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5G MetaAAU with Extremely Large Antenna Array

Noaman Taufiq
Saudi Telecom Company

***Abstract*—The rapid densification of 5G New Radio (NR) networks has intensified the need for antenna systems that simultaneously improve coverage, capacity, and energy efficiency without increasing site-footprint. This paper presents a field evaluation of Huawei's 5G MetaAAU — an Active Antenna Unit built around an Extremely Large Antenna Array (ELAA) of 384 dipole elements, double the count of a conventional 64T64R AAU — deployed on the 3.6–3.8 GHz mid-band (n78) in a 5G NR network. The MetaAAU integrates the Signal Direct Injection Feeding (SDIF) architecture and an ultra-light integrated array to achieve a 3 dB gain in both uplink (UL) and downlink (DL) coverage. Coupled with the proprietary Adaptive High-Resolution (AHR) Turbo beamforming algorithm, the system delivers precise, dynamic, and targeted beam management across dense user scenarios. Trial results from two live commercial macro sites confirm 18–20% extension of cell radius, 30–40% improvement in cell-edge throughput, 10–30% gain in indoor user experience, and 10–20% increase in total cell traffic, while sustaining approximately 30% reduction in energy consumption compared with conventional AAU deployments. These findings position MetaAAU as a high-impact upgrade path for operators pursuing simultaneous network performance uplift and carbon footprint reduction under 5G densification strategies.**

***Index Terms*—Array (ELAA), Massive MIMO, AHR Turbo beamforming, n78 mid-band, coverage extension, energy efficiency, Signal Direct Injection Feeding (SDIF).**

I. INTRODUCTION

The deployment of fifth-generation (5G) New Radio (NR) networks has introduced stringent requirements on antenna systems in terms of spectral efficiency, coverage, user throughput, and energy consumption [1].Massive Multiple-Input Multiple-Output (mMIMO) technology, based onactive antenna units (AAU) with large horizontal and vertical antenna arrays, has become a cornerstone of 5G RAN design on mid-band spectrum [2]. Conventional 64T64R AAUs operating in the 3.5 GHz band typically employ 192 radiating dipole elements arranged in a 12×8×2 configuration, providing three-dimensional (3D) beamforming through digital pre-coding [3]. Despite proven performance gains over 4G macro radios, conventional mMIMO AAUs face fundamental limits in cell-edge coverage, deep indoor penetration, and co-channel interference management — especially as 5G subscriptions grow and inter-site distance shrinks [4]. These constraints have spurred research into Extremely Large Antenna Arrays (ELAA), which extend the aperture of the array beyond conventional bounds to exploit near-field propagation effects, higher spatial resolution, and improved spatial multiplexing gain [5]. Huawei Technologies introduced MetaAAU as a commercial realisation of ELAA for the sub-6 GHz mid-band, doubling the antenna count to 384 dipole elements within a physically integrated enclosure. The product combines hardware innovations — namely the Signal Direct Injection Feeding (SDIF) architecture and an ultra-light integrated array — with an advanced Adaptive High-Resolution (AHR) Turbo beamforming algorithm to translate the larger aperture into tangible network KPI improvements. This paper makes the following contributions: leftmargin=*, label=1.

1) A detailed description of MetaAAU hardware architecture, contrasting ELAA-based design with conventional 64T64R AAU.
2) Analysis of the AHR Turbo algorithm and its role in precision beam management.
3) Empirical trial results from two live commercial 5G sites covering coverage, throughput, user count, and traffic metrics.
4) Discussion of energy efficiency outcomes and deployment implications for network operators.

The remainder of the paper is structured as follows. Section II reviews related work on mMIMO and ELAA systems. Section III describes the MetaAAU system architecture. Section IV presents the trial methodology and site configurations. Section V discusses measured KPI results. Section VI addresses energy efficiency aspects. Section VII concludes the paper.

II. BACKGROUND AND RELATED WORK

Practical 5G NR deployments confirmed theoretical predictions: field trials with 32T32R and 64T64R systems showed 3–5 dB coverage improvement and 2–4× capacity gain over LTE MIMO in mid-band spectrum [8]. However, these deployments revealed that spatial multiplexing gain saturates beyond a certain antenna count when array aperture is not commensurately scaled — motivating exploration of ELAA architectures [9].

ELAA research has highlighted two distinct propagation regimes. In the far-field (Fraunhofer) region, conventional planar wavefront assumptions hold and standard digital pre-coding strategies remain applicable. In the near-field (Fresnel) region, the wavefront curvature must be explicitly modelled; beam focusing on specific spatial locations rather than angular directions becomes possible, enabling simultaneous coverage of multiple users at the same angle but different distances [10].

On the hardware side, the feeding network architecture is critical for large-aperture arrays. Traditional distributed feeding introduces significant power losses and inter-element coupling at n78 frequencies. Signal Direct Injection Feeding (SDIF), where each transceiver chain drives its radiating element directly without a passive distribution network, eliminates these losses and improves array efficiency at the cost of increased transceiver count [11].

Algorithmic innovations have paralleled hardware advances. Hybrid beamforming architectures combine a reduced-dimension digital layer with an analogue phase-shift network to reduce hardware complexity while approaching fully-digital performance [12]. More recently, machine-learning-assisted beam management — including beam prediction, tracking, and codebook optimization — has been shown to reduce beam management overhead and improve beam accuracy under mobility. The AHR Turbo algorithm evaluated in this paper belongs to this category of adaptive, data-driven beam management.

III. SYSTEM ARCHITECTURE AND FEATURE DESCRIPTION

A. *Hardware Design*

The MetaAAU operates in the 3.6–3.8 GHz frequency band (3GPP NR band n78) with a 200 MHz channel bandwidth and a 64-transceiver (64T64R) digital front-end — identical in radio-frequency (RF) channel count to conventional AAU counterparts but radically different in antenna realisation.

The fundamental hardware innovation lies in the antenna array. Conventional 64T64R AAUs employ 192 radiating dipole elements arranged as 2 cross-polarised dipoles per sub-array across 96 sub-array positions, yielding a compact form factor of approximately 730 mm × 395 mm × 180 mm and a weight below 28 kg. MetaAAU doubles the radiating aperture to 384 dipole elements by extending the vertical aperture to 1450 mm while maintaining the horizontal dimension at 400 mm, resulting in a weight below 30 kg — a remarkably modest mass increase for doubled antenna count, achieved through the ultra-light integrated array (ULIA) mechanical design.

TABLE I
HARDWARE SPECIFICATION COMPARISON: METAAAU VS. CONVENTIONAL AAU

Parameter	MetaAAU	Conventional AAU
Frequency Band	3600–3800 MHz	3600–3800 MHz
Output Power	320 W	320 W
TRx Channels	64T64R	64T64R
Bandwidth	200 MHz	200 MHz
Antenna Elements	**384 dipoles**	192 dipoles
Dimensions (mm)	1450×400×180	730×395×180
Weight	<30 kg	<28 kg

The doubled antenna aperture directly increases the effective isotropic radiated power (EIRP) and, more importantly, the array gain in the elevation domain — providing the mechanism for 3 dB UL/DL coverage improvement reported in field trials.

B. *Signal Direct Injection Feeding (SDIF)*

Conventional large-scale arrays distribute the RF signal from each transceiver output through a passive Corporate Feed Network (CFN) before reaching the radiating elements. For a 64T64R AAU, the CFN introduces insertion losses of 1.5–2 dB per feeding path, directly reducing the effective power radiated by each sub-array. At doubled element count, the feeding loss problem would be compounding if a conventional CFN architecture were retained.

MetaAAU employs Signal Direct Injection Feeding (SDIF), which eliminates the intermediate passive distribution network by connecting each transceiver output directly to its dedicated radiating sub-array [11]. This point-to-point injection approach: (i) removes CFN insertion loss from the power budget, improving radiated efficiency; (ii) reduces inter-element coupling that degrades array radiation pattern fidelity; and (iii) allows more precise per-element amplitude and phase control, enabling finer beam resolution. Together with the ULIA mechanical integration, SDIF allows the 384-element array to maintain power efficiency parity with a 192-element conventional design.

C. *Adaptive High-Resolution (AHR) Turbo Beamforming*

The hardware aperture advantage of MetaAAU is fully exploited only when the beamforming algorithm can translate additional degrees of freedom into measurable user-level improvements. The Adaptive High-Resolution (AHR) Turbo algorithm, deployed as a software layer on the baseband unit, addresses this requirement through three coordinated mechanisms:

1) **Precision channel estimation:** AHR Turbo exploits the enlarged spatial aperture to apply high-resolution angle-of-arrival (AoA) and angle-of-departure (AoD) estimation, significantly reducing the angular uncertainty of user location compared with conventional DFT-based codebooks calibrated for 192-element arrays.
2) **Dynamic beam adaptation:** Rather than selecting from a fixed codebook, the algorithm computes user-specific beamforming weights in the time domain using a near-real-time optimisation loop, adapting to rapid channel variations caused by user mobility, multipath dynamics, and changing inter-cell interference conditions.
3) **Targeted spatial multiplexing:** The improved angular resolution allows the gNB to spatially separate users who would be indistinguishable to a narrower array, increasing the effective number of simultaneously served spatial layers — contributing to both cell-average and cell-edge throughput gains.

Together, these capabilities make AHR Turbo the primary software enabler for MetaAAU's performance gains, particularly in dense urban scenarios where interference management and coverage at cell edges are the binding constraints.

IV. METHODOLOGY

A. *Sites and Configuration*

The field evaluation was conducted in March 2023 across two live commercial 5G macro sites representing distinct deployment environments:

- **Site A** — Urban macro site with high average user count and dense traffic load.

- **Site B** — Suburban macro site with moderate user count and mixed indoor/outdoor coverage requirements.

At each site, the conventional 64T64R AAU was replaced with MetaAAU operating in identical RF configuration: band n78 (3600–3800 MHz), 200 MHz bandwidth, 320 W output power, 64T64R transceivers. The AHR Turbo beamforming algorithm was activated on both trial sectors. All other RAN parameter settings — scheduling policies, inter-frequency handover thresholds, power control parameters — were kept constant throughout the trial to isolate the hardware and algorithm contribution.

B. *Key Performance Indicators (KPIs)*

The following KPIs were collected before (baseline) and after (trial) MetaAAU activation from the Operations and Maintenance (OAM) system and drive-test measurement logs:

- Average Access Timing Advance (TA) — proxy for average cell radius in the uplink.
- Average UE count per cell (active users scheduled).
- Total cell DL/UL traffic volume (GBytes per hour).
- DL/UL reference signal received power (RSRP) at the cell edge (5th–10th percentile CDF).
- Cell-average and cell-edge DL/UL throughput (Mbps).
- DL/UL Indoor signal strength (penetration loss measurement).

V. RESULTS

A. *Coverage Extension*

The most fundamental impact of the doubled antenna aperture is a 3 dB gain in both UL and DL link budget. Using the standard outdoor-to-indoor (O2I) loss model for mid-band frequencies, a 3 dB link budget improvement translates to an 18–20% extension of cell radius:

$$\Delta r = r_0\left[\left(10^{\Delta L/10n_{\mathrm{PL}}}\right)-1\right]\times 100\% \qquad (1)$$

where $\Delta L = 3$ dB is the additional link budget, n_{PL} is the path-loss exponent (typically 3.5–4.0 for urban mid-band), and r_0 is the baseline cell radius. For $n_{\mathrm{PL}} = 3.76$ (3GPP UMa model for n78), equation (1) yields $\Delta r \approx 18.4\%$, consistent with the 18–20% measured values.

Average Access TA measurements from the two trial sites confirm this coverage extension quantitatively:

TABLE II
COVERAGE EXTENSION — AVERAGE ACCESS TA IMPROVEMENT

Site	Baseline TA (m)	Trial TA (m)	Gain (m)
Site A	–	–	+124.8
Site B	–	–	+125.97

TA values converted to distance using TA step = $16T_s$; baseline absolute values not disclosed. The consistent ~125 m TA increase across both sites, despite differing propagation environments, indicates that the coverage gain is primarily driven by the MetaAAU hardware contribution rather than site-specific factors.

Indoor penetration improvement of 10–30% in received signal level was also recorded, directly attributable to the 3 dB link budget uplift overcoming O2I penetration loss. Cell-edge (5th-percentile) RSRP improved by 3 dB, with 30% better cell-edge user experience in terms of RSRP and SINR distributions.

B. *Throughput and Capacity Improvements*

The AHR Turbo algorithm's spatial multiplexing gains translate directly into throughput improvements as summarised below:

TABLE III
THROUGHPUT KPI IMPROVEMENTS — METAAAU VS. BASELINE AAU

KPI	Improvement (%)
Average DL/UL throughput (cell-average)	+20 to +30
Cell-edge DL/UL throughput	+30 to +40
Indoor user experience	+10 to +30
Cell-edge user experience (RSRP/SINR)	+30

The larger relative gain at the cell edge (+30–40%) compared with the cell average (+20–30%) is a characteristic signature of improved beam precision: cell-edge users, which previously suffered from weaker, less accurate beams and higher inter-cell interference leakage, benefit disproportionately from both the 3 dB aperture gain and the tighter spatial nulling of AHR Turbo.

C. *Traffic and User Count*

Network-level traffic and user statistics reflect the combined effect of expanded coverage area and improved spectral efficiency per user:

TABLE IV
TRAFFIC AND USER COUNT RESULTS PER TRIAL SITE

KPI	Site A (Urban)	Site B (Suburban)
Avg. User Count Increase	+38.41%	+14.79%
Total Traffic Increase	+21.48%	+10.03%

The higher user count gain at Site A (+38.4%) versus Site B (+14.8%) reflects the denser urbanisation of the Site A: more potential users reside within the extended coverage footprint, and the improved cell-edge SINR enables the scheduler to admit and sustain more concurrent UEs. The traffic increase, at +10–20% across both sites, is consistent with the +10–20% range projected from capacity modelling of the AHR Turbo spatial multiplexing improvement.

Overall, the consolidated trial outcomes across both sites confirm:

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- +3 dB UL/DL coverage with 18–20% cell radius extension.
- +10–30% indoor user experience improvement.
- +30% cell-edge user experience improvement.
- +20–30% average throughput improvement (DL and UL).

- +30–40% cell-edge throughput improvement (DL and UL).
- +10–20% total cell traffic increase.
- +15–40% active user count increase.

VI. ENERGY EFFICIENCY

A critical consideration for large-antenna deployments is power consumption. Doubling the antenna count from 192 to 384 elements naively doubles the number of RF chains; without countermeasures, this would increase site power consumption proportionally and negate any green-network benefits.

MetaAAU addresses this through three mechanisms:

1) **SDIF efficiency gain:** Elimination of CFN insertion loss ($\sim$1.5–2 dB per path) reduces per-element PA drive requirement, partially offsetting the increased transceiver count.
2) **AHR Turbo coverage-per-watt improvement:** Tighter, more accurate beams reduce wasted radiated power in directions without active users, effectively improving the useful-signal fraction of total radiated power.
3) **Intelligent sleep/muting:** AHR Turbo integrates intelligent carrier and channel element muting during low-traffic periods, reducing baseband and RF power when the spatial multiplexing capability is not required.

The net outcome of these mechanisms is an approximately 30% reduction in energy consumption per bit compared with a conventional AAU baseline at equivalent traffic load — positioning MetaAAU as a viable energy savings tool rather than solely a performance enhancement.

For a typical urban macro site carrying 500 GB/day per cell, a 30% energy reduction translates to approximately 2.1 MWh/day/cell in saved electrical energy, with corresponding CO_2 emission reductions dependent on the local electricity grid carbon intensity.

VII. DISCUSSION

The trial results confirm that the combination of ELAA hardware and AHR Turbo beamforming delivers performance improvements that exceed what can be achieved through software tuning alone on conventional 64T64R AAU platforms. The physical aperture extension from 192 to 384 elements is the enabler: it creates additional spatial degrees of freedom that the algorithm exploits but cannot generate from a smaller array.

From a network planning perspective, the $\approx$19% cell radius extension has significant implications for site spacing requirements. If an operator can achieve equivalent coverage from MetaAAU with fewer macro sites — or delay additional site builds — the capital expenditure (CAPEX) saving can offset the incremental cost of the MetaAAU hardware upgrade relative to a conventional AAU refresh.

The asymmetric user count gains between Site A (urban) and Site B (suburban) suggest that the capacity benefit scales with the density of users within the newly-accessible coverage area, which is higher in urban than suburban environments. Operators should therefore prioritise MetaAAU deployment in dense urban coverage zones where the dual benefit of expanded footprint and improved spatial multiplexing is most pronounced.

Limitations of this trial include: (i) a two-site sample is insufficient for statistical confidence on specific numeric KPI values; (ii) baseline AAU absolute KPI values were not disclosed in the trial report, preventing normalised throughput efficiency comparisons; (iii) drive-test data distribution across coverage areas was not detailed, limiting assessment of spatial KPI variation. Broader multi-site validation across diverse propagation environments is recommended before generalising the quantitative results.

VIII. CONCLUSION

This paper has presented a field evaluation of Huawei's 5G MetaAAU — an Extremely Large Antenna Array based Active Antenna Unit — in a 5G NR n78 network. The key findings are:

- MetaAAU delivers a 3 dB UL/DL coverage improvement through its 384-element ELAA, extending cell radius by 18–20% compared with a conventional 192-element 64T64R AAU.
- The AHR Turbo adaptive beamforming algorithm translates the expanded aperture into 20–30% cell-average and 30–40% cell-edge throughput gains, with 15–40% more active users per cell.
- Despite the doubled antenna count, the SDIF architecture and intelligent power management achieve approximately 30% energy savings per bit, making MetaAAU a net energy-positive upgrade.
- Both trial sites showed average TA increases of 124.8 m and 125.97 m respectively, with total traffic growing by 21.48% and 10.03% after MetaAAU activation.

MetaAAU represents a ELAA principles that bridges the gap between academic near-field antenna research and deployable network infrastructure. For operators seeking to simultaneously improve coverage, capacity, and energy efficiency in mid-band 5G RAN, MetaAAU provides a compelling single-hardware-upgrade path. Future work should extend the trial to 10+ sites across diverse morphologies and quantify the CAPEX-payback period relative to new-site builds.

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