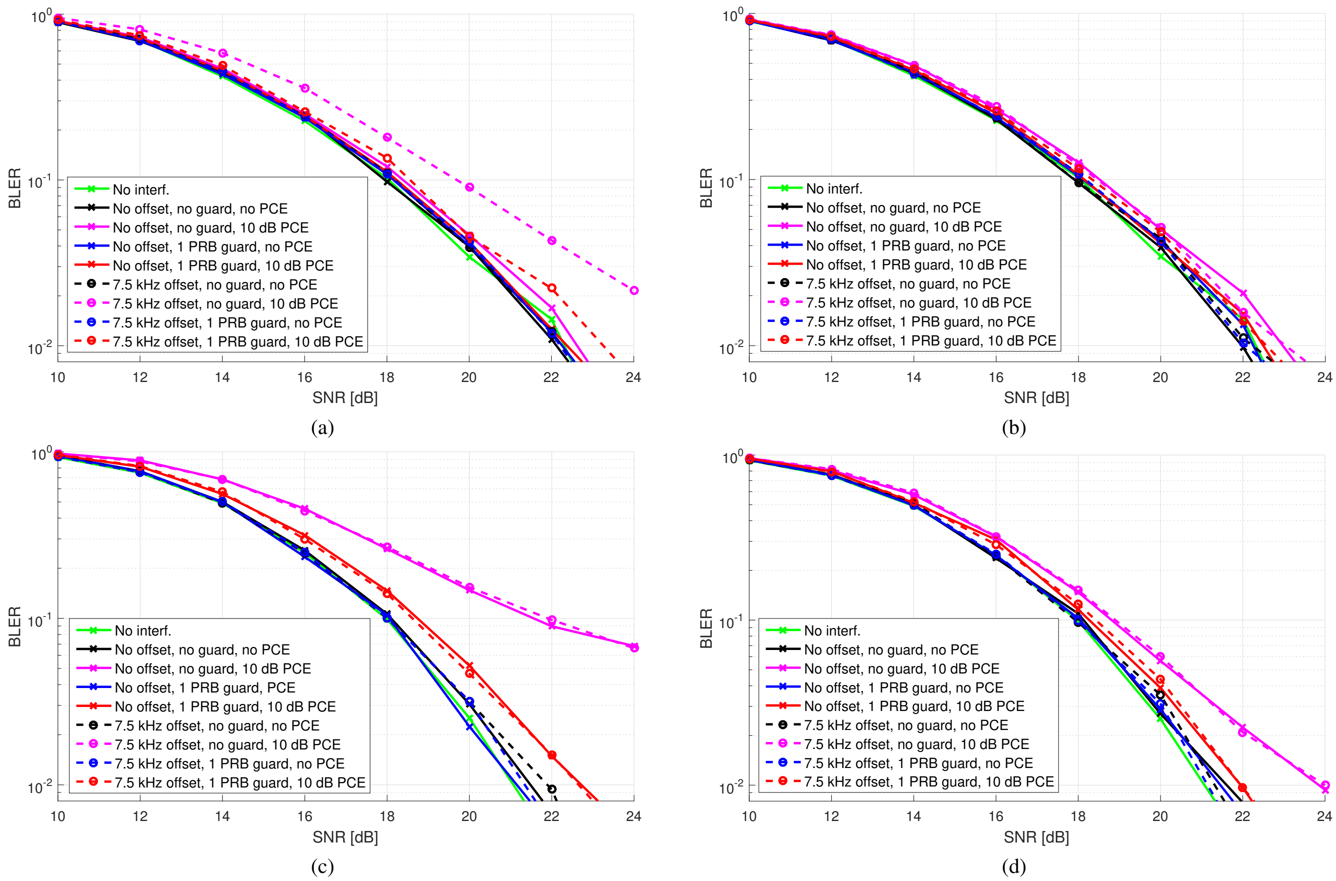


Fig. 4: 5G NR link performance with 15 kHz SCS is shown in (a)-(b) and with 30 kHz SCS in (c)-(d), assuming 64-QAM modulation and $R = 3/4$. The interferer is a LTE signal with 16-QAM modulation. In (a),(c), the performance with channel filtered CP-OFDM receiver is shown and in (b),(d) with FC-F-OFDM based receiver. PCE refers to power control error, as further elaborated in text.

as observed for QPSK modulation. Thus, to allow the 5G NR to benefit from the new, higher SCS and reduced latency, there is no need to align the SC rasters and one PRB GB is sufficient to ensure good LTE link performance in UL with coexisting 5G NR signal using 30 kHz SCS.

In Table II, the LTE link SNR loss results for evaluated PCE values for different MCS, GB, and SC grid alignment options are provided for LTE system interfered by a 5G NR system using a 15 kHz SCS. A ”-” marker indicates that the target 10% BLER value is not reached within the evaluated SNR points. It can be observed that with aligned SC grid, performance is within 1 dB from interference free scenario with PCE values 4 dB or 5 dB for no or one PRB GB, respectively. With non-aligned SC grids, performance without GP is poor even without any PCE , due to the heavy interference from the lost orthogonality. With one PRB GB, PCE level up to 3 dB can be tolerated to stay within 1 dB from the interference free link performance.

Finally, in Table III, the LTE link SNR loss results for evaluated PCE values for different MCS, GB, and SC grid alignment options are provided for LTE system interfered by a 5G NR system using a 30 kHz SCS. Now, as seen already in Figures 3 (b) and (d), there is very little difference between aligning or not aligning the SC rasters. With 7.5 kHz offset and no GB, the performance is worse than with aligned SC grid because the interfering signal is closer to the desired signal. With one PRB GB there are practically no differences between aligned or non-aligned SC rasters, independently of the power control accuracy. With or without SC grid alignment the 5G NR PCE should be below 3 dB to have SNR loss within 1 dB when compared to interference free performance.

These results indicate that for LTE UL link performance, no significant degradation is observed with one PRB GB and sufficiently accurate power control loop in 5G NR. Another indication of the QPSK modulated LTE UL link performance results is that NB-IoT UL channels can also be allocated to the LTE allocation edge to provide a robust channel generating a virtual GP for the LTE PUSCH.

IV. 5G NR Performance in Coexistence Scenarios

In this section, the corresponding performance of the 5G NR UL in coexistence with LTE UL is evaluated. The simulations follow the scenario (c) as shown in Fig. 2. First, in Figures 4 (a)-(b), the 5G NR link using 15 kHz SCS is evaluated. In Fig. 4 (a), the performance assuming an LTE like Rx using a channel filter designed for the LTE channel is evaluated. We can observe that the 5G NR link performance is not affected by the LTE signal unless there is no GB and the PCE in the LTE link is 10 dB. In Fig. 4 (b), the performance with FC-F-OFDM based Rx, which is capable to separately filter the six PRB subband used by the 5G NR and significantly attenuate the interference caused by the LTE link is used. It can be observed that with advanced subband wise filtering there is no degradation on the 5G NR link performance induced by the LTE system even under an extreme PCE of 10 dB.

In Figures 4 (c)-(d), the 5G NR link using 30 kHz SCS is evaluated with LTE like Rx using channel filtering results given in (c) and advanced FC-F-OFDM based Rx results given in (d). In Fig. 4 (c), clearer degradation in the performance is observed if 10 dB PCE is assumed for the LTE signal. This is mainly due to the lack of orthogonality due to different SCS in LTE system. With one PRB GB there is a 0.7 dB degradation in the required SNR at BLER target 10% and without GB the degradation is 4 dB, assuming a 10 dB PCE. This shows that even with the simple channel filter based Rx, 5G NR link using 30 kHz SCS can operate within 1 dB SNR loss compared to the interference free scenario if one PRB GB is used in the deployment.

In Fig. 4 (d) the 30 kHz 5G NR link performance with advanced FC-F-OFDM Rx processing is shown. With one PRB GB the SNR degradation is 0.3 dB and without GB the SNR degradation is 0.8 dB at BLER target 10%. This shows that advanced subband wise Rx filtering can allow the 5G NR UL to operate without GB in LTE co-existence scenario while supporting high throughput link with minor SNR degradation even if up to 10 dB power control errors are considered within the LTE system.

For the 5G NR link performance, there is no significant difference between aligned and non-aligned system wise SC rasters. Furthermore, 5G NR system with advanced base station side Rx processing is capable to suppress the LTE link interference even without GB and supports different SCS in UL without significant performance degradation.

V. Conclusion

In this paper, an UL coexistence scenario between 5G NR and LTE systems was studied and evaluated. Several different parameters affecting the UL link performance for both systems were considered, including SC raster alignment between the two systems, effect of GB, and the effect of advanced subband wise filtering in the 5G NR basestation Rx. The performance evaluations include a realistic UE PA model which increases the practical value of the presented results.

With 15 kHz SCS 5G NR interferer, the LTE link performance is not significantly affected with sufficiently accurate power control loop in the 5G NR UL. Aligned SC rasters provide relatively better performance without GB, but with 1 PRB GB the non-aligned SC raster has relatively small effect on the link performance as long as the 5G NR power control error is less than or equal to 4 dB.

With 30 kHz SCS 5G NR interferer, the LTE link performance degradation is not affected by the SC grid alignment because the use of different SC spacing leading to different OFDM symbol lengths already destroys the orthogonality between the two signals. In this case, LTE link performance is not significantly affected with one PRB GB and up to 5 dB power control error in 5G NR. As discussed, the presented results do not assume any additional robust channels between 5G NR and LTE PUSCH (e.g. PUCCH). Thus, the presented results can be considered as the worst case scenario for the LTE link performance.

For the 5G NR link with LTE interferer, there are no issues with performance except in the case of 10 dB LTE power control error, no GB and simple channel filter based Rx implementation. If the 5G NR base station Rx is using advanced subband wise filtering scheme, e.g., FC-F-OFDM processing, the loss compared to no interference scenario is less than 1 dB in all evaluated scenarios. This shows that the high throughput 5G NR allocation is robust against LTE induced interference and enhanced waveform processing technologies can further improve the performance.

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