# Throughput Analysis of Carrier Aggregation Scheme for Enhancing Bandwidth in Healthcare Applications

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**Abstract: Fifth generation (5G) wireless communication supports high data rates and is vital for broadband applications such as healthcare and agriculture. To meet growing bandwidth demands, Carrier Aggregation (CA) has emerged as a key technique, combining multiple frequency bands into broader channels to enhance throughput, capacity, and network performance. This study simulates both contiguous and non-contiguous CA schemes using Network Simulator (NetSim) for LTE and LTE-Advanced networks. The simulation includes appropriate base stations (eNBs) and user equipment (UEs), with throughput evaluated under different CA configurations. Results show that intra-band contiguous CA achieves higher throughput than non-contiguous CA due to reduced spectral dispersion. Further analysis across varying power levels highlights CA's potential in enabling reliable, real-time healthcare services—such as remote diagnostics, teleconsultations, live surgical support, and continuous transmission of patient vitals.**

**Keywords: Carrier Aggregation, Contiguous, Non-contiguous, LTE, Throughput**

## I. INTRODUCTION

The healthcare industry is rapidly evolving with innovations in wireless communication technologies, driving the need for high-speed, reliable connectivity, especially in telemedicine, remote monitoring, smart hospitals, and emergency services. Current networks struggle to meet the demands of real-time data transfer, low latency, and high throughput. Carrier Aggregation (CA), a key feature of LTE-Advanced and 5G, addresses these challenges by combining multiple frequency bands to boost network capacity, speed, and efficiency.

CA benefits healthcare in various ways: improving video quality and reducing disruptions in telemedicine, enabling continuous data exchange for wearable medical devices, and supporting fast communication in smart hospitals, robotic surgeries, and AI diagnostics. As defined by 3GPP, CA allows devices to receive or transmit multiple component carriers (CCs) with bandwidths ranging from 1.4 to 20 MHz Initially, up to five CCs could be aggregated for a maximum 100 MHz bandwidth. With 5G, devices can aggregate many more CCs for even higher bandwidths.

5G-equipped ambulances with real-time diagnostic tools use Carrier Aggregation to transmit high-speed data, allowing timely medical responses by sending patient information to hospitals before arrival. In rural areas with limited healthcare access, CA enhances spectrum efficiency and provides faster, secure telemedicine connections. As healthcare adopts technologies like AI, big data, and machine learning, Carrier Aggregation supports faster data speeds, reduced latency, and seamless integration of AI-driven solutions for predictive diagnoses, remote surgeries, and real-time health monitoring.

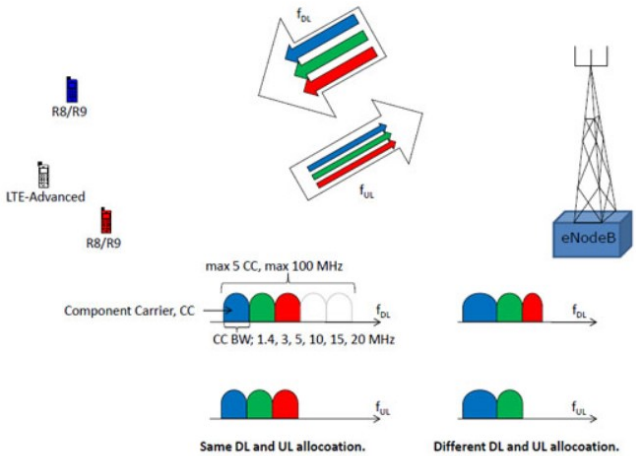


Fig. 1: Carrier Aggregation Model
(Source: 3GPP Release Notes)

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*1.1 Types of Carrier Aggregation (based on the organization of the frequency bands)*

- ***Intra-band Contiguous CA:*** This is where two or more carriers within the same frequency band, which are contiguous, are aggregated. This method gives least complexity in terms of implementation but demands a lot of contiguous bandwidth.
- ***Intra-band Non-contiguous CA*:** Several carriers are bundled in the same frequency band but are not contiguous to one another. This benefits operators who lack contiguous blocks of spectrum but still wish to take advantage of higher bandwidth in a single band.
- ***Inter-band Non-contiguous CA:*** In this case, carriers are pooled across various frequency bands. This is the most adaptable form, where operators can utilize spectrum in multiple bands. Though it provides major capacity benefits, it is more complicated to implement.

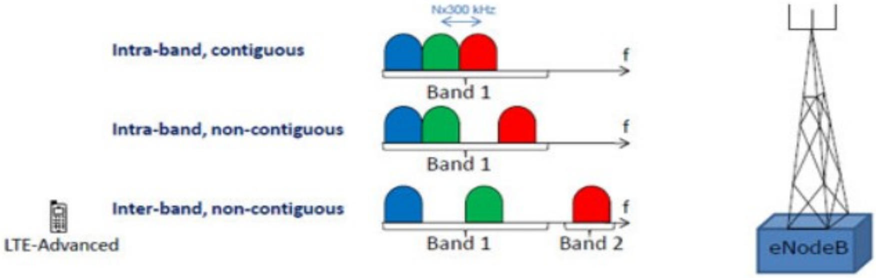


Fig. 2: Types of Carrier Aggregation
(Source: 3GPP Release Notes)

Rest of the paper is structured as follows. Section-2 reviews the extant literature. Section-3 explains the methodology of research. Section-4 discusses the results and findings. Section-5 delves into real-world relevance of the findings. Section-6 summarises the conclusion of the paper.

## II. Literature Review

The paper (Paul Ushiki Adamu et al., 2024) explores Carrier Aggregation (CA) as a capacity enhancer and diversity technique to improve spectral efficiency and security. A mathematical model shows that CA enhances spectral efficiency and secures communication channels without requiring additional spectrum, redefining its role in optimizing existing spectrum. Future research could focus on optimizing CA configurations to balance diversity and security in networks.

The authors (Yingrui Zhang et al., 2013) proposed an algorithm to enhance medical image and video transmission over LTE-A networks, addressing bandwidth limits in GBR-based healthcare. The Best-fit Carrier Dial-up (BCD) algorithm uses Carrier Aggregation (CA) to allocate bandwidth dynamically, reducing latency and signalling overhead. Simulations show BCD improves network efficiency and QoS for critical applications like emergency care and remote diagnostics. Compatible with LTE-A standards, it provides a practical solution for mobile healthcare, highlighting the need for smart bandwidth allocation to ensure reliable, high-speed medical data transmission.

In (Imen Ben Chaabane et al., 2015), a component carrier selection strategy reduces handovers and balances network load, increasing successful handovers by ~10%. The study highlights the importance of load balancing in LTE-A networks to improve user experience. Future research could explore adaptive handover algorithms for seamless connectivity in high-speed environments.

Authors (Iskandar and R. Galih, 2015) explore throughput optimization in LTE-A networks using different carrier aggregation (CA) configurations. Simulations show non-contiguous CA delivers better throughput, especially on lower frequency bands, due to stronger signal strength and range. The study finds it more effective under specific frequency conditions, offering a promising strategy for LTE-A networks and aiding operators in maximizing throughput and resource efficiency.

The paper (Desiana Ginting et al., 2015) addresses inter-cell interference in LTE-Advanced networks by combining carrier aggregation (CA) with Coordinated Multipoint (CoMP) to reduce edge interference. Simulations show improved Signal-to-Interference-plus-Noise Ratio (SINR) at cell boundaries. The results highlight the potential of CA-CoMP integration to enhance LTE-A performance and user experience. Future research may optimize their interaction for better interference management.

## III. METHODOLOGY

*3.1 Software Used*

- Name: NetSim
- Developer: Tetcos
- Version: 13.3
- Edition: Academic Edition

*3.2 Technologies Used*

- LTE (Long Term Evolution) and LTE-Advanced
- Carrier Aggregation schemes:
  - Intra-band Contiguous
  - Intra-band Non-Contiguous
  - Inter-band Non-Contiguous

*3.3 Network Topology*

The network topology is designed to model real-world healthcare environments, consisting of 16 nodes (figure 3), including User Equipment (UE), eNodeBs (eNB), Layer 2 switches, and wired nodes. The simulation setup includes:

- User Equipment (UE): Six UE devices (UE_5 to UE_15) representing medical IoT devices such as patient monitoring systems, wearable sensors etc. These devices are distributed into two clusters connected to different eNBs, simulating a healthcare scenario.
- eNodeBs (eNB): Two eNBs (eNB_1 and eNB_2) link UEs to the core network, representing distinct access points for critical healthcare data transmission. This setup models real-time patient monitoring.

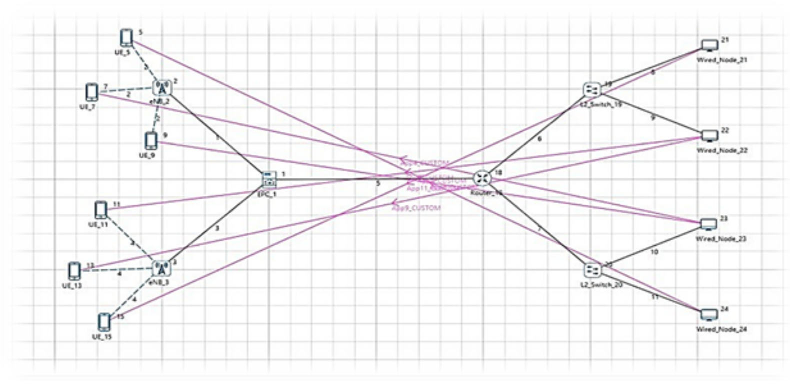


Fig. 3: Network Design (Source: Author's Compilation)

Table-1 Components Used Network Simulator with specifications

| Component Type | Details / Specifications |
|---|---|
| Simulation Software | NetSim (Version 13.3, Academic Edition) |
| eNodeBs (Base Stations) | 2 units (eNB_1 and eNB_2), support CA with multiple carriers |
| User Equipment (UE) | 6 units (UE_5 to UE_15), support dynamic carrier switching |
| Switches | Layer 2 switches for internal connectivity |
| Wired Nodes | Backhaul network simulation |
| Primary Carrier | Carries control and primary data |
| Secondary Carrier(s) | Used for added data throughput |
| Carrier Bandwidths | 10 MHz and 20 MHz per carrier (configurable as 2x20 MHz, etc.) |
| Frequency Bands Used | 700 MHz (low band), 1800 MHz (mid band) |
| Modulation Schemes | 64-QAM, 256-QAM (for higher throughput) |
| Power Levels Tested | 30 dBm (high power), -30 dBm (low power) |
| Channel Models | Urban, Rural, Indoor (Path loss and fading conditions) |
| Fading Models | Rayleigh, Rician fading |
| Core Network | Evolved Packet Core (EPC) for authentication, handovers, routing |

Table-2 Simulation Parameters

| *Parameter* | *Value / Setting* |
|---|---|
| ***Simulation Time*** | 10–30 minutes (per scenario) |
| ***Number of UEs*** | 10 to 100 (to simulate different loads) |
| ***Channel Bandwidth*** | 10 MHz (per carrier) |
| ***Power Levels Tested*** | 30 dBm vs -30 dBm |
| ***Carrier Types*** | Single band, Inter-band, Intra-band (contiguous & non-contiguous) |
| ***Traffic Type*** | FTP, VoIP, Video Streaming, HTTP |
| ***CA Modes Tested*** | Intra-Band Contiguous, Intra-Band Non-Contiguous, Inter-Band |

*3.4 Performance Metrics and Key Indicators*

To understand the performance of CA for healthcare networks, several standard metrics can be measured for its performance efficiency. Out of these, the following sections discuss and demonstrate the metric 'Throughput' in relation to Carrier Aggregation.

- ***Throughput:*** It gives the data rate for uplink and downlink and determines whether bandwidth-intensive applications like remote surgery, medical imaging (MRI/CT scans), and high-definition video consultations can be used without session failure.
- ***Latency:*** Measures packet round trip time from UE to eNB, which is very important for real-time services like robotic surgery, ambulance telemetry etc.
- ***Signal Quality:*** Checks Signal-to-Noise Ratio (SNR) and Signal-to-Interference-plus-Noise Ratio (SINR) for stable and interference-free communication.
- ***Handover Success Rate:*** Examines the success rate of handovers between eNBs, which is critical for mobile healthcare applications such as patient monitoring in ambulances in motion, remote healthcare units, and wearable device mobility within hospitals.

## IV. METHODOLOGY

*Evaluates intra-band contiguous and non-contiguous Carrier Aggregation*

Table-3 Throughput Analysis for intra-band contiguous and non-contiguous

| Sr No. | Channel Bandwidth 1 (MHz) | Channel Bandwidth 2 (MHz) | Channel Bandwidth 2 (MHz) | Source ID | Destination ID | Throughput for Intra Band Contiguous | Throughput for Intra Band Non-Contiguous |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 10 | 10 | 24 | 5 | 50.827 | 33.000 |
| 2 | 10 | 10 | 10 | 23 | 11 | 0.057 | 33.000 |
| 3 | 10 | 10 | 10 | 22 | 7 | 50.826 | 33.000 |
| 4 | 10 | 10 | 10 | 24 | 14 | 33.914 | 35.441 |
| 5 | 10 | 10 | 10 | 21 | 4 | 33.916 | 33.290 |
| 6 | 10 | 10 | 10 | 23 | 11 | 33.918 | 35.772 |

Contiguous CA demonstrates high peak throughput (table-3), reaching up to 50.827 Mbps, but also suffers from significant fluctuations, with drops as low as 0.057 Mbps. While beneficial for high- bandwidth applications like remote surgery and AI-assisted diagnostics, its instability under varying conditions makes it less reliable for critical healthcare scenarios. Non-contiguous CA offers more stable throughput, ranging between 33.000 Mbps and 35.772 Mbps, making it ideal for continuous and reliable healthcare connectivity. Its consistent performance benefits telemedicine, ICU monitoring, and real-time patient telemetry, ensuring uninterrupted data flow for medical applications.

While contiguous CA offers high peak performance, its instability limits real-time healthcare use. Non-contiguous CA, though slower, provides stable connectivity ideal for monitoring and emergencies. A dynamic hybrid CA model could optimize 5G healthcare based on real-time needs. The study shows CA significantly benefits healthcare—contiguous CA suits high-speed imaging, while non-contiguous CA ensures reliable communication. Adaptive CA strategies are crucial for advancing IoT-based healthcare and real-time data transmission.

Table 4: Throughput Analysis for Inter Band and Single Band

| Sr No. | Total Channel Bandwidth (MHz) | Source ID | Destination ID | Throughput for Inter Band | Throughput for Single Band |
|---|---|---|---|---|---|
| 1 | 10 | 24 | 5 | 10.877 | 11.328 |
| 2 | 10 | 23 | 11 | 10.877 | 11.328 |
| 3 | 10 | 22 | 7 | 10.881 | 10.473 |
| 4 | 10 | 21 | 14 | 10.927 | 12.115 |
| 5 | 10 | 21 | 4 | 10.927 | 10.464 |
| 6 | 10 | 23 | 11 | 11.079 | 12.115 |

The throughput for the inter band setup remains stable (table-4), ranging from 10.877 Mbps to 11.079 Mbps, with minimal variation across different source-destination pairs. This indicates a consistent performance with reliable data transmission. Throughput in the single band setup fluctuates slightly more, ranging from 10.464 Mbps to 12.115 Mbps. While it achieves a higher peak throughput than inter band, the variation suggests sensitivity to different source-destination conditions.

- Higher Maximum Throughput: The single band setup reaches 12.115 Mbps, surpassing the 11.079 Mbps maximum in inter band.
- Consistency: Inter band shows less variation, ensuring more reliable performance across different conditions.
- Inter Band: More stable and reliable for applications requiring uniform throughput.
- Single Band: Offers slightly higher peak speeds but with greater variation, making it more suitable for scenarios where maximum throughput is prioritized over stability.

Table-5: Throughput Analysis at 30 dBm and -30 dBm

| Sr No. | Channel Bandwidth 1 (MHz) | Source ID | Destination ID | Throughput at 30 dBm | Throughput at -30 dBm |
|---|---|---|---|---|---|
| 1 | 10 | 21 | 4 | 11.328 | 0.981 |
| 2 | 10 | 21 | 6 | 11.328 | 0.055 |
| 3 | 10 | 22 | 7 | 10.473 | 2.898 |
| 4 | 10 | 22 | 9 | 12.115 | 0.555 |
| 5 | 10 | 23 | 11 | 10.464 | 0.478 |
| 6 | 10 | 23 | 13 | 12.115 | 0.576 |

The throughput analysis (table-5) at different power levels reveals significant variations in performance. At 30 dBm, throughput values remain high and stable, ranging from 10.464 Mbps to 12.115 Mbps, regardless of the source-destination pair. This consistency suggests that higher power levels enable maximum throughput with minimal fluctuations, making it suitable for applications requiring reliable, high-speed data transfer. In contrast, at -30 dBm, throughput varies significantly, ranging from as low as 0.055 Mbps to a peak of 2.898 Mbps. This wide variation indicates that lower power levels introduce greater sensitivity to environmental factors, such as interference and distance, leading to inconsistent performance. The comparison between the two power levels highlights the strong dependency of throughput on transmission power.
While 30 dBm ensures steady and efficient data flow, -30 dBm results in a drastic reduction in throughput and increased instability. Even the maximum throughput at -30 dBm (2.898 Mbps) is significantly lower than the minimum throughput at 30 dBm (10.464 Mbps), demonstrating the major performance gap. Ultimately, the findings suggest that higher power transmission (30 dBm) is optimal for maintaining consistent and high-speed connectivity, whereas lower power (- 30 dBm) is only suitable for low-data-rate applications where energy efficiency is a priority.

Carrier Aggregation (CA) is essential for 5G, enhancing bandwidth, data rates, and coverage. In healthcare, it supports high-quality video consultations, remote surgeries, and improves diagnostic accuracy. CA boosts data transfer for IoMT devices, enabling real-time monitoring and timely intervention. It ensures low-latency for devices like heart rate monitors and speeds up transmission of large files like MRI scans. CA also powers AR/VR tools in surgical training and rehabilitation through stable, high-speed connections. Overall, CA enables faster, more reliable healthcare services, improving outcomes and efficiency.

## V. Conclusion

Throughput analysis highlights the role of power levels and band selection in optimizing wireless network performance. High-power configurations (30dBm) provide stable, high throughput, ideal for telemedicine, remote diagnostics, and real-time monitoring. Low-power configurations (-30 dBm) lower throughput but improve energy efficiency, crucial for battery-powered medical devices and IoT healthcare systems. Reliable wireless communication is vital for devices like wearable sensors and cloud diagnostics. High-throughput networks are needed for applications such as medical imaging, robotic surgeries, and emergency teleconsultations, where data delays are critical. Low-power setups ensure long operational life for devices like glucose meters and ECG sensors. Optimizing network settings for throughput, stability, and energy use enhances patient outcomes with better monitoring, faster diagnoses, and improved telemedicine services.

## REFERENCES


[1] Zhang, Y., Huang, A., Wang, D., Duan, X., Jiao, B., & Xie, L. (2013). To enable stable medical image and video transmission in mobile healthcare services: A Best-fit Carrier Dial-up (BCD) algorithm for GBR-oriented applications in LTE-A networks. IEEE ICC 2013 - Selected Areas in Communications Symposium, 4368-4372. https://doi.org/10.1109/ICC.2013.6655310

[2] Ben Chaabane, Imen, Hamouda, Soumaya, and Tabbane, Sami. "Enhanced Component Carrier Selection Strategy for LTE-A Under Carrier Aggregation Mode." Proceedings of the 2015 International Conference on Wireless Communications and Signal Processing (WCSP), 2015, pp. 1-6.

[3] Iskandar, and R. Galih. "Throughput Evaluation in LTE-Advanced Network Access Using Carrier Aggregation." Proceedings of the 2015 International Conference on Communications and Electronics (ICCE), 2015, pp. 165-170.

[4] Ginting, Desiana, Fahmi, Arfianto, and Kurniawan, Adit. "Performance Evaluation of Inter-cell Interference Using Carrier Aggregation and CoMP Techniques." Proceedings of the 2015 IEEE International Conference on Communication Systems (ICCS), 2015, pp. 149-154.

[5] Adamu, Paul Ushiki, and López-Benítez, Miguel. "Analysis of Carrier Aggregation as a Diversity Technique for Improved Spectral Efficiency and Secrecy Performance in Mobile Communications." Journal of Communications and Networks, vol. 26, no. 3, 2024, pp. 230-241.

[6] Sani, Ahmad Shahrizal, Razak, Nur Idora Abdul, and Sarnin, Suzi Seroja. "Measurement Study on Carrier Aggregation Implementation in LTE-Advanced Network." Proceeding of the 2020 IEEE 5th International Symposium on Telecommunication Technologies (ISTT), 2020, pp. 129-132.https://doi.org/10.1109/ISTT49018.2020.9339917:contentReference[oaicite:0]{index=0}.

[7] Ludant, Norbert, Bui, Nicola, García Armada, Ana, and Widmer, Joerg. "Data-Driven Performance Evaluation of Carrier Aggregation in LTE-Advanced." Proceedings of the 2017 IEEE 17th International Symposium on Communications and Information Technologies (ISCIT), 2017, pp. 342-347. https://doi.org/10.1109/ISCIT.2017.8297866:contentReference[oaicite:1]{index=1}.

[8] Joda, Roghayeh, Elsayed, Medhat, Abou-Zeid, Hatem, Atawia, Ramy, Sediq, Akram Bin, Boudreau, Gary, and Erol-Kantarci, Melike. "Carrier Aggregation with Optimized UE Power Consumption in 5G." IEEE Networking Letters, vol. 3, no. 2, 2021, pp. 61-64. https://doi.org/10.1109/LNET.2021.3076409:contentReference[oaicite:2]{index=2}.

[9] For Figure 1: 3GPP. *Figure 1: Carrier Aggregation (FDD)*. 3GPP, 2013, https://www.3gpp.org/technologies/101-carrier-aggregation-explained

[10] For Figure 2: 3GPP. *Figure 2: Carrier Aggregation; Intra-band and inter-band aggregation alternatives*. 3GPP, 2013, https://www.3gpp.org/technologies/101-carrier-aggregation-explained