

Response to 5G Challenge NOI

OpenAirX-Labs

An open consortium for development, testing and integration for 5G and Beyond

Abhimanyu Gosain

<agosain@coe.neu.edu>

**In Partnership with OpenAirInterface Software Alliance, Qualcomm, Facebook, InterDigital,
Northeastern University, North Carolina State University, Texas A&M University**

Table of Contents

I A How could a Challenge be structured such that it would take advantage of DOD’s role as an early U.S. Government adopter of 5G technology to mature the open 5G stack ecosystem faster, encourage more participation in open 5G stack development including encouraging new participants, and identify any roadblocks to broader participation? 2

I B. How could a Challenge be structured to focus on the greatest impediments to the maturation of end-to-end open 5G stack development? 3

I D. How will the open 5G stack market benefit from such a Challenge? How could a Challenge be structured to provide dual benefit to both the Government and the open 5G stack market? 4

II A. What are the incentives in open 5G stack ecosystem development that would maximize cooperation and collaboration, promote interoperability amongst varied open 5G stack components developed by different participants, and mature desired featured sets faster with greater stability? 5

II. D Many open 5G stack organizations have developed partial implementations for different aspects of an open 5G stack. What portions of the open 5G stack has your organization successfully developed with working code? What portions of the open 5G stack does your organization believe can be developed quickly (6 months or less)? What development support would best enable test and evaluation of the different elements of an open 5G stack? 6

II E. What 5G enabling features should be highlighted in the Challenge, such as software defined networking, network slicing, network function virtualization, radio access network intelligent controller, radio access network virtualization? 13

III A. What software and hardware infrastructure will be needed to successfully execute this Challenge? 13

I A How could a Challenge be structured such that it would take advantage of DOD's role as an early U.S. Government adopter of 5G technology to mature the open 5G stack ecosystem faster, encourage more participation in open 5G stack development including encouraging new participants, and identify any roadblocks to broader participation?

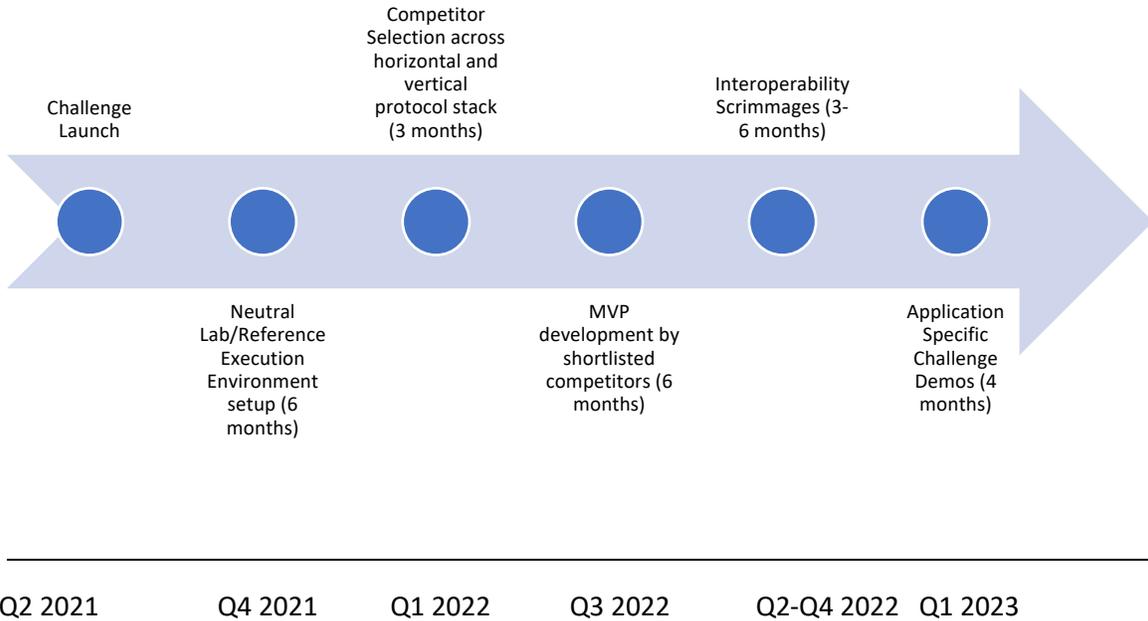
Any challenge or competition needs a benchmark system or a common execution environment to validate functionality, measure, audit and compare against different solutions and approaches. The DoD 5G-NextG program under OUSD also needs a reference architecture implementation built on open source components across all its thrusts as a development and test platform; Smart Base, Innovate Beyond 5G and Operate Through. This system will codify open, disaggregated, interoperable network elements across all network layers, into a broad range of end-to-end solutions for specific deployment cases to be supported for DoD stakeholders. As an early adopter with varied needs for 5G, the DoD can look into its portfolio of executed grand challenges. The DARPA SC2 competition that commissioned The Colosseum wireless research test bed to execute experiments for collaborative intelligent radio networks is a reference framework to apply. The 5Gchallenge needs to be structured around a benchmark, baseline end to end 5G system implementation in a vendor neutral lab environment. This will mobilize a large ecosystem of developers, test engineers and application providers from various domains and disciplines to interact with this system and lower barriers to entry for specialized and domain specific participants to contribute to development. Any benchmark reference architecture compliant system implementation will need to provide :

1. A remotely accessible or locally reproducible testing environment where competitors evaluate, using CI/CD principles, their software contributions, feature enhancements or deploy the software on radios and end user devices to test applications.
2. A shared platform where competitors could formally or informally "bring their components" for conformance testing or inter-operability verification, allowing each the ability to measure, validate and develop within the test bed framework and exercise their solutions.
3. A playing field for formal integration/inter-operability or functional validation supervised by DoD stakeholders at scheduled milestones to demonstrate the advancements and implementations of features desired.

The second facet to encouraging, sustaining and broadening participation; domestic and international, is to seed or partner with an open source community. OpenAirX-Labs brings the OpenAirInterface Software Alliance community of developers, test and integration engineers from various academic and Industry members with a strong focus on North American participation. A key difference from other open source projects such as SRS-LTE and Free-5GC is community sourced contributions and active engagement whereas the former projects have a closed developer group and minimal support except via mailing list participation.

A suggested process and timeline for the 5G challenge is articulated below and expanded on in subsequent sections.

Overall Process



I B. How could a Challenge be structured to focus on the greatest impediments to the maturation of end-to-end open 5G stack development?

Limitations of the open 5G stack ecosystem include [11]: (i) Open implementations often do not keep pace with standard specifications; (ii) latency and scalability issues of software-based solutions; (iii) limited availability of open and/or open source projects focusing on the RAN; (iv) the lack of robust, reliable, well-documented software, ready to be deployed without additional development or integration efforts, and (v) the need for security-driven development in open 5G stack projects.

The development pipeline for 5G software protocol stacks follows the ideate, define, build, test, release and deploy model. The open source building model excels at the development paradigm but has severe gaps and lacks proficiency when it comes to operational deployment. The leap from development to operation is predicated on rigorous testing and defining testing regimes but the reality is that these are not executed on or prioritized in the open source ecosystem today. However, An open source stack is feature rich and has increased development velocity just not tested thoroughly. Hence, A key parameter to influence for the 5G challenge to benefit the DoD and general open source ecosystem would be **Large-Scale System Integration and Interoperability**. 5G has been defined as a service-based architecture with componentized and modular functions from the radio access network to edge to the core. The challenge developer(s) need to hone in on this integration testing bottleneck that puzzles system integrators/operators and test platform provider(s) by defining CI/CD tools and processes for validating software development, interoperability, and standards compliance by competitors.

The proposed challenge is based on principle of “Coopetition”—which signifies competition in the same horizontal (e.g. among various compliant MIMO radio vendors) but collaboration across vertically connected network stack elements (MIMO Radio <-> CU <-> Edge <-> Core), divided into two stages across RAN, UE, Edge, Core and Service Management and Orchestration (SMO) always with an application scenario (taken from DoD Smart Base thrusts) problem statement associated with the key metrics of evaluation:

Stage 1: Standards and Specification Compliance

In this stage, competitors bring standard and/or specification compliant implementations to be validated via a CI/CD process by challenge organizers. This stage is a competitive “intra” network i.e. RAN components such as CU/DU/RU and different Core Network Functions (CNF) are validated for the RAN and Core Network implementations respectively.

Stage 2: Interoperability Score.

In this next stage, competitors ‘cross stack’ are invited for an interoperability exercise to validate Control and User plane functionality and form an end to end architecture with a dedicated neutral system integrator/lab providing the interconnection and host platform capability to address set metrics for an application use case such as Tactical Edge Networks.

Table 1

A sample Application Specific Evaluation for eMBB service

Standards and Specification Compliance	Interoperability Score across Control, Signal and User Plane	RAN	UE	Edge Platform	Core Network	SMO
RAN						
UE						
Edge Platform						
Core Network						
SMO						

I D. How will the open 5G stack market benefit from such a Challenge? How could a Challenge be structured to provide dual benefit to both the Government and the open 5G stack market?

An extreme lead user such as DoD would cause a seismic shift in the open 5G stack market and will command attention to its requirements and needs. The open 5G stack market is miniscule compared to computer networking or datacenter cloud open market given the specialized hardware and engineering disciplines required for an entry level engineer. The open 5G stack market is divided into two segments and we advise any challenge to have clearly defined eligibility criteria for participation in the relevant track with appropriate resource allocations to reflect market costs for development and acquisition:

1. Open Source 5G Implementations: These implementations publish software following one of the licenses : GPL,OAI Public License, BSD-3, Creative Commons etc. for use and right to modify code.
2. Open Access Implementations: Commercial test and integration software suites that are available in source form for a technology access fee + license fee + royalty. There are strict rules on right to use, modify and re-distribute for these stacks.

Our response focuses on the open source implementation benefits as a long-term strategic investment to stimulate the US ecosystem. We do acknowledge the completeness and rigorous testing of the open access implementation(s) and suggest inclusion of these components in the immediate term in a parallel track focused on operational deployments and compliance testing. It is in the DoD and US federal govt's best interest to devote separate resources for these two tracks. The open source implementation track of the challenge should be considered as the primary development, test and future roadmap track. There is also a pathway to converge open access and open source implementations in interoperability scrimmages to test compliance and integration. It will only improve the overall ecosystem. In terms of a cost benefit or amortization of investment analysis, the long term impact on the open source US ecosystem greatly outweighs the immediacy or all-in approach in the open access ecosystem.

II A. What are the incentives in open 5G stack ecosystem development that would maximize cooperation and collaboration, promote interoperability amongst varied open 5G stack components developed by different participants, and mature desired featured sets faster with greater stability?

As mentioned above, open 5G architecture elements are developed primarily in two forms; open source and open access. A key metric of success for both approaches converges in successful interoperability demonstrations across 3GPP and open interfaces (such as O-RAN) at various points of the protocol stack. An interoperability exercise is usually the purview of a system integrator or a 3rd party lab, who has an end to end architecture setup and can swap different components to evaluate against interface specifications for validation. These interoperability exercises, hackathons and plug fests happen formally quite often for open access stacks but open source implementations are not incentivized to participate. The open access and open source communities are not against collaboration but the mechanisms of access and licensing often prevent the stakeholders from the respective projects/companies to co-mingle. A material incentive model that offers financial rewards and non-material incentive such as public recognition through awards and certifications at conclusion of the challenge should be considered. The challenge developers need to define Key Performance Indicators (KPI) over multiple different Key Result Areas (KRA) and assign each performer an individual compliance score and a team interoperability score which combined results in the Overall Performance Score (OPS). An OPS threshold can be set to segment financial incentives in a tiered manner and amplified with non-material recognition.

At the heart of the challenge, A structured central umbrella lab ecosystem that is moderated by DoD or a designated affiliate should become the focal point for integration and interoperability challenges and

frequent focused challenges on technical themes and enabling technologies need to be explored to strengthen and deliver robust implementations. The incentive to provide this central reference architecture as a challenge executor is also a strong motivating factor.

II. D Many open 5G stack organizations have developed partial implementations for different aspects of an open 5G stack. What portions of the open 5G stack has your organization successfully developed with working code? What portions of the open 5G stack does your organization believe can be developed quickly (6 months or less)? What development support would best enable test and evaluation of the different elements of an open 5G stack?

OpenAirX-Labs (OAX-Labs) is a partnership of dedicated US faculty, professional engineering staff and students organized in working groups for each of the best of breed consortia/alliances to track development: OAI, ONF, TIP, and O-RAN and distill the software available to build an open source end to end 5G implementation. Its charter reflects contributing to development, testing, integration and community participation in all open 5G forums. OAX-Labs is the coordinating entity providing conformance testing and system integration to the OAI RAN and Core software.

The primary composition is of all US based OpenAirInterface Software Alliance (OSA) Board members along with other academic and industry partners. This partnership is the designated North American partner of OSA in the OAI RAN and Core working groups to deliver a fully compliant open source end to end 5G architecture.

Introduction to Open Air Interface

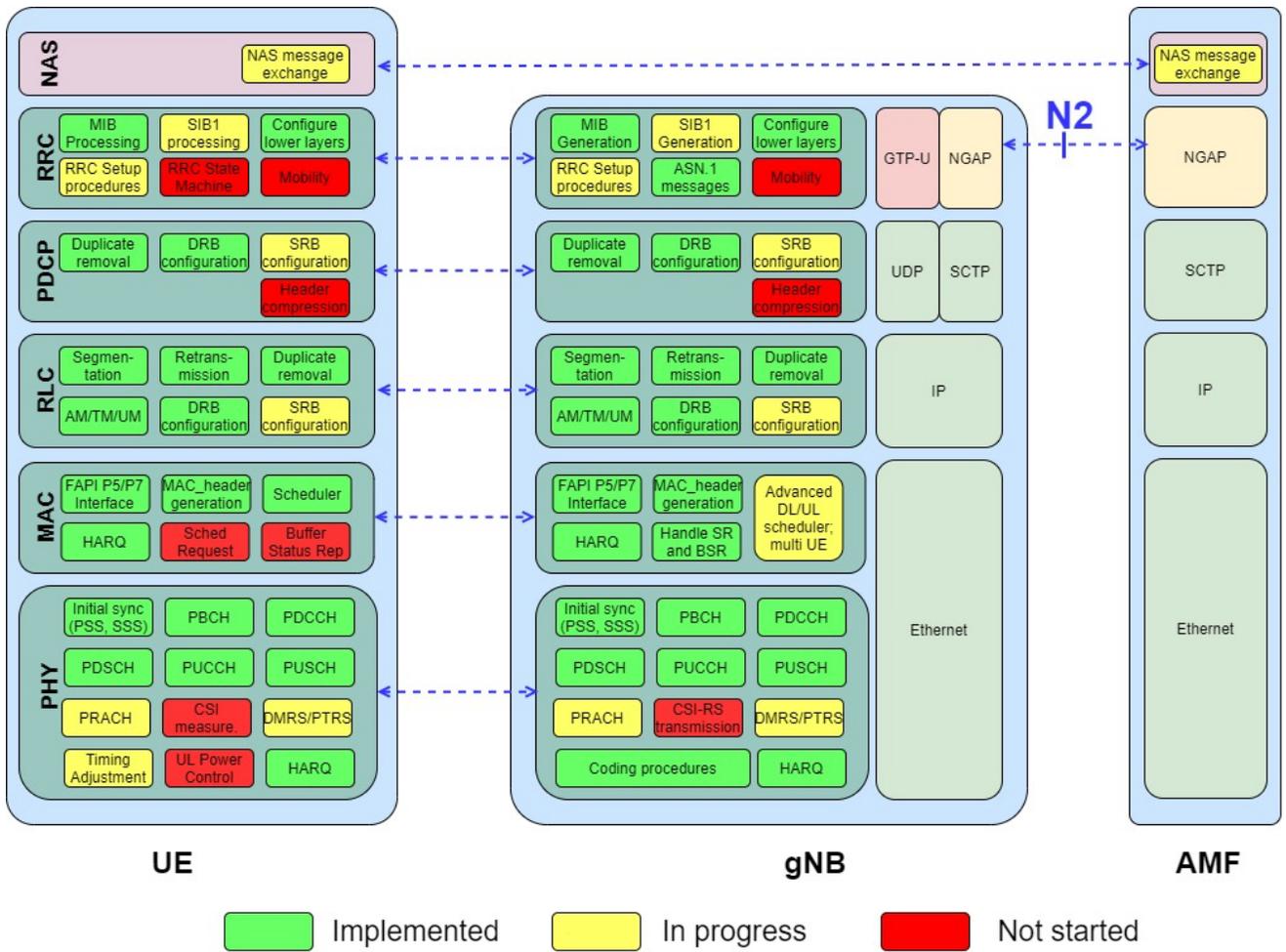
OpenAirInterface (OAI) is an open-source project led by the Open Software Alliance (OSA) that implements 3GPP-compliant 4G and 5G Radio Access Network (RAN) and Core Network (CN) protocol stacks [1]. The resulting software runs on general-purpose x86 computing hardware and Off-The-Shelf (COTS) Software Defined Radio (SDR) and provides adaptability to different use cases and deployment scenarios, making it an ideal platform for industrial and academic research [2]. OAI implementations supports the deployment of 5G Network in Non-Standalone (NSA) mode (completed) and Standalone (SA) mode (under development).

Open Air interface 5G Radio Access Network Project

The scope of the OAI 5G RAN project is to implement 5G RAN protocol stack for gNodeB and UE.

Current Status

The following block diagram shows the availability of features in OAI RAN implementation.



Software Architecture

The OAI gNB follows a pipeline structure that distributes the processing of different blocks over multiple threads. Some computationally intensive tasks like LDPC encoding are further parallelized using worker threads. The architecture adapts to the number of cores available on the system [5].

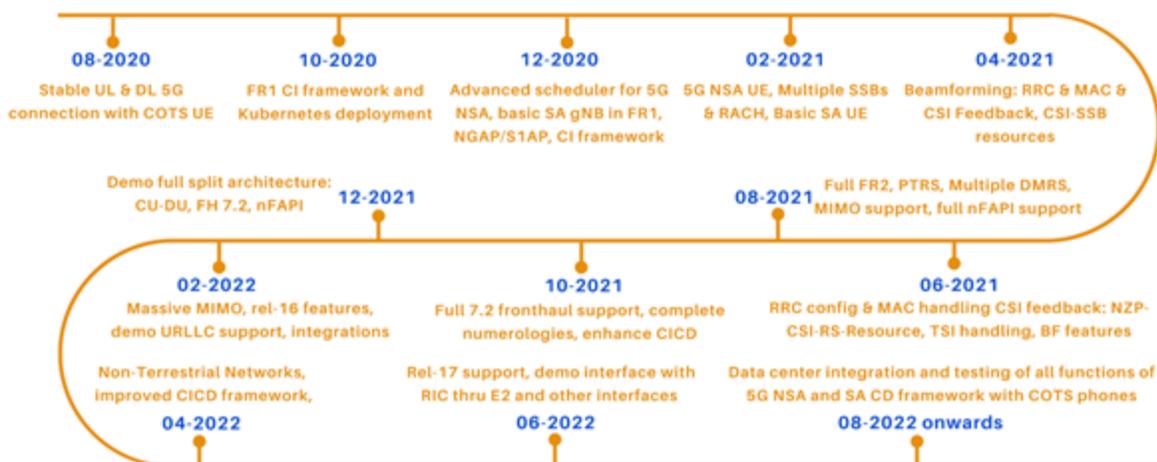
The OAI UE is also a multithreaded application and includes parallel processing of different slots as well as parallelization of LDPC decoding over segments.

Roadmap

The overall roadmap for OAI-RAN is shown below.

OAI 5G RAN Project Group

Timeline



The end-to-end Standalone mode implementation is under way. With most user-plane features already in place, the primary tasks for SA mode implementation are in control plane. Following are the details of SA features under development with the timelines.

Feature	Details	Status	Timeline
PHY/MAC	SIB1 scheduling in MIB and transmission of SIB1	development complete, testing in progress	Feb 2021
PHY/MAC	Completion of Random Access Procedure including Msg 3 and Msg 4	under development	Feb 2021
RRC	RRC message exchange (RRCSetupRequest, RRCSetup, RRCReconfiguration, RRCReconfigurationComplete)	under development and testing	Feb 2021
PDCP/RLC	Extend PDCP/RLC for handling SRBs	under development	Mar 2021
NAS	Transfer of NAS messages between AMF and UE	Completed; to be integrated	Apr 2021
NGAP	NGAP message exchange between gNB and AMF	under development	Apr 2021
N3 interface	GTP-U implementation and extensions	under development	Apr 2021
CU/DU split	F1-C and F1-U implementation	under development	June 2021
Interoperability and Testing		continuous	Dec 2021

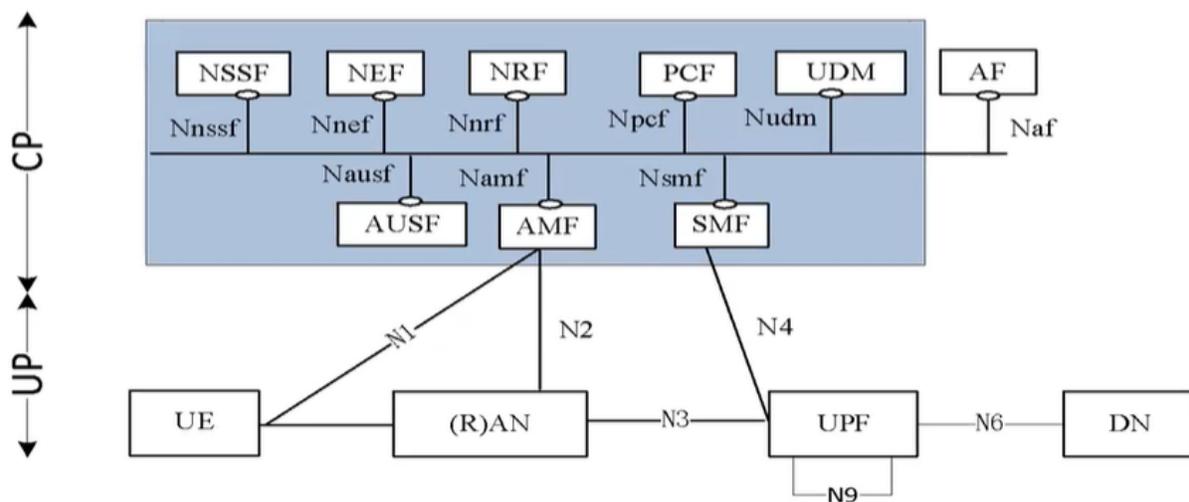
Overview

The goal of OAI-CN project is to deliver a 3GPP compliant 5G core network.

Current Status

The current implementation of OAI-CN provides a viable implementation of 5G core, including basic implementation of AMF, SMF and UPF (4G SPGWU currently serves as UPF). Basic call flows are supported for registration/de-registration of UE and service requests. Session management procedures are supported including PDU session establishment, modification, and release. These basic procedures enable the UE to attach to the core network and exchange IP traffic with data network.

The following diagram shows the 5G core network architecture as defined in 3GPP specifications [9].



5G System Architecture (source: 3GPP TS23.501)

AMF (Access and Mobility Management Function)

OAI implementation of AMF currently supports the following functions [8][10]:

- Termination of RAN control plane interface N2, which enables communication with gNB via NGAP message exchange
- Termination of N1 interface used to communicate with UE via NAS messages.
- NAS ciphering and integrity protection
- Registration/connection management
- Provide transport for session management messages between UE and SMF
- Locally implemented access authentication and authorization (without AUSF/UDM)

SMF (Session Management Function)

Following SMF conformance functions are currently implemented [8]:

- Session management, including maintaining tunnel between UPF and AN node

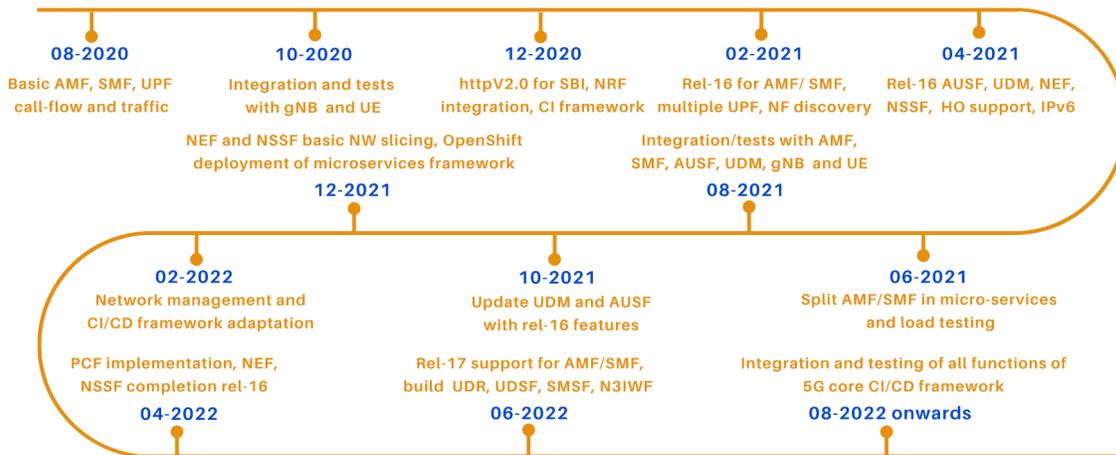
- UE IP address allocation and management
- Selection of UPF function
- N4, N10 and N11 interfaces

Roadmap

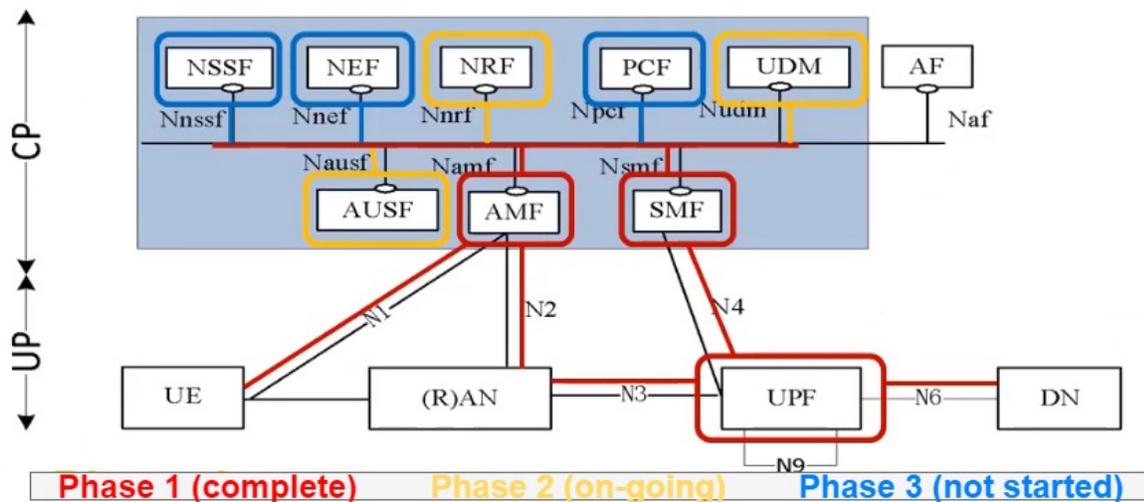
The following figure shows the overall roadmap of the OAI 5G CN project.

OAI 5G CN Project Group

Timeline



Shown below is a high level breakdown of the tasks into phases and the status of development.



Phase 1 (complete): This phase involved implementation of AMF, SMF and UPF with basic call flows as described in the previous subsection. This also included having a CI/CD framework in place.

Phase 2 (on-going):

- Implementation of additional features for existing components (AMF, SMF, UPF), such as IPv6 support, handover etc.
- Introduction of additional network components including UDM, AUSF and NRF.
- Integration and validation with OAI gNB and COTS UE.
- Performance evaluation of 5GC components.

Phase 3 (not started): this will include full standalone 5G core implementation and complete deployment framework for a microservices-based architecture.

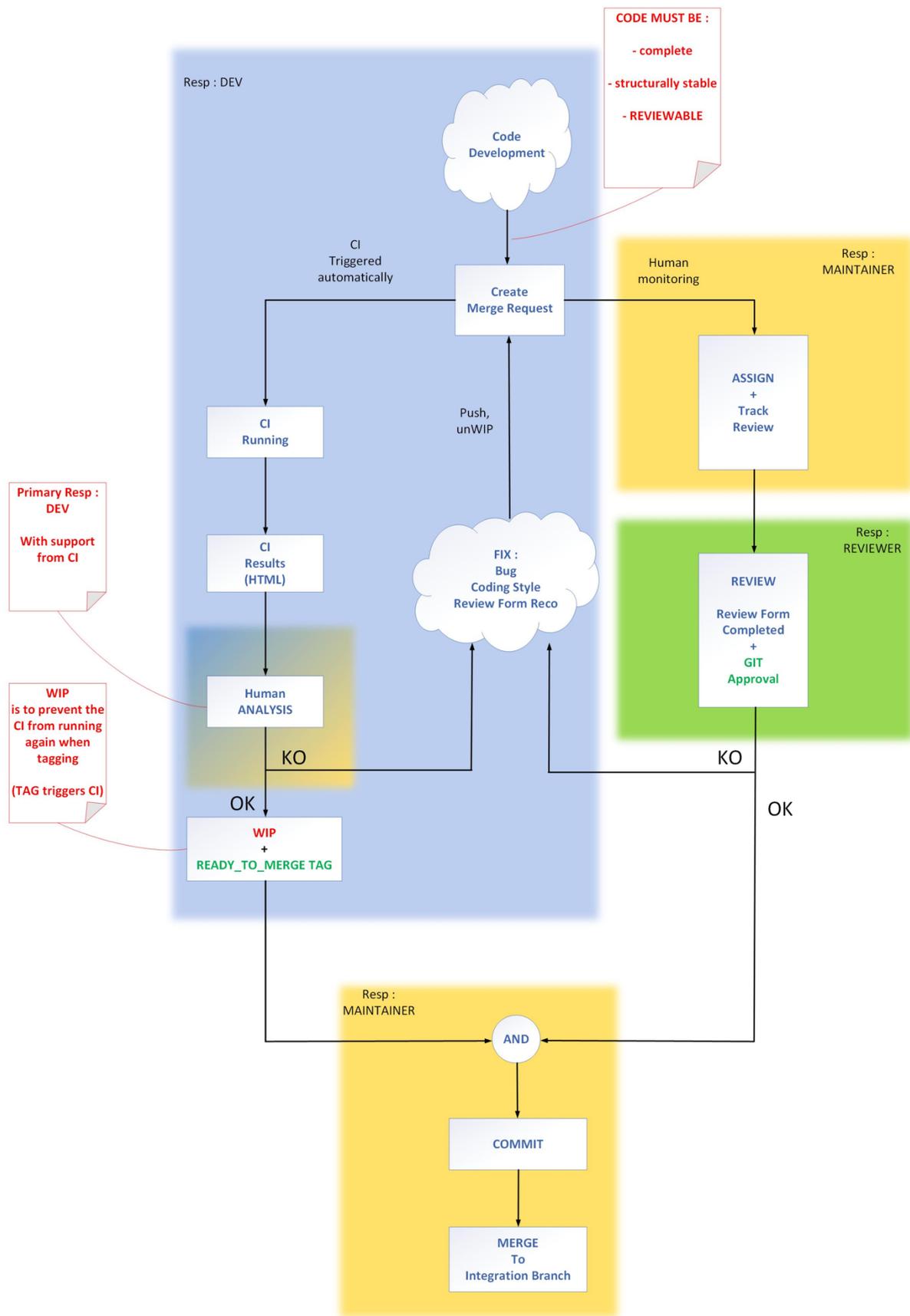
OpenAirX-Labs Continuous Integration

The OAI and OAX-labs developer community keeps in sync with each other and collaborates via frequent meetings, including a weekly developer call, a dedicated weekly call for Standalone mode development and several sync up meetings between smaller groups of developers working on related features. The Gitlab page is a common landing zone not just for the main OAI codebase, but also for keeping track of all development efforts and collaboration. When a developer thinks their changes are ready to be merged into the main codebase, their code must first pass the CI process and must be approved via a code review process. This ensures the quality and functionality of the code without breaking existing functionality in the main codebase.

The CI process runs a suite of tests on multiple test benches with different configurations (the OAI CI process is explained in a later section). The process ensures the following:

- Quality control by validating new features and their compatibility with existing features/code.
- Proper integration of parallel contributions from different developers.
- Faster development time by catching issues and incompatibilities sooner.

The following diagram illustrates the process for merging new code into the OAI codebase.



II E. What 5G enabling features should be highlighted in the Challenge, such as software defined networking, network slicing, network function virtualization, radio access network intelligent controller, radio access network virtualization?

The proposed 5G Challenge needs to recognize individual technologies, such as those aforementioned, as foundational to an end to end 5G open stack. However, it is important not to think in discrete terms and realize that these technologies will continuously change. Hence, the most important activity to undertake as 5G enabling features are identified is “Building a Roadmap”. This will allow DoD/NTIA to identify the level of maturity of each component, recognize break points or gaps where attention is needed, advertise its needs to the Industry and open source community, influence the rate of advance of each contributing technology and introduce the developed technologies into the 5G stack when ready. This approach can be considered at an application level such as thrusts addressed in the DoD Smart Base program.

The challenge developer(s) need to build a modular decomposition framework of the technologies to understand what works and what does not. This framework also identifies “pre-competitive” software driven features that can be accelerated with such a challenge. The inputs to such a roadmap requires a parsing of standardization and specification documents provided by 3GPP and O-RAN Alliance to distill the architectural elements of an end-to-end 5G implementation.

III A. What software and hardware infrastructure will be needed to successfully execute this Challenge?

Following subsections list the hardware and software requirements for development, testing and continuous integration of OAI 5G stack by OAX-labs.

Hardware Requirements

Hardware	Purpose	Recommended equipment
Intel Architecture based compute nodes	Development and testing; OAI gNB and OAI UE are run on x86 hardware	Intel architecture based PCs/servers (min 4 cores): <ul style="list-style-type: none"> • Generation 3/4/5/6 Intel Core i5,i7 • Generation 2/3/4 Intel Xeon • Intel Atom Rangeley, E38xx, x5-z8300
Software Defined Radios	Testing; Signal processing related to PHY layer is performed on FPGAs in SDRs	USRP X310 USRP N310 USRP B210 Blade RF Lime SDR
Commercial 5G-enabled smartphones	For interoperability testing with OAI gNB-OAI CN	Samsung S20 5G SIMCOM Quectel

Faraday cage	May be used when testing in licensed bands	
Antennas	For over the air testing	
SMA cables	For connecting the antennas with USRPs	
Synchronization modules	Synchronization of USRPs allow for easier testing and eliminates vulnerability to frequency and timing offsets	NI OctoClock

Software Requirements:

Software Required	Recommended Tools
Operating System	Ubuntu 16.04 or higher with low latency kernels
Virtualization Tools	LXC, Docker, Kubernetes, OpenStack
GNB/UE simulator to test core network	DsTester
Debugging Tools	Wireshark, Tttracer, GDB debugger
CI/CD Tool	Jenkins
Coding guidelines checker	Coverity scan/cppcheck
Tools for controlling commercial UE	ADB (Android debugger), minicom

OAI 5G RAN and CN repositories are available on Gitlab [3],[4]. These use Cmake-based build environment and include all the necessary build scripts. OAI builds and runs in an Ubuntu environment. Hence a PC with Ubuntu 16.04 or later is the best to use as a development environment. A Windows or MAC system may be used alternatively with a virtualized Ubuntu installation using a tool such as VirtualBox. The build scripts included in the OAI codebase take care of installing all the prerequisite packages needed for building OAI.

Unit Testing

OAI provides several tools for unit testing. These are primarily simulators that allow testing of new and existing RAN features without the use of SDRs.

PHY simulators: These are unitary simulators that allow testing of various PHY and MAC features by allowing unit tests to be run in a local environment. These simulators are part of the codebase and developers add new test cases to these as they are adding new features into the codebase.

RF Simulator: RF simulator is an OAI device that replaces the radio heads (e.g. USRP device). It allows an OAI UE to connect to an OAI gNB via a network interface and allows testing in a controlled environment. RF simulator also provides support for basic channel modeling. This is a useful tool for testing implementations of various protocols and algorithms.

“noS1” mode: Although this mode runs over actual SDRs, it allows connection between OAI UE and gNB without the need of a core network. A TUN interface is created at the PDCP layer which can be used to inject/receive user plane traffic.

Lab Testing

Two kinds of RAN tests are performed in lab environments:

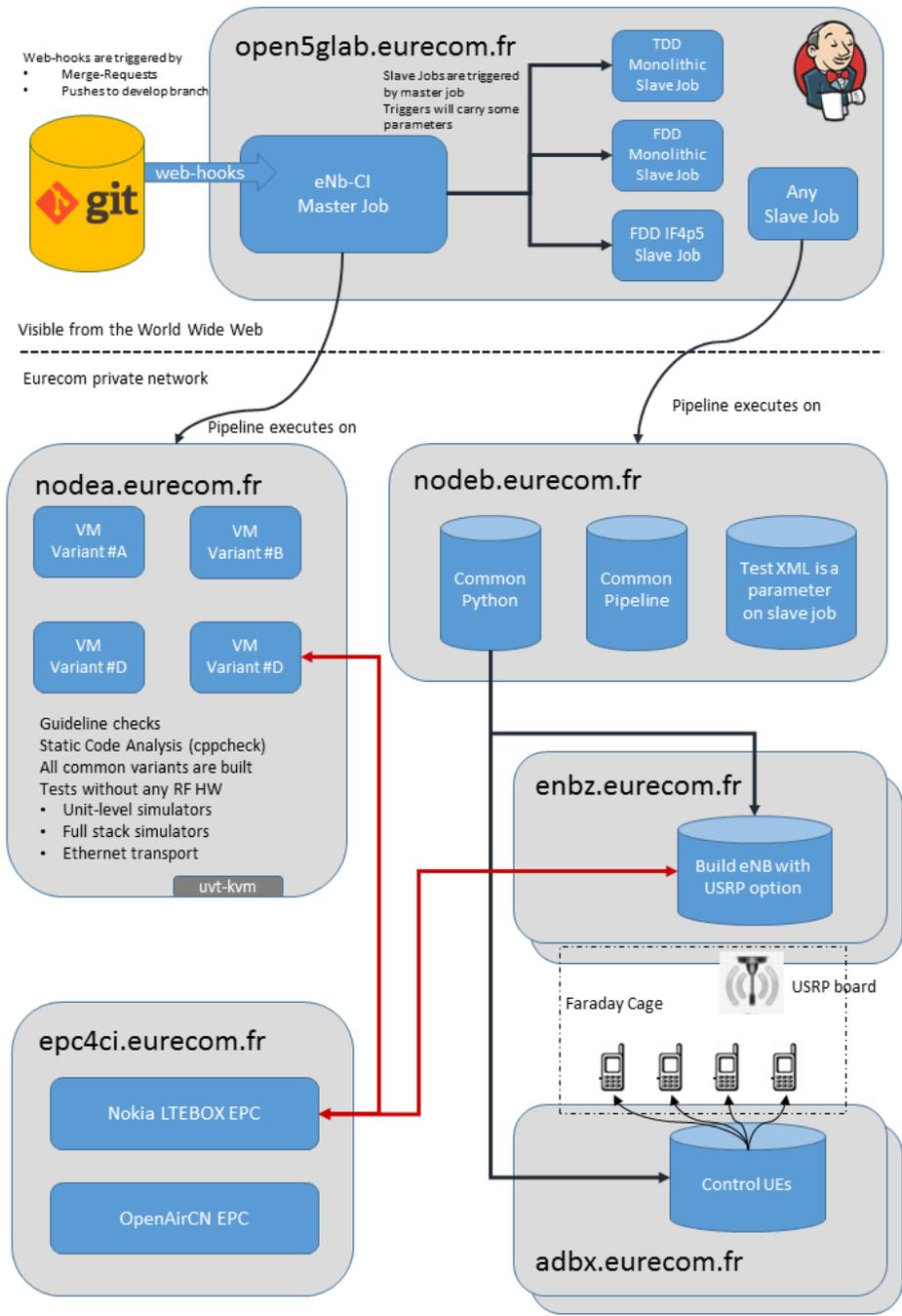
- Testing of OAI gNB with OAI UE
- Interoperability testing of OAI gNB with commercial UEs

Core Network is currently tested with a gNB/UE simulator called DsTester. Core network components are deployed in Docker containers.

Currently, 5G OAI-RAN and 5G OAI-CN cannot be tested together as the interfaces between them are under development as part of the effort to enable Standalone mode. The required functions are expected to be available soon and will allow end-to-end deployment and testing of OAI 5G Standalone network.

OpenAirX-Labs CI/CD and Interoperability Testing:

OAX-Labs has a completely automated CI system that is fully integrated with GitLab and replicates the OAI processes. The following block diagram provides an overview of the architecture of the CI system. The Jenkins server (open5glab.eurecom.fr) is visible to developers/users via the World Wide Web. This provides an overview of the pipeline status and provides access to build and test logs after the pipeline is complete. The CI pipeline runs on other servers on Virtual machines and consists of stages including guidelines check, static code analysis, building of all code variants and testing with equipment [6].



References:

[1] www.openinterface.org

[2] F. Kaltengerger, A. P. Silva, A. Gosain, L. Wang, and T.-T. Nguyen, "OpenAirInterface: Democratizing Innovation in the 5G Era," *Computer Networks*, no. 107284, May 2020.

[3] <https://gitlab.eurecom.fr/oai/openairinterface5g>

[4] <https://gitlab.eurecom.fr/oai/cn5g>

[5] T.-H. Wang , R. Knopp , OpenAirInterface: A pipeline structure for 5G, in: DSP 2018, IEEE International Conference on Digital Signal Processing, 19–21 November 2018, Shanghai, China, Shanghai, CHINA, 2018.

[6] <https://gitlab.eurecom.fr/oai/openairinterface5g/-/wikis/ci/continuous-integration-home>

[7]

<https://www.openairinterface.org/docs/workshop/1stOAINorthAmericaWorkshop/Training/DEFOSSEUX-OAI-CI-Training-2019-06-25.pdf>

[8] <https://www.openairinterface.org/docs/workshop/2020-11-VIRTUAL-EVENT/2-NGUYEN-OAI-CN-5G-EURECOM.mp4>

[9] 3GPP TS 23.501

[10] https://gitlab.eurecom.fr/oai/cn5g/oai-cn5g-amf/-/blob/develop/docs/FEATURE_SET.md

[11] Bonati, M. Polese, S. D'Oro, S. Basagni, and T. Melodia, "Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead," *Computer Networks*, vol. 182, August 2020.