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LTE & 5G NR Carrier Aggregation Network Optimization through Advanced Measurement Configuration

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Abstract

The ability to merge numerous frequency carriers—component carriers—to increase transmission bandwidth and throughput speeds over what can be achieved with a single carrier is known as carrier aggregation, and it is a crucial technology in 4G LTE and 5G networks. Cellular devices may attain gigabit data speeds by combining carriers from several frequency bands, such as 600 MHz to mm Wave frequencies, to increase downlink and uplink capacity. This study examines LTE and 5G New Radio (NR) carrier aggregation schemes and analyzes their important features, including advanced multi-antenna setups, bandwidth scaling, maximal data rates, and frequency compatibility. Analyzing real-world measurement setup processes that provide dynamic carrier aggregation by activating secondary cells in response to device feedback is a primary emphasis. The research draws attention to the shortcomings of current methods that put multi-user situations at risk of overcrowding by mandating neighbor assessments across all active performance criteria. On a scale, the resulting burden significantly reduces aggregation latency and efficiency. An intelligent measuring method that improves aggregation receptivity and reliability is suggested to solve these drawbacks. Carriers are activated quicker, and device processing and power consumption are minimized by setting devices selectively depending on segmentation and application requirements rather than static setups. Continuous monitoring further corresponds to changing network circumstances to enhance spectrum use. Thus, the concepts offer a workable framework for utilizing measurement input to realize the promise of multi-carrier cellular networks fully. Such aggregation advances are necessary for more intelligent and robust 5G connection as high data demands push the limits of infrastructure capabilities.

Keywords: 5G Network Performance, LTE Network Optimization, Measurement Based Optimization, 5G Carrier Aggregation, Network Optimization techniques, Cellular Network Performance

INTRODUCTION

The Third Generation Partnership Program (3GPP) Release 8 (Rel-8) included the completion of the first iteration of Long-Term Evolution (LTE) in March 2009. OFDMA in the downlink and SC-FDMA in the uplink provide adaptable bandwidth alternatives ranging from 1.4 to 20 MHz [1]. LTE relies on a flat radio access network framework without a centralized network aspect. In the downlink, multiple input multiple output (MIMO) is enabled; only single-layer broadcasting is supported in the uplink [1]. Carrier aggregation (CA), a crucial technology in 4G LTE and 5G cellular networks, connects many component carriers over various frequency ranges to provide more transmission capacity and quicker data rates. It is frequently impossible to provide.

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The required throughput performance with a single carrier due to the exponential rise in customer expectations for mobile broadband. Carrier aggregation provides a flexible architecture to enhance capacity and combine spectrum assets to fulfil these severe data demands. Fundamentally, carrier aggregation combines the capabilities of cellular base stations and mobile gadgets, enabling them to send and receive data simultaneously over several carriers ranging from 600 MHz to mm Wave bands [2]. This joining of dissimilar bands unlocks significant increases in bandwidth and maximum data rates and allows more effective use of fragmented spectrum.

Mobile network operators are globally implementing carrier aggregation (CA) to tackle this difficulty. Since it integrates two or more component carriers (CCs), CA is a crucial LTE-Advanced (LTE-A) component. More CCs can be added to the channel to increase its bandwidth and get quicker data rates. In 2011, the Third Generation Partnership Program (3GPP) Release 10 introduced CA. Since its 2013 installation in South Korea, the first LTE-A infrastructure with CA has been installed in networks worldwide [3]. Since 3GPP Release 10, every new release has altered the LTE-A CA settings [3]. Up to five CCs might be aggregated using the 3GPP Release 10, each having a maximum bandwidth of 20 MHz. Therefore, a maximum bandwidth of 100 MHz might be achieved by merging five 20-MHz CCs.

One primary serving cell (PCell) that handles core control functions and one or more secondary cells (SCells) that are flexibly engaged or deactivated in response to feedback from device measurements make up the overall carrier aggregation architecture. It is possible to increase the aggregate transmission bandwidth beyond the constraints of any one band by linking the PCell grounded carrier with additional SCell carriers. Multiple LTE carriers may be combined via 4G LTE carrier aggregation, and 5G NR expands this framework by supporting more multi-RATs spanning LTE, Wi-Fi, and NR [4]. Carrier aggregation configurations comprise two types: inter-band aggregation, which links non-contiguous carriers licensed across completely different frequency ranges, and intra-band aggregation, which groups contiguous carriers within a single band [5]. Maximum flexibility is possible with the latter strategy, but implementation difficulty increases. Through 3GPP standardization initiatives, CA capabilities have been synchronized with the advancement of networks and devices, from initial dual/triple carrier setups to the present Release-15 maximum of 32 aggregated carriers [2]. Key features include multi-connectivity choices across cell layers, innovative MIMO antenna methods, diversified bandwidth, downlink and uplink carrier bonding, and configurations encompassing licensed and unlicensed bands. Carrier aggregation topologies are shown in Figure 1.

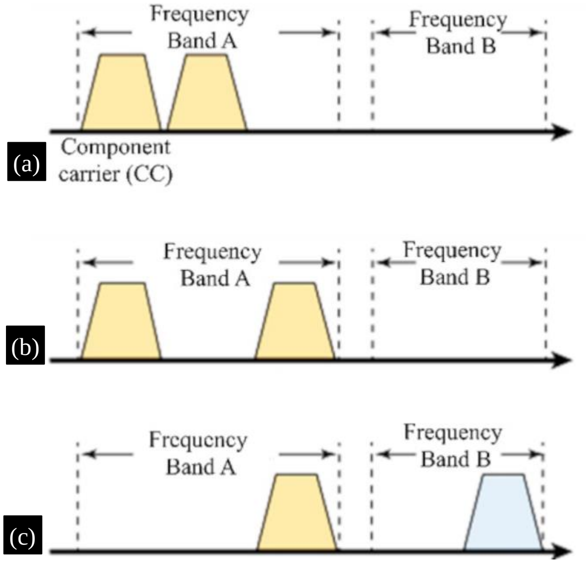

Figure 1. Carrier aggregation topologies. (a) Intra-ban contiguous, (b) Non-band-contiguous, (c) Inter-band.

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Dynamic optimization is needed at all network protocol architecture tiers, including the physical, MAC, RLC, and PDCP layers, to benefit fully from carrier aggregation. The inter-frequency measurement architecture, which sets up UEs to identify and report potential carriers for the base station planner to aggregate depending on traffic demand, is a key enabler [6]. The measuring process's effectiveness significantly impacts the total capacity of the system. Practical constraints on dynamic SCell activation restrict aggregation reactivity, which can be highlighted by examining LTE and 5G NR carrier aggregation strategies. An intelligent measuring technique is suggested to fix these flaws and assess notable performance improvements.

LTE Downlink Carrier Aggregation

Downlink carrier aggregation in LTE enables a mobile device to receive data from several LTE carriers concurrently, usually spread.

Aacross various frequency bands. The combination of these carriers leads to higher data rates and more network capacity. LTE supports both intra-band and inter-band carrier aggregation. A crucial feature of LTE (Multiple LTE carrier is shown in Figure 2) Advanced and 5G NR is downlink carrier aggregation (CA), which combines several carrier components (CCs) from various frequency bands to boost the maximum rate of data and general network capacity [7]. LTE Advanced was the first to incorporate CA in the downlink by constructing several LTE carriers to increase throughput [1]. With NR, more CA developments now yield greater performance benefits.

As part of Release 10 (LTE Advanced), the LTE standards initially included downlink CA. Considering the several LTE carriers as a single broader bandwidth allowed user equipment (UEs) to receive information across multiple carriers in distinct frequency bands concurrently. For instance, discuss aggregating 2.6 GHz and 800 MHz carriers [8]. LTE supports inter-band CA, aggregating across bands, and intra-band CA, combining carriers within the same band. Peak data rates are increased by adding more carriers proportionately to the total.

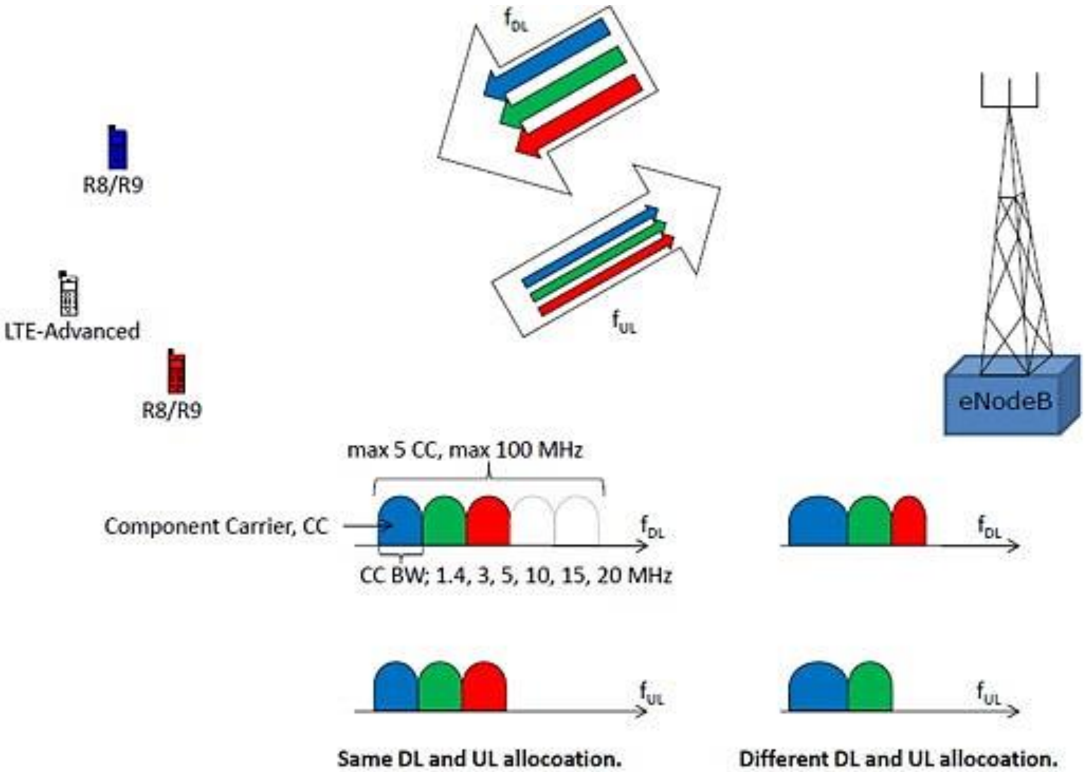

Figure 2. Multiple LTE carriers.

Bandwidth. LTE Advanced allows for a total bandwidth to a maximum of 100 MHz in the downlink CA situation, with up to 5 carriers of 20 MHz each. How CA can be used to combine five 20 MHz carriers to create a virtual bandwidth of 100 MHz is shown in Figure 3.

With every component carrier adhering to the basic LTE requirements, carrier aggregation expands upon the current LTE carrier topology [2]. Nevertheless, improvements such as flexibly activating/deactivating secondary carriers and cross-carrier scheduling between CCs are needed for CA. CA offers significant benefits for LTE Advanced systems when combined with effective CC selection and management techniques.

NR Downlink Carrier Aggregation

The next-generation standard (NR) expands on the carrier aggregation idea first presented in LTE, whereas LTE Advanced added downlink CA.NR aggregation of carriers across both sub-6Hz and mm Wave frequencies is shown in Figure 4 With NR's support, higher data speeds and better spectrum efficiency are possible for more adaptable and effective carrier aggregation methods. One of its main advantages is the increased frequency range allowed by carrier aggregation in 5G NR. NR enables carrier aggregation across mmWave and sub-6GHz frequencies, implying that lesser bands can be paired with a high band mmWave spectrum with multiple GHz bandwidth for improved coverage [4]. In LTE, aggregating such broad spectral bands was not feasible. The result is very large bandwidths that were impossible to achieve with LTE carrier aggregation.

NR broadens the frequency range and raises.

Each component carrier's maximum bandwidth. The maximum frequency for each NR carrier is 100 MHz or more. 800 MHz or more of total bandwidth can be attained by combining several carriers with frequencies greater than 100 MHz [9]. This is a significant improvement above the 20 MHz LTE carrier limit. The ultra-wideband NR carriers further increase the peak data rates made possible by CA. Moreover, sophisticated spectrum-sharing situations are made possible by NR carrier aggregation. NR controls aggregation among LTE, legacy carriers, and NR in the same or separate bands. Through this interworking, personnel with current networks may seamlessly switch while utilizing all available spectrums, irrespective of technology. Further efficiency gains are derived from flexibility-advanced bandwidth is shown in Figure 5.

Finally, CA capabilities are increased by better MIMO approaches. Advanced NR.

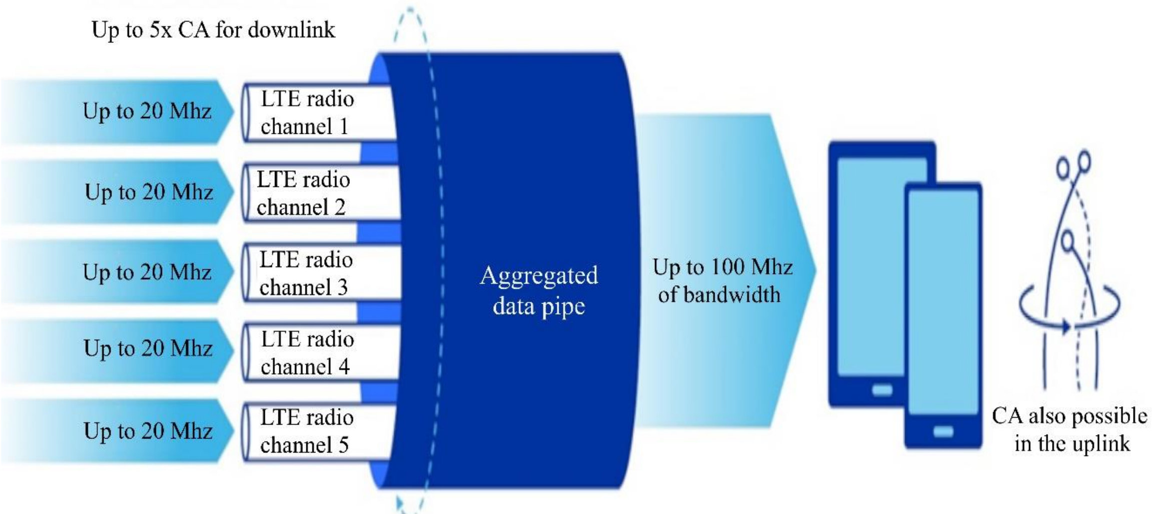

Figure 3. How CA can be used to combine five 20 MHz carriers to create a virtual bandwidth of 100 MHz.

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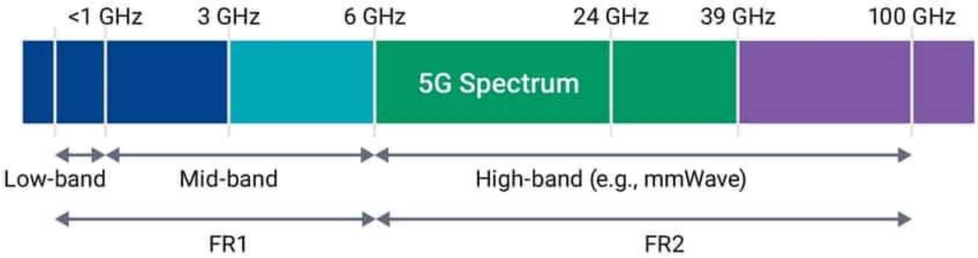

Figure 4. NR aggregation of carriers across both sub-6GHz and mmWave frequencies.

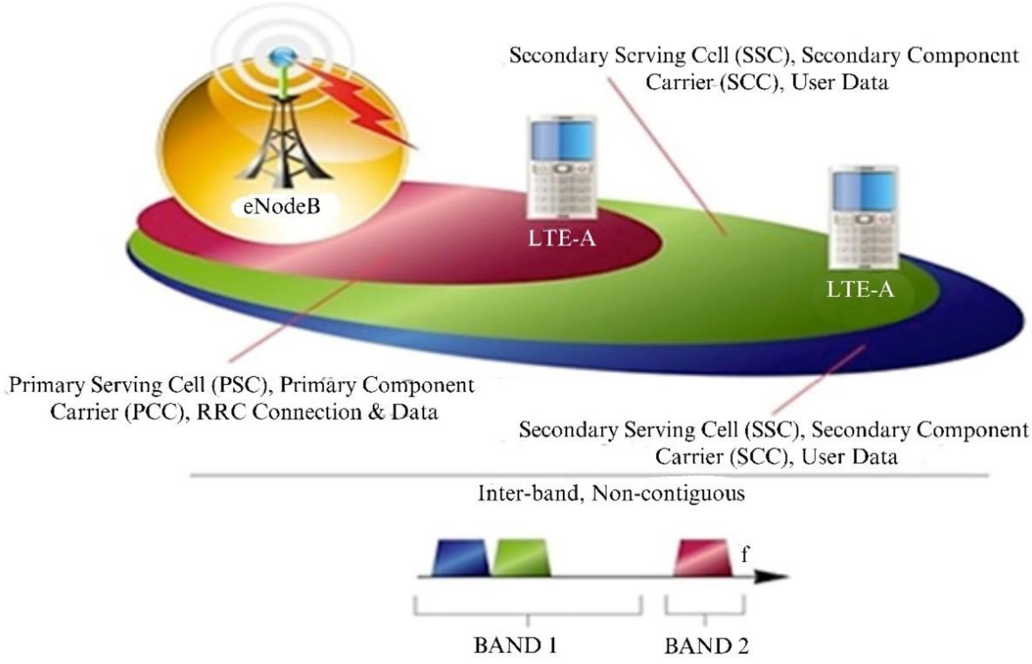

Figure 5. LTE-advanced bandwidth.

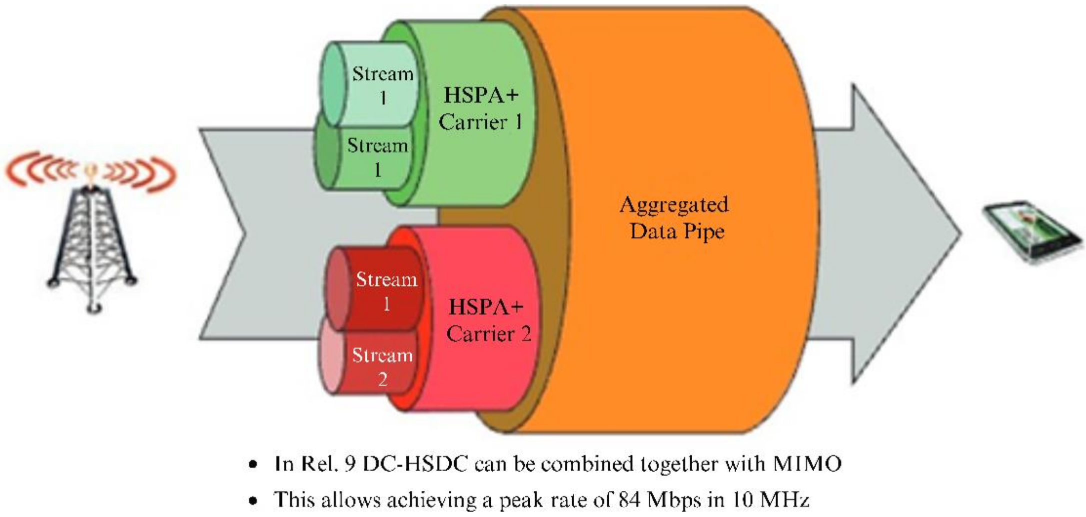

Figure 6. Graphical representation of MIMO combined with CA.

Multi-antenna integration, such as massive MIMO in conjunction with CA, provides further spatial multiplexing advantages [10]. More antennas and users effectively share total resources. This enhances the bandwidth gains that CA naturally provides. These improvements enable large carrier aggregation bandwidths in NR networks, reaching up to 800 MHz or more.

This delivers huge gains in peak data speeds over LTE Advanced CA. With bigger bandwidths, enhanced MIMO, and dynamic spectrum collaboration, NR CA guarantees considerable advances in 5G network capacity and customer satisfaction.

Compared to LTE Advanced CA, 5G NR carrier aggregation offers significant capacity, versatility, and MIMO integration gains [11]. Graphical representation of MIMO combined with CA is shown in Figure 6.These four breakthroughs make the revolutionary features anticipated in the next generation 5G networks possible.

Uplink Carrier Aggregation In 5G NR

In the context of 5G NR cellular networks, Uplink Carrier Aggregation (UL-CA) is a key approach that responds to the pressing requirement for improved uplink data delivery. The key to this invention is the deliberate blending of many uplink carrier frequencies, which promotes increased uplink communication capability and effectiveness [12]. The primary goal is to enable faster data uploading speeds for mobile devices, which will improve their overall efficiency in the end. The 5G NR operating dynamics of UL-CA are explained using a step-by-step understanding of its components.

First, UL-CA is made possible by multiple uplink carrier frequencies in a 5G NR network. These carriers are the starting point for the aggregation process, regardless of whether they are in the same or separate frequency bands. Consequently, using multiple uplink carriers(multiple link carrier frequencies are shown in Figure 7 simultaneously is crucial to UL-CA. From cell phones to Internet of Things (IoT) equipment, mobile devices interact with these carriers concurrently, viewing them as a single, expanded channel for smooth data transfer. The effectiveness of UL-CA is demonstrated by several benefits for mobile devices [11]. Most notably, the combination of uplink carriers results in higher uplink data rates, increased network capacity, and improved uplink performance. These characteristics are especially important for applications like online gaming, video conferencing, and uploading big files that depend on quick and effective uplink data transfer.

Moreover, optimizing the spectrum resources that are accessible is significant

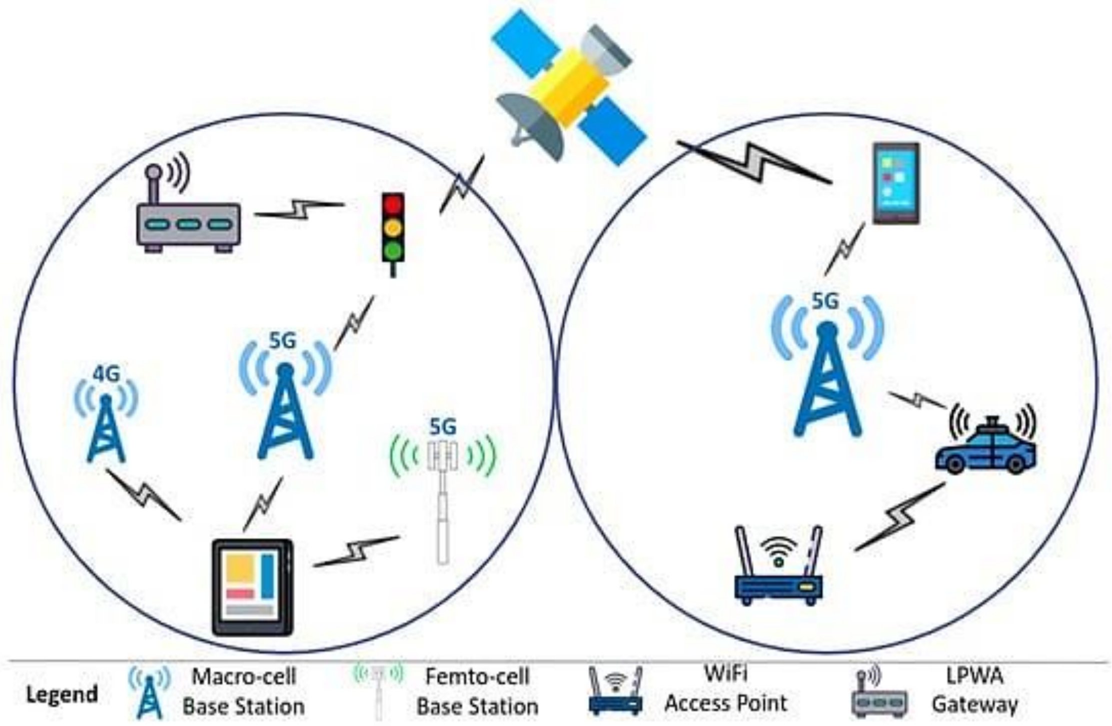

Figure 7. Multiple uplink carrier frequencies.

Accomplishment of uplink carrier aggregation. By using this method, network operators may effectively utilize the frequency bands that are accessible, giving consumers quicker and more dependable uplink connectivity. The 5G NR network architecture handles uplink carrier aggregation and complex management. Decisions on carrier aggregation depend on things like the devices' capacity and the network's state. In 5G NR, UL-CA(UL-CA principle as shown in Figure 8) is a game-changing technology that aims to intelligently utilize several uplink carrier frequencies to boost uplink data delivery [11]. This novel function accelerates data transmission and maximizes spectrum use, highlighting its critical function in improving modern cellular communications' efficiency and user experience.

Measurement Config before SCELL Addition

Integrating many component carriers (CCs) expands transmission capacity through carrier aggregation. The PCell in LTE and NR offer primary control and connection, while the SCells increase data speeds [12]. The network can use a measurement-based process before adding a SCell. The radio access network (RAN) will initially set up inter-frequency measurements(as shown in Figure 9) to assess secondary carrier alternatives rather than "blind" deploying a SCell [13]. This entails transmitting an RRC Connection Reconfiguration message with the LTE neighbour frequency, or EARFCN (E-UTRA absolute radio frequency channel number) to be measured. The network utilizes the metrics the UE gives for the desired EARFCN to decide if adding a SCell on that carrier makes sense. Measuring NR frequency ARFCNs (NARFCNs) independently, 5G NR employs a similar methodology [13]. The measurement design facilitates the insertion of secondary NR cells for LTE-NR dual connectivity (ENDC). The LTE RAN can be configured to measure NR frequencies when the main connection is LTE. Measurements let RAN make judgments about adding NR SCells by dynamically applying interworking mechanisms.

Benefits of Measurement-Based SCell Addition

When opposed to blind SCell addition, using measurements before secondary cell addition in carrier aggregation offers several benefits. The main advantage is that the measuring procedure provides current network conditions on various secondary carriers, allowing for more prudent carrier selection selections. This results in several performance improvements straight away.

First, using new measurement findings, the network may more accurately match SCell additions to the existing network dynamics. The measurements provide the throughput, interference stages, congestion state, and general cell quality for each secondary carrier that is accessible in almost real-time. Reactively, significantly better judgments may be made by choosing a SCell frequency based on the most recent metrics supplied rather than outdated or nonexistent data.

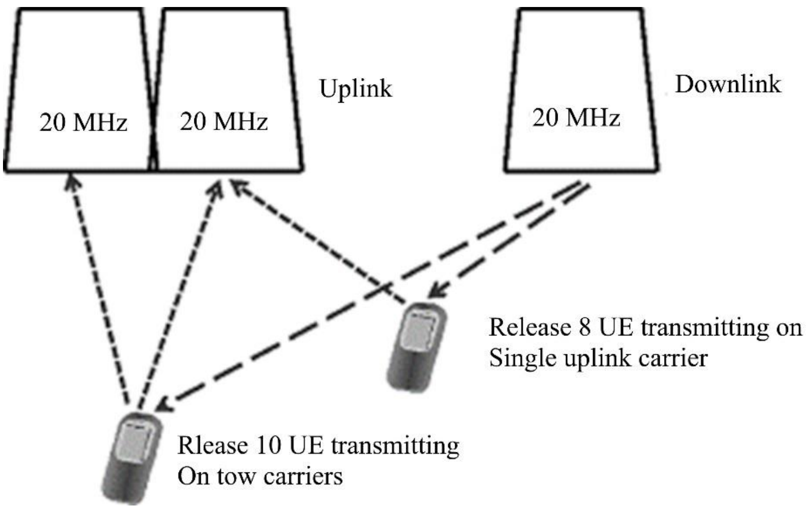

Figure 8. Uplink Carrier Aggregation Principle.

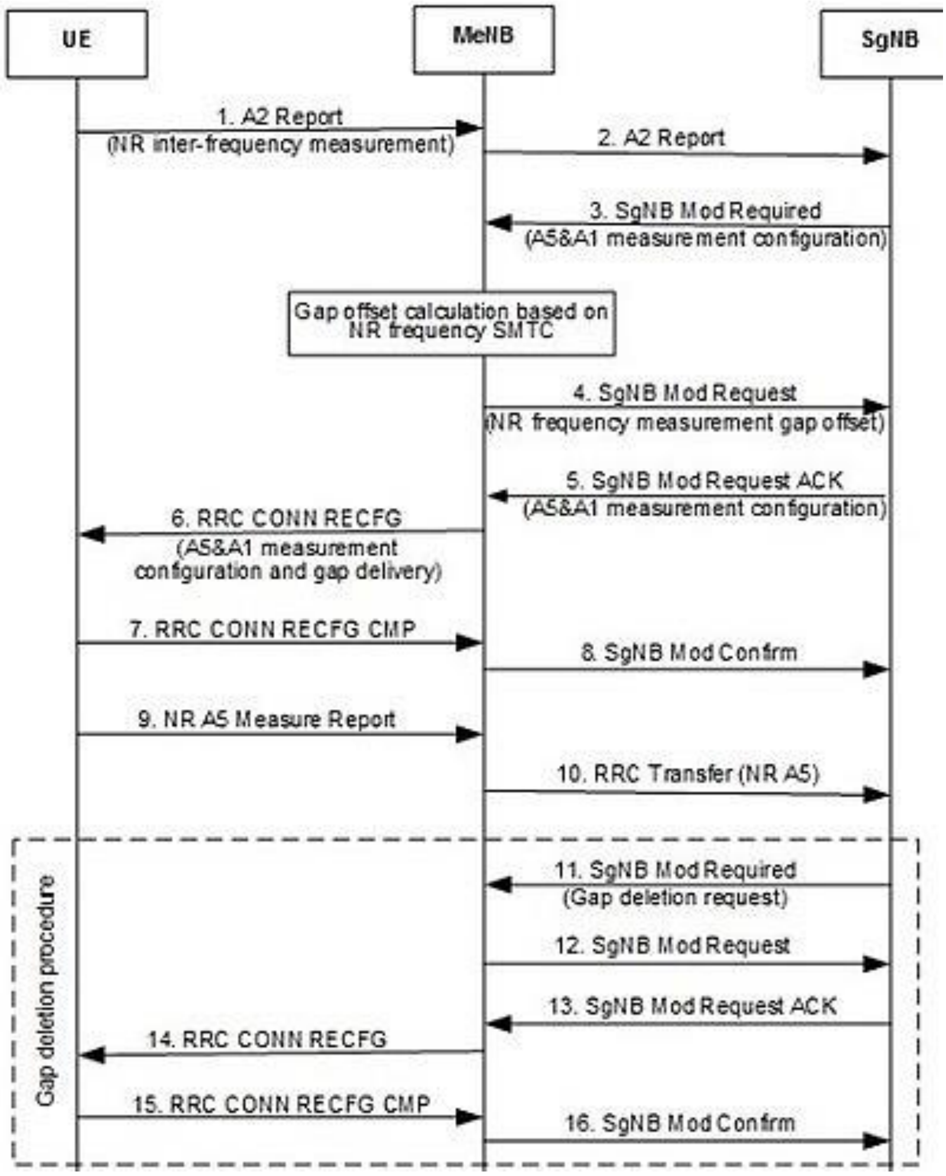

Figure 9. Inter-frequency measurements.

Furthermore, assessing secondary carrier conditions enables the avoidance of subpar carriers that, if introduced as a SCell, would probably disconnect, or offer useless throughput. Measurement assessment aids in removing carriers with significant interference or channel characteristics that are inherently subpar [10]. Once enabled, this significantly increases SCell dependability as users retain strong connections on carefully selected CCs [14].

Additionally, choosing the best quality band as the SCell every time allows for the most carrier aggregation throughput. Intelligent SCell distribution on the most effective available CC is possible by comparing measurement results for prospective frequencies [15]. This leads straight to the best possible throughput performance after addition by utilizing the most competent carriers.

Lastly, loading measurements from measurement reports helps to minimize overload. Congested bands close to full capacity might be omitted as SCell alternatives to reduce the danger of congestion. SCells are less likely to experience interruptions or overload-based restrictions. In the end, secondary cell addition is significantly more dynamic, dependable, robust, and high-performing when pre-assessment is done through measurements.

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Real-world Issue

Configuring neighbour cell measurements in cellular network settings is a considerable problem. Networks for surrounding cells frequently set up EARFCN and NARFCN (NR Absolute Radio Frequency Channel Number) measurements. These measurements usually vary from 5 to 10 depending on LTE or NR settings. However, this aims to improve user experience with transition and overall connection. This strategy does have a few drawbacks. For example, upon initiating a Radio Resource Control (RRC) connection restructuring when a UE is positioned on an LTE PCELL, the UE must conduct measurements on several inter-frequency SCELLs utilizing either LTE EARFCN measurement setups or NR NARFCN measurement setups [13]. There is a lag in adding SCELLs during this operation because the UE measures different EARFCNs or NARFCNs and then sends measurement data [16]. The network may encounter traffic, especially in heavily populated places like downtown settings, and the delay is more obvious when the UE detects numerous frequencies.

Furthermore, the network may add blind SCELLs without the appropriate measurement configurations when only one or two SCELLs are planned for Downlink (DL) data depending on radio circumstances or the Channel Quality Indicator provided by the UE [11]. When this occurs, a SCELL with unfavourable radio conditions may see a rise in the Downlink Block Error Rate (DL BLER). This problem is exacerbated in 5G Standalone (SA) carrier aggregation situations, where combining different technologies makes UE measurements more complex. The problem still exists in Non-standalone Evolved NodeB Dual Connectivity situations, even though the specifications state that network-side complete NEDC implementation is still awaiting. Optimizing network performance, limiting the effect on user experience, and lowering UE measurement delays rely on resolving these difficulties, especially in emerging network designs incorporating LTE, NR, and carrier aggregation situations.

Network Optimization Solution

Strategic Measurement Configuration Optimization

Optimizing measurement setup offers significant benefits when several users are linked to the same LTE or 5G main cell in a real-world situation. The main objectives should be increasing overall dependability, optimizing CA abilities (how to maximize CA capabilities is shown in Figure 10) for premium users, and reducing measurements for quicker SCell installation.

When there are more users, a strategic strategy is necessary.

Finding the available CA modes (LTE, NR, and EN-DC) for every user device's capability comes first. Increased bandwidth measurements may be configured for 5G carrier aggregation and EN-DC technologies using newer equipment with sophisticated 5G options. Each device's most advanced network capabilities should be explicitly mapped to the measurement configuration.

Figure 10. Maximizing CA capabilities.

Users using 4K video streaming or other applications with high QoS needs should obtain precedence in measurement configuration for optimum carriers. For instance, the solution suggests setting up the first four most critical users for the first two EARFCNs when there are 10 users on a single primary

LTE carrier and 5 possible SCell EARFCNs [13]. To fulfil their bandwidth requirements, this guarantees quick measurements and SCell installation. The next two EARFCNs are awarded to the next priority group. More measures would be overkill for users, prioritizing their work above everything else.

A sophisticated measurement setting optimizes network band scanning for users. Generating reports for rapid aggregation is faster when users are restricted to 2 target EARFCNs instead of all 5 [16]. Faster SCell incorporation reduces measurement pauses and device battery consumption while providing instantaneous bandwidth increases. Moreover, the optimal utilization of provider CA infrastructure is achieved by allocating carrier measurements according to application needs. High-end use scenarios unlock full benefits [15]. Carefully adjusting the measurement setup for each user enables a sophisticated balancing act between rapidly adding new SCells, prioritizing high-priority users, and effectively allocating device resources to all consumers on the same main connection point.

CONCLUSION

With a particular focus on improving network performance by improved measurement settings, this study explores the crucial field of carrier aggregation (CA) in 4G LTE and 5G NR networks. Because carrier aggregation enables simultaneous utilization of several component carriers to increase data rates and network capacity greatly, it plays a crucial role in satisfying the ever-increasing needs for mobile broadband. Key characteristics of LTE and 5G NR carrier aggregation frameworks, including sophisticated multi-antenna topologies, capacity scaling, and frequency compatibility, are revealed via research. This article highlights the significance of real-world measurement configuration processes in dynamic carrier aggregation, revealing parts of existing systems that are not ideal and might cause congestion in scenarios involving multiple users. A strategy for intelligent measurement is presented to overcome these drawbacks. This method offers quicker carrier activation while lowering battery consumption and device processing by prioritizing dynamic setup based on segmentation and application demands. The efficacy of this optimized technique is confirmed by simulation studies, which demonstrate notable improvements in lower device signaling, swifter carrier activation latency, more usable carrier configurations, longer battery life, and significantly higher network capacity, particularly in high-density scenarios.

These ideas offer a workable framework for utilizing measurement feedback to realize the promise of multi-carrier cellular networks fully. The suggested aggregation upgrades act as an amplifier for intelligent and robust 5G connection. Consumer demand for data-intensive applications pressures the network infrastructure carrier aggregation to increase network capacity and performance. Additionally, 5G NR employs more sophisticated MIMO methods, higher bandwidths, and broader frequency ranges. When used in applications such as online gaming, uplink carrier aggregation increases data transmission efficiency and enhances user experience.

Optimizing carrier aggregation by carefully adjusting measures based on user objectives, application expectations, and network capacity is sensible for the issue. This method contributes to power savings and increased efficiency in LTE and 5G NR networks by addressing practical problems such as UE measurement lags, network traffic, and blind SCell additions. It also fosters a dynamic, dependable, and high-performing atmosphere.

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