Carrier Aggregation in the Scheduling Schemes for LTE Advanced Systems

Njiraine Morris M. and Stephen Musyoki

Abstract**—**Carrier aggregation (CA) is a major technological advancement and a key enabler for the 3GPP in the Long Term Evolution (LTE) Advanced systems for the achievement of the IMT-Advanced requirements. Multiple component carrier with varying bandwidth, dispersed within inter bands and intra bands can be utilized through carrier aggregation in a simultaneous manner to achieve better coverage, high data rates and lower latency, and great user throughput.

Despite the aspect of backward compatibility of CA, the introduction of the technology has required some changes from the LTE release 8 baseline as well as modification in functionality to the network radio resource function. This paper offers a review of the carrier aggregation technique with the functionality of Radio Resource Management (RRM) and requirements for the CA support. Current ongoing and recent research on scheduling algorithms and the aspects of RRM for LTE advanced in support of CA are reviewed. The paper also outlines the technical challenges presented in the packet scheduler design and for future research.

Keywords**—**Carrier Aggregation (CA), Component Carrier (CC), LTE Advanced, Radio Resource Management (RRM), packet scheduling.

I. Introduction

With the high growth of mobile data consumption with demanding services and increasing wireless devices, there is need to exploit technology in meeting the user needs. Long Term Evolution (LTE) was introduced in its first version of 3GPP Release 8 in March 2009 that set significant pace towards the 4G technology [1]. With a flat radio access network architecture and features introduced, LTE aimed at offering flexible bandwidth options, packet optimized network, low latency and higher data rates [2]. LTE Advanced extended advancements of the features in LTE to operate in wider system bandwidth and meet the high capability advanced requirements for International Mobile Telecommunications, IMT Advanced, with discussion already underway for IMT-2020 [3].

Carrier aggregation (CA) offers one of the most significant and distinct feature in LTE advanced that when combined with other new features attains higher data rates, lower latency, better coverage and an overall better user experience [4]. As the main feature in the 3GPP release 10 for LTE advanced, carrier aggregation enabled 3GPP attain the peak data rate requirements for IMT- Advanced, 500 Mbps and 1 Gbps for uplink and downlink, respectively [5]. With carrier aggregation, network operators can desirably employ the flexibility introduced to meet the rapidly increasing data transmission demand.

The system bandwidth is easily extended when CA is applied through non-continuous or continuous aggregation of multiple components carriers (CCs), up to 100 MHz for 20 MHz, using 5 CCs (for 3GPP Release 10). The concept of CA is not completely new and has been deployed as Dual Carrier HSPA (DC-HSPA) in the HSPA based network in which adjacent carriers in the downlink/uplink were aggregated [6]. However, LTE advanced extended the same concept to have both contiguous and non-contiguous aggregation for different spectrum bands. Since CCs follow the LTE specifications, eNodeB and Radio Frequency specifications, carrier aggregation guarantees backward compatibility between 3GPP Release 8/9, LTE, and the later 3GPP releases. Through the reuse of LTE design on the CCs, minimal specification and implementation efforts are achieved [7].

Introduction of CA to LTE Advanced, however, has required some modifications to the link layer as well as introduction of new functionalities to radio resource management. Configurations and implementation of CA in LTE advanced challenges have been reported, specifically in choice of CCs activated under the User Equipment (UE)'s Quality of Service (QoS) requirements and attaining minimal impact on the running LTE protocol [8]. Other radio resource management (RRM) aspects such as packet scheduling and CC assignment need to be investigated for the CA functionality in the downlink transmission [9]. This paper provides a detailed overview of CA for the LTE advanced networks, the functionality of RRM with CA support, while presenting technical challenges, modifications necessary for RRM design with CA support and upcoming issues.

II. Review of the Carrier Aggregation Technique

Carrier aggregation in LTE advanced has been a significant functionality whose main aim has been to achieve a greater bandwidth accessible to the users. CA can be applied for both the TDD and FDD, and can be configured with carriers of any available bandwidth, including bandwidths that are different, in any frequency band. The uplink and downlink can be configured independently, with a limitation that the uplink carriers cannot be more than the downlink carriers [5].

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A. Carrier Aggregation Types

According to the arrangement of the CCs frequencies, three different carrier aggregation types are identified.

Intra-band contiguous CA: This CA type makes use of the same operating frequency band. A bandwidth wider than 20 MHz and next to other is applied for the LTE advanced. However, with the frequency allocations today, contiguous bandwidth wider than 20 MHz may not be likely possible but would be common in the near future when spectrum bands like 3.5 GHz are allocated in the various parts of the world. The spacing between centre frequencies is made to be a multiple of 300 kHz for the contiguously aggregated CCs in order to be compatible with the frequency raster of 100 kHz for release 8/9 and also preserve the subcarrier orthogonally with spacing of 15 kHz [5].

Intra-band non-contiguous CA: In this case, the spectrum blocks that are contiguous are not available for aggregation and multiple non-contiguous carriers belonging to the same frequency band are used. This type of CA is more complicated as multi-carrier signal cannot be assumed as a single signal and thus two transceivers are needed. This form adds significant complexity especially in consideration of power, space and cost for the UE [4].

Inter-band non-contiguous CA: Different frequency bands such as 800 MHz and 2 GHz are used in this CA mode. The use of two carriers can greatly improve the communication throughput and the use of multiple carriers with various environments for propagations can improve stability. Mobility and robustness can also be achieved by this kind of aggregation through exploiting the various characteristics of the radio propagation of different frequency bands [10]. This kind of CA, however, introduces complexities due to the requirements to minimize cross modulation and inter-modulation from the transceivers.

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B. Deployment Scenarios

The first case is the common typical envisaged scenario in which the eNodeB antennas have the same beam patterns/directions for the CCs. Assuming frequency one cell to be of higher frequency and frequency two cell to be the lower frequency (F1 and F2, respectively) for the area, this scenario have both the F1 and F2 cells overlaid and co-located within the same band, and thus offer nearly the same coverage [12]. Mobility can be supported in both layers and sufficient coverage is also offered to both layers [13].

In the second scenario, F1 and F2 cells are also overlaid and co-located in different bands in which the spectrum allocation for a network operator is often dispersed across different frequency bands. F2 has a smaller coverage in this case due to a higher path loss. F2 is used in offering throughput and only F1 offers sufficient coverage [14].

In another likely case, scenario three, the F1 and F2 cells could be co-located but the antennas for F2 are directed intentionally to the F1 cell boundaries so that the throughput of the cell edge is increased [14]. In In this case, sufficient coverage would be provided by F1 while due to larger path loss, F2 would potentially have holes. Aggregation would be possible where there is overlaps of coverage for the CCs of the same eNodeB. In the fourth scenario, macro coverage is offered by F1 to provide continuous service whereas remote radio heads are used to offer throughput at hotspots of F2. The RRHs cells are connected to the eNodeB through optical fibres, and thus allow aggregation between the RRH cell and the underlying microcells. Such deployment scenario would enable the operator to improve system throughput through the use of low cost RRH equipment [15].

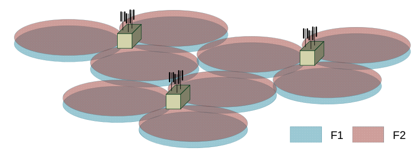

Fig. 1 (a) CA Deployment Scenario 1 [12]

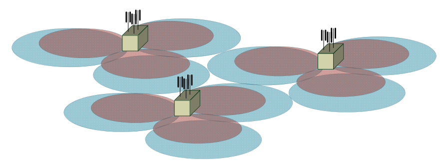

Fig. 1 (b) CA Deployment Scenario 2 [12]

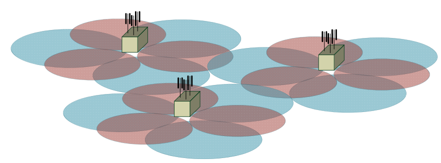

Fig. 1 (c) CA Deployment Scenario 3 [12]

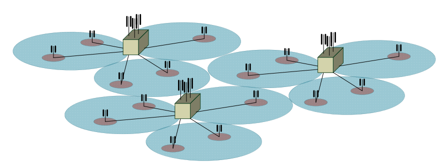

Figure 1 (d) CA Deployment Scenario 4 [12]

III. Radio Resource Management (RRM) with Carrier Aggregation

There are many similarities retained for the RRM framework of LTE Advanced from the LTE design [6]. With carrier aggregation in LTE advanced, however, a user can possibly be scheduled simultaneously on multiple component carriers that would likely exhibit different characteristics for radio channel. Supporting operations of multiple carrier components introduces some new challenges in the RRM framework for LTE advanced network [4]. With respect to RRM, this section takes a look at the distinctions between LTE advanced and LTE system. For carrier aggregation system, the RRM structure is as illustrated in Fig. 2.

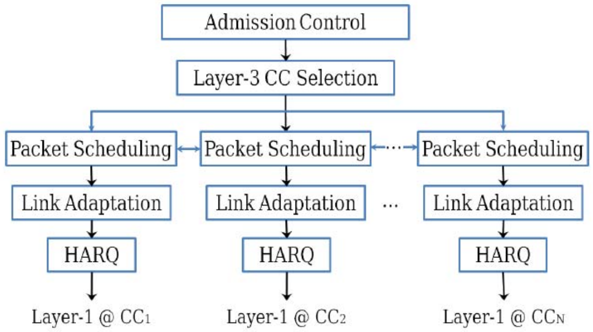

Fig. 2 Structure of RRM for LTE advanced with Carrier Aggregation Support [21]

The admission control is performed by the eNodeB before the establishment of new radio bearers and configuration of the QoS parameters. The QoS parameters are the same for the LTE advanced and LTE, and are therefore CC-independent. Based on traffic loads and the QoS requirements, the eNodeB configures a set of CCs for users and through multiplexing of multiple users on each CC, the resource block scheduling is carried out [16]. Independent layer 1 transmission that contain Hybrid Automatic repeat Request (HARQ) and Link Adaptation, per CC is used in line with the LTE assumptions to ensure backward compatibility so that LTE Advanced users and LTE users can coexist [17].

Transmission on different CCs is optimised by the use of independent link adaption per CC according to the radio conditions that are experienced [10]. By configuring different transmit powers for individual CCs, different levels for coverage could be provided by CCs. While the capability of aggregation offers the flexibility to deal with bandwidth needed to achieve wider coverage and higher data rates [18], resource allocation of multiple component carrier and adaptive adjustment of transmission parameters for the various CCs should be considered jointly [19]. Due to uplink signalling, there is large amount of transmission overhead incurred by the independent layer-1 transmissions. Therefore, for channel aware link adaptation and packet scheduling, the UE has to feedback the channel quality indicator (CQI) containing channel quality information and acknowledgement/non-acknowledgement (ACK/NACK) per CC. This should indicate whether the transmission has been successful or not for the independent layer 1 transmission on each carrier component. In the case we have multiple CCs allocations for a user, a great amount of uplink overhead will be experienced due to uplink signalling from the users [20]. Several techniques have been suggested to reduce this type of overhead at various slayers as detailed and evaluated in [11].

As shown in Fig. 3, physical layer protocol and the MAC layer are the mainly influenced by the introduction of carrier aggregation. There are also introduction of some new RRC messages.

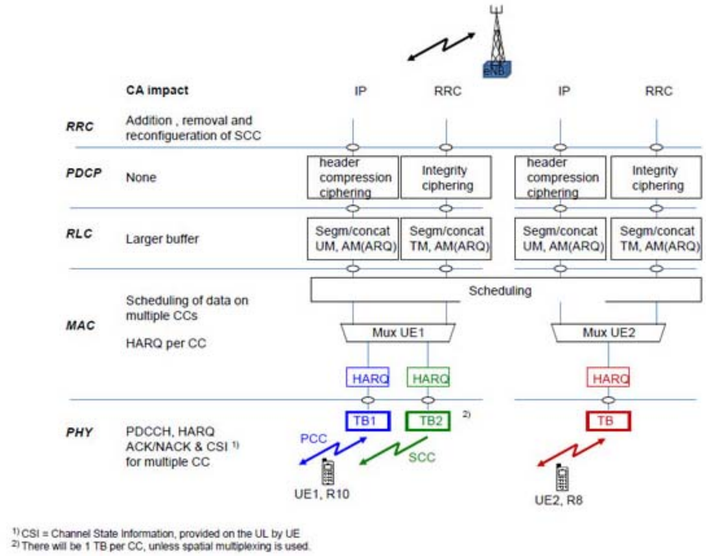

Fig. 3 Radio Interface LTE protocols, with CA Introduction [22]

A. *Carrier Component Management and Selection*

D For the LTE advanced systems, this functionality of CC selection in which users are assigned multiple CCs is introduced for RRM. For the selection of the CC, information of the UE such as terminal capability and the QoS requirements are exploited together with information measured such as the traffic load per CC, the overall traffic level and the channel quality information given from the UEs [22]. In establishing the CCs number required for a particular user, QoS parameters such as the guaranteed bit rate for the GBR bearers, QoS class identifiers (QCI) and aggregated maximum bit rate (AMBR) for non-GBR bearers can be utilised [22]. In the Voice over IP (VoIP) users, for example, a single CC can be assigned in order to satisfy the QoS requirements of the user. Where the users have the best effort traffic, for example, AMBR requirements can be applied in estimating the CC set size appropriate for them [22]. Approximately equal load on the different CCs is however desired during configuration for optimal system performance. Where there is unbalanced traffic loads across the CCs, there may be under-utilisation of the spectrum resources [19]. Trunking efficiency can be maximised by assigning the users all the CCs and the frequency domain packet scheduling gain can also be optimised [23].

At low levels of traffic, the performance gain from utilising the multiple CCs by aggregation over using a single CC is important in respect to the average user throughput. According to the simulation study carried out in [23], assigning all CCs to users is indicated to achieve 100-300% higher coverage and user throughput than assigning a single CC for each user. The gain, however, diminishes with the increase in traffic while employing different techniques of load balancing attain roughly similar performance [24]. Since a higher power processing power and signalling complexity is attained increasing the number of CCs received by a user, then at high traffic loads there should be only configuration of small number of CCs [16].

The maximum transmission power is a constraint, particularly for the uplink transmission [20]. When the UE reaches its maximum transmission power, increasing the bandwidth do not have a direct impact in the increase of the data rates in the uplink transmission. Further, when a UE is transmitting simultaneously over multiple CCs, there is increase in peak-to-average power ratio which results to effective reduction of the maximum transmission power of the UE [15]. It is not always appropriate for power limited users to allocate multiple CCs, especially for those who experience unfavourable channel conditions. Due to this challenge of power constraint in the uplink transmission, the CC selection scheme plays a major role in the system performance optimisation with aggregation for the uplink transmission than that for downlink transmission from the perspective of RRM [25].

Fairness can be issue since the LTE advanced UEs will be assigned on more CCs than the LTE UEs, thereby having lower throughput in the LTE UEs than in the LTE Advanced UEs [26]. With the CC mobility management, CC removal or addition and intra/inter-frequency handover, control over coverage is enabled and overall signal quality in CA deployments areas. These operations can however lead to signalling overhead that is related to the configurations of the RRC [20]. As there is dynamically changing of CCs with respect to the radio conditions, there is an increase in the frequency of the RRC configuration that lead to the increased RRC signalling [27]. Various management policies for CC that offer various overheads of RRC signalling under various scenarios are investigated in [27].

It is still a key issue in the resource management schemes design for the LTE advanced CA based system on how best to assign the CCs to every user as according to the environmental conditions and its carrier capability, and also how to users can be multiplexed in each CC [13] [28] [29] [30].

B. *Packet Scheduling*

Packet scheduling is done across the CCs following configurations of multiple CCs. The packet scheduling aims at prioritising the allocation of the resource blocks to the users that have an environment of good channel quality while benefiting from the multiuser frequency domain scheduling diversity. The functionality of packet scheduling for the LTE advanced with support of CA remain very similar to the packet scheduling applied in the LTE-Release 8, expect that the packet scheduling for LTE advanced is allowed to schedule users across multiple CCs which are activated and configured for UEs [24]. Similar to the framework for LTE packet scheduling, the smallest frequency domain scheduling resolution within each CC is a physical resource block of 12 subcarriers that constitute a 180 kHz equivalent bandwidth. One physical resource block also corresponds to a time domain sub frame, with transmission time interval of 1 ms [5] [16].

LTE advanced relies on HARQ per CC, link adaptation and independent transport blocks, and such independent operation per CC given chance for different options for the scheduler implementation. Scheduling could be carried out either independently for each CC or jointly across multiple CCs as demonstrated in figure. Extra complexity is introduced to the system by joint scheduling by the exchange of information between independent schedulers or the introduction of a more sophisticated scheduler operating across the multiple CCs. resource allocation across multiple CCs as compared with independent scheduling increases eNodeB scheduling load as well as uplink overheads. Scheduling across the multiple CCs achieves better performance since load balancing is enabled between carriers and ultimately have an improved fairness.

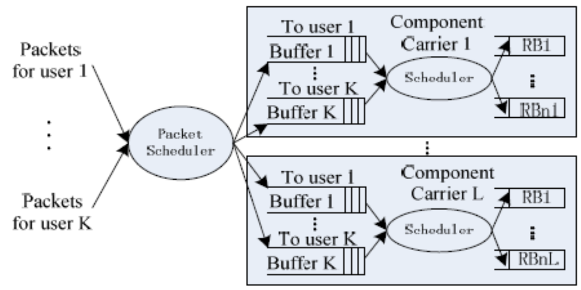

Fig. 4 (a) Disjoint Queue Scheduler Model [31]

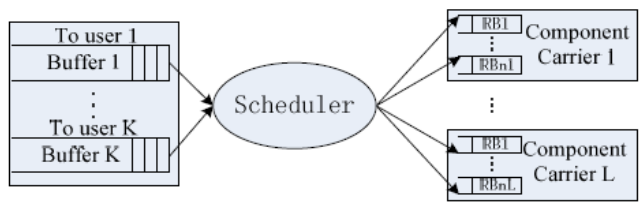

Fig. 4 (b) Joint Queue Scheduler Model [31]

The requirements for packet scheduler design in the LTE advanced system support for Carrier aggregation would need to address: the need to handle the multiple CCs environment during packet scheduling; the need to support QoS required for the different types of traffic, and; the need to maintain fairness amount the LTE and LTE advanced users, as identified in [32].

The problem of radio resource allocation can be formulated for the co-existing LTE and LTE advanced users as described in [14]. The formulation in the study presents a non-linear integral programming problem, and the computational complexity can be reduced by decomposing the resource allocation with carrier aggregation into two sequence steps; CC selection and RB assignment on every CC [13] [33] [34]. The first step would thus involve CC selection by the eNodeB in assigning the proper CCs to the users and once the users are assigned onto the CCs, the assignment of resource blocks that belong to the CC is carried out [14].

IV. Ongoing and Future Research on Scheduling Schemes for LTE Advanced Systems

Downlink transmission of wireless systems has been considered in most of the resource allocation for CA study as higher application throughput are required in the downlink transmission than in the uplink. The maximum transmission power is a constraint in the uplink, even though there are few similarities between the radio resource management for the uplink and the downlink. CA based systems introduced two scheduler structures for resource scheduling as introduced in Fig. 4 (a) and Fig. 4 (b) for joint carrier and independent carrier, respectively [31]. The performance of the joint carrier in the CA scheduling is compared with the non-CA independent carrier scheduling in the case of two CCs belonging to the same frequency band has been carried out in [33] [31] [35].

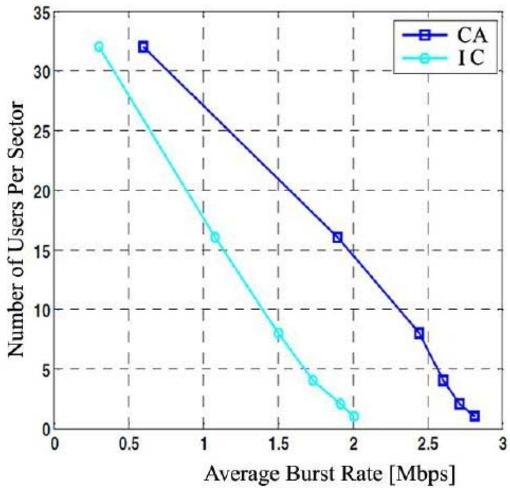

Fig. 5 (a) Throughput performance of CA and Non-CA Independent Carrier Scheduler for Burst Traffic [31]

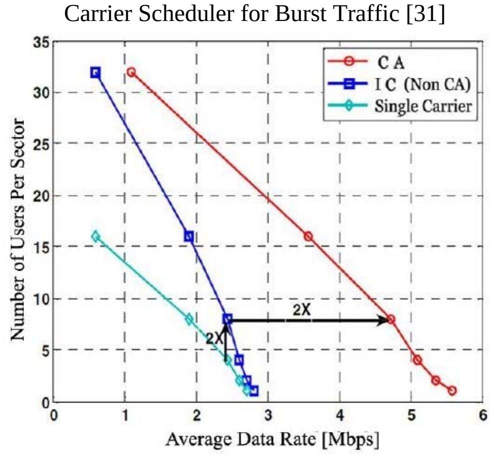

Fig. 5 (b) Throughput performance of CA, Independent Carrier and Single Carrier Scheduler for Burst Traffic [31]

The effect of the CA was shown to have growth in the user throughput through a study carried out in [36]. The peak data rate link level and the overall system throughput was shown to increase substantially in the CA LTE advanced users as compared to the LTE release 8 users [36]. While comparing between inter-band non-contiguous CA scenario on 1800 MHz and 900 MHz frequencies and intra-band non-contiguous CA scenario on 1899 MHz frequency, a recent study [37] indicated that inter-band non-contiguous network offer better performance based on Carrier to Interference-plus-Noise Ratio (CINR) level and throughput. Throughput of non-contiguous intra-band CA scenario was shown to have better performance in a [38] as compared to contiguous CA scenario.

Latest developments in carrier aggregation is to support up to 32 CCs in the LTE release 13 with flexibility to aggregate large carrier numbers in different frequency bands [39]. This would introduce challenging implications on the current support for control signalling both in the uplink and downlink [40]. As identified already in a section above [15], one of the major challenges with the CA implementation is the severe increase in the peak-to-average-power ratio (PAPR) in the uplink transmission [15], that further affect the efficiency of the power amplifier. [41] A recent study has aimed at addressing the issue through the use of Karhunen-Loeve Transform (KLT) using the NxSC-FDMA signals [42]. A low complexity joint leaving method to reduce the PAPR was introduced in [43], in which 66% reduction in terms of real additional and multiplication operations was achieved. This PAPR reduction issue when multicarrier transmission is employed remains an important issue for research and recent attempts to address the issue have been studied in [44] [45] [46] [47] [48] [49] [50].

V. Conclusion

Carrier aggregation remains an important feature that offers efficient and flexible utilisation of frequency resources that would consequently result to improved data rates for the users although the rate of data rates increase slows down at high loads of traffic. The introduction of carrier aggregation, however, introduces the decision of which bands and how many bands need to be used in satisfying the requirements given various constraints. This introduces the RRM mechanisms design challenges for the CA based systems. Implementation complexity need to be addressed with novel optimal CC selection methods required, with consideration of both resource block scheduling and the CC selection.

Due to these issues raised on regard to radio resource management, proper resource scheduling techniques of RB and power control, solutions need to be put into place by the LTE advanced system implementers in order to achieve the benefits of carrier aggregation and concurrently enhance the fairness of the users. There would be likely scenarios for starvation by some UE users if resources are not distributed accordingly and the QoS of users will be certainly be affected. As the next generation of mobile systems would have application delay requirements, further studies need to improve the delay aspect of scheduling schemes to ensure optimal performance. Finally, in the intra-band contiguous CA scenario, the subcarriers in the guard bands between the CCs can be exploited for transmission and methods could be investigated in order to increase spectrum utilisation and spectral efficiency.

REFERENCES

[1] H. Holma and A. Toskala, LTE for UMTS: Evolution to LTE-Advanced, West Sussex: John Wiley & Sons, 2011.

[2] M. Poikselkä, H. Holma, J. Hongisto, J. Kallio and A. Toskala, Voice Over Long Term Evolution, West Sussex: John Wiley & Sons, 2012.

[3] Marcus, "5G and "IMT for 2020 and beyond" [Spectrum Policy and Regulatory Issues]," IEEE Wireless Communications, vol. 22, no. 4, pp. 2-3, 2015.

[4] M. Al-Shibly, M. Habaebi and J. Chebil, "Carrier Aggregation in Long Term Evolution-Advanced," in Control and System Graduate Research Colloquium (ICSGRC), Shah Alam, Selangor, 2012.

[5] E. Dahlman, S. Parkvall and J. Sköld, 4G LTE/LTE-Advanced for Mobile Broadband, Oxford: Academic Press, 2011.

[6] M. Sauter, From GSM to LTE: An Introduction to Mobile Networks and Mobile Broadband, West Sussex: John Wiley & Sons, 2011.

[7] Z. Shen, A. Papasakellariou, J. Montojo and F. Xu, "Overview of 3GPP LTE-Advanced Carrier Aggregation for 4G Wireless Communications," IEEE Communications Magazine, vol. 50, pp. 89-95, 2012.

[8] C.-Y. Wang, H.-Y. Wei and W.-T. Chen, "Resource Block Allocation with Carrier-Aggregation: A Strategy-Proof Auction Design," IEEE Transactions on Mobile Computing, vol. PP, no. 99, pp. 1-14, 2016.

[9] H.-S. Liao, P.-Y. Chen and W.-T. Chen, "An Efficient Downlink Radio Resource Allocation with Carrier Aggregation in LTE-Advanced Networks," IEEE Transactions on Mobile Computing, vol. 13, no. 10, pp. 2229-2239, 2014.

[10] L. Liu, M. Li, J. Zhou, X. She, L. Chen, Y. Sagae and M. Iwamura, "Component Carrier Management for Carrier Aggregation in LTE-Advanced System," in Vehicular Technology Conference (VTC Spring), Budapest, 2011.

[11] Y. Wang, K. I. Pedersen, M. Navarro, P. E. Mogensen and T. B. Sørensen, "Uplink overhead analysis and outage protection for multi-carrier LTE-Advanced systems," in 2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications, Tokyo, 2009.

[12] 3GPP TS 36.300, "Evolved Universal Terrestrial Radio Access (E-UTRA); Stage 2 Description," 3GPP, 2010.

[13] L. Liu, M. Li, J. Zhou, X. She, L. Chen, Y. Sagae and M. Iwamura, "Component carrier management for carrier aggregation in lte-advanced systems," in 2011 IEEE 73rd Vehicular Technology Conference. (VTC Spring), Budapest, 2011.

[14] F. Wu, Y. Mao, S. Leng and X. Huang, "A Carrier Aggregation Based Resource Allocation Scheme for Pervasive Wireless Networks," in 2011 Ninth IEEE International Conference on Dependable, Autonomic and Secure Computing, Sydney, NSW, 2011.

[15] 3GPP, "LTE-A MC RF requirements for contiguous carriers," TR R4-091910, 3GPP TSG-RAN WG4 51, 2009.

[16] A.-E. Taha, H. Hassanein and N. A. Ali, LTE, LTE-ADVANCED and WiMAX: TOWARDS IMT-ADVANCED, West Sussex: John Wiley & Sons, 2012.

[17] 3GPP, "Further Advancements of E-UTRA Physical Layer Aspects," TR 36.814, 3rd Generation Partnership Project (3GPP), Feb. 2009.

[18] Y.-L. Chung and Z. Tsai, "A quantized water-filling packet scheduling scheme for downlink transmissions in LTE-Advanced systems with Carrier Aggregation," in 2010 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Dubrovnik, 2010.

[19] H. Wang, C. Rosa and K. Pedersen, "Performance Analysis of Downlink Inter-Band Carrier Aggregation in LTE-Advanced," in 2011 IEEE Vehicular Technology Conference (VTC Fall), San Francisco, CA, 2011.

[20] H. Wang, C. Rosa and K. Pedersen, "Uplink component carrier selection for lte-advanced systems with carrier aggregation," in 2011 IEEE International Conference on Communications (ICC), Kyoto, 2011.

[21] Y. Wang, K. Pedersen, P. Mogensen and T. Sørensen, "Resource allocation considerations for multi-carrier LTE-Advanced systems operating in backward compatible mode," in 2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications , Tokyo, 2009.

[22] 3GPP TR 36.808 V10.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Carrier Aggregation; Base Station (BS) radio transmission and reception (Release 10)," 3GPP, 2012.

[23] Y. Wang, K. Pedersen, P. Mogensen and T. Sørensen, "Carrier load balancing methods with bursty traffic for lte-advanced systems," in 2009 IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications, Tokyo, 2009.

[24] K. I. Pedersen, F. Frederiksen, C. Rosa, H. T. Nguyen, L. G. U. Garcia and Y. Wang, "Carrier aggregation for LTE-advanced: functionality and performance aspects," IEEE Communications Magazine, vol. 49, no. 6, pp. 89-95, 2011.

[25] H. Tian, S. Gao, J. Zhu and L. Chen, "Improved Component Carrier Selection Method for Non-Continuous Carrier Aggregation in LTE-Advanced Systems," in 2011 IEEE Vehicular Technology Conference (VTC Fall), San Francisco, CA, 2011.

[26] Y. Wang, K. Pedersen, T. Sørensen and Preben Mogensen, "Carrier load balancing and packet scheduling for multi-carrier systems," IEEE Transactions on Wireless Communications, vol. 9, no. 5, pp. 1780-1789, 2010.

[27] [27] T. N. H. I. Kengo Yagyu, M. Iwamura, N. Miki, T. Asai and J. Hagiwara, "Investigation on Mobility Management for Carrier Aggregation in LTE-Advanced," in 2011 IEEE Vehicular Technology Conference (VTC Fall), San Francisco, CA, 2011.

[28] M. Alotaibi, M. Sirbu and J. Peha, "Impact of spectrum aggregation technology and frequency on cellular networks performance," in 2015 IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), Stockholm, 2015.

[29] P.-R. Li, C.-W. Kuo, K.-T. Feng and T.-S. Chang, "Joint Base Station Association and Radio Resource Allocation for Downlink Carrier Aggregation in LTE-Advanced Systems," in 2015 IEEE 81st Vehicular Technology Conference (VTC Spring), Glasgow, 2015.

[30] M. K. Ismail, M. S. Johal and A. Awang, "Current developments in LTE-ADVANCED: Radio resource management review," in 2014 IEEE Student Conference on Research and Development (SCOReD), Batu Ferringhi, 2014.

[31] 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 (VTC 2009-Fall), Anchorage, AK, 2009.

[32] Y.-L. Chung, L.-J. Jang and Z. Tsai, "An Efficient Downlink Packet Scheduling Algorithm in LTE-Advanced Systems with Carrier Aggregation," in The 8th Annual IEEE Consumer Communications and Networking Conference, Las Vegas, NV, 2011.

[33] Zhang, Zheng, Wang and Huang, "Performance analysis on carrier scheduling schemes in the long-term evolution-advanced system with carrier aggregation," IET Communications, vol. 5, no. 5, pp. 612-619, 2011.

[34] Wang, Pedersen, Sorensen and Mogensen, "Utility Maximization in LTE-Advanced Systems with Carrier Aggregation," in 2011 IEEE 73rd Vehicular Technology Conference (VTC Spring), Yokohama, 2011.

[35] Zhang, Wang, Huang, Wang and Wang, "QoS performance analysis on carrier aggregation based LTE-A systems," in IET International Communication Conference on Wireless Mobile and Computing (CCWMC 2009), Shanghai, 2009.

[36] M. Oproiu, A. Vulpe and I. Marghescu, "Effects of enabling carrier aggregation in a mobile operator network," in 2015 23rd Telecommunications Forum Telfor (TELFOR), Belgrade, 2015.

[37] D. W. Saputra, U. K. Usman and L. Meylani, "Planning LTE-Advanced using carrier aggregation intra-band non-contiguous and inter-band non-contiguous method," in 2015 IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob), Bandung, 2015.

[38] Iskandar and Galih, "Throughput evaluation in LTE-Advanced network access using carrier aggregation," in 2015 1st International Conference on Wireless and Telematics (ICWT) , Manado, Indonesia, 2015.

[39] 3GPP, "TSG RP-142286: LTE Carrier Aggregation Enhancement Beyond 5 Carriers," 3GPP, 2014.

[40] A. Bhamri, K. Hooli and A. Prasad, "Overview of uplink control channel for carrier aggregation enhancements in LTE Rel. 13," in 2015 IEEE Conference on Standards for Communications and Networking (CSCN), Tokyo, 2015.

[41] J. Bai, Z. Hao, H. Du and Y. Wang, "A resource reserved PF algorithm for LTE-A with power allocation," in 2015 International Conference on Estimation, Detection and Information Fusion (ICEDIF), Harbin, 2015.

[42] A.-k. Ajami and H. A. Artail, "KLT-based PAPR reduction technique for LTE-Advanced uplink with carrier aggregation," in 2015 IEEE 11th

International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), , Abu Dhabi , 2015.

[43] A.-k. Ajami, H. Artail and M. Mansour, "PAPR reduction in LTE-Advanced carrier aggregation using low-complexity joint interleaving technique," in 2015 IEEE Wireless Communications and Networking Conference (WCNC) , New Orleans, LA, 2015.

[44] F. Foukalas and T. Khattab, "Optimal Power Allocation in Dsipersed cognitive radio systems with carrier Aggregation," in 2016 International Conference on Computing, Networking and Communications (ICNC) , Kauai, HI, USA, 2016.

[45] A.-k. Ajami, H. Artail and M. Mansour, "A Low-complexity PAPR Reduction technique for LTE Advanced uplink with Carrier Aggregation," in 2015 IEEE Global Communications Conference (GLOBECOM) , San Diego, CA , 2015.

[46] Y. Meng, G. Shen, W. Zheng, Q. Jiang, Y. Tang, H. Sun and J. Liu, "PAPR reduction with multiple antennas transmission for carrier aggregation," in 2012 IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications - (PIMRC) , 2012 IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications - (PIMRC) , 2012.

[47] L. An, X. Zhu, G. Guo and L. Wu, "PAPR reduction for carrier aggregated uplink in LTE-A system," in 2013 15th IEEE International Conference on Communication Technology (ICCT), Guilin, 2013.

[48] B. Xiong, X. Zhu, W. Li and G. Guo, "Analysis of Maximum Power Reduction of Uplink for Carrier Aggregation in LTE-A System," in 2012 International Conference on Connected Vehicles and Expo (ICCVE) , Beijing, China, 2012.

[49] P. Yen, H. Minn and C.-C. Chong, "PAPR Reduction for Bandwidth-Aggregated OFDM and SC-FDMA Systems," in 2011 IEEE Wireless Communications and Networking Conference, Cancun, Quintana Roo, 2011.

[50] L. Kewen and X. Ning, "PAPR reduction of uplink for carrier aggregation in LTE-Advanced," in The 2nd International Conference on Information Science and Engineering, Hangzhou, China, 2010.