3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

A Study on Cross-Carrier Scheduler for Carrier Aggregation in Beyond 5G Networks

Nidhi(1), Bahram Khan(2), Albena Mihovska(1), Ramjee Prasad(1) and Fernando J. Velez(2)
(1) Department of Business Development and Technology, Aarhus University, Herning, Denmark,
(2) Instituto de Telecomunicac ̧˜oes and Universidade da Beira Interior,

Abstract

This work aims to provide a detailed study on Carrier Aggregation (CA) techniques for 5G New Radio (5G NR) networks while elaborating on CA deployment scenarios, CA-enabled 5G networks, and resource management and scheduling techniques. CA empowers the User Equipment (UE) and the network to aggregate carrier frequencies in licensed, unlicensed, or Shared Access (SA) bands of the same or different spectrum bands to boost the achieved data rates. We also analyze the cross-carrier scheduling scheme in CA-enabled 5G networks for Downlink (DL) resource allocation. The requirements, challenges, and opportunities are addressed in the allocation of Resource Blocks (RBs) and Component Carriers (CCs). The study and analysis of various multi-band scheduling techniques are made while keeping in mind that high throughput and reduced power usage needs to be achieved at the UE. Finally, we present CA as the critical enabler to advanced systems while discussing how it meets the demands and holds the potential to support beyond 5G networks. To conclude, we discuss many open issues in resource allocation and scheduling techniques.

1. Introduction

Coverage and capacity for the 5G user experience are the essential elements. Carrier Aggregation (CA) emerged as one of the key technologies for 5G that can extend the coverage by considering the mid, low, and high bands leading to increased capacity. CA and the coordination of Radio Access Network (RAN) are possible solutions for low latency, high capacity, and optimized coverage for 5G mid-band and high-band deployment. To overcome the demands of wireless data and applications, the service providers need to research the new spectrum source that can be using the existing spectrum efficiently. 5G enables a new spectrum source, both the mid-band and high-band radio frequencies, to enable the latest applications and provide better data speeds. Getting more benefits from these new spectrum bands, solutions are needed to extend cell coverage. CA is one of the solutions that use the spectrum efficiently. Third Generation Partnership Project (3GPP) Release 15 [1] introduced 5G New Radio (NR) in 2018 as the global standard for the air interface and explained CA in licensed and unlicensed bands and consider aggregation in shared spectrum scenarios as well. A solution that allows expanding the spectrum assets when deploying 5G is Inter-band NR CA. This type of CA can extend the cell coverage area of mid-band Time Division Duplex (TDD) by a factor of 2.5 [2]. On the other hand, carrier aggregation with NR in the highest frequency bands (i.e., millimeter wavebands) allows coverage area extension by a factor of four.

In Release 16, the number of rate-matching patterns available in NR has been increased to allow spectrum sharing when CA is used for LTE. Besides, Release 16 reduces latency for setup and activation of CA/Dual Connectivity (DC), by this means leading to improved system capacity and the aptitude to achieve higher data rates. Unlike Release 15, where measurement configuration and reporting does not take place until the UE comes into the fully connected state, in Release 16 the connection can be resumed after periods of inactivity without the need for extensive signaling for configuration and reporting [3]. Additionally, Release 16 introduces a periodic triggering of Channel State Information (CSI) reference signal transmissions in case of the aggregation of carriers with different numerology. In the Release 17 Enhanced Mobile Broadband (eMBB) trend, NR frequency range will be extended to allow for exploiting more spectrum (above 52.6 GHz), including the 60 GHz unlicensed band while defining new Orthogonal Frequency Division Multiplexing (OFDM) numerology and channel access mechanism to comply with regulatory requirements applicable to unlicensed spectrum.

The rest of the paper is structured as follows. Section II addresses the CA-enabled 5G networks. Section III describes various resource management and scheduling techniques. In Section IV, we discuss the research challenges. In section V, the role of standards and relevant standardization bodies is discussed. Finally, conclusions are drawn in Section VI.

2. Carrier Aggregation Enabled 5G Networks

3GPP has parted the band into three parts for 5G services [2]. The frequency band of less than 1 GHz is considered a low-band, while the 2.4 GHz - 40 GHz is a high band and 1GHz - 2.6 GHz and then 3.5 GHz- 6 GHz is considered a mid-band.

With the combination of these bands, the deployment of 5G and beyond will support a high data rate and less resource utilization. The range of a single low band (below 7 GHz

Frequency Division Duplex, FDD) can cover hundreds of square miles considering 5G services whose speed range is from 30 to 250 megabits per second (Mbps) These are the most common services to deploy, providing a wide area coverage. The mid-band (below 7 GHz, Time Division Duplex, TDD) can provide up to a several-mile radius with currently goodput ranging from 100 to 900 Mbps. While the high band (above 2.4 GHz) is just covering the shortest cell radius with a goodput range from 1 up to 3 Gbps. By deploying 5G networks in these combinations of frequency bands/ranges and speeds the networks not only support a high data rate but also provides the best solution for 5G spectrum requirements.

Carrier Aggregation with Millimetre Wavebands

Millimetre Wave (mmWave) is one of the promising technologies to address the shortage of spectrum in a wireless network. It became the redeemer of 4G/5G mobile operators. It will be suitable for its coexistence with the LTE network [4]. CA and mmWave band scenarios are extensively researched in [5][6]. These papers consider the channel state information and low computational complexity to improve carrier aggregation technique and reduce energy consumption in 5G scenarios. The aggregation of the mmWave and sub-6 GHz frequencies is the need of the network. It can deliver the massive capacity and multi-Gigabit speeds desired for consumers and enterprise applications. Combining the different combinations of spectrum resources will make it possible for 5G devices to achieve wired broadband-class speeds wirelessly.

5G Networks in Unlicensed Spectrum

5G's essential design model intends to support diversified spectrum bands. 3GPP introduced unlicensed spectrum bands for 5G NR as Unlicensed 5G NR (5G NR-U) to enhance the LTE's Licensed Assisted Access (LAA) with the release 16 [1]. It also marked 5G NR-U deployments in the license-exempted 5 GHz and 6 GHz bands. The supported deployment modes for 5G NR-U are (i) Carrier Aggregation, (ii) Dual Connectivity (DC), and (iii) Standalone. In both CA and DC deployment modes, the unlicensed bands support the amplification of the user-plane capacity in DL. In dual connectivity mode, NR-U supports Uplink (UL) in addition to the DL. CA deployment mode is built on LTE-LAA, where the DC deployment mode is based on the extended LAA (eLAA) []. In either deployment mode, the control-plane data resides over the licensed bands. The standalone mode relies independently on the unlicensed spectrum for control and user plane operations. It will lead to an open 5G network to eliminate dependencies on the licensed mobile network operators (MNOs). With its underlying enhancements, NR-U is foreseen to bring new opportunities to enhance spectral efficiency.

Carrier Aggregation in Heterogeneous Networks

CA and Heterogeneous networks (HetNets) are two distinct features of the beyond 5G cellular networks [7]. The Small Cell (SC) deployment in HetNets is advantageous for data offloading, coverage, and improved cell edge spectral efficiency. CA facilitates increased transmission bandwidth and capacity by scheduling the multiple Component Carriers (CC) on the physical layer [8]. The general realization of CA is facilitated by the addition and removal of a secondary CC without interrupting resource allocation. The resources are made available to the users from SCs within the macrocell topology. Fronthaul network connects the Remote Radio Heads (RRHs) to the Baseband Unit (BBU) same as the Macro and Small Cell. Figure 1 illustrates the conventional CA deployment in the same macrocell site.

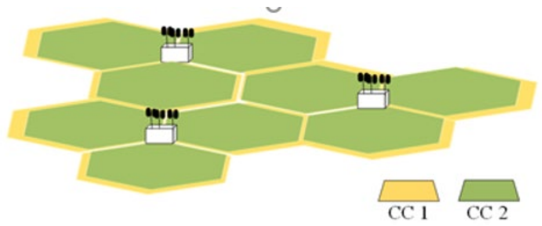

Figure 1. Carrier Aggregation Deployment in the same Macrocell.

Enormous traffic and connection requests are eminent in dense heterogeneous networks with SCs, making the establishment of multimedia sessions critical. CA offers a great solution in such scenarios by facilitating SC deployments inside macrocells. The evolved NodeB (eNBs) offload the high traffic on the small cells with CA. Figure 2 illustrates the CA deployment between macro and small cells.

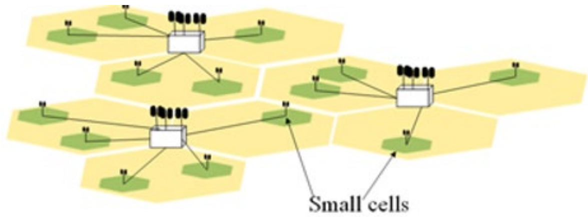

Figure 2. Carrier Aggregation Deployment between Macrocell and Small Cell.

Next Generation NodeB (gNBs) deployments by the Mobile Network Operators (MNOs) ensure better services by increasing the system capacity. Small cells enable flexible deployments while ensuring affordability in price and enhanced energy and spectral efficiency. SC technologies integrate multiple radio access (CA) technologies to increase the coverage capacity and service availability. CA-enabled SC deployments exploit lesser physical space as compared to the macro cell deployments [9]. The deployment of small cells with carrier aggregation within the macro cell becomes a viable and economical solution to improve the performance of the entire 5G NR network.

Cell Dormancy

3GPP Release 16 introduced the concept of small cell dormancy, which improves the power consumption in CA-enabled scenarios. The considered dormant cell device stops the monitoring of the physical downlink control channel while keeping the channel state information measurements and beam management [10]. This method did not consider the dormant cell deactivated, but comparatively, fewer activities save power. For power saving, deactivation is also another possibility. With deactivation, it does not provide the channel state information reports. Also, reactivation of the small cell takes longer time than returning from dormancy [7].

3. Resource Management and Scheduling Techniques

Cross-Carrier Scheduling

In CA-enabled scenarios, the UE is served by more than one CCs either from the same or different macro/small cells. The resources are scheduled based on the Scheduling Grants (SG) and the Scheduling Assignments (SA) corresponding to the data. The scheduler decides for each carrier and transmits individual SAs. Thus, a device receives multiple Physical Downlink Control Channels (PDCCHs). Scheduling is called "Self-Scheduling" when the SG and SA are transmitted on the same cell as the data, and it is known as Cross-Carrier Scheduling (CCS) when SG and SA are transmitted on different cells than the data. For CCS, the Downlink Control Information (DCI) accommodating the SG for a carrier is received on a different carrier [11]. CCS was initially introduced in 3GPP Release 10 with a carrier indicator field (CIF) limited to 3 bits to support aggregation up to 5 CCs. When a UE is in search mode, the CIF value affects the DL control channel and defines the carrier for SG. In the primary cell (PC) configuration, CIF-Presence-r10 indicates the availability of CIF in PDCCH DCI. A CIF value of 0 indicates PC, while another indicates the secondary cells (SCs). To support 32 CCs enhancements for CA with the latest 3GPP releases, the CIF length increased from 3 to 5 bits.

Packet Scheduling Schemes

Packet Scheduling Algorithms (PCA) hold utmost importance in Radio Resource Management as they indicate how transmission occurs. An efficient PCA in a CA environment has the following requirements [12] for (i) tolerant to multi-CCs environment, (ii) high QoS, (iii) high system throughput, (iv) optimized fairness and (v) low complexity.

In [13], authors have proposed an improved proportional fair (PF) scheduling algorithm for a multi-carrier system. A novel carrier weight factor (CWF) is used to limit the usage accessibility of the CCs. CWF defines the carrier coverage weight factor and the user category weight factor. In [14], authors have addressed the resource scheduling with CA and demonstrated enhanced spectral efficiency and reduced energy consumption. They used a discontinuous reception mechanism from LTE-LAA, allowing UEs to go into sleep when inactive and addressed CCs scheduling mechanisms to reduce the wake-up time. In [15], authors have proposed multi-band scheduling strategies to optimize RBs distribution in the multiple CCs environment with strict QoS constraints. The implementation is demonstrated using the LTE-SIM framework and proposed migration to the 5G framework.

Scheduler Structure for CA

To allocate resource blocks (RBs) in CA, the eNB requests UE for the carrier specifications, including QoS. eNB takes calls for carrier activators and PC assignments for the UE and indicates through the PDCCH signals for fixed time slots. Delay is observed in the case of larger time slots. Thus, the scheduler response time is critical in CA systems to manage delay and throughput trade-offs with the UE [16].

In [16, 17], the authors have explained two scheduler structures, Disjoint Queue Scheduler (DQS) and Joint Queue Scheduler (JQS), to optimize the time slot to enhance the QoS at the UE. DQS allows users to have independent traffic queues on each CCs, whereas JQS allows the users have a shared/joint queue to access the CCs, resulting in a single-layer scheduling platform.

Intelligent Spectrum Management

Different Spectrum Sharing and Management techniques allow cooperative and simultaneous use of the under-utilized radio and statically assigned frequency spectrum [18] by several independent entities in a particular geographical area. Licensed Shared Access (LSA) can effectively exploit the white spaces. Also, application Machine Learning (ML) and Artificial Intelligence (AI) at various levels of the network can provide scalable and flexible solutions to manage complex generations of communication. AI can administer MNOs in determining demand and re-configuring the network. In CA-enabled networks application of ML algorithms can determine the CCs to select based on the available spectrums [18, 19].

4. Open Research Issues

Efficient and intelligent future usage of frequency spectrum will need to be addressed for beyond 5G. The mobile communication sector is requesting more and more spectrum to accommodate higher traffic volumes and more demanding quality of service requirements. Traditionally, greater throughput was mainly obtained by increasing the available spectrum bandwidth and deploying more infrastructure. Providing greater throughput without wasting precious spectrum requires more and more complex radio spectrum management. AI-based spectrum management solutions have not yet been fully exploited since [19]. Future mobile and wireless networks will comprise heterogeneous, small cells overlaid with macro and microcells. Flying UAVs acting as relays are also of great interest in these beyond 5G ecosystems, as well as studies on the resulting cost/revenue trade-off and business plans. Different solutions based on intelligent interference management (or avoidance), evolved multi-band scheduling (on top of packet scheduling to manage radio resources), big data and machine learning strategies. Both sub-6 GHz bands and future mmWaves needed to be investigated [20].

5. Conclusions

In this paper, we have presented CA techniques and enhancements concerning the latest 3GPP releases on enhancements. Different scheduling techniques have been discussed. CA enabled 5G networks have been discussed in detail with various opportunities in licensed, unlicensed spectrum bands, mmWave bands, and HetNets. The structure for the schedulers has been discussed in detail as well. Finally, we have presented an overview of the CA scheduling techniques and introduced the scope of AI/ML in-network sensing and management aspects.

6. Acknowledgements

This work was supported by FCT/MCTES through national funds and cofounded EU funds under the project UIDB/50008/2020, ORCIP (22141-01/SAICT/2016) and TeamUp5G (MSCA-ETN grant agreement No. 813391).

References

[1] K. Flynn, "A Global Partnership." [Online]. Available: https://www.3gpp.org/release-16

[2] Ericsson. (2021) Carrier aggregation in 5G. [Online]. Available: https://www. ercsson.com/en/ran/carrier-aggregation.

[3] Y.-N. R. Li, M. Chen, J. Xu, L. Tian, and K. Huang, "Power saving techniques for 5G and beyond," IEEE Access, vol. 8, pp. 108 675–108 690, 2020.

[4] P. U. Adamu and M. Lopez-Benitez, "Performance Evaluation of Carrier Aggregation as a Diversity Technique in mmWave bands," in 2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring). IEEE, 2021, pp. 1–5.

[5] J. M. Romero-Jerez, F. J. Lopez-Martinez, J. F. Paris, and A.Goldsmith, "The fluctuating two-ray fading model for mmWave communications," in 2016 IEEE Globecom Workshops (GC Wkshps). IEEE, 2016, pp.1–6.

[6] J. Zhang, W. Zeng, X. Li, Q. Sun, and K. P. Peppas, "New results on the fluctuating two-ray model with arbitrary fading parameters and its applications," IEEE Transactions on Vehicular Technology, vol. 67, no. 3, pp. 2766–2770, 2017.

[7] T. Takiguchi, K. Kiyoshima, Y. Sagae, K. Yagyu, H. Atarashi, and S. Abeta, "Performance Evaluation of LTE-Advanced Heterogeneous Network Deployment Using Carrier Aggregation between Macro and Small Cells," IEICE transactions on communications, vol. 96, no. 6, pp. 1297–1305, 2013.

[8] B. Khan and F. J. Velez, "Deployment of Beyond 4G Wireless Communication Networks with Carrier Aggregation," in International Conference on Electronics and Electrical Engineering, July 16, 2020, Online. World Academy of Science, Engineering and Technology, 2020.

[9] O. Holland, A. Attar, O. Cabral, F. J. Velez, and A. H. Aghvami, "Intraoperator spectrum sharing concepts for energy efficiency and throughput enhancement," in 2010 3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL 2010). IEEE, 2010, pp. 1–6.

[10] K. Huang, J. Xu, M. Chen, and Y. Li, "Power saving Techniques for 5G and Beyond," IEEE Access, 2020.

[11] Nidhi, A. Mihovska, and R. Prasad, "Overview of 5G New Radio and Carrier Aggregation: 5G and Beyond Networks," in 2020 23rd International Symposium on Wireless Personal Multimedia Communications (WPMC), 2020, pp. 1–6.

[12] Y.-L. Chung, L.-J. Jang, and Z. Tsai, "An efficient downlink packet scheduling algorithm in LTE-advanced systems with carrier aggregation," in 2011 IEEE Consumer Communications and Networking Conference (CCNC), 2011, pp. 632–636.

[13] W. Fu, Q. Kong, Y. Zhang, and X. Yan, "A resource scheduling algorithm based on carrier weight in LTE-advanced system with carrier aggregation," in 2013 22nd Wireless and Optical Communication Conference. IEEE, 2013, pp. 1–5.

[14] L. Sharma, J.-M. Liang, and S.-L. Wu, "Energy-efficient resource scheduling within DRX cycles for LTE-a networks with carrier aggregation," IEEE Access, vol. 6, pp. 28 501–28 513, 2018.

[15] D. Robalo, F. J. Velez, R. R. Paulo, and G. Piro, "Extending the lte-sim simulator with multi-band scheduling algorithms for carrier aggregation in lte-advanced scenarios," in 2015 IEEE 81st Vehicular Technology Conference (VTC Spring). IEEE, 2015, pp. 1–6.

[16] L. Chen, W. Chen, X. Zhang, and D. Yang, "analysis and simulation for spectrum aggregation in lte-advanced system," in 2009 IEEE 70th Vehicular Technology Conference Fall.

[17] D. P. Sharma and S. K. Gautam, "Distributed and prioritised scheduling to implement carrier aggregation in lte advanced systems," in 2014 Fourth International Conference on Advanced Computing Communication Technologies, 2014, pp. 390–393.

[18] U. Challita, L. Dong, and W. Saad, "Proactive resource management for LTE in unlicensed spectrum: A deep learning perspective," IEEE transactions on wireless communications, vol. 17, no. 7, pp. 4674–4689, 2018.

[19] F. Fourati and M.-S. Alouini, "Artificial intelligence for satellite communication: A review," arXiv preprint arXiv:2101.10899, 2021.

[20] N. Kumar and R. Khanna, "A two element MIMO antenna for sub-6 GHz and mmWave 5G systems using characteristics mode analysis," Microwave and Optical Technology Letters, vol. 63, no. 2, pp. 587–95, 2021.