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Evaluating the Impact of Carrier Aggregation on LTE Performance in Zambian Urban

Tionge Lewis Phiri[1], Kondwani Simukonda[1], Terence Malama[2]

[1]School of Engineering, The University of Zambia, Lusaka, Zambia
[2]Technonlogy Advisory and Development Unit (TDAU), The University of Zambia, Lusaka, Zambia
Email: teltzap1@gmail.com, terencemalama@gmail.com

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Abstract

Carrier Aggregation (CA) is pivotal for enhancing LTE network performance in urban environments. This research investigated the practical impact of 2CA inter-band contiguous CA, combining 20 MHz and 10 MHz component carriers (CCs), on LTE networks in urban Zambia, focusing on downlink (DL) throughput and Physical Resource Block (PRB) utilization. While theoretical peak DL throughput for Category 6 User Equipment (UE) was 300 Mbps, this study examined real-world deviations and challenges faced by Mobile Network Operators (MNOs). Employing a mixed-methods approach, including drive and stationary tests, and analysis of network Key Performance Indicators (KPIs), the study assessed network performance before and after CA activation. Key challenges identified were spectrum availability and high spectrum auction costs. However, empirical data revealed significant end-user benefits. Peak user data rates reached 126.2 Mbps, a 129% increase over pre-CA conditions. Average throughput improved by 88%, from 36.17 Mbps to 68.14 Mbps. Additionally, PRB utilization decreased from 44.30% to 41.40%, indicating enhanced network efficiency. The findings confirm CA's crucial role in optimizing LTE performance and meeting escalating urban data demands. This research provides valuable insights into CA deployment, highlighting its contribution to network advancement and improved user satisfaction, demonstrating that CA is a viable solution for enhancing LTE networks in densely populated areas.

Keywords

Carrier Aggregation (CA), Component Carriers (CC), Downlink (DL) Throughput, Inter-Band Contiguous, Long Term Evolution (LTE), Mobile Network Operator (MNO), Physical Resource Block (PRB), User Equipment (UE)

1. Introduction

The rapid advancement of communication technologies and the widespread adoption of mobile applications have driven exponential growth in mobile data consumption [1]. To accommodate this surge, Fourth Generation-Long Term Evolution (4G-LTE) networks were developed, offering enhanced capacity, higher throughput, and lower latency through packet-switched services [2]-[4]. LTE Release 8 introduced key technologies to improve spectrum utilization and increase data rates [5]-[8]. However, as mobile broadband traffic continues to rise—particularly in regions like Zambia, where data consumption grew by nearly 48.9% in the first half of 2022 [9]—further enhancements are required. In urban areas, high population densities and data-intensive applications contribute to increased LTE traffic and network congestion [10]. **Figure 1** illustrates the relationship between data volume, user throughput, and PRB utilization, highlighting performance constraints at high PRB utilization levels.

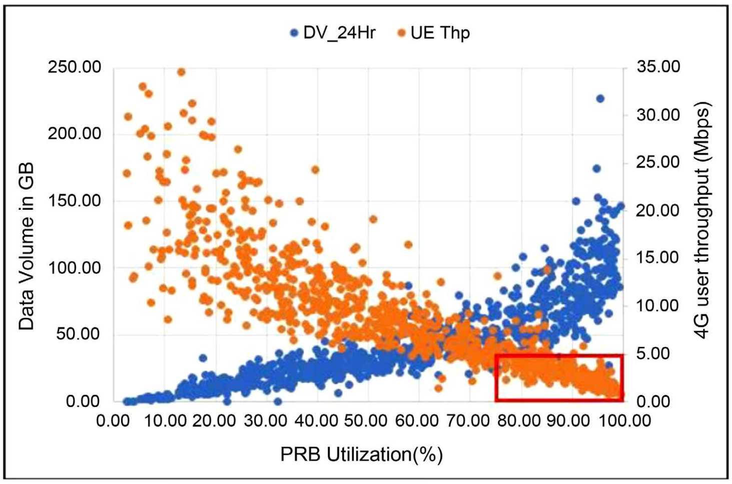

Figure 1. Relationship of data volume, user throughput and PRB utilization [11].

To address these challenges, Carrier Aggregation (CA) was introduced in LTE Release 10, enhancing network capacity and throughput [12]-[16]. By combining multiple spectrum bands into wider channels, CA enables higher data rates and improved coverage. Studies conducted in South Korea have demonstrated significant improvements in user data rates following CA deployment [11]. However, its specific impact on LTE performance in Zambian urban areas remains largely unexplored. This study aims to assess the impact of CA on LTE networks in Chelstone, Lusaka, focusing on Operator X's network.

The growing number of mobile devices and increasing data demand in Zambia are placing immense pressure on existing LTE networks [11]. While 5G deployment is underway, LTE and its advancements, including LTE-Advanced (LTE-A), remain vital. This research seeks to explore how technologies like CA can enhance LTE performance in urban Zambia, where network capacity and user experience are critical concerns.

The study aimed at:

i) Identifying the challenges faced by Mobile Network Operators (MNOs) in implementing CA.

ii) Determining the effect of CA on network capacity and throughput.

iii) Evaluating the performance improvements achieved through CA in LTE-A networks.

The findings of this research will provide valuable insights for LTE network planning and optimization in Zambia. By understanding CA's effectiveness, network operators can enhance capacity, mitigate congestion, and improve user experience. Additionally, this study will guide MNOs in leveraging CA for optimal spectrum utilization and better service provision.

2. Literature Review

Cellular mobile communication systems have evolved through several generations: 1G analog, 2G digital, 3G broadband, 4G-LTE (or 3.9G in some publications), and the currently developing 5G [17]. LTE, like electricity, has become a necessity in modern society, representing an evolutionary step beyond 3G. It offers flexible deployment options and service offerings [18]. LTE utilizes an all-IP-based architecture, where mobile devices communicate via IP addresses. **Figure 2** illustrates the LTE network architecture [18].

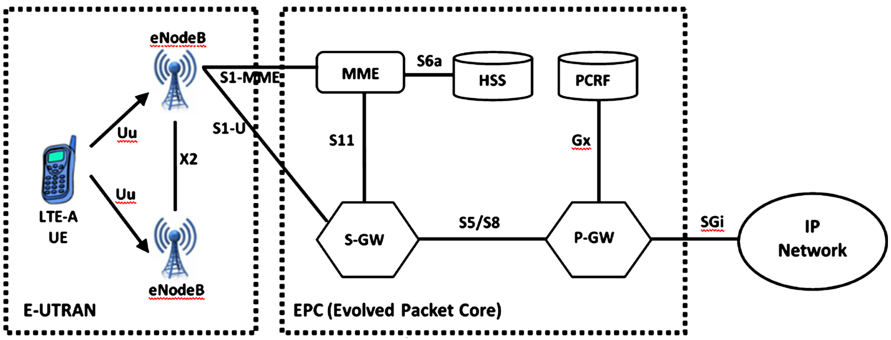

Figure 2. LTE network architecture [11].

LTE-Advanced (LTE-A), introduced in LTE Release 10, aimed to meet the International Mobile Telecommunications Advanced (IMT-Advanced) requirements by enhancing LTE with features like OFDMA/SC-FDMA, 20 MHz bandwidth support, MIMO, and advanced modulation, while maintaining backward compatibility [13] [16]. A key feature of LTE-A is Carrier Aggregation (CA), which increases bandwidth by aggregating multiple Component Carriers (CCs). CA enhances data rates, improves downlink coverage, and allows operators to utilize fragmented spectrum effectively. Multiple LTE carriers, each up to 20 MHz, can be transmitted in parallel, enabling wider bandwidths and higher data rates.

There are three modes of CA, allowing operators to exploit fragmented spectrum allocations. CCs do not need to be contiguous in frequency, and up to five CCs, possibly of different bandwidths up to 20 MHz, can be aggregated, resulting in overall transmission bandwidths up to 100 MHz. Terminals supporting CA can simultaneously receive or transmit on multiple CCs, which are backward compatible with earlier LTE releases. Figure 3 depicts the different modes of CA [19]-[21].

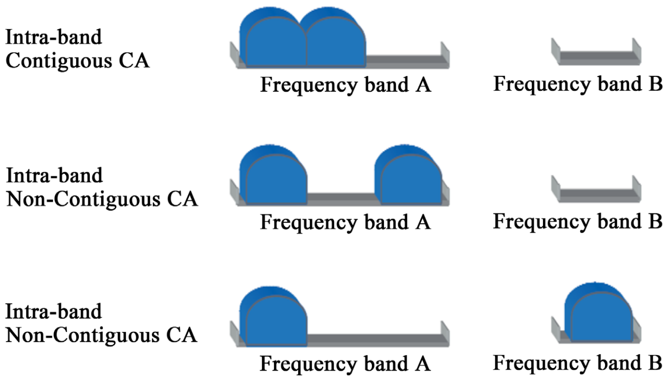

Figure 3. Different types of carrier aggregation [11].

A literature comparison matrix, as shown in Table 1, provides a structured comparison of multiple research studies. It includes authors, publication dates, research questions, methodologies, findings, and conclusions. This matrix helps identify patterns, contradictions, knowledge gaps, and trends within the research area, facilitating the synthesis of existing literature and informing future research directions.

Table 1. Literature comparison matrix.

Authors & Year	Aim of the Study	Method Used	Major Findings	Identified Gaps
Archana, B. (2015)	Investigated the evolution of communication systems	Extensive literature review	Identified methods, challenges, and future scope of resource allocation in LTE	Limited focus on practical deployment challenges
Cox, C. (2012)	Studied the Evolved Packet System (EPS) and multiple access schemes in LTE	Comprehensive technical review	Explained Evolved Packet System (EPS), Frequency Division Duplex (FDD), Time Division Duplex (TDD), Orthogonal Frequency Division Multiple Access (OFDMA) for downlink, and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink	Lack of empirical data on the performance of EPS in diverse environments
Dahlman, E., Parkvall, S., & Skold, J. (2013)	Delved into LTE technologies such as Massive Input Massive Output (MIMO)	Technical exploration and analysis of LTE	Provided insights into MIMO technology in LTE	Needs more exploration into integration challenges and MIMO scalability
Jeanette, W. (2013)	Studied the basics of Carrier Aggregation (CA)	Review of CA concepts and examples	Explained CA fundamentals, types of CA, and possible band combinations	Insufficient analysis of CA impact on other network KPIs like latency
Lee, S. *et al.* (2017)	Investigated the impact of CA on commercial networks in South Korea	Measurement study on commercial LTE-Advanced networks	Demonstrated significant benefits of CA in commercial LTE networks	Limited focus on CA performance in different geographic regions and conditions
Tanner, A. (2016)	Examined key performance indicators (KPIs) for CA	Technical measurements and performance analysis	Identified KPIs, analyzed 2CC measurements, and linked CA to physical throughput	Lack of studies to assess long-term impacts of CA on network

3. Methodology

To address the research objectives, this study adopted a mixed-methods approach, integrating both quantitative and qualitative data collection and analysis to assess LTE performance and the impact of CA in urban Zambia.

Quantitative data was collected through drive tests, stationary tests, and statistical data from Operator X's network sites in the Chelstone area. The drive tests followed a predefined route encompassing diverse terrain types—residential, commercial, and open spaces. Tests were conducted between 11:00 and 14:00 hours to ensure consistency in network conditions. During the tests, a 5 GB file was downloaded with CA initially disabled, while key performance indicators (KPIs) such as RSRP, SINR, and throughput were recorded using diagnostic tools. GPS logging was used to correlate network performance with specific geographic locations. After completing the first test, CA was enabled and verified, and the same route was driven again for a 30-minute period to allow accurate before-and-after comparisons. All test logs and screenshots were backed up for analysis.

Stationary tests involved downloading a 1 GB file at two fixed points within Chelstone—one near a cell tower and another in an indoor environment—to reflect different network conditions. As with the drive tests, these were conducted with CA both disabled and enabled, using a Xiaomi Note 4 smartphone (a CA-capable Category 6 UE) to ensure consistent device capability.

Qualitative data was gathered through stakeholder interviews and structured questionnaires. A modified Delphi approach was employed to gather expert insights on the deployment and performance of Carrier Aggregation in LTE networks [22]. Although only a single round of structured questionnaires and interviews was conducted, the method retained key Delphi principles such as expert selection, anonymity, and systematic data collection. This approach enabled the inclusion of informed perspectives from industry professionals, providing qualitative depth to complement the quantitative analysis. Participants were selected based on two criteria: i) at least five years of experience in the telecommunications sector, and ii) direct involvement in projects related to LTE and CA deployment. This strict selection criterion limited the pool to nine qualified personnel across three MNOs at the time of the study, representing a notable constraint. Completed questionnaires were reviewed, coded, and analyzed using Google Docs and Excel.

Challenges faced by MNOs in deploying CA were identified through questionnaires, interviews, and a literature review. Additionally, empirical data from Operator X's network before and after CA activation were analyzed using testing tools and software to evaluate performance changes. The quantitative design was appropriate due to the study's reliance on measurable variables and statistical data [20].

The combined use of quantitative and qualitative methods was justified for the following reasons: i) the first objective did not require complex numerical analysis; ii) the research design was structured and naturally applicable; iii) the methodological procedures were value-free, minimizing researcher bias; and iv) the research utilized statistical data analysis.

Figure 4 illustrates the research process.

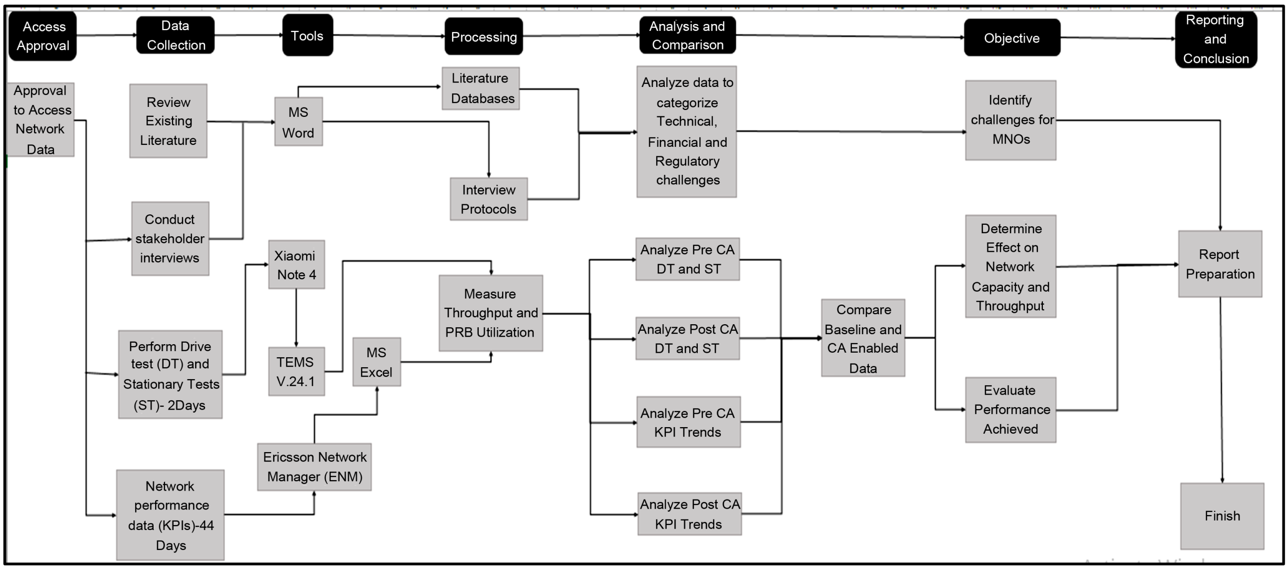

Figure 4. Research outline.

The sample size was calculated using Gogtay's guidelines [23] [24]. Specifically, the following equation was used:

$$n = \frac{2\left(Z_{1-\frac{\alpha}{2}} + Z_{1-\beta}\right)^2}{d^2}$$

where:

n = sample size

$Z_{1-\frac{\alpha}{2}}$ = Z-score corresponding to the desired significance level (α)

$Z_{1-\beta}$ = Z-score corresponding to the desired power ($1-\beta$)

d = effect size

Using this equation, with a 90% power (β = 0.10) and 5% significance level (α = 0.05), the calculated sample size was n = 44 days. Network KPI data were collected over 44 days (22 days pre-CA, 22 days post-CA), with daily analysis. Drive and stationary tests were conducted between 11:00 and 14:00 hours to maintain controlled conditions and avoid busy hours. Drive tests captured mobile network performance across Chelstone, while stationary tests assessed performance at selected locations. Both tests compared performance with and without CA.

The test location included drive test routes and stationary locations in Chelstone (see Figure 5), chosen for their CA-capable sites belonging to Operator X.

Measurements were conducted on Operator X's commercial network using TEMS V.24.1 Drive Test Software, a professional tool for outdoor and indoor measurements. Logs were analyzed using TEMS Investigation software. Pre- and post-CA KPIs were collected over 44 days for comparison. Logs were also collected from the Ericsson Network Manager (ENM) and analyzed in Microsoft Excel. The Xiaomi Note 4, a CA-capable Category 6 UE, was used for testing.

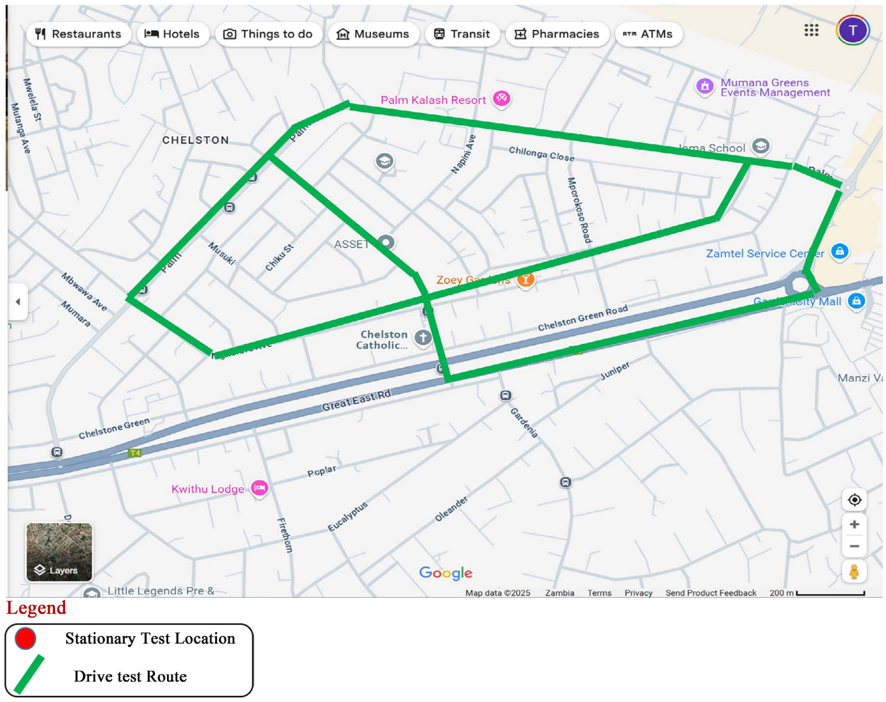

Figure 5. Drive routes and stationary locations where tests were conducted.

To address the first research question, questionnaires were distributed to qualified personnel from three MNOs, with criteria ensuring respondents had substantial telecommunications experience and involvement in CA deployment. Human Resource departments verified respondent qualifications. Participants received introductory letters and were assured anonymity. The questionnaire, consisting of 45 multiple-choice questions across four sections (Technical, Finance, Legal/Regulatory, and General), was analyzed using percentages and Google Docs.

For the other research questions, CA RF KPI measurements were conducted in Chelstone. Drive tests covered diverse terrains, with data collected using testing tools while downloading a 5GB file with CA disabled and enabled. Data included LTE signal strength (RSRP), SINR, and throughput. Stationary tests involved downloading a 1 GB file at two locations, with tests conducted at similar times as drive tests, with CA disabled and enabled. OSS KPIs were downloaded from the ENM server for pre- and post-CA comparisons over 22 days.

Limitations of the study included: i) a small pool of interview respondents, mitigated by cross-verification with multiple data sources; ii) lack of calibration verification for tools and software, mitigated by using internationally calibrated and ZICTA-approved tools; and iii) single urban location, chosen for better control over confounding variables.

4. Results

4.1. Response Rate

Nine questionnaires were distributed to staff members from X, Y, and Z, with a target acquisition of 4, 3, and 2 respectively. Six questionnaires were completed and returned, representing a 67% response rate. Table 2 shows the response rate per MNO. Three questionnaires were not returned.

Table 2. Response rate.

MNO	Target Acquired	Response	Percentage %
X	4	3	75%
Y	2	1	50%
Z	3	2	67%
Total	**9**	**6**	**67%**

The questionnaires revealed that MNOs require LTE spectrum or different LTE band combinations to implement CA. All MNOs confirmed CA activation on their networks. Figure 6 summarizes the most prevalent challenges identified by MNOs, categorized by technical, financial, and legal domains.

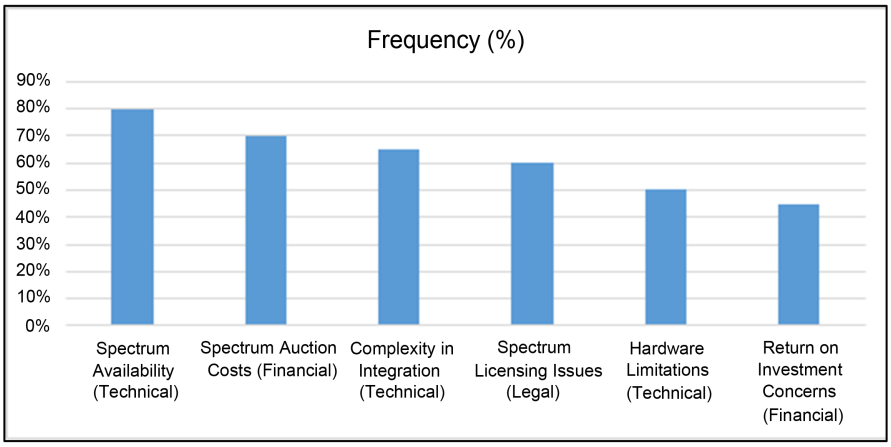

Figure 6. Challenges identified by MNOs.

4.2. Operator X System Configuration

Table 3 shows Operator X's LTE operational spectrum, and Table 4 shows the bands and CA types achievable with the configuration.

Table 3. Operator X LTE operational spectrum.

Spectrum	Band	Bandwidth	Spectrum type
800 MHz	B20	20 MHz	Contiguous
1800 MHz	B3	10 MHz	Contiguous
2600 MHz	B41	60 MHz	Contiguous

Table 4. Operator X bands and the types of carrier aggregation.

Combination	Primary Band (MHz)	Secondary Band (s) (MHz)	Total Bandwidth (MHz)	Type of CA	Bands Combination
800 MHz + 1800 MHz	800 MHz (20 MHz)	1800 MHz (10 MHz)	30 MHz	2CA (Inter-band)	B20 + B3
800 MHz + 2600 MHz	800 MHz (20 MHz)	2600 MHz (20 MHz)	80 MHz	2CA (Inter-band)	B20 + B41
1800 MHz + 2600 MHz	1800 MHz (10 MHz)	2600 MHz (20 MHz)	70 MHz	2CA (Inter-band)	B3 + B41
800 MHz + 1800 MHz + 2600 MHz	800 MHz (20 MHz)	1800 MHz (10 MHz), 2600 MHz (20 MHz)	90 MHz	3CA (Inter-band)	B20 + B3 + B41
2600 MHz	2600 MHz (20 MHz)	2600 MHz (40 MHz)	60 MHz	3CA (Intra-band)	B41

4.3. Measurement Environment

The research tested contiguous 2CA (Inter-band) aggregation between B20 (20 MHz) and B3 (10 MHz). The theoretical DL peak data rate was 225 Mbps. Table 5 shows the measurement environment.

Table 5. Measurement environment.

LTE-A CA system deployed in Operator X Network	Parameter
Number of CCs	2
CC one, carrier frequency	1800 (3GPP Band 3)
CC one, BW (number of RBs)	10 MHz (50RBs)
CC one, antenna configuration	DL 2 × 2 MIMO, UL 1 × 2 Rx diversity
CC one, antenna gain	16 dBi HPBW being 65˚
CC one, cell transmit power	80W
CC two, carrier frequency	800 (3GPP Band 8)
CC two, BW (number of RBs)	20 MHz (100 RBs)
CC two, antenna configuration	DL 2 × 2 MIMO, UL 1 × 2 Rx diversity
CC two, antenna gain	16 dBi with HPBW 65˚
CC two, cell transmit power	40W
eNB average antenna height (m)	36m
eNB location	Band 3 and Band 8 eNBs are collocated
Drive test speed	30 km/h average
Area (Location)	**Urban (Chelstone, Lusaka, Zambia)**

Continued

Measurement area size distance (Km)	7.6
Number of sites in the measurement area	4
Average Intersite distance (m)	500

4.4. Measurement Results and Analysis

4.4.1. Carrier Aggregation

Figure 7 shows a print screen from TEMS V.24 Drive Test Software, demonstrating single carrier operation (left) and CA activation (right).

Figure 7. Carrier aggregation print screen.

4.4.2. DL_Throughput

Figure 8 and Figure 12 represent DL throughput at driven locations pre- and post-CA activation.

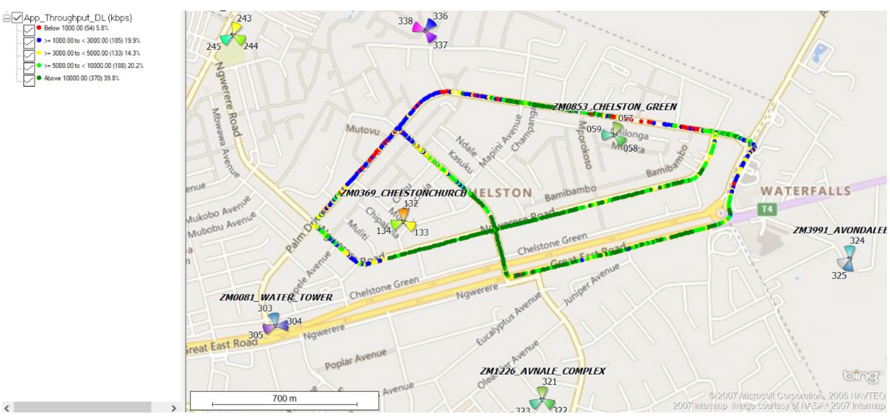

Figure 8. Non CA DL_throughput drive test plot.

1) Pre CA Activation

994 samples were collected. 45% of samples had throughputs > 5 Mbps. Table 6 shows the throughput distribution. Figure 9 and Figure 10 show stationary test results.

The wireless channel conditions measurement analyzed were Reference Signal Receive Power (RSRP) and Signal to Interference and Noise Ratio (SINR). Figure 11 and Figure 12 show the values recorded. Pre CA activations show good radio conditions resulting in good quality conditions.

2) Post CA Activation

930 samples were recorded. 60% of samples had throughputs > 5 Mbps. Figure 13 and Table 7 show the throughput distribution. Figure 14 and Figure 15 show stationary test results. Figure 16 shows trended daily throughput.

Table 6. Non CA DL_throughput drive test legend.

Description	Samples	Percentage %
Below 1 Mbps	95	10%
≥1 Mbps to <3 Mbps	236	24%
≥3 Mbps to <5 Mbps	216	22%
≥5 Mbps to <10 Mbps	263	26%
Above 10 Mbps	184	19%
Total	**994**	

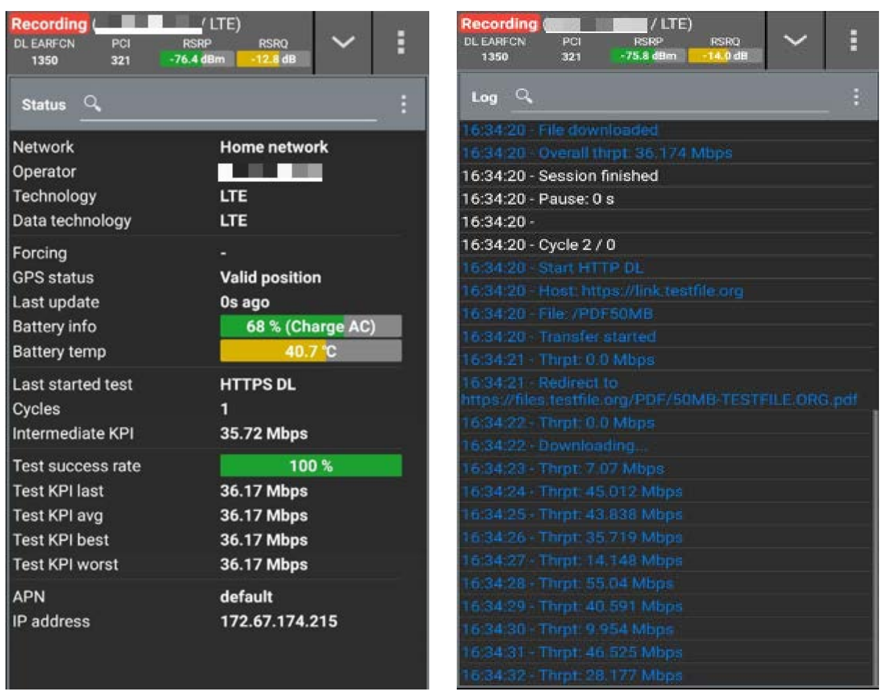

Figure 9. Non CA DL_throughput stationary tests chelstone catholic church.

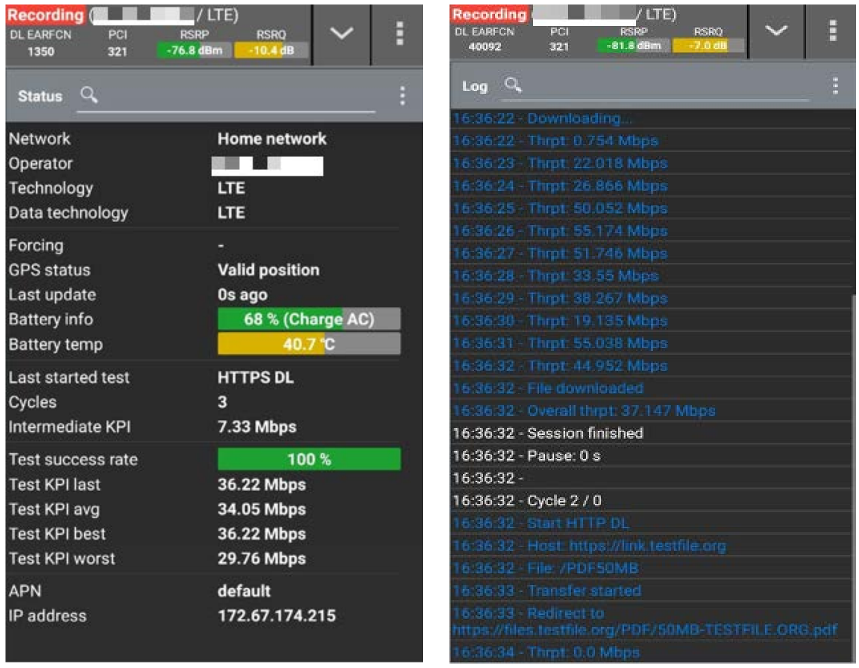

Figure 10. Non CA DL_throughput stationary tests chelstone market.

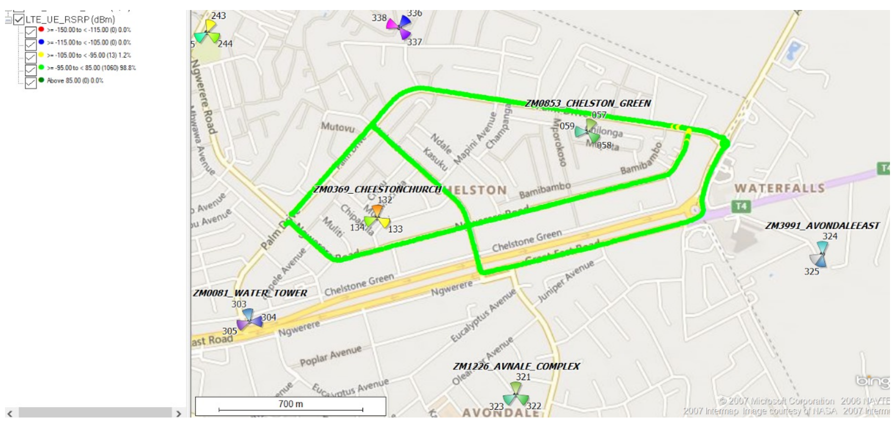

Figure 11. Non CA RSRP drive tests plot.

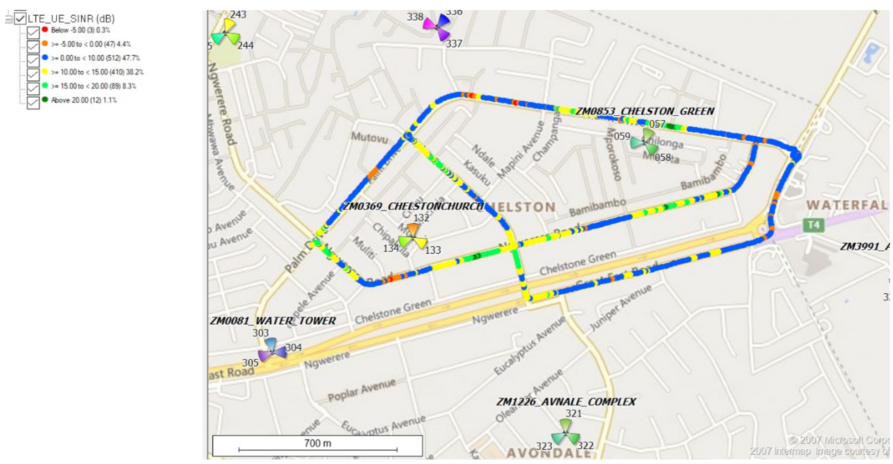

Figure 12. Non CA SINR drive tests plot.

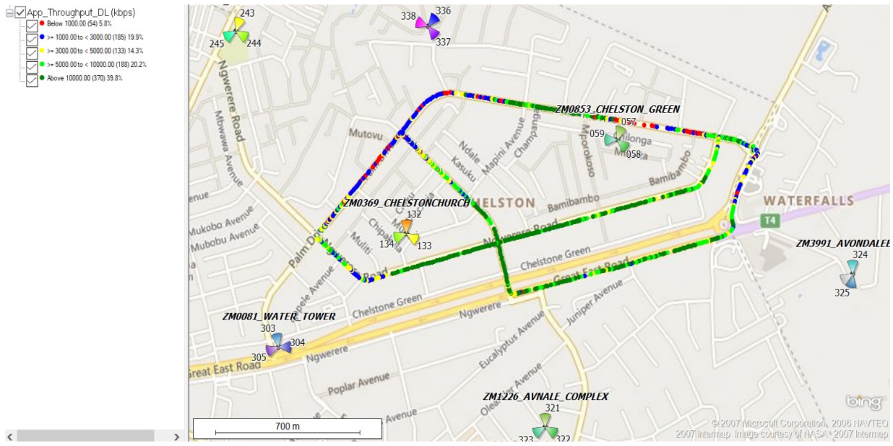

Figure 13. 2CA Inter-band DL_throughput drive tests plot.

Table 7. 2CA Inter-band DL_throughput drive test legend.

Description	Samples	Percentage %
Below 1 Mbps	54	6%
≥1 Mbps to <3 Mbps	185	20%
≥3 Mbps to <5 Mbps	133	14%
≥5 Mbps to <10 Mbps	188	20%
Above 10 Mbps	370	40%
Total	**930**	

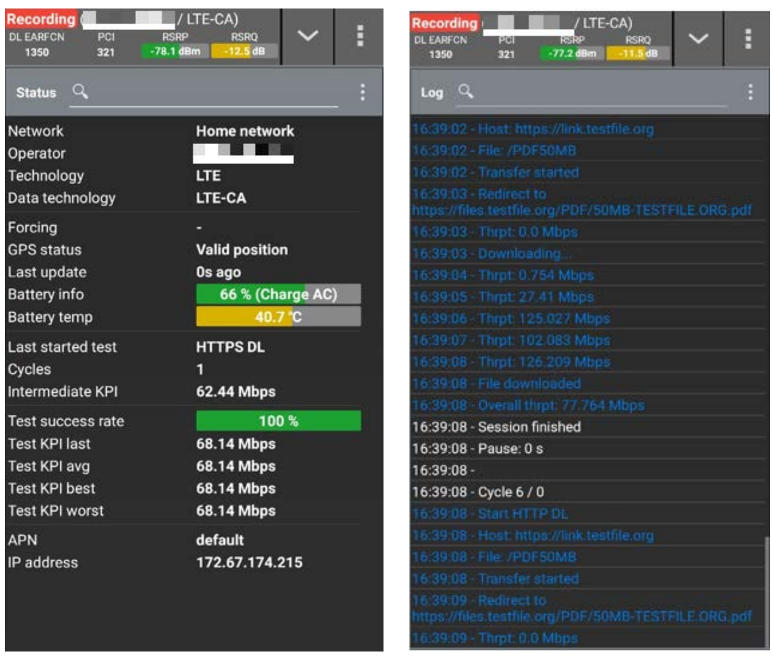

Figure 14. 2CA Inter-band DL_throughput stationary tests chelstone catholic church.

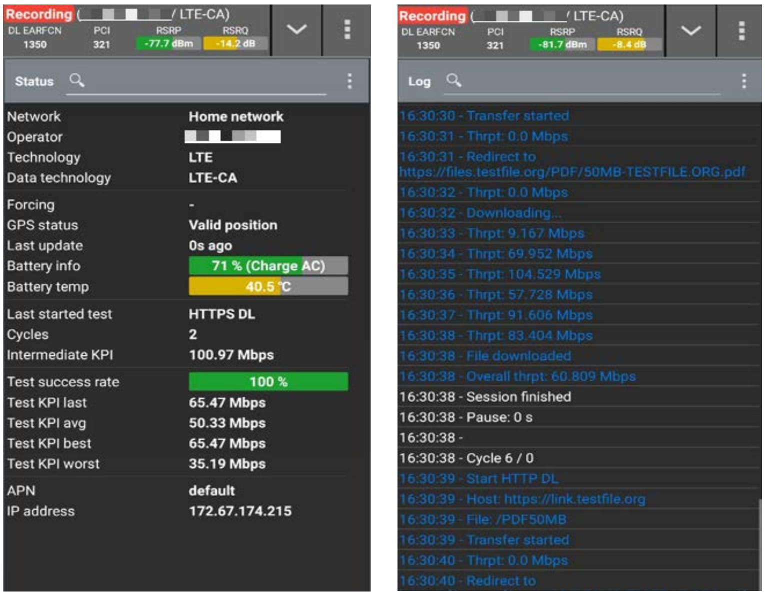

Figure 15. 2CA Inter-band DL_throughput stationary tests chelstone market.

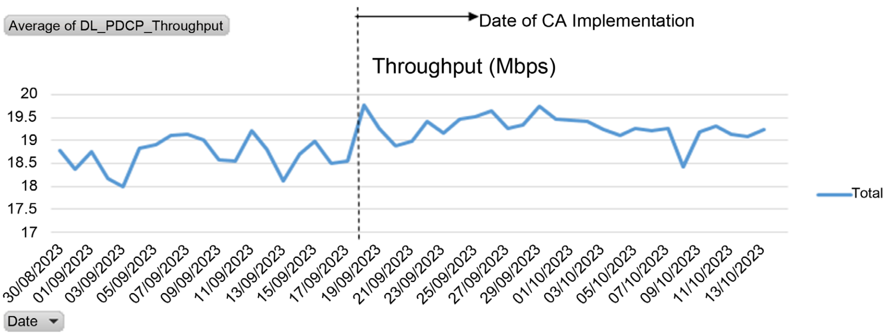

Figure 16. Trended DL_Throughput from OSS.

Figure 17 and **Figure 18** show Post CA activations show also show good radio conditions resulting in good quality conditions. No conclusive evidence can be attributed to the good signal received due to 2CC CA because the inter-site distance between Operator X sites in Chelstone is 500 m.

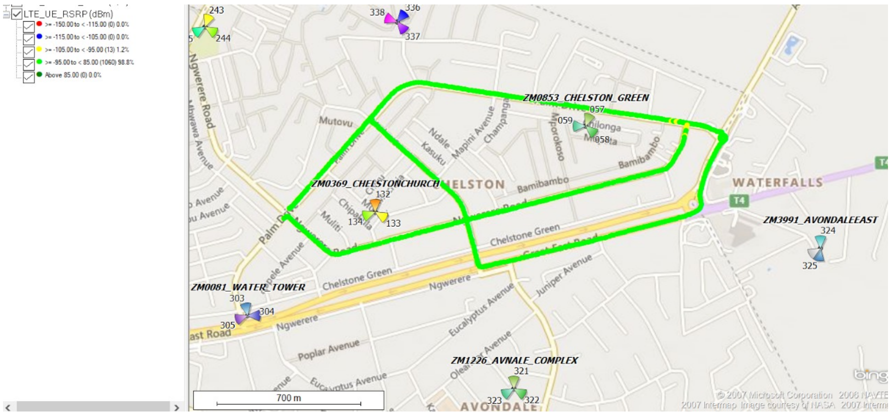

Figure 17. CA RSRP drive tests plot.

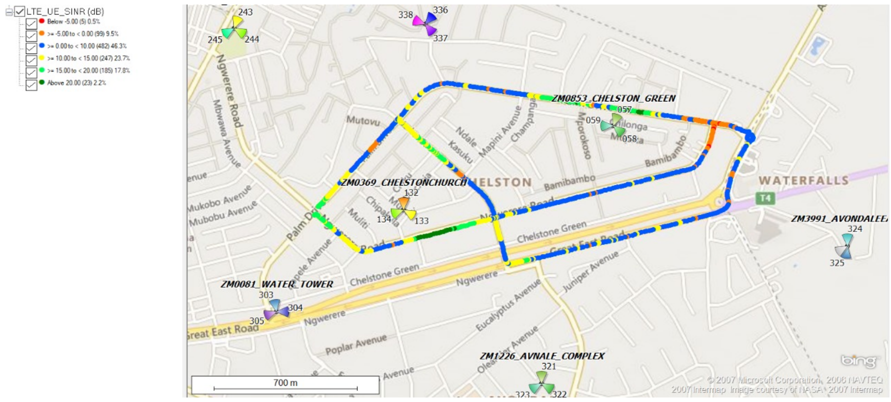

Figure 18. CA SINR drive tests plot.

4.4.3. PRB Usage Per TTI DL

CA resulted in a 6% reduction in PRB utilization. **Figure 19** shows DL PRB utilization.

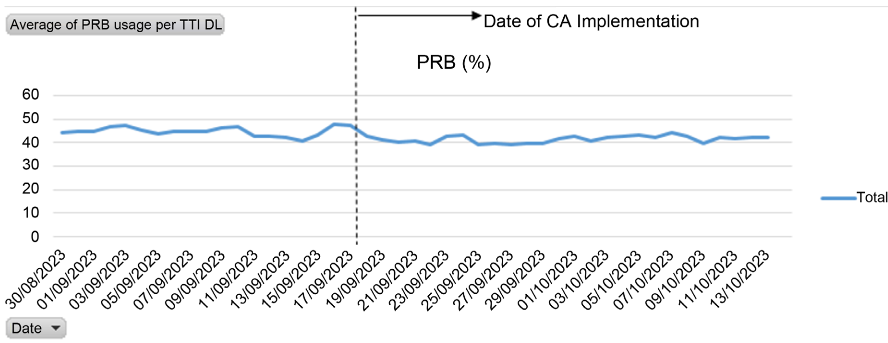

Figure 19. DL PRB utilization from OSS.

4.4.4. Coverage Parameters

DL BLER (%)

Figure 20 shows similar BLER values pre- and post-CA.

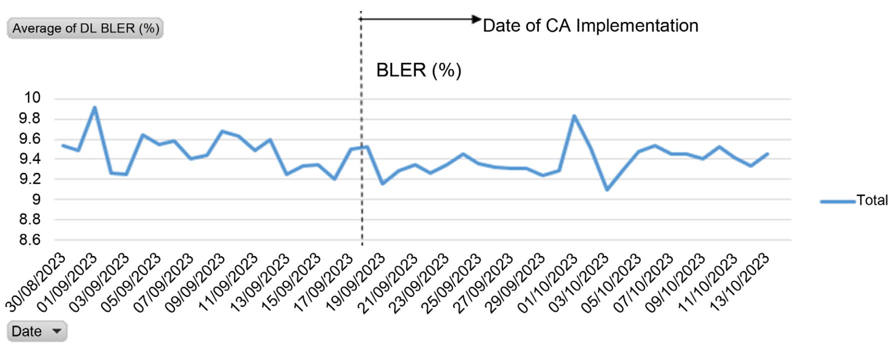

Figure 20. Trended DL BLER from OSS.

5. Discussion

5.1. MNO Challenges

The questionnaire responses revealed several critical challenges that hinder the deployment of CA in Zambia:

Spectrum Fragmentation: Many MNOs face difficulty aggregating carriers due to non-contiguous spectrum allocations. This technical limitation reduces the feasibility of implementing inter-band CA configurations, which are necessary for meaningful performance gains.

High Spectrum Auction Costs: Acquiring extra spectrum licenses for CA can be extremely costly for MNOs.

Technical Complexities: Integrating different frequency bands and technologies can be technically challenging, requiring significant upgrades to network infrastructure, devices and new skills training for engineers.

5.2. DL Throughput Comparison

The drive test results showed a 15% overall gain in throughput for speeds greater than 5 Mbps with 2CA inter-band compared to Non-CA. Notably, the "Above 10 Mbps" category exhibited a 21% increase in samples with 2CA inter-band, as detailed in Table 8. This significant improvement aligns with the expected benefits of CA, as it effectively increases the available bandwidth, allowing for higher data rates [13]-[15].

Table 8. Drive test comparison

Throughput Category	Non-CA (L1800)	%	2CA inter-band	%	Gain in % (2CA-Non-CA)
Below 1 Mbps	95	10%	54	6%	−4%
≥1 Mbps to <3 Mbps	236	24%	185	20%	−4%
≥3 Mbps to <5 Mbps	216	22%	133	14%	−8%
≥5 Mbps to <10 Mbps	263	26%	188	20%	−6%
Above 10 Mbps	184	19%	370	40%	21%
Total (Above 5 Mbps)	**447**	**45%**	**558**	**60%**	**15%**

In stationary tests, the 2CA inter-band configuration demonstrated substantial improvements in both average and peak throughput. The average throughput increased by approximately 88%, from 36.17 Mbps (Non-CA) to 68.14 Mbps (2CA inter-band). The peak throughput more than doubled, showing a 129% increase from 55.04 Mbps to 126.2 Mbps, as shown in Table 9. These results are consistent with findings from studies conducted in South Korea, which demonstrated significant user data rate enhancements through CA deployment [11]. This confirms that CA, when applied to commercial networks, dramatically improves the real user data rate.

5.3. Performance Evaluation

The performance evaluation, based on drive and stationary tests, indicated significant improvements after activating CA. The drive tests showed a 15% increase in samples with throughput greater than 5 Mbps and a 21% gain in samples with throughput above 10 Mbps. The stationary tests showed an 88% improvement in average throughput and a 129% increase in peak throughput. These findings underscore the effectiveness of CA in enhancing network capacity and user experience [13]-[16].

Table 9. Stationary test comparison

Configuration	Average Throughput (Mbps)	Peak Throughput (Mbps)
Non-CA	36.17	55.04
2CA Inter-band	68.14	126.2

Additionally, a 3% increase in daily average throughput and a 6% reduction in PRB utilization were observed in the OSS KPIs, indicating improved network efficiency. The stable BLER values, staying below 10%, reflect consistent wireless channel conditions, attributed to similar configurations and collocated antennas. The RSRP measurements indicated good radio conditions, with minimal interference observed in the SINR measurements. The overall performance is shown in **Table 10** and **Figure 21** below.

The significant improvements in throughput and the reduction in PRB utilization after CA activation highlight the benefits of this technology. The stable wireless channel conditions (RSRP and SINR) suggest that the enhancements are primarily due to the increased bandwidth provided by CA. This aligns with the understanding that CA effectively boosts network capacity and enhances user experience by aggregating multiple carriers, allowing for wider bandwidths and higher data rates [20].

The results of both stationary and drive tests indicate that CA contributes positively to LTE network performance. In particular, Downlink Throughput showed marked improvement in CA-enabled scenarios. This aligns with the theoretical benefits of CA, which combines multiple carriers to increase available bandwidth and support higher data rates. The enhanced throughput is especially crucial in densely populated urban areas such as Chelstone, where user demand for data services is consistently high.

Similarly, PRB Utilization was more efficient under CA configurations, indicating better spectrum efficiency and improved management of available network resources. This suggests that CA can be an effective tool for MNOs to optimize their existing spectrum allocations rather than seeking additional frequencies.

Although RSRP and SINR values remained relatively stable between CA and non-CA scenarios, higher SINR values imply reduced interference and better signal quality, contributing to improved user experience.

Given the demonstrated performance benefits, CA should be considered a critical part of the LTE enhancement strategy for urban centers in Zambia. However, its implementation must be approached strategically. Operators may need to prioritize CA deployment in high-traffic zones where performance gains can justify investment costs. Additionally, efforts to improve end-user device compatibility and build local technical capacity will be essential in maximizing the impact of CA.

Table 10. Performance evaluation

Metric	Pre-CA (Non-CA)	Post-CA (2CA Inter-band)	Gain (%)
Samples > 5 Mbps (Drive)	45%	60%	15%
Samples > 10 Mbps (Drive)	19%	40%	21%
Average Throughput (Stationary)	36.17 Mbps	68.14 Mbps	88%
Peak Throughput (Stationary)	55.04 Mbps	126.20 Mbps	129%
Daily Average Throughput (44 days KPIs)	18.8 Mbps	19.3 Mbps	3%
PRB Utilization	44.30%	41.40%	−6%

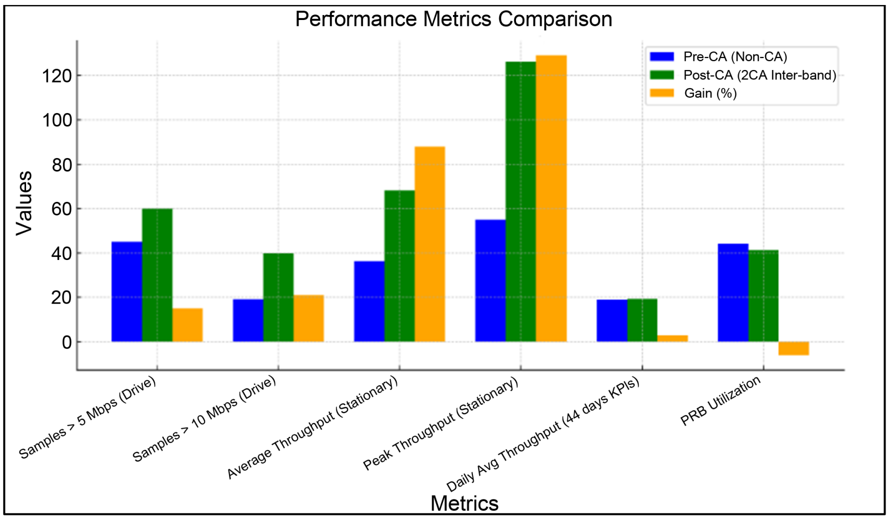

Figure 21. Performance metrics comparison.

6. Conclusions

Although Category 6 UEs can theoretically achieve 300 Mbps downlink with 40 MHz aggregated bandwidth, reaching such speeds in live networks is difficult. However, this study demonstrated that CA can significantly enhance user experience, with observed peak data rates reaching 126.20 Mbps in a commercial setting.

The results confirm that CA boosts real-world data rates and network capacity by aggregating carriers, reducing PRB utilization, and maintaining robust coverage. These improvements are especially beneficial in urban areas facing increased data demand and congestion.

Overall, the study successfully met its objectives, showing that CA is an effective solution for optimizing LTE-Advanced networks in urban Zambia. It offers practical insights for network planning and improving service quality in high-traffic environments.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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