



OPEN
Compute Project



WHITE PAPER: VISION AND ADVANCED CONCEPTS FOR EVENSTAR OPEN RADIO UNIT PLATFORM

VERSION 1.0.0

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Version Table

Note, refer to the OCP Contribution Versions, Revisions and Errata best practices documentation. Versions and revisions are made to this document and logged here. Errata is a separate document such that the contribution specification document it refers to was not revised. Ex: Version 1, Errata E1

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Executive Summary

The global move toward open, disaggregated network architectures is transforming the mobile industry and driving a fundamental reimagining of the Radio Access Network (RAN). This white paper outlines the Open Compute Project's (OCP) vision for an open and modular RAN, realized through the Evenstar project, originally incubated within Meta.

Evenstar builds on Meta's initial concept by focusing on the development of open, cost-effective, and efficient modular Radio Units (RUs) that ensure true multi-vendor interoperability while adhering to 3GPP and O-RAN Alliance specifications. Through implementation of the O-RAN 7.2x split architecture and enhanced Common Public Radio Interface (eCPRI), the project seeks to optimize resource utilization and reduce fronthaul bandwidth requirements.

A core component of Evenstar is the Radio Abstraction Interface (RAI)—a standardized API layer that enables seamless integration of multi-vendor components. This approach provides flexibility for both cost-efficient and premium solutions. Developers can deliver RUs and feature sets tailored to specific use cases without extensive redevelopment, including support for current and future radio waveforms. Modularity extends from system-level components down to analog front ends, leveraging Universal Chiplet Interconnect Express (UCIe) and OCP Open Domain Specific Architecture Bunch of Wires (BoW) for die-to-die connectivity. This approach allows cost-effective scalability from 4T4R to massive MIMO configurations. The design also employs Linux-based containerization, features configurable antenna systems for sub-6GHz and mmWave bands, and provides intelligent power management for both indoor and outdoor scenarios.

Security underpins the Evenstar platform, with a zero-trust architecture implemented from silicon to services. A dedicated Radio Unit Secure Control Module (RU-SCM) root of trust, aligned with NIST SP 800-1611, ensures component integrity throughout the supply chain. The OCP Security Assurance Framework (S.A.F.E.) governs cryptographic verification and secure boot, while integration with Internet Engineering Task Force (IETF) Supply Chain Integrity, Transparency, and Trust (SCITT)¹ ensures immutable supply chain tracking. Furthermore, the CI/CD pipeline incorporates Supply-chain Levels for Software Artifacts (SLSA) guidelines², automating the validation of software, firmware, and FPGA configurations.

This initiative elevates wireless network architecture by offering a flexible, secure, and cost-effective infrastructure built upon open standards, modular design, and robust security practices. The project's success depends on continued industry-wide collaboration. We invite all stakeholders to join us in defining a new era of open, innovative mobile connectivity.

¹ <https://datatracker.ietf.org/wg/scitt/about/>

² <https://slsa.dev/>

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1 Introduction

The Open Compute Project (OCP) is a collaborative effort to address specific challenges in the open within the technology infrastructure domain. It brings together diverse individuals and organizations with shared interests and expertise to develop open system specifications, best practices, and thought leadership, focusing on software, firmware, specifications, and holistic solutions.

This white paper outlines the history of the Evenstar project and its journey from its inception to reimagining a 3GPP-compatible wireless radio unit.

Vision Statement

The Open Compute Project (OCP) envisions a future where the complexities of interoperability and supply chains are no longer barriers to innovation. To this end, we aim to develop open, modular, and interoperable radio units that, combined with OCP's modular specification process, create a flexible “palette” of solutions drawn from a diverse, multi-supplier ecosystem. By defining specifications for an open 5G/xG radio platform aligned with 3GPP standards, O-RAN Alliance specifications, and relevant [ATIS zero-trust and supply chain](#) security requirements, OCP seeks to democratize radio technology—unleashing innovation, driving ecosystem growth, reducing costs, and accelerating next-generation wireless deployments in critical infrastructure.

This vision spans an end-to-end, open, transparent, and traceable development pipeline. It begins with open design principles across hardware (HW), software (SW), and OCP's domain expertise to achieve HW/SW Co-design. It also incorporates continuous integration standardization. This holistic approach fosters a robust supply chain, bringing together best-in-class software, testing, manufacturing, regulatory compliance, and interoperability efforts, culminating in streamlined deployment and ongoing support.

Finally, OCP is committed to making these radio units' design, deployment, and operation as simple as possible—on par with, or even easier than, today's enterprise wireless solutions. This emphasis on simplicity is especially important for private wireless networks, where ease of use is key to lowering barriers to adoption.

Brief Introduction to Open RAN

Mirroring trends in data center computing and networking, mobile operator radio access networks (RAN) have seen pressure towards openness, virtualization (vRAN), and disaggregation. The forces that prompted carriers to show interest in software-defined networking (SDN), network function virtualization (NFV), disaggregation, white box, and cloud platforms are also driving Open RAN initiatives (with the additional factor of geopolitics).

To help coordinate and unify global efforts, telecom providers founded the O-RAN Alliance in 2018 to formalize and standardize an open RAN architecture. The core design for the O-RAN Alliance's open RAN is based on three elements: the centralized unit (CU), the distributed unit (DU), and the radio unit (RU). The Alliance also defines the standardization of the functional splits between the core, CU, DU, RU, and the interfaces that connect and allow an operator to interact with them.

The Evenstar project is focused on the radio unit (RU) within the Open RAN architecture.

History of Evenstar

Meta's Evenstar project started with the goal of building a low-cost, outdoor 8T8R 5G Open RAN-compatible radio unit. The idea was to create a solution that is easily deployed and integrated into existing wireless networks while adhering to open standards and specifications. Meta's extensive work laid the foundation for a more open and collaborative approach to radio unit design, development, and cross-component interconnection.

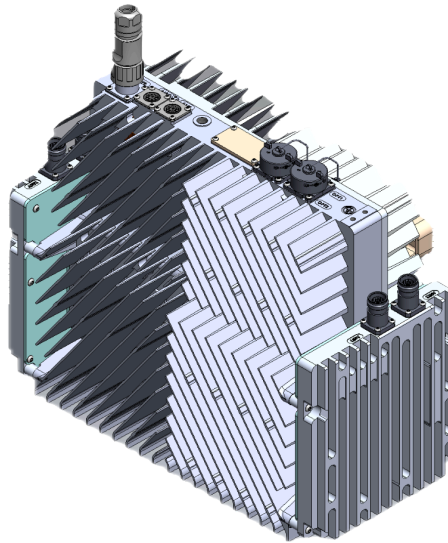


Figure 1: 3D Rendering of the 8T8R 5G Open RAN compatible radio unit

Recognizing Evenstar's potential industry impact, Meta contributed the project to the Open Compute Project (OCP). Meta's goal was to leverage OCP's expertise, community, and resources to further develop and refine the design, making it accessible to a broader range of wireless industry stakeholders. That's how the OCP Evenstar Workstream was born.

For more information, you can consult the [OCP Contribution Evenstar Base Specification](#). The actual design files are contained within the OCP Evenstar repository.

From the Previous Evenstar Specification to Our Vision

Building on Meta's foundation, OCP's Evenstar Workstream is evolving the initial design into an open 5G/xG radio unit platform. This expanded scope will move beyond the original outdoor radio unit to a versatile platform adaptable to many use cases and deployment scenarios that have emerged in recent years but weren't addressed in the initial design.

OCP has established a collaborative framework to achieve this vision, bringing together industry leaders, hardware and software developers, and academic institutions. This diverse community will work together to define the specifications, architecture, and interfaces of the open radio unit platform, ensuring compatibility with 3GPP and Open RAN specifications. The platform will

support key features along the 3GPP and O-RAN Alliance roadmaps, using best-in-class solutions, technologies, and sustainability practices. This effort will be further enhanced through cross-collaboration with other OCP projects.

The path from Evenstar's original RU to an Open RAN compatible open RU platform includes several key milestones:

- **Establishing a modular and scalable wireless architecture**, allowing easy tailoring to diverse vertical applications, enable RAN-to-RAN interoperability (e.g., X2/Xn interfaces), facilitate customization, and support upgradability of radio units to support multiple RF waveforms via Radio Frequency Integrated Circuits (RFICs) or Software-Defined Radios (SDRs). It should also scale from single- to multi-carrier operations.
- **Providing for optional but scalable AI-capable onboard acceleration** by leveraging high-performance interconnects. This provides optionality to support advanced AI functionality as needed.
- **Developing and integrating open interfaces and communication protocols** based on the Radio Abstraction Interface (RAI) to ensure interoperability between different vendors' components, similar to the Switch Abstraction Interface (SAI) used in projects like SONiC.
- **Optimizing the platform for power efficiency, reliability, and security** using components like those found in OCP's [Datacenter Secure Control Module](#) (DC-SCM) to meet the unique challenges of 5G and future wireless networks. It should also support advanced Power Amplifier (PA) designs, including classes F/G/H.
- **Developing and integrating open interfaces and communication protocols** to enable interoperability across multiple vendors. A Radio Abstraction Interface (RAI) similar to the Switch Abstraction Interface (SAI) defined by OCP's Networking project and used in the popular SONiC initiative would enable a plug-and-play ecosystem across diverse stakeholders.
- **Providing comprehensive documentation, reference designs, and testing frameworks** to support the deployment and integration of open radio units into wireless networks.

- Fostering a vibrant ecosystem of hardware and software partners to drive innovation and accelerate adoption.** This includes encouraging broad participation across the supply chain, promoting open collaboration, and helping end users discover solutions via OCP thought leadership and tools like the OCP Marketplace.

OCP's Collaborative Design Process for Accelerated Evenstar Development

The Open Compute Project (OCP) has a wide range of domain expertise gained in defining the state of the art in IT equipment and data center technology. Collaboration between Evenstar and these areas (e.g., edge systems, hardware root of trust, synchronization and timing, chiplets, AI design, advanced interfaces and composability, photonics, and advanced manageability) allows for rapid design reuse, reducing effort and achieving advanced functionality that may not be available in commercial radio platforms.

To facilitate this design reuse, OCP utilizes its Modular Specification process, enabling community collaboration on problem definition and concept integration. As ideas progress, they evolve from initial frameworks to production-ready specifications. The diagram below illustrates this process.

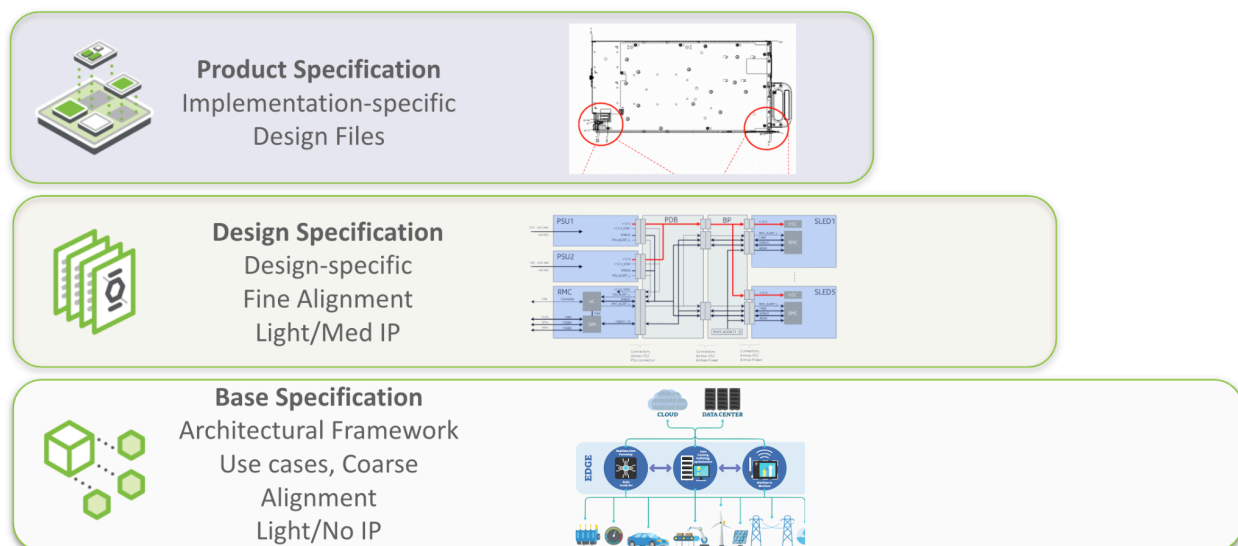


Figure 2: Modular Specification Process Layers

The OCP Modular Specification process³ mirrors the principles of software development, where Application Programming Interfaces (APIs) relied on to enable modularity and extensibility. Likewise, OCP's Modular Specification defines an extensible solution family that maximizes component commonality. This 'build once, refine many' approach allows core requirements to be established and then tailored for specific applications, avoiding costly re-development. The success of the Data Center Modular Hardware System (DC-MHS) and the vision for the upcoming Edge-MHS serve as prime examples.

Edge-MHS Building Blocks

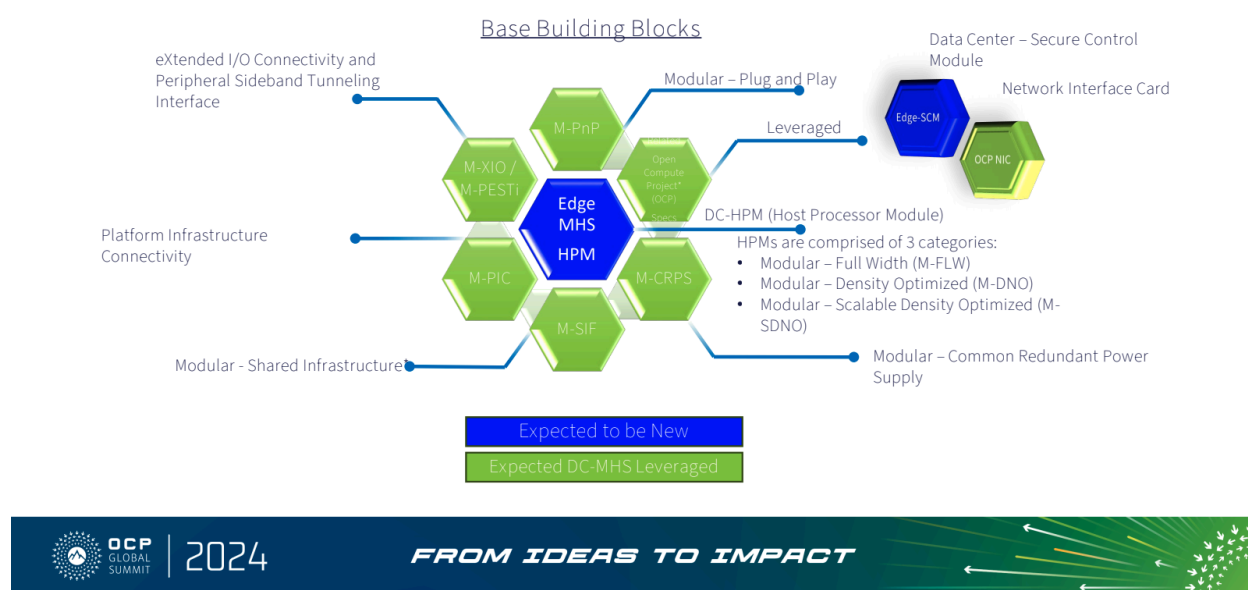


Figure 3: Slide Presented at 2024 OCP Global Summit showing MHS Building Blocks

At the 2024 OCP Global Summit, Dirk Blevins and Vincent Nguyen highlighted the MHS Building Blocks⁴ (Figure 3), showcasing a 'plug and play' architecture designed for seamless integration of common components. This concept extends from the data center core to the far edge, promoting maximum commonality. Since the introduction of MHS specifications in late

³<https://146a55aca6f00848c565-a7635525d40ac1c70300198708936b4e.ssl.cf1.rackcdn.com/images/e5fce25b79e3ea02fae512735809e90bb961bb0c.pdf>

⁴ <https://www.youtube.com/watch?v=jiL7LKXBp60>

2022, a vibrant ecosystem has emerged, fostering a marketplace for suppliers and enabling new features like workload composability for end users. Evenstar can leverage this proven model.

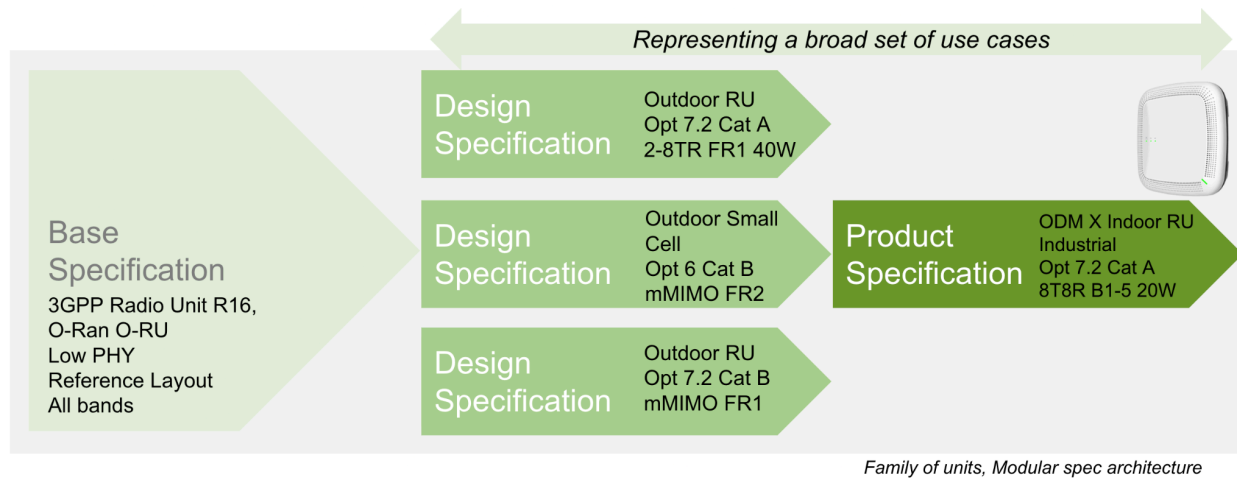


Figure 4: Conceptual specification path to 8T8R 5G OpenRAN compatible indoor open radio unit for production

To illustrate, consider how the OCP Modular Specification process could be applied to build an Open Radio Unit platform (Figure 4). A base specification for a 3GPP-compatible, Open RAN-compliant Open Radio Unit could define common elements such as processing and transceiver architecture. These requirements can then be adapted for specific design specifications for various market segments. From these refined designs, open products can be developed and brought to market.

The Evenstar platform is designed to incorporate the best technology available, inside and out. For example, we can integrate industry-leading Network Interface Cards (NIC) developed by the OCP Networking Project, saving time and leveraging existing expertise. Other valuable OCP contributions, such as chiplet technology, robust security frameworks, edge computing solutions, and advanced cooling techniques, can also be seamlessly woven into the design.

Empowering Accessible and Simplified Wireless Networks

The Open Compute Project (OCP) Evenstar Open Radio Platform aspires to redefine wireless network infrastructure, making it open, transparent, and accessible. Supporting Open RAN and 5G/xG deployments and others via its open waveform approach, this flexible platform fosters collaboration and innovation among operators, vendors, and developers—ultimately aiming to deliver cost-effective, high-performance, and sustainable wireless services worldwide.

A key objective is to simplify the design, deployment, and operation of radio units, making them as easy to manage as enterprise Wi-Fi networks. This simplicity is crucial for private wireless networks, where organizations may not have specialized telecom expertise, promoting wider adoption of advanced wireless technologies.

The availability of a truly open, 3GPP-compatible Open RAN RU enables individuals and organizations to experiment with and explore new designs and use cases. Just as Raspberry Pi, DD-WRT, and OpenWRT spurred innovation in IoT and home networking, an open mobile platform can unleash a “long tail” of wireless innovation—fueling fresh ideas, applications, and markets.

2 General-purpose RAN Software Architecture

This reference architecture prioritizes **modularity, efficiency, and openness**. The design supports a multi-vendor supply chain for digital and wireless components, enabling integration into various solutions for traditional telecom providers and enterprise/private networks. Its scalability accommodates diverse vertical applications (e.g., agriculture, manufacturing, retail). Modularity allows Radio Units (RUs) to function as adaptable building blocks, with configurations tailored to specific use cases—minimizing design effort overall and leveraging component scale economies while enabling customization—a significant advancement over current RU platforms.

Logical/SW Entities - HW Entities

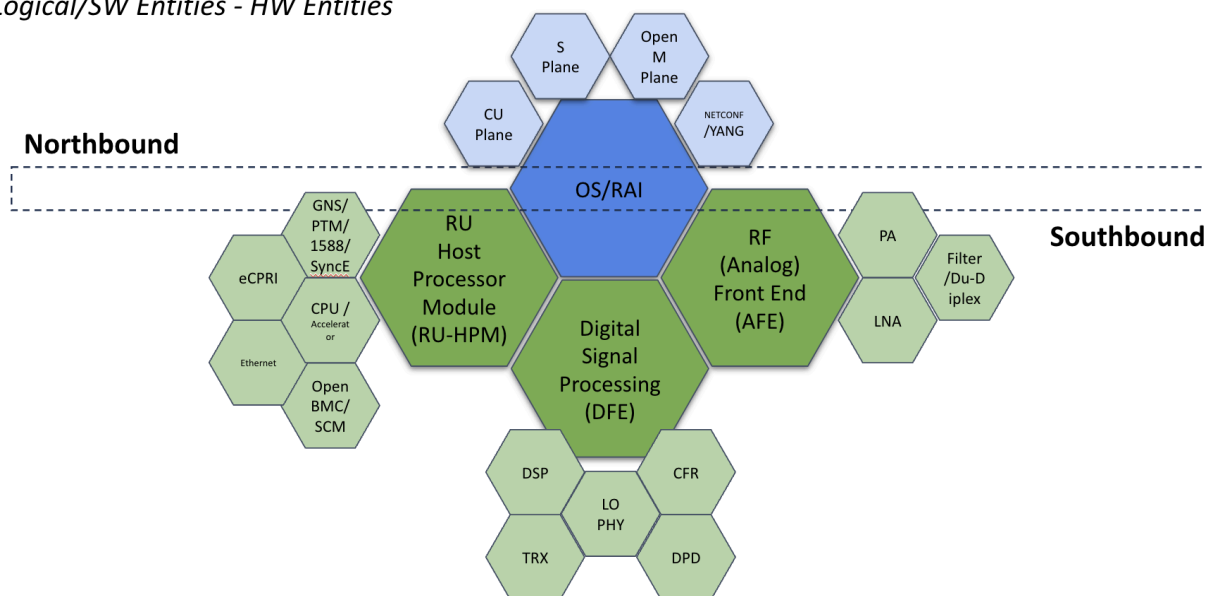


Figure 5: Fundamental building blocks towards radio modularity in an Evenstar OpenRU.

In addition to modular, scalable hardware, the architecture is designed with an open software stack for extensible feature support. It can accommodate 3rd-party software layers in a highly

flexible and easily integrated system ready for deployment. Security features ensure the HW platform, SW, and firmware are protected, manageable, and resilient.

Figure 5 illustrates the software stack's fundamental functional blocks. The blue blocks represent software, and the dark green blocks represent logical entities. The remaining components may be discreet or aggregated, either as physical or logical stages or devices. Central to the design is the **Radio Abstraction Interface (RAI)**, which bridges the Application Programming Interface (API) in Linux user space with the underlying software drivers and hardware layers. The RAI provides a consistent interface for developers, creating an abstraction over different hardware, each of which may require different functionality to interface between logical entities and the software/firmware components. Disaggregation via modular packaging also allows mix-and-match RU components (RF Front End, Compute Interface Module, RF Digital Subsystem) from different vendors, promoting flexibility and innovation while supporting customization and rebranding.

Containerization further enhances software portability and agility. Decoupling the OS from the physical RU 'bare metal' allows a build-once portability for the developer and technically lets radio digital subsystem applications operate independently. For example, enabling network slicing at the RAN while maximizing flexibility for rapid deployment and updates. Supporting containers or sandboxes for use in safe customization environments is also possible.

The architecture's extensibility accommodates diverse configurations. For instance, we could integrate support for the **Switching Abstraction Interface (SAI)** of the SONiC Project, opening up a broad ecosystem of networking hardware (FPGAs, ASICs, CPUs) for advanced wired networking. SAI streamlines design, offering vendor-independent interface control via standardized APIs. This enables rapid adaptation for specific applications using a consistent interface and shared application stack, simplifying the base router platform and accelerating time-to-market. This feature could prove valuable for Ethernet backhaul and future applications.

Additionally, the architecture can integrate third-party APIs, such as the [Small Cell Forum's](#) Functional Application Platform Interface (FAPI). This would allow the Evenstar Open RU platform to be configured as a 5G small cell, with developers only needing to build virtual layers using the RAI.

An ideal OS for hosting these abstraction layers would be open, lightweight, and well-supported. Potential candidates include the Linux Foundation's [Zephyr](#), other Linux-based OSes like [SONiC/DENT](#), or even BSD-based OSes like [FreeBSD/OpenBSD](#). If the priority is an OS with strong community support and existing momentum, SONiC or DENT are particularly appealing: both are open and already integrate SAI, making the addition of RAI support relatively straightforward. Nevertheless, the project remains open to other possibilities.

Ultimately, the vision for Evenstar is for an open and modern radio platform with composable hardware and software modularity that aligns with 3GPP/Open RAN specifications.

3GPP Reference NG-RAN and O-RAN Architecture Overview

O-RAN Alliance Specifications

The Evenstar project leverages the O-RAN Alliance open fronthaul specifications (CUS- and M-Plane) between the DU and RU, as outlined in O-RAN Alliance WG4. The O-RAN reference architecture provides a flexible, open framework for next-generation wireless networks, incorporating openness, virtualization, and disaggregation to enable innovation and interoperability across the network stack.

Adhering to 3GPP guidelines ensures O-RAN deployments seamlessly integrate with existing cellular networks and leverage advancements in radio access technologies.

3GPP Reference NG-RAN Architecture Overview

Release 15 of 3GPP introduced the Next Generation RAN (NG-RAN) architecture. This architecture departs from traditional monolithic base stations by splitting the 5G protocol stack into a Central unit (CU) and a Distributed Unit (DU) connected via the F1 interface.

The DU manages the PHY, MAC, and RLC layers, while the CU handles the remaining 5G protocol stack layers. Notably, AI/ML algorithms, models, and model performance feedback details fall outside the 3GPP's scope (3GPP TS38.300).

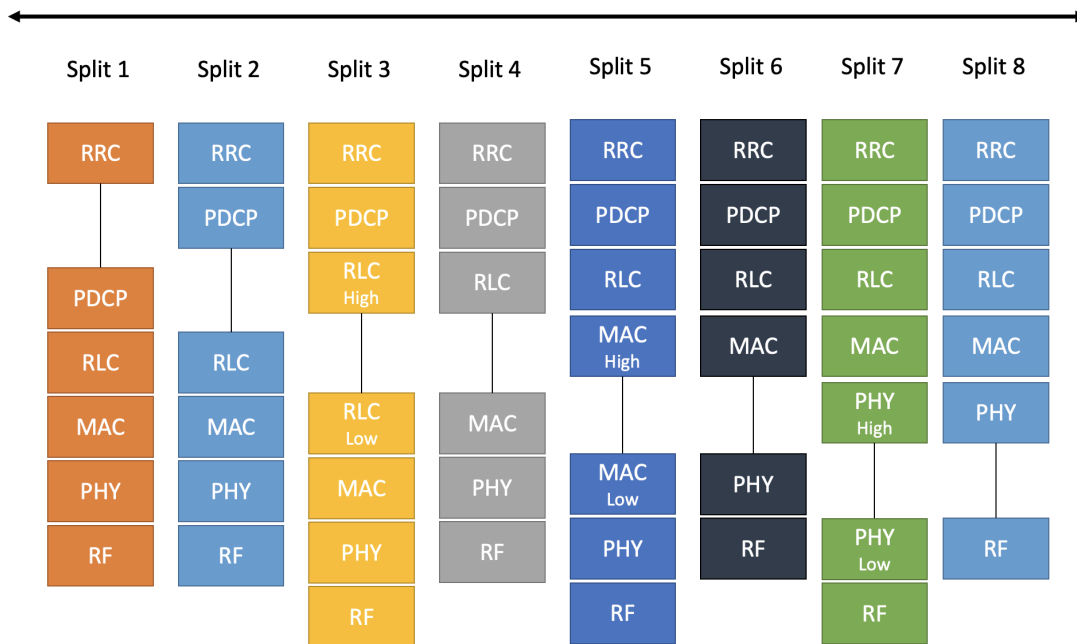


Figure 6: O-RAN defined 5G functional splits

As mentioned, the O-RAN Alliance further defines the component responsibilities. In the 7.2x split, the RU houses the RF and lower PHY; the DU handles the higher PHY, MAC, and RLC protocols; and the CU manages the rest of the 3GPP 5G protocol stack. Figure 7 illustrates this division.

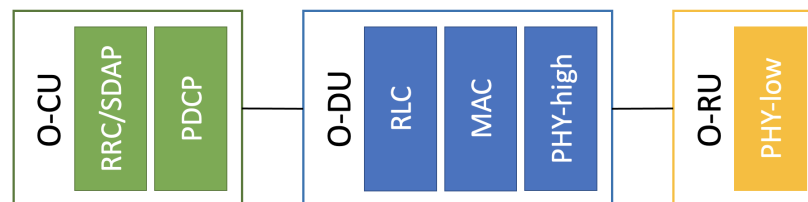


Figure 7: O-RAN CU-DU-RU stack split

Numerous operators are exploring O-RAN solutions featuring open fronthaul, open northbound interfaces, and disaggregated components, all while adhering to O-RAN Alliance standards. This approach promises enhanced network intelligence, diversified suppliers, and reduced TCO—a key competitive advantage. Figure 8 presents a logical RAN architecture based on O-RAN Alliance specifications, with a baseline of O-RAN Alliance Rel-003 (March 2023).

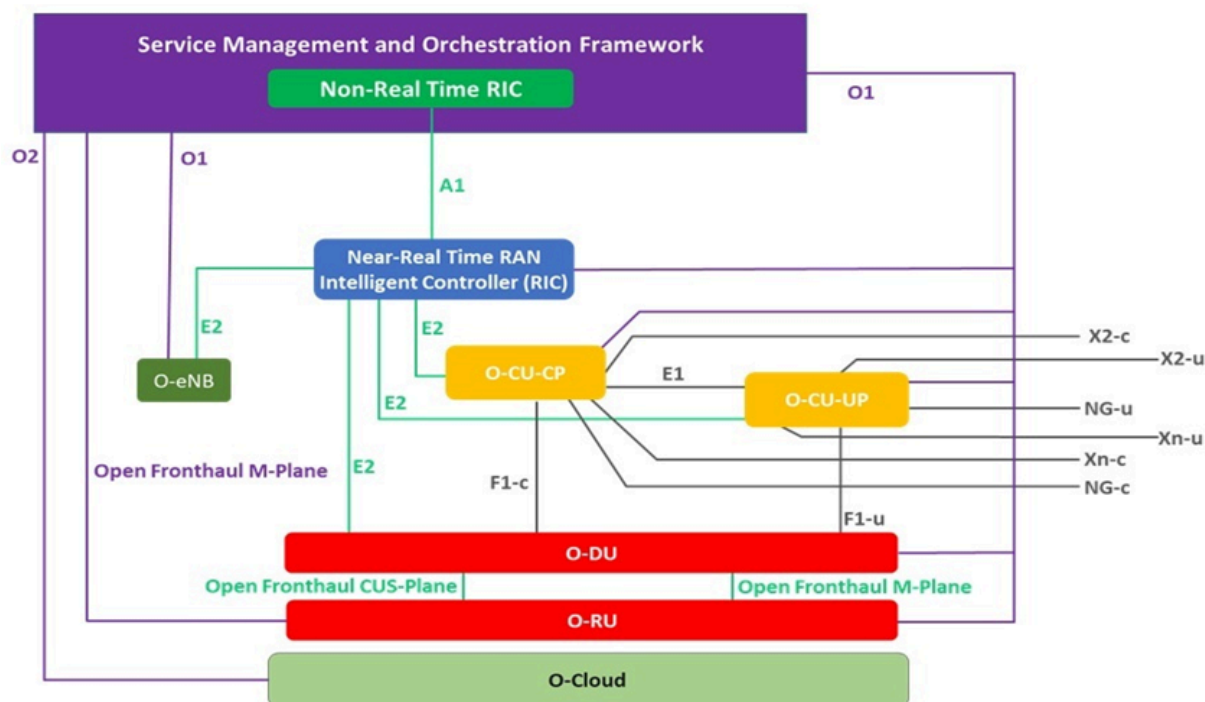


Figure 8: O-RAN Architecture

Key Components of the O-RAN Architecture

Figure 8 illustrates several key O-RAN entities, defined as follows:

- Open Central Unit (O-CU):** This unit manages higher-layer processing and control, including radio resources, mobility, and session management. It interfaces with the core network via RRC, SDAP, and PDCP protocols and orchestrates distributed RU operations.
 - CP (Control Plane):** A logical node hosting RRC and the control-plane PDCP protocol.

- UP (User Plane): A logical node hosting the user-plane PDCP and SDAP protocols.
- **Open Distributed Unit (O-DU)**: This unit handles mid-layer RLC, MAC, and High-PHY processing, such as channel coding, modulation, and beamforming, based on a specified functional split. Placed closer to the RAN edge, it helps minimize latency and optimize radio resource usage.
- **Open Radio Unit (O-RU)**: This unit implements the Low-PHY layer of the wireless interface, including RF transmission/reception and FFT/iFFT functions. It is deployed at cell sites and interfaces with user devices. Although similar to a 3GPP Remote Radio Head (RRH), it is more specific about low-PHY functionality.
- **O1**: The interface between the Service Management and Orchestration Framework (SMO) and O-RAN-managed elements, used for operations and management (FCAPS), software, and file management.
- **O1***: The interface between the SMO and an Infrastructure Management Framework that supports O-RAN virtual network functions.
- **xAPP**: An independent software plug-in for the Near-RT RIC platform, allowing third parties to extend RAN functionality.

O-RAN Alliance Work Groups and Specifications

The O-RAN specification work is divided among multiple technical Work Groups (WGs). WG7, the White-Box Hardware Workgroup, focuses on developing high-performance, spectral- and energy-efficient white-box base stations. Its work includes creating reference hardware and software documentation, detailed schematics, proof-of-concept hardware, and test cases for base station verification and certification.

The proposed WG7 specifications for O-RAN Alliance adoption won't mandate specific chipsets or components. Instead, multiple specifications may be delivered based on deployment scenarios and architecture (e.g., integrated vs. split with multiple LLS). Each specification potentially includes information for O-CU, O-DU, O-RU, and Fronthaul Gateway (if needed).

Waveform Agnostic Radio Units (RU)

A key strength of the Evenstar Open RU Platform architecture is its inherent programmability, enabling “waveform-agnostic” radio units. By adopting a modular hardware and/or software-defined approach, these RUs can dynamically adapt to various waveform technologies—such as LTE, 5G NR, and future 6G—offering greater flexibility, scalability, and interoperability. This allows operators to deploy mixed-generation networks, allocate resources based on real-time demand, and efficiently share spectrum across different radio access technologies (RATs). As a result, operators can reduce costs and simplify logistics by avoiding the need for separate hardware for each waveform.

RU Connectivity

Another key consideration for Evenstar's design is optical connectivity between the RU and DU. The O-RAN FH specification addresses the lower-layer functional split using the Lower-Layer Split M-plane (LLS-M), which facilitates O-RU initialization, configuration, and management (see Figure 9). For legacy RUs, low PHY functionality can be performed in the fronthaul gateways, converting the low-level split interface to the O-RAN fronthaul interface for O-DU connectivity. The fronthaul gateways' Low PHY module can also convert existing Common Public Radio Interface (CPRI) to eCPRI for legacy radio compatibility.

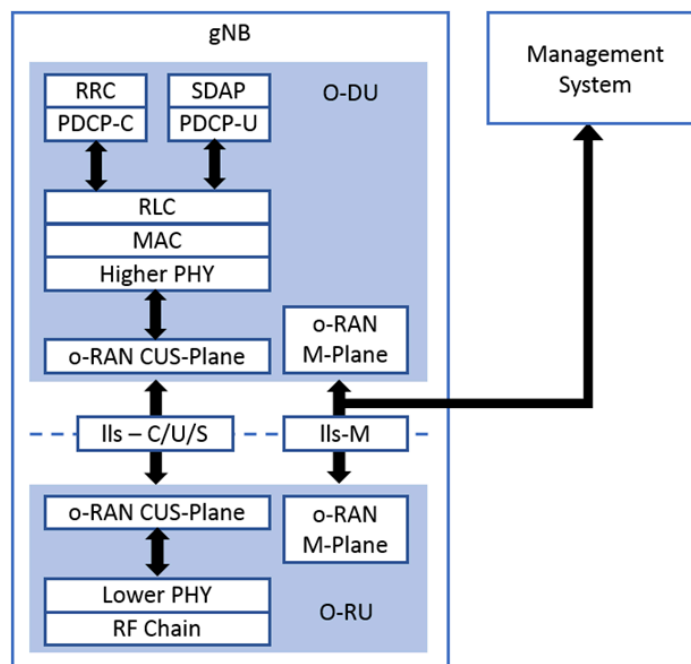


Figure 9: O-RAN Logical Entity Architecture

Both the Common Public Radio Interface (CPRI) and the Ethernet enhanced version, eCPRI handles data transport between base stations and radio units (RUs) and these are typically handled via accelerators. Compared to CPRI, eCPRI offers increased bandwidth, lower latency, and improved synchronization, which are essential for meeting the demands of today's mobile data traffic and higher data rates. The enhanced synchronization provided by eCPRI also improves coordination between multiple base stations, thereby boosting overall network performance. Furthermore, eCPRI's use of optical fiber makes it highly immune to electromagnetic interference. Although eCPRI requires a more complex and costly optical infrastructure, its superior performance makes it the preferred choice for Evenstar RUs in scenarios requiring high bandwidth, low latency, and reliable connectivity. There is also the flexibility to use other Ethernet-based transport methods with various enhancements. It is also worth noting that a design with multiple Ethernet ports—sufficient to connect directly via the 3GPP Xn interface and/or function as local area network (LAN) switch ports—can serve a variety of use cases, from macro cells to small cells.

Development Collaboration with Open Compute Projects

As has been referenced a few times, there are multiple relevant contributions from the OCP Project Community. The Evenstar platform can realize a massive developmental gain from adopting best-in-class OCP Contributions and Subject Matter Expertise (SME) collaboration efforts including:

- Synchronization and timing from the OCP Time Appliance Project (TAP)
- Elements of the Network Interface Card (NIC) from the Server project
- Chiplets from OCP Server Open Domain Specific Architecture (ODSA)
- AI HW/SW Codesign, Accelerators, Platform Root of Trust (PRoT), and systems layout from OCP Server
- Platform firmware management from the Open Platform Firmware (OPF) Project
- Edge computing concepts from both OCP Server and OCP Telco edge projects
- Hardware manageability and RAS from OCP Hardware Management
- Thermal management from the OCP Cooling Environment (CE) Project

And many others.

Infrastructure Collaboration with the Linux Foundation

By embracing open-source software and standardized interfaces, Open RAN deployments can benefit from rapid innovation, community collaboration, and reduced vendor lock-in. The Linux Foundation Connectivity (under the umbrella of the Linux Foundation) fosters many open-source projects and initiatives that advance networking technologies and standards within the Linux ecosystem. It focuses on developing software-defined networking (SDN), network function virtualization (NFV), and connectivity solutions for modern telecommunications, cloud computing, and IoT environments.

One such project is the **Open M-Plane project**, a software component designed to simplify the configuration and management of ORAN-compliant RUs, including FCAPS functions. This hardware-agnostic and ORAN-compliant software offers flexibility to operators integrating third-party RUs. Its key advantage is the inclusion of middle-layer software above the firmware, which communicates with network management servers.

The project's core goals are fully achievable when we consider coupling with the Evenstar **Radio Abstraction Interface (RAI)**, a hardware abstraction layer with APIs that ensure portability across diverse hardware platforms. This abstraction layer simplifies disaggregation with the firmware and connection to relevant APIs, promoting flexibility, innovation, and third-party development, ultimately leading to a wider range of applications and services.

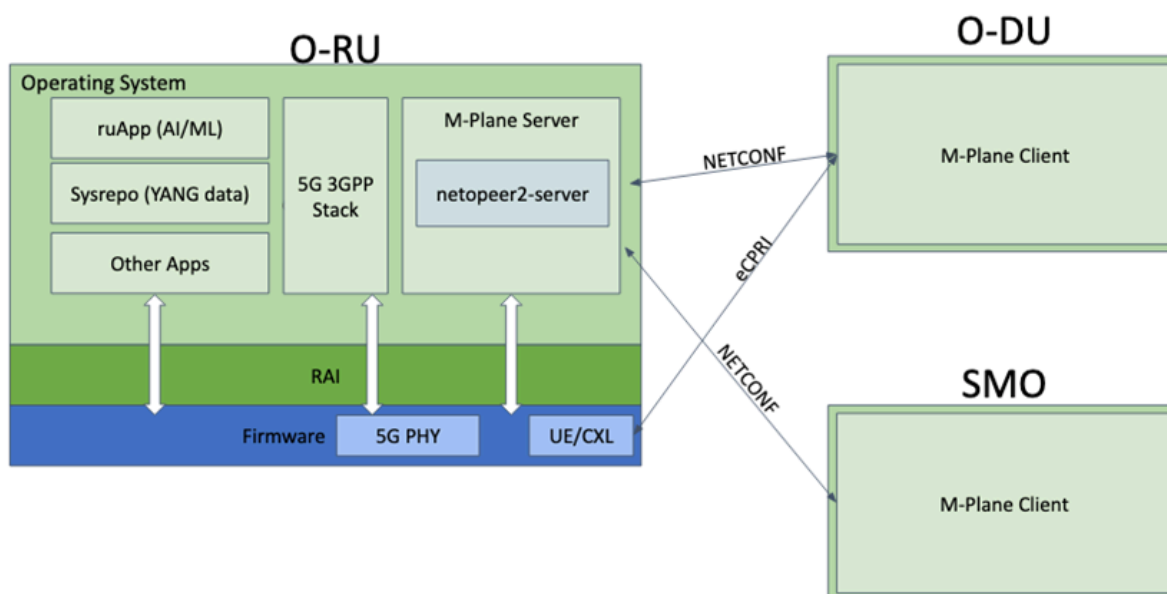


Figure 10: Evenstar Logical Entity Architecture

Furthermore, similar to the dApp module at the O-DU, bringing AI functionality to the edge presents a key opportunity, particularly for use cases where low latency is critical. The ruApp can potentially process applications like smarter DPD or AI/ML-enabled use cases for air interface and RAN-UE collaborations.

3 Radio Modularity

The rapid evolution of communication technology demands highly flexible and scalable RF systems. 3GPP has introduced 5G NR Release 18 in 2023 and are now working toward Release 19⁵. To track evolving standards, an ideal Radio Unit (RU) should be able to adapt or upgrade to meet new requirements. The following roadmap highlights 3GPP's progress:

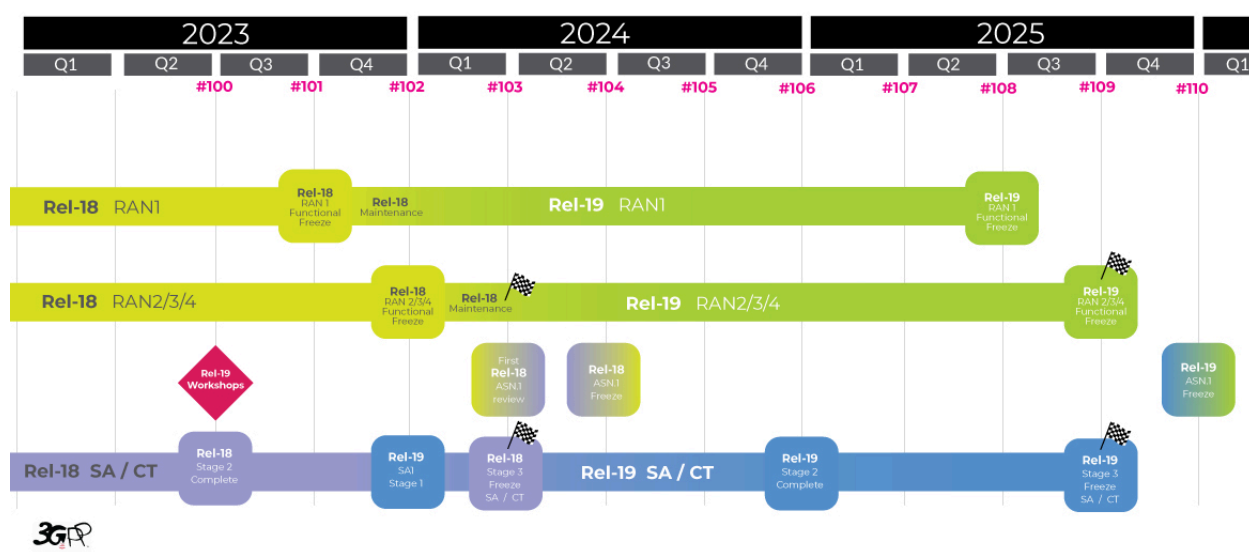


Figure 11: 3GPP Recent Release Roadmap through 2025

Modular antenna RF systems offer unprecedented adaptability and customization. However, the challenge lies in balancing the benefits of modularity against potential increases in development costs and interface complexity.

Finding the sweet spot for modularity depends heavily on the use case. With 5G NR standards evolving rapidly (Figure 11), and the ITU already sketching out 6G,⁶ making radio platforms future-ready with modular design is a smart move. Even 3GPP Release 18 provides numerous options—support for multiple frequencies, flexibility between Frequency Division Duplex (FDD)

⁵ <https://www.3gpp.org/specifications-technologies/releases/release-19>

⁶ <https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx>

and Time Division Duplex (TDD), and scaling from 2T2R indoor setups to massive MIMO arrays like 64T64R, with eyes on 256T256R for high-frequency 6G.

Of course, more modularity means more flexibility and upgradeability, but it also adds complexity and cost. Implementing modularity through physical connections sounds straightforward, but it demands careful planning. Consider the "headwinds": board size, connector choices, manufacturing, and power and data distribution. Designers might opt for mezzanine cards for compactness or multiple boards for easier upgrades. Each path has its pros and cons, so aligning with project needs is crucial.

A key advantage of modular RF systems is their adaptability to specific niches. Designers can select modules tailored to performance, size, and power demands, mixing and matching as needed to meet unique use cases. We're striving for flexibility—whether through a single clever layout or other methods—while avoiding wasted space and resources. The OCP Community has discussed a number of private wireless use cases and there are many more such as public safety. In some instances the features or performance may need to be optimized, others it may be the packaging. Building a solid and adaptable base design specification is the foundation that can unleash innovation. By establishing a robust highly modular base RU, designers can focus on adding new features without reinventing the underlying architecture, accelerating development and ensuring a consistent platform for future advancements.

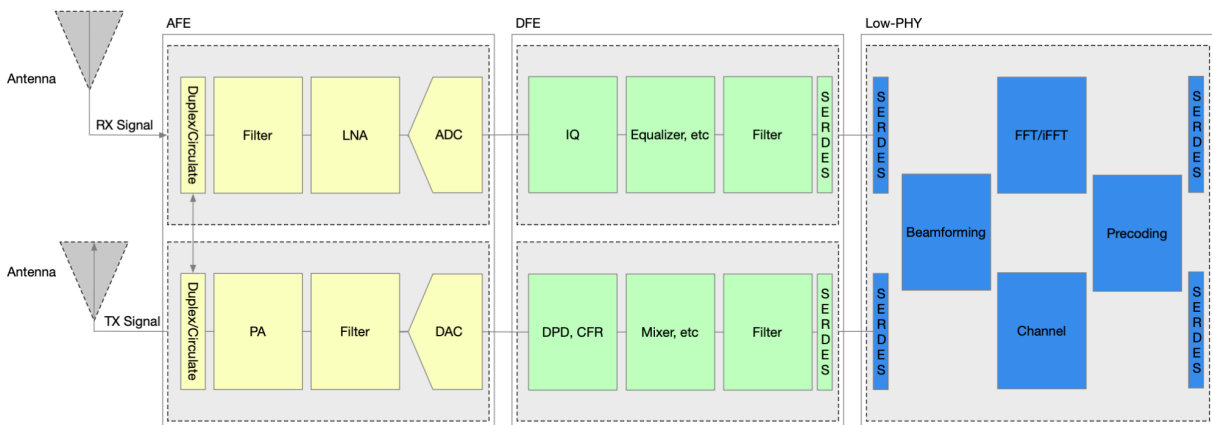


Figure 12: Notional Logical Radio Chain Architecture

Radio Frequency (RF) / Analog Front End (AFE) Considerations

The RF Front End is the link between the digital portion of the RU and the analog realm of radio waves. Its primary job is to transmit and receive RF signals at various operating frequencies. In the popular heterodyne architecture, this stage handles the conversion of RF signals to and from an Intermediate Frequency (IF). One of the main functions of the AFE stage is to adapt the system such that it can operate in a specific frequency range and band.

The 3GPP defines Frequency Ranges (FRs) for mobile services like 5G and 4G LTE. As of 3GPP NR Release 16, these include FR1 (410 – 7125 MHz), FR2 (24.25 - 71.0 GHz), and FR3 (7.125 – 24.25 GHz). Each band can have unique filtering and power requirements, which the AFE design must account for. Looking ahead, it's important to design with future expansion in mind, as there's talk of adding a 4th and 5th range for 6G⁷.

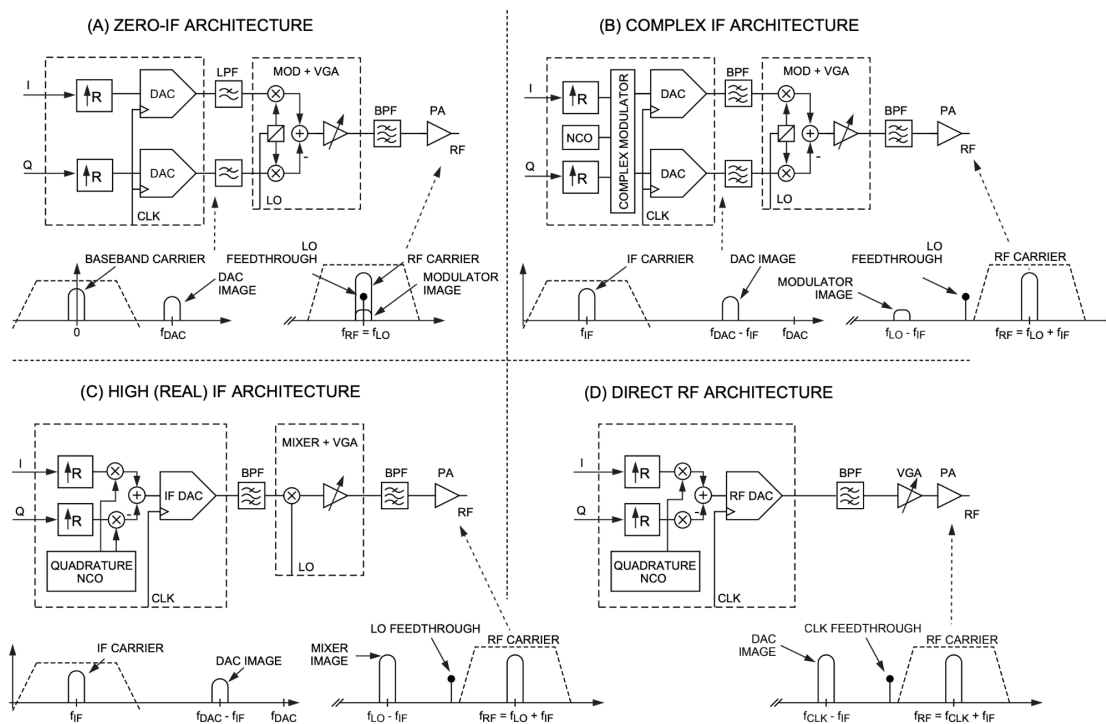


Figure 13: Four Types of Typical Architectures for the AFE

(Source: Analog Devices)

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<https://rww2020.iot.ieee.org/wp-content/uploads/sites/124/2020/01/01-26-2020-Xiaoxia-Zhang-Qualcomm-Presentation.pdf>

In Figures 13B and 13C, the AFE, on the outbound Transmit (TX) path, converts digital samples from the digital signal processing stages through the transceiver into an analog signal using a digital-to-analog converter (DAC). This analog signal then undergoes various operations, such as mixing with a preset RF frequency and modulation, before being sent out through the antenna.

On the receiver path (RX), the antenna system's inbound RF signals are connected to the AFE input through a matching network to optimize signal power transfer. The received signal then passes through a low-noise amplifier (LNA) to boost weak signals while minimizing noise. In a heterodyne architecture, these amplified signals are mixed with a signal from the local oscillator (LO) to down-convert them to the intermediate frequency (IF).

The key advantage of a heterodyne architecture is its long-standing, proven design. Separating functions allows for straightforward, function-specific modifications to accommodate a wide range of applications.

Figures 13A and 13D show an alternative approach without an RF conversion with an IF. Heterodyne radio architecture has remained popular compared to a zero-IF or direct-to-RF design. This is mainly because other design challenges, such as susceptibility to DC offsets, local oscillator (LO) leakage, and poor image rejection, require additional circuitry for proper signal fidelity.

For example, Evenstar's modular design enables AFE composition by choosing a heterodyne approach to handle high frequencies beyond 3GPP FR1 bands. However, this Open RU architecture is flexible and allows implementers to "flatten" the signal chain, for example, as a low-cost solution for small cells or to meet ultra-low latency communication (URLLC) needs. As the state of the art in components evolves, there is the potential to continuously optimize AFE performance beyond the minimum 3GPP requirements, resulting in tangible end-user benefits and driving the need for modularity.

Analog-to-Digital and Digital-to-Analog Conversion

Selecting the proper Analog and Digital conversion performance is key to developing a performant and efficient radio chain.

As mentioned earlier, the DAC is responsible for creating the analog signal for transmission from digital samples. The Analog-to-Digital Converter (ADC) is a vital component on the receiver side. It converts the continuous-time signal into a discrete-time, binary-coded signal. Several parameters characterize ADC performance:

- **Signal-to-Noise Ratio (SNR):** The ratio of signal power to noise power in the output.
- **Resolution:** The number of bits per sample.
- **Spurious-Free Dynamic Range (SFDR):** The ratio of the carrier signal strength to the next strongest noise component or spur.
- **Power Dissipation:** The amount of power consumed by the ADC.

Advances in Software-Defined Radio (SDR) development have driven improvements in ADC performance. For instance, energy-efficient ADCs have been developed to extend the battery life of SDRs, and the evolution of materials has allowed increases in speed and performance allowing for far greater flexibility. Positioning the ADC as close as possible to the received RF signal within the AFE—and similarly placing the DAC near the digital stage—minimizes the RF path, thereby reducing internal signal impairments.

Standardization is important for fostering a diverse and competitive ecosystem of component vendors. When designing the TX and RX chains in the AFE, especially for an Evenstar direct-to-RF approach, it's key to include excellent filtering, favorable gain characteristics, and keep a low noise figure. While we won't discuss details in this paper, subsequent Open RU Base Specifications will define a highly performant TX/RX chain. Furthermore, by establishing a uniform interface and pinout definition for the AFE, we can ensure multi-vendor support and simplify the integration of different AFE modules. Integration with extensible and high-speed interfaces like SERDES-based JESD204C⁸ is essential to provide bandwidth and low latency for demanding applications.

Chiplet-based AFE

The chiplet interconnect concept and the emergence of an open chiplet economy presents exciting possibilities for modular RF systems. By tapping into a market of chiplet components,

⁸ Joint Electron Devices Engineering Council (JEDEC) specification JESD204C.1
<https://www.jedec.org/standards-documents/docs/jesd204c1>

designers can construct radios from diverse and best-in-class RF elements, optimizing for performance and cost. This spurs innovation and competition, potentially yielding advanced and cost-effective solutions. Chiplet tiling, coupled with established die-to-die connection standards like UCle and BoW, offers an efficient path to design AFEs tailored for specific indoor and outdoor modular RF system applications while maintaining cost-effectiveness. This streamlines design and ensures interoperability between modules.

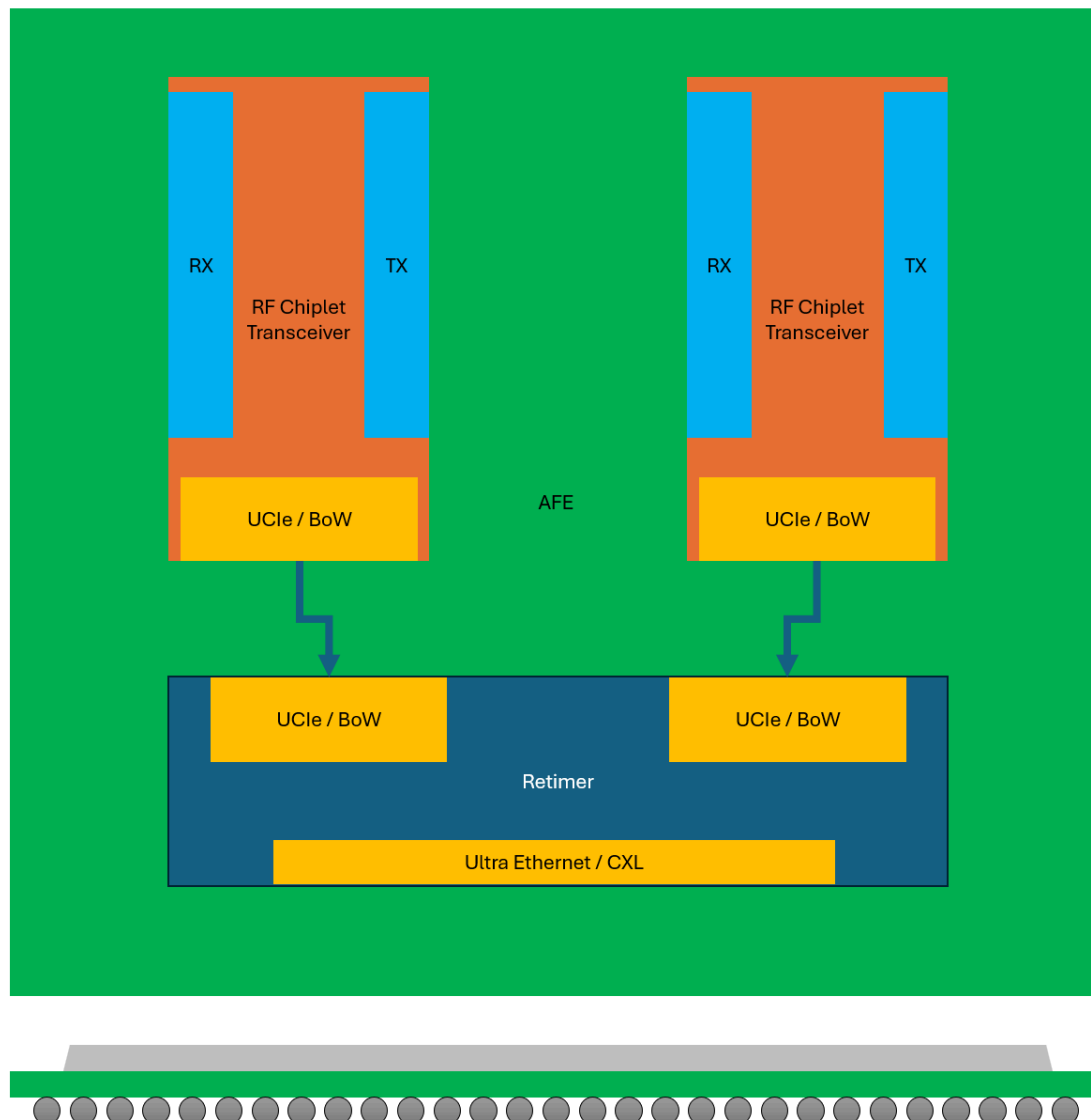


Figure 14: Example of a Chiplet-based AFE

A chiplet-based design to achieve open modularity at both the system and AFE levels would significantly enhance RF system flexibility. This involves utilizing interfaces like OCP's Open Domain Specific Architecture (ODSA) Bunch of Wires (BoW)⁹ or UCle¹⁰, along with an open chiplet marketplace, to enable mix-and-match hardware creation. Further modularity could be achieved through substrate planning, allowing for easy integration and replacement of chiplets and substrates. This dual-level modularity maximizes system flexibility and scalability, facilitating swift adaptation to evolving requirements and technologies.

Well-designed interfaces, such as those between chiplets or between the AFE and digital stages, are essential for realizing truly modular systems, enabling efficient signal transfer and maximal flexibility to serve the broadest set of frequencies and waveforms with common components.

Design Strategy for Digital Front End and Low-PHY Processing

A critical architectural decision in designing a Radio Unit (RU) is selecting the right technology for its digital processing core. Engineers can choose from several options, each with distinct trade-offs:

- **Processors (for a Software-defined Radio approach):** These offer the flexibility of software-defined radio, where much of the signal processing functions are implemented in software. Due to mass production, processors are readily available and relatively inexpensive. General-purpose CPUs come in various instruction set architectures (ISAs), including ARM, RISC-V, and x86; plus, many GPU options are available. However, developing a high-performance solution with processors can be complex and require significant engineering effort, as general-purpose instructions often need extensive optimization.
- **Custom Silicon (ASICs or SoCs):** Application-specific integrated Circuits (ASICs) and Systems on Chips (SoCs) provide the highest levels of performance and power efficiency in a small physical footprint. These chips integrate all or most digital processing functions onto a single chip. However, custom silicon is expensive to design and manufacture, requiring high production volumes to justify the investment.

⁹ BoW Specification: <https://www.opencompute.org/documents/bow-specification-v2-0d-1-pdf>

¹⁰ UCle: <https://www.uciexpress.org/specifications>

- **Field Programmable Gate Arrays (FPGAs):** FPGAs offer a middle ground between processors and custom silicon. They provide a high degree of adaptability and reconfigurability through programmability, allowing engineers to customize the hardware for specific tasks. FPGAs can also accelerate performance for certain operations, making them ideal for rapid prototyping, digital processing in specialized applications, and adapting to evolving requirements. The trade-off is that FPGAs have a higher component cost compared to processors.
- **System in Package (SiP), aka Chiplet:** Chiplets deliver functionality similar to a system on chip (SoC) but with the added advantage of composable sub-functions. A single company might develop a highly specialized SoC to meet its market needs; however, many independent vendors offer excellent discrete components—such as analog-to-digital converters, protocol encoders/decoders, or timing solutions—to address specific problems. By treating these components as logical building blocks with well-defined interfaces, chiplets enable seamless integration of core functions into a tightly coupled system.

This flexibility allows an organization to develop all or some of the necessary sub-functions for a solution in-house or select from an ecosystem of traditionally purpose-built discrete ICs. Examples in the market include Apple's A- and M-series SoCs and NVIDIA's B200 series. Formally referred to as package-level integration with multi-chip modules (MCMs), the chiplet approach is less complex, risky, and more cost-effective than creating monolithic SoCs, fueling its rapid rise in market interest.

Commercial solutions often integrate the Digital Front End (DFE) and Low-PHY layers to simplify development and capture more value. In contrast, Evenstar's digital radio sections are intentionally disaggregated to maximize design flexibility—enabling the reuse of common elements while accommodating different waveforms (5G, 6G), frequencies, and channel/carrier requirements. Typically, the Analog Front End (AFE)—the initial stage—is less integrated with the subsequent stages due to size, weight, and power (SWaP) constraints, whereas DFE and Low-PHY functionality is frequently bundled into a single product. This platform disaggregates these stages and interconnects them via the SERDES-based JESD204C interface to maximize performance and integration possibilities. Although this modular approach offers extensive

flexibility, it remains a guideline; implementers may still choose aggregated solutions as needed if they meet platform specifications.

Separating these stages provides significant flexibility for different use cases. With a digital interconnection between the AFE and DFE, manufacturers can choose components that meet specific frequency and channel requirements without redesigning the entire system for each configuration. This approach enables faster, more cost-effective responses to market demand.

Radio Platform Modularity

By separating key stages—such as the Analog and Digital Front Ends—and employing open, well-defined interfaces, developers can rapidly adapt to changing standards, frequencies, and performance needs. For a high level visual of this layout, see figure 15 below.

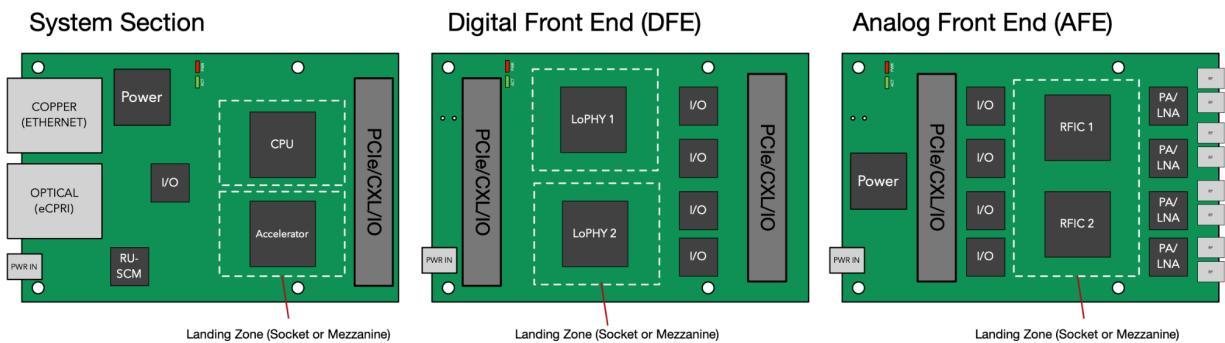


Figure 15: Example of a Modular Staged Evenstar RU

This design strategy strikes a balance between cost and complexity, enabling rapid customization without extensive overhaul. To change frequency bands, simply swap out components in the AFE. By using sockets or mezzanine connectors, the hardware can be tailored during manufacturing—far more efficient than designing entirely new boards for each band, channel, or RF path (like switching between 2T2R and massive MIMO).

Reimagining the original Evenstar outdoor Radio Unit (RU) through the lens of the Evenstar Open RU Platform, we see a physical layout that closely resembles the initial design (Figure 16). This is just one example; other applications may demand unique packaging.

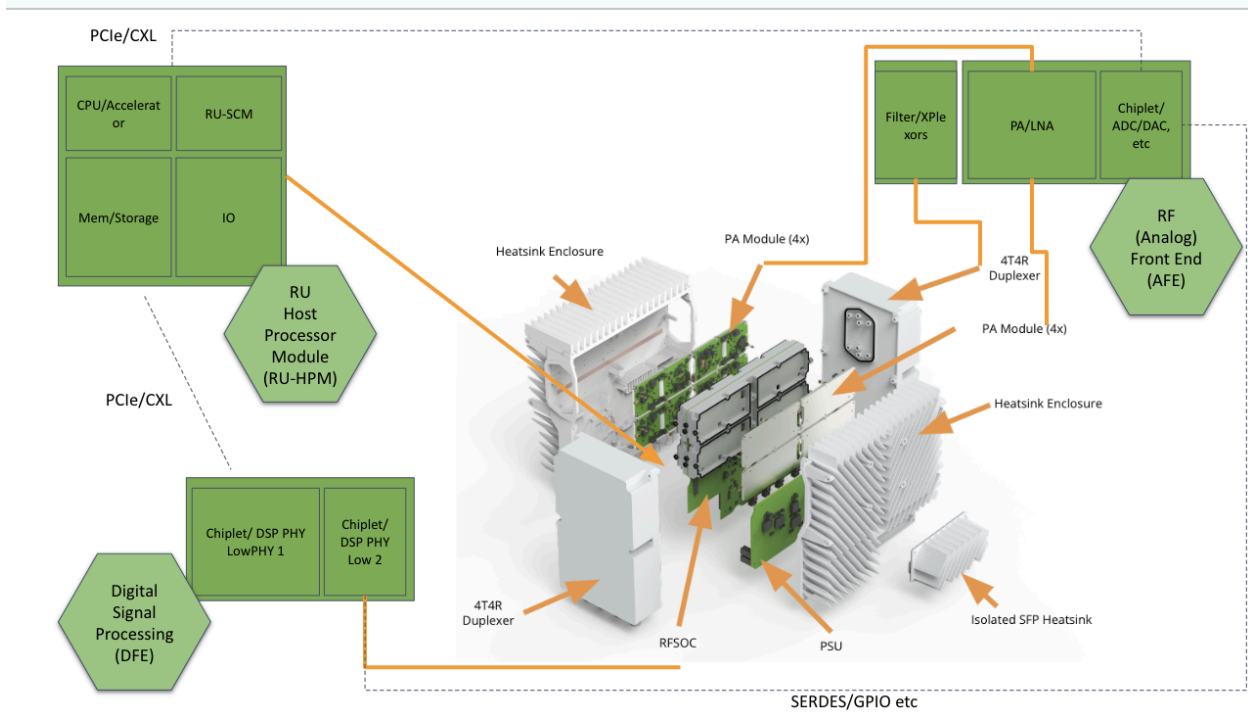


Figure 16: Example Physical Model of a Modular Staged Evenstar RU Platform

Crucially, this isn't just about hardware. With hardware-software co-design and frameworks like the Radio Abstraction Interface (RAI), we can support a diverse range of component architectures on a unified platform. Careful implementation of modularity accelerates innovation and lays a future-proof foundation for next-generation wireless.

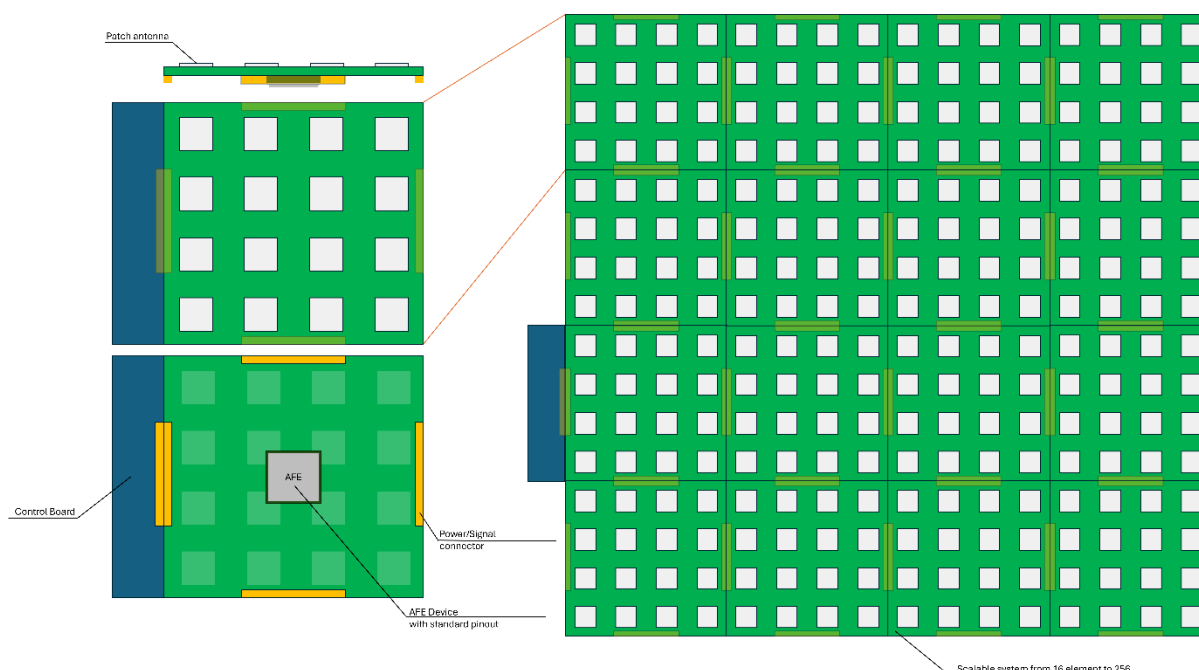


Figure 17: Example of a modular massive MIMO base station design

Example of 6G massive-MIMO Modular System

Consider a modular massive MIMO base station for 6G (Figure 17). The basic antenna unit features multiple patch antennas designed for a specific frequency range. 6G standards are still evolving¹¹, but the 3GPP's FR3 band (7.125 – 24.25 GHz) is a strong contender. The antenna elements in our design are optimized for this range. Designers can use off-the-shelf patch antennas for simplicity, or engineer custom antennas for both sub-6 GHz and mmWave bands.

A dedicated control board, shown in blue in Figures 17 and 18, manages communication with the Distributed Unit (DU). Connectors on each side allow for flexible interconnection, enabling various configurations without size limitations. This modular approach not only reduces costs but also significantly enhances adaptability.

Cost-effectiveness is a key design principle. The unit centers on an AFE, employing budget-friendly materials to minimize power loss over short distances. The AFE integrates essential components such as power amplifiers (PAs), LNAs, and filters. The control board's

¹¹ https://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-WRC.16-2024-PDF-E.pdf

flexible placement within the assembled units supports versatile configurations. An AFE network enables the system to autonomously detect the overall antenna size and configuration, dynamically adapting to user demand. This real-time adaptability facilitates power-down or reconfiguration of system elements based on active usage, optimizing efficiency and dependability.

Implementation hurdles include power distribution, consistent delivery across boards without substantial IR drop, and data latency management to adhere to 5G/6G specifications. Protocol options include SERDES, Ultra-Ethernet, or CXL, providing a framework for efficient AFE access and synchronization. An RF chiplet transceiver architecture for the AFE can further enhance cost-efficiency and modularity. This modular design bolsters fail-safe operation, allowing continued functionality even with a single module failure. The system's intelligence can pinpoint underperforming boards and adjust accordingly, preserving overall performance while simplifying maintenance.

Indoor Modular Antenna System

The adaptability of a modular system shines in indoor wireless network design. While indoor systems have unique constraints (e.g., limited antenna power, fewer elements), the modular approach allows customization based on the specific wireless standard: Wi-Fi 5 (802.11ac), Wi-Fi 6 (802.11ax), Wi-Fi 6E (802.11ax at 6 GHz), or Wi-Fi 7 (802.11be). This flexibility ensures seamless connectivity for diverse devices in homes, offices, and large venues. Figure 18 illustrates an example of an indoor antenna system based on an outdoor design.

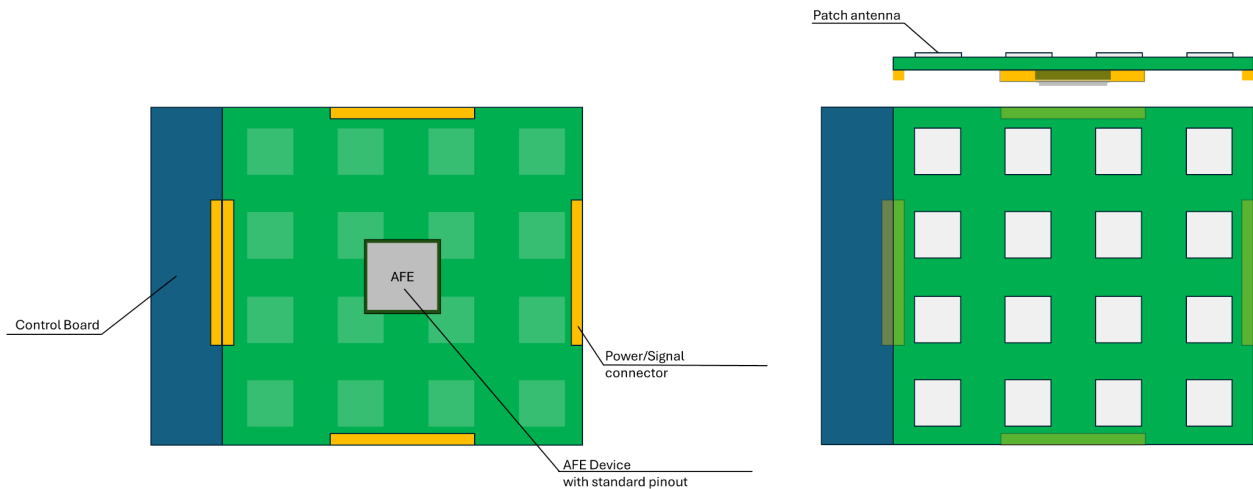


Figure 18: Example of an indoor antenna system

Moreover, diverse modular board tiles can cater to various radio configurations (e.g., m-MIMO arrays, macro/femto radios), each with specific functionalities combinable into a complete radio system. This promotes flexibility and customization, enabling radios tailored to performance and deployment needs. The OCP model champions modularity without embedded application code; thus, a single motherboard can support diverse configurations (e.g., 4T with four tiles, 8T, 16T, and beyond), underscoring the importance of flexible system design that accommodates varied use cases without major hardware changes. Meticulous consideration of modularity levels, physical interconnections, component selection, and integration strategies empowers designers to craft highly flexible and scalable RF systems that meet current communication technology demands and lay a robust foundation for future innovation.

Case Study: Massive Beams Modular Radio Architecture

In this section, we examine Massive Beams' implementation, which aligns closely with Evenstar's Open RU platform and showcases advanced Massive MIMO radio architectures. The primary aim is to illustrate the core principles of modular radio unit design and provide a practical example of how to extend, enhance, and scale the basic radio platform previously discussed. This case study highlights how ecosystem partners can actively engage with and benefit from the Evenstar initiative.

A cornerstone of the Evenstar project is a modular radio architecture that segments the Radio Unit (O-RU) into distinct, yet tightly coupled hardware and software components. This design approach enhances flexibility, simplifies upgrades, and maximizes reuse across different cell types and configurations. Massive Beams' massive MIMO RU embodies these modular design principles are reflected in the following design principles in a three-module implementation detailed below:

1. **Compute Module (CM)**
2. **Transmit/Receive Module (Tx/Rx)**
3. **Front-End and Antenna Module**

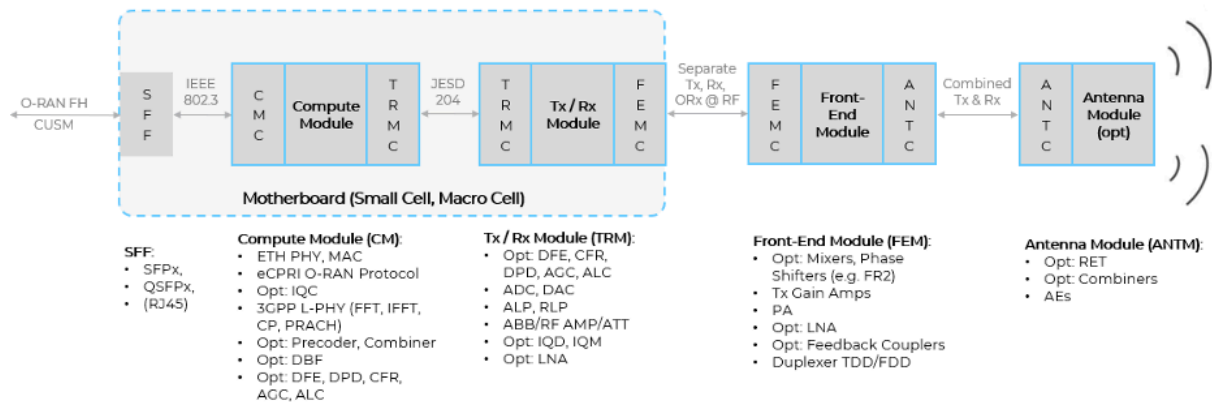


Figure 19: Decomposition of a modular radio system

Compute and Tx/Rx Modules

The Compute Module (CM) and Tx/Rx Module share common architectural principles, facilitating use across multiple cell types. This commonality drives standardization and reduces development costs for new implementations. Key features include:

- Support for both Time-Division Duplexing (TDD) and Frequency-Division Duplexing (FDD) modes.
- High bandwidth capabilities for sub-7GHz frequencies (FR1) and millimeter-wave (mmWave) frequencies (FR2).
- Efficient IQ data processing to reduce fronthaul data rates.

The Compute Module typically runs a Linux-based operating system, ensuring an open platform for implementing synchronization (PTP, SyncE) and control functionality (e.g., M-Plane and S-Plane). It interacts with the Tx/Rx Module to efficiently manage signal transmission and reception.

Front-End and Antenna Module

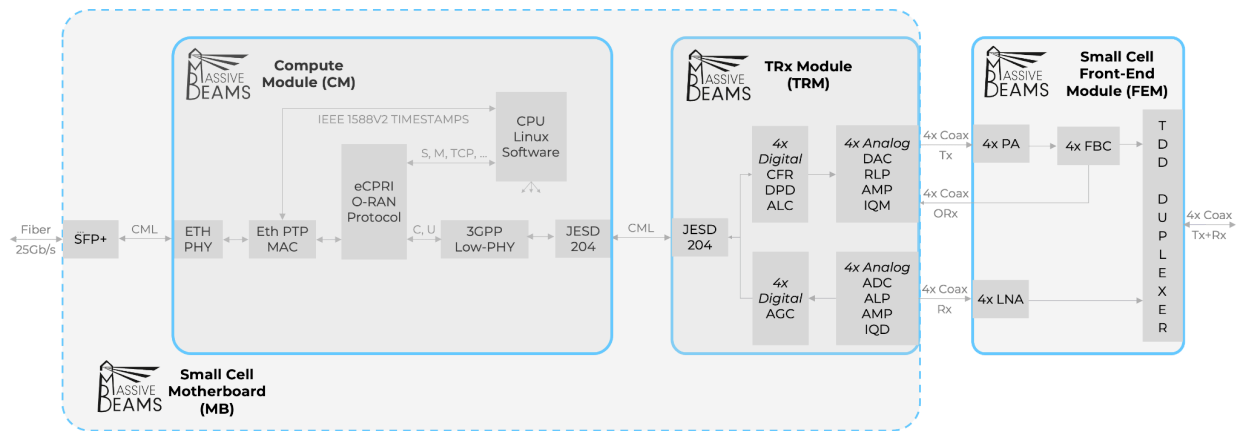


Figure 20: Small cells with low-power outputs ($\leq 0.5W$ per antenna port)

The Front-End Module is tailored to specific deployment scenarios, such as small cells, macro cells, or multi-band configurations. This module can be further subdivided for macro-cell applications, encompassing PA Modules and duplexers (an example is depicted in Figure 21).

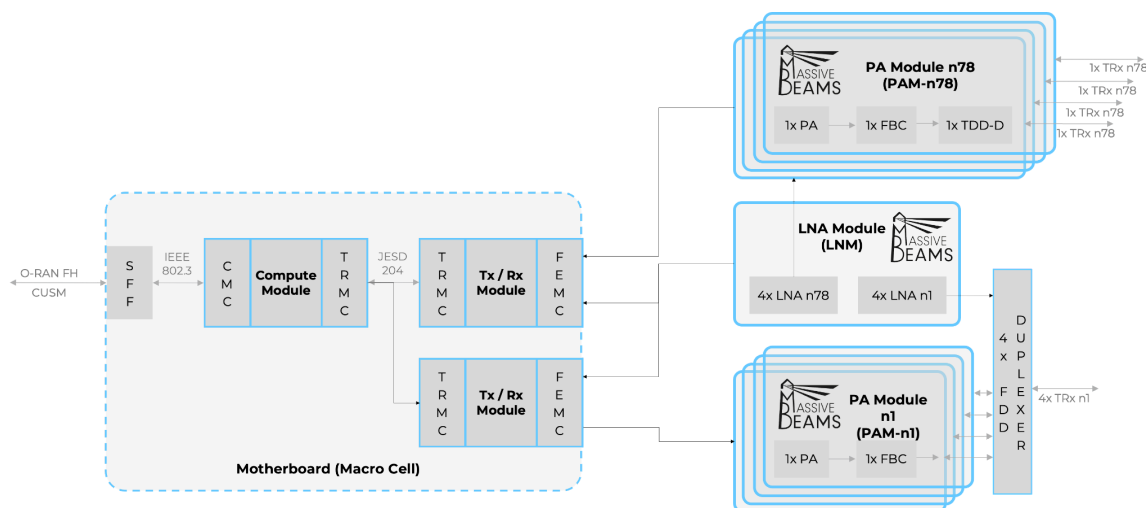


*Figure 21: Macro cells delivering high-power outputs ($\geq 40\text{dBm}$ per antenna port).
 Support for dual-band operations, e.g., n78 (TDD) and n1 (FDD).
 (CM&TRM reused, single PA modules)*

This modularity enables operators to adapt RUs to diverse network requirements, optimizing for cost and performance.

Hardware Interfaces

The interoperability of hardware modules is critical for achieving a modular design. Interfaces such as COM-HPC for the Compute Module and FMC+ for the Tx/Rx Module ensure compatibility and facilitate integration. Standardization of electrical properties, module connectors, and pin assignments through industry organizations like IEEE, JEDEC, and the O-RAN Alliance further strengthens this approach.

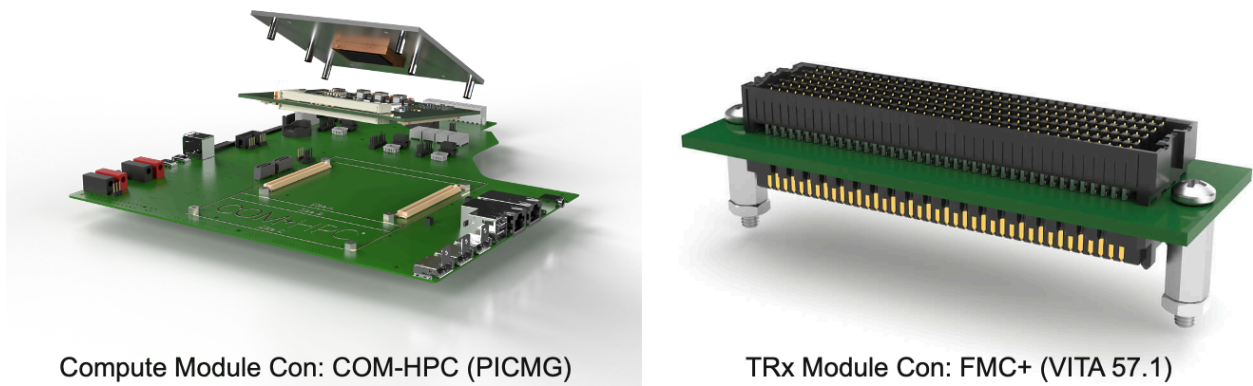


Figure 22: Examples of interfaces between compute and TRx modules

(Source: COM-HPC Module from Wikipedia, TRx Module from Samtec)

5G-NR gNB with O-RAN

Integrating 5G-NR (New Radio) gNB with O-RAN introduces innovative fronthaul data rate optimizations. By using O-RAN fronthaul splits, operators can:

- Balance cell site size and transport capacity.
- Achieve pooling gains while managing interference coordination.

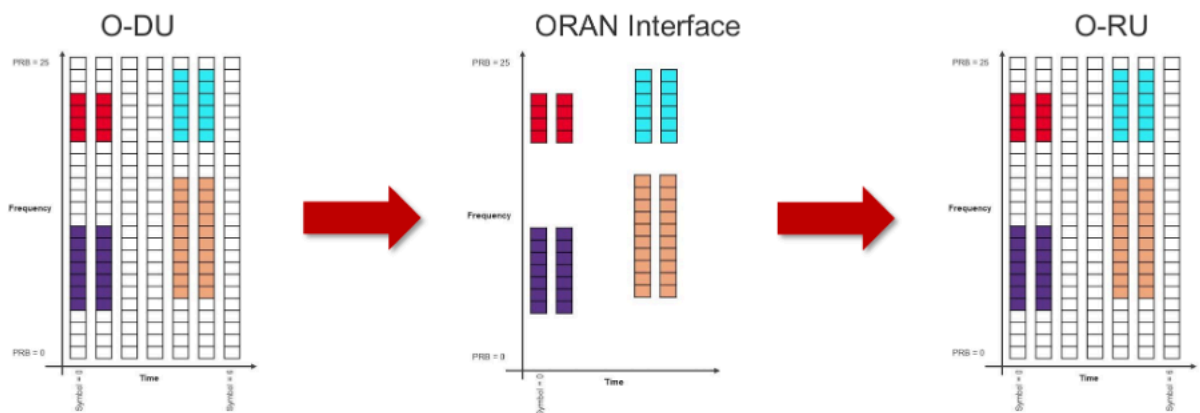


Figure 23: Reduction of required fronthaul data rate through the exchange of frequency-domain and not time-domain samples

(Source: Keysight, "Enabling Interoperability & Adherence to O-RAN Fronthaul Interface," Keysight World 2020)

Key techniques to reduce fronthaul data rates include:

- IQ compression.
- Sharing utilized OFDM frequency-domain samples.
- Adding cyclic prefixes within the RU.
- Optional precoding in the O-RU.

These methods adhere to 3GPP standards, supporting efficient and scalable 5G-NR deployments while addressing modern networks' increased transport capacity demands.

Software Modularity and Open APIs

Software is pivotal in modular radio systems, enabling seamless communication between hardware components. Key aspects include:

- **Open Platforms:** Utilizing Linux-based systems ensures accessibility and promotes innovation in implementing open S-Plane and M-Plane functionalities.
- **Standardized APIs:** Open APIs and drivers are essential for controlling hardware modules and enabling vendor interoperability. Defining these standards requires collaboration with other organizations, including the Linux Foundation and O-RAN Alliance.
- **Synchronization and Control:** The modular radio architecture supports precision timing protocols (PTP, SyncE) and network management (NETCONF), ensuring alignment with O-RAN specifications.

Benefits of Modularity

The modular approach to radio design provides significant advantages:

- **Flexibility:** Operators can tailor configurations to specific use cases, such as urban small or rural macro cells.
- **Cost Efficiency:** Standardized components reduce development and operational costs while enabling economies of scale.

- **Scalability:** Modular systems can be easily scaled or upgraded to support new technologies and standards.
- **Interoperability:** Open interfaces ensure compatibility across diverse ecosystems, fostering vendor collaboration.

Radio modularity is a key advancement in the Open RAN ecosystem, bridging the gap between standardization and customization. As shown in the previous sections, there is an existing body of work from Evenstar and a vision for organizing into an open RU platform. The market for 3GPP 5G RUs is established, and there is an active ecosystem with multiple software (including open source), component, and hardware suppliers. By leveraging modular hardware and software designs, this Open RU platform effort seeks to build on existing solutions and synthesize these into an extensible platform, fostering the ecosystem's growth. In doing so, private and public network operators can utilize stronger supply chains and achieve greater efficiency, adaptability, and cost savings.

4 Security in a Highly Modular Radio Platform

Given its role in critical network infrastructure, the Evenstar O-RU's security requirements become increasingly stringent as it adapts to the expanding 5G and future 6G landscape. Designed for modularity and multi-vendor compatibility, the Evenstar platform integrates key security frameworks from OCP, the Linux Foundation OpenSSF, CNCF & LfEdge projects, and industry leaders. Key aspects include factory provisioning, secure ownership transfer, modular hardware root-of-trust (HrOT), and OCP's S.A.F.E. guidelines. These elements support a secure-by-design approach for hardware and software, ensuring compliance with critical infrastructure standards and seamless interoperability within Open RAN environments.

Comprehensive Security Across the Device Lifecycle

Evenstar's O-RU security architecture spans the entire device lifecycle, from manufacturing and initial provisioning to deployment and ongoing management. It secures both hardware and firmware across numerous use cases. By adopting frameworks like the IETF SCITT (Supply Chain Integrity, Transparency, and Trust) initiative, Evenstar enables ledger-based supply chain traceability and aligns with critical regulations, including the EU Cyber Resilience Act (CRA) and U.S. NIST Secure Software Development Framework ([SSDF](#)). This comprehensive approach ensures that Evenstar functions securely within a modular telecom environment, offering a resilient platform suitable for critical infrastructure.

Integrating Platform Root of Trust (PRoT) for Resilient Hardware Security

In the context of Evenstar's distributed modular design, the OCP S.A.F.E. framework and a Radio Unit Security Control Module (RU-SCM) are introduced. The RU-SCM is directly derived from the DC-SCM concept, and acts as Platform Root of Trust (PRoT) to provide enhanced assurance. The S.A.F.E. framework offers a structure for firmware management and attestation that's particularly well-suited for the decentralized nature of Open RAN. The RU-SCM offers a hardware-level trust anchor, strengthening security across each module in the O-RU.

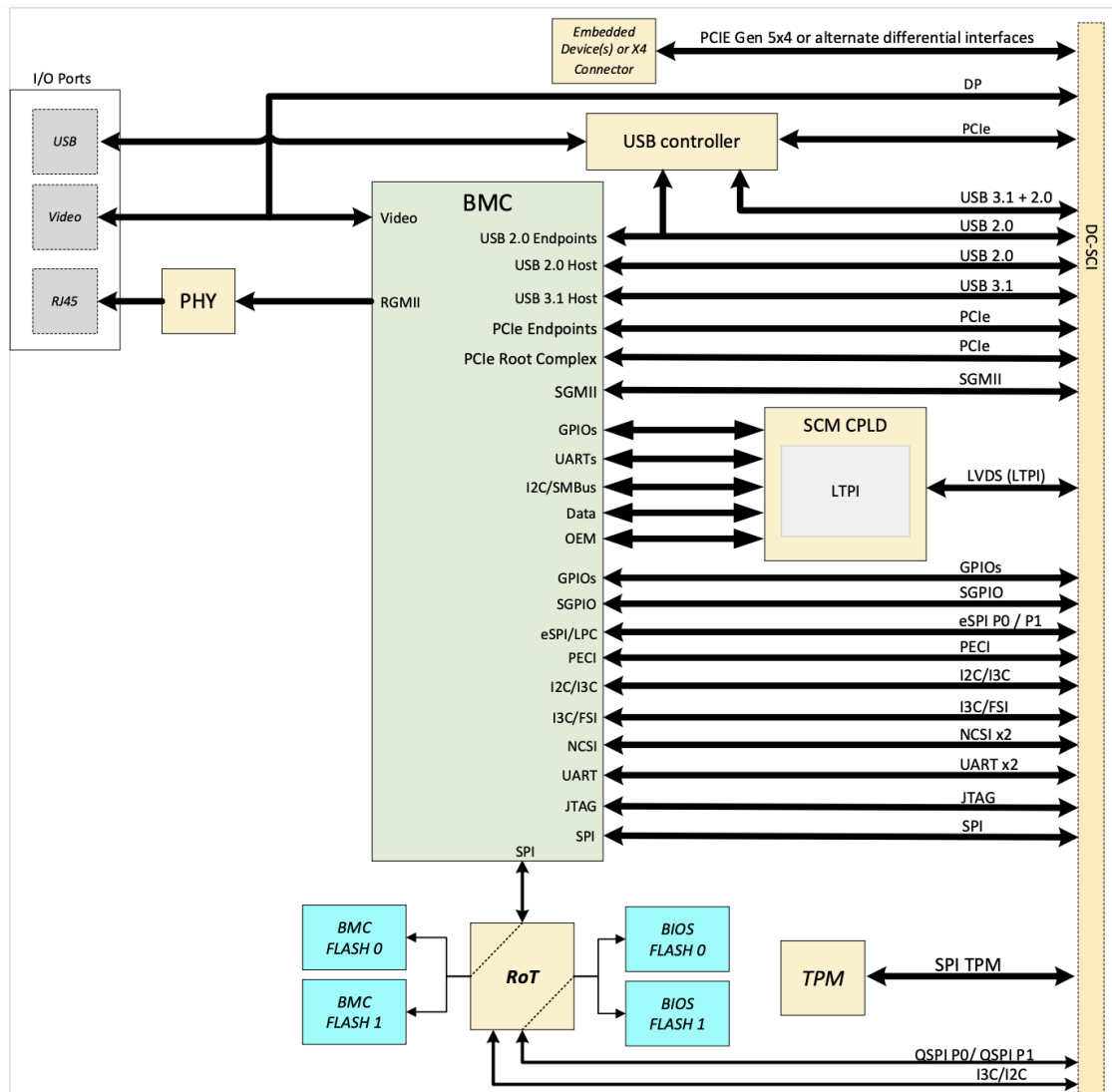


Figure 24: Example Block Diagram DC/RU-SCM

The DC-SCM architecture as shown in Figure 24 above, consists of the following elements:

- BMC – The Baseboard Management Controller is a specialized service processor that
- monitors the physical state of the system
- BMC Flash – One or more flash devices used to contain the BMC firmware image
- BIOS Flash – One or more flash devices used to contain the BIOS firmware image for
- each node
- CPLD – A programmable logic device that contains application-specific logic

- and optional LTPI interface
- RoT Security Processor – An optional security processor responsible for attesting the
- BMC, BIOS, and/or other firmware images on the system
- TPM – Trusted Platform Module – An optional dedicated chip or module designed to
- Secure hardware through integrated cryptographic keys

The RU-SCM serves as a secure, immutable anchor, verifying device integrity at the hardware level, providing remote debugging, and managing a trusted chain from the earliest stages of device operation. Embedded in Evenstar O-RU's hardware, RU-SCM validates the integrity of critical firmware during boot and enforces a continuous chain of trust throughout device operation. This includes both boot processes and dynamic security states for running firmware, which is crucial in a modular, multi-component system like Open RAN. The RU-SCM's role in establishing an unbroken chain of trust aligns with NIST SP 800-1611 guidance by ensuring component integrity throughout the supply chain. All components verified by the RU-SCM contribute to a secure, documented history of device integrity, supporting NIST's requirement for comprehensive provenance tracking and secure verification of firmware and configuration states.

The RU-SCM manages secure boot and runtime attestation using standards-based cryptographic measurements. These measurements validate firmware authenticity and ensure only authorized firmware loads on the device. By protecting firmware and configuration integrity, RU-SCM helps prevent unauthorized modifications, addressing potential attack vectors that could compromise radio unit functionality. Additionally, the RU-SCM module's hardware identity features, derived from cryptographically embedded keys, enable secure device onboarding and ownership transfer, supporting zero-trust principles across the O-RU's lifecycle.

OCP S.A.F.E. Security Assurance Framework for Firmware Integrity

The OCP Security Assurance Framework (S.A.F.E.) bolsters firmware integrity within the Evenstar O-RU by requiring cryptographic signing and attestation. This ensures firmware provenance and transparency throughout the supply chain, which is especially vital for reprogrammable FPGA configurations central to radio functionality.

Each firmware update within the S.A.F.E. framework undergoes compliance checks in conformance with NIST SP 800-161r1 guidelines, aligning with current security protocols and supply chain risk assessments. Auditing mechanisms validate supplier adherence to security practices, enabling Evenstar operators to track firmware provenance, detect unauthorized modifications, and maintain transparency.

All firmware updates within S.A.F.E. undergo rigorous cryptographic verification, further strengthened by the RU-SCM module, to guarantee authenticity and thwart tampering. Over-the-air (OTA) firmware updates are also securely managed, with RU-SCM-backed verification ensuring that each update aligns with OCP's resilience standards and international compliance requirements. By adhering to S.A.F.E. guidelines, Evenstar effectively mitigates supply chain risks linked to unauthorized firmware alterations, thus enhancing overall security and dependability.

Enhancing Supply Chain Integrity with IETF SCITT

Integrating the IETF's SCITT framework into the Evenstar platform ensures supply chain integrity. SCITT provides distributed, immutable ledger-based tracking for each device's firmware, hardware components, and configuration history. Evenstar establishes a tamper-proof record that boosts traceability and accountability by recording every firmware and hardware change within a SCITT-compliant ledger. This aids regulatory compliance under frameworks like the EU CRA and NTIA guidelines for firmware provenance.

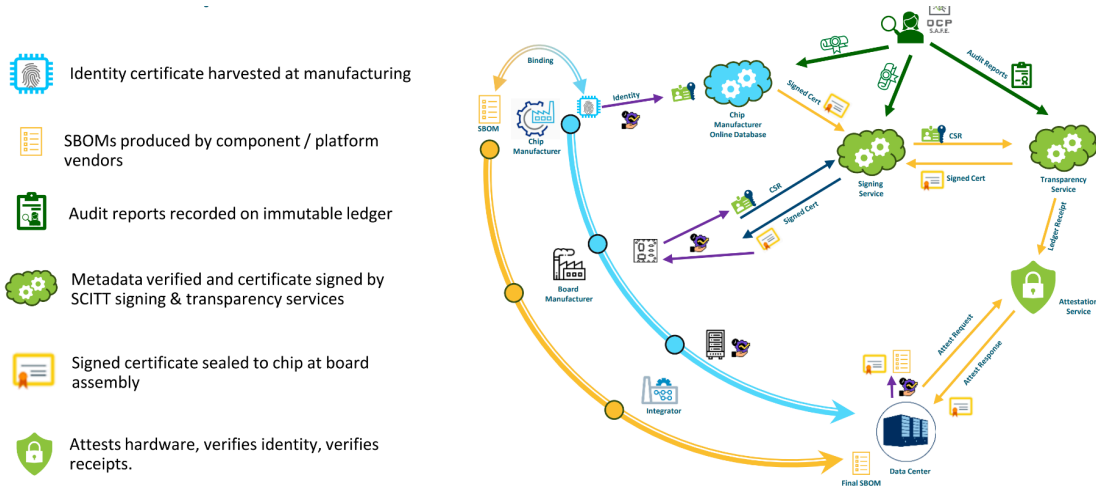


Figure 25: IETF SCITT (Supply Chain Integrity, Transparency, and Trust) Framework

SCITT's attestation and artifact verification mechanisms allow Evenstar operators to validate component integrity and authenticity. This ledger offers a comprehensive view of device provenance, ensuring that each module aligns with security standards before integration with other Open RAN elements. SCITT's ability to generate receipts and maintain signed records for hardware and firmware transactions adds another layer of assurance, bolstering confidence in device compliance with security best practices.

Secure Device Lifecycle Management and Compliance in Open RAN

Integrating SLSA (Supply-chain Levels for Software Artifacts) requirements, the Evenstar O-RU's robust CI/CD pipeline streamlines compliance verification for software and firmware, enabling automated validation and traceability throughout the device lifecycle. Each update is cryptographically signed and verified against artifact provenance records, safeguarding the system from unauthorized software or firmware. FPGA-specific configurations undergo additional CI/CD pipeline verification, ensuring secure deployment. This comprehensive process minimizes risks associated with unverified components and allows operators to monitor device integrity continuously.

Secure Network Onboarding and Interoperability within Open RAN

Evenstar enforces a zero-trust network onboarding model, mandating mutual TLS (mTLS) and identity-based authentication for device resource access. This ensures only verified devices with authenticated cryptographic credentials interact within the Open RAN environment, minimizing the potential attack surface and enforcing robust access controls. Adhering to O-RAN Alliance's open fronthaul standards and secure protocols, Evenstar supports seamless interoperability and flexible, secure interactions across diverse network components. Integrating OCP S.A.F.E. principles and PRoT functions, this approach assures operators that each component meets Evenstar's stringent security criteria, regardless of vendor.

Summary of Evenstar Security Approach

Evenstar's comprehensive security framework unifies foundational security with the game-changing RU-SCM firmware integrity, automated onboarding (FDO), lifecycle management (S.A.F.E.), supply chain transparency (SCITT and Witness), and identity-based access control (SPIFFE). These elements create a cohesive, end-to-end security model, safeguarding each device from manufacturing to decommissioning. This layered approach ensures that every Open RAN module remains secure, trusted, and compliant, upholding the flexibility and interoperability essential to Open RAN while maintaining robust security against evolving threats.

5 Conclusion - Shaping the Future of Open RAN Together

The Evenstar Open RU project marks a pivotal step in the evolution of telecommunications infrastructure. By embracing open standards, modular design, and collaborative innovation, we are poised to usher in a new and open era for RAN- one as transformative as OCP projects' impact on data centers and IT infrastructure. With community support, this initiative has the potential to fundamentally change how wireless networks are designed, deployed, and scaled.

The advantages of this open model are substantial for many stakeholders:

- **Operators** gain greater flexibility, reduced costs, and accelerated innovation cycles while avoiding vendor lock-in.
- **Network equipment providers** find new opportunities to specialize and differentiate in an open ecosystem in hardware and software domains.
- **End users** benefit from improved network performance, reliability, and coverage at a reduced cost.
- The **industry will gain** a robust, secure, and adaptable infrastructure that can meet the demands of our increasingly connected world.

Open-source projects thrive on community engagement. To reach its full potential, the Evenstar project needs your help:

1. **Join the Evenstar Open Radio Unit Project:** Visit our project site (<https://www.opencompute.org/projects/evenstar-open-radio-unit>) to learn more.
2. **Contribute your expertise:** Whether you are a hardware engineer, software developer, security expert, or telecom professional, you can help shape the future of Open RAN.
3. **Pilot the technology:** Network operators, explore how Evenstar can transform your infrastructure.
4. **Spread the word:** Share this white paper with your colleagues and industry partners. The larger and more diverse our community, the stronger our innovation.
5. **Attend our next workshop and join our project calls.**



The future of telecommunications is open, modular, and collaborative. With Evenstar, we can redefine what's possible in wireless networking. Don't just witness the revolution—be a part of it.

Glossary

3GPP (3rd Generation Partnership Project): An organization that develops protocols for mobile telecommunications, providing global standards for mobile technologies including 5G.

AFE (Analog Front End): The analog circuitry in a radio system that interfaces between the antenna and digital processing components, handling signal transmission and reception.

ATIS (Alliance for Telecommunications Industry Solutions): A standards organization that develops technical and operational standards for the telecommunications industry.

BoW (Bunch of Wires): A chiplet interconnect standard for die-to-die communications in multi-chip modules.

Caliptra: An open-source silicon-based Hardware Root of Trust implementation, initiated within OCP and hosted by the Linux Foundation's Chips Alliance. Project resources at: <https://github.com/chipsalliance/Caliptra>

CPRI (Common Public Radio Interface): A protocol specification for data transmission between radio equipment controllers and radio equipment.

CU (Central Unit): In O-RAN architecture, the component responsible for the radio access network's higher-layer processing and control functions.

DENT: A Linux Foundation-hosted open-source network operating system (NOS) project built on top of the Linux kernel, leveraging Switchdev, and other Linux-based projects designed specifically for distributed edge computing environments.

DC-SCM (Datacenter Secure Control Module): An OCP specification for secure management controllers in data center equipment.

DU (Distributed Unit): In O-RAN architecture, the component handles lower-layer processing tasks such as radio channel coding and modulation.

eCPRI (enhanced Common Public Radio Interface): An evolution of CPRI optimized for 5G networks, utilizing packet-based transport over Ethernet.

FPGA (Field Programmable Gate Array): An integrated circuit designed to be configured after manufacturing, providing flexible hardware programmability.

HRoT (Hardware Root of Trust): A hardware-based security foundation that provides fundamental security services and maintains system integrity.

IETF SCITT (Supply Chain Integrity, Transparency, and Trust): A framework for ensuring supply chain security through distributed ledger technology.

M-Plane (Management Plane): The interface responsible for radio unit management functions in O-RAN architecture.

Massive MIMO (Multiple-Input Multiple-Output): An advanced antenna technology that uses a huge number of antennas to improve network coverage, capacity, and user throughput.

O-RAN (Open Radio Access Network): An industry initiative to make radio access networks more open and intelligent, using standardized interfaces.

PRoT (Platform Root of Trust): A security architecture component that provides a foundation for secure boot and runtime attestation.

RAI (Radio Abstraction Interface) is a standardized API layer that enables seamless integration between different vendors' radio components.

RU (Radio Unit): The component in a wireless network that handles the physical radio frequency transmission and reception.

RU-SCM (Radio Unit Secure Control Module): An OCP specification for secure management controllers in open radio unit equipment.

ruApp (Radio Unit Application): An on-board application that can provide added customization or intelligence for a wireless application.

S.A.F.E. (Security Assurance Framework for Everyone): An OCP framework for ensuring firmware security and integrity.

SAI (Switch Abstraction Interface): An abstraction layer that provides a vendor-independent method of controlling network switches.

SLSA (Supply-chain Levels for Software Artifacts): A framework for ensuring software supply chain integrity and security.

SoC (System on Chip): An integrated circuit that integrates all or most components of a computer or electronic system.

SONiC (Software for Open Networking in the Cloud): An open-source network operating system based on Linux.

UCIe (Universal Chiplet Interconnect Express): An industry standard for die-to-die interconnects in chiplet-based designs.

vRAN (Virtualized Radio Access Network): A network architecture concept where radio access network functions are implemented in software running on general-purpose hardware.

Zephyr: A small real-time operating system (RTOS) project and hosted by the Linux Foundation for resource-constrained and embedded devices.

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The Open Compute Project (OCP) is a collaborative Community of hyperscale data center operators, telecom, colocation providers and enterprise IT users, working with the product and solution vendor ecosystem to develop open innovations deployable from the cloud to the edge. The OCP Foundation is responsible for fostering and serving the OCP Community to meet the market and shape the future, taking hyperscale-led innovations to everyone. Meeting the market is accomplished through addressing challenging market obstacles with open specifications, designs and emerging market programs that showcase OCP-recognized IT equipment and data center facility best practices. Shaping the future includes investing in strategic initiatives and programs that prepare the IT ecosystem for major technology changes, such as AI & ML, optics, advanced cooling techniques, composable memory and silicon. OCP Community-developed open innovations strive to benefit all, optimized through the lens of impact, efficiency, scale and sustainability. Learn more at www.opencompute.org.