OpenAirInterface5G as a Platform for Beyond 5G/6G-NTN Research

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***Abstract*—Non-Terrestrial Networks (NTN) are increasingly being considered a native component of 6G systems, enabling ubiquitous coverage, resilience, and new service classes across multi-orbit constellations and integrated terrestrial–non-terrestrial architectures. While 5G-NTN has been standardized in 3GPP Release 17 and further advanced in Releases 18 and 19, beyond-5G/6G-NTN concepts require validation using tools that bridge the gap between high-level simulation and standard-compliant, end-to-end prototyping. This paper positions OpenAirInterface5G (OAI) as a practical, standard-aligned, and modifiable baseline for early 6G-NTN research, continuing our earlier work that positioned OAI for 5G-NTN experimentation. In addition to summarizing OAI's current NTN capabilities, we provide (i) a taxonomy of 6G-NTN requirements and research gaps, (ii) a mapping of representative OAI-based 5G-NTN foundations and ongoing B5G/6G-NTN projects, and (iii) a structured mapping of representative emerging 6G-NTN research directions to relevant OAI capabilities and current limitations, highlighting areas for future OAI development and experimental validation. These contributions are intended to give the research community a practical, open-source starting point for prototyping and validating B5G/6G-NTN concepts on standard-compliant infrastructure.**

***Index Terms*—5G, 6G, Non-Terrestrial Networks (NTN), SDR**

I. Introduction

NTN extends cellular connectivity beyond terrestrial deployments by exploiting satellites (GEO/MEO/LEO), High-Altitude Platforms (HAPS), and airborne nodes. 5G-NTN was introduced in 3GPP Release 17 with FR1-NTN (L/S-band) support for NR and NB-IoT/CAT-M over transparent (bent-pipe) payloads, extended in Release 18 with FR2-NTN, VSAT terminals, and mobility enhancements, and further advanced in Release 19 with regenerative payload architectures, store-and-forward operation, and GNSS-independent positioning [1], [2]. This trajectory reflects a broader shift in NTN's role: from an isolated access technology in early releases toward a natively integrated network resource in Release 20 and beyond, where terrestrial and non-terrestrial domains share a common core, policy, and service level agreement framework. In 6G visions, NTN is no longer an "add-on" access technology but a foundational component to enable ubiquitous coverage, mission-critical resilience, 3D-networking, and integrated communications-computing-sensing paradigms. Ongoing standardization efforts increasingly treat NTN as a native 6G component, which in turn raises the urgency of establishing end-to-end validation methodologies aligned with pre-standardization timelines [3].

A major obstacle for applied 6G-NTN research is that emerging concepts are often evaluated either (i) analytically or through high-level simulations, or (ii) using proprietary protocol stacks that are difficult to modify, reproduce, or share. In the 5G-NTN domain, the research community has benefited from open-source, standards-compliant implementations, particularly OpenAirInterface5G (OAI), which has enabled rapid prototyping and the development of experimental testbeds [4], [5]. Prior work demonstrated how OAI can be adapted for 5G-NTN research and over-the-satellite experimentation [6]–[12]. This naturally raises the question of whether OAI can serve as an effective open-source baseline for prototyping and evaluating B5G/6G-NTN innovations. Building on its role in 5G-NTN experimentation, this paper investigates how OAI can be extended to support emerging 6G-NTN research directions and experimental needs.

We argue that OAI is well suited for this role for two main reasons. First, recent 6G-NTN vision and survey works identify several near-term research directions as evolutionary extensions of 5G-Advanced/NR-NTN, including multi-orbit operation, AI-native control loops, regenerative-payload functional splits, and NTN-assisted positioning and sensing [3], [13]–[16]. Such directions can already be meaningfully investigated using an NR-based implementation, even before a fully native 6G air interface is specified. Second, OAI provides an open, modifiable, and NTN-capable implementation of NR, with publicly documented NTN functionality and an active evolution toward beyond-5G/6G experimentation [4], [5].

This paper extends our earlier OAI-for-5G-NTN work [6] by mapping emerging B5G/6G-NTN requirements directly to open-source implementation pathways. Specifically, our main contributions are:

- We identify emerging 6G-NTN challenges and highlight critical gaps in current experimentation tools (§ II–§ III).
- We review state-of-the-art 5G-NTN capabilities in OAI and analyze key experimental achievements realized using the stack (§ IV).
- We detail ongoing B5G/6G-NTN projects and testbeds that actively leverage OAI for experimental validation (§ V).

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- We map OAI's current capabilities to emerging 6G-NTN research challenges, highlighting current limitations and future directions (§ VI).

The discussion in this paper refers to the public OAI RAN documentation accessed in August 2026 and to the corresponding OAI NR codebase in the 2024–2026 timeframe; exact feature behavior therefore depends on the specific commit and configuration used.

Paper organization

The rest of this paper is organized as follows: Section II introduces the main beyond-5G/6G-NTN challenges, while Section III discusses tooling gaps and positions OAI relative to other NTN experimentation platforms; Section IV summarizes OAI as an NTN-capable baseline and reviews key OAI-based 5G-NTN achievements; Section V surveys representative beyond-5G/6G-NTN projects and initiatives using (or enabled by) OAI; Section VI maps OAI capabilities to 6G-NTN research challenges and discusses limitations and future work; and Section VII concludes the paper.

II. Challenges in 6G-NTN Beyond 5G-NTN

While long RTT, Doppler, and mobility remain key challenges, 6G-NTN extends beyond them through the native integration of terrestrial, airborne, and satellite networks. Building on 5G-NTN and 5G-Advanced, it targets joint operation across multiple orbits, domains, and services [3], introducing requirements such as AI-native RAN control and cross-domain orchestration:

- *Multi-orbit integration and 3D multi-connectivity:* Coordination and mobility across GEO/MEO/LEO/HAPS/UAV and terrestrial networks, including vertical handovers, multi-link aggregation, and policy-driven path selection across heterogeneous links [3], [13]–[15].
- *Regenerative payloads and distributed processing:* Placement of RAN and core functions across satellite, edge, and cloud nodes, subject to split-interface delay and jitter, time-varying feeder links, and limited onboard computing resources [1], [3], [14], [15].
- *AI-driven closed-loop control:* RRM, beam management, routing, and congestion control under delayed feedback and non-stationary orbital and traffic conditions, while maintaining stability, explainability, and service guarantees [13]–[16].
- *Integrated sensing, positioning, and timing:* Joint use of communication signals and measurements for sensing and NTN-assisted PNT, including fusion with GNSS, NTN, and terrestrial observations.
- *Resilience and security across space and ground segments:* Secure coordination across operators and distributed network functions, and continued service under intermittent links, moving coverage, partial constellation outages, or during GNSS-denied events [3], [14], [16], [17].

TABLE I
Typical 5G-NTN experimentation tool categories and gaps

Tool type	Gaps
Link/system simulators	Scalable NR studies, but limited support for higher-layer procedures, HARQ/RLC interactions, timers, and real-time operation over satellite scale RTT constraints. [18], [19].
Network simulators/emulators	Abstract PHY cannot fully capture time-varying Doppler, timing drift, modem impairments, or their effects on scheduling and protocol operation. [19].
Open-source stacks	Standard-aligned and modifiable, but NTN support depends on the software version. Reproducibility requires fixed commits, configurations, and orbit/channel traces, while dynamic LEO/MEO emulation, OTA testing, and KPI collection may need additional tool-specific integration, Table II details status of current such tools [8], [9], [12], [20]–[24].
Proprietary stacks	High realism and mature NTN features, but limited openness, flexibility, and reproducibility; licensing may also restrict redistribution. [25], [26].

- *Energy and compute aware operation:* Joint management of UE power saving, onboard payload energy, processing load, and thermal constraints while preserving latency and throughput requirements [3], [13], [16].

III. Comparable NTN Platforms and Gaps

NTN experimentation tools range from abstract simulators to full protocol-stack implementations, with different trade-offs in scalability, realism, flexibility, OTA support, and reproducibility. B5G/6G-NTN studies also require realistic evaluation of multi-orbit connectivity, regenerative architectures, and AI-assisted control.

Table I highlights a remaining gap: no widely adopted, standard-aligned, and modifiable platform combines satellite-channel emulation with OTS support for reproducible end-to-end B5G/6G-NTN studies. To examine how representative platforms address this gap, Table II furthermore compares them in terms of 3GPP alignment, modifiability, Over-The-Satellite (OTS) validation capability, and licensing. Among these, *3GPP alignment* and *modifiability* are qualitative, author-assessed attributes: The former reflects real-time protocol fidelity; the latter reflects code flexibility. Together, they highlight each platform's complementary strengths. In particular:

- Open-source stacks such as OCUDU support practical NTN-capable gNB experimentation, while commercial platforms such as Amarisoft provide mature 5G NR NTN features and demonstrated satellite trials, albeit with more limited modifiability and independent reproducibility [22]–[26].
- OCUDU RAN has also been demonstrated end-to-end with the OAI UE Simulator over ZMQ for GEO and LEO NTN scenarios, including propagation-delay and Doppler effects for a modelled 600 km LEO orbit; these demonstrations are simulation-only, without SDR/RF hardware

TABLE II
QUALITATIVE COMPARISON OF CONTEMPORARY 5G-NTN TOOLS

Tool	3GPP alignment	Customizability	OTS Validated	License	Remarks
OAI	High	High	Yes	CSSL v1.0 (Open)	End-to-end prototyping; cross-layer studies; RFsim and OTA/SDR testbeds
ns-3 / simulators	Low–Med	Low	No	Open	Large-scale sweeps; abstracted-stack algorithm evaluation
OCUDU	Med–High	Med	No (see Remarks)	Open (BSD-3-Clause)	GEO/LEO E2E demoed with OAI UE-Sim, sim-only
Amarisoft	High	Low	Yes	Closed	Documented gNB and UE tutorials and OTA/SDR testbeds
Commercial stacks	High	Low	Varies	Closed	High-realism testing, conformance trials; limited modification

[27], [28]. OCUDU's tutorial additionally documents a TLE-driven channel-emulation setup using a licensed Amarisoft UE [24].

While abstract simulators excel at scalable parameter sweeps and commercial stacks provide realistic, feature-complete performance, both have trade-offs in protocol flexibility or behavior under NTN timing. OAI bridges this gap by combining openness, protocol modifiability, and end-to-end execution via simulation as well as OTS(Over The Satellite)/SDR setups, making it the ideal baseline for prototyping early B5G/6G-NTN concepts.

IV. OAI AS A B5G/6G-NTN PROTOTYPING BASELINE

A. Current OAI NTN Capabilities and Maturity

OAI provides an end-to-end implementation of 3GPP cellular systems and has previously been established as a practical platform for 5G-NTN research and experimentation [6]. It enables satellite and hardware free experimentation through channel simulation, thus, allowing researchers to start from a standard-aligned NR implementation and introduce NTN-specific effects such as long propagation delays, time-varying Doppler, and channel impairments. Their impact can then be observed across the actual PHY/MAC/RLC protocol stack, including synchronization, timing advance, HARQ operation, protocol timers, scheduling, and end-to-end traffic performance [20], [29].

OAI has progressively integrated Rel-17/18 NR-NTN features into its codebase, supporting GEO and LEO channels. Supported features include delay, Doppler emulation, NTN aware MAC/HARQ, SIB19, and timing/Doppler compensation for both transparent and regenerative payloads. Conversely, mobility management, continuous frequency-offset handling, and dynamic-state integration remain under active development [20]. Table III outlines OAI's NTN capabilities and implementation maturity. Core protocol support spans multiple layers, though maturity remains heterogeneous; key PHY and upper-layer functions are fully operational, whereas critical LEO-oriented mechanisms are evolving.

B. Lessons from OAI 5G-NTN

Extensive OAI-based 5G-NTN research across simulation, lab, and OTS environments [6]–[12] yields three critical cross-layer lessons for B5G/6G-NTN prototyping:

- **Protocol Adaptation for Large RTT.** Satellite scale RTT requires cross-layer adaptations, spanning uplink scheduling, HARQ operation, and RLC/PDCP/RRC timers and buffers: to ensure protocol stability under GEO and LEO delays [6], [10], [31]. These insights highlight the core NR functions requiring early modification when latency becomes a major system constraint.
- **Synchronization, Doppler, and Mobility.** 5G-NTN experimentation demonstrated that synchronization, timing drift, Doppler, and mobility are active implementation level bottlenecks rather than static channel parameters. OAI studies highlight that synchronization and mobility must be evaluated alongside the live protocol stack in rapidly varying NGSO scenarios [9]: a requirement that intensifies in 6G-NTN due to multi-orbit topologies and tighter cross-layer control.
- **From Emulation to OTS Validation.** OAI based OTS demonstrations; alongside ESA projects (e.g., 5G-GOA, 5G-LEO): provided key insights into KPI observability, overhead, and protocol tuning under operational link conditions [12], [32], [33]. This progression from emulation to live OTS testing offers a reusable methodology for validating B5G/6G-NTN concepts.

C. OAI as a Baseline for Early 6G-NTN Research

Although 6G air-interface specifications are not finalized, several near-term 6G-NTN research directions can already be investigated on an NR(-NTN) baseline, including multi-orbit mobility, AI-native RRM and closed-loop control, and regenerative-payload functional splits. This follows a common pre-standardization approach in which emerging concepts are prototyped and experimentally evaluated before feeding implementation insights into subsequent standardization activities [3], [5].

OAI is not considered here as a 6G air interface implementation, but as an experimental baseline for evaluating evolutionary B5G/6G-NTN concepts under realistic cross-layer interactions. Its modifiable stack enables candidate mechanisms to be tested against real-world timing, scheduling, retransmissions, and traffic constraints rather than simplified abstractions. Proven across lab testbeds and over-the-satellite trials, this approach offers a validated framework for advanced NTN prototyping [6], [8], [9], [12].

V. BEYOND-5G/6G-NTN PROJECTS USING (OR ENABLED BY) OAI

This section summarizes representative projects connecting OAI with beyond-5G/6G-NTN research. While some are formally 5G-NTN initiatives, they offer essential NR-NTN baselines and validated engineering patterns for B5G/6G-NTN prototyping. Table IV outlines thirteen key publicly documented activities.

TABLE III
DEDICATED SUMMARY OF NTN-RELATED FEATURES PUBLICLY VISIBLE IN OAI DURING THE WRITING OF THIS PAPER

Area	NTN-related feature in OAI	Status	Evidence / practical meaning
gNB MAC	NTN-aware scheduling hooks, including long-RTT handling, HARQ-related adaptations, and use of `cellSpecificKoffset-r17`	Implemented	Public OAI material and merged NTN support indicate gNB-side NTN MAC support aligned with NR-NTN experimentation [20], [30].
UE MAC	NTN-aware UE MAC behavior, including extended HARQ-process handling for large-RTT operation	Implemented	OAI feature material lists UE-side NTN MAC support as part of the public NR-NTN capability set [20], [30].
UE RRC	Processing of `ntn-Config-r17`, SIB19-related configuration, and `ntn-UlSyncValidityDuration-r17`	Implemented, with edge cases under development	Public documentation and tracked fixes show this path is real and usable, but still undergoing hardening in dedicated-mode and target-cell transitions (e.g., MR !3652 and MR !3659) [20].
UE PHY	Timing-advance adjustment, DL Doppler compensation, UL Doppler pre-compensation, and LEO-oriented time-drift handling	Implemented / experimental	OAI documents NTN UE PHY support, while LEO-oriented refinements remain a major experimental focus (e.g., MR !2893 and MR !3581) [20].
RFsim GEO	Fixed long-delay GEO satellite-channel emulation	Implemented	OAI supports reproducible GEO-like propagation delay in RFsim and documents runnable NTN GEO configurations [20], [29].
RFsim LEO	Time-varying LEO delay and Doppler channel emulation	Experimental (usable)	Mainline LEO enabler with continuing fixes; see MRs !2893 and !3194.
gNB SI broadcast	SIB19 initialization, insertion into SIB scheduling, and broadcast from the gNB	Implemented	Mainline gNB support; see MR !2899.
nrUE SI monitoring	SIB19 reception and storage at the UE	Implemented	Mainline UE support; see MR !2920 [20].
Dynamic NTN state update	Continuous SIB19 update path for RFsim LEO scenarios via `nr_update_sib19()`	Implemented	RFsim-specific dynamic update; MR !3398 [20].
Configuration and run-time support	Public NTN sample configs and run-time options for GEO/LEO setups	Implemented	Public configs and run options for reproducible GEO/LEO setups [20], [29].
FR2 NTN bands	Up to 400 MHz bandwidth; Ka and Ku bands are defined in NTN standardization, but full OAI support is not yet fully implemented	In progress	Standardization includes Ka/Ku band definitions, while public OAI support remains in active development and is primarily demonstrated for GEO/LEO-oriented experimentation.
Mobility / handover	NTN-specific location/time-based triggering concepts for mobility in fast-moving constellations	In progress	Draft mobility support; see MR !2716.
Regression hardening	Re-establishment, epoch-time correctness, long-period SIB19 timer behavior, and duplex/band fixes	In active hardening	Ongoing fixes; see MRs !3360, !3652, !3659, !3666, and !3777.

OAI's relevance to NTN experimentation is evidenced by its widespread adoption across European and industrial programs including ESA ARTES, SNS JU/Horizon Europe, CELTIC-NEXT, and private initiatives. In these frameworks, OAI serves as a core platform for prototyping and validating GEO, LEO, HAPS, hybrid TN/NTN, and in-orbit scenarios. We categorize these activities into two domains: OAI-based 5G-NTN foundations and ongoing B5G/6G-NTN projects:

A. OAI-Based 5G-NTN Foundations

The first category comprises foundational projects that transitioned OAI from a terrestrial NR stack to a validated 5G-NTN platform. Through protocol updates, lab testbeds, and live satellite trials, these initiatives established core NTN capabilities across GEO and LEO scenarios.

- *5G-METEORS* was among the earliest projects to demonstrate software-defined 5G NR over a GEO satellite using OAI. Integrating OAI-based gNB and UE stacks with real GEO links, it validated bidirectional NR communication, random access, timing advance, and end-to-end traffic [34].
- *5G-GOA* integrated foundational GEO-NTN extensions into OAI across the PHY and upper layers—adapting protocol timers, synchronization, timing relationships, and random access for satellite-scale delays. Validated in lab setups and live GEO trials, these enhancements were directly merged into the public OAI codebase [6], [32].
- *5G-LEO* extended OAI to NGSO systems by introducing adaptations for time-varying delays, high Doppler/Doppler rates, timing drift, and mobility procedures. Using SDRs and channel emulation, the project built an end-to-end LEO testbed whose features were merged into OAI's main codebase [9], [33].
- *ENGAGE* leveraged the OAI NTN implementation for a live GEO satellite campaign with SES, evaluating end-to-end 5G NR under operational link conditions. The trial yielded practical insights into synchronization, timing advance, HARQ/RLC tuning, and implementation overhead [12], [21].

Taken together, these projects established the implementation and validation basis on which later B5G/6G-NTN activities using OAI could build.

B. Ongoing B5G/6G-NTN Projects

The second category comprises projects in which OAI is reused as an experimental enabler within broader B5G/6G-NTN research objectives, including integrated TN/NTN mobility, federated experimentation, onboard processing, in-orbit validation, and AI-assisted satellite systems.

- *SEVECODE* targets hybrid TN/NTN automotive V2X applications, demonstrating seamless service continuity across a 5G Standalone TN (band n7) and a GEO S-band (n256) NTN link via a dual 5G Core architecture [35], [36]. The vehicle-mounted terminal utilizes an SDR-based OAI 5G NR NTN stack with SIB19-based timing advance compensation for GEO delays. Multi-Link Gateways manage UDP-tunneled traffic and trigger automatic handovers emulating 3GPP SSC Mode 3 based on a 4 dB SINR threshold. Validated across lab, OTS, and public-road driving trials in Erlangen, Germany, the setup demonstrated zero-packet-loss emergency messaging, video streaming up to 2.5 Mbps, and IP session continuity during seamless TN↔NTN handovers.
- *6G LINO* targets a reconfigurable 16U CubeSat laboratory in polar LEO (500–600 km) for 5G-Advanced and 6G experimentation [37]. Built on an AMD Versal adaptive SoC, the satellite executes an OAI-based regenerative gNB with integrated UPF and optional hardware low-PHY acceleration. The project validates direct NR-NTN access, transparent/regenerative payloads, voice calls, TN-to-NTN handovers, AI-driven spectrum management, and dynamic on-orbit software updates, paving the way for an open in-orbit testing platform for external experimenters.
- *ETHER* develops a unified, energy- and cost-efficient 3D architecture integrating terrestrial, aerial, and multi-orbit satellite layers under a common 5G Core toward 6G [38], [39]. Within its direct handheld Ka-band access showcase (UC2), ETHER employs OAI for its RAN stack, validated via a hardware-in-the-loop setup with FPGA-based LEO channel emulation. The platform demonstrates beam-steerable handheld tracking antennas and energy-aware vertical TN-to-NTN handovers, incorporating dynamic selection between OFDM and OTFS modulations based on Doppler conditions.
- *6G-DIFERENTE* evaluates TN/NTN mobility continuity for emergency vehicle tracking across a federated testbed. OAI provides both the RAN and Core software, running the 5G NR gNB stacks (band n78 for TN, GEO configuration for NTN) connected to a unified OAI 5G Core (CN5G) instance. Using progressive channel emulation—from OAI RFSimulator and GNU Radio up to a commercial Keysight PropSim F64 emulator, the OAI setup confirmed synchronization tolerances, achieved a complete 5G NR attach, and sustained 2–3 Mbps throughput. The trial validated coordinate- and link-monitoring-based application handovers with a 100% success rate, maintaining service continuity at 60–80 ms (TN) and 300 ms (GEO) latencies.
- *5G Nanosatellite* evaluates spaceborne 5G NTN feasibility using OAI across both space and ground segments for a 3U Sun-synchronous CubeSat (500 km) scheduled for launch in 2027 [40], [41]. OAI serves as the baseband software for the spaceborne 5G UE running on an AMD Xilinx Zynq UltraScale+ RFSoC platform, while the three ground stations utilize an OAI-based gNB stack paired with Ettus USRP SDRs. The architecture optimizes the OAI UE stack for ARM-based embedded processing with FPGA task offloading, managing CP-OFDM peak-to-average-power ratio under channel nonlinearities. Ground trials at Altice Labs successfully demonstrated real-time camera video streaming over OAI, targeting in-orbit validation of multi-gNB IP handovers (every 3–6 min) and over-the-air firmware upgrades.
- *SPAICE* evaluates COTS-based onboard AI/ML algorithms and signal processing for a 12U Sun-synchronous LEO (600 km) partially regenerative payload on an AMD Versal AI Edge and RFSoC SDR platform [42]. OAI serves as the standard-compliant 5G NR network framework providing both gNB-DU (Split-7.2x) and UE instances, generating traffic and handling upper-layer gNB-DU/MAC scheduling around the payload. The payload offloads downlink low-PHY processing (CP-OFDM, digital front-end, time-domain beamforming) while real-time AI models execute onboard to optimize beamwidth, EIRP, and adaptive beamforming coefficients. Evaluated across emulated LEO beams and channel conditions, the setup uses OAI gNB-DUs and UEs to close the end-to-end communication loop, dynamically feeding traffic demand back into the AI payload manager.
- *5G-EMERGE* envisages to develop an open multi-tenant ecosystem that seamlessly integrates Near Edges well connected to Satellite Teleport with distributed Far Edges through a virtualised satellite connection to 5G- base stations [43]. This solution is a hybrid, native IP, infrastructure based on open standards to deploy edges in both 5G and non 5G-network head-ends, home networks and networks in vehicles. The edge architecture can host applications and expose popular content transparently to end-users, with caching and satellite backhaul as core service.
- *COSMIC* evaluates 5G-NTN Direct-to-Vehicle (D2V) communications over Mobile Satellite Systems, utilizing the C-band spectrum for LEO satellites [44]. The testbed leverages the OAI 5G-NTN suite for both the gNB and UE stacks to support antenna validation and assess C-band NTN channel impairments.
- *REMUS* evaluates a 3GPP-aligned multi-connectivity framework to ensure enhanced reliability and service continuity across complex multi-orbital (LEO, MEO, and GEO) satellite networks [45]. The evaluation relies on OAI to instantiate concurrent terrestrial and NTN 5G NR gNB stacks connected to a unified Core and advanced FPGA-based channel emulators. By adapting the OAI

UE to monitor multiple orbital links simultaneously, the architecture manages extreme differential delays across disparate orbits.

- *6G-NTN^2-NEXUS* evaluates unified terrestrial and non-terrestrial 6G architectures to enable direct-to-mobile platform/vehicle broadband connectivity and integrated Positioning, Navigation, and Timing (PNT) systems [46]. The architecture combines multiple OAI gNBs connected to a single core network, an O-RAN controller, and a multi-channel satellite emulator to establish a 4-satellite-in-view scenario enabling GNSS-independent PNT. An OAI UE, featuring optimized delay and Doppler tracking loops, provides PNT observables and satellite ephemeris to the navigation motor, successfully resolving the position and time of the mobile UE.

Taken together, these projects show how OAI is being reused beyond basic NTN link validation as a building block for integrated TN/NTN mobility, multi-orbit multi-connectivity, federated experimentation, onboard RAN processing, in-orbit systems, AI-assisted satellite-network research, and NTN-based positioning and timing.

VI. Mapping OAI Capabilities to 6G-NTN Research Challenges

OAI does not currently implement a 6G-NR or 6G-NR-NTN air interface. Its modifiable 5G-NR stack nevertheless offers a practical starting point for investigating selected B5G/6G-NTN challenges identified in Section II. Table V relates these challenges to features available in the public OAI codebase and to evidence from OAI-based projects, distinguishing publicly available capabilities from project-specific demonstrations. This section then outlines concrete extensions and controlled experiments through which the remaining challenges could be studied.

Overall, OAI already provides several relevant NR-NTN building blocks, while the cited projects demonstrate how these capabilities are being extended toward broader 6G-NTN objectives. The remaining gaps therefore concern complete multi-orbit operation, native AI control, NTN positioning and sensing, satellite-specific resilience and security, and energy-aware operation.

VII. Conclusion

6G-NTN research requires experimental platforms that go beyond abstract simulation by enabling standard-aligned, end-to-end, and reproducible prototyping under realistic NTN conditions. This paper positions OpenAirInterface5G as a practical candidate for this role by combining three complementary elements: an established 5G-NTN implementation and validation baseline, adoption across European and industry-supported B5G/6G-NTN projects and experimental activities, and a mapping that links emerging research directions to concrete implementation and validation paths within OAI. OAI can strongly support implementation-level investigation of topics such as multi-orbit integration, regenerative architectures and functional splits, AI-driven NTN control, NTN positioning and sensing, satellite-specific resilience and security, and energy-aware operation while retaining realistic cross-layer protocol interactions. The key takeaway is not that OAI already implements a future 6G air interface, but that its open and modifiable NR-NTN stack provides a credible experimental foundation on which early 6G-NTN concepts can be introduced, evaluated, and progressively matured.

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TABLE IV
PROJECTS AND EXPERIMENTAL ACTIVITIES USING OAI FOR NTN (2021–2026)

Project	Funder	Period	Orbit/Platform	OAI Role	Ref.
OAI-Based 5G-NTN Foundations					
5G-GOA	ESA ARTES	2021–2022	GEO (transparent)	gNB+UE prototypes; PHY/MAC/RLC/PDCP NTN extensions; GEO over-air demo	[6], [32]
5G-LEO	ESA ARTES	2021–2023	LEO (transparent)	Full Rel-17 NR stack (gNB+UE); NGSO support; merged into OAI main branch	[9], [33]
ENGAGE	Industrial (SES)	2022–2023	GEO (real satellite)	Over-the-satellite OAI testbed; USRP X300; DVB-S2X comparison	[12], [21]
5G-METEORS	ESA ARTES	2022–2024	GEO (real satellite)	Over-the-air 5G NR over GEO; OAI-based gNB/UE demonstrations	[34]
Ongoing B5G/6G-NTN Projects					
SEVECODE	ESA ARTES	2023–ongoing	GEO (TN/NTN)	SDR-based OAI UE stack with SIB19 TA for hybrid V2X continuity	[35], [36]
6G LINO	ESA	2023–ongoing	LEO (CubeSat)	Onboard regenerative gNB with UPF integration on Versal SoC	[37]
ETHER	SNS JU	2023–2026	Multi-platform (TN/NTN)	RAN software stack for Ka-band handheld showcase (UC2); HIL LEO emulator	[38], [39]
6G-DIFERENTE	Horizon Europe	2023–ongoing	Multi-platform (TN/NTN)	Federated TN/NTN testbed; n78 TN gNB, GEO NTN gNB, and OAI CN5G	[47], [48]
5G-Nanosatellite	ESA IC	2024–2029	LEO (CubeSat)	Onboard 3U UE (RFSoC) and 3 ground gNBs (USRP); launch 2027	[40], [41]
SPAICE	ESA ARTES	2021–2026	Regenerative payload	OAI gNB-DUs and UEs provide 5G-NR context around Versal AI payload	[42]
COSMIC	FNR JC5G (SES)	2025–2028	LEO (C-band, D2V)	OAI 5G-NTN gNB+UE stacks for C-band antenna validation and channel-impairment assessment	[44]
REMUS	FNR BRIDGES (SES)	2026–2029	Multi-orbit (LEO/MEO/GEO)	Concurrent terrestrial + NTN OAI gNB stacks on a unified core with FPGA channel emulators; multi-orbit-aware OAI UE	[45]
6G-NTN^2-NEXUS	HE SNS JU	2026–2029	Multi-GEO/LEO (PNT)	Multiple OAI gNBs + O-RAN controller + multi-channel satellite emulator; OAI UE with Doppler/delay tracking for GNSS-independent PNT	[46]

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TABLE V
MAPPING OF 6G-NTN CHALLENGES TO EXISTING OAI CAPABILITIES AND PROJECT ACTIVITIES

6G-NTN challenge	Available capability or project evidence	Current limitation
Multi-orbit integration and 3D multi-connectivity	OAI supports multi-gNB/multi-DU configurations, F1-based handover, SIB19 exchange, and dynamic NTN-state updates (MRs !2899, !2920, and !3398). NTN-specific mobility is under development in MR !2716. TN/NTN mobility has also been studied in SEVECODE, ETHER, and 6G-DIFERENTE [35], [36], [38], [39], [47], [48], while REMUS adapts an OAI UE to monitor concurrent LEO/MEO/GEO links and manage their differential delays [45].	Concurrent connectivity and coordinated mobility across multiple satellite orbits are still being validated rather than available as complete, generally-usable OAI functions.
Regenerative payloads and distributed processing	OAI supports CU/DU separation over F1, multi-DU operation, F1-based handover, CU-CP/CU-UP separation over E1, and multiple CU-UPs [49], [50]. OAI-based regenerative and onboard-processing architectures are being investigated in 6G LINO and SPAICE [37], [42].	Dynamic function placement under time-varying feeder-link, processing, and onboard-resource constraints requires further development.
AI-driven closed-loop control	OAI provides modifiable scheduling, measurement, and logging functions that can be connected to external control algorithms. AI-assisted beamforming, spectrum management, and payload control are being investigated in SPAICE and 6G LINO [37], [42].	OAI does not currently provide a complete native AI-based NTN control loop.
Integrated sensing, positioning, and timing	OAI implements timing-advance processing, DL Doppler compensation, UL Doppler pre-compensation, and LEO-oriented timing-drift handling, including developments reported in MRs !2893 and !3581. 6G-NTN^2-NEXUS builds on an OAI UE with optimized delay/Doppler tracking loops to derive PNT observables from a multi-satellite emulated scenario, enabling GNSS-independent positioning and timing [46].	These functions provide relevant PHY measurements, but complete, standardized NTN positioning and sensing procedures beyond individual project demonstrations are not currently implemented.
Resilience and security	OAI provides standard mobility, handover, and connection-recovery procedures. NTN-related re-establishment, SIB19 handling, timer behaviour, and target-cell transitions are being hardened through MRs !3360, !3652, !3659, !3666, and !3777. Service continuity has been demonstrated in SEVECODE and 6G-DIFERENTE [35], [36], [47], [48]. A terrestrial OAI gNB extension and xApp have also been used to detect and mitigate RRC signaling-storm attacks in over-the-air tests [51].	NTN-specific resilience across intermittent links and distributed satellite/ground nodes remains incomplete, while dedicated satellite-security mechanisms require further work.
Energy- and compute-aware operation	ETHER investigates energy-aware TN/NTN handover, while 6G LINO and SPAICE use OAI in onboard-processing platforms with hardware acceleration and constrained computing resources [37]–[39], [42]. Terrestrial OAI-based studies have evaluated FPGA-based FFT offloading and power consumption [52], as well as adaptive AI/conventional PHY processing and GPU-power tradeoffs on an OAI–NVIDIA Aerial platform [53].	These projects use OAI as an experimental component; general energy-aware NTN scheduling and power-management functions are not yet available in the public OAI stack.

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