

Exhibit A - U.S. Patent No. 7,924,802 (“’802 Patent”)

Accused Instrumentalities: cellular base stations, mobile products, and services that support 3GPP carrier aggregation, including without limitation Apple mobile products, and all versions and variations thereof since the issuance of the asserted patent.

For each and every claim identified below, the Accused Products include Defendant’s current, past, and future 3GPP 4G and 5G NR Radio Access Network (RAN) solutions and cellular base stations supporting 4G and 5G carrier aggregation capable radios and basebands compliant with the 3GPP 4G and 5G Standards, that are provided to Defendant from Nokia, Ericsson, and Samsung. The charts below describe 4G and 5G base stations and UEs compliant with carrier aggregation technologies supported in the eNB/gNB infrastructure and UEs that are provided to the defendant by the infrastructure and UE vendors.

The following charts apply to each Accused Product because, as described below, each Accused Product implements carrier aggregation wireless technology, including but not limited to functionality set forth in the 3GPP 4G and 5G NR Standard (a communications Standard to which each Accused Product is advertised as compliant) in a manner that causes each Accused Product to function in substantially the same manner with respect to the Asserted Claims.

Claim 1

Claim 1	Public Documentation
[1pre] A method of transmitting information in a wireless communication channel comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. <i>See, e.g.:</i> <u>T-MOBILE US USED THE SAMSUNG GALAXY S22 PHONE POWERED BY SNAPDRAGON 8 GEN 1 MOBILE PLATFORM</u> <u>T-Mobile US said it was able to aggregate three channels of mid-band 5G spectrum, reaching speeds over 3 Gbps on its standalone 5G network. The carrier used the Samsung Galaxy S22 phone powered by Snapdragon 8 Gen 1 Mobile Platform with Snapdragon X65 Modem-RF System on a live production network.</u> “This test demonstrates the incredible power of mid-band spectrum and represents another huge step forward for standalone 5G,” said Neville Ray, president of Technology at T-Mobile. “Only T-Mobile is delivering a

Claim 1	Public Documentation
	nationwide standalone 5G network to customers today, and we’re blazing a trail with new performance-boosting capabilities that generate incredible speeds and deliver on our vision to create the highest capacity network in the country.” T-Mobile US noted that 5G Carrier Aggregation (NR CA) allows the combination of multiple 5G channels to improve speed and performance. In this test, the carrier merged three 5G channels — <u>two channels of 2.5 GHz Ultra Capacity 5G and one channel of 1900 MHz spectrum</u> — to create an effective 210 MHz 5G channel. T-Mobile claimed to be the first operator in the world to launch a nationwide SA 5G network nearly two years ago. NR CA is already live in parts of T-Mobile’s network combining two 2.5 GHz 5G channels. The telco said that those customers with the Samsung Galaxy S22 will be among the first to experience a third 1900 MHz 5G channel later this year. This capability will expand across the carrier’s network and to additional devices in the near future. Earlier this month, T-Mobile U.S. announced that customers in limited areas of Portland and Salt Lake City who have the Samsung Galaxy S21 5G now have access to Voice Over New Radio (VoNR) services. The carrier said additional cities will be added to the list throughout the remainder of this year. According to T-Mobile US, VoNR brings the promise of Standalone (SA) 5G “one step closer” by enabling advanced capabilities like network slicing that rely on a continuous connection to a 5G core. At the recent Big 5G Event in Austin, Texas, Ray told <i>RCR Wireless News</i> that in addition to ultimately supporting 5G voice calls, VoNR, without a Non-Standalone 5G or LTE anchor, sees its investment in low-band as the “foundation” of the company’s network. The carrier’s Extended Range 5G (low-band 600 MHz spectrum) covers 315 million people across 1.8 million square miles, while 225 million people nationwide are covered with its Ultra Capacity 5G (2.5 GHz spectrum). The carrier expects to cover 260 million in 2022 and 300 million next year. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>T-Mobile Revs Up 5G with Four-Carrier Aggregation</u> July 25, 2023

Claim 1	Public Documentation
	What’s the news: T-Mobile has begun rolling out four-carrier aggregation for customers, boosting speeds on its 5G standalone (SA) network. Why it matters: 5G SA is the future of wireless, delivering a whole new level of performance with faster speeds and lower latency (quicker response times). 5G carrier aggregation allows T-Mobile to turbocharge 5G SA speeds, giving customers a game-changing performance boost. Who it’s for: T-Mobile customers across the country. Pedal, meet metal. T-Mobile (NASDAQ: TMUS) today announced it has begun rolling out four-carrier aggregation on its 5G SA network, delivering the capability for insanely fast speeds to customers across the country. If you need help translating ... insanely fast = peak speeds topping 3.3 Gbps in recent tests. Four-carrier aggregation is live in parts of T-Mobile’s network now and will be available nationwide in the coming weeks. “T-Mobile is blazing the trail for wireless customers around the globe, delivering new capabilities that unleash the true potential of 5G,” said Ulf Ewaldsson, President of Technology at T-Mobile. “With the only nationwide 5G standalone network in the country, T-Mobile is the ONLY provider bringing game-changing technologies like four-carrier aggregation to customers across the country.” 5G carrier aggregation allows T-Mobile to combine multiple 5G channels (or carriers) to deliver greater speed and performance. The Un-carrier is now merging four 5G channels of sub-6 GHz spectrum – <u>two channels of 2.5 GHz Ultra Capacity 5G, one channel of 1900 MHz and one channel of 600 MHz spectrum</u>. That’s like taking four separate highways and turning them into a massive superhighway where traffic can zoom faster than before. Customers with the Samsung Galaxy S23 will be the first to experience four-carrier aggregation with more devices to follow. This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across two million square miles – more square miles than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity this year – nearly everyone in the country.

Claim 1	Public Documentation
	https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>SRG tests T-Mo’s FDD-TDD CA: ‘You can have your cake and eat it too’</u> January 11, 2022 The aggregation of 600 MHz + 2.5 GHz uses low-band, FDD spectrum to improve performance The aggregation of low and mid-band carriers in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) spectrum improves cell edge performance in T-Mobile US’ network, according to recent testing by Signals Research Group. <u>SRG tested the FDD+TDD carrier aggregation (CA) in T-Mobile US’ commercial network.</u> The testing was conducted during the first week of December, at a large cluster of Ericsson sites in a 180-square-kilometer swath of the suburban Maryland/Washington, D.C. area. “A few mobile operators have already launched TDD-TDD CA in other parts of the world but to the best of our knowledge T-Mobile is the first operator in the world to deploy FDD-TDD CA functionality in a commercial network,” SRG noted. SRG said that T-Mobile US provided the test SIMs and insight into the cluster where the testing was conducted, as well as two Galaxy S21 smartphones — one with pre-commercial software on it that allowed the consulting group to test some of the features it was interested in. Intriguingly, however, SRG found that both devices appeared to support much the same functionality, with a bit of finessing of “hidden” menu options to force the smartphones into the modes of operation that it wanted to test. SRG used test tools from Accuver Americas and Spirent Communications to conduct the study. <u>The firm said that the cell cluster supported a “wide range of different technologies,” including both NSA and SA 5G, using T-Mo’s 600 MHz (FDD) and/or 2.5 GHz (TDD) spectrum. In terms of 5G New Radio CA, the sites either used two 5G NR carriers at 2.5 GHz, leveraging T-Mo’s deep midband holdings for TDD-TDD carrier aggregation; or they paired a single radio channel of 600 MHz spectrum with a single channel of 2.5 GHz — the FDD-TDD CA that SRG sought to test.</u>

Claim 1	Public Documentation
	https://www.rcrwireless.com/20220111/test-and-measurement/srg-tests-t-mos-fdd-tdd-ca-you-can-have-your-cake-and-eat-it-too T-Mobile to Expand and Advance the Nation’s Largest 5G Network with New 5-Year Agreements <i>These multi-billion-dollar deals with both Ericsson and Nokia will continue to supercharge T-Mobile’s nationwide 5G network</i> January 13, 2021 06:29 PM Eastern Standard Time BELLEVUE, Wash.--(BUSINESS WIRE)--Today, T-Mobile (NASDAQ: TMUS) announced five-year, multi-billion-dollar agreements with both Ericsson (NASDAQ: ERIC) and Nokia (NYSE: NOK) to continue advancing and expanding the nation’s largest 5G network. Part of the network investment following last year’s merger with Sprint, these deals enable T-Mobile to add even more 5G coverage, capacity, speed and advanced technical capabilities across all of its spectrum bands. “T-Mobile already has the largest 5G network in the country,” said Neville Ray, T-Mobile President of Technology. “These agreements with our longstanding 5G partners Nokia and Ericsson will help us take our 5G leadership even further, delivering ever-better experiences for our customers for years to come.” Building on two decades of partnership, the Un-carrier will work with Ericsson and Nokia to expand its nationwide 5G network for better 5G coverage and future game-changing experiences, and advanced network capabilities like 5G carrier aggregation. T-Mobile launched the world’s first nationwide standalone 5G network last summer, and recently pulled off the world’s first 5G standalone (SA) data session with New Radio Carrier Aggregation (NR CA). T-Mobile is the first and only U.S. provider to combine the power of Extended Range and Ultra Capacity 5G, boosting speed and performance. T-Mobile also plans to add advanced technical capabilities like voice over 5G (VoNR), network slicing, and multi-user massive MIMO to its 5G network. T-Mobile is already America’s 5G leader with the most advanced 5G network and fast 5G speeds in more places than any other wireless provider. T-Mobile’s Extended Range 5G now covers 280 million people across nearly 1.6 million square miles — that’s more than 2.5x the geographic coverage of AT&T and nearly 4x more than Verizon! And with Sprint now part of T-Mobile, the Un-carrier is widening its lead, lighting up Ultra Capacity 5G across the country and bringing fast 5G speeds to more places than anyone else. Ultra Capacity 5G can deliver average speeds of 300 Mbps with peaks approaching 1 Gbps and is now available in more than 1,000

Claim 1	Public Documentation
	cities and towns, covering more than 106 million people! That’s 50x more than Verizon covers with Ultra-Wideband! And at T-Mobile, 5G access is included at no extra charge in all smartphone plans. For more information on T-Mobile’s 5G network, visit: www.t-mobile.com/coverage/coverage-map. Follow T-Mobile’s Official Twitter Newsroom @TMobileNews to stay up-to-date with the latest company news. Ultra Capacity 5G includes dedicated mid- and/or high-band 5G signals. T-Mobile’s Ultra Capacity 5G covers hundreds of cities and millions of people, with more added all the time; see T-Mobile.com/5Glayers. Capable device required; coverage not available in some areas. Some uses may require certain plan or feature; see T-Mobile.com. https://www.businesswire.com/news/home/20210113005934/en/T-Mobile-to-Expand-and-Advance-the-Nation%E2%80%99s-Largest-5G-Network-with-New-5-Year-Agreements) <u>T-Mobile Supercharges 5G Standalone Uplink Speeds with Carrier Aggregation First</u> May 04, 2023 BELLEVUE, Wash. — May 4, 2023 What’s the news: T-Mobile worked with Nokia and Qualcomm to reach uplink speeds topping 200 Mbps in a 5G data call leveraging uplink carrier aggregation – the first-ever on a live commercial 5G standalone network in the U.S. Why it matters: Increased uplink speeds allow greater amounts of data to be transmitted from customer devices at a quicker rate, enhancing applications like video livestreaming/calling, gaming and Extended Reality (XR). Who it’s for: T-Mobile 5G customers nationwide. Speed ... UP! T-Mobile (NASDAQ: TMUS) announced today it achieved another 5G U.S. first by leveraging uplink (UL) carrier aggregation in the field on the country’s only nationwide 5G standalone (SA) network. Working with Nokia and a test smartphone powered by Snapdragon® 5G Modem-RF System from Qualcomm Technologies, Inc., the Un-carrier hit a top UL speed of 207 Mbps in the test – the <i>fastest ever</i> recorded using sub-6 GHz spectrum! This comes just weeks after T-Mobile made the same move in the lab, hitting similar speeds.

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	“T-Mobile has led the industry with 5G standalone since 2020, and we’re continuing to drive breakthroughs that advance 5G technology around the globe,” said Ulf Ewaldsson, President of Technology at T-Mobile. “We’re building the most advanced 5G network in the world, opening the door for massive innovation and laying the foundation for new capabilities that will transform the world around us.” 5G carrier aggregation allows T-Mobile to combine multiple channels (or carriers) to deliver greater speed and performance. In this test, the Un-carrier merged two 5G channels of mid-band spectrum – 2.5 GHz Ultra Capacity 5G and 1900 MHz. That’s like taking two separate highways and turning them into a superhighway where traffic can zoom faster than before. Customers with compatible devices will begin taking advantage of UL 5G carrier aggregation early next year when T-Mobile begins rolling it out. This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across 2 million square miles – more than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity – nearly everyone in the country – this year. https://www.t-mobile.com/news/network/t-mobile-supercharges-5g-standalone-uplink-speeds-with-carrier-aggregation-first WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations. We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates.

Claim 1	Public Documentation
	Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today. 5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation. Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation. https://www.nokia.com/networks/mobile-networks/carrier-aggregation/ Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners. Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson's collaboration with partners has so far resulted in several 5G firsts:

Claim 1	Public Documentation
	• World's first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5 GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile's mid-band 5G. It's also a key step in expanding T-Mobile's nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020) • A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung's Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek's Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020) • Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020) Per Narvinger, Head of Product Area Networks, Ericsson says: "From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we've developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer." Ericsson's 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation

Ericsson ups the tempo on 5G Carrier Aggregation with world's first downlink 6CC data call

Available in English [日本語](#)

Ericsson revs up the tempo on 5G Carrier Aggregation by combining six component carriers to set a record download speed of 5.7Gbps for the world's first 6CC (component carrier) data call.

NEWS

AUG 17, 2023

The data call was achieved using three FDD (frequency division duplex) bands combined with three TDD (time division duplex) bands in sub-6GHz, enabled by Ericsson RAN Compute hardware, state-of the-art carrier aggregation software, and innovative Advanced RAN Coordination functionality.

The 3FDD + 3TDD carrier aggregation testing was carried out in an Ericsson lab with a user equipment (UE) simulator. By combining FDD spectrum with TDD spectrum, more users can benefit from carrier aggregation gains.

In total, 400MHz of bandwidth was aggregated with FDD bandwidths ranging 20MHz to 50MHz to achieve the 5.7Gbps throughput. With six-component carrier capability, communications service providers can optimize use of network and spectrum assets to deliver higher data speeds and capacity that improve the experience of downlink-heavy applications. This can mean better audio and video quality for streaming users, faster file downloads, and a better working environment for digital nomads.

Sibel Tombaz, Head of Product Line 5G RAN at Ericsson Networks, says: "We are keeping the momentum on carrier aggregation by continuously stretching its potential to boost capacity and speed. Our successful 6CC data call shows how versatile our solution is and that we are poised to work with ecosystem partners to make this new band combination a reality. Our goal, as always, is to help customers meet end users' growing appetite for high-capacity, ultrahigh-speed 5G."

"Carrier Aggregation is crucial to getting the best possible 5G performance out of scattered spectrum assets," Tombaz adds. "And with 6CC, service providers will be able to maximize use of allocated spectrum and optimize the combined bandwidth for superior mobile experience."

<https://www.ericsson.com/en/news/2023/8/ericsson-ups-the-tempo-on-5g-carrier-aggregation-with-worlds-first-downlink-6cc-data-call>

Samsung Galaxy S20



Released 2020, March 06
163g, 7.9mm thickness
<> Android 10, up to Android 13, One UI 5
128GB storage, microSDXC

6.2"
1440x3200 pixels

64MP
4320p

8GB RAM
Exynos 990

4000mAh
Li-Ion

18%
6,985,860 HITS

456
BECOME A FAN

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Also available with 5G

NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE	COLLAPSE
	2G bands	GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only) CDMA 800 / 1900 & TD-SCDMA	
	3G bands	HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100 CDMA2000 1xEV-DO	
	4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66	
	Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps	

https://www.gsmarena.com/samsung_galaxy_s20-10081.php

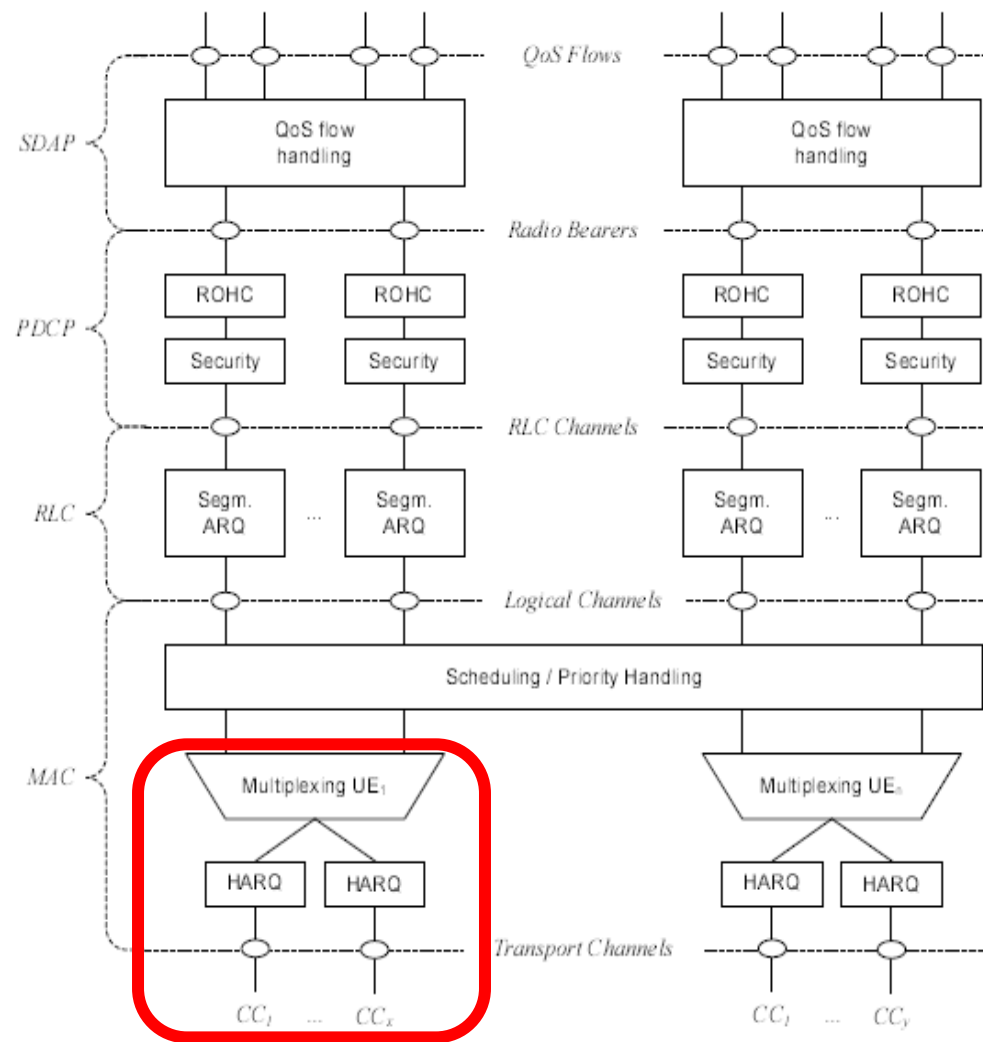
Claim 1	Public Documentation
	<i>5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work?</i> The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 1	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 1	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least \$140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

Claim 1	Public Documentation
	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/) <i>See, e.g.:</i> 5.2 Downlink 5.2.1 Downlink transmission scheme A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 V17.4.0) 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities:

Claim 1	Public Documentation
	- A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)

**Figure 6.7-1: Layer 2 Structure for DL with CA configured**

(3GPP TS 38.300 V17.4.0)

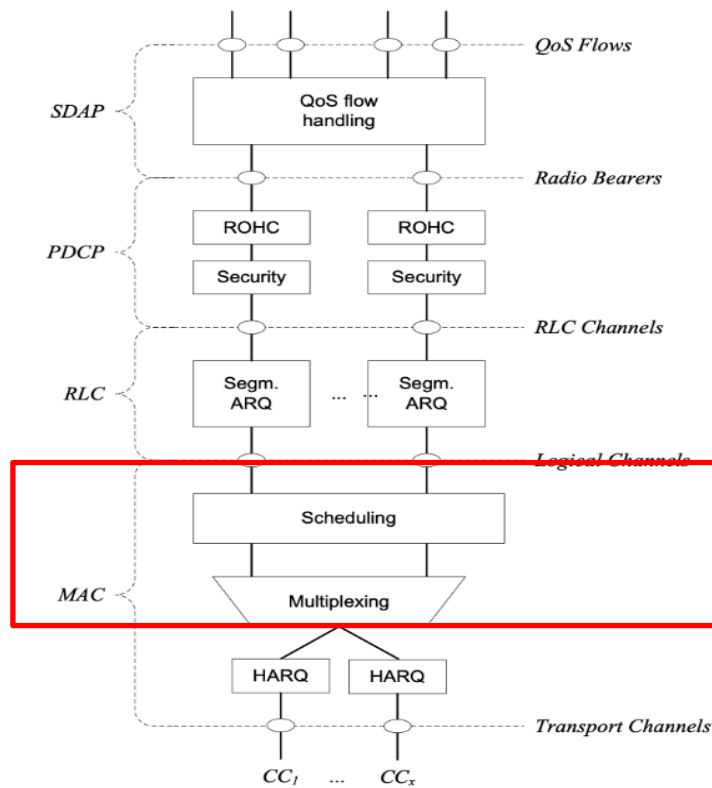


Figure 6.7-2: Layer 2 Structure for UL with CA configured

(3GPP TS 38.300 V17.4.0)

Claim 1	Public Documentation
	<i>5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work?</i> The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 1	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/

Claim 1	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least \$140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

SEE WHAT CARRIER AGGREGATION CAN DO FOR YOUR NETWORK

5G Carrier Aggregation -with Coverage Boost- powered by Advanced RAN Coordination is a versatile and blended solution for high-performing 5G networks. It is a game-changer for delivering extended coverage and increased network capacity while supporting

- Higher peak rates
- Flexible band combinations
- Intra and inter RAN Compute
- Both platforms, [Ericsson Radio System](#) and [Cloud RAN](#)

(<https://www.ericsson.com/en/ran/carrier-aggregation>)

THE BIG FEATURE: ENHANCED 5G CARRIER AGGREGATION ON IPHONE 13



The Qualcomm X60 is the first 5G modem capable of combining different types of 5G signals together.

The additional 5G bands are actually not the biggest cellular change with the iPhone 13.

Assuming the speculation proves true and Apple is indeed using the Qualcomm X60 modem - the real key cellular feature of the iPhone 13 is support for enhanced 5G carrier aggregation.

In addition to being much more power efficient, the big jump between the X55 and X60 modems revolves around improved 5G carrier aggregation - allowing the modem to better combine multiple signals on different frequency bands.

Claim 1	Public Documentation
	To get deeper into the nitty gritty of why this is (and why we've encouraged many to consider waiting for the X60), see our featured story from June 2021: 5G Industry Update: 5G Routers, Hotspots & Antennas Are Here – But Should You Wait? In a nutshell - the X60 is just more adept at combining long range and short range 5G signals. For example, the X60 can combine super short range mmWave with longer range mid-band or low-band 5G, helping to compensate for mmWave's range limitations. A more specific example: the X60 will allow T-Mobile's long-range low-band band n71 and super-fast mid-band n41 to be used by the modem simultaneously. This will give many T-Mobile customers the range of n71, without sacrificing the speed of n41. And another example - Verizon or AT&T will be able to combine their upcoming C-Band deployments (n77) with their longer range Sub-6 GHz 5G signals in ways that the X55 is just not capable of. (https://www.rvmobileinternet.com/apples-fall-2021-cellular-updates-new-iphone-13-modem-analysis-ipad-mini-goes-5g/#The_Big_Feature_Enhanced_5G_Carrier_Aggregation_on_iPhone_13)
[1a] transmitting first information across a first frequency range using a wireless transmitter, the first frequency range having a first center frequency, a first highest frequency, and a first lowest frequency; and	The Accused Instrumentalities perform a method including transmitting first information across a first frequency range using a wireless transmitter, the first frequency range having a first center frequency, a first highest frequency, and a first lowest frequency. For example, the Accused Instrumentalities transmit uplink information on a first component carrier with a frequency range with a first center frequency (labeled $F_{C,low}$ in the excerpt from 3GPP TS 38.101 V17.9.0 below), first highest frequency (highlighted in red below), and first lowest frequency (highlighted in blue below). This applies in the cases of intra-band contiguous, intra-band non-contiguous, and inter-band CA. <i>See, e.g.:</i> 5.2 Downlink 5.2.1 Downlink transmission scheme

Claim 1	Public Documentation
	A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 V17.4.0) 5.3 Uplink 5.3.1 Uplink transmission scheme Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission. For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI. A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. When transform precoding is used, only a single MIMO layer transmission is supported. Transmission durations from 1 to 14 symbols in a slot is supported. Aggregation of multiple slots with TB repetition is supported. (3GPP TS 38.300 V17.4.0)

5.4 Carrier aggregation

5.4.1 Carrier aggregation

In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities:

- A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG);
- A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell;
- A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG).

CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL.

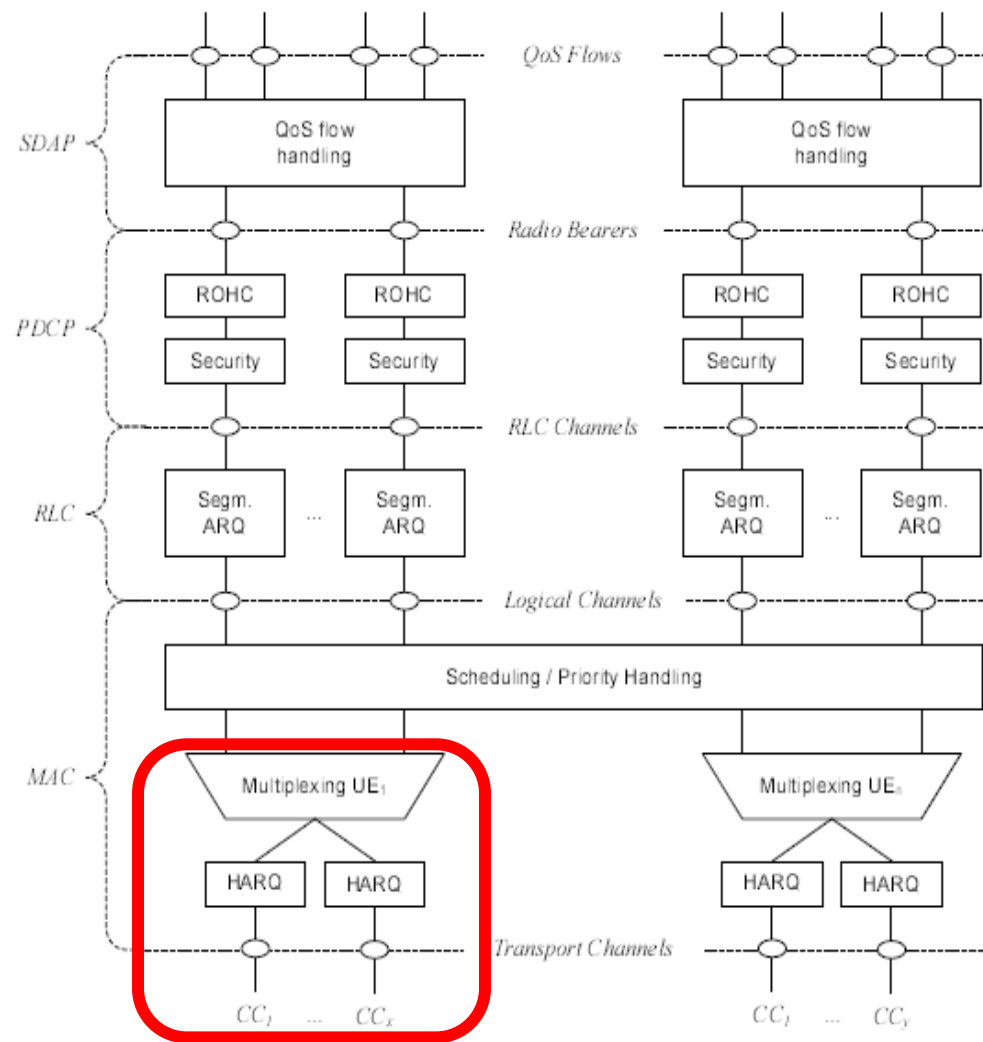
(3GPP TS 38.300 V17.4.0)

6.7 Carrier Aggregation

In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

(3GPP TS 38.300 V17.4.0)

**Figure 6.7-1: Layer 2 Structure for DL with CA configured**

(3GPP TS 38.300 V17.4.0)

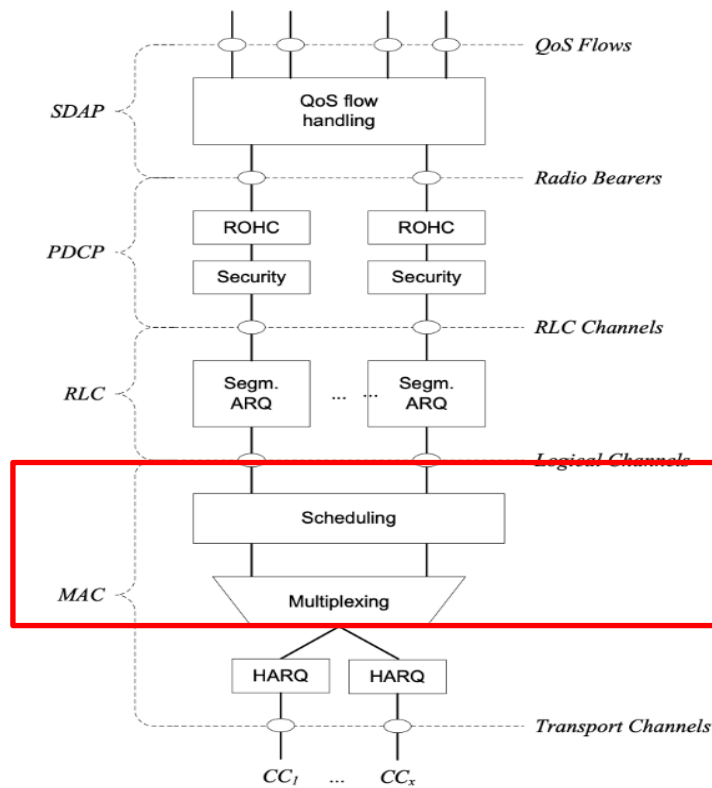


Figure 6.7-2: Layer 2 Structure for UL with CA configured
(3GPP TS 38.300 V17.4.0)

5.3A.2 Maximum transmission bandwidth configuration for CA

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

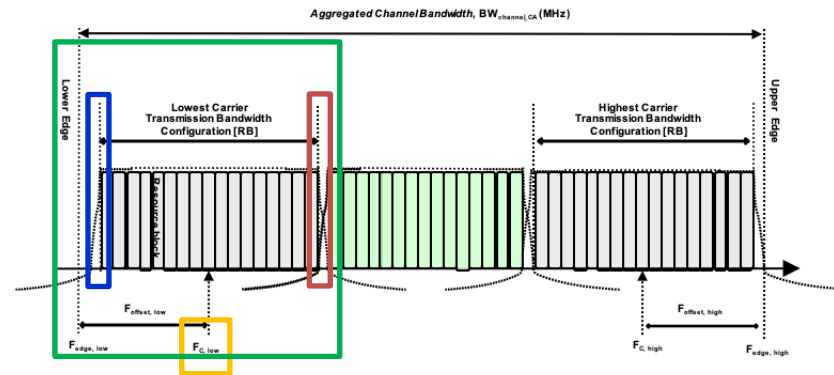


Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation

The *aggregated channel bandwidth*, $BW_{Channel_CA}$, is defined as

$$BW_{Channel_CA} = F_{edge,high} - F_{edge,low} \text{ (MHz)}.$$

The lower bandwidth edge $F_{edge,low}$ and the upper bandwidth edge $F_{edge,high}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

$$\begin{aligned} F_{edge,low} &= F_{C,low} - F_{offset,low} \\ F_{edge,high} &= F_{C,high} + F_{offset,high} \end{aligned}$$

The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as

$$F_{offset,low} = (N_{RB,low} * 12 + 1) * SCS_{low} / 2 + BW_{GB} \text{ (MHz)}$$

$$F_{offset,high} = (N_{RB,high} * 12 - 1) * SCS_{high} / 2 + BW_{GB} \text{ (MHz)}$$

$$BW_{GB} = \max(BW_{GB,Channel(k)})$$

$N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low} , SCS_{high} , $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $BW_{GB,Channel(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value.

In case there is no common μ value for both of the channel bandwidths, $\mu=1$ is used for SCS_{low} , SCS_{high} , $N_{RB,low}$, $N_{RB,high}$ and $BW_{GB,Channel(k)}$.

5.5A.1 Configurations for intra-band contiguous CA

Power class 3 is supported for all uplinks. Power classes other than power class 3 are supported as indicated in Table 5.5A.1-1.

Table 5.5A.1-1: NR CA configurations and bandwidth combination sets defined for intra-band contiguous CA

NR CA configuration / Bandwidth combination set								
NR CA configuration	Uplink CA configurations or single uplink carriers ⁵	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum aggregate bandwidth (MHz)	Bandwidth combination set
CA_n1B	-	10	10, 15				40	0
		15	15, 20					
		20	20					
CA_n2B	-	5	15				20	0
		10	10					
CA_n3B	-	5	15, 20, 25, 30				60	0
		10	10, 15, 20, 25, 30					
		15, 20, 25, 30	5, 10, 15, 20, 25, 30					
CA_n5B	CA_n5B	5, 10, 15	5, 10, 15				20	0
CA_n7B	CA_n7B	10	10, 15, 20, 30, 40				50	0
		15	15, 20, 30					
		20	20, 30					
CA_n25B	-	5	15				20	0
		10	10					
CA_n38B	-	5	15, 20, 25				50	0
		10	10, 15, 20, 25					
		15, 20, 25	5, 10, 15, 20, 25					
CA_n40B	-	20	80				100	0
		50	50					
	CA_n40B	10, 15, 20, 30, 40, 50, 60, 80	10, 15, 20, 30, 40, 50, 60, 80				100	1
CA_n41B	n41 ³	10, 20, 30, 40, 50	10, 20, 30, 40, 50				100	0
CA_n41C	n41 ^{3,4}	40	80, 100				180	0
	CA_n41C ³	50, 60, 80	60, 80, 100					
		10	100				190	1
		15, 20	90, 100					
		40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		10	100				190	2
		15, 20	90, 100					
		30, 40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier ²					190	4 and 5
CA_n46B	-	20, 40, 60	20, 40				100	0
CA_n46C	-	60, 80	60, 80				160	0
CA_n46D	-	60, 80	80	80			240	0
CA_n46M	-	20, 40, 60	20, 40	20, 40			140	0
CA_n46N	-	Void						0
	-	20, 40, 60	20, 40	20, 40	20, 40		180	1
CA_n46Q	-	20, 60	20, 40	20, 40	20, 40	20, 40	220	0
CA_n48B	CA_n48B	5	15, 20				40	0
		10, 15, 20	10, 15, 20					
		15, 20	15, 20					
	-	10	50, 60, 80, 90				100	1

(3GPP TS 38.101 V17.9.0)

5.5A.2 Configurations for intra-band non-contiguous CA

Table 5.5A.2-1: NR CA configurations and bandwidth combination sets defined for intra-band non-contiguous CA

NR CA Configuration	Uplink CA Configurations or single uplink carrier ^a	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum Aggregated bandwidth (MHz)	Bandwidth combination set
CA_n1(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n2(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n3(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
	-	5, 10, 15, 20, 25, 30	5, 10, 15, 20, 25, 30			60	1
CA_n5(2A)	-	5, 10, 15, 20	5, 10, 15, 20			25	0
CA_n7(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n12(2A)	-	5	5			10	0
CA_n25(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
	-	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40			60	1
	-	See n25 channel bandwidths in Table 5.3.5-1 for each carrier				60	4 and 5
CA_n25(3A)	-	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40		55	0
	-	See n25 channel bandwidths in Table 5.3.5-1 for each carrier				55	4 and 5
CA_n41(2A)	n41 ^{3,4} CA_n41(2A)	40, 50, 60, 80, 100	40, 50, 60, 80, 100			180	0
	-	10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100			190	1
	-	10, 15, 20, 30, 40, 50, 60, 80, 90	15, 20, 30, 40, 50, 60, 80, 90, 100			190	2
	-	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100			190	3
	-	See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(3A)	n41 ^{3,4}	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100		190	0
	-	See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(4A)	n41 ³	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	190	0
	-	See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n48(2A)		10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100			140 ²	0
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100			140 ²	1
CA_n48(3A)	-	10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100		140 ²	0
	-	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100		140 ²	1

(3GPP TS 38.101 V17.9.0)

Claim 1	Public Documentation
[1b] simultaneously transmitting second information across a second frequency range using the same wireless transmitter, the second frequency range having a second center frequency greater than the first center frequency, a second highest frequency, and a second lowest frequency.	The Accused Instrumentalities perform a method including simultaneously transmitting second information across a second frequency range using the same wireless transmitter, the second frequency range having a second center frequency greater than the first center frequency, a second highest frequency, and a second lowest frequency. For example, the Accused Instrumentalities transmit uplink information on a second component carrier with a frequency range with a second center frequency (labeled $F_{C,high}$ in the excerpt from 3GPP TS 38.101 V17.9.0 below), second highest frequency (highlighted in red below), and second lowest frequency (highlighted in blue below). This applies in the cases of intra-band contiguous, intra-band non-contiguous, and inter-band CA. The transmission is performed simultaneously using the same wireless transmitter, as set out in section 5.4 of 3GPP TS 38.300 V17.4.0. <i>See, e.g.:</i> 5.2 Downlink 5.2.1 Downlink transmission scheme A closed loop Demodulation Reference Signal (DMRS) based spatial multiplexing is supported for Physical Downlink Shared Channel (PDSCH). Up to 8 and 12 orthogonal DL DMRS ports are supported for type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions. The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of Physical Resource Blocks (PRBs) denoted Precoding Resource Block Group (PRG). Transmission durations from 2 to 14 symbols in a slot is supported. Aggregation of multiple slots with Transport Block (TB) repetition is supported. (3GPP TS 38.300 V17.4.0) 5.3 Uplink 5.3.1 Uplink transmission scheme Two transmission schemes are supported for PUSCH: codebook based transmission and non-codebook based transmission.

Claim 1	Public Documentation
	For codebook based transmission, the gNB provides the UE with a transmit precoding matrix indication in the DCI. The UE uses the indication to select the PUSCH transmit precoder from the codebook. For non-codebook based transmission, the UE determines its PUSCH precoder based on wideband SRI field from the DCI. A closed loop DMRS based spatial multiplexing is supported for PUSCH. For a given UE, up to 4 layer transmissions are supported. The number of code words is one. When transform precoding is used, only a single MIMO layer transmission is supported. Transmission durations from 1 to 14 symbols in a slot is supported. Aggregation of multiple slots with TB repetition is supported. (3GPP TS 38.300 V17.4.0) 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

Claim 1	Public Documentation
	- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. (3GPP TS 38.300 V17.4.0)

5.3A.2 Maximum transmission bandwidth configuration for CA

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

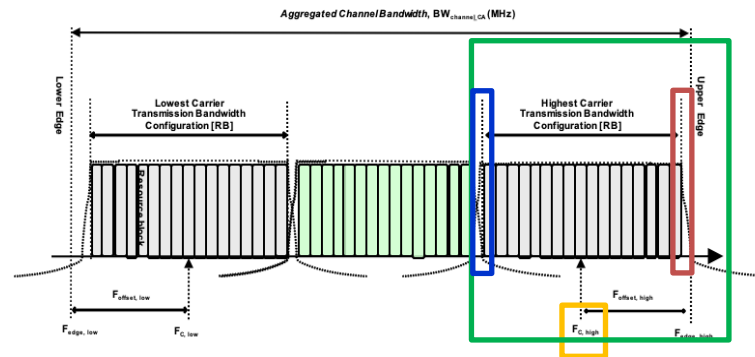


Figure 5.3A.3-1: Definition of Aggregated Channel Bandwidth for intra-band carrier aggregation

The aggregated channel bandwidth, $BW_{Channel_CA}$, is defined as

$$BW_{Channel_CA} = F_{edge,high} - F_{edge,low} \text{ (MHz)}.$$

The lower bandwidth edge $F_{edge,low}$ and the upper bandwidth edge $F_{edge,high}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

$$F_{edge,low} = F_{C,low} - F_{offset,low}$$

$$F_{edge,high} = F_{C,high} + F_{offset,high}$$

The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as

$$F_{offset,low} = (N_{RB,low} * 12 + 1) * SCS_{low} / 2 + BW_{GB} \text{ (MHz)}$$

$$F_{offset,high} = (N_{RB,high} * 12 - 1) * SCS_{high} / 2 + BW_{GB} \text{ (MHz)}$$

$$BW_{GB} = \max(BW_{GB,Channel(k)})$$

$N_{RB,low}$ and $N_{RB,high}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low} , SCS_{high} , $N_{RB,low}$, $N_{RB,high}$, and $BW_{GB,Channel(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $BW_{GB,Channel(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value.

In case there is no common μ value for both of the channel bandwidths, $\mu=1$ is used for SCS_{low} , SCS_{high} , $N_{RB,low}$, $N_{RB,high}$ and $BW_{GB,Channel(k)}$.

(3GPP TS 38.101 V17.9.0)

5.5A.1 Configurations for intra-band contiguous CA

Power class 3 is supported for all uplinks. Power classes other than power class 3 are supported as indicated in Table 5.5A.1-1.

Table 5.5A.1-1: NR CA configurations and bandwidth combination sets defined for intra-band contiguous CA

NR CA configuration / Bandwidth combination set								
NR CA configuration	Uplink CA configurations or single uplink carrier ¹	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum aggregated bandwidth (MHz)	Bandwidth combination set
CA_n1B	-	10	10, 15				40	0
		15	15, 20					
		20	20					
CA_n2B	-	5	15				20	0
		10	10					
CA_n3B	-	5	15, 20, 25, 30				60	0
		10	10, 15, 20, 25, 30					
		15, 20, 25, 30	5, 10, 15, 20, 25, 30					
CA_n5B	CA_n5B	5, 10, 15	5, 10, 15				20	0
CA_n7B	CA_n7B	10	10, 15, 20, 30, 40				50	0
		15	15, 20, 30					
		20	20, 30					
CA_n25B	-	5	15				20	0
		10	10					
CA_n38B	-	5	15, 20, 25				50	0
		10	10, 15, 20, 25					
		15, 20, 25	5, 10, 15, 20, 25					
CA_n40B	-	20	80				100	0
		50	50					
	CA_n40B	10, 15, 20, 30, 40, 50, 60, 80	10, 15, 20, 30, 40, 50, 60, 80					
CA_n41B	n41 ³ CA_n41B	10, 20, 30, 40, 50	10, 20, 30, 40, 50				100	0
		40	80, 100					
CA_n41C	n41 ^{3,4} CA_n41C ³	50, 60, 80	60, 80, 100				180	0
		10	100					
		15, 20	90, 100					
		40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		10	100				190	1
		15, 20	90, 100					
		30, 40	80, 90, 100					
		50, 60, 80, 90	60, 80, 90, 100					
		See n41 channel bandwidths in Table 5.3.5-1 for each carrier ²						
CA_n46B	-	20, 40, 60	20, 40				100	0
CA_n46C	-	60, 80	60, 80				160	0
CA_n46D	-	60, 80	80	80			240	0
CA_n46M	-	20, 40, 60	20, 40	20, 40			140	0
CA_n46N	-	Void						0
CA_n46O	-	20, 40, 60	20, 40	20, 40	20, 40		180	1
		20, 60	20, 40	20, 40	20, 40	20, 40	220	0
		5	15, 20				40	0
CA_n48B	CA_n48B	10, 15, 20	10, 15, 20				100	1
		15, 20	15, 20					
		10	50, 60, 80, 90					

(3GPP TS 38.101 V17.9.0)

5.5A.2 Configurations for intra-band non-contiguous CA

Table 5.5A.2-1: NR CA configurations and bandwidth combination sets defined for intra-band non-contiguous CA

NR CA Configuration	Uplink CA Configurations or single uplink carrier ^a	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Maximum Aggregated bandwidth (MHz)	Bandwidth combination set
CA_n1(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n2(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n3(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
	-	5, 10, 15, 20, 25, 30	5, 10, 15, 20, 25, 30			60	1
CA_n5(2A)	-	5, 10, 15, 20	5, 10, 15, 20			25	0
CA_n7(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
CA_n12(2A)	-	5	5			10	0
CA_n25(2A)	-	5, 10, 15, 20	5, 10, 15, 20			40	0
	-	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40			60	1
	-	See n25 channel bandwidths in Table 5.3.5-1 for each carrier				60	4 and 5
CA_n25(3A)	-	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40	5, 10, 15, 20, 25, 30, 40		55	0
	-	See n25 channel bandwidths in Table 5.3.5-1 for each carrier				55	4 and 5
CA_n41(2A)	n41 ^{3,4} CA_n41(2A)	40, 50, 60, 80, 100	40, 50, 60, 80, 100			180	0
	-	10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100			190	1
	-	10, 15, 20, 30, 40, 50, 60, 80, 90	15, 20, 30, 40, 50, 60, 80, 90, 100			190	2
	-	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100			190	3
	-	See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(3A)	n41 ^{3,4}	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100		190	0
	-	See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n41(4A)	n41 ³	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	190	0
	-	See n41 channel bandwidths in Table 5.3.5-1 for each carrier				190	4 and 5
CA_n48(2A)		10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100			140 ²	0
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100			140 ²	1
CA_n48(3A)	-	10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100	10, 15, 20, 40, 50, 60, 80, 90, 100		140 ²	0
		10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100	10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100		140 ²	1

(3GPP TS 38.101 V17.9.0)

Claim 1	Public Documentation
	5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0)

Claim 2

Claim 2	Public Documentation
[2] The method of claim 1 wherein frequency difference between the first	The Accused Instrumentalities perform a method wherein the frequency difference between the first center frequency and the second center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range.

Claim 2	Public Documentation
center frequency and the second center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range.	For example, the bandwidth from the center of the first carrier component (“first frequency”) to the second carrier component (“second frequency”) comprising half of the first carrier component and half of the second carrier component plus the guard band between the two carrier component, is greater than the half of the first frequency and half of the second frequency. <i>See, e.g.:</i> 5.3A.2 Maximum transmission bandwidth configuration for CA For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2. 5.3A.3 Minimum guardband and transmission bandwidth configuration for CA For intra-band contiguous carrier aggregation, <i>Aggregated Channel Bandwidth</i> and <i>Guard Bands</i> are defined as follows, see Figure 5.3A.3-1.

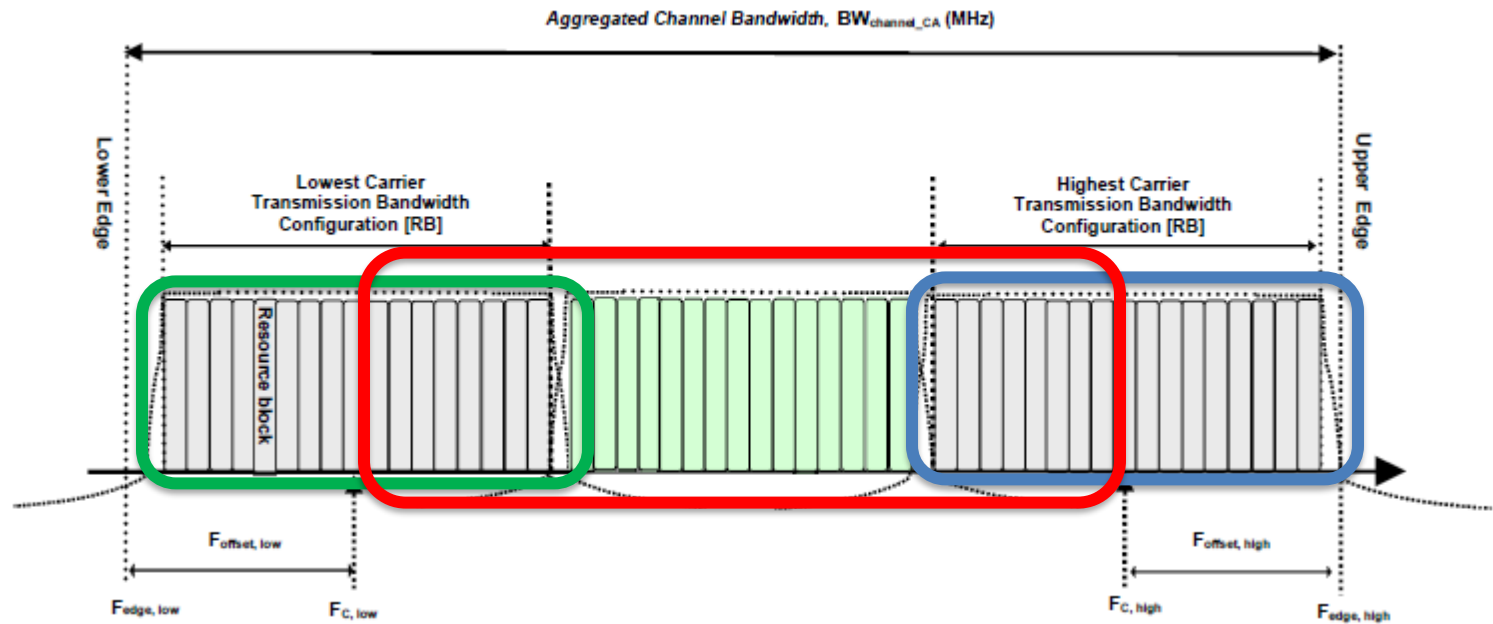


Figure 5.3A.3-1: Definition of Aggregated Channel Bandwidth for intra-band carrier aggregation

$$BW_{\text{Channel_CA}} = F_{\text{edge,high}} - F_{\text{edge,low}} \text{ (MHz)}.$$

The lower bandwidth edge $F_{\text{edge,low}}$ and the upper bandwidth edge $F_{\text{edge,high}}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

$$F_{\text{edge,low}} = F_{C,\text{low}} - F_{\text{offset,low}}$$

$$F_{\text{edge,high}} = F_{C,\text{high}} + F_{\text{offset,high}}$$

The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as

$$F_{\text{offset,low}} = (N_{RB,\text{low}} * 12 + 1) * SCS_{\text{low}} / 2 + BW_{GB} \text{ (MHz)}$$

Claim 2	Public Documentation
	$\text{Offset}_{\text{high}} = (\text{NRB}_{\text{high}} * 12 - 1) * \text{SCS}_{\text{high}} / 2 + \text{BWGB} \text{ (MHz)}$ $\text{BWGB} = \max(\text{BWGB}_{\text{Channel}(k)})$ NRB_{low} and NRB_{high} are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low}, SCS_{high}, NRB_{low}, NRB_{high}, and BWGB_{Channel(k)} use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and BWGB_{Channel(k)} is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value. In case there is no common μ value for both of the channel bandwidths, $\mu=1$ is used for SCS_{low}, SCS_{high}, NRB_{low}, NRB_{high}, and BWGB_{Channel(k)}. (3GPP TS 38.101-1 V17.5.0)

Claim 3

Claim 3	Public Documentation
[3] The method of claim 1 wherein the first and second information are transmitted using the same power amplifier in said wireless transmitter.	The Accused Instrumentalities perform a method wherein the first and second information are transmitted using the same power amplifier in said wireless transmitter. <i>See, e.g.:</i>

Claim 3	Public Documentation
	11.3.2.1 Transmitter architecture Figure 11.3.2.1-1 illustrates various TX architectures options according to where the component carriers are combined, i.e., at digital baseband, or in analog waveforms before RF mixer, or after mixer but before the PA, or after the PA. Option A - In an adjacent <i>contiguous common carrier</i> aggregation scenario, the UE very likely has one PA. Connected to the PA can be a single RF chain (a zero-IF mixer, a wideband DAC, and a wideband IFFT) Option-B - Combines analog baseband waveforms from component Carrier first (e.g., via a mixer operating at an IF of roughly the bandwidth of the other component carrier in the example of 2-component carrier aggregation). Then the resulting wideband signal is up-converted to RF. Option-C - <u>Does ZIF up-conversion of each component carrier before combining and feeding into a single PA.</u> Option-D - Employs multiple RF chains and multiple PAs after which the high-power signals are combined and fed into a single antenna. PA coupling at the UE can be challenging for option-D. (3GPP TR 36.912 version 15.0.0 Release 15)

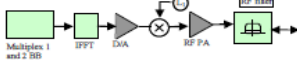
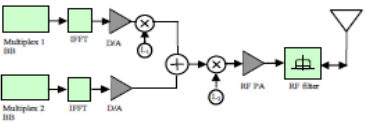
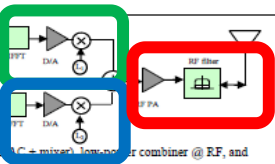
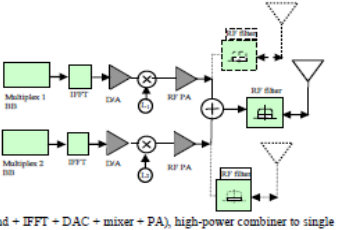
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios
(3GPP TR 36.912 version 15.0.0 Release 15)

Claim 4

Claim 4	Public Documentation
[4] The method of claim 3 wherein the bandwidth of said power amplifier is greater than the difference between the first lowest frequency and the second highest frequency.	The Accused Instrumentalities perform a method wherein the bandwidth of said power amplifier is greater than the difference between the first lowest frequency and the second highest frequency.  PRODUCT SUMMARY SKY77786-11 High Band Multimode Multiband Power Amplifier Module Supporting LTE Advanced Applications Applications • Multiband 4G / LTE handsets • FDD LTE Bands 7 and 30 • TDD LTE Band 38, 40, 41 Features • Two T/R (RX) port and 3 outputs • Industry-leading PAE for 4G • Optimized for APT DCDC operation • Fully programmable Mobile Industry Processor Interface (MIPI) control • MIPI programmable bias modes optimize best 4G efficiency/linearity performance. • Small, low profile package: - 3.0 x 3.0 x 0.71 mm - 20-pad configuration  Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to Skyworks Definition of Green™, document number SQ04-0074. Description Skyworks SKY77786-11 SkyLiTETM is a multimode multiband (MMMR) Power Amplifier Module (PAM) that supports 4G handsets and operates efficiently in LTE bands from 2.3 GHz to 2.7 GHz. The module is fully programmable through a Mobile Industry Processor Interface (MIPI®). The PAM consists of a single high band LTE block, a Multi-Function Control (MFC) block, and a T/R switch block. RF input/output ports internally matched to 50 Ω to reduce the number of external components. A CMOS integrated circuit uses standard MIPI controls to provide the internal MFC interface and operation. Extremely low leakage current maximizes handset standby time. The InGaP die and the silicon die and passive components are mounted on a multi-layer laminate substrate. The assembly is encapsulated in a 3.0 mm x 3.0 mm x 0.71 mm, 20-pad MCM, SMT package which is a more highly manufacturable, low cost solution. 4G: The SKY77786-11 supports 1.4, 3, 5, 10, 15, 20, 30, 35, 40 MHz channel bandwidths. Similar to 3G operation, output power is controlled by varying the input power and V_{CC} is adjusted using a DCDC converter to maximize efficiency for each power level. 4G Modulation scheme includes: - FDD LTE - TDD LTE - Uplink Carrier Aggregation (CA) support for Bands 40/41 (up to 40 MHz)

Claim 4	Public Documentation

Claim 6

Claim 6	Public Documentation
[6] The method of claim 1 wherein the first information corresponds to a first wireless protocol and the second information corresponds to a second wireless protocol.	The Accused Instrumentalities perform a method wherein the first information corresponds to a first wireless protocol and the second information corresponds to a second wireless protocol. <i>See, e.g.:</i> Cellular operators, for example T-MO, have deployed carrier aggregation in mid band (2.5 GHz, 3.5 GHz), in 1900 MHz PCS band as well as the 600 MHz band. In the mid band such as the 2.5 GHz or 3.5 GHz TDD protocol has been deployed. In the PCS 1900 MHz and 600 MHz bands, FDD 5G and LTE protocols have been deployed. Two protocols, FDD and TDD, are used in these carrier aggregation deployments. The carrier aggregation tested by Galaxy 22 and Galaxy 23 on T-MO network supported both TDD and FDD protocols. <u>SRG tests T-Mo's FDD-TDD CA: 'You can have your cake and eat it too'</u> January 11, 2022 The aggregation of 600 MHz + 2.5 GHz uses low-band, FDD spectrum to improve performance The aggregation of low and mid-band carriers in <u>both Frequency Division Duplex (FDD)</u> and <u>Time Division Duplex (TDD)</u> spectrum improves cell edge performance in T-Mobile US' network, according to recent testing by Signals Research Group. SRG tested the <u>FDD+TDD</u> carrier aggregation (CA) in T-Mobile US' commercial network. The testing was conducted during the first week of December, at a large cluster of Ericsson sites in a 180-square-kilometer swath of the suburban Maryland/Washington, D.C. area.

Claim 6	Public Documentation
	“A few mobile operators have already launched TDD-TDD CA in other parts of the world but to the best of our knowledge T-Mobile is the first operator in the world to deploy FDD-TDD CA functionality in a commercial network,” SRG noted. SRG said that <u>T-Mobile US provided the test SIMs and insight into the cluster where the testing was conducted, as well as two Galaxy S21 smartphones</u> — one with pre-commercial software on it that allowed the consulting group to test some of the features it was interested in. Intriguingly, however, SRG found that both devices appeared to support much the same functionality, with a bit of finessing of “hidden” menu options to force the smartphones into the modes of operation that it wanted to test. SRG used test tools from Accuver Americas and Spirent Communications to conduct the study. The firm said that the cell cluster supported a “wide range of different technologies,” including both NSA and SA 5G, using <u>T-Mo’s 600 MHz (FDD) and/or 2.5 GHz (TDD) spectrum</u>. In terms of 5G New Radio CA, the sites either used two 5G NR carriers at 2.5 GHz, leveraging T-Mo’s deep midband holdings for TDD-TDD carrier aggregation; <u>or they paired a single radio channel of 600 MHz spectrum with a single channel of 2.5 GHz — the FDD-TDD CA that SRG sought to test.</u> https://www.rcrwireless.com/20220111/test-and-measurement/srg-tests-t-mos-fdd-tdd-ca-you-can-have-your-cake-and-eat-it-too <u>T-MOBILE US USED THE SAMSUNG GALAXY S22 PHONE POWERED BY SNAPDRAGON 8 GEN 1 MOBILE PLATFORM</u> <u>T-Mobile US said it was able to aggregate three channels of mid-band 5G spectrum, reaching speeds over 3 Gbps on its standalone 5G network. The carrier used the Samsung Galaxy S22 phone powered by Snapdragon 8 Gen 1 Mobile Platform with Snapdragon X65 Modem-RF System on a live production network.</u> “This test demonstrates the incredible power of mid-band spectrum and represents another huge step forward for standalone 5G,” said Neville Ray, president of Technology at T-Mobile. “Only T-Mobile is delivering a nationwide standalone 5G network to customers today, and we’re blazing a trail with new performance-boosting capabilities that generate incredible speeds and deliver on our vision to create the highest capacity network in the country.”

Claim 6	Public Documentation
	T-Mobile US noted that 5G Carrier Aggregation (NR CA) allows the combination of multiple 5G channels to improve speed and performance. In this test, the carrier merged three 5G channels — <u>two channels of 2.5 GHz Ultra Capacity 5G</u> and <u>one channel of 1900 MHz spectrum</u> — to create an effective 210 MHz 5G channel. T-Mobile claimed to be the first operator in the world to launch a nationwide SA 5G network nearly two years ago. NR CA is already live in parts of T-Mobile’s network combining two 2.5 GHz 5G channels. The telco said that those customers with the Samsung Galaxy S22 will be among the first to experience a third 1900 MHz 5G channel later this year. This capability will expand across the carrier’s network and to additional devices in the near future. Earlier this month, T-Mobile U.S. announced that customers in limited areas of Portland and Salt Lake City who have the Samsung Galaxy S21 5G now have access to Voice Over New Radio (VoNR) services. The carrier said additional cities will be added to the list throughout the remainder of this year. According to T-Mobile US, VoNR brings the promise of Standalone (SA) 5G “one step closer” by enabling advanced capabilities like network slicing that rely on a continuous connection to a 5G core. At the recent Big 5G Event in Austin, Texas, Ray told <i>RCR Wireless News</i> that in addition to ultimately supporting 5G voice calls, VoNR, without a Non-Standalone 5G or LTE anchor, sees its investment in low-band as the “foundation” of the company’s network. The carrier’s Extended Range 5G (low-band 600 MHz spectrum) covers 315 million people across 1.8 million square miles, while 225 million people nationwide are covered with its Ultra Capacity 5G (2.5 GHz spectrum). The carrier expects to cover 260 million in 2022 and 300 million next year. https://www.rcrwireless.com/20220615/5g/t-mobile-us-tops-3-gbps-standalone-5g- <u>T-Mobile Revs Up 5G with Four-Carrier Aggregation</u> July 25, 2023 What’s the news: T-Mobile has begun rolling out four-carrier aggregation for customers, boosting speeds on its 5G standalone (SA) network.

Claim 6	Public Documentation
	Why it matters: 5G SA is the future of wireless, delivering a whole new level of performance with faster speeds and lower latency (quicker response times). 5G carrier aggregation allows T-Mobile to turbocharge 5G SA speeds, giving customers a game-changing performance boost. Who it's for: T-Mobile customers across the country. Pedal, meet metal. T-Mobile (NASDAQ: TMUS) today announced it has begun rolling out four-carrier aggregation on its 5G SA network, delivering the capability for insanely fast speeds to customers across the country. If you need help translating ... insanely fast = peak speeds topping 3.3 Gbps in recent tests. Four-carrier aggregation is live in parts of T-Mobile's network now and will be available nationwide in the coming weeks. "T-Mobile is blazing the trail for wireless customers around the globe, delivering new capabilities that unleash the true potential of 5G," said Ulf Ewaldsson, President of Technology at T-Mobile. "With the only nationwide 5G standalone network in the country, T-Mobile is the ONLY provider bringing game-changing technologies like four-carrier aggregation to customers across the country." 5G carrier aggregation allows T-Mobile to combine multiple 5G channels (or carriers) to deliver greater speed and performance. The Un-carrier is now merging four 5G channels of sub-6 GHz spectrum – two channels of 2.5 GHz Ultra Capacity 5G, one channel of 1900 MHz and one channel of 600 MHz spectrum. That's like taking four separate highways and turning them into a massive superhighway where traffic can zoom faster than before. <u>Customers with the Samsung Galaxy S23 will be the first to experience four-carrier aggregation with more devices to follow.</u> This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country's largest, fastest and most awarded 5G network. The Un-carrier's 5G network covers 326 million people across two million square miles – more square miles than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile's super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity this year – nearly everyone in the country. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation

Claim 6	Public Documentation

Claim 7

Claim 7	Public Documentation
[7] The method of claim 1 wherein the first information and the second information are the same data transmitted across two different frequencies.	The Accused Instrumentalities perform a method wherein the first information and the second information are the same data transmitted across two different frequencies. For example, the packet duplication feature of 5G release 15 transmits the same data on two carrier components of carrier aggregation transmission method, i.e., the first and second data destined to two carriers are the same. (3GPP TS 38.300 version 16.2.0) See, e.g.: 16.1.3 <u>Packet Duplication</u> <u>When duplication is configured for a radio bearer by RRC, at least one secondary RLC entity is added to the radio bearer to handle the duplicated PDCP PDUs as depicted on Figure 16.1.3-1</u>, where the logical channel corresponding to the primary RLC entity is referred to as <i>the primary logical channel</i>, and the logical channel corresponding to the secondary RLC entity(ies), the <i>secondary logical channel(s)</i>. All RLC entities have the same RLC mode. Duplication at PDCP therefore consists in submitting the same PDCP PDUs multiple times: once to each activated RLC entity for the radio bearer. With multiple independent transmission paths, packet duplication therefore increases reliability and reduces latency and is especially beneficial for URLLC services. <pre>graph TD PDCP[PDCP] --> RLC_primary[RLC primary] PDCP -.-> RLC_secondary[RLC secondary] RLC_primary --> Primary_LCH[Primary LCH] RLC_secondary -.-> Secondary_LCH[Secondary LCH]</pre> Figure 16.1.3-1: Packet Duplication

Claim 7	Public Documentation
	When configuring duplication for a DRB, RRC also sets the state of PDCP duplication (either activated or deactivated) at the time of (re-)configuration. After the configuration, the PDCP duplication state can then be dynamically controlled by means of a MAC control element and in DC, the UE applies the MAC CE commands regardless of their origin (MCG or SCG). When duplication is configured for an SRB the state is always active and cannot be dynamically controlled. When configuring duplication for a DRB with more than one secondary RLC entity, RRC also sets the state of each of them (i.e. either activated or deactivated). Subsequently, a MAC CE can be used to dynamically control whether each of the configured secondary RLC entities for a DRB should be activated or deactivated, i.e. which of the RLC entities shall be used for duplicate transmission. Primary RLC entity cannot be deactivated. When duplication is deactivated for a DRB, all secondary RLC entities associated to this DRB are deactivated. When a secondary RLC entity is deactivated, it is not re-established, the HARQ buffers are not flushed, and the transmitting PDCP entity should indicate to the secondary RLC entity to discard all duplicated PDCP PDUs. When activating duplication for a DRB, NG-RAN should ensure that at least one serving cell is activated for each logical channel of the DRB; and when the deactivation of SCells leaves no serving cells activated for a logical channel of the DRB, NG-RAN should ensure that duplication is also deactivated. <u>When duplication is activated, the original PDCP PDU and the corresponding duplicate(s) shall not be transmitted on the same carrier. The primary and secondary logical channels can either belong to the same MAC entity (referred to as CA duplication) or to different ones (referred to as DC or DC+CA duplication). CA duplication can be configured together with DC duplication when duplication over more than two legs is configured in the UE. In CA duplication, logical channel mapping restrictions are used in MAC to ensure that the primary and secondary logical channels are not sent on the same carrier.</u> When CA duplication is configured for an SRB, one of the logical channels associated to the SRB is mapped to SpCell. When CA duplication is deactivated for a DRB, the logical channel mapping restrictions of the primary and secondary logical channels are lifted for as long as duplication remains deactivated. When an RLC entity acknowledges the transmission of a PDCP PDU, the PDCP entity shall indicate to the other RLC entity(ies) to discard it. In addition, in case of CA duplication, when an RLC entity restricted to only SCell(s) reaches the maximum number of retransmissions for a PDCP PDU, the UE informs the gNB but does not trigger RLF.

Claim 7	Public Documentation
	(3GPP TS 38.300 version 16.2.0)

Claim 8

Claim 8	Public Documentation
[8] The method of claim 1 wherein the first information and the second information are from the same data stream.	The Accused Instrumentalities perform a method wherein the first information and the second information are from the same data stream. For example, the packet duplication may be deactivated. When packet duplication is deactivated, the same data stream is multiplexed onto the multiple component carriers (CCs) of carrier aggregation method. The data transmitted on the first component carrier (“first information”) and the data transmitted on the second component carrier (“second information”) are from multiplexing the same data stream for transmission onto the two carriers. <i>See, e.g.:</i> 5.11.1 ACTIVATION/DEACTIVATION OF PDCP DUPLICATION For the PDCP entity configured with <i>pdcp-Duplication</i>, the transmitting PDCP entity shall: - for SRBs: - activate the PDCP duplication; - for DRBs: - if the activation of PDCP duplication is indicated for the DRB: - activate the PDCP duplication for the DRB; - if the activation of PDCP duplication is indicated for at least one associated RLC entities: - activate the PDCP duplication for the indicated associated RLC entities; - activate the PDCP duplication for the DRB; - if the deactivation of PDCP duplication is indicated for the DRB: - deactivate the PDCP duplication for the DRB; - <u>if the deactivation of PDCP duplication is indicated for at least one associated RLC entities:</u> - <u>deactivate the PDCP duplication for the indicated associated RLC entities;</u> - <u>if all associated RLC entities other than the primary RLC entity are deactivated for PDCP duplication:</u> - <u>deactivate the PDCP duplication for the DRB.</u>

(3GPP TS 38.323 V17.4.0)

6.7 CARRIER AGGREGATION

In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

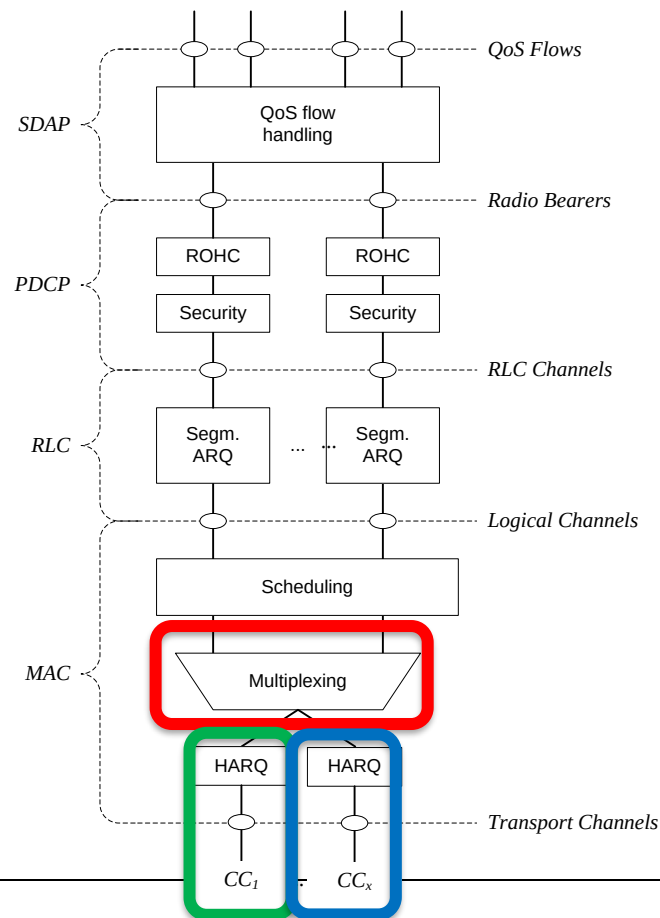


Figure 6.7-2: Layer 2 Structure for UE with CA configured.

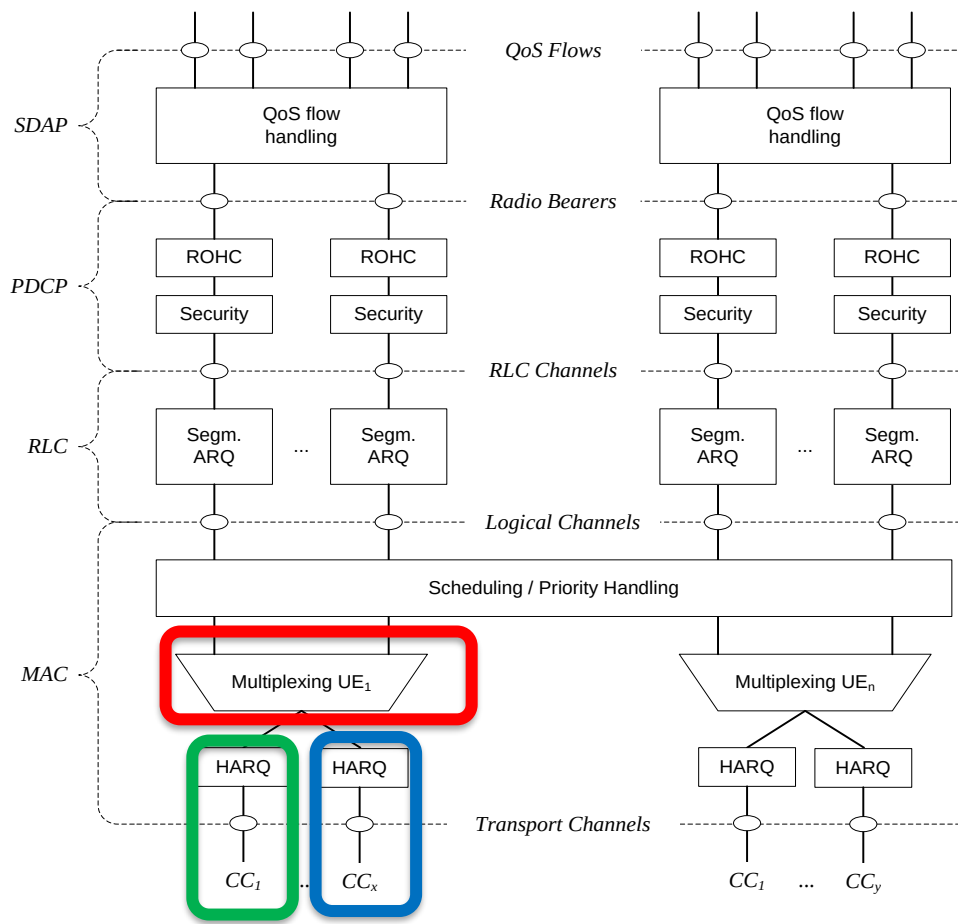


Figure 6.7-1: Layer 2 Structure for DL with CA configured.

Claim 8	Public Documentation
	(3GPP TS 38.300 V17.4.0)

Claim 9

Claim 9	Public Documentation
[9] The method of claim 1 wherein first information and second information comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first frequency range and a second symbol is transmitted during the first time slot across the second frequency range, and wherein a third symbol is transmitted during a second time slot across the first frequency range and a fourth symbol is transmitted during the second time slot across a second frequency range.	The Accused Instrumentalities perform a method wherein first information and second information comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first frequency range and a second symbol is transmitted during the first time slot across the second frequency range, and wherein a third symbol is transmitted during a second time slot across the first frequency range and a fourth symbol is transmitted during the second time slot across a second frequency range. For example, the 5G frame structure comprises frames of length 10 msec long, each frame comprises 10 sub-frames, each subframe comprises at least two time slots, and each frame comprises at least 20 time slots. Each time slot comprises a multitude of OFDM symbols. A transport block, data payload, in 5G is divided into a set of code blocks, each code block is transmitted on frequency resources of OFDM symbols that comprise a time slot. In a Carrier Aggregation (CA) method, a data stream is multiplexed onto multiple Component Carriers (CCs), e.g., onto a first and a second data stream. The first and second data (“information”) streams are transmitted on a first and a second CC, respectively. The first data stream is transmitted on a first CC, on frequency resources of an OFDM symbol in a time slot of the first CC, and the second data stream is transmitted on a second CC, on frequency resources of an OFDM symbol in the time slot of the second CC. The code blocks of the transport block (payload, data stream) are multiplexed onto the CCs and transmitted in consecutive time slots. <i>See, e.g.:</i> 6.7 CARRIER AGGREGATION In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

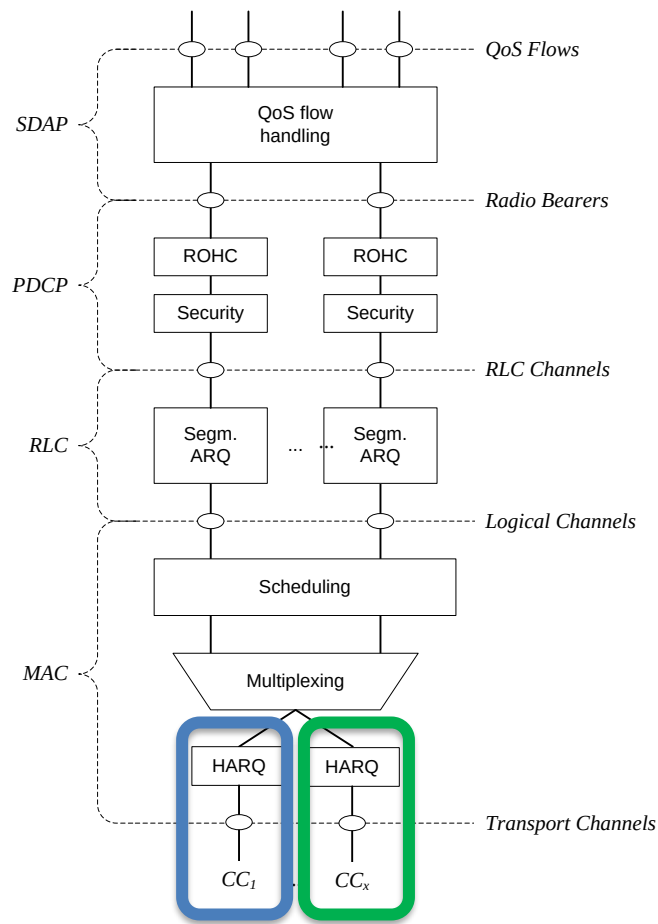


Figure 6-2: Layer 2 Structure for UL with CA configured.

(3GPP TS 38.300 V17.4.0)

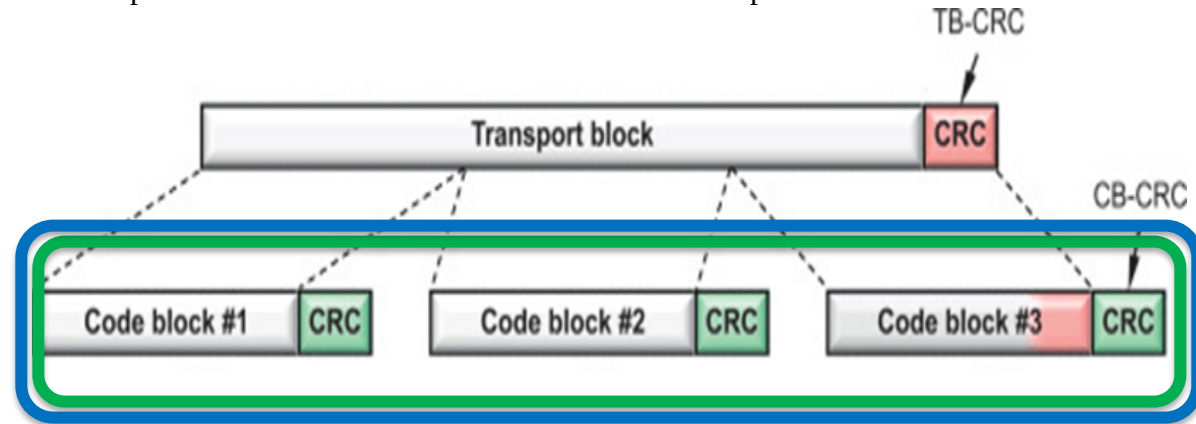
Frame structure and physical resources

4.1 GENERAL

Claim 9	Public Documentation																		
	Throughout this specification, unless otherwise noted, the size of various fields in the time domain is expressed in time units $T_c = 1/(\Delta f_{\max} \cdot N_f)$ where $\Delta f_{\max} = 480 \cdot 10^3$ Hz and $N_f = 4096$. The constant $\kappa = T_s/T_c = 64$ where $T_s = 1/(\Delta f_{\text{ref}} \cdot N_{f,\text{ref}})$, $\Delta f_{\text{ref}} = 15 \cdot 10^3$ Hz and $N_{f,\text{ref}} = 2048$. Throughout this specification, unless otherwise noted, statements using the term "UE" in clauses 4, 5, 6, or 7 are equally applicable to the IAB-MT part of an IAB node. 4.2 NUMEROLOGIES Multiple OFDM numerologies are supported as given by Table 4.2-1 where μ and the cyclic prefix for a downlink or uplink bandwidth part are obtained from the higher-layer parameter <i>subcarrierSpacing</i> and <i>cyclicPrefix</i>, respectively. Table 4.2-1: Supported transmission numerologies. <table><tr><th>μ</th><th>$\Delta f = 2^\mu \cdot 15$ [kHz]</th><th>Cyclic prefix</th></tr><tr><td>0</td><td>15</td><td>Normal</td></tr><tr><td>1</td><td>30</td><td>Normal</td></tr><tr><td>2</td><td>60</td><td>Normal, Extended</td></tr><tr><td>3</td><td>120</td><td>Normal</td></tr><tr><td>4</td><td>240</td><td>Normal</td></tr></table> 4.3 FRAME STRUCTURE 4.3.1 FRAMES AND SUBFRAMES Downlink, uplink, and sidelink transmissions are organized into frames with $T_f = (\Delta f_{\max} N_f / 100) \cdot T_c = 10\text{ms}$ duration, each consisting of ten subframes of $T_{\text{sf}} = (\Delta f_{\max} N_f / 1000) \cdot T_c = 1\text{ms}$ duration. The number of consecutive OFDM symbols per subframe is $N_{\text{symb}}^{\text{subframe},\mu} = N_{\text{symb}}^{\text{slot}} N_{\text{slot}}^{\text{subframe},\mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9. There is one set of frames in the uplink and one set of frames in the downlink on a carrier.	μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix	0	15	Normal	1	30	Normal	2	60	Normal, Extended	3	120	Normal	4	240	Normal
μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix																	
0	15	Normal																	
1	30	Normal																	
2	60	Normal, Extended																	
3	120	Normal																	
4	240	Normal																	

Claim 9	Public Documentation
	Uplink frame number i for transmission from the UE shall start $T_{TA} = (N_{TA} + N_{TA,offset})T_c$ before the start of the corresponding downlink frame at the UE where $N_{TA,offset}$ is given by [5, TS 38.213], except for msgA transmission on PUSCH where $T_{TA} = 0$ shall be used. Figure 4.3.1-1: Uplink-downlink timing relation. 4.3.2 SLOTS For subcarrier spacing configuration μ, slots are numbered $n_s^\mu \in \{0, \dots, N_{slot}^{subframe,\mu} - 1\}$ in increasing order within a subframe and $n_{s,f}^\mu \in \{0, \dots, N_{slot}^{frame,\mu} - 1\}$ in increasing order within a frame. There are N_{symb}^{slot} consecutive OFDM symbols in a slot where N_{symb}^{slot} depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. <u>The start of slot n_s^μ in a subframe is aligned in time with the start of OFDM symbol $n_s^\mu N_{symb}^{slot}$ in the same subframe.</u> <u>OFDM symbols in a slot</u> in a downlink or uplink frame can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in clause 11.1 of [5, TS 38.213]. (3GPP TS 38.211 V16.1.0) <u>5G NR Transport Block Size (TBS) Calculation</u> <u>August 16, 2020</u><u>Author</u><u>3GPP Specification, 5G MAC Layer, 5G NR, 5G Physical Layer</u> Frame structure and physical resources Transport Block in 5G NR, is nothing but the payload, which is passed between the MAC and Phy Layers, specifically for the shared data channel such as PDSCH and PUSCH. A Transport Block undergoes Phy layer

processing at the transmitter before being mapped onto the PDSCH for transmission over the air interface. A Transport block is added with CRC and segmented into code blocks as shown as below. The transport block consists of up to million bits and the code block consists of up to 8448 bits.



(<https://www.techplayon.com/5g-nr-transport-block-size-tbs-calculatin>)

TIME-FREQUENCY RESOURCE

A **resource element** is the smallest time-frequency resource over one subcarrier of a single OFDM symbol. It is identified as $(k, l)_{p, \mu}$ where k is the index of the subcarrier in the frequency domain, l is the OFDM symbol position in time domain, p is the antenna port and μ is the subcarrier spacing configuration defined in Table 1 above.

A **resource block** (a.k.a **physical resource block – PRB**) is a block of $N^{RB}_{sc} = 12$ subcarriers over which the transmissions are scheduled. 5G NR physical layer uses time-frequency resource (**physical resource block**) for transmission.

A resource grid consists of $N_{grid,x}^{size,\mu}$ subcarriers and $N_{subframe,\mu}^{subframe,\mu}$ number of OFDM symbols (*Table 2 and 3*).

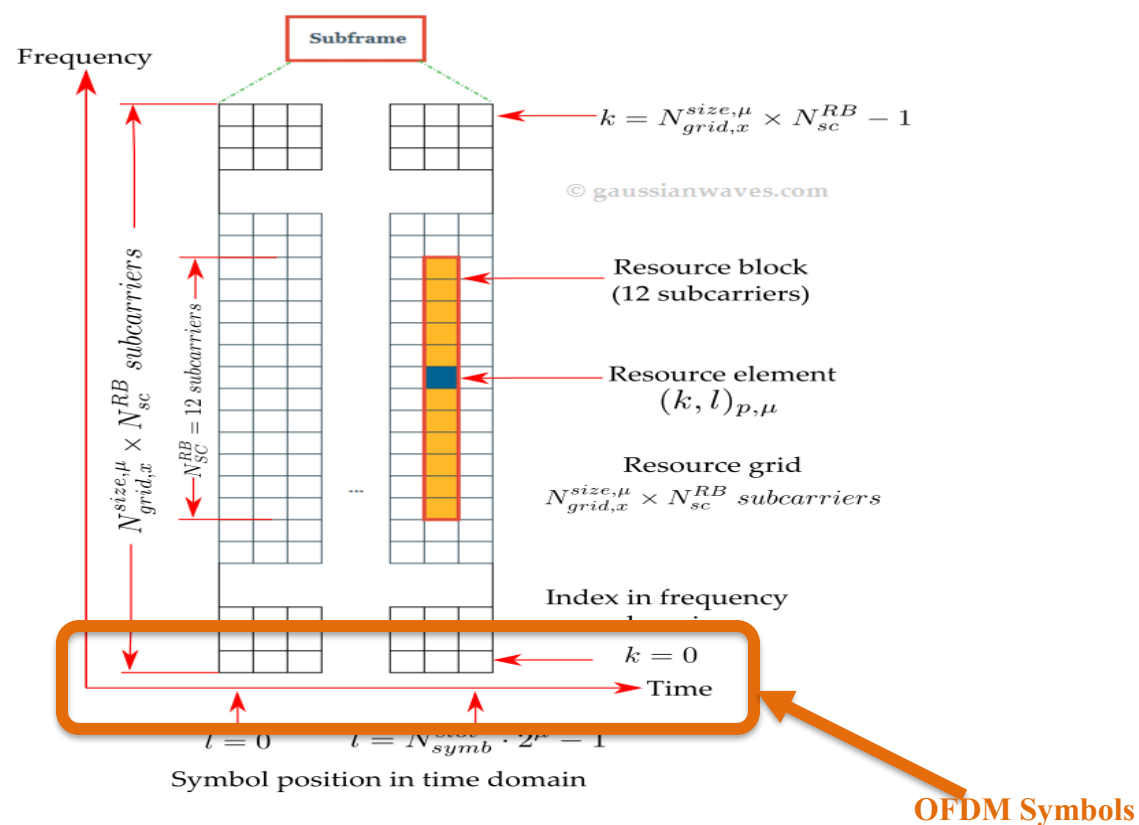


Figure 3: Resource element, Resource block, Resource grid in 5G NR

(<https://www.gaussianwaves.com/2022/02/5g-nr-resource-block>)

Claim 10

Claim 10	Public Documentation
[10pre] A method of transmitting information in a wireless communication channel comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. <i>See, e.g.:</i> 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

(3GPP TS 38.300 V17.4.0)

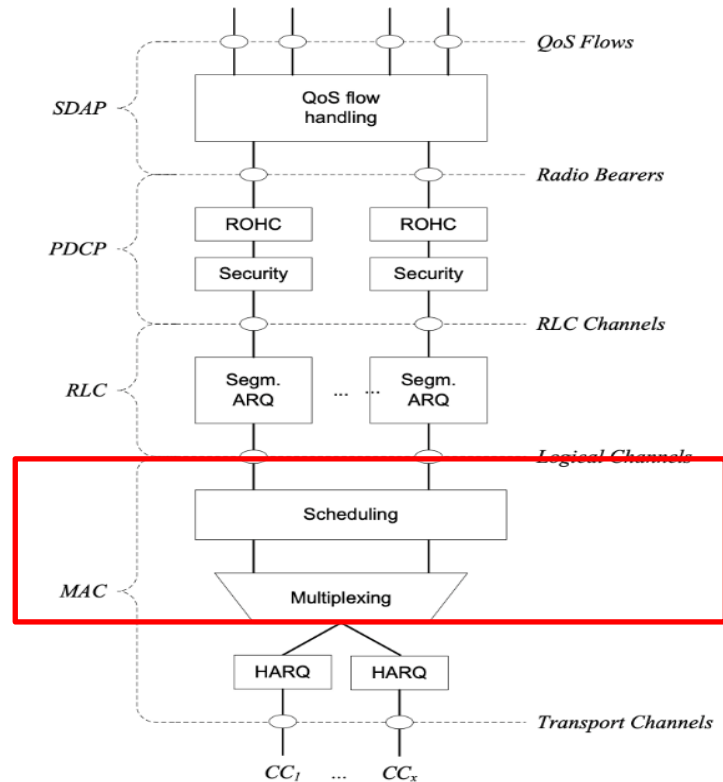


Figure 6.7-2: Layer 2 Structure for UL with CA configured

(3GPP TS 38.300 V17.4.0)

Claim 10	Public Documentation
	<i>5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work?</i> The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 10	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 10	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least \$140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

Claim 10	Public Documentation
	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/) <u>T-MOBILE US USED THE SAMSUNG GALAXY S22 PHONE POWERED BY SNAPDRAGON 8 GEN 1 MOBILE PLATFORM</u> <u>T-Mobile US said it was able to aggregate three channels of mid-band 5G spectrum, reaching speeds over 3 Gbps on its standalone 5G network. The carrier used the Samsung Galaxy S22 phone powered by Snapdragon 8 Gen 1 Mobile Platform with Snapdragon X65 Modem-RF System on a live production network.</u> “This test demonstrates the incredible power of mid-band spectrum and represents another huge step forward for standalone 5G,” said Neville Ray, president of Technology at T-Mobile. “Only T-Mobile is delivering a nationwide standalone 5G network to customers today, and we’re blazing a trail with new performance-boosting capabilities that generate incredible speeds and deliver on our vision to create the highest capacity network in the country.” T-Mobile US noted that 5G Carrier Aggregation (NR CA) allows the combination of multiple 5G channels to improve speed and performance. In this test, the carrier merged three 5G channels — <u>two channels of 2.5 GHz Ultra Capacity 5G and one channel of 1900 MHz spectrum</u> — to create an effective 210 MHz 5G channel. T-Mobile claimed to be the first operator in the world to launch a nationwide SA 5G network nearly two years ago. NR CA is already live in parts of T-Mobile’s network combining two 2.5 GHz 5G channels. The telco said that those customers with the Samsung Galaxy S22 will be among the first to experience a third 1900 MHz 5G channel later this year. This capability will expand across the carrier’s network and to additional devices in the near future. Earlier this month, T-Mobile U.S. announced that customers in limited areas of Portland and Salt Lake City who have the Samsung Galaxy S21 5G now have access to Voice Over New Radio (VoNR) services. The carrier said additional cities will be added to the list throughout the remainder of this year. According to T-Mobile US, VoNR brings the promise of Standalone (SA) 5G “one step closer” by enabling advanced capabilities like network slicing that rely on a continuous connection to a 5G core. At the recent Big 5G Event in Austin,

Claim 10	Public Documentation
	Texas, Ray told RCR Wireless News that in addition to ultimately supporting 5G voice calls, VoNR, without a Non-Standalone 5G or LTE anchor, sees its investment in low-band as the “foundation” of the company’s network. The carrier’s Extended Range 5G (low-band 600 MHz spectrum) covers 315 million people across 1.8 million square miles, while 225 million people nationwide are covered with its Ultra Capacity 5G (2.5 GHz spectrum). The carrier expects to cover 260 million in 2022 and 300 million next year. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>T-Mobile Revs Up 5G with Four-Carrier Aggregation</u> July 25, 2023 What’s the news: T-Mobile has begun rolling out four-carrier aggregation for customers, boosting speeds on its 5G standalone (SA) network. Why it matters: 5G SA is the future of wireless, delivering a whole new level of performance with faster speeds and lower latency (quicker response times). 5G carrier aggregation allows T-Mobile to turbocharge 5G SA speeds, giving customers a game-changing performance boost. Who it’s for: T-Mobile customers across the country. Pedal, meet metal. T-Mobile (NASDAQ: TMUS) today announced it has begun rolling out four-carrier aggregation on its 5G SA network, delivering the capability for insanely fast speeds to customers across the country. If you need help translating ... insanely fast = peak speeds topping 3.3 Gbps in recent tests. Four-carrier aggregation is live in parts of T-Mobile’s network now and will be available nationwide in the coming weeks. “T-Mobile is blazing the trail for wireless customers around the globe, delivering new capabilities that unleash the true potential of 5G,” said Ulf Ewaldsson, President of Technology at T-Mobile. “With the only nationwide 5G standalone network in the country, T-Mobile is the ONLY provider bringing game-changing technologies like four-carrier aggregation to customers across the country.” 5G carrier aggregation allows T-Mobile to combine multiple 5G channels (or carriers) to deliver greater speed and performance. The Un-carrier is now merging four 5G channels of sub-6 GHz spectrum – <u>two channels of 2.5 GHz Ultra Capacity 5G, one channel of 1900 MHz and one channel of 600 MHz spectrum</u>. That’s like taking four separate highways and turning them into a massive superhighway where traffic can zoom faster than before. Customers with the Samsung Galaxy S23 will be the first to experience four-carrier aggregation with more devices to follow.

Claim 10	Public Documentation
	This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across two million square miles – more square miles than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity this year – nearly everyone in the country. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>SRG tests T-Mo’s FDD-TDD CA: ‘You can have your cake and eat it too’</u> January 11, 2022 The aggregation of 600 MHz + 2.5 GHz uses low-band, FDD spectrum to improve performance The aggregation of low and mid-band carriers in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) spectrum improves cell edge performance in T-Mobile US’ network, according to recent testing by Signals Research Group. <u>SRG tested the FDD+TDD carrier aggregation (CA) in T-Mobile US’ commercial network.</u> The testing was conducted during the first week of December, at a large cluster of Ericsson sites in a 180-square-kilometer swath of the suburban Maryland/Washington, D.C. area. “A few mobile operators have already launched TDD-TDD CA in other parts of the world but to the best of our knowledge T-Mobile is the first operator in the world to deploy FDD-TDD CA functionality in a commercial network,” SRG noted. SRG said that T-Mobile US provided the test SIMs and insight into the cluster where the testing was conducted, as well as two Galaxy S21 smartphones — one with pre-commercial software on it that allowed the consulting group to test some of the features it was interested in. Intriguingly, however, SRG found that both devices appeared to support much the same functionality, with a bit of finessing of “hidden” menu options to force the smartphones into the modes of operation that it wanted to test.

Claim 10	Public Documentation
	SRG used test tools from Accuver Americas and Spirent Communications to conduct the study. The firm said that the cell cluster supported a “wide range of different technologies,” including both NSA and SA 5G, using <u>T-Mo’s 600 MHz (FDD) and/or 2.5 GHz (TDD) spectrum. In terms of 5G New Radio CA, the sites either used two 5G NR carriers at 2.5 GHz, leveraging T-Mo’s deep midband holdings for TDD-TDD carrier aggregation; or they paired a single radio channel of 600 MHz spectrum with a single channel of 2.5 GHz — the FDD-TDD CA that SRG sought to test.</u> https://www.rcrwireless.com/20220111/test-and-measurement/srg-tests-t-mos-fdd-tdd-ca-you-can-have-your-cake-and-eat-it-too T-Mobile to Expand and Advance the Nation’s Largest 5G Network with New 5-Year Agreements <i>These multi-billion-dollar deals with both Ericsson and Nokia will continue to supercharge T-Mobile’s nationwide 5G network</i> January 13, 2021 06:29 PM Eastern Standard Time BELLEVUE, Wash.--(BUSINESS WIRE)--Today, T-Mobile (NASDAQ: TMUS) announced five-year, multi-billion-dollar agreements with both Ericsson (NASDAQ: ERIC) and Nokia (NYSE: NOK) to continue advancing and expanding the nation’s largest 5G network. Part of the network investment following last year’s merger with Sprint, these deals enable T-Mobile to add even more 5G coverage, capacity, speed and advanced technical capabilities across all of its spectrum bands. “T-Mobile already has the largest 5G network in the country,” said Neville Ray, T-Mobile President of Technology. “These agreements with our longstanding 5G partners Nokia and Ericsson will help us take our 5G leadership even further, delivering ever-better experiences for our customers for years to come.” Building on two decades of partnership, the Un-carrier will work with Ericsson and Nokia to expand its nationwide 5G network for better 5G coverage and future game-changing experiences, and advanced network capabilities like 5G carrier aggregation. T-Mobile launched the world’s first nationwide standalone 5G network last summer, and recently pulled off the world’s first 5G standalone (SA) data session with New Radio Carrier Aggregation (NR CA). T-Mobile is the first and only U.S. provider to combine the power of Extended Range <i>and</i> Ultra Capacity 5G, boosting speed and performance. T-Mobile also plans to add advanced technical capabilities like voice over 5G (VoNR), network slicing, and multi-user massive MIMO to its 5G network.

Claim 10	Public Documentation
	T-Mobile is already America’s 5G leader with the most advanced 5G network and fast 5G speeds in more places than any other wireless provider. T-Mobile’s Extended Range 5G now covers 280 million people across nearly 1.6 million square miles — that’s more than 2.5x the geographic coverage of AT&T and nearly 4x more than Verizon! And with Sprint now part of T-Mobile, the Un-carrier is widening its lead, lighting up Ultra Capacity 5G across the country and bringing fast 5G speeds to more places than anyone else. Ultra Capacity 5G can deliver average speeds of 300 Mbps with peaks approaching 1 Gbps and is now available in more than 1,000 cities and towns, covering more than 106 million people! That’s 50x more than Verizon covers with Ultra-Wideband! And at T-Mobile, 5G access is included at no extra charge in all smartphone plans. For more information on T-Mobile’s 5G network, visit: www.t-mobile.com/coverage/coverage-map. Follow T-Mobile’s Official Twitter Newsroom @TMobileNews to stay up-to-date with the latest company news. Ultra Capacity 5G includes dedicated mid- and/or high-band 5G signals. T-Mobile’s Ultra Capacity 5G covers hundreds of cities and millions of people, with more added all the time; see T-Mobile.com/5Glayers. Capable device required; coverage not available in some areas. Some uses may require certain plan or feature; see T-Mobile.com. https://www.businesswire.com/news/home/20210113005934/en/T-Mobile-to-Expand-and-Advance-the-Nation%E2%80%99s-Largest-5G-Network-with-New-5-Year-Agreements) <u>T-Mobile Supercharges 5G Standalone Uplink Speeds with Carrier Aggregation First</u> May 04, 2023 BELLEVUE, Wash. — May 4, 2023 What’s the news: T-Mobile worked with Nokia and Qualcomm to reach uplink speeds topping 200 Mbps in a 5G data call leveraging uplink carrier aggregation – the first-ever on a live commercial 5G standalone network in the U.S. Why it matters: Increased uplink speeds allow greater amounts of data to be transmitted from customer devices at a quicker rate, enhancing applications like video livestreaming/calling, gaming and Extended Reality (XR). Who it’s for: T-Mobile 5G customers nationwide. Speed ... UP! T-Mobile (NASDAQ: TMUS) announced today it achieved another 5G U.S. first by leveraging uplink (UL) carrier aggregation in the field on the country’s only nationwide 5G standalone (SA) network. Working with Nokia and a test smartphone powered by Snapdragon® 5G Modem-RF System from Qualcomm Technologies, Inc., the Un-

Claim 10	Public Documentation
	carrier hit a top UL speed of 207 Mbps in the test – the <i>fastest ever</i> recorded using sub-6 GHz spectrum! This comes just weeks after T-Mobile made the same move in the lab, hitting similar speeds. “T-Mobile has led the industry with 5G standalone since 2020, and we're continuing to drive breakthroughs that advance 5G technology around the globe,” said Ulf Ewaldsson, President of Technology at T-Mobile. “We’re building the most advanced 5G network in the world, opening the door for massive innovation and laying the foundation for new capabilities that will transform the world around us.” 5G carrier aggregation allows T-Mobile to combine multiple channels (or carriers) to deliver greater speed and performance. In this test, the Un-carrier merged two 5G channels of mid-band spectrum – 2.5 GHz Ultra Capacity 5G and 1900 MHz. That’s like taking two separate highways and turning them into a superhighway where traffic can zoom faster than before. Customers with compatible devices will begin taking advantage of UL 5G carrier aggregation early next year when T-Mobile begins rolling it out. This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across 2 million square miles – more than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity – nearly everyone in the country – this year. https://www.t-mobile.com/news/network/t-mobile-supercharges-5g-standalone-uplink-speeds-with-carrier-aggregation-first WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations.

Claim 10	Public Documentation
	We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates. Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today. 5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation. Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation. https://www.nokia.com/networks/mobile-networks/carrier-aggregation/ Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners.

Claim 10	Public Documentation
	Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson's collaboration with partners has so far resulted in several 5G firsts: • World's first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5 GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile's mid-band 5G. It's also a key step in expanding T-Mobile's nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020) • A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung's Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek's Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020) • Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020) Per Narvinger, Head of Product Area Networks, Ericsson says: "From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we've developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer." Ericsson's 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation

Ericsson ups the tempo on 5G Carrier Aggregation with world's first downlink 6CC data call

Available in English [日本語](#)

Ericsson revs up the tempo on 5G Carrier Aggregation by combining six component carriers to set a record download speed of 5.7Gbps for the world's first 6CC (component carrier) data call.

NEWS

AUG 17, 2023

The data call was achieved using three FDD (frequency division duplex) bands combined with three TDD (time division duplex) bands in sub-6GHz, enabled by Ericsson RAN Compute hardware, state-of the-art carrier aggregation software, and innovative Advanced RAN Coordination functionality.

The 3FDD + 3TDD carrier aggregation testing was carried out in an Ericsson lab with a user equipment (UE) simulator. By combining FDD spectrum with TDD spectrum, more users can benefit from carrier aggregation gains.

In total, 400MHz of bandwidth was aggregated with FDD bandwidths ranging 20MHz to 50MHz to achieve the 5.7Gbps throughput. With six-component carrier capability, communications service providers can optimize use of network and spectrum assets to deliver higher data speeds and capacity that improve the experience of downlink-heavy applications. This can mean better audio and video quality for streaming users, faster file downloads, and a better working environment for digital nomads.

Sibel Tombaz, Head of Product Line 5G RAN at Ericsson Networks, says: "We are keeping the momentum on carrier aggregation by continuously stretching its potential to boost capacity and speed. Our successful 6CC data call shows how versatile our solution is and that we are poised to work with ecosystem partners to make this new band combination a reality. Our goal, as always, is to help customers meet end users' growing appetite for high-capacity, ultrahigh-speed 5G."

"Carrier Aggregation is crucial to getting the best possible 5G performance out of scattered spectrum assets," Tombaz adds. "And with 6CC, service providers will be able to maximize use of allocated spectrum and optimize the combined bandwidth for superior mobile experience."

<https://www.ericsson.com/en/news/2023/8/ericsson-ups-the-tempo-on-5g-carrier-aggregation-with-worlds-first-downlink-6cc-data-call>

Claim 10	Public Documentation																												
	Samsung Galaxy S20  Released 2020, March 06 163g, 7.9mm thickness <> Android 10, up to Android 13, One UI 5 128GB storage, microSDXC 6.2" 1440x3200 pixels 64MP 4320p 8GB RAM Exynos 990 4000mAh Li-Ion 18% 6,985,860 HITS 456 BECOME A FAN REVIEW OPINIONS COMPARE PICTURES Also available with 5G <table><tr><td>NETWORK</td><td>Technology</td><td>GSM / CDMA / HSPA / EVDO / LTE</td><td>COLLAPSE</td></tr><tr><td></td><td>2G bands</td><td>GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)</td><td></td></tr><tr><td></td><td></td><td>CDMA 800 / 1900 & TD-SCDMA</td><td></td></tr><tr><td></td><td>3G bands</td><td>HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100</td><td></td></tr><tr><td></td><td></td><td>CDMA2000 1xEV-DO</td><td></td></tr><tr><td></td><td>4G bands</td><td>1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66</td><td></td></tr><tr><td></td><td>Speed</td><td>HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps</td><td></td></tr></table> https://www.gsmarena.com/samsung_galaxy_s20-10081.php	NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE	COLLAPSE		2G bands	GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)				CDMA 800 / 1900 & TD-SCDMA			3G bands	HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100				CDMA2000 1xEV-DO			4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66			Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps	
NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE	COLLAPSE																										
	2G bands	GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)																											
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	4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66																											
	Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps																											
[10a] receiving a first digital signal comprising first data to be transmitted;	The Accused Instrumentalities perform a method that includes receiving a first digital signal comprising first data to be transmitted. For example: 6.7 CARRIER AGGREGATION In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:																												

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

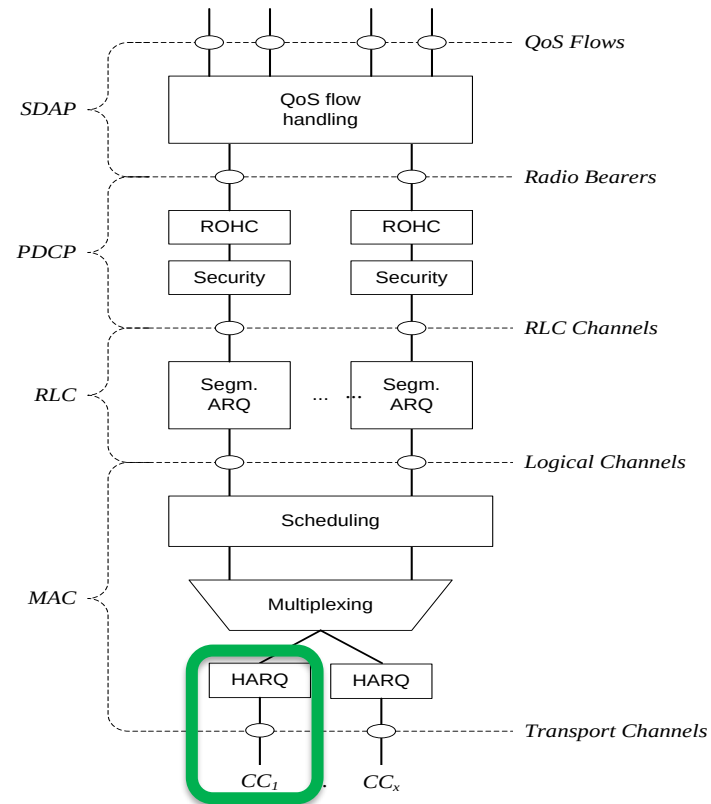


Figure 6.7-2: Layer 2 Structure for UL with CA configured

(3GPP TS 38.300 V17.5.0)

Claim 10	Public Documentation
[10b] receiving a second digital signal comprising second data to be transmitted;	The Accused Instrumentalities perform a method that includes receiving a second digital signal comprising second data to be transmitted. For example: 6.7 CARRIER AGGREGATION In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell. Figure 6.7-2: Layer 2 Structure for UL with CA configured (3GPP TS 38.300 V17.5.0)

Claim 10	Public Documentation
[10c] converting the first digital signal into a first analog signal using a first digital-to-analog converter, the first analog signal carrying the first data across a first frequency range;	The Accused Instrumentalities perform a method that includes converting the first digital signal into a first analog signal using a first digital-to-analog converter, the first analog signal carrying the first data across a first frequency range. For example: 11.3.2.1 Transmitter architecture Figure 11.3.2.1-1 illustrates various TX architectures options according to where the component carriers are combined, i.e., at digital baseband, or in analog waveforms before RF mixer, or after mixer but before the PA, or after the PA. Option A - In an adjacent <i>contiguous common carrier</i> aggregation scenario, the UE very likely has one PA. Connected to the PA can be a single RF chain (a zero-IF mixer, a wideband DAC, and a wideband IFFT) Option-B - Combines analog baseband waveforms from component Carrier first (e.g., via a mixer operating at an IF of roughly the bandwidth of the other component carrier in the example of 2-component carrier aggregation). Then the resulting wideband signal is up-converted to RF. Option-C - Does ZIF up-conversion of each component carrier before combining and feeding into a single PA. Option-D - Employs multiple RF chains and multiple PAs after which the high-power signals are combined and fed into a single antenna. PA coupling at the UE can be challenging for option-D.

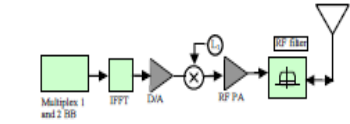
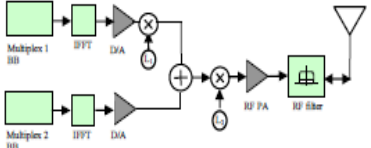
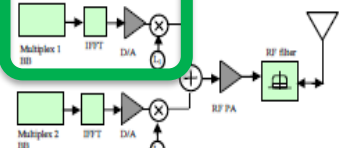
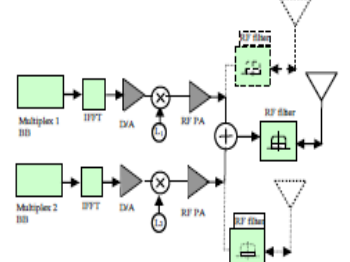
Tx Characteristics			
Option	Description (Tx architecture)	Intra Band aggregation	
		Contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes	
B	 Multiple (baseband + IFFT + DAC + single (stage-1) IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes
X	OTHERS		

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

[10d] converting the second digital signal into a second analog signal using a second digital-to-analog converter, the second analog signal carrying the second data across a second frequency range;

The Accused Instrumentalities perform a method that includes converting the second digital signal into a second analog signal using a second digital-to-analog converter, the second analog signal carrying the second data across a second frequency range. For example:

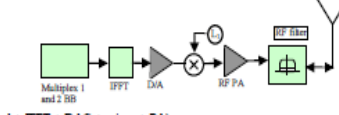
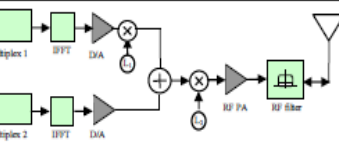
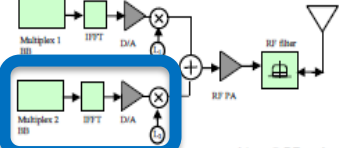
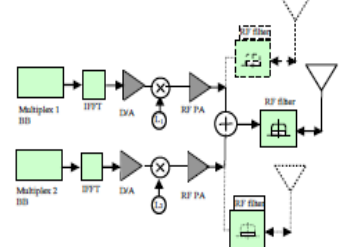
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC), multiple power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

[10e] up-converting the first analog signal to a first RF center frequency to produce a first up-converted analog signal, wherein the first up-converted analog signal comprises a first up-converted frequency range from the first RF center frequency minus one-half the first frequency range to the first RF center frequency plus one-half the first frequency range;

The Accused Instrumentalities perform a method that includes up-converting the first analog signal to a first RF center frequency to produce a first up-converted analog signal, wherein the first up-converted analog signal comprises a first up-converted frequency range from the first RF center frequency minus one-half the first frequency range to the first RF center frequency plus one-half the first frequency range. For example:

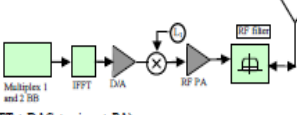
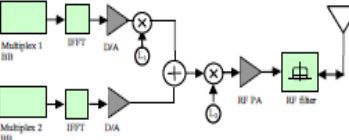
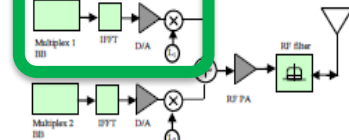
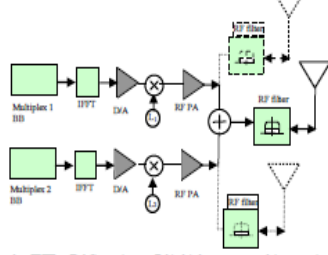
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC + single (shared) RF mixer + combiner @ RF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios
(3GPP TR 36.912 version 15.0.0 Release 15)

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

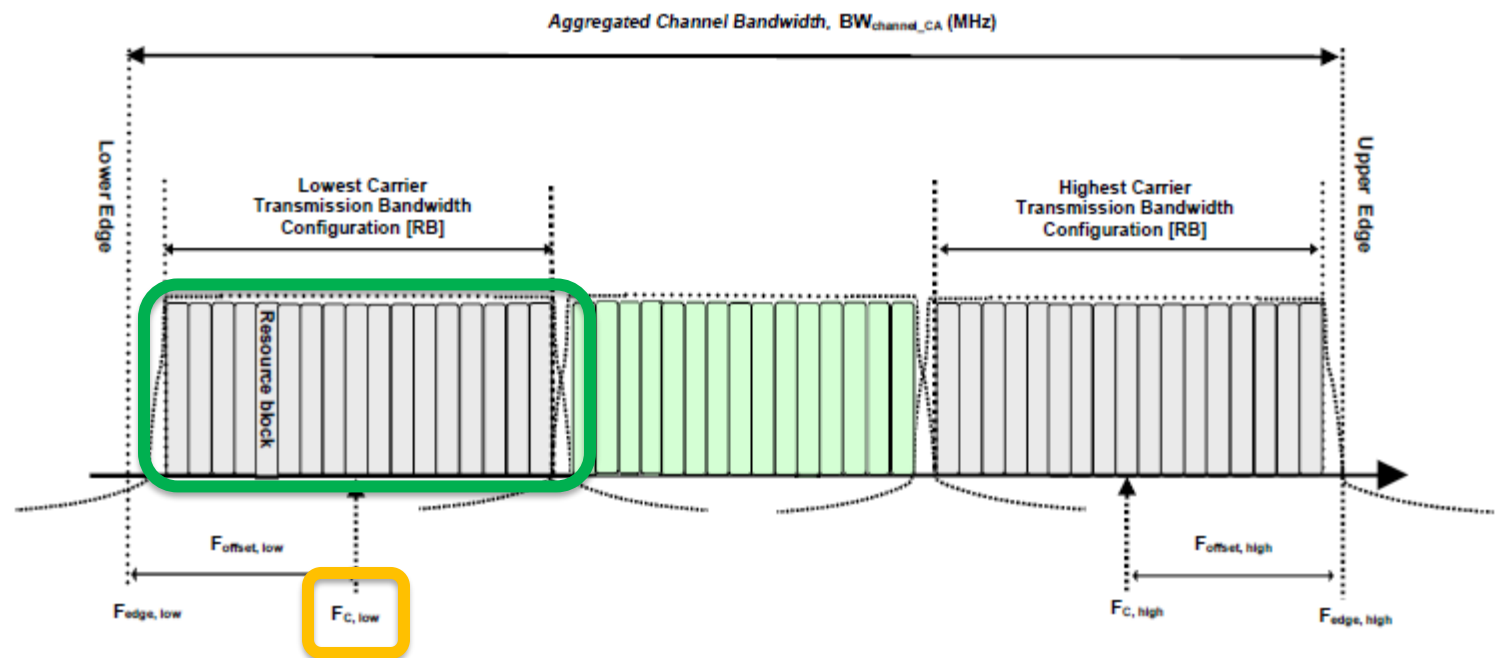


Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation

$$BW_{\text{Channel_CA}} = F_{\text{edge,high}} - F_{\text{edge,low}} \text{ (MHz)}.$$

Claim 10	Public Documentation
	The lower bandwidth edge $F_{\text{edge, low}}$ and the upper bandwidth edge $F_{\text{edge, high}}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by $F_{\text{edge, low}} = F_{\text{C, low}} - F_{\text{offset, low}}$ $F_{\text{edge, high}} = F_{\text{C, high}} + F_{\text{offset, high}}$ The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as $F_{\text{offset, low}} = (N_{\text{RB, low}} * 12 + 1) * S_{\text{CS, low}} / 2 + B_{\text{WGB}} \text{ (MHz)}$ $F_{\text{offset, high}} = (N_{\text{RB, high}} * 12 - 1) * S_{\text{CS, high}} / 2 + B_{\text{WGB}} \text{ (MHz)}$ $B_{\text{WGB}} = \max(B_{\text{WGB, Channel}(k)})$ $N_{\text{RB, low}}$ and $N_{\text{RB, high}}$ are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, $S_{\text{CS, low}}$ and $S_{\text{CS, high}}$ are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. $S_{\text{CS, low}}$, $S_{\text{CS, high}}$, $N_{\text{RB, low}}$, $N_{\text{RB, high}}$, and $B_{\text{WGB, Channel}(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $B_{\text{WGB, Channel}(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value. In case there is no common μ value for both of the channel bandwidths, $\mu=1$ is used for $S_{\text{CS, low}}$, $S_{\text{CS, high}}$, $N_{\text{RB, low}}$, $N_{\text{RB, high}}$, and $B_{\text{WGB, Channel}(k)}$. (3GPP TS 38.101-1 V17.5.0)

[10f] up-converting the second analog signal to a second RF center frequency greater than the first center RF frequency to produce a second up-converted analog signal, wherein the second up-converted analog signal comprises a second up-converted frequency range from the second RF center frequency minus one-half the second frequency range to the second RF center frequency plus one-half the second frequency range, and wherein a frequency difference between the first RF center frequency and the second RF center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range. For example:

The Accused Instrumentalities perform a method that includes up-converting the second analog signal to a second RF center frequency greater than the first center RF frequency to produce a second up-converted analog signal, wherein the second up-converted analog signal comprises a second up-converted frequency range from the second RF center frequency minus one-half the second frequency range to the second RF center frequency plus one-half the second frequency range, and wherein a frequency difference between the first RF center frequency and the second RF center frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range. For example:

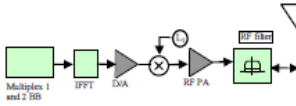
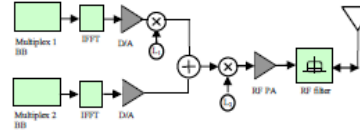
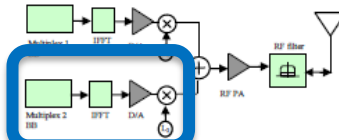
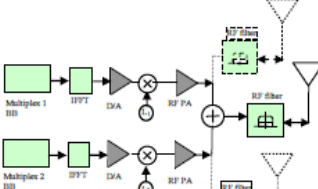
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC), high-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

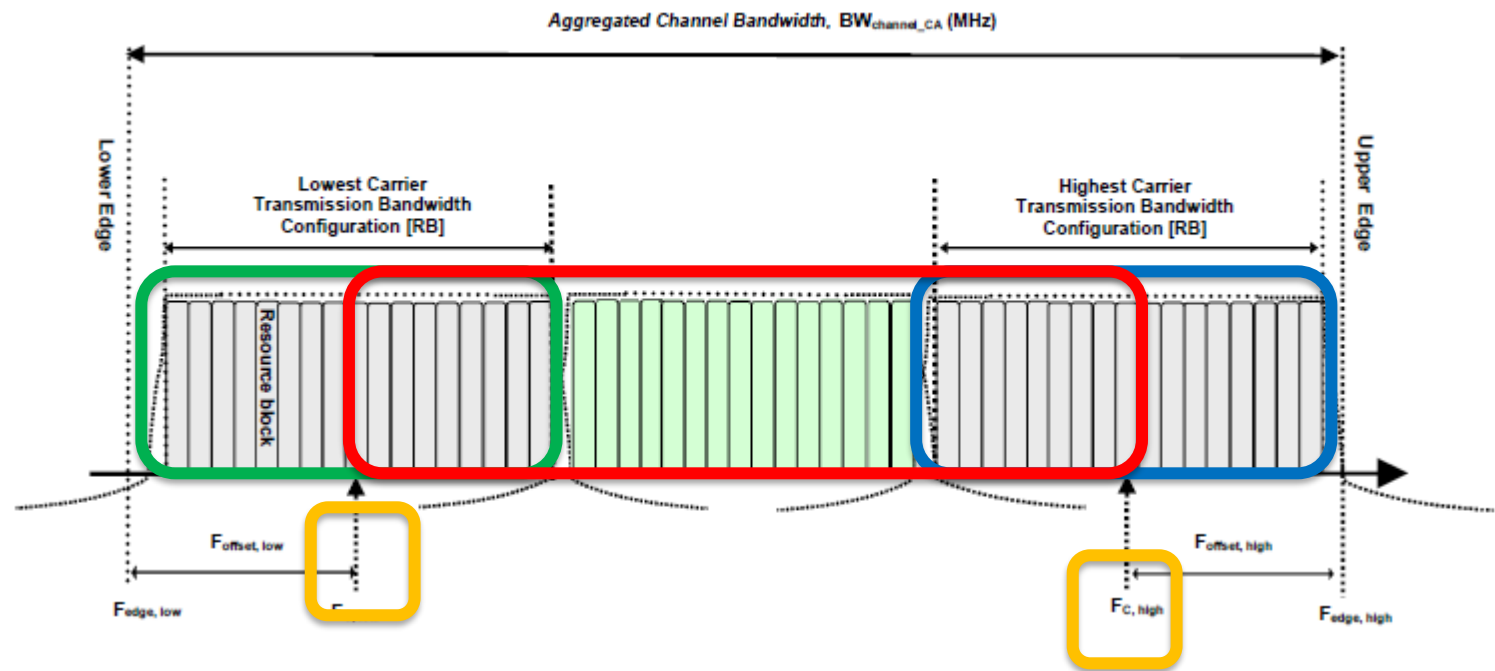


Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation

(3GPP TS 38.101-1 V17.5.0)

[10g] combining the first up-converted analog signal and the second up-converted analog signal to produce a combined up-converted signal;

The Accused Instrumentalities perform a method that includes combining the first up-converted analog signal and the second up-converted analog signal to produce a combined up-converted signal. For example:

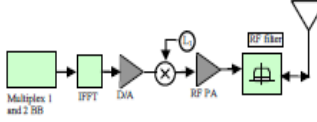
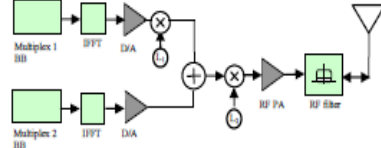
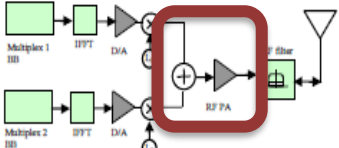
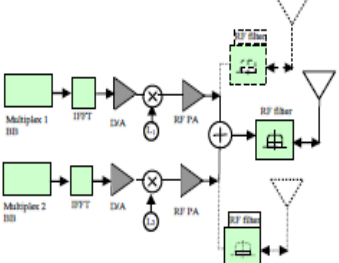
Tx Characteristics			
Option	Description (Tx architecture)	Intra Band aggregation	
		Contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes	
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes
X	OTHERS		

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

[10h] amplifying the combined up-converted signal in a power amplifier resulting in an amplified combined up-converted signal; and

The Accused Instrumentalities perform a method that includes amplifying the combined up-converted signal in a power amplifier resulting in an amplified combined up-converted signal. For example:

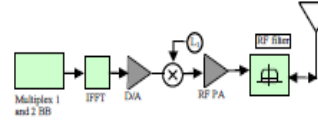
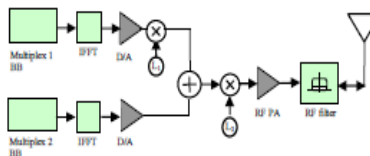
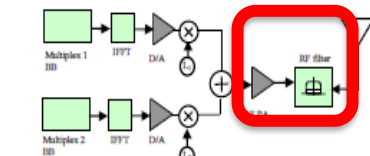
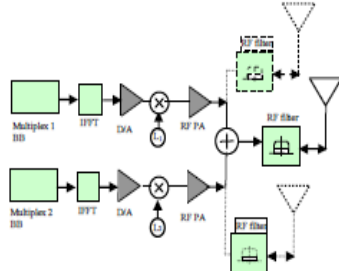
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

[10i] transmitting the amplified combined up-converted signal on a first antenna,

The Accused Instrumentalities perform a method that includes transmitting the amplified combined up-converted signal on a first antenna. For example:

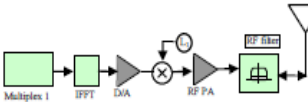
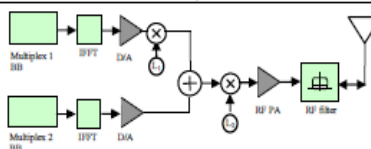
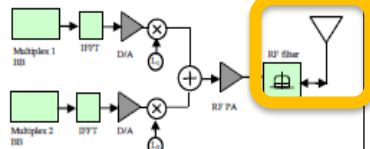
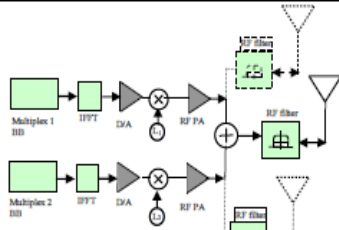
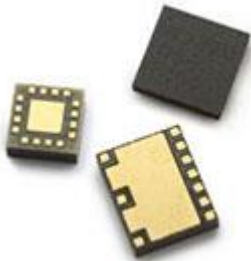
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

Claim 10	Public Documentation
[10j] wherein the bandwidth of said power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range.	The Accused Instrumentalities perform a method wherein the bandwidth of said power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range. For example, in power amplifier designs believed to be representative of those used in the Accused Instrumentalities: Mobile RF FEM  Broadcom provides custom RF frond end module (FEM) devices for mobile wireless applications. These devices incorporate <u>multiband power amplifiers (PA)</u>, FBAR duplexers and multiplexers, SOI multi-mode LNAs and antenna switch, coupler and MIPI controller, designed to support <u>various carrier aggregation (CA)</u> for both FDD and TDD bands. <u>Broadcom has shipped billions of RF FEM devices to the world's leading smartphone manufacturers.</u> The Broadcom ACFM-2S13 is a quadplexer device that combines Band 1 and Band 3 duplexers into a single, miniature package. Band 4 duplexer is co-banded. The device features a single antenna connection, eliminating the need for antenna switching. High Isolation between bands enables the use of carrier aggregation. The ACFM-2S13 is designed with Broadcom's innovative filter capability which makes possible ultra-small, high-Q filters at a fraction of their usual size. Low Tx Insertion Loss of the ACFM-2S13 reduces power amplifier current, extending battery life. The device enhances receiver sensitivity and dynamic range with low Rx Insertion Loss and high rejection of Tx signals at the Rx ports. Features • Single antenna • High cross band isolation • <u>Enables carrier aggregation</u> • Band 4 co-banding • Miniature size • 2.0 x 2.5 mm footprint • 0.710 mm typ. height • High Power Rating • Environmental • RoHS 6 Compliant • Halogen Free • TBBPA Free https://www.broadcom.com/products/wireless/demo-boards/acfm-2s13



PRODUCT SUMMARY

SKY77786-11 High Band Multimode Multiband Power Amplifier Module Supporting LTE Advanced Applications

Applications

- Multiband 4G / LTE handsets
- FDD LTE Bands 7 and 30
- TDD LTE Band 38, 40, 41

Features

- Two T/R (RX) port and 3 outputs
- Industry-leading PAE for 4G
- Optimized for APT DCDC operation
- Fully programmable Mobile Industry Processor Interface (MIPI) control
- MIPI programmable bias modes optimize best 4G efficiency/linearity performance.
- Small, low profile package:
 - 3.0 x 3.0 x 0.71 mm
 - 20-pad configuration



Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to Skyworks *Definition of Green™*, document number SQ04-0074.

Description

Skyworks SKY77786-11 SkyFi™ is a multimode multiband (MMMR) Power Amplifier Module (PAM) that supports 4G handsets and operates efficiently in LTE bands from 2.3 GHz to 2.7 GHz. The module is fully programmable through a Mobile Industry Processor Interface (MIPI®).

The PAM consists of a single high band LTE block, a Multi-Function Control (MFC) block, and a T/R switch block. RF input/output ports internally matched to 50 Ω to reduce the number of external components. A CMOS integrated circuit uses standard MIPI controls to provide the internal MFC interface and operation. Extremely low leakage current maximizes handset standby time.

The InGaP die and the silicon die and passive components are mounted on a multi-layer laminate substrate. The assembly is encapsulated in a 3.0 mm x 3.0 mm x 0.71 mm, 20-pad MCM, SMT package which is a more highly manufacturable, low cost solution.

4G: The SKY77786-11 supports 1.4, 3, 5, 10, 15, 20, 30, 35, 40 MHz channel bandwidths. Similar to 3G operation, output power is controlled by varying the input power and V_{CC} is adjusted using a DCDC converter to maximize efficiency for each power level.

4G Modulation scheme includes:

- FDD LTE
- TDD LTE
- Uplink Carrier Aggregation (CA) support for Bands 40/41 (up to 40 MHz)

Claim 13

Claim 13	Public Documentation
[13] The method of claim 10 wherein the first digital signal is encoded using a first wireless protocol and the second digital signal is encoded using a second wireless protocol.	The Accused Instrumentalities perform a method wherein the first digital signal is encoded using a first wireless protocol and the second digital signal is encoded using a second wireless protocol. For example: Cellular operators, for example T-MO, have deployed carrier aggregation in mid band (2.5 GHz, 3.5 GHz), in 1900 MHz PCS band as well as the 600 MHz band. In the mid band such as the 2.5 GHz or 3.5 GHz TDD protocol has been deployed. In the PCS 1900 MHz and 600 MHz bands FDD 5G and LTE protocols have been deployed. Two protocols, FDD and TDD, are used in these carrier aggregation deployments. The carrier aggregation tested by Galaxy 22 and Galaxy 23 on T-MO network supported both TDD and FDD protocols. <u>SRG tests T-Mo’s FDD-TDD CA: ‘You can have your cake and eat it too’</u> January 11, 2022 The aggregation of 600 MHz + 2.5 GHz uses low-band, FDD spectrum to improve performance The aggregation of low and mid-band carriers in <u>both Frequency Division Duplex (FDD)</u> and <u>Time Division Duplex (TDD)</u> spectrum improves cell edge performance in T-Mobile US’ network, according to recent testing by Signals Research Group. SRG tested the <u>FDD+TDD</u> carrier aggregation (CA) in T-Mobile US’ commercial network. The testing was conducted during the first week of December, at a large cluster of Ericsson sites in a 180-square-kilometer swath of the suburban Maryland/Washington, D.C. area. “A few mobile operators have already launched TDD-TDD CA in other parts of the world but to the best of our knowledge T-Mobile is the first operator in the world to deploy FDD-TDD CA functionality in a commercial network,” SRG noted. SRG said that <u>T-Mobile US provided the test SIMs and insight into the cluster where the testing was conducted, as well as two Galaxy S21 smartphones</u> — one with pre-commercial software on it that allowed the consulting group to test some of the features it was interested in. Intriguingly, however, SRG found that both devices appeared to support much the same functionality, with a bit of finessing of “hidden” menu options to force the smartphones into the modes of operation that it wanted to test.

Claim 13	Public Documentation
	SRG used test tools from Accuver Americas and Spirent Communications to conduct the study. The firm said that the cell cluster supported a “wide range of different technologies,” including both NSA and SA 5G, using <u>T-Mo’s 600 MHz (FDD)</u> and/or <u>2.5 GHz (TDD) spectrum</u>. In terms of 5G New Radio CA, the sites either used two 5G NR carriers at 2.5 GHz, leveraging T-Mo’s deep midband holdings for TDD-TDD carrier aggregation; <u>or they paired a single radio channel of 600 MHz spectrum with a single channel of 2.5 GHz — the FDD-TDD CA that SRG sought to test.</u> https://www.rcrwireless.com/20220111/test-and-measurement/srg-tests-t-mos-fdd-tdd-ca-you-can-have-your-cake-and-eat-it-too <u>T-MOBILE US USED THE SAMSUNG GALAXY S22 PHONE POWERED BY SNAPDRAGON 8 GEN 1 MOBILE PLATFORM</u> <u>T-Mobile US said it was able to aggregate three channels of mid-band 5G spectrum, reaching speeds over 3 Gbps on its standalone 5G network. The carrier used the Samsung Galaxy S22 phone powered by Snapdragon 8 Gen 1 Mobile Platform with Snapdragon X65 Modem-RF System on a live production network.</u> “This test demonstrates the incredible power of mid-band spectrum and represents another huge step forward for standalone 5G,” said Neville Ray, president of Technology at T-Mobile. “Only T-Mobile is delivering a nationwide standalone 5G network to customers today, and we’re blazing a trail with new performance-boosting capabilities that generate incredible speeds and deliver on our vision to create the highest capacity network in the country.” T-Mobile US noted that 5G Carrier Aggregation (NR CA) allows the combination of multiple 5G channels to improve speed and performance. In this test, the carrier merged three 5G channels — <u>two channels of 2.5 GHz Ultra Capacity 5G</u> and <u>one channel of 1900 MHz spectrum</u> — to create an effective 210 MHz 5G channel. T-Mobile claimed to be the first operator in the world to launch a nationwide SA 5G network nearly two years ago. NR CA is already live in parts of T-Mobile’s network combining two 2.5 GHz 5G channels. The telco said that those customers with the Samsung Galaxy S22 will be among the first to experience a third 1900 MHz 5G channel later this year. This capability will expand across the carrier’s network and to additional devices in the near future. Earlier this month, T-Mobile U.S. announced that customers in limited areas of Portland and Salt Lake City who have the Samsung Galaxy S21 5G now have access to Voice Over New Radio (VoNR) services. The carrier said additional cities will be added to the list throughout the remainder of this year.

Claim 13	Public Documentation
	According to T-Mobile US, VoNR brings the promise of Standalone (SA) 5G “one step closer” by enabling advanced capabilities like network slicing that rely on a continuous connection to a 5G core. At the recent Big 5G Event in Austin, Texas, Ray told RCR Wireless News that in addition to ultimately supporting 5G voice calls, VoNR, without a Non-Standalone 5G or LTE anchor, sees its investment in low-band as the “foundation” of the company’s network. The carrier’s Extended Range 5G (low-band 600 MHz spectrum) covers 315 million people across 1.8 million square miles, while 225 million people nationwide are covered with its Ultra Capacity 5G (2.5 GHz spectrum). The carrier expects to cover 260 million in 2022 and 300 million next year. https://www.rcrwireless.com/20220615/5g/t-mobile-us-tops-3-gbps-standalone-5g- <u>T-Mobile Revs Up 5G with Four-Carrier Aggregation</u> July 25, 2023 What’s the news: T-Mobile has begun rolling out four-carrier aggregation for customers, boosting speeds on its 5G standalone (SA) network. Why it matters: 5G SA is the future of wireless, delivering a whole new level of performance with faster speeds and lower latency (quicker response times). 5G carrier aggregation allows T-Mobile to turbocharge 5G SA speeds, giving customers a game-changing performance boost. Who it’s for: T-Mobile customers across the country. Pedal, meet metal. T-Mobile (NASDAQ: TMUS) today announced it has begun rolling out four-carrier aggregation on its 5G SA network, delivering the capability for insanely fast speeds to customers across the country. If you need help translating ... insanely fast = peak speeds topping 3.3 Gbps in recent tests. Four-carrier aggregation is live in parts of T-Mobile’s network now and will be available nationwide in the coming weeks. “T-Mobile is blazing the trail for wireless customers around the globe, delivering new capabilities that unleash the true potential of 5G,” said Ulf Ewaldsson, President of Technology at T-Mobile. “With the only nationwide 5G standalone network in the country, T-Mobile is the ONLY provider bringing game-changing technologies like four-carrier aggregation to customers across the country.” 5G carrier aggregation allows T-Mobile to combine multiple 5G channels (or carriers) to deliver greater speed and performance. The Un-carrier is now merging four 5G channels of sub-6 GHz spectrum – two channels of 2.5 GHz Ultra Capacity 5G, one channel of 1900 MHz and one channel of 600 MHz spectrum. That’s like taking four separate highways

Claim 13	Public Documentation
	and turning them into a massive superhighway where traffic can zoom faster than before. <u>Customers with the Samsung Galaxy S23 will be the first to experience four-carrier aggregation with more devices to follow.</u> This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across two million square miles – more square miles than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity this year – nearly everyone in the country. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation

Claim 14

Claim 14	Public Documentation
[14pre] The method of claim 10 wherein the second data is the same as the first data, the method further comprising:	The Accused Instrumentalities perform a method wherein the second data is the same as the first data. For example: 16.1.3 Packet Duplication <u>When duplication is configured for a radio bearer by RRC, at least one secondary RLC entity is added to the radio bearer to handle the duplicated PDCP PDUs as depicted on Figure 16.1.3-1, where the logical channel corresponding to the primary RLC entity is referred to as <i>the primary logical channel</i>, and the logical channel corresponding to the secondary RLC entity(ies), the <i>secondary logical channel(s)</i>. All RLC entities have the same RLC mode. Duplication at PDCP therefore consists in submitting the same PDCP PDUs multiple times: once to each activated RLC entity for the radio bearer. With multiple independent transmission paths, packet duplication therefore increases reliability and reduces latency and is especially beneficial for URLLC services.</u> Figure 16.1.3-1: Packet Duplication (3GPP TS 38.300 version 16.2.0)

Claim 14	Public Documentation
[14a] receiving the transmitted signal on a second antenna; [14b] amplifying the received signal in a low noise amplifier resulting in an amplified received up-converted signal, wherein the bandwidth of said low noise amplifier is greater than the difference between the lowest frequency in the first up-converted frequency range and the highest frequency in the second up-converted frequency range;	The Accused Instrumentalities perform a method that includes amplifying a signal received on a second antenna in a low noise amplifier resulting in an amplified received up-converted signal, wherein the bandwidth of said low noise amplifier is greater than the difference between the lowest frequency in the first up-converted frequency range and the highest frequency in the second up-converted frequency range. For example, in low noise amplifier designs believed to be representative of the kinds of power amplifiers used in the Accused Instrumentalities: PRODUCT SUMMARY SKY5™-8255-11 Front-End Module for LTE and NR Applications • Multi-band 4G/5G handsets - Band B42, B48, n77, n78, and n79 Features • Full Baseband-Agnostic Design • Full Power APT support without DPD • UHB S-PAD covering B42, B48, n77, n78, n79, and separate Auxiliary TX • MIPI® v2.1 compliant 52 MHz RFFE bus - Two Tx control connections / one Rx control connection • Two ET/APT PA cores • Two LNA cores • Support 2x2 UL-MIMO using two TX placements • Support Fast SRS Hopping timing requirements • Supports system connectivity for: - MIMO-UL with single-feed or diplexed/separate-feed n77/n79 - SISO-UL with single-feed or diplexed/separate-feed n77/n79 • ASM switch with two selectable ANT ports and 6 AUX ports for seamless SRS Hopping support • Switchable LAA input • 50 ohm input/output impedance with internal DC-blocking • Continuous bias control via RFFE interface • Low Supply voltage • Low leakage current in power-down mode Features • Supports full SRS connectivity with minimal external switches • SRS RX ports for sharing coax cables • Integrated Antenna and band select switches • Integrated LNA with MIPI® control features - up to seven gain modes - independent gain and bias control • Integrated wide bandwidth filters • Small, low profile package - 5.5 mm x 4.5 mm x 0.8 mm (Max) - 42-pad configuration (includes 15-pad ground array) Description SKY58255-11 is a recent addition to our Sky5™ portfolio of 5G Technology products. Packaged in a single 5.5 mm x 4.5 mm x 0.8 mm (Max) form factor, this versatile and fully matched Front-End Module (FEM) supports multi-band 4G/5G and LTE/NR applications. The 42-pad surface mount (SMT) module consists of PA blocks, input and output matching, a MIPI standard digital control block, single-ended filters, antenna and band-select switches and low Noise amplifier (LNA). Utilizing an enhanced architecture, SKY58255-11 covers multiple bands and meets the spectral linearity requirements of CP-OFDM and DFTS-OFDM modulations with up to 100 MHz bandwidth and up to 273 resource block allocations. Output power is controlled by varying input power and adjusting VCC maximizes efficiency. Extremely low leakage current maximizes handset stand-by time Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to Skyworks Definition of Green™, document number SQ04-0074.

[14c] down-converting the amplified received up-converted signal using a first down-converter and a signal corresponding to the first RF center frequency to produce a fourth analog signal corresponding to the first analog signal; and

The Accused Instrumentalities perform a method that includes down-converting the amplified received up-converted signal using a first down-converter and a signal corresponding to the first RF center frequency to produce a fourth analog signal corresponding to the first analog signal. For example, in power amplifier designs believed to be representative of those used in the Accused Instrumentalities:

TI Designs

Multi-Band RF Sampling Receiver Solution



TI Designs

The RF sampling receiver captures signals directly in the radio frequency (RF) band. In a multi-band application, the desired signals do not have a very wide band, but they are spaced far apart within the spectrum. The ADC32RF80 is a dual-channel, 14-bit, 3-GSPS RF sampling telecom receiver. The 3-dB input bandwidth is 3 GHz, and it captures signals up to 4 GHz. The device includes two digital down converters (DDC) per channel. The DDC offers decimation values from 8 to 32 and includes a 16-bit numerically controlled oscillator to move the captured signal down to digital baseband. With the high sampling rate of the ADC32RF80, the device captures a large swatch of the RF spectrum, which contains signals in multiple bands and potentially undesired interferers. The DDC independently mixes the desired bands to digital baseband. Decimation reduces the output data rate to a lower level and provides digital filtering around the desired band to eliminate interference and to improve signal-to-noise ratio (SNR) performance. This feature is critical for high-end telecommunication receivers that require high dynamic range.

(<https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf>)

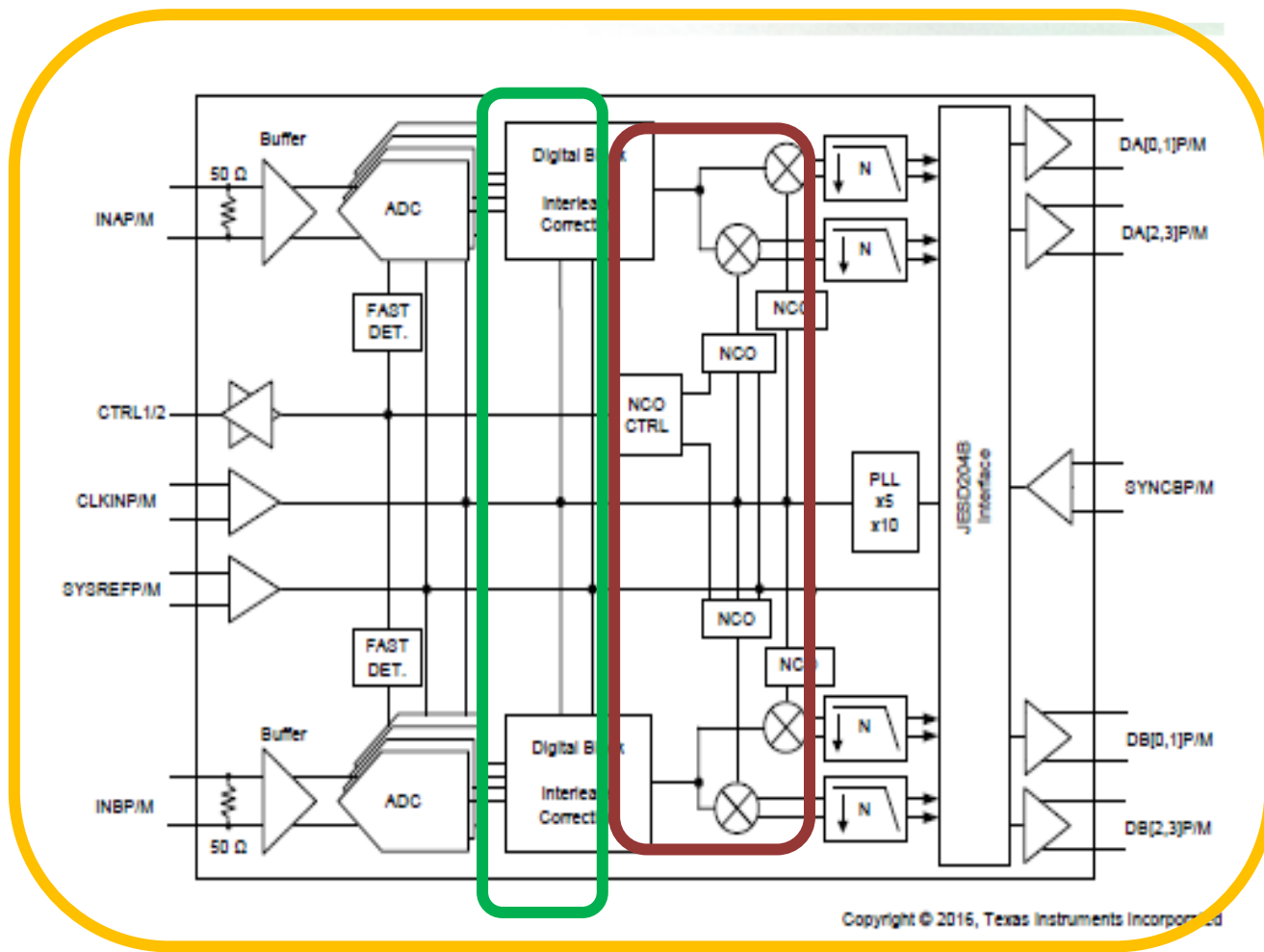
Design Features

- 3-GSPS RF Sampling Receiver Solution
- Low Noise, High Dynamic Range RF Sampling Receiver Solution
- Programmable Decimation from 8 to 32
- Dual Digital Down-Converter With Independent Numerically Controlled Oscillators

Featured Applications

- Wireless Base Station Multi-Band or Multi-Mode Receiver
- Multi-carrier GSM Receiver
- Digital Pre-Distortion Feedback Receiver
- Telecommunications Receiver
- Carrier Aggregation Receiver

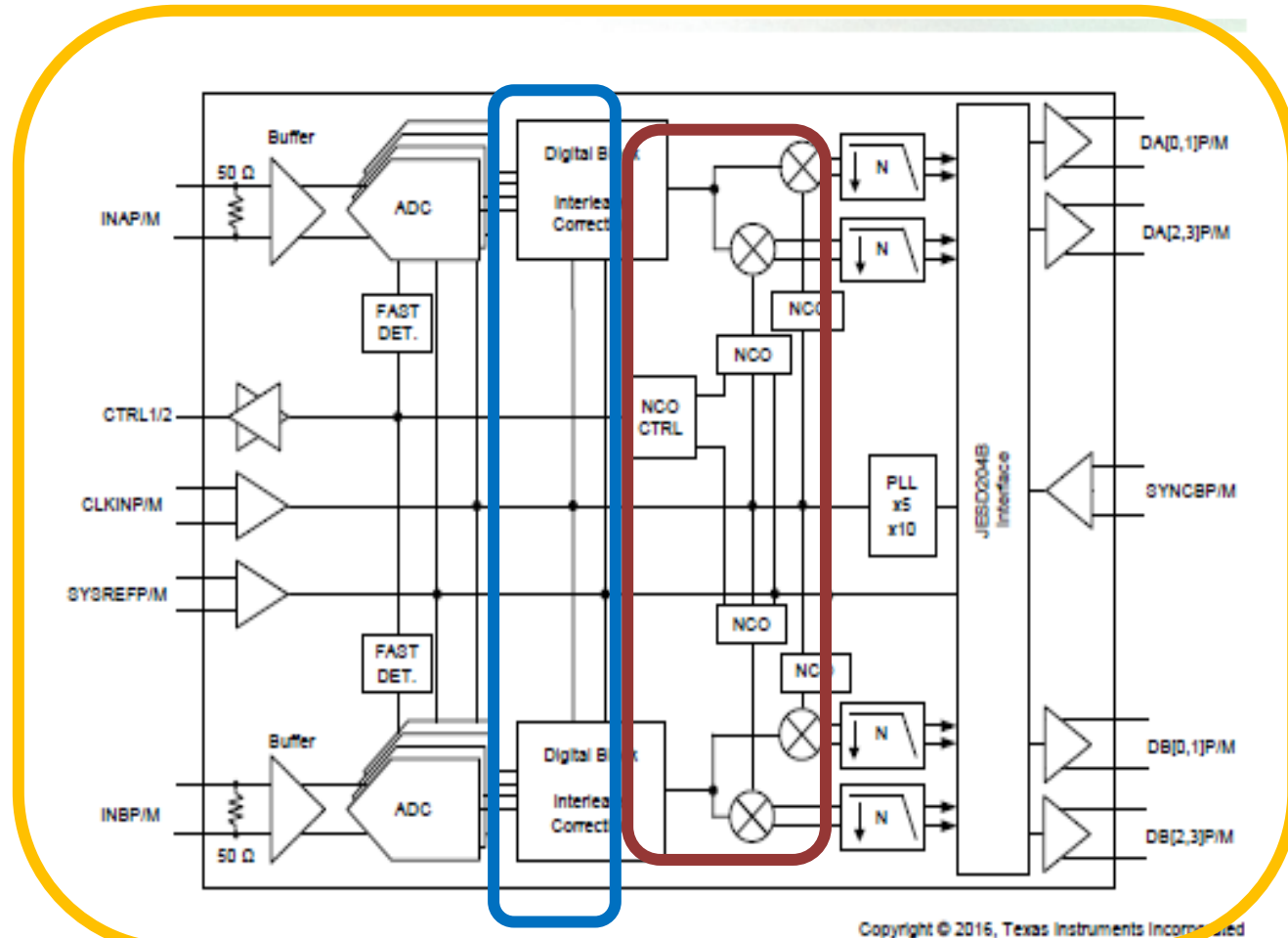




<https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf>

[14d] down-converting the amplified received up-converted analog signal using a second down-converter and a signal corresponding to the second RF center frequency to produce a fifth analog signal corresponding to the second analog signal.

The Accused Instrumentalities perform a method that includes down-converting the amplified received up-converted analog signal using a second down-converter and a signal corresponding to the second RF center frequency to produce a fifth analog signal corresponding to the second analog signal. For example:



<https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf>

Claim 17

Claim 17	Public Documentation
[17pre] A wireless communication system comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. <i>See, e.g.:</i> 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

(3GPP TS 38.300 V17.4.0)

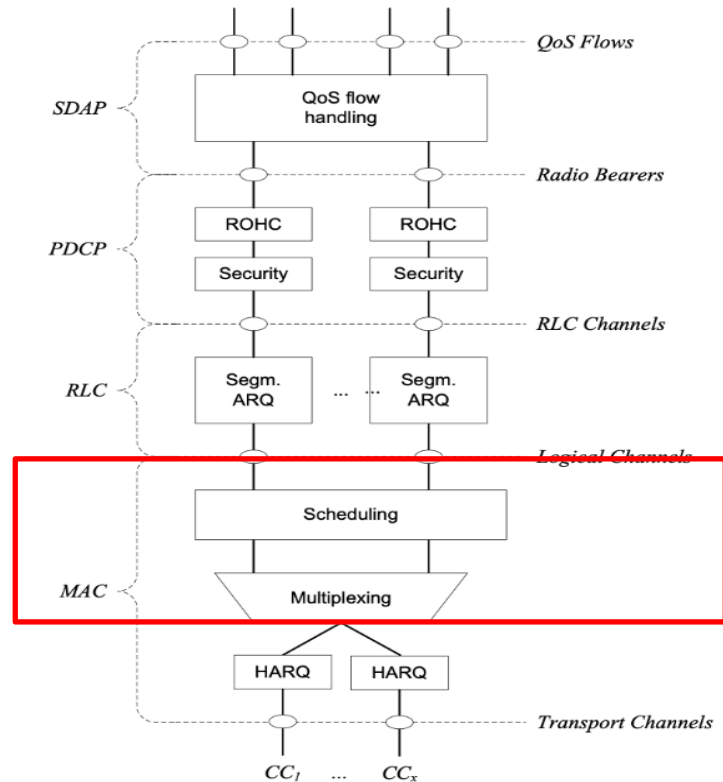


Figure 6.7-2: Layer 2 Structure for UL with CA configured

(3GPP TS 38.300 V17.4.0)

Claim 17	Public Documentation
	<i>5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work?</i> The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 17	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 17	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least \$140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

Claim 17	Public Documentation
	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/) <u>T-MOBILE US USED THE SAMSUNG GALAXY S22 PHONE POWERED BY SNAPDRAGON 8 GEN 1 MOBILE PLATFORM</u> <u>T-Mobile US said it was able to aggregate three channels of mid-band 5G spectrum, reaching speeds over 3 Gbps on its standalone 5G network. The carrier used the Samsung Galaxy S22 phone powered by Snapdragon 8 Gen 1 Mobile Platform with Snapdragon X65 Modem-RF System on a live production network.</u> “This test demonstrates the incredible power of mid-band spectrum and represents another huge step forward for standalone 5G,” said Neville Ray, president of Technology at T-Mobile. “Only T-Mobile is delivering a nationwide standalone 5G network to customers today, and we’re blazing a trail with new performance-boosting capabilities that generate incredible speeds and deliver on our vision to create the highest capacity network in the country.” T-Mobile US noted that 5G Carrier Aggregation (NR CA) allows the combination of multiple 5G channels to improve speed and performance. In this test, the carrier merged three 5G channels — <u>two channels of 2.5 GHz Ultra Capacity 5G and one channel of 1900 MHz spectrum</u> — to create an effective 210 MHz 5G channel. T-Mobile claimed to be the first operator in the world to launch a nationwide SA 5G network nearly two years ago. NR CA is already live in parts of T-Mobile’s network combining two 2.5 GHz 5G channels. The telco said that those customers with the Samsung Galaxy S22 will be among the first to experience a third 1900 MHz 5G channel later this year. This capability will expand across the carrier’s network and to additional devices in the near future. Earlier this month, T-Mobile U.S. announced that customers in limited areas of Portland and Salt Lake City who have the Samsung Galaxy S21 5G now have access to Voice Over New Radio (VoNR) services. The carrier said additional cities will be added to the list throughout the remainder of this year. According to T-Mobile US, VoNR brings the promise of Standalone (SA) 5G “one step closer” by enabling advanced capabilities like network slicing that rely on a continuous connection to a 5G core. At the recent Big 5G Event in Austin,

Claim 17	Public Documentation
	Texas, Ray told RCR Wireless News that in addition to ultimately supporting 5G voice calls, VoNR, without a Non-Standalone 5G or LTE anchor, sees its investment in low-band as the “foundation” of the company’s network. The carrier’s Extended Range 5G (low-band 600 MHz spectrum) covers 315 million people across 1.8 million square miles, while 225 million people nationwide are covered with its Ultra Capacity 5G (2.5 GHz spectrum). The carrier expects to cover 260 million in 2022 and 300 million next year. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>T-Mobile Revs Up 5G with Four-Carrier Aggregation</u> July 25, 2023 What’s the news: T-Mobile has begun rolling out four-carrier aggregation for customers, boosting speeds on its 5G standalone (SA) network. Why it matters: 5G SA is the future of wireless, delivering a whole new level of performance with faster speeds and lower latency (quicker response times). 5G carrier aggregation allows T-Mobile to turbocharge 5G SA speeds, giving customers a game-changing performance boost. Who it’s for: T-Mobile customers across the country. Pedal, meet metal. T-Mobile (NASDAQ: TMUS) today announced it has begun rolling out four-carrier aggregation on its 5G SA network, delivering the capability for insanely fast speeds to customers across the country. If you need help translating ... insanely fast = peak speeds topping 3.3 Gbps in recent tests. Four-carrier aggregation is live in parts of T-Mobile’s network now and will be available nationwide in the coming weeks. “T-Mobile is blazing the trail for wireless customers around the globe, delivering new capabilities that unleash the true potential of 5G,” said Ulf Ewaldsson, President of Technology at T-Mobile. “With the only nationwide 5G standalone network in the country, T-Mobile is the ONLY provider bringing game-changing technologies like four-carrier aggregation to customers across the country.” 5G carrier aggregation allows T-Mobile to combine multiple 5G channels (or carriers) to deliver greater speed and performance. The Un-carrier is now merging four 5G channels of sub-6 GHz spectrum – <u>two channels of 2.5 GHz Ultra Capacity 5G, one channel of 1900 MHz and one channel of 600 MHz spectrum</u>. That’s like taking four separate highways and turning them into a massive superhighway where traffic can zoom faster than before. Customers with the Samsung Galaxy S23 will be the first to experience four-carrier aggregation with more devices to follow.

Claim 17	Public Documentation
	This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across two million square miles – more square miles than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity this year – nearly everyone in the country. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>SRG tests T-Mo’s FDD-TDD CA: ‘You can have your cake and eat it too’</u> January 11, 2022 The aggregation of 600 MHz + 2.5 GHz uses low-band, FDD spectrum to improve performance The aggregation of low and mid-band carriers in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) spectrum improves cell edge performance in T-Mobile US’ network, according to recent testing by Signals Research Group. <u>SRG tested the FDD+TDD carrier aggregation (CA) in T-Mobile US’ commercial network.</u> The testing was conducted during the first week of December, at a large cluster of Ericsson sites in a 180-square-kilometer swath of the suburban Maryland/Washington, D.C. area. “A few mobile operators have already launched TDD-TDD CA in other parts of the world but to the best of our knowledge T-Mobile is the first operator in the world to deploy FDD-TDD CA functionality in a commercial network,” SRG noted. SRG said that T-Mobile US provided the test SIMs and insight into the cluster where the testing was conducted, as well as two Galaxy S21 smartphones — one with pre-commercial software on it that allowed the consulting group to test some of the features it was interested in. Intriguingly, however, SRG found that both devices appeared to support much the same functionality, with a bit of finessing of “hidden” menu options to force the smartphones into the modes of operation that it wanted to test.

Claim 17	Public Documentation
	SRG used test tools from Accuver Americas and Spirent Communications to conduct the study. The firm said that the cell cluster supported a “wide range of different technologies,” including both NSA and SA 5G, using <u>T-Mo’s 600 MHz (FDD) and/or 2.5 GHz (TDD) spectrum. In terms of 5G New Radio CA, the sites either used two 5G NR carriers at 2.5 GHz, leveraging T-Mo’s deep midband holdings for TDD-TDD carrier aggregation; or they paired a single radio channel of 600 MHz spectrum with a single channel of 2.5 GHz — the FDD-TDD CA that SRG sought to test.</u> https://www.rcrwireless.com/20220111/test-and-measurement/srg-tests-t-mos-fdd-tdd-ca-you-can-have-your-cake-and-eat-it-too T-Mobile to Expand and Advance the Nation’s Largest 5G Network with New 5-Year Agreements <i>These multi-billion-dollar deals with both Ericsson and Nokia will continue to supercharge T-Mobile’s nationwide 5G network</i> January 13, 2021 06:29 PM Eastern Standard Time BELLEVUE, Wash.--(BUSINESS WIRE)--Today, T-Mobile (NASDAQ: TMUS) announced five-year, multi-billion-dollar agreements with both Ericsson (NASDAQ: ERIC) and Nokia (NYSE: NOK) to continue advancing and expanding the nation’s largest 5G network. Part of the network investment following last year’s merger with Sprint, these deals enable T-Mobile to add even more 5G coverage, capacity, speed and advanced technical capabilities across all of its spectrum bands. “T-Mobile already has the largest 5G network in the country,” said Neville Ray, T-Mobile President of Technology. “These agreements with our longstanding 5G partners Nokia and Ericsson will help us take our 5G leadership even further, delivering ever-better experiences for our customers for years to come.” Building on two decades of partnership, the Un-carrier will work with Ericsson and Nokia to expand its nationwide 5G network for better 5G coverage and future game-changing experiences, and advanced network capabilities like 5G carrier aggregation. T-Mobile launched the world’s first nationwide standalone 5G network last summer, and recently pulled off the world’s first 5G standalone (SA) data session with New Radio Carrier Aggregation (NR CA). T-Mobile is the first and only U.S. provider to combine the power of Extended Range <i>and</i> Ultra Capacity 5G, boosting speed and performance. T-Mobile also plans to add advanced technical capabilities like voice over 5G (VoNR), network slicing, and multi-user massive MIMO to its 5G network.

Claim 17	Public Documentation
	T-Mobile is already America’s 5G leader with the most advanced 5G network and fast 5G speeds in more places than any other wireless provider. T-Mobile’s Extended Range 5G now covers 280 million people across nearly 1.6 million square miles — that’s more than 2.5x the geographic coverage of AT&T and nearly 4x more than Verizon! And with Sprint now part of T-Mobile, the Un-carrier is widening its lead, lighting up Ultra Capacity 5G across the country and bringing fast 5G speeds to more places than anyone else. Ultra Capacity 5G can deliver average speeds of 300 Mbps with peaks approaching 1 Gbps and is now available in more than 1,000 cities and towns, covering more than 106 million people! That’s 50x more than Verizon covers with Ultra-Wideband! And at T-Mobile, 5G access is included at no extra charge in all smartphone plans. For more information on T-Mobile’s 5G network, visit: www.t-mobile.com/coverage/coverage-map. Follow T-Mobile’s Official Twitter Newsroom @TMobileNews to stay up-to-date with the latest company news. Ultra Capacity 5G includes dedicated mid- and/or high-band 5G signals. T-Mobile’s Ultra Capacity 5G covers hundreds of cities and millions of people, with more added all the time; see T-Mobile.com/5Glayers. Capable device required; coverage not available in some areas. Some uses may require certain plan or feature; see T-Mobile.com. https://www.businesswire.com/news/home/20210113005934/en/T-Mobile-to-Expand-and-Advance-the-Nation%E2%80%99s-Largest-5G-Network-with-New-5-Year-Agreements <u>T-Mobile Supercharges 5G Standalone Uplink Speeds with Carrier Aggregation First</u> May 04, 2023 BELLEVUE, Wash. — May 4, 2023 What’s the news: T-Mobile worked with Nokia and Qualcomm to reach uplink speeds topping 200 Mbps in a 5G data call leveraging uplink carrier aggregation – the first-ever on a live commercial 5G standalone network in the U.S. Why it matters: Increased uplink speeds allow greater amounts of data to be transmitted from customer devices at a quicker rate, enhancing applications like video livestreaming/calling, gaming and Extended Reality (XR). Who it’s for: T-Mobile 5G customers nationwide. Speed ... UP! T-Mobile (NASDAQ: TMUS) announced today it achieved another 5G U.S. first by leveraging uplink (UL) carrier aggregation in the field on the country’s only nationwide 5G standalone (SA) network. Working with Nokia and a test smartphone powered by Snapdragon® 5G Modem-RF System from Qualcomm Technologies, Inc., the Un-

Claim 17	Public Documentation
	carrier hit a top UL speed of 207 Mbps in the test – the <i>fastest ever</i> recorded using sub-6 GHz spectrum! This comes just weeks after T-Mobile made the same move in the lab, hitting similar speeds. “T-Mobile has led the industry with 5G standalone since 2020, and we're continuing to drive breakthroughs that advance 5G technology around the globe,” said Ulf Ewaldsson, President of Technology at T-Mobile. “We’re building the most advanced 5G network in the world, opening the door for massive innovation and laying the foundation for new capabilities that will transform the world around us.” 5G carrier aggregation allows T-Mobile to combine multiple channels (or carriers) to deliver greater speed and performance. In this test, the Un-carrier merged two 5G channels of mid-band spectrum – 2.5 GHz Ultra Capacity 5G and 1900 MHz. That’s like taking two separate highways and turning them into a superhighway where traffic can zoom faster than before. Customers with compatible devices will begin taking advantage of UL 5G carrier aggregation early next year when T-Mobile begins rolling it out. This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across 2 million square miles – more than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity – nearly everyone in the country – this year. https://www.t-mobile.com/news/network/t-mobile-supercharges-5g-standalone-uplink-speeds-with-carrier-aggregation-first WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations.

Claim 17	Public Documentation
	We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates. Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today. 5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation. Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation. https://www.nokia.com/networks/mobile-networks/carrier-aggregation/ Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners.

Claim 17	Public Documentation
	Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson's collaboration with partners has so far resulted in several 5G firsts: • World's first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5 GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile's mid-band 5G. It's also a key step in expanding T-Mobile's nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020) • A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung's Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek's Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020) • Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020) Per Narvinger, Head of Product Area Networks, Ericsson says: "From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we've developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer." Ericsson's 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation

Ericsson ups the tempo on 5G Carrier Aggregation with world's first downlink 6CC data call

Available in English [日本語](#)

Ericsson revs up the tempo on 5G Carrier Aggregation by combining six component carriers to set a record download speed of 5.7Gbps for the world's first 6CC (component carrier) data call.

NEWS

AUG 17, 2023

The data call was achieved using three FDD (frequency division duplex) bands combined with three TDD (time division duplex) bands in sub-6GHz, enabled by Ericsson RAN Compute hardware, state-of the-art carrier aggregation software, and innovative Advanced RAN Coordination functionality.

The 3FDD + 3TDD carrier aggregation testing was carried out in an Ericsson lab with a user equipment (UE) simulator. By combining FDD spectrum with TDD spectrum, more users can benefit from carrier aggregation gains.

In total, 400MHz of bandwidth was aggregated with FDD bandwidths ranging 20MHz to 50MHz to achieve the 5.7Gbps throughput. With six-component carrier capability, communications service providers can optimize use of network and spectrum assets to deliver higher data speeds and capacity that improve the experience of downlink-heavy applications. This can mean better audio and video quality for streaming users, faster file downloads, and a better working environment for digital nomads.

Sibel Tombaz, Head of Product Line 5G RAN at Ericsson Networks, says: "We are keeping the momentum on carrier aggregation by continuously stretching its potential to boost capacity and speed. Our successful 6CC data call shows how versatile our solution is and that we are poised to work with ecosystem partners to make this new band combination a reality. Our goal, as always, is to help customers meet end users' growing appetite for high-capacity, ultrahigh-speed 5G."

"Carrier Aggregation is crucial to getting the best possible 5G performance out of scattered spectrum assets," Tombaz adds. "And with 6CC, service providers will be able to maximize use of allocated spectrum and optimize the combined bandwidth for superior mobile experience."

<https://www.ericsson.com/en/news/2023/8/ericsson-ups-the-tempo-on-5g-carrier-aggregation-with-worlds-first-down-link-6cc-data-call>

Samsung Galaxy S20



Released 2020, March 06

163g, 7.9mm thickness

<> Android 10, up to Android 13, One UI 5

128GB storage, microSDXC

6.2"

1440x3200 pixels

64MP

4320p

8GB RAM

Exynos 990

4000mAh

Li-Ion

18%

6,985,860 HITS

456

BECOME A FAN

REVIEW

OPINIONS

COMPARE

PICTURES

Also available with 5G

NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE	COLLAPSE
	2G bands	GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only) CDMA 800 / 1900 & TD-SCDMA	
	3G bands	HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100 CDMA2000 1xEV-DO	
	4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66	
	Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps	

https://www.gsmarena.com/samsung_galaxy_s20-10081.php

[17a] a baseband digital system for providing a first digital signal comprising a first data to be transmitted and a second digital signal comprising a second data to be transmitted;	The Accused Instrumentalities include a baseband digital system for providing a first digital signal comprising a first data to be transmitted and a second digital signal comprising a second data to be transmitted. For example: 6.7 CARRIER AGGREGATION In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:
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- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

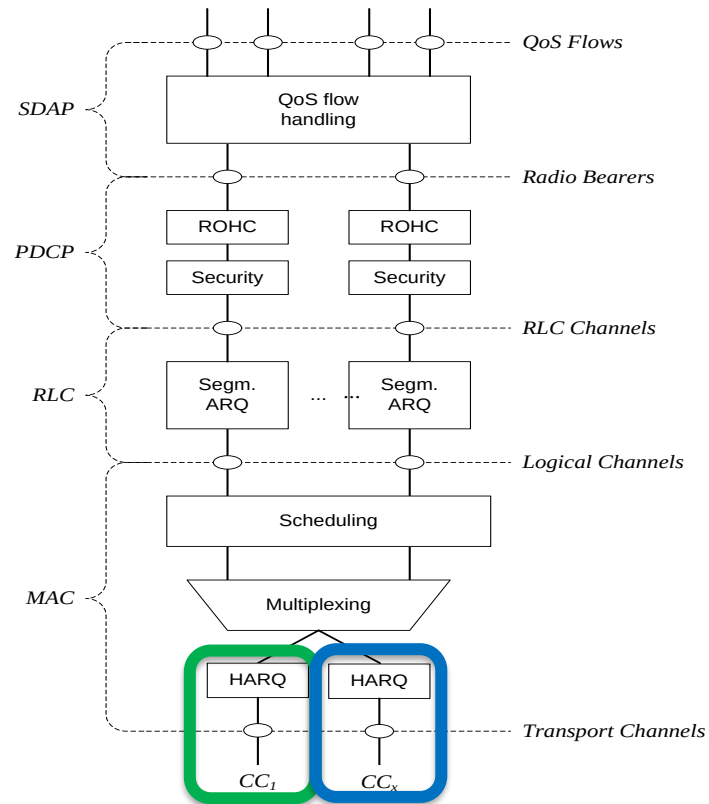


Figure 6.7-2: Layer 2 Structure for UL with CA configured

(3GPP TS 38.300 V17.5.0)

Claim 17	Public Documentation
[17b] a first digital-to-analog converter for receiving the first digital signal and converting the first digital signal into a first analog signal, the first analog signal carrying the first data across a first frequency range;	The Accused Instrumentalities include a first digital-to-analog converter for receiving the first digital signal and converting the first digital signal into a first analog signal, the first analog signal carrying the first data across a first frequency range. For example: 11.3.2.1 Transmitter architecture Figure 11.3.2.1-1 illustrates various TX architectures options according to where the component carriers are combined, i.e., at digital baseband, or in analog waveforms before RF mixer, or after mixer but before the PA, or after the PA. Option A - In an adjacent <i>contiguous common carrier</i> aggregation scenario, the UE very likely has one PA. Connected to the PA can be a single RF chain (a zero-IF mixer, a wideband DAC, and a wideband IFFT) Option-B - Combines analog baseband waveforms from component Carrier first (e.g., via a mixer operating at an IF of roughly the bandwidth of the other component carrier in the example of 2-component carrier aggregation). Then the resulting wideband signal is up-converted to RF. Option-C - Does ZIF up-conversion of each component carrier before combining and feeding into a single PA. Option-D - Employs multiple RF chains and multiple PAs after which the high-power signals are combined and fed into a single antenna. PA coupling at the UE can be challenging for option-D. (3GPP TR 36.912 version 15.0.0 Release 15)

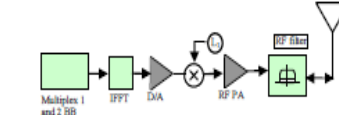
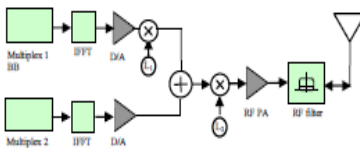
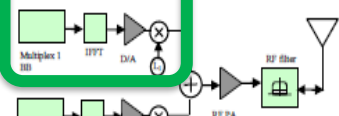
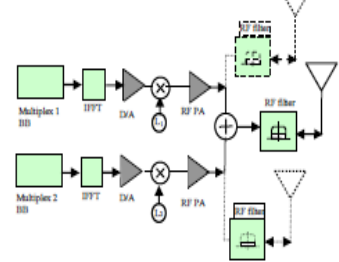
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC + mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

[17c] a second digital-to-analog converter for receiving the second digital signal and converting the second digital signal into a second analog signal, the second analog signal carrying the second data across a second frequency range;

The Accused Instrumentalities include a second digital-to-analog converter for receiving the second digital signal and converting the second digital signal into a second analog signal, the second analog signal carrying the second data across a second frequency range. For example:

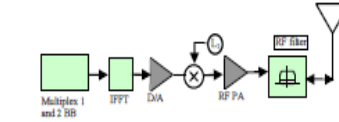
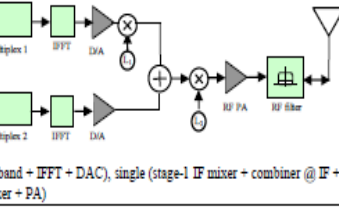
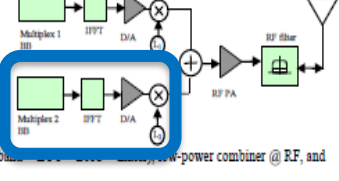
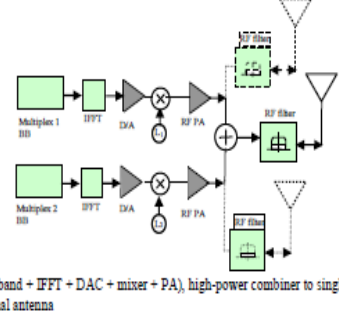
Tx Characteristics			
Option	Description (Tx architecture)	Intra Band aggregation	
		Contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes	
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes
C	 Multiple (baseband + IFFT + DAC + mixer + PA)	Yes	Yes
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes
X	OTHERS		

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios
(3GPP TR 36.912 version 15.0.0 Release 15)

[17d] a first up-converter circuit having a first input coupled to receive the first analog signal and a second input coupled to receive a first modulation signal having a first RF frequency, wherein the first up-converter outputs a first up-converted analog signal comprising a first up-converted frequency range from the first RF frequency minus one-half the first frequency range to the first RF frequency plus one-half the first frequency range;

The Accused Instrumentalities include a first up-converter circuit having a first input coupled to receive the first analog signal and a second input coupled to receive a first modulation signal having a first RF frequency, wherein the first up-converter outputs a first up-converted analog signal comprising a first up-converted frequency range from the first RF frequency minus one-half the first frequency range to the first RF frequency plus one-half the first frequency range. For example:

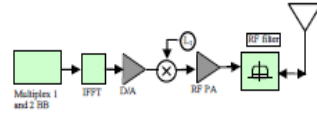
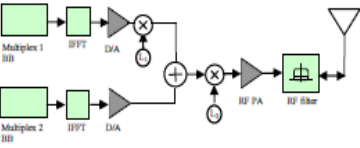
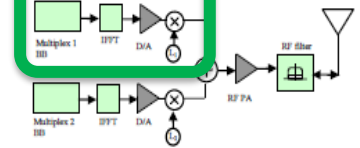
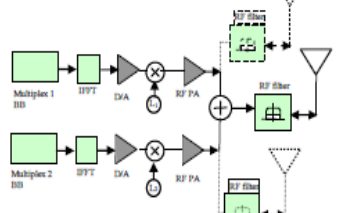
Tx Characteristics			
Option	Description (Tx architecture)	Intra Band aggregation	
		Contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes	
B	 Multiple (baseband + IFFT + DAC + mixer) (stage 1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes
X	OTHERS		

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

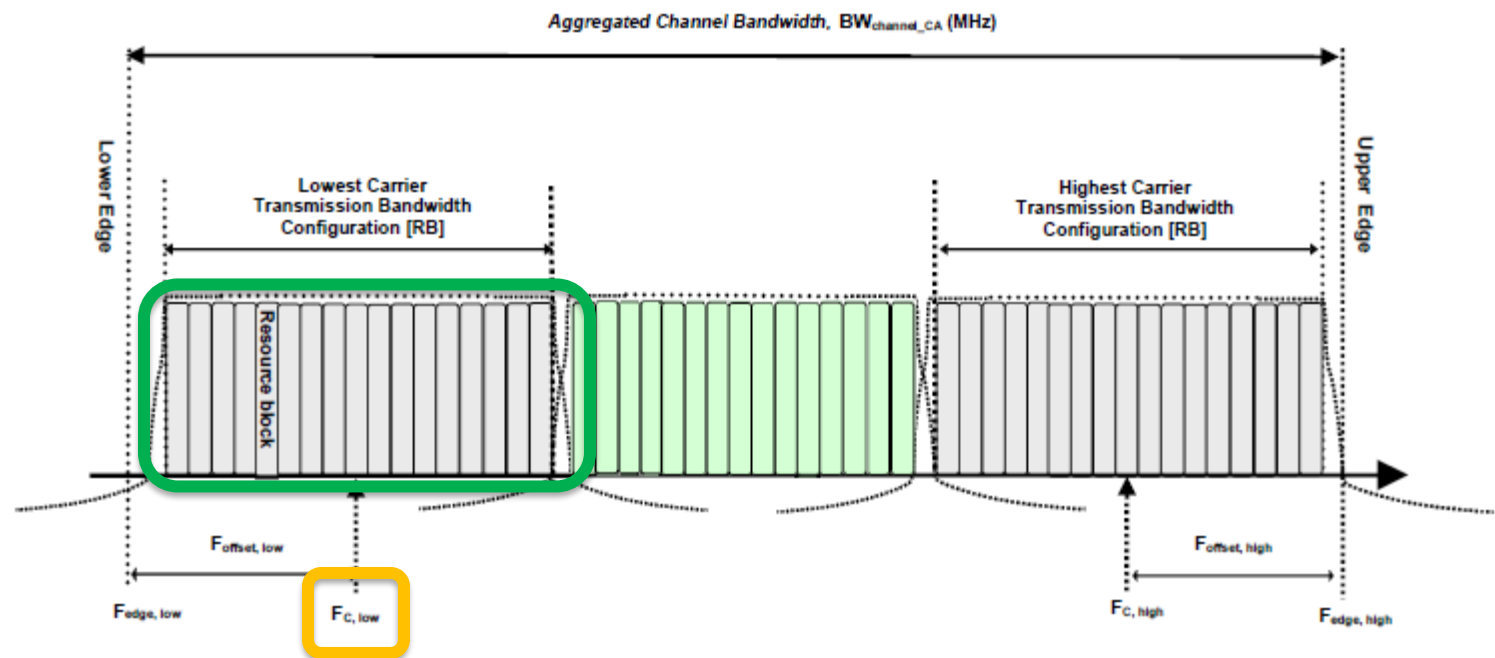


Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation

$$BW_{\text{Channel_CA}} = F_{\text{edge,high}} - F_{\text{edge,low}} \text{ (MHz)}.$$

The lower bandwidth edge $F_{\text{edge, low}}$ and the upper bandwidth edge $F_{\text{edge,high}}$ of the aggregated channel bandwidth are used as frequency reference points for transmitter and receiver requirements and are defined by

Claim 17	Public Documentation
	$F_{\text{edge,low}} = F_{\text{C,low}} - F_{\text{offset,low}}$ $F_{\text{edge,high}} = F_{\text{C,high}} + F_{\text{offset,high}}$ The lower and upper frequency offsets depend on the transmission bandwidth configurations of the lowest and highest assigned edge component carrier and are defined as $F_{\text{offset,low}} = (\text{NRB}_{\text{low}} * 12 + 1) * \text{SCS}_{\text{low}} / 2 + \text{BWGB} \text{ (MHz)}$ $F_{\text{offset,high}} = (\text{NRB}_{\text{high}} * 12 - 1) * \text{SCS}_{\text{high}} / 2 + \text{BWGB} \text{ (MHz)}$ $\text{BWGB} = \max(\text{BWGB}_{\text{Channel}(k)})$ NRB_{low} and NRB_{high} are the transmission bandwidth configurations according to Table 5.3.2-1 for the lowest and highest assigned component carrier, SCS_{low} and SCS_{high} are the sub-carrier spacing for the lowest and highest assigned component carrier respectively. SCS_{low}, SCS_{high}, NRB_{low}, NRB_{high}, and $\text{BWGB}_{\text{Channel}(k)}$ use the largest μ value among the subcarrier spacing configurations supported in the operating band for both of the channel bandwidths according to Table 5.3.5-1 and $\text{BWGB}_{\text{Channel}(k)}$ is the minimum guard band for carrier k according to Table 5.3.3-1 for the said μ value. In case there is no common μ value for both of the channel bandwidths, $\mu=1$ is used for SCS_{low}, SCS_{high}, NRB_{low}, NRB_{high}, and $\text{BWGB}_{\text{Channel}(k)}$. (3GPP TS 38.101-1 V17.5.0)

[17e] a second up-converter circuit having a first input coupled to receive the second analog signal and a second input coupled to receive a second modulation signal having a second RF frequency, wherein the second up-converter outputs a second up-converted analog signal comprising a second up-converted frequency range from the second RF frequency minus one-half the second frequency range to the second RF frequency plus one-half the second frequency range, and wherein frequency difference between the first RF frequency and the second RF frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range; and

The Accused Instrumentalities include a second up-converter circuit having a first input coupled to receive the second analog signal and a second input coupled to receive a second modulation signal having a second RF frequency, wherein the second up-converter outputs a second up-converted analog signal comprising a second up-converted frequency range from the second RF frequency minus one-half the second frequency range to the second RF frequency plus one-half the second frequency range, and wherein frequency difference between the first RF frequency and the second RF frequency is greater than the sum of one-half the first frequency range and one-half the second frequency range. For example:

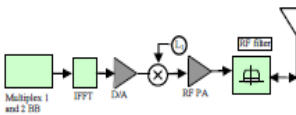
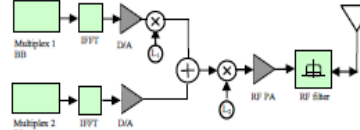
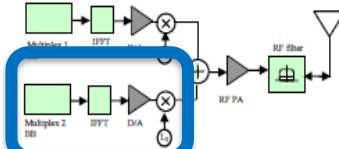
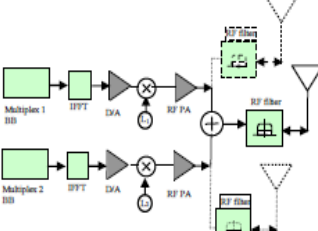
Tx Characteristics			
Option	Description (Tx architecture)	Intra Band aggregation	
		Contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes	
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes
C	 Multiple (baseband + IFFT + DAC + mixer + PA), power combiner @ RF, and single PA	Yes	Yes
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes
X	OTHERS		

Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

For carrier aggregation, the maximum transmission bandwidth configuration is defined per component carrier and the requirement is specified in clause 5.3.2.

5.3A.3 Minimum guardband and transmission bandwidth configuration for CA

For intra-band contiguous carrier aggregation, *Aggregated Channel Bandwidth* and *Guard Bands* are defined as follows, see Figure 5.3A.3-1.

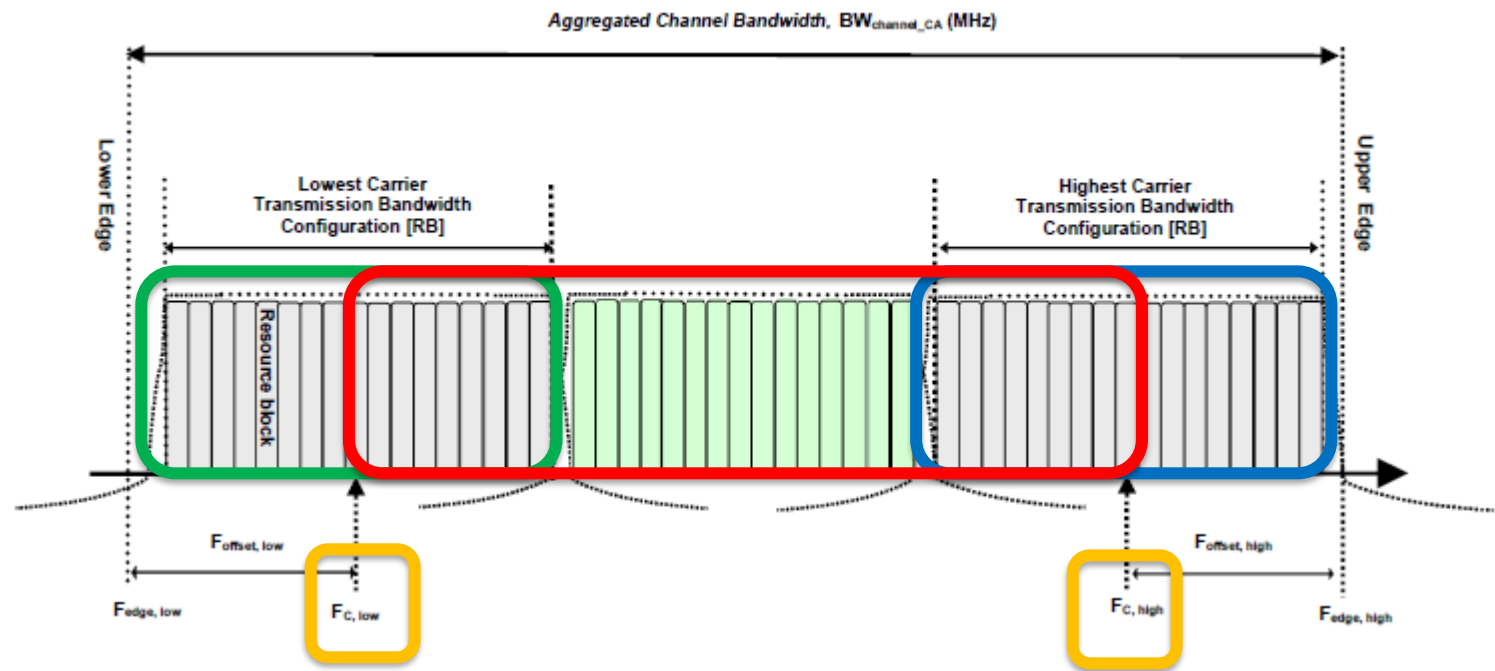


Figure 5.3A.3-1: Definition of *Aggregated Channel Bandwidth* for intra-band carrier aggregation
(3GPP TS 38.101-1 V17.5.0)

[17f] a power amplifier coupled to receive the first and second up-converted analog signals, wherein the bandwidth of the power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range.

The Accused Instrumentalities include a power amplifier coupled to receive the first and second up-converted analog signals, wherein the bandwidth of the power amplifier is greater than the difference between a lowest frequency in the first up-converted frequency range and a highest frequency in the second up-converted frequency range. For example:

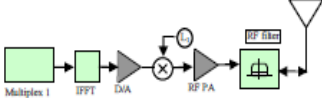
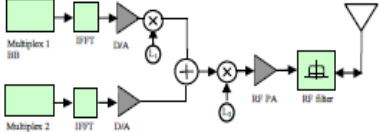
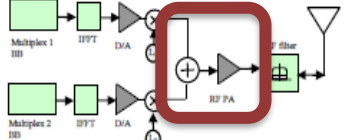
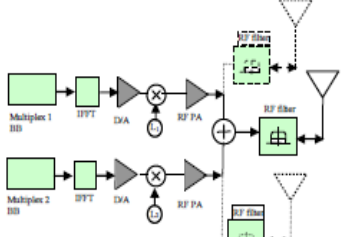
Tx Characteristics				
Option	Description (Tx architecture)	Intra Band aggregation		Inter Band aggregation
		Contiguous (CC)	Non contiguous (CC)	Non contiguous (CC)
A	 Single (baseband + IFFT + DAC + mixer + PA)	Yes		
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)	Yes	Yes	
C	 Multiple (baseband + IFFT + DAC + mixer), low-power combiner @ RF, and single PA	Yes	Yes	
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Yes	Yes	Yes + (depending on the specific EUTRA bands being aggregated),
X	OTHERS			

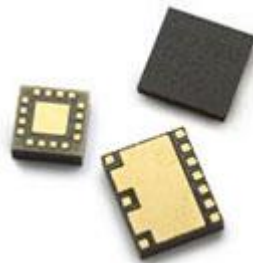
Figure 11.3.2.1-1: Possible UE Architectures in three aggregation scenarios

(3GPP TR 36.912 version 15.0.0 Release 15)

As a further example, in power amplifier designs believed to be representative of those used in the Accused Instrumentalities:

<https://www.broadcom.com/products/wireless/rf-front-end-modules/mobile-rf-fem>

Mobile RF FEM



Broadcom provides custom RF front end module (FEM) devices for mobile wireless applications. These devices incorporate multiband power amplifiers (PA), FBAR duplexers and multiplexers, SOI multi-mode LNAs and antenna switch, coupler and MIPI controller, designed to support various carrier aggregation (CA) for both FDD and TDD bands.

Broadcom has shipped billions of RF FEM devices to the world's leading smartphone manufacturers.

The Broadcom ACFM-2S13 is a quadplexer device that combines Band 1 and Band 3 duplexers into a single, miniature package. Band 4 duplexer is co-banded. The device features a single antenna connection, eliminating the need for antenna switching. High Isolation between bands enables the use of carrier aggregation.

The ACFM-2S13 is designed with Broadcom's innovative filter capability which makes possible ultra-small, high-Q filters at a fraction of their usual size. Low Tx Insertion Loss of the ACFM-2S13 reduces power amplifier current, extending battery life. The device enhances receiver sensitivity and dynamic range with low Rx Insertion Loss and high rejection of Tx signals at the Rx ports.

Features

- Single antenna
- High cross band isolation
 - Enables carrier aggregation
- Band 4 co-banding
- Miniature size
 - 2.0 x 2.5 mm footprint
 - 0.710 mm typ. height
- High Power Rating
- Environmental
 - RoHS 6 Compliant
 - Halogen Free
 - TBBPA Free

<https://www.broadcom.com/products/wireless/demo-boards/acfm-2s13>



PRODUCT SUMMARY

SKY77786-11 High Band Multimode Multiband Power Amplifier Module Supporting LTE Advanced Applications

Applications

- Multiband 4G / LTE handsets
- FDD LTE Bands 7 and 30
- TDD LTE Band 38, 40, 41

Features

- Two T/R (RX) port and 3 outputs
- Industry-leading PAE for 4G
- Optimized for APT DCDC operation
- Fully programmable Mobile Industry Processor Interface (MIPI) control
- MIPI programmable bias modes optimize best 4G efficiency/linearity performance.
- Small, low profile package:
 - 3.0 x 3.0 x 0.71 mm
 - 20-pad configuration



Skyworks Green™ products are compliant with all applicable legislation and are halogen-free. For additional information, refer to Skyworks *Definition of Green™*, document number SQ04-0074.

Description

Skyworks SKY77786-11 SkyLiTETM is a multimode multiband (MMMB) Power Amplifier Module (PAM) that supports 4G handsets and operates efficiently in LTE bands from 2.3 GHz to 2.7 GHz. The module is fully programmable through a Mobile Industry Processor Interface (MIPI®).

The PAM consists of a single high band LTE block, a Multi-Function Control (MFC) block, and a T/R switch block. RF input/output ports internally matched to 50 Ω to reduce the number of external components. A CMOS integrated circuit uses standard MIPI controls to provide the internal MFC interface and operation. Extremely low leakage current maximizes handset standby time.

The InGaP die and the silicon die and passive components are mounted on a multi-layer laminate substrate. The assembly is encapsulated in a 3.0 mm x 3.0 mm x 0.71 mm, 20-pad MCM, SMT package which is a more highly manufacturable, low cost solution.

4G: The SKY77786-11 supports 1.4, 3, 5, 10, 15, 20, 30, 35, 40 MHz channel bandwidths. Similar to 3G operation, output power is controlled by varying the input power and V_{CC} is adjusted using a DCDC converter to maximize efficiency for each power level.

4G Modulation scheme includes:

- FDD LTE
- TDD LTE
- Uplink Carrier Aggregation (CA) support for Bands 40/41 (up to 40 MHz)

Claim 17	Public Documentation
	Elevating Performance with Industry-Leading Primary Path Architectures Skyworks is enabling technology evolutions industry-wide with its advanced cellular transmit solutions for mobile devices. Leveraging decades of systems and module expertise, we architect baseband agnostic solutions that utilize our advanced power amplifier, low noise amplifier, filter and switch technologies. Our portfolio covers 2G, 3G, 4G and 5G applications, addressing specific customer priorities for system efficiency, solution size and total cost. Skyworks' latest modules for 5G from our SKY5® portfolio feature the highest transmit efficiency — optimizing battery life and enhancing thermal benefits — and advanced BAW and TC-SAW technologies in an exceptionally compact form factor, <u>while supporting the maximum combination of carrier aggregation (CA) bands.</u> Our products uniquely provide the best performance at targeted frequency bands, supporting up to 100 MHz wide bandwidth, maximizing data throughput at ultra-fast speeds. https://www.skyworksinc.com/en/System-Solutions/Transmit

Claim 21

Claim 21	Public Documentation
[21] The communication system of claim 17 wherein the first data of the first digital signal is encoded using a first wireless protocol and the first data of the second digital signal is encoded using a second wireless protocol.	In the Accused Instrumentalities the first data of the first digital signal is encoded using a first wireless protocol and the first data of the second digital signal is encoded using a second wireless protocol. For example: Cellular operators, for example T-MO, have deployed carrier aggregation in mid band (2.5 GHz, 3.5 GHz), in 1900 MHz PCS band as well as the 600 MHz band. In the mid band such as the 2.5 GHz or 3.5 GHz TDD protocol has been deployed. In the PCS 1900 MHz and 600 MHz bands FDD 5G and LTE protocols have been deployed. Two protocols, FDD and TDD, are used in these carrier aggregation deployments. The carrier aggregation tested by Galaxy 22 and Galaxy 23 on T-MO network supported both TDD and FDD protocols. <u>SRG tests T-Mo’s FDD-TDD CA: ‘You can have your cake and eat it too’</u> January 11, 2022 The aggregation of 600 MHz + 2.5 GHz uses low-band, FDD spectrum to improve performance The aggregation of low and mid-band carriers in <u>both Frequency Division Duplex (FDD) and Time Division Duplex (TDD)</u> spectrum improves cell edge performance in T-Mobile US’ network, according to recent testing by Signals Research Group. SRG tested the <u>FDD+TDD</u> carrier aggregation (CA) in T-Mobile US’ commercial network. The testing was conducted during the first week of December, at a large cluster of Ericsson sites in a 180-square-kilometer swath of the suburban Maryland/Washington, D.C. area. “A few mobile operators have already launched TDD-TDD CA in other parts of the world but to the best of our knowledge T-Mobile is the first operator in the world to deploy FDD-TDD CA functionality in a commercial network,” SRG noted. SRG said that <u>T-Mobile US provided the test SIMs and insight into the cluster where the testing was conducted, as well as two Galaxy S21 smartphones</u> — one with pre-commercial software on it that allowed the consulting group to test some of the features it was interested in. Intriguingly, however, SRG found that both devices appeared to support much the same functionality, with a bit of finessing of “hidden” menu options to force the smartphones into the modes of operation that it wanted to test.

Claim 21	Public Documentation
	SRG used test tools from Accuver Americas and Spirent Communications to conduct the study. The firm said that the cell cluster supported a “wide range of different technologies,” including both NSA and SA 5G, using <u>T-Mo’s 600 MHz (FDD) and/or 2.5 GHz (TDD) spectrum</u>. In terms of 5G New Radio CA, the sites either used two 5G NR carriers at 2.5 GHz, leveraging T-Mo’s deep midband holdings for TDD-TDD carrier aggregation; <u>or they paired a single radio channel of 600 MHz spectrum with a single channel of 2.5 GHz — the FDD-TDD CA that SRG sought to test.</u> https://www.rcrwireless.com/20220111/test-and-measurement/srg-tests-t-mos-fdd-tdd-ca-you-can-have-your-cake-and-eat-it-too <u>T-MOBILE US USED THE SAMSUNG GALAXY S22 PHONE POWERED BY SNAPDRAGON 8 GEN 1 MOBILE PLATFORM</u> <u>T-Mobile US said it was able to aggregate three channels of mid-band 5G spectrum, reaching speeds over 3 Gbps on its standalone 5G network. The carrier used the Samsung Galaxy S22 phone powered by Snapdragon 8 Gen 1 Mobile Platform with Snapdragon X65 Modem-RF System on a live production network.</u> “This test demonstrates the incredible power of mid-band spectrum and represents another huge step forward for standalone 5G,” said Neville Ray, president of Technology at T-Mobile. “Only T-Mobile is delivering a nationwide standalone 5G network to customers today, and we’re blazing a trail with new performance-boosting capabilities that generate incredible speeds and deliver on our vision to create the highest capacity network in the country.” T-Mobile US noted that 5G Carrier Aggregation (NR CA) allows the combination of multiple 5G channels to improve speed and performance. In this test, the carrier merged three 5G channels — <u>two channels of 2.5 GHz Ultra Capacity 5G</u> and <u>one channel of 1900 MHz spectrum</u> — to create an effective 210 MHz 5G channel. T-Mobile claimed to be the first operator in the world to launch a nationwide SA 5G network nearly two years ago. NR CA is already live in parts of T-Mobile’s network combining two 2.5 GHz 5G channels. The telco said that those customers with the Samsung Galaxy S22 will be among the first to experience a third 1900 MHz 5G channel later this year. This capability will expand across the carrier’s network and to additional devices in the near future.

Claim 21	Public Documentation
	Earlier this month, T-Mobile U.S. announced that customers in limited areas of Portland and Salt Lake City who have the Samsung Galaxy S21 5G now have access to Voice Over New Radio (VoNR) services. The carrier said additional cities will be added to the list throughout the remainder of this year. According to T-Mobile US, VoNR brings the promise of Standalone (SA) 5G “one step closer” by enabling advanced capabilities like network slicing that rely on a continuous connection to a 5G core. At the recent Big 5G Event in Austin, Texas, Ray told RCR Wireless News that in addition to ultimately supporting 5G voice calls, VoNR, without a Non-Standalone 5G or LTE anchor, sees its investment in low-band as the “foundation” of the company’s network. The carrier’s Extended Range 5G (low-band 600 MHz spectrum) covers 315 million people across 1.8 million square miles, while 225 million people nationwide are covered with its Ultra Capacity 5G (2.5 GHz spectrum). The carrier expects to cover 260 million in 2022 and 300 million next year. https://www.rcrwireless.com/20220615/5g/t-mobile-us-tops-3-gbps-standalone-5g- <u>T-Mobile Revs Up 5G with Four-Carrier Aggregation</u> July 25, 2023 What’s the news: T-Mobile has begun rolling out four-carrier aggregation for customers, boosting speeds on its 5G standalone (SA) network. Why it matters: 5G SA is the future of wireless, delivering a whole new level of performance with faster speeds and lower latency (quicker response times). 5G carrier aggregation allows T-Mobile to turbocharge 5G SA speeds, giving customers a game-changing performance boost. Who it’s for: T-Mobile customers across the country. Pedal, meet metal. T-Mobile (NASDAQ: TMUS) today announced it has begun rolling out four-carrier aggregation on its 5G SA network, delivering the capability for insanely fast speeds to customers across the country. If you need help translating ... insanely fast = peak speeds topping 3.3 Gbps in recent tests. Four-carrier aggregation is live in parts of T-Mobile’s network now and will be available nationwide in the coming weeks. “T-Mobile is blazing the trail for wireless customers around the globe, delivering new capabilities that unleash the true potential of 5G,” said Ulf Ewaldsson, President of Technology at T-Mobile. “With the only nationwide

Claim 21	Public Documentation
	5G standalone network in the country, T-Mobile is the ONLY provider bringing game-changing technologies like four-carrier aggregation to customers across the country.” 5G carrier aggregation allows T-Mobile to combine multiple 5G channels (or carriers) to deliver greater speed and performance. The Un-carrier is now merging four 5G channels of sub-6 GHz spectrum – <u>two channels of 2.5 GHz Ultra Capacity 5G, one channel of 1900 MHz and one channel of 600 MHz spectrum</u>. That’s like taking four separate highways and turning them into a massive superhighway where traffic can zoom faster than before. <u>Customers with the Samsung Galaxy S23 will be the first to experience four-carrier aggregation with more devices to follow.</u> This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the <u>first in the world</u> to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like <u>carrier aggregation and VoNR</u>. T-Mobile is <u>the leader in 5G</u>, delivering the country’s largest, fastest and most awarded <u>5G network</u>. The Un-carrier’s 5G network covers 326 million people across two million square miles – more square miles than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity this year – nearly everyone in the country. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation

Claim 23

Claim 23	Public Documentation
[23] The communication system of claim 17 wherein first and second data to be transmitted comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first up-converted frequency range and a second symbol is transmitted during the first time slot across the second up-converted frequency range, and wherein a third symbol is transmitted during a second time slot across the first up-converted frequency range and a fourth symbol is transmitted during the second time slot across a second up-converted frequency range.	In the Accused Instrumentalities, first and second data to be transmitted comprise a plurality of OFDM symbols, wherein a first symbol is transmitted during a first time slot across the first up-converted frequency range and a second symbol is transmitted during the first time slot across the second up-converted frequency range, and wherein a third symbol is transmitted during a second time slot across the first up-converted frequency range and a fourth symbol is transmitted during the second time slot across a second up-converted frequency range. For example: 5G frame structure comprises frames of length 10 msec long, each frame comprises 10 sub-frames, each sub-frame comprises at least two time slots, and each frame comprises at least 20 time slots. Each time slot comprises a multitude of OFDM symbols. A transport block, data payload, in 5G is divided into a set of code blocks, each code block is transmitted on frequency resources of OFDM symbols that comprise a time slot. In a Carrier Aggregation (CA) method, a data stream is multiplexed onto multiple Component Carriers (CCs), e.g., onto a first and a second data stream. The first and second data (“information”) streams are transmitted on a first and a second CC, respectively. The first data stream is transmitted on a first CC, on frequency resources of an OFDM symbol in a time slot of the first CC, and the second data stream is transmitted on a second CC, on frequency resources of an OFDM symbol in the time slot of the second CC. The code blocks of the transport block (payload, data stream) are multiplexed onto the CCs and transmitted in consecutive time slots. 6.7 CARRIER AGGREGATION In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

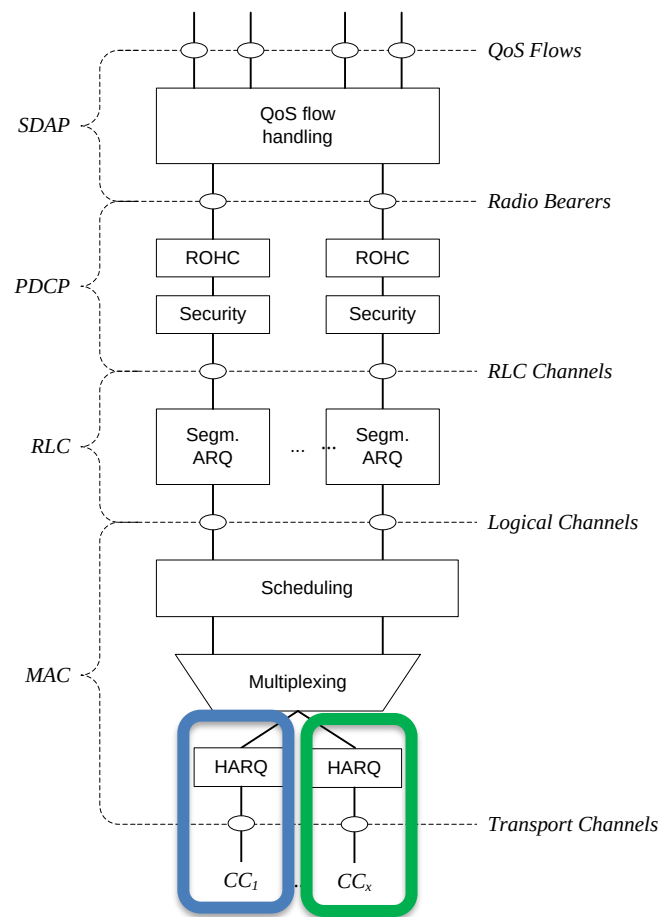


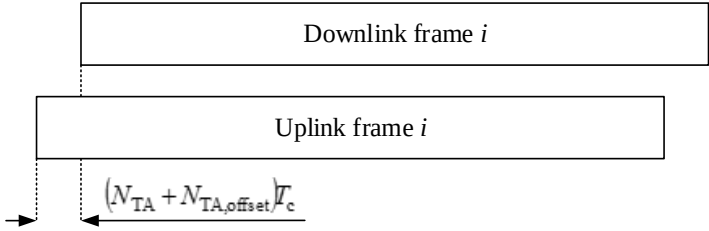
Figure 6.-2: Layer 2 Structure for UL with CA configured.

(3GPP TS 38.300 V17.4.0)

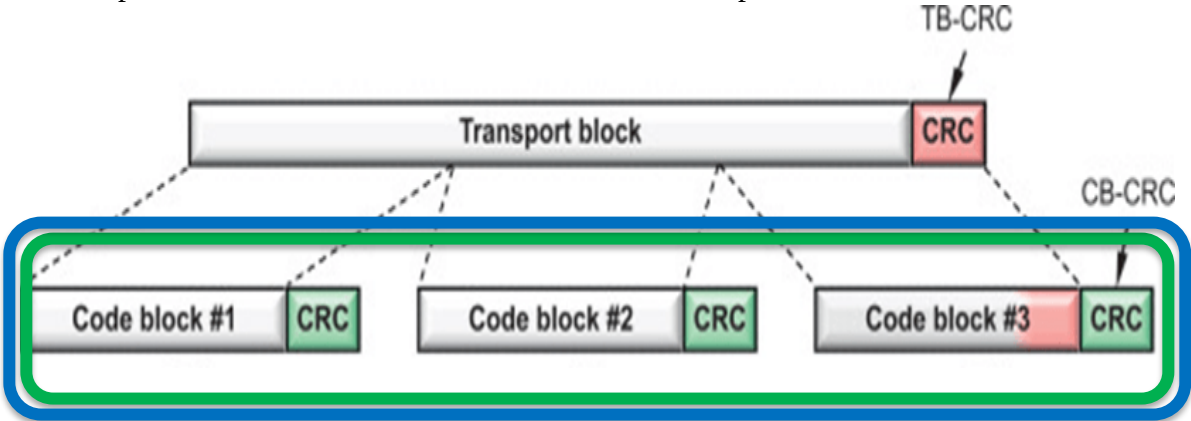
Frame structure and physical resources

4.1 GENERAL

Claim 23	Public Documentation																		
	Throughout this specification, unless otherwise noted, the size of various fields in the time domain is expressed in time units $T_c = 1/(\Delta f_{\max} \cdot N_f)$ where $\Delta f_{\max} = 480 \cdot 10^3$ Hz and $N_f = 4096$. The constant $\kappa = T_s/T_c = 64$ where $T_s = 1/(\Delta f_{\text{ref}} \cdot N_{f,\text{ref}})$, $\Delta f_{\text{ref}} = 15 \cdot 10^3$ Hz and $N_{f,\text{ref}} = 2048$. Throughout this specification, unless otherwise noted, statements using the term "UE" in clauses 4, 5, 6, or 7 are equally applicable to the IAB-MT part of an IAB node. 4.2 NUMEROLOGIES Multiple OFDM numerologies are supported as given by Table 4.2-1 where μ and the cyclic prefix for a downlink or uplink bandwidth part are obtained from the higher-layer parameter <i>subcarrierSpacing</i> and <i>cyclicPrefix</i>, respectively. Table 4.2-1: Supported transmission numerologies. <table><tr><th>μ</th><th>$\Delta f = 2^\mu \cdot 15$ [kHz]</th><th>Cyclic prefix</th></tr><tr><td>0</td><td>15</td><td>Normal</td></tr><tr><td>1</td><td>30</td><td>Normal</td></tr><tr><td>2</td><td>60</td><td>Normal, Extended</td></tr><tr><td>3</td><td>120</td><td>Normal</td></tr><tr><td>4</td><td>240</td><td>Normal</td></tr></table> 4.3 FRAME STRUCTURE 4.3.1 FRAMES AND SUBFRAMES Downlink, uplink, and sidelink transmissions are organized into frames with $T_f = (\Delta f_{\max} N_f / 100) \cdot T_c = 10\text{ms}$ duration, each consisting of ten subframes of $T_{\text{sf}} = (\Delta f_{\max} N_f / 1000) \cdot T_c = 1\text{ms}$ duration. The number of consecutive OFDM symbols per subframe is $N_{\text{symb}}^{\text{subframe},\mu} = N_{\text{symb}}^{\text{slot}} N_{\text{slot}}^{\text{subframe},\mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9. There is one set of frames in the uplink and one set of frames in the downlink on a carrier.	μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix	0	15	Normal	1	30	Normal	2	60	Normal, Extended	3	120	Normal	4	240	Normal
μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix																	
0	15	Normal																	
1	30	Normal																	
2	60	Normal, Extended																	
3	120	Normal																	
4	240	Normal																	

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	Uplink frame number i for transmission from the UE shall start $T_{TA} = (N_{TA} + N_{TA,offset})T_c$ before the start of the corresponding downlink frame at the UE where $N_{TA,offset}$ is given by [5, TS 38.213], except for msgA transmission on PUSCH where $T_{TA} = 0$ shall be used.  Figure 4.3.1-1: Uplink-downlink timing relation. 4.3.2 SLOTS For subcarrier spacing configuration μ, slots are numbered $n_s^\mu \in \{0, \dots, N_{slot}^{subframe,\mu} - 1\}$ in increasing order within a subframe and $n_{s,f}^\mu \in \{0, \dots, N_{slot}^{frame,\mu} - 1\}$ in increasing order within a frame. There are N_{symb}^{slot} consecutive OFDM symbols in a slot where N_{symb}^{slot} depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. <u>The start of slot n_s^μ in a subframe is aligned in time with the start of OFDM symbol $n_s^\mu N_{symb}^{slot}$ in the same subframe.</u> <u>OFDM symbols in a slot</u> in a downlink or uplink frame can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in clause 11.1 of [5, TS 38.213]. (3GPP TS 38.211 V16.1.0) <u>5G NR Transport Block Size (TBS) Calculation</u> <u>August 16, 2020</u> <u>Author</u> <u>3GPP Specification</u>, <u>5G MAC Layer</u>, <u>5G NR</u>, <u>5G Physical Layer</u> Frame structure and physical resources Transport Block in 5G NR, is nothing but the payload, which is passed between the MAC and Phy Layers, specifically for the shared data channel such as PDSCH and PUSCH. A Transport Block undergoes Phy layer

processing at the transmitter before being mapped onto the PDSCH for transmission over the air interface. A Transport block is added with CRC and segmented into code blocks as shown as below. The transport block consists of up to million bits and the code block consists of up to 8448 bits.



(<https://www.techplayon.com/5g-nr-transport-block-size-tbs-calculatin>)

TIME-FREQUENCY RESOURCE

A **resource element** is the smallest time-frequency resource over one subcarrier of a single OFDM symbol. It is identified as $(k, l)_{p, \mu}$ where k is the index of the subcarrier in the frequency domain, l is the OFDM symbol position in time domain, p is the antenna port and μ is the subcarrier spacing configuration defined in Table 1 above.

A **resource block** (a.k.a **physical resource block – PRB**) is a block of $N^{RB}_{sc} = 12$ subcarriers over which the transmissions are scheduled. 5G NR physical layer uses time-frequency resource (**physical resource block**) for transmission.

A resource grid consists of $N_{grid,x}^{size,\mu}$ subcarriers and $N_{subframe,\mu}^{subframe,\mu}$ number of OFDM symbols (*Table 2 and 3*).

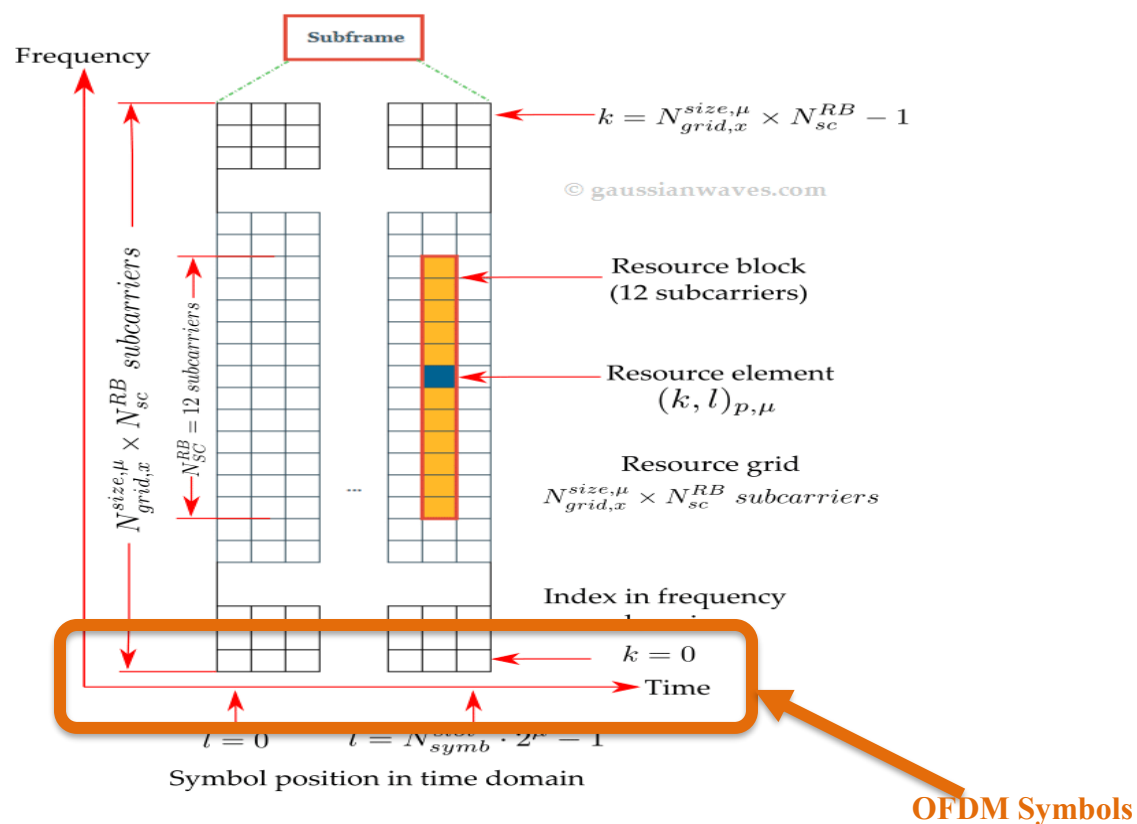


Figure 3: Resource element, Resource block, Resource grid in 5G NR

(<https://www.gaussianwaves.com/2022/02/5g-nr-resource-block>)

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[24pre] An electronic circuit comprising:	To the extent the preamble is found to be limiting, the Accused Instrumentalities perform a method of transmitting information in a wireless communication channel. For example, Defendant deploys and uses 4G and 5G RAN Solutions by vendors Ericsson and Nokia. These 4G and 5G RAN Solutions are 4G and 5G NR cellular radio access network systems supporting carrier aggregation, and the accused systems include all the installed components for the 4G and 5G NR RAN solution systems deployed by Defendant. <i>See, e.g.:</i> 5.4 Carrier aggregation 5.4.1 Carrier aggregation In Carrier Aggregation (CA), two or more Component Carriers (CCs) are aggregated. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities: - A UE with single timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells sharing the same timing advance (multiple serving cells grouped in one TAG); - A UE with multiple timing advance capability for CA can simultaneously receive and/or transmit on multiple CCs corresponding to multiple serving cells with different timing advances (multiple serving cells grouped in multiple TAGs). NG-RAN ensures that each TAG contains at least one serving cell; - A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only (one serving cell in one TAG). CA is supported for both contiguous and non-contiguous CCs. When CA is deployed frame timing and SFN are aligned across cells that can be aggregated, or an offset in multiples of slots between the PCell/PSCell and an SCell is configured to the UE. The maximum number of configured CCs for a UE is 16 for DL and 16 for UL. (3GPP TS 38.300 V17.4.0) 6.7 Carrier Aggregation In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

(3GPP TS 38.300 V17.4.0)

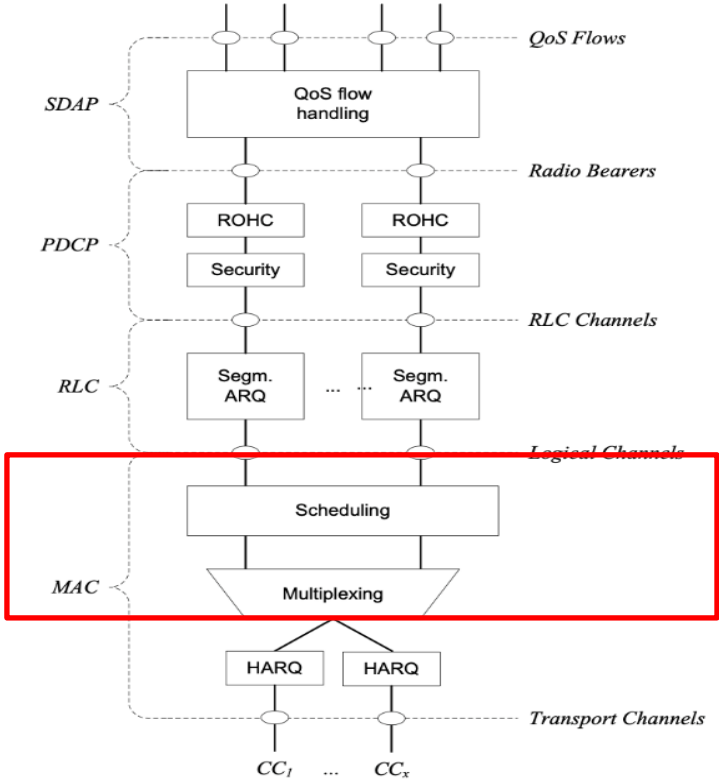


Figure 6.7-2: Layer 2 Structure for UL with CA configured

(3GPP TS 38.300 V17.4.0)

Claim 24	Public Documentation
	<i>5G Carrier Aggregation is set to deliver a significant performance boost to mobile users but what is it and how does it work?</i> The ongoing rollout of commercial 5G networks has significantly improved the experience for mobile subscribers around the world. As the ecosystem matures, a growing number of more advanced 5G Standalone (5G SA) networks will be central to delivering the speed and ultra-low latency to support cutting-edge applications. 5G Carrier Aggregation will play a vital role in underpinning the significant performance boost promised by 5G SA, representing an important milestone in the evolution of wireless infrastructure. Carrier Aggregation is a software functionality in Radio Access Networks and user devices which allows Mobile Network Operators (MNOs) to combine the capabilities of radio cells at distinct frequency allocations to enhance the end user experience. A key technology already in the LTE-Advanced networks, Carrier Aggregation enabled the evolution to Gigabit-LTE, achieving user data rates of more than 1 Gbps. However, in 5G networks, Carrier Aggregation will enable the evolution to multi-Gigabit-5G, reaching user data rates of about 4 Gbps and above. 5G Carrier Aggregation is also capable of improving the geographic availability, more commonly referred to as coverage, of high data rates. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 24	Public Documentation
	Carrier Aggregation in 5G Networks To accelerate rollout, the initial commercial 5G networks relied on the LTE infrastructure in radio access and the core network, referred to as 5G non-Standalone (5G NSA). 5G NSA allows MNOs to increase the bandwidth available to end users by bundling 4G and 5G carriers through 4G-5G Dual Connectivity. This allowed 5G users to benefit from existing LTE Carrier Aggregation capabilities with up to two 5G carriers aggregated alongside LTE carriers. To unlock the full capability of 5G, including ultra-low latency, reliability, and efficiency, MNOs are introducing 5G Standalone (5G SA) with a dedicated 5G Core and highly efficient 5G air interface, without dependency on existing LTE networks. The number of specified 5G SA Carrier Aggregation band combinations is increasing with each quarterly revision of the 3GPP specifications, enabling further options to achieve multi-Gigabit 5G data rates. These specifications are important to ensure interoperability between user equipment, such as smartphones, and networks. Between 2021 to 2022, the focus of the specifications for Carrier Aggregation in 5G SA in FR1 shifted from two component carriers to three and four component carriers. As the number of 5G frequency bands exceeds that of LTE-A, the possible Carrier Aggregation band combinations are greatly expanded, offering increased deployment options and flexibility for MNOs in different markets. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/)

Claim 24	Public Documentation
	Key benefits of 5G Carrier Aggregation Improved data speeds and throughput 5G Carrier Aggregation will boost the network performance to meet the requirements of data-hungry applications, such as augmented and virtual reality services, for both industrial and consumer use cases. Greater cell coverage As operators are looking to maximize the use of their available spectrum assets in different FDD and TDD bands, Carrier Aggregation is the key to reaching extended coverage range. This helps reduce the need to deploy new cell sites, bringing cost savings to operators. It also improves mobile user experience with consistent level of service across the network. Enhanced energy efficiency In 2019, the mobile industry made a milestone commitment to transform the sector and reach net zero carbon emissions by 2050. Carrier Aggregation has been demonstrated to reduce overall power consumption levels while increasing throughput and maintaining high service levels. This indicates that the technology could contribute to reducing overall energy usage and the mobile industry's carbon footprint. Improved coverage can also contribute to longer battery life for individual devices, requiring less frequent charging. Greater ROI According to data from GSA, the total amount raised in 2021 from spectrum auctions and assignments reached at least \$140.1Bn. Radio spectrum is a finite and extremely valuable resource, representing a considerable financial burden for most MNOs. Therefore, with ever increasing demands for bandwidth, utilising this spectrum in the most efficient way becomes a top operational priority. 5G CA represents one of the most effective methods for MNOs to get the most from their outlay by maximising spectral efficiency. (https://www.nokia.com/about-us/newsroom/articles/5g-carrier-aggregation-explained/) Samsung Galaxy users in the United States will now enjoy faster 5G speeds, all thanks to T-Mobile's carrier aggregation technology. At the Mobile World Congress 2023 event in Barcelona, T-Mobile announced the successful deployment of 5G carrier aggregation on its standalone 5G network.

Claim 24	Public Documentation
	Ericsson, Nokia, Qualcomm Technologies, Inc., and Samsung teamed up with T-Mobile in the completion of the 5G Carrier Aggregation tech. The phone used for the project was a Samsung Galaxy S23 series model. Consequently, T-Mobile customers with a Galaxy S23, Galaxy S23+, or Galaxy S23 Ultra will be the first to benefit from four-carrier aggregations later this year. (https://www.sammobile.com/news/t-mobile-carrier-aggregation-5g-samsung-galaxy-s23/) <u>T-MOBILE US USED THE SAMSUNG GALAXY S22 PHONE POWERED BY SNAPDRAGON 8 GEN 1 MOBILE PLATFORM</u> <u>T-Mobile US said it was able to aggregate three channels of mid-band 5G spectrum, reaching speeds over 3 Gbps on its standalone 5G network. The carrier used the Samsung Galaxy S22 phone powered by Snapdragon 8 Gen 1 Mobile Platform with Snapdragon X65 Modem-RF System on a live production network.</u> “This test demonstrates the incredible power of mid-band spectrum and represents another huge step forward for standalone 5G,” said Neville Ray, president of Technology at T-Mobile. “Only T-Mobile is delivering a nationwide standalone 5G network to customers today, and we’re blazing a trail with new performance-boosting capabilities that generate incredible speeds and deliver on our vision to create the highest capacity network in the country.” T-Mobile US noted that 5G Carrier Aggregation (NR CA) allows the combination of multiple 5G channels to improve speed and performance. In this test, the carrier merged three 5G channels — <u>two channels of 2.5 GHz Ultra Capacity 5G and one channel of 1900 MHz spectrum</u> — to create an effective 210 MHz 5G channel. T-Mobile claimed to be the first operator in the world to launch a nationwide SA 5G network nearly two years ago. NR CA is already live in parts of T-Mobile’s network combining two 2.5 GHz 5G channels. The telco said that those customers with the Samsung Galaxy S22 will be among the first to experience a third 1900 MHz 5G channel later this year. This capability will expand across the carrier’s network and to additional devices in the near future. Earlier this month, T-Mobile U.S. announced that customers in limited areas of Portland and Salt Lake City who have the Samsung Galaxy S21 5G now have access to Voice Over New Radio (VoNR) services. The carrier said additional cities will be added to the list throughout the remainder of this year.

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	According to T-Mobile US, VoNR brings the promise of Standalone (SA) 5G “one step closer” by enabling advanced capabilities like network slicing that rely on a continuous connection to a 5G core. At the recent Big 5G Event in Austin, Texas, Ray told RCR Wireless News that in addition to ultimately supporting 5G voice calls, VoNR, without a Non-Standalone 5G or LTE anchor, sees its investment in low-band as the “foundation” of the company’s network. The carrier’s Extended Range 5G (low-band 600 MHz spectrum) covers 315 million people across 1.8 million square miles, while 225 million people nationwide are covered with its Ultra Capacity 5G (2.5 GHz spectrum). The carrier expects to cover 260 million in 2022 and 300 million next year. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>T-Mobile Revs Up 5G with Four-Carrier Aggregation</u> July 25, 2023 What’s the news: T-Mobile has begun rolling out four-carrier aggregation for customers, boosting speeds on its 5G standalone (SA) network. Why it matters: 5G SA is the future of wireless, delivering a whole new level of performance with faster speeds and lower latency (quicker response times). 5G carrier aggregation allows T-Mobile to turbocharge 5G SA speeds, giving customers a game-changing performance boost. Who it’s for: T-Mobile customers across the country. Pedal, meet metal. T-Mobile (NASDAQ: TMUS) today announced it has begun rolling out four-carrier aggregation on its 5G SA network, delivering the capability for insanely fast speeds to customers across the country. If you need help translating ... insanely fast = peak speeds topping 3.3 Gbps in recent tests. Four-carrier aggregation is live in parts of T-Mobile’s network now and will be available nationwide in the coming weeks. “T-Mobile is blazing the trail for wireless customers around the globe, delivering new capabilities that unleash the true potential of 5G,” said Ulf Ewaldsson, President of Technology at T-Mobile. “With the only nationwide 5G standalone network in the country, T-Mobile is the ONLY provider bringing game-changing technologies like four-carrier aggregation to customers across the country.” 5G carrier aggregation allows T-Mobile to combine multiple 5G channels (or carriers) to deliver greater speed and performance. The Un-carrier is now merging four 5G channels of sub-6 GHz spectrum – <u>two channels of</u>

Claim 24	Public Documentation
	<u>2.5 GHz Ultra Capacity 5G, one channel of 1900 MHz and one channel of 600 MHz spectrum</u>. That’s like taking four separate highways and turning them into a massive superhighway where traffic can zoom faster than before. Customers with the Samsung Galaxy S23 will be the first to experience four-carrier aggregation with more devices to follow. This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the first in the world to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like carrier aggregation and VoNR. T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded 5G network. The Un-carrier’s 5G network covers 326 million people across two million square miles – more square miles than AT&T and Verizon combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity this year – nearly everyone in the country. https://www.t-mobile.com/news/network/t-mobile-revs-up-5g-with-four-carrier-aggregation <u>SRG tests T-Mo’s FDD-TDD CA: ‘You can have your cake and eat it too’</u> January 11, 2022 The aggregation of 600 MHz + 2.5 GHz uses low-band, FDD spectrum to improve performance The aggregation of low and mid-band carriers in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) spectrum improves cell edge performance in T-Mobile US’ network, according to recent testing by Signals Research Group. <u>SRG tested the FDD+TDD carrier aggregation (CA) in T-Mobile US’ commercial network</u>. The testing was conducted during the first week of December, at a large cluster of Ericsson sites in a 180-square-kilometer swath of the suburban Maryland/Washington, D.C. area.

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	“A few mobile operators have already launched TDD-TDD CA in other parts of the world but to the best of our knowledge T-Mobile is the first operator in the world to deploy FDD-TDD CA functionality in a commercial network,” SRG noted. SRG said that T-Mobile US provided the test SIMs and insight into the cluster where the testing was conducted, as well as two Galaxy S21 smartphones — one with pre-commercial software on it that allowed the consulting group to test some of the features it was interested in. Intriguingly, however, SRG found that both devices appeared to support much the same functionality, with a bit of finessing of “hidden” menu options to force the smartphones into the modes of operation that it wanted to test. SRG used test tools from Accuver Americas and Spirent Communications to conduct the study. The firm said that the cell cluster supported a “wide range of different technologies,” including both NSA and SA 5G, using <u>T-Mo’s 600 MHz (FDD) and/or 2.5 GHz (TDD) spectrum. In terms of 5G New Radio CA, the sites either used two 5G NR carriers at 2.5 GHz, leveraging T-Mo’s deep midband holdings for TDD-TDD carrier aggregation; or they paired a single radio channel of 600 MHz spectrum with a single channel of 2.5 GHz — the FDD-TDD CA that SRG sought to test.</u> https://www.rcrwireless.com/20220111/test-and-measurement/srg-tests-t-mos-fdd-tdd-ca-you-can-have-your-cake-and-eat-it-too T-Mobile to Expand and Advance the Nation’s Largest 5G Network with New 5-Year Agreements <i>These multi-billion-dollar deals with both Ericsson and Nokia will continue to supercharge T-Mobile’s nationwide 5G network</i> January 13, 2021 06:29 PM Eastern Standard Time BELLEVUE, Wash.--(BUSINESS WIRE)--Today, T-Mobile (NASDAQ: TMUS) announced five-year, multi-billion-dollar agreements with both Ericsson (NASDAQ: ERIC) and Nokia (NYSE: NOK) to continue advancing and expanding the nation’s largest 5G network. Part of the network investment following last year’s merger with Sprint, these deals enable T-Mobile to add even more 5G coverage, capacity, speed and advanced technical capabilities across all of its spectrum bands.

Claim 24	Public Documentation
	“T-Mobile already has the largest 5G network in the country,” said Neville Ray, T-Mobile President of Technology. “These agreements with our longstanding 5G partners Nokia and Ericsson will help us take our 5G leadership even further, delivering ever-better experiences for our customers for years to come.” Building on two decades of partnership, the Un-carrier will work with Ericsson and Nokia to expand its nationwide 5G network for better 5G coverage and future game-changing experiences, and advanced network capabilities like 5G carrier aggregation. T-Mobile launched the world’s first nationwide standalone 5G network last summer, and recently pulled off the world’s first 5G standalone (SA) data session with New Radio Carrier Aggregation (NR CA). T-Mobile is the first and only U.S. provider to combine the power of Extended Range <i>and</i> Ultra Capacity 5G, boosting speed and performance. T-Mobile also plans to add advanced technical capabilities like voice over 5G (VoNR), network slicing, and multi-user massive MIMO to its 5G network. T-Mobile is already America’s 5G leader with the most advanced 5G network and fast 5G speeds in more places than any other wireless provider. T-Mobile’s Extended Range 5G now covers 280 million people across nearly 1.6 million square miles — that’s more than 2.5x the geographic coverage of AT&T and nearly 4x more than Verizon! And with Sprint now part of T-Mobile, the Un-carrier is widening its lead, lighting up Ultra Capacity 5G across the country and bringing fast 5G speeds to more places than anyone else. Ultra Capacity 5G can deliver average speeds of 300 Mbps with peaks approaching 1 Gbps and is now available in more than 1,000 cities and towns, covering more than 106 million people! That’s 50x more than Verizon covers with Ultra-Wideband! And at T-Mobile, 5G access is included at no extra charge in all smartphone plans. For more information on T-Mobile’s 5G network, visit: www.t-mobile.com/coverage/coverage-map. Follow T-Mobile’s Official Twitter Newsroom @TMobileNews to stay up-to-date with the latest company news. Ultra Capacity 5G includes dedicated mid- and/or high-band 5G signals. T-Mobile’s Ultra Capacity 5G covers hundreds of cities and millions of people, with more added all the time; see T-Mobile.com/5Glayers. Capable device required; coverage not available in some areas. Some uses may require certain plan or feature; see T-Mobile.com. https://www.businesswire.com/news/home/20210113005934/en/T-Mobile-to-Expand-and-Advance-the-Nation%E2%80%99s-Largest-5G-Network-with-New-5-Year-Agreements)

T-Mobile Supercharges 5G Standalone Uplink Speeds with Carrier Aggregation First

May 04, 2023

BELLEVUE, Wash. — May 4, 2023

What’s the news: T-Mobile worked with Nokia and Qualcomm to reach uplink speeds topping 200 Mbps in a 5G data call leveraging uplink carrier aggregation – the first-ever on a live commercial 5G standalone network in the U.S.

Why it matters: Increased uplink speeds allow greater amounts of data to be transmitted from customer devices at a quicker rate, enhancing applications like video livestreaming/calling, gaming and Extended Reality (XR).

Who it’s for: T-Mobile 5G customers nationwide.

Speed ... UP! T-Mobile (NASDAQ: TMUS) announced today it achieved another 5G U.S. first by leveraging uplink (UL) carrier aggregation in the field on the country’s only nationwide 5G standalone (SA) network. Working with Nokia and a test smartphone powered by Snapdragon® 5G Modem-RF System from Qualcomm Technologies, Inc., the Un-carrier hit a top UL speed of 207 Mbps in the test – the ***fastest ever*** recorded using sub-6 GHz spectrum! This comes just weeks after T-Mobile made the same move in the lab, hitting similar speeds.

“T-Mobile has led the industry with 5G standalone since 2020, and we’re continuing to drive breakthroughs that advance 5G technology around the globe,” said Ulf Ewaldsson, President of Technology at T-Mobile. “We’re building the most advanced 5G network in the world, opening the door for massive innovation and laying the foundation for new capabilities that will transform the world around us.”

5G carrier aggregation allows T-Mobile to combine multiple channels (or carriers) to deliver greater speed and performance. In this test, the Un-carrier merged two 5G channels of mid-band spectrum – 2.5 GHz Ultra Capacity 5G and 1900 MHz. That’s like taking two separate highways and turning them into a superhighway where traffic can zoom faster than before. Customers with compatible devices will begin taking advantage of UL 5G carrier aggregation early next year when T-Mobile begins rolling it out.

This is just the latest in a series of important 5G SA milestones for T-Mobile. The Un-carrier was the [first in the world](#) to launch a nationwide 5G SA network in 2020 – one that remains the ONLY nationwide 5G SA network in the U.S. Since then, T-Mobile has been driving toward a true 5G-only experience for customers by spearheading advancements like [carrier aggregation and VoNR](#).

T-Mobile is the leader in 5G, delivering the country’s largest, fastest and most awarded [5G network](#). The Un-carrier’s 5G network covers 326 million people across 2 million square miles – more than AT&T and Verizon

Claim 24	Public Documentation
	combined. 275 million people nationwide are covered by T-Mobile’s super-fast Ultra Capacity 5G, and the Un-carrier plans to reach 300 million people with Ultra Capacity – nearly everyone in the country – this year. (https://www.t-mobile.com/news/network/t-mobile-supercharges-5g-standalone-uplink-speeds-with-carrier-aggregation-first) WHY CHOOSE NOKIA 5G CARRIER AGGREGATION? Together with the leading mobile network operators across the world and the user equipment ecosystem, we have commercially introduced two component, three component and four component 5G Carrier Aggregation to enable Multi-Gigabit 5G on sub-6 GHz frequency allocations. We also have Carrier Aggregation commercially available for high-band. On millimeter wave spectrum, Carrier Aggregation with eight component carriers in downlink and four component carriers in uplink enables reaching even higher data rates. Nokia 5G Carrier Aggregation: • Works in 5G Non-Standalone and 5G Standalone in the same cells for smooth migration from NSA to SA • Boosts 5G performance • By aggregating low-band carriers for coverage and mid-band carriers for capacity, helps deliver Multi-Gigabit user data speeds already today. 5G Carrier Aggregation is software running on the baseband unit, easy to activate in Nokia 5G networks. The supported Carrier Aggregation band combinations are following the quarterly 3GPP specification updates. Our quarterly software updates ensure the best possible band combination support, and bring more flexibility for mobile operators to optimize their network coverage and capacity. Nokia 5G Carrier Aggregation works with massive MIMO and dynamic spectrum sharing, enabling a further capacity boost on mid-band and more flexibility for low-band aggregation.

Claim 24	Public Documentation
	Nokia AirScale ensures uncompromised RF bandwidth for efficient multi-carrier sub-6 GHz Carrier Aggregation. Additionally, our AirScale baseband is optimized for providing the processing capacity and scalability for multi-carrier, large bandwidth Carrier Aggregation. https://www.nokia.com/networks/mobile-networks/carrier-aggregation/ Ericsson spearheads 5G carrier aggregation milestones with key partners Ericsson has achieved groundbreaking milestones for carrier aggregation in 5G New Radio (NR) technology together with key customers and ecosystem partners. Ericsson has recently pushed 5G carrier aggregation (5G CA) technology to new levels after a series of successful interoperability tests with customers including T-Mobile and Optus, and ecosystem partners such as Qualcomm and MediaTek. The interoperability tests use carrier aggregation to extend the coverage of 5G, boost network capacity, and increase data speeds. Ericsson’s collaboration with partners has so far resulted in several 5G firsts: • World’s first 5G standalone (SA) data session with 5G CA on a commercial smartphone completed with T-Mobile, LG and MediaTek. With 5G CA, T-Mobile can combine its different 5G spectrum bands – starting with 2.5 GHz mid-band and 600 MHz low-band – boosting speeds and increasing the footprint of T-Mobile’s mid-band 5G. It’s also a key step in expanding T-Mobile’s nationwide standalone architecture 5G network by increasing SA 5G capacity and speeds. (October 2020) • A 2300 + 3500MHz 5G Non-Standalone Carrier Aggregation call made by Optus using Ericsson technology and Samsung’s Galaxy S20 5G handset range. The call showed the benefit of using both spectrum frequencies simultaneously, namely, a significant increase in the average and peak 5G speeds that customers, with an eligible handset, will benefit from as the capability becomes available. (August 2020) • First to complete all three combinations of NR time division duplex (TDD) and frequency division duplex (FDD) carrier aggregation (CA) together with MediaTek. The companies carried out a 5G SA data call by aggregating 20MHz on FDD spectrum and 100MHz on TDD spectrum with MediaTek’s Dimensity 1000+ chipset at the Ericsson Lab in Kista. (September 2020)

Claim 24	Public Documentation
	Completed pioneering interoperability tests for 5G SA carrier aggregation across both FDD/TDD and TDD/TDD bands together with Qualcomm Technologies. 5G CA allows service providers to use multiple sub-6 GHz spectrum channels simultaneously to transfer data between base stations and a 5G mobile device. (August 2020) Per Narvinger, Head of Product Area Networks, Ericsson says: “From technology development to wider area deployments, Ericsson continues to spearhead 5G innovation with customers and industry partners. To maximize the full potential of the mid-band spectrum, we’ve developed 5G NR carrier aggregation solutions that will help our customers deploy a better 5G with greater coverage, increased capacity and higher data speeds. These solutions will extend the coverage of the high capacity mid-band spectrum. By enabling peak speeds, coverage and capacity, 5G carrier aggregation will be a real game-changer.” Ericsson’s 5G NR carrier aggregation solution will be commercially available in the fourth quarter of 2020 with a global rollout expected during 2021. https://www.ericsson.com/en/news/2020/10/5g-carrier-aggregation

Claim 24	Public Documentation																			
	Samsung Galaxy S20  Released 2020, March 06 163g, 7.9mm thickness <> Android 10, up to Android 13, One UI 5 128GB storage, microSDXC 6.2" 1440x3200 pixels 64MP 4320p 8GB RAM Exynos 990 4000mAh Li-Ion 18% 6,985,860 HITS 456 BECOME A FAN REVIEW OPINIONS COMPARE PICTURES Also available with 5G <table><tr><td rowspan="6">NETWORK</td><td>Technology</td><td>GSM / CDMA / HSPA / EVDO / LTE</td><td rowspan="6">COLLAPSE</td></tr><tr><td>2G bands</td><td>GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)</td></tr><tr><td></td><td>CDMA 800 / 1900 & TD-SCDMA</td></tr><tr><td>3G bands</td><td>HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100</td></tr><tr><td></td><td>CDMA2000 1xEV-DO</td></tr><tr><td>4G bands</td><td>1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66</td></tr><tr><td>Speed</td><td colspan="2">HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps</td><td></td></tr></table> https://www.gsmarena.com/samsung_galaxy_s20-10081.php	NETWORK	Technology	GSM / CDMA / HSPA / EVDO / LTE	COLLAPSE	2G bands	GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)		CDMA 800 / 1900 & TD-SCDMA	3G bands	HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100		CDMA2000 1xEV-DO	4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66	Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps			[24a] a first down-converter circuit having a first input coupled to receive a first up-converted signal, a second input coupled to receive a first demodulation signal having a first RF frequency, and an output, wherein the first down-converter circuit outputs a first down-converted signal on the first down-converter output; The Accused Instrumentalities include a first down-converter circuit having a first input coupled to receive a first up-converted signal, a second input coupled to receive a first demodulation signal having a first RF frequency, and an output, wherein the first down-converter circuit outputs a first down-converted signal on the first down-converter output. For example: 6.7 CARRIER AGGREGATION In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figures 6.7-1 and 6.7-2 below: - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per assignment/grant per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.
NETWORK	Technology		GSM / CDMA / HSPA / EVDO / LTE	COLLAPSE																
	2G bands		GSM 850 / 900 / 1800 / 1900 - SIM 1 & SIM 2 (Dual SIM model only)																	
			CDMA 800 / 1900 & TD-SCDMA																	
	3G bands		HSDPA 850 / 900 / 1700(AWS) / 1900 / 2100																	
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	4G bands	1, 2, 3, 4, 5, 7, 8, 12, 13, 17, 18, 19, 20, 25, 26, 28, 32, 38, 39, 40, 41, 66																		
Speed	HSPA 42.2/5.76 Mbps, LTE-A (7CA) Cat20 2000/200 Mbps																			

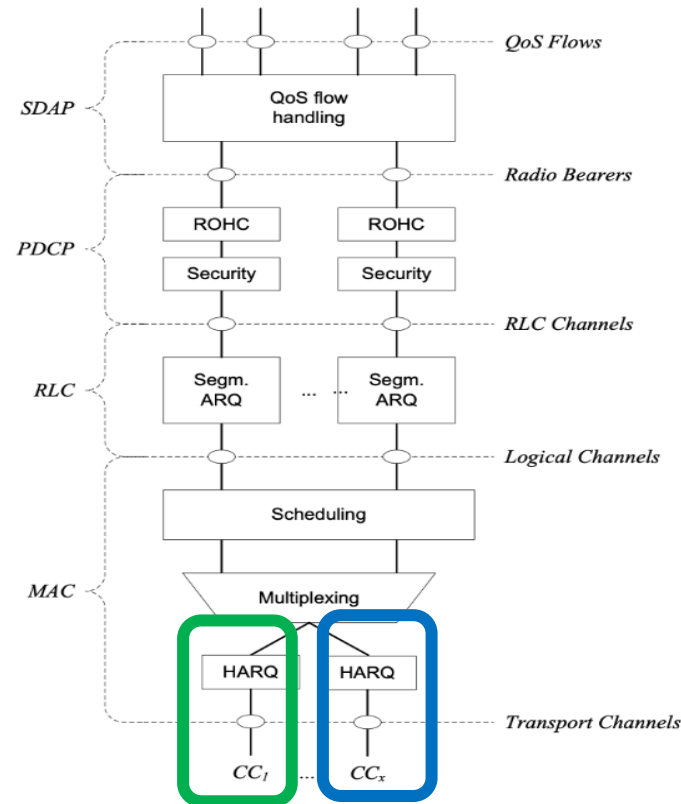


Figure 6.7-2: Layer 2 Structure for UL with CA configured
(3GPP TS 38.300 V17.5.0)

used in the Accused Instrumentalities:

TI Designs Multi-Band RF Sampling Receiver Solution



TI Designs

The RF sampling receiver captures signals directly in the radio frequency (RF) band. In a multi-band application, the desired signals do not have a very wide band, but they are spaced far apart within the spectrum. The ADC32RF80 is a dual-channel, 14-bit, 3-GSPS RF sampling telecom receiver. The 3-dB input bandwidth is 3 GHz, and it captures signals up to 4 GHz. The device includes two digital down converters (DDC) per channel. The DDC offers decimation values from 8 to 32 and includes a 16-bit numerically controlled oscillator to move the captured signal down to digital baseband. With the high sampling rate of the ADC32RF80, the device captures a large swath of the RF spectrum, which contains signals in multiple bands and potentially undesired interferers. The DDC independently mixes the desired bands to digital baseband. Decimation reduces the output data rate to a lower level and provides digital filtering around the desired band to eliminate interference and to improve signal-to-noise ratio (SNR) performance. This feature is critical for high-end telecommunication receivers that require high dynamic range.

(<https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf>)

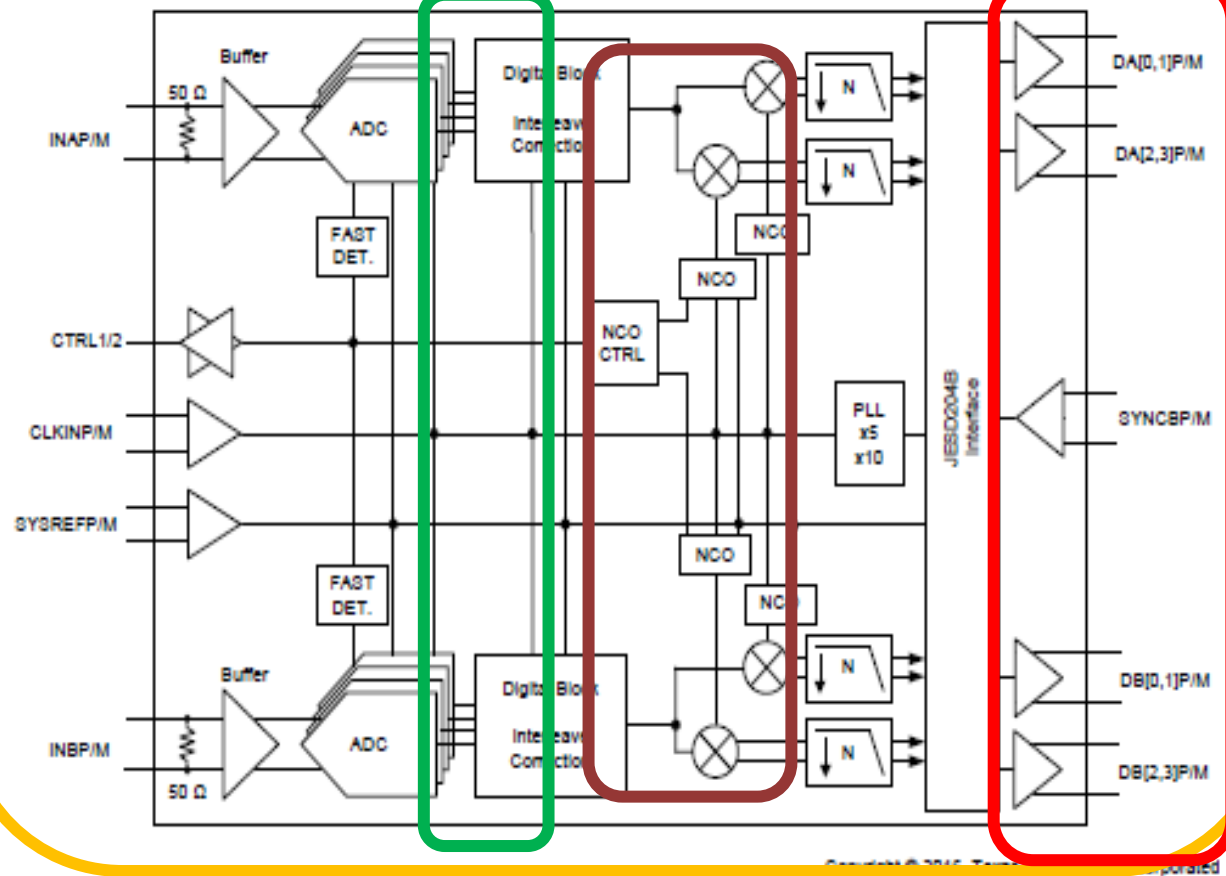
Design Features

- 3-GSPS RF Sampling Receiver Solution
- Low Noise, High Dynamic Range RF Sampling Receiver Solution
- Programmable Decimation from 8 to 32
- Dual Digital Down-Converter With Independent Numerically Controlled Oscillators

Featured Applications

- Wireless Base Station Multi-Band or Multi-Mode Receiver
- Multi-carrier GSM Receiver
- Digital Pre-Distortion Feedback Receiver
- Telecommunications Receiver
- Carrier Aggregation Receiver



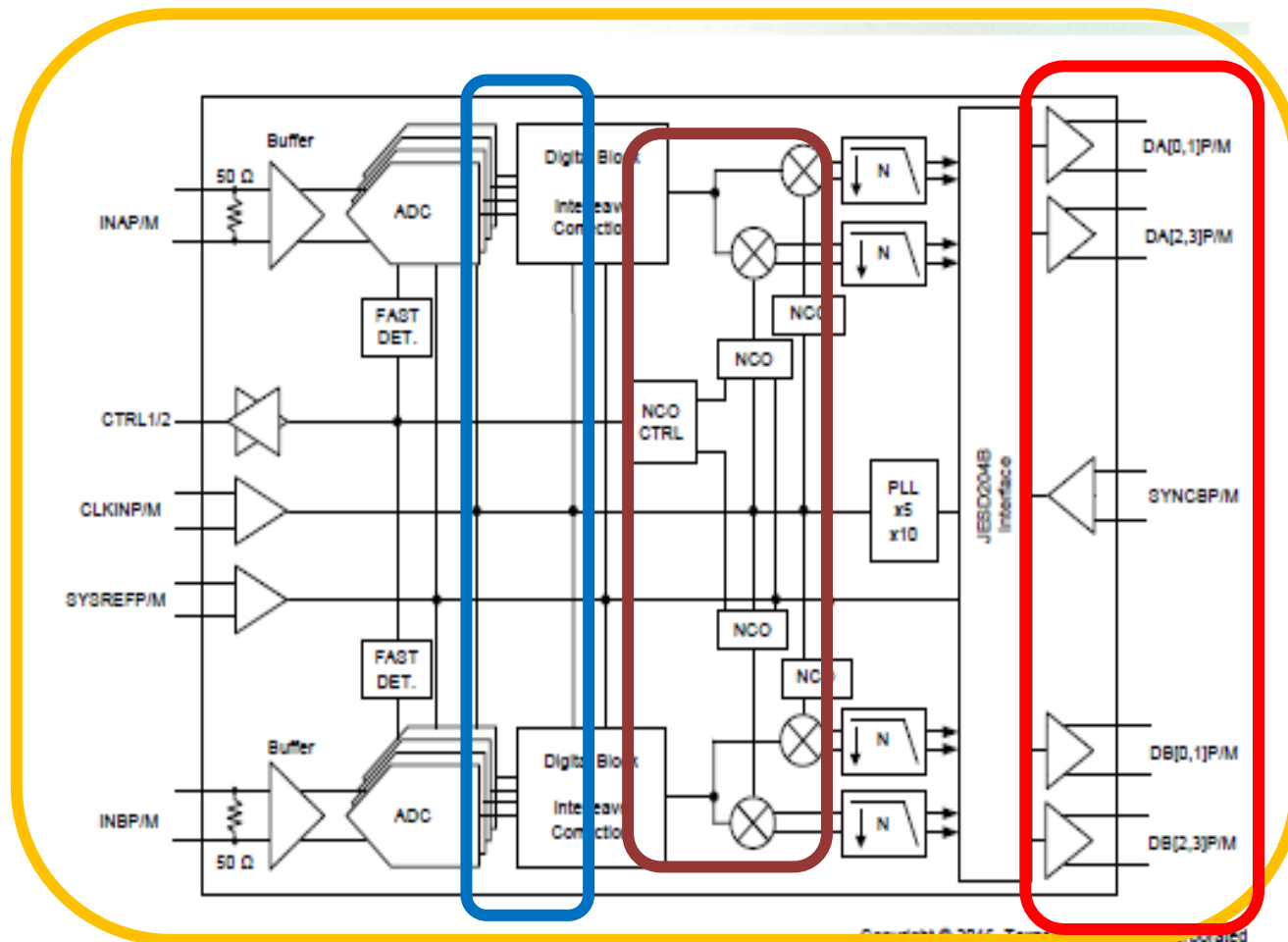


(<https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf>)

Claim 24	Public Documentation
	The Broadcom ACFM-2S13 is a quadplexer device that combines Band 1 and Band 3 duplexers into a single, miniature package. Band 4 duplexer is co-banded. The device features a single antenna connection, eliminating the need for antenna switching. <u>High Isolation between bands enables the use of carrier aggregation.</u> The ACFM-2S13 is designed with Broadcom's innovative filter capability which makes possible ultra-small, high-Q filters at a fraction of their usual size. Low Tx Insertion Loss of the ACFM-2S13 reduces power amplifier current, extending battery life. The device enhances receiver sensitivity and dynamic range with low Rx Insertion Loss and high rejection of Tx signals at the Rx ports. Features • Single antenna • High cross band isolation • <u>Enables carrier aggregation</u> • Band 4 co-banding • Miniature size • 2.0 x 2.5 mm footprint • 0.710 mm typ. height • High Power Rating • Environmental • RoHS 6 Compliant • Halogen Free • TBBPA Free https://www.broadcom.com/products/wireless/demo-boards/acfm-2s13)

[24b] a second down-converter circuit having a first input coupled to receive the first up-converted signal, a second input coupled to receive a second demodulation signal having a second RF frequency different than the first RF frequency, and an output, wherein the second down-converter outputs a second down-converted signal on the second down-converter output, wherein the first up-converted signal comprises a first signal modulated at the first RF frequency and a second signal modulated at the second RF frequency; and

The Accused Instrumentalities include a second down-converter circuit having a first input coupled to receive the first up-converted signal, a second input coupled to receive a second demodulation signal having a second RF frequency different than the first RF frequency, and an output, wherein the second down-converter outputs a second down-converted signal on the second down-converter output, wherein the first up-converted signal comprises a first signal modulated at the first RF frequency and a second signal modulated at the second RF frequency. For example, in receiver designs believed to be representative of those used in the Accused Instrumentalities:



(<https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf>)

Claim 24	Public Documentation
[24c] a filter having an input coupled to the output of the first down-converter and the output of the second down-converter, and in accordance therewith, the filter receives the first and second down-converted signals.	The Accused Instrumentalities include a filter having an input coupled to the output of the first down-converter and the output of the second down-converter, and in accordance therewith, the filter receives the first and second down-converted signals. For example, in receiver designs believed to be representative of those used in the Accused Instrumentalities: TI Designs Multi-Band RF Sampling Receiver Solution  TI Designs The RF sampling receiver captures signals directly in the radio frequency (RF) band. In a multi-band application, the desired signals do not have a very wide band, but they are spaced far apart within the spectrum. The ADC32RF80 is a dual-channel, 14-bit, 3-GSPS RF sampling telecom receiver. The 3-dB input bandwidth is 3 GHz, and it captures signals up to 4 GHz. The device includes two digital down converters (DDC) per channel. The DDC offers decimation values from 8 to 32 and includes a 16-bit numerically controlled oscillator to move the captured signal down to digital baseband. With the high sampling rate of the ADC32RF80, the device captures a large swatch of the RF spectrum, which contains signals in multiple bands and potentially undesired interferers. The DDC independently mixes the desired bands to digital baseband. <u>Decimation reduces the output data rate to a lower level and provides digital filtering around the desired band to eliminate</u> interference and to improve signal-to-noise ratio (SNR) performance. This feature is critical for high-end telecommunication receivers that require high dynamic range. (https://www.ti.com/lit/ug/tidubq3/tidubq3.pdf) Design Features • 3-GSPS RF Sampling Receiver Solution • Low Noise, High Dynamic Range RF Sampling Receiver Solution • Programmable Decimation from 8 to 32 • Dual Digital Down-Converter With Independent Numerically Controlled Oscillators Featured Applications • Wireless Base Station Multi-Band or Multi-Mode Receiver • Multi-carrier GSM Receiver • Digital Pre-Distortion Feedback Receiver • Telecommunications Receiver • <u>Carrier Aggregation Receiver</u> 

Analog versus digital filters

If an analog engineer and digital engineer discuss filters, the digital engineer may dismiss analog. This would be a mistake. The filtering standard with any analog-to-digital (A/D) conversion is to have the analog LPF before the digital filter (Figure 1).

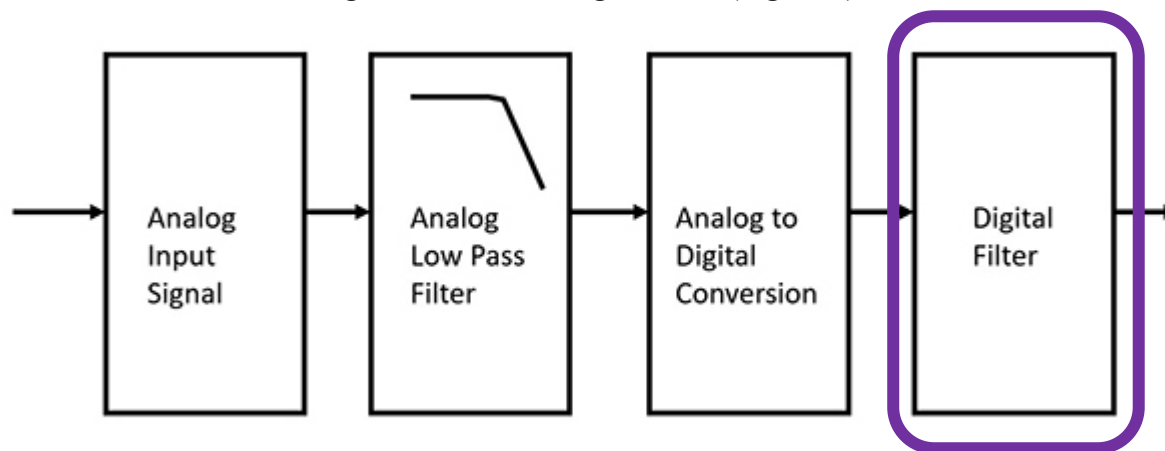


Figure 1: A block diagram of an analog-to-digital signal chain with the analog filter before the digital filter. (Image source: DigiKey)

After the analog LPF attenuates higher frequencies above the bandwidth of interest, the ADC converts the signal into a digital word. Following this accomplishment, the digital filter can operate on the signal within the bandwidth of interest.

(<https://www.digikey.com/en/articles/why-and-how-to-use-digital-filters-for-analog-to-digital-conversions>)