Enabling Efficient 5G NR and 4G LTE Coexistence

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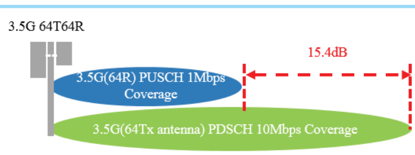
Introduction

Global efforts to enable fifth generation (5G) wireless communication are well underway, including spectrum allocation, standardization, and implementation. One key to the success of 5G is efficient utilization of spectrum due to its scarcity. The International Mobile Telecommunications (IMT) spectrum identified in the International Telecommunication Union's (ITU's) World Radiocommunication Conference (WRC) 2015 and 2019 (which are below 6 GHz and above 24 GHz, respectively) is being considered for 5G deployments. The Third Generation Partnership Project (3GPP) defines frequency bands for the 5G New Radio (5G-NR) air interface based on the guidance both from ITU and from the regional regulators, with prioritization according to operators' commercial 5G plans. As we understand, different frequency ranges have different characteristics, including path loss, available spectrum bandwidth, and so on, to support enhanced mobile broadband (eMBB), ultra reliable and low latency (URLLC), and massive machine type communication (mMTC) services [1], which are the three major use cases identified for 5G. For eMBB and mMTC services, good coverage is of fundamental importance to ensure access to the network for as many users as possible. From the coverage perspective, low frequencies (i.e., below 2 GHz), although they are widely used in existing 4G Long Term Evolution (LTE) deployments [2], will continue to play an essential role in the 5G era for wide area and/or indoor environments. In addition, for eMBB and URLLC services, a substantial amount of spectrum is needed to achieve high data rate and reliability with low latency. However, frequency range with larger channel bandwidth is primarily located above 3 GHz, which has larger path loss than lower frequency. Thus, it is clear that to ensure good coverage, high data rate, and low latency, 5G deployment requires the use of both lower frequency and higher frequency. Considering that the existing LTE networks are going to be in service for the near/middle future, 5G-NR deployed in lower frequency needs to coexist well with LTE in the same frequency band. To achieve efficient coexistence, both research in the wireless industry and standardization in 3GPP have been carried out. In the following, we present two coexistence scenarios that have been considered in 3GPP, namely co-carrier sharing and adjacent carrier sharing, where a carrier means a modulated waveform conveying data/control signals that is transmitted over an RF channel. Note that in the co-carrier sharing scenario, there are two cases, where 5G-NR shares uplink (UL) carrier [3] with LTE or 5G-NR shares downlink (DL) carrier with LTE. In 3GPP, they are also known as UL spectrum sharing and DL spectrum sharing, respectively.

UL Spectrum Sharing: UL/DL Decoupling

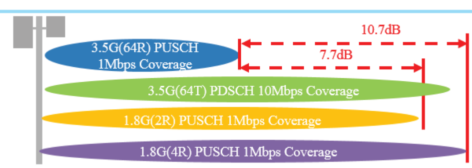
Currently, the most likely spectrum below 6 GHz for 5G-NR deployment is C-Band (3.2~5 GHz), where one operator could obtain 100 MHz or more spectrum, and time-division duplex (TDD) is used to facilitate the use of advanced massive multiple-input multiple-output (MIMO) technologies. Compared with the 2 GHz or lower frequency bands that are widely used for LTE systems, C-band suffers larger path loss and penetration loss. This issue is even more severe for the UL due to the higher frequency and smaller portion of UL resource allocation, and the coverage is up to 15.4 dB smaller than that of the DL, as shown in Fig. 1. This UL-DL coverage gap will largely limit the cell coverage and hence increase the number of base station (BS) sites in order to cover the same geographical area, which will translate into higher deployment costs for operators.

To enable operators to reuse their existing LTE BS sites and at the same time address the issue of UL-DL coverage gap, the



Key parameters	3.5GHz UL (1Mbps)	3.5G DL (10Mbps)	GAP: 15.4dB
Transmission power	26dBm (400mW)	53dBm (200W)	-27dB
# of RB	40	272	+8.4dB
UE OTA loss Body loss Penetration loss	4dB 3dB 20dB	4dB 3dB 20dB	
BS antenna height	25m	25m	
BS antenna gain	10dBi	10dBi	
Required signal-to-interference-noise ratio	-17.2dB (MCS3)	-22.5dB (MCS0)	-5.3dB
Noise figure	3.5dB	7dB	+3.5dB
Interference margin	3dB	8dB	+5dB
Shadow fading margin	9dB	9dB	

OTA: over the air
MCS: modulation and coding scheme
64T: 64 transmit antenna ports
PUSCH: physical uplink shared channel
PDSCH : physical downlink shared channel
64R: 64 receive antenna ports



Key parameters	1.8GHz UL 1Mbps	3.5GHz UL 1Mbps	GAP 7.7dB (2R) 10.7dB (4R)
Frequency	1.8GHz	3.5GHz	+5.7dB
UE transmission power	23dBm	26dBm	-3dB
Penetration loss	14dB	20dB	+6dB
Body loss UE OTA loss	3dB 4dB	3dB 4dB	
DL:UL resource allocation	0:5	4:1	+7dB
BS antennas	2R / 4R	64R	2R:-15.5dB 4R:-12.5dB
BS antenna gain	17dBi	10dBi	+7dB
Cable loss	0.5dB	0	-0.5dB
Noise figure	1.5dB	3.5dB	+2dB
Interference margin	5dB	3dB	-2dB
Shadow fading	8dB	9dB	+1dB

BS: base station

FIGURE 1. Coverage comparison between 3 GHz UL, DL and 1.8 GHz UL.

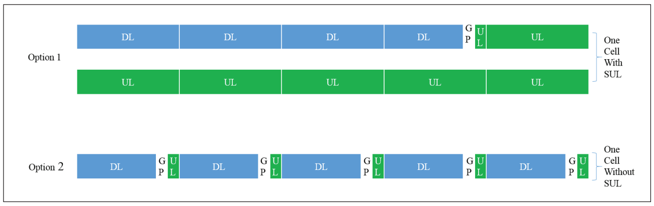


FIGURE 2. Frame structure and carrier options for low DL/UL rate.

5G-NR bands			5G-NR band combinations	
			Standalone (SA)	Non-standalone (NSA)
Band no.	Frequency	Duplex	Band combination number	
n77	3.3–4.2 GHz	TDD	SUL_n78-n80	DC_1-SUL_n78-n84
n78	3.3–3.8 GHz	TDD	SUL_n78-n81	DC_3-SUL_n78-n80
n79	4.4–5.0 GHz	TDD	SUL_n78-n82	DC_3-SUL_n78-n82
n80	1710–1785 MHz	SUL	SUL_n78-n83	DC_8-SUL_n78-n81
n81	880–915 MHz	SUL	SUL_n78-n84	DC_20-SUL_n78-82
n82	832–862 MHz	SUL		DC_28-SUL_n78-n83
n83	703–748 MHz	SUL	DC: dual connectivity	
n84	1920–1980 MHz	SUL		

TABLE 1. SUL frequency band and band combination definition [5].

concept of UL/DL decoupling is introduced in 5G-NR design. Unlike a traditional cell, where there is only one UL carrier and one DL carrier, UL/DL decoupling for 5G-NR proposes to use an additional 5G-NR UL carrier to supplement a 5G-NR TDD carrier. Note that this additional UL carrier and the TDD carrier are in different frequency bands; say the additional UL carrier is in 1.8 GHz band and the TDD carrier is in 3.5 GHz band. As such, there will be one DL carrier and two UL carriers in the same cell where either of the UL carriers can be used with the DL carrier. When a user equipment (UE) is at the cell center where there is good channel quality, the normal TDD carrier can be used, and when the UE is at the cell edge where UL coverage is not guaranteed, the additional UL, which is called supplementary UL (SUL) in 3GPP specifications, can be used. In this way, the UL/DL decoupling can enhance the UL coverage of a 5G-NR cell.

Besides the coverage improvement, latency performance of 5G-NR in C-Band is also improved. The reason is that TDD is used for C-Band, and a smaller portion of the resources are allocated to UL because normally DL traffic (e.g., MBB traffic) is dominant. Therefore, the UL traffic or the acknowledgment (ACK)/negative ACK (NACK) for DL data packets will have to wait until there are available UL slots, and this will result in larger traffic latency as compared to frequency-division duplex (FDD). On the other hand, if more UL-DL switching points are introduced to reduce latency, spectrum efficiency will be degraded. As shown in Fig. 2, to achieve similar latency performance (option 1: 1.5 ms, option 2: 2.6 ms), option 2 has 14.3 percent guard period (GP) overhead compared with the 2.8 percent GP overhead of option 1 [4].

To enable the UL/DL decoupling and UL sharing between LTE and 5G-NR SUL, several important aspects mentioned below were standardized.

SUL frequency band definition: SUL frequency bands and related standalone (SA) and non-standalone (NSA) band combinations are defined in Table 1.

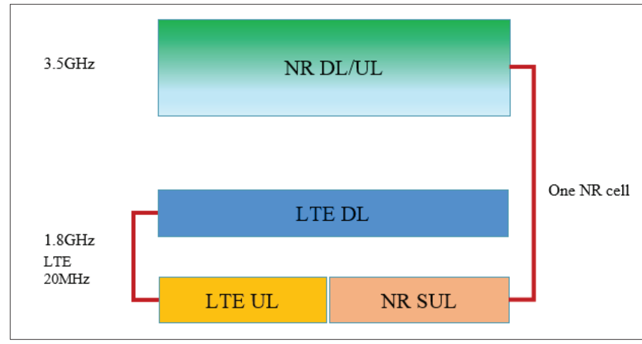


FIGURE 3. UL sharing from the UE perspective (spectrum combination for one UE).

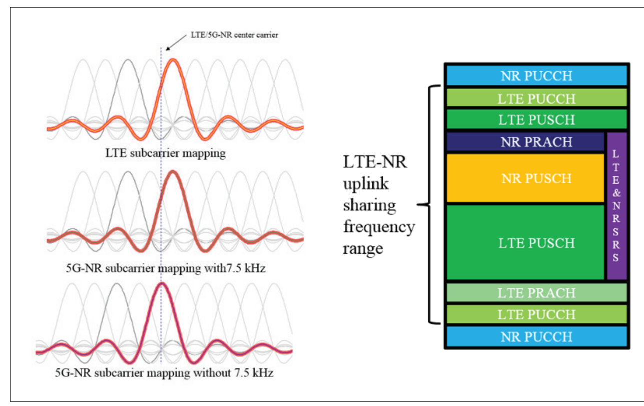


FIGURE 4. Subcarrier alignment and resource sharing between LTE and 5G-NR.

As can be seen, the SUL frequencies overlap the UL frequencies of LTE bands. As we know, for an LTE FDD cell that has symmetric DL/UL bandwidth (i.e., DL and UL bandwidths are equal) and asymmetric DL/UL traffic (i.e., light UL traffic and heavy DL traffic), the UL resources are underutilized. With SUL used by another 5G-NR cell, this issue of underutilization can be resolved, which is the third benefit of UL/DL decoupling.

As seen from Table 1, an SA SUL band combination consists of an SUL band and a TDD band, and an NSA band combination consists of an LTE frequency band and an SUL band combination where the LTE UL carrier frequency is the same as the 5G-NR SUL carrier frequency. One example is DC_3-SUL_n78-n80. In this case, it is called UL sharing from UE perspective (ULSUP) in 3GPP, as shown in Fig. 3. To facilitate the description, in one cell with SUL configuration, the UL carrier other than the SUL is called normal UL (NUL).

100 kHz channel raster and 7.5 kHz frequency shifts for SUL: Since LTE and 5G-NR are both based on orthogonal frequency-division multiplexing (OFDM) technology and the same numerologies for OFDM, an SUL carrier can share the currently deployed LTE FDD UL carrier efficiently when orthogonality between the two can be ensured [6]. This is achieved by aligning the RF channels with the same 100 Hz channel raster when a 7.5 kHz frequency shifts to the SUL carrier, as depicted in Fig. 4. Note that this frequency shift is configurable. Besides the subcarrier alignment, the uplink resource blocks (RBs) of LTE and 5G-NR SUL are aligned so that the RBs to LTE and 5G-NR can be adjacent to each other without interference to each other, as shown in Fig. 4.

UL/SUL selection for random access: NUL and SUL in one cell can be selected by an idle UE for random access based on its channel quality to increase the random access success probability for the UE at the cell edge.

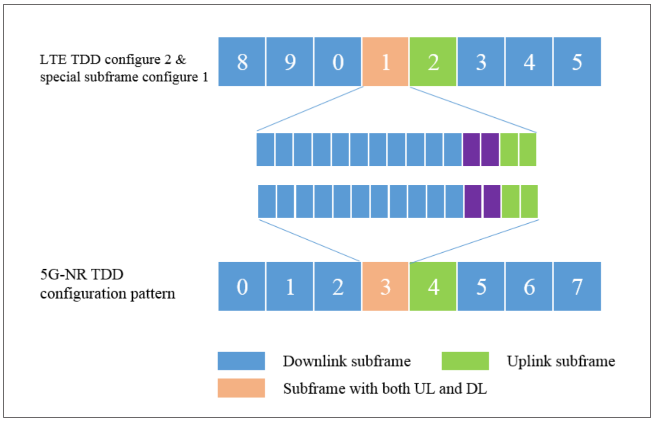


FIGURE 5. UL/DL transmission direction alignment between LTE and 5G-NR in the same TDD band.

Dynamic/semi-static switching between SUL and NUL: When a UE is configured with both SUL and NUL, the UE can be dynamically or semi-statically scheduled on the NUL or SUL to fully utilize the UL resource in the cell. For dynamic scheduling, different traffic can be scheduled on NUL or SUL. One example is that the traffic with low latency requirement can be scheduled on SUL due to its always available UL resources. To avoid signal transmission overlap between the SUL and NUL, the timing adjustment is unified (i.e., the NUL and SUL share the same timing advance adjustment command from the network).

Single TX between LTE UL and SUL: For a UE in NSA mode with SUL, the LTE UL and SUL carriers are both supposed to carry uplink signals. However due to total power limitation of the UE, the power has to be shared between LTE UL, 5G-NR SUL, and NUL. To guarantee the uplink performance, the LTE UL and SUL/NUL ability to be transmitted by the same UE based on a TDM pattern is supported, so the LTE UL and SUL/UL signal will not overlap in the time domain, and full UE power can be used by either 5G-NR NUL, SUL, or LTE UL. The UE also supports dynamic switching between LTE UL and SUL without switching time to avoid the switching time overhead.

Other enablers of the UL/DL decoupling are also supported, including the UL power control, UL feedback on SUL, and so on.

DL Spectrum Sharing

LTE and 5G-NR can also share the same DL frequency. This DL sharing is also useful for operators that have no additional lower frequency for 5G-NR deployment. For DL sharing, the challenge is that the LTE is transmitting cell-specific reference signal (CRS) in 4 or 6 OFDM non-continuous symbols of each subframe. The 5G-NR DL signal has to be designed to not collide with CRS to avoid performance degradation to LTE users.

SSB pattern: The 4 OFDM symbol 5G-NR synchronization signal block (SSB) using 30 kHz subcarrier spacing can be placed on the OFDM symbols between two LTE CRS symbols. This special SSB time pattern is called case C in 3GPP specification.

Initial COREST position: The starting OFDM symbol of the 5G-NR control resource set in a subframe can be indicated by the SSB so that it can also be placed on the OFDM symbols not occupied by LTE CRS.

LTE CRS rate matching: When 5G-NR physical downlink shared channel (PDSCH) is using 15 kHz subcarrier spacing, the subcarrier of LTE and 5G-NR are also orthogonal. To avoid the LTE CRS subcarriers, a 5G-NR user is configured with the LTE CRS frequency information so that the 5G-NR user can calculate the LTE CRS positions as reserved resources, and the 5G-NR PDSCH will rate match around those reserved resources. By rate matching, 5G-NR PDSCH can also be scheduled on the OFDM symbols with CRS, but on the subcarriers not occupied by CRS.

LTE NB-IoT and LTE-M coexistence with 5G-NR: The LTE narrowband Internet of Things (NB-IoT) and LTE-M [7] are expected to continue in service even after the LTE spectrum is re-farmed to 5G-NR. One of the options is to deploy the LTE IoT systems within a 5G-NR carrier. 5G-NR introduced a symbol-RB level reserved resource to accommodate the existing LTE IoT systems deployed in the same carrier.

It is worth nothing that to provide the random access functionalities on a 5G-NR DL carrier shared with an LTE DL carrier, UL sharing is also needed to share with an LTE UL carrier.

Adjacent Carrier Coexistence

To deploy 5G-NR and LTE on the same frequency band, the interference between the two systems should be guaranteed. The most critical coexistence challenge happens in a TDD frequency band, where the transmission direction (UL or DL) should be aligned between LTE and 5G-NR to avoid UL/DL interference. LTE defined seven TDD configurations for different UL/DL traffic ratios. In 5G-NR the UL/DL transmission direction is flexibly designed and can be fully aligned with LTE TDD UL/DL transmission direction. One example is that for LTE TDD configuration 2 and special subframe configuration 1, 5G-NR can configure its cell as 5 ms periodicity with 51 DL OFDM symbols in the front of the 5-subframe period and 16 UL OFDM symbols (subcarrier spacing is 15 kHz) in the rear of the period. Furthermore, since 5G-NR starts with DL symbols and ends with UL symbols in UL-DL periodicity, there will be two subframe shifts between the subframe number of LTE and 5G-NR, as depicted in Fig. 5.

Conclusions

This article introduces the efficient coexistence between LTE and 5G-NR. Through the UL only sharing known as UL/DL decoupling, 5G-NR provides a tool to extend its coverage with C-Band deployment, and makes it possible to deploy a C-Band 5G-NR network using existing LTE sites for seamless coverage. Moreover, the co-site deployment of 5G-NR and LTE greatly reduces the 5G-NR network cost and speeds up the 5G-NR commercialization. The UL sharing between LTE and 5G-NR also provides a powerful tool to strike a good balance between spectrum efficiency and low latency, and between coverage and channel bandwidth. The simultaneous 5G-NR DL/UL sharing with an LTE DL/UL carrier provides the possibility of early and low load 5G-NR deployment since the FDD LTE DL may have such high traffic load that only a shared low traffic load on 5G-NR DL can be accommodated. The 5G-NR is also designed to coexist with a TD-LTE system in the same TDD band to align the UL/DL transmission direction. Overall, 5G-NR is designed to allow efficient coexistence with 4G LTE for very flexible deployments and use cases.

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