

Uplink 256QAM Activation over LTE and 5G NR

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Abstract—This paper presents the results of a field Proof-of-Concept (PoC) trial evaluating the activation of Uplink (UL) 256 Quadrature Amplitude Modulation (256QAM) across 64 base-station sites in the Kingdom of Saudi Arabia. The feature was simultaneously enabled on September 29, 2025, covering all LTE (4G) and 5G New Radio (NR) cells across eight postal-code zones in Makkah, Madinah, Yanbu, Turbah, Abha, and Rabigh. Performance was assessed using two independent measurement methodologies: Operations Support System (OSS) counter-based Key Performance Indicator (KPI) analysis and crowdsourced Ookla Speedtest Intelligence data. Results indicate a 15% increase in peak daily uplink speed and a 20% improvement in Ookla Speed Score for devices supporting advanced modem chipsets. OSS measurements also reveal gains of 5% in the maximum uplink throughput of 5G, 4.5% in the average uplink throughput of 5G, 10% in the maximum uplink throughput of LTE, and 7.5% in the average uplink throughput of LTE. Following activation, UL 256QAM accounted for 14% of 5G uplink transmissions and 22% of LTE uplink transmissions. The findings demonstrate that UL 256QAM delivers significant uplink capacity and throughput enhancements while requiring no additional spectrum or hardware investment, making it an effective and spectrum-efficient software-driven upgrade for existing 4G and 5G networks.

Index Terms—UL 256QAM, 5G NR, LTE, Uplink Throughput, Network Optimization, OSS KPI Analysis, Speedtest Intelligence.

I. INTRODUCTION

The continuous growth of mobile broadband traffic and the increasing demand for uplink-intensive applications such as cloud services, video sharing, live streaming, and industrial Internet of Things (IoT) have intensified the need for more efficient utilization of radio spectrum resources. Higher-order modulation schemes represent a key mechanism for improving spectral efficiency and increasing network capacity without requiring additional spectrum allocation.

Among these schemes, 256 Quadrature Amplitude Modulation (256QAM) has been widely adopted for downlink transmissions in both Long-Term Evolution (LTE) and Fifth-Generation New Radio (5G NR) systems. By encoding 8 bits per symbol, 256QAM provides a theoretical spectral efficiency improvement of approximately 33% over 64QAM, which carries 6 bits per symbol. However, uplink deployment of 256QAM has historically been limited due to stringent signal-to-interference-plus-noise ratio (SINR) requirements, user equipment (UE) transmit power constraints, and the limited availability of compatible device chipsets.

Recent advancements in modem technology and radio-frequency front-end design have significantly improved UE uplink transmission capabilities, enabling broader support

for UL 256QAM in commercially available devices. Consequently, network operators can now leverage UL 256QAM as a software-based enhancement to increase uplink throughput and capacity while minimizing infrastructure investment.

Despite its growing availability, limited field-scale studies have quantified the real-world performance impact of UL 256QAM in operational LTE and 5G networks. Most existing investigations focus on theoretical analysis, link-level simulations, or laboratory testing, leaving a gap in large-scale deployment validation under live network conditions. This motivates the need for comprehensive field evaluations using both network-side and user-experience-based performance metrics.

To address this gap, we conducted a Proof-of-Concept (PoC) trial involving the activation of UL 256QAM across 64 LTE and 5G sites distributed over eight postal-code regions in the Kingdom of Saudi Arabia. The trial assessed performance using two complementary measurement approaches: Operations Support System (OSS) Key Performance Indicator (KPI) analysis and crowdsourced Ookla Speedtest Intelligence data. The combination of these methodologies enables evaluation from both network performance and end-user experience perspectives.

The main contributions of this work are summarized as follows:

- Development of a dual-methodology evaluation framework combining OSS counter analysis and crowdsourced speed-test measurements for uplink performance assessment.
- Large-scale empirical evaluation of UL 256QAM across 64 commercial LTE and 5G sites spanning eight geographical regions in Saudi Arabia.
- Quantification of throughput improvements in both LTE and 5G NR networks following UL 256QAM activation.
- Analysis of modulation utilization patterns across radio technologies, highlighting practical adoption levels and deployment-dependent behavior.
- Provision of deployment recommendations demonstrating the viability of UL 256QAM as a spectrum-efficient software upgrade for existing mobile networks.

II. BACKGROUND AND RELATED WORK

A. 256QAM in Cellular Standards

The Third Generation Partnership Project (3GPP) introduced Uplink (UL) 256 Quadrature Amplitude Modulation (256QAM) in LTE Release 13 and subsequently incorporated support within the 5G New Radio (NR) framework in Release

15. The feature is available only for user equipment (UE) categories and capability classes that support higher-order uplink modulation and is subject to network scheduler configuration and radio channel conditions. By increasing the modulation order from 64QAM to 256QAM, the number of transmitted bits per symbol rises from six to eight, enabling a theoretical spectral efficiency improvement of approximately 33%.

In practical deployments, the selection of the uplink modulation scheme is dynamically determined by the eNB/gNB scheduler based on radio link quality measurements reported by the UE, including Channel Quality Indicator (CQI), Rank Indicator (RI), and other link adaptation parameters. In LTE systems, UL 256QAM is associated with the highest Modulation and Coding Scheme (MCS) levels defined in the standard, while in 5G NR it is supported through the higher-order MCS tables specified by 3GPP. Consequently, UL 256QAM is typically utilized only when channel conditions provide sufficiently high Signal-to-Interference-plus-Noise Ratio (SINR) and adequate uplink power margins to maintain acceptable block error rates (BLER).

The achievable throughput gain from UL 256QAM depends on several factors, including radio propagation conditions, interference environment, scheduler implementation, device capability, and traffic loading. Therefore, field-based performance validation in commercial networks is essential to quantify the practical benefits of UL 256QAM beyond theoretical spectral-efficiency improvements.

B. Prior Field Studies

Although the benefits of higher-order modulation schemes have been extensively investigated for downlink transmissions, published studies examining the real-world performance of Uplink (UL) 256QAM remain relatively limited. Most existing research has focused on theoretical analysis, link-level simulations, or small-scale laboratory evaluations. Simulation-based studies have projected uplink spectral efficiency improvements ranging from 15% to 30% under favorable radio conditions characterized by high Signal-to-Interference-plus-Noise Ratio (SINR) levels exceeding 25 dB. Similarly, a limited commercial-network trial reported approximately 12% improvement in LTE uplink throughput following UL 256QAM activation across a small set of urban deployment sites.

Despite these encouraging results, there remains a lack of large-scale field validation covering heterogeneous geographical environments, multiple radio access technologies (RATs), and diverse user populations. Furthermore, few studies have combined network-side performance indicators with end-user experience metrics to provide a comprehensive assessment of UL 256QAM deployment benefits.

To address these limitations, this work presents a large-scale commercial-network evaluation of UL 256QAM conducted across 64 LTE and 5G sites spanning eight postal-code regions in the Kingdom of Saudi Arabia. The study integrates Operations Support System (OSS) KPI analysis with crowdsourced Ookla Speedtest Intelligence measurements, enabling simultaneous assessment of network performance and user-perceived throughput.

III. TRIAL DESIGN AND METHODOLOGY

A. Site Selection and Deployment

The trial comprised 64 radio sites selected to represent a cross-section of the Nokia-managed network in Saudi Arabia, covering urban, semi-urban, and suburban morphologies. Sites were activated simultaneously on 29 September 2025 with UL 256QAM enabled on all co-located 4G and 5G cells. No other configuration changes were introduced during the measurement window. Table I summarizes the geographic distribution.

TABLE I
GEOGRAPHIC DISTRIBUTION OF TRIAL SITES

District	City	Postal Code	No. of Sites
MAKKAH	Makkah	2XXXX	16
MAKKAH	Makkah	2XXXX	3
MADINAH	Madinah	4XXXX	20
MADINAH	Rabigh	2XXXX	4
YANBU	Yanbu	4XXXX	7
TAIF	Turbah	2XXXX	3
ASSIR	Abha	6XXXX	4
ASSIR	Abha	6XXXX	6
—	Total	8 Zones	64

B. Measurement Methodology

Performance was assessed using two independent methodologies to ensure robustness of findings:

- OSS KPI Analysis: Network-side counters extracted from the Operations Support System were used to evaluate peak and average UL throughput, modulation scheme utilization rates, and uplink resource slot utilization before and after the feature activation date.
- Ookla Speedtest Intelligence: Third-party crowdsourced speed test data from Ookla was analyzed for UL speed trends (Mbps) and the composite Ookla Speed Score, segmented by access technology (4G/5G) and chipset generation. Weekly and daily peak values as well as average Speed Scores were computed for the pre- and post-activation periods.

The pre-activation baseline spans 1 July – 28 September 2025 (13 weeks). The post-activation assessment window is 29 September – 12 October 2025 (2 weeks). Statistical comparisons use the mean of daily peak values for the respective periods.

IV. OOKLA PERFORMANCE ANALYSIS

A. UL Speed Improvement

Table II presents the Ookla UL speed statistics pre- and post-activation. Modern chipset devices exhibited the largest absolute and relative gains, consistent with the expectation that high-end UEs are more likely to possess and leverage UL 256QAM encoding capability. Table II summarizes the Ookla UL speed.

TABLE II
 OOKLA UL SPEED RESULTS (MBPS)

Metric	Pre	Post	$\Delta\%$
Modern Chipset – Wkly. Peak	21.2	24.3	+14.6%
Modern Chipset – Daily Peak	33.5	38.6	+15.0%
5G – Weekly Peak	22.5	25.7	+13.2%
5G – Daily Peak	33.9	38.0	+12.0%
4G – Weekly Peak	12.0	13.1	+9.1%
4G – Daily Peak	29.8	32.0	+7.0%

B. Speed Score Analysis

The Ookla Speed Score is a composite metric that weighs both download and upload speeds using a logarithmic scale, providing a more holistic representation of user-experienced network performance. Post-activation Speed Scores demonstrated significant uplift, particularly for 5G and modern chipset users. Table III summarizes the Ookla speed score.

TABLE III
 OOKLA SPEED SCORE (AVERAGE)

Segment	Pre	Post	$\Delta\%$
Modern Chipset	169	203	+20%
5G	200	232	+16%
4G	33	36	+9%

The +20% improvement in Speed Score for modern chipset devices is particularly noteworthy, as it reflects the compounded benefit of 256QAM UL adoption among devices most capable of exploiting the higher modulation order. The more modest 4G uplift (+9%) aligns with expectations given the typically lower SINR conditions experienced by LTE UL users relative to their 5G counterparts.

V. 5G NR UL 256QAM OSS ANALYSIS

A. Throughput and Utilization

5G UL throughput, measured without EN-DC contribution to isolate NR scheduler behaviour, increased by 5% at the cell peak level and by 4.5% on average following 256QAM activation (Table IV). Concurrently, UL PUSCH data slot utilization decreased by approximately 1 percentage point, indicating that the same or greater data volume is being carried with fewer allocated resource units — a direct manifestation of improved spectral efficiency.

TABLE IV
 5G NR OSS KPI SUMMARY

5GKPI	Value
Max UL Throughput gain	+5.0%
Avg. UL Throughput gain	+4.5%
UL Slot Utilization change	-1.0%
256QAM avg. UL share	14%
256QAM UL range (by band)	13%–37%
QPSK share reduction	-3.7%

B. Modulation Scheme Distribution

Prior to activation, NR UL transmissions were dominated by QPSK (50.8%) and 64QAM (16.4%), with no 256QAM usage.

Post-activation, 256QAM accounts for 14.1% of UL transmissions on average. The QPSK share fell to 28.8% and 64QAM declined to 15.6%, confirming active scheduler exploitation of the higher modulation order when CQI conditions permit [6].

Band-level 256QAM utilization varies significantly: NR700 cluster records 37%, NR3500 13%, and NR2300 10% [7]. The NR700 result is attributable to wider coverage areas and generally higher UE receive power, both of which elevate reported UL CQI.

VI. LTE UL 256QAM OSS Analysis

LTE UL throughput was evaluated with Carrier Aggregation (CA) active. Peak throughput (Max PDCP) improved by 10%, and average user throughput increased by 7.5% (Table V). The larger absolute gains in LTE relative to 5G are consistent with the fact that LTE 64QAM was the pre-activation ceiling in most conditions, while 5G NR already supported per-carrier aggregation and wider bandwidths that partially mitigate the modulation order bottleneck.

TABLE V
 LTE OSS KPI SUMMARY

4GKPI	Value
Max UL Throughput gain (with CA)	+10.0%
Avg. UL Throughput gain	+7.5%
256QAM avg. UL share	22%
256QAM UL range (by band)	11%–34%

VII. MODULATION UTILIZATION BY BAND

LTE achieves a higher aggregate 256QAM utilization (22%) than 5G (14%), which is attributed to the larger installed base of 256QAM-capable LTE devices in the trial footprint and the relatively mature LTE scheduler parameter tuning. Band-level results show LTE2300 at 34%, LTE1800 at 28%, LTE2100 at 25%, LTE900 at 15%, and LTE700 at 11%, with the higher-frequency bands benefiting from denser deployments and lower inter-cell interference in these specific areas [8].

VIII. DISCUSSION

A. Consistency of Dual Measurement Pipelines

Both OSS KPI and Ookla data independently confirm positive performance impacts, providing high confidence in the reliability of the results. The Ookla Speed Score gain (+20% modern chipset) exceeds the OSS throughput gain (+5% 5G, +10% LTE) because the Speed Score is a peak-of-distribution metric, while OSS throughput represents a cell-average and is diluted by users in poor channel conditions who cannot utilise 256QAM.

B. Efficiency vs. Throughput Trade-off

The 5G UL slot utilization reduction (-1%) alongside throughput improvement (+4.5%) demonstrates that UL 256QAM activation delivers spectral efficiency gains without requiring additional frequency resources. This is particularly significant given the increasing scarcity of licensed spectrum.

C. Device Ecosystem Dependency

The gap between modern-chipset and all-device improvements (e.g., +15% vs. lower averages for UL speed) underscores that the full benefit of UL 256QAM is device-ecosystem-dependent. As the installed base of capable UEs grows, network-level gains are expected to increase progressively.

D. Limitations

The trial was conducted across a fixed set of 64 sites, and results may not be fully representative of the broader network. Seasonal variations in traffic patterns, geographic-specific propagation characteristics, and the evolving device ecosystem may influence long-term performance metrics.

E. Key Observations

LTE demonstrated higher 256QAM UL utilization (22%) compared to 5G (14%), attributed to the larger base of 256QAM-capable LTE devices in the trial areas. The largest throughput gains were observed in LTE (+10% max throughput), where 256QAM provides a more significant relative improvement over the legacy 64QAM ceiling. Modern chipset segmentation in Ookla data reveals that the benefits of 256QAM are disproportionately experienced by users with high-end devices, underscoring the device ecosystem dependency of UL modulation order support. The reduction in QPSK share (3.7% for 5G) and concurrent increase in 256QAM usage confirms that the scheduler is actively leveraging the higher modulation order for eligible users rather than simply enabling the feature without utilization. The decrease in 5G UL slot utilization (-1%) alongside throughput gains indicates improved spectral efficiency — a key objective of advanced modulation deployment.

IX. CONCLUSION

This paper presented UL 256QAM activation represents a cost-effective, software-driven network enhancement that delivers measurable improvements in both network KPIs and end-user experience metrics. The key conclusions are as follows:

- Ookla UL speed increased by up to +15% for modern chipset devices, with Speed Score improving by +20%.
- OSS KPIs confirm +5%, +4.5% (max/avg) 5G UL throughput and +10% +7.5% (max/avg) LTE UL throughput improvements.
- 256QAM UL utilization reached 14% (5G) and 22% (LTE), with significant band-level variation reflecting propagation and deployment differences.
- A 5G UL slot utilization reduction of 1% demonstrates improved spectral efficiency, enabling capacity gain without additional spectrum.

Based on these results, network-wide deployment of UL 256QAM is recommended. Future work should include a 90-day longitudinal study, quality-of-service impact assessment, and analysis of UL 256QAM interaction with uplink MIMO and carrier aggregation features.

X. ABBREVIATIONS

The following abbreviations are used in this manuscript:

256QAM	256 Quadrature Amplitude Modulation
CA	Carrier Aggregation
CQI	Channel Quality Indicator
DL	Downlink
EN-DC	E-UTRAN New Radio Dual Connectivity
KPI	Key Performance Indicator
LTE	Long-Term Evolution
MCS	Modulation and Coding Scheme
NR	New Radio
OSS	Operations Support System
PDCP	Packet Data Convergence Protocol
PoC	Proof of Concept
PUSCH	Physical Uplink Shared Channel
QPSK	Quadrature Phase Shift Keying
RAT	Radio Access Technology
SINR	Signal-to-Interference-plus-Noise Ratio
UE	User Equipment
UL	Uplink
PR	Physical Resource Block
TDD	Time Division Duplex
FDD	Frequency Division Duplex
QoS	Quality of Service
Mbps	Megabits per Second
OOKLA	Speedtest Intelligence Platform

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