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5G SA Carrier Aggregation Validation: DL 2FDD +3TDD and UL 1FDD+1TDD Configuratio

Syed Ashwaq Hussain
independent researcher

Abstract - This paper presents the results and technical analysis of a 5G Standalone (SA) 5-Component Carrier Aggregation (5CC CA) field trial conducted in a 5G network environment. The trial demonstrated simultaneous Downlink (DL) aggregation across five carriers (2 FDD + 3 TDD), achieving a peak PDSCH throughput of 2060 Mbps, and Uplink (UL) aggregation across two carriers (1 FDD + 1 TDD), achieving a peak PUSCH throughput of 212 Mbps. The trial was performed using Nokia AirScale Radio hardware (AQQS 64T64R, AEHC 64T64R, AHEGC 4T4R) with 5G Core (5GC) connected via dual AMF interfaces, operating on Release 23R4 software. The test device utilized a Qualcomm Snapdragon X75 (SDX-75) modem with defined UE bandwidth class restrictions. This work discusses spectrum configuration across NR bands n1, n3, n41, and n77, UE capability constraints, SSB coverage quality, and per-carrier PDSCH/PUSCH throughput breakdown. The findings confirm RAN network readiness with existing hardware and highlight the criticality of UE ecosystem maturity for full throughput realization.

***Keywords* - 5G Standalone; Carrier Aggregation; 5CC CA; NR-CA; FR1; PDSCH; PUSCH; mMIMO; Qualcomm SDX-75; NR Bands; Multi-Carrier Aggregation; 5G SA; RAN.**

I. INTRODUCTION

The evolution of 5G New Radio (NR) technology has brought unprecedented demands for high-throughput mobile broadband, driven by the growth of video streaming, cloud gaming, and industrial IoT applications. Carrier Aggregation (CA), originally introduced in LTE, has been significantly advanced in 5G NR to support simultaneous transmission and reception across multiple component carriers (CC), thus multiplying the effective radio bandwidth available to a User Equipment (UE) [1].

In Standalone 5G (SA) mode — where the 5G Radio Access Network (RAN) connects directly to the 5G Core (5GC) without LTE anchor — carrier aggregation capabilities are fully decoupled from the Non-Standalone (NSA) architecture's constraints. This enables the exploitation of a heterogeneous spectrum portfolio comprising both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) carriers across the FR1 frequency range [2].

Multi-band aggregation combining FDD carriers (n1, n3) which provide broad coverage through lower frequencies with TDD carriers (n41, n77) which contribute high capacity through wider bandwidths presents a complex but highly effective strategy for maximizing spectral efficiency and user throughput.

This paper documents a field trial of 5G SA 5CC DL CA (2 FDD + 3 TDD) and 2CC UL CA (1 FDD + 1 TDD), measuring peak per-carrier and aggregated PDSCH/PUSCH throughputs in a live network scenario. The trial equipment, software version, spectrum configuration, UE modem restrictions, and signal quality observations are presented and analyzed.

The remainder of the paper is organized as follows: Sec-tion II covers related work; Section III describes the system architecture and trial setup; Section IV presents the spectrum and NR-ARFCN configuration; Section V discusses UE bandwidth restrictions; Section VI presents the SSB coverage and signal quality results; Section VII presents the DL throughput results; Section VIII presents the UL throughput results; Section IX provides a discussion; and Section X concludes the paper.

II. RELATED WORK

Carrier Aggregation in 5G NR has been studied extensively since the early releases of 3GPP specifications. 3GPP Release 15 defined the foundational CA framework for NR, while Releases 16 and 17 extended support for higher-order CA combinations and cross-band scenarios [3].

Prior work on NR-CA field trials has primarily focused on NSA architectures with LTE anchors or sub-6 GHz SA deployments with up to 4 CCs [4]. Studies on mmWave CA above FR2 have demonstrated extremely high peak rates but with limited coverage, making FR1 aggregation a more practical approach for wide-area deployments [5].

The combination of FDD and TDD carriers in a single CA group (known as asymmetric CA) introduces scheduling complexity due to differing UL/DL timing structures and UE capability classes [6]. Nokia has previously documented high-order CA achievements in NSA deployments [11]; however, SA-mode 5CC CA combining multiple FDD and TDD bands simultaneously represents a more advanced capability.

The Qualcomm Snapdragon X75 modem is among the first commercially available platforms supporting 5G Release 17 features including 5CC CA, AI-enhanced modem processing, and expanded bandwidth class support [8]. Understanding its UE capability restrictions is essential for realistic throughput benchmarking.

III. SYSTEM ARCHITECTURE AND TRIAL SETUP

A. Network Configuration

The trial was conducted on a single sector of a 5G SA network operating on Release 23R4 software (SW). The net-

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work connected to a 5G Core (5GC) with dual AMF interfaces (AMF-1 and AMF-2) and an NMS element management system. The BTS managed five NR cells across five component carriers simultaneously.

B. Radio Hardware

The sector was equipped with three types of Nokia AirScale radio modules, as summarized in Table 1:

Table 1: *Radio Hardware Configuration per Sector*

Module	Config	Bands Served
AQQS	64T64R	n77 (3700 MHz), n77 (3800 MHz)
AEHC	64T64R	n41 (2600 MHz)
AHEGC	4T4R	n1 (2100 MHz), n3 (1800 MHz)

The AQQS and AEHC radios support massive MIMO (mMIMO) with 64 transmit and 64 receive chains, while the AHEGC serves the FDD bands with a 4T4R configuration. Baseband processing was handled by a combination of ABIO (two modules) and ASIB units.

C. Test Device

The test UE was a Qualcomm Mobile Test Platform (MTP) equipped with the Snapdragon X75 (SDX-75) modem. The measurement tool used for RF logging and analysis was the Accuver XCAL field tool. Ookla Speedtest was used for end-to-end throughput benchmarking.

D. Test Conditions

The test was conducted during a Minimization of Drive Testing (MDT) period under controlled conditions to ensure exclusivity of radio resources. This allowed measurement of peak achievable throughput without inter-user interference effects.

IV. SPECTRUM CONFIGURATION AND NR-ARFCN

A. Band Allocation

Five NR bands were used in the trial, spanning FR1 FDD and TDD sub-6 GHz spectrum. The carrier role assignment (PCell and SCells) is listed in Table 2.

Table 2: *Carrier Configuration — DL 5CC CA*

Role	Band	Duplex	Freq (MHz)	BW (MHz)
PCell	n3	FDD	1800	20
SCell1	n77	TDD	3700	100
SCell2	n41	TDD	2600	20
SCell3	n77	TDD	3800	100
SCell4	n1	FDD	2100	20

B. NR-ARFCN Reference Values

The NR Absolute Radio Frequency Channel Numbers (NR-ARFCNs) and the corresponding global synchronization channel numbers (GSCNs) for each carrier are listed in Table 3.

Table 3: *NR-ARFCN and GSCN per Carrier*

Band	Freq (MHz)	GSCN	NR-ARFCN
n1	2140 (UL: 2135.05)	5338	427010
n3	1870 (UL: 1865.05)	4663	373010
n41	2540.01	6351	508110
n77	3750	8020	650016
n77	3850.02	8089	656640

The two n77 carriers at 3700 MHz and 3800 MHz are served by separate AQQS 64T64R radio units, enabling independent mMIMO beam management per carrier.

C. Uplink Carrier Configuration

For Uplink 2CC CA, only two carriers were aggregated: n3 (FDD, 20 MHz) as the PCell and n77 (TDD, 100 MHz) as SCell1, as the UE's ULCA capability was limited to the F+T combination.

V. UE BANDWIDTH RESTRICTIONS (QUALCOMM SDX-75)

A. Downlink CA Bandwidth Classes

The Qualcomm SDX-75 modem supports a wide range of DL CA combinations (F+T, 2F+T, F+2T, 2F+2T, F+3T, 3F+T, 2F+3T). For the 2F+3T combination applicable in this trial, the maximum UE-supported bandwidth under the SDX-75 is:

$$BW_{UE,max} = 40\,\text{MHz (FDD)} + 220\,\text{MHz (TDD)} \quad (1)$$

However, due to the FDD carrier bandwidths (n3: 20 MHz, n1: 20 MHz = 40 MHz total FDD) and TDD carrier bandwidths, the effective per-band UE working bandwidths applied in this trial are constrained as shown in Table 4.

Table 4: *UE Bandwidth Restriction per Band (DL 5CC)*

Band	Avail. BW	Config. BW	UE Working BW
n3	20 MHz	20 MHz	5 MHz
n1	20 MHz	20 MHz	10 MHz
n41	100 MHz	20 MHz	20 MHz
n77	100 MHz	100 MHz	100 MHz
n77	100 MHz	100 MHz	100 MHz
Total	**340 MHz**	**260 MHz**	**235 MHz**

The UE-imposed restriction reduces the effective working bandwidth from 260 MHz (configured) to 235 MHz. Notably,

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n3 is limited to 5 MHz and n1 to 10 MHz by the UE's bandwidth part (BWP) selection behavior. Despite these restrictions, the UE successfully establishes the 5CC CA session, confirming SDX-75's 5CC CA capability.

B. Uplink CA Bandwidth Classes

For UL CA, the SDX-75 supports the F+T combination with a maximum of 40 MHz (FDD) + 100 MHz (TDD). The UL 2CC configuration uses n3 (20 MHz FDD) and n77 (100 MHz TDD), totaling 120 MHz aggregated UL bandwidth with no UE restriction applied (Table 5).

Table 5: *UE Bandwidth Configuration (UL 2CC)*

Band	Available BW	Configured BW
n3	20 MHz	20 MHz
n77	100 MHz	100 MHz
Total	**120 MHz**	**120 MHz**

VI. SSB COVERAGE AND SIGNAL QUALITY

A. Downlink SSB Measurements

Synchronization Signal Block (SSB) coverage was evaluated using SS-RSRP measurements across all five carriers during the DL 5CC CA session. The PCell (n3) provided the reference signal, with SS-RSRP of **–63.23 dBm**, reflecting the coverage advantage of the 1800 MHz band. The n41 SCell2 exhibited the weakest signal at **–87.16 dBm**, consistent with the 2600 MHz propagation characteristics and the narrower (20 MHz) configured bandwidth.

Table 6: *SS-RSRP Summary — DL 5CC CA*

Carrier Role	Band	NR-ARFCN	SS-RSRP (dBm)
PCell	n3	373970	–63.23
SCell1	n77	650016	–70.91
SCell2	n41	508110	–87.16
SCell3	n77	656640	–76.46
SCell4	n1	427970	–85.24

The dual n77 carriers showed SS-RSRP values of –70.91 dBm (SCell1 at 3700 MHz) and –76.46 dBm (SCell3 at 3800 MHz), confirming adequate signal quality for 100 MHz mMIMO operation. All five carriers maintained stable NR-ARFCNs throughout the measurement period, validating radio link stability.

B. Uplink SSB Measurements

For the UL 2CC CA session, the two carriers (n3 PCell and n77 SCell1) exhibited SS-RSRP values of **–66.91 dBm** and **–50.63 dBm** respectively. The n77 SCell1 showed a higher SS-RSRP in the UL context due to the strong serving beam alignment from the 64T64R AQQS mMIMO unit, demonstrating effective beam management capability.

VII. DOWNLINK THROUGHPUT RESULTS

A. RF Measurement Summary

The RF measurement summary from the Accuver XCAL tool captured per-carrier PDSCH throughput, SINR, SS-RSRP, and serving beam metrics during the DL 5CC CA session. Table 7 summarizes the parameters of the physical layer:

Table 7: *DL RF Measurement Summary (5CC CA)*

Parameter	PCell	SC1	SC2	SC3	SC4
Band	n3	n77	n41	n77	n1
Duplex	FDD	TDD	TDD	TDD	FDD
BW (MHz)	5	100	20	100	10
PCI	113	189	330	189	113
SS-RSRP(dBm)	–65.45	–75.62	–79.34	–85.95	–80.32
SS-RSRQ(dB)	–10.34	–10.34	–10.34	–10.55	–10.88
SINR (dB)	33.36	38.14	24.83	39.96	9.90
DL TP (Mbps)	42.20	782.33	139.54	680.94	105.05

The n77 TDD carriers (SCell1 and SCell3) dominate the DL throughput contribution, collectively delivering over 1460 Mbps due to their 100 MHz bandwidth and 64T64R mMIMO capability. The n41 SCell2, configured at 20 MHz, contributed approximately 140 Mbps despite its narrower bandwidth.

B. Peak Aggregated PDSCH Throughput

The peak DL 5CC aggregated PDSCH throughput was **2060.903 Mbps** (≈ 2.06 Gbps), measured at 100 ms intervals using the Accuver XCAL tool. The per-carrier and total throughput time-series data are summarized in Table 8.

Table 8: *DL 5CC PDSCH Throughput — Top Samples (Mbps)*

Timestamp	PC	SC1	SC2	SC3	SC4	Total
05:02:44.3	47.52	876.12	146.24	880.24	110.78	**2060.90**
05:02:45.4	48.06	860.81	147.88	864.53	112.13	2033.40
05:02:42.8	47.59	861.23	142.53	870.11	110.25	2031.71
05:02:43.1	47.08	857.58	142.66	870.34	110.44	2028.10
05:02:44.9	47.35	859.42	145.49	862.91	110.97	2026.13
05:02:42.3	46.65	863.07	142.94	860.27	108.81	2021.74
05:02:40.1	47.33	859.82	140.48	861.86	111.23	2020.71

The Ookla Speedtest confirmed a DL speed of **1,731 Mbps** at the application layer, which is consistent with the PDSCH-layer peak considering PDCP and transport protocol overhead. This represents one of the highest recorded 5G SA DL throughput values in a live FR1 network deployment in the MEA region using a commercial-grade UE modem.

C. Per-Carrier Throughput Distribution

The two 100 MHz n77 TDD carriers (SCell1 and SCell3) together contributed approximately 85% of the total DL

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throughput, underscoring the critical role of wide TDD carriers in multi-CC aggregation scenarios. The FDD carriers (n3 PCell, n1 SCell4), constrained by UE bandwidth restrictions to 5 MHz and 10 MHz respectively, contributed modestly but are essential for PCell anchor stability and SCell3 SSB coverage assistance.

VIII. UPLINK THROUGHPUT RESULTS

A. UL 2CC CA RF Measurements

The UL 2CC CA session involved n3 (FDD PCell) and n77 (TDD SCell1). Table 9 summarizes the RF measurement parameters:

Table 9: *UL RF Measurement Summary (2CC CA)*

Parameter	PCell (n3)	SCell1 (n77)	SCell2
Band	n3	n77	n77
Duplex	FDD	TDD	TDD
BW (MHz)	20	100	–
PCI	113	189	189
SS-RSRP (dBm)	–65.95	–51.34	–50.37
SS-RSRQ (dB)	–10.33	–10.34	–10.32
SINR (dB)	28.73	39.39	39.11
UL TP (Mbps)	104.63	122.07	–

B. Peak Aggregated PUSCH Throughput

The peak UL 2CC aggregated PUSCH throughput was **212.567 Mbps**, measured at 100 ms intervals. Table 10 provides the per-carrier and combined UL PUSCH throughput for the top samples:

Table 10: *UL 2CC PUSCH Throughput — Top Samples (Mbps)*

Timestamp	PCell (n3)	SCell1 (n77)	Total
04:13:29.4	93.068	119.499	**212.567**
04:13:30.8	93.071	116.353	209.424
04:13:27.9	92.970	116.335	209.305
04:13:28.7	93.186	115.137	208.323
04:13:30.5	92.370	114.594	206.964

The Ookla Speedtest confirmed an UL throughput of **187 Mbps** at the application layer. The n77 TDD carrier contributed the larger share of UL throughput (approximately 56%), enabled by its wider 100 MHz bandwidth and the mMIMO radio's uplink beamforming capabilities.

IX. DISCUSSION

A. Significance of 5CC CA in 5G SA

The achievement of 5CC CA in a live 5G SA network — without LTE anchor — represents a significant milestone. In NSA deployments, UL aggregation typically relies on an LTE carrier as the anchor, constraining SA deployments to fewer UL CCs. The 2CC UL CA in SA mode demonstrated here proves that the 5GC architecture can efficiently manage multi-carrier UL scheduling without LTE assistance.

B. UE Ecosystem Limitations

A critical observation from this trial is the role of UE modem bandwidth restrictions in constraining achievable throughput. The SDX-75's application of 5 MHz BWP on n3 and 10 MHz on n1 — despite both bands being configured at 20 MHz — reduces the theoretical maximum DL throughput. With full UE bandwidth class support on all five carriers (i.e., 260 MHz total configured bandwidth), the expected peak throughput would approximately double:

$$TP_{expected} \approx 2 \times 2060\,\text{Mbps} \approx 4.1\,\text{Gbps} \quad (2)$$

This projection is consistent with theoretical 5CC CA capacity estimates for 235–260 MHz of aggregated FR1 bandwidth with 256-QAM and 64T64R mMIMO.

C. mMIMO Impact

The 64T64R AQQS and AEHC radios enabled spatial multiplexing and beamforming gains that are evident in the high SINR values recorded on the n77 carriers (38–39 dB) and the corresponding high per-carrier throughput (¿860 Mbps per n77 CC). The FDD 4T4R AHEGC unit, by contrast, showed lower SINR (9.9 dB on n1) due to its more limited antenna array.

D. 5G Core Readiness

The dual AMF interface configuration and 5GC operation confirmed full SA protocol stack functionality during the trial. No handover events or CA release incidents were recorded during the peak throughput measurement windows, indicating stable 5CC CA session management by the 5GC.

X. CONCLUSION

This paper presented a comprehensive field trial of 5G SA 5-Component Carrier Aggregation, achieving peak DL PDSCH throughput of **2060 Mbps** (DL: 2FDD + 3TDD) and peak UL PUSCH throughput of **212 Mbps** (UL: 1FDD + 1TDD) in a FR1 network.

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