EURECOM
Sophia Antipolis

Academic research, Standardization and Open-Prototyping

Raymond Knopp
Communication Systems Department
Networked-Systems Group

GRADUATE SCHOOL & RESEARCH CENTER IN DIGITAL SCIENCE

Institut Mines-Télécom

EURECOM

Sophia Antipolis

Academia

Institut Mines-Télécom

Politecnico di Torino

Aalto University

Technische Universität München

NTNU
Norwegian University of Science and Technology

CHALMERS
UNIVERSITY OF TECHNOLOGY

CZECH TECHNICAL UNIVERSITY IN PRAGUE

Industry and Institutions

orange

SAP

BMW GROUP THE NEXT 100 YEARS

IABG

Symantec.

monaco telecom

Gouvernement Princier
PRINCIPAUTÉ DE MONACO

www.eurecom.fr

Overview

- Some lessons learned from past mistakes
- Opportunities for researchers in 5G standardization, in particular signal processing
- “open-source” prototyping
- The OpenAirInterface initiative

Lessons Learned in Academic Research

- Think carefully before publishing research results with a section entitled "**Practical Considerations**" or phrases like "**Imagine now a signaling scheme where** …"
- Getting carried away and quickly publishing results pertinent to real systems can be costly
  - Good for your academic reputation
  - Bad for you institute's budget …
- As an academic institution
  - If it's a receiver algorithm, no problem, go ahead
  - If it's a "transmission scheme" or "signaling mechanism" be very careful

Lessons Learned in Academic Research

shown in Fig. 2, along with the spectral efficiency of a non-fading Gaussian channel with the same transmit power S,

$$C_G = W\ln\left(1+\frac{S}{WN_0}\right). \tag{16}$$

As the number of users increases, the spectral efficiency of SSMA approaches the Gaussian channel. The gap between the curves for SSMA and FDMA is on the order of $0.5772/\ln 2$ (*bits/s/Hz*) for $K = 16$ and high SNR as in (12). In terms of spectral efficiency (with an infinite observation interval), SSMA is not much better than FDMA, however we believe that the capacity vs. outage characteristics of SSMA as defined in [2] are better than those of FDMA because of added diversity. We see that feedback of the channel responses can yield a significant improvement in capacity, especially with a large number of users. Moreover, we believe the same is true for the capacity vs. outage, since a user transmits only where and when his channel is good.

V PRACTICAL CONSIDERATIONS

Partitioning of the available bandwidth in the optimal fashion may be difficult to achieve practically. A more practical alternative would be to divide the entire bandwidth into N equal size sub-bands and allocate a single user to each these sub-bands based on their instantaneous frequency response over the entire bandwidth. In general, a user may occupy more than one sub-band at any given time, or may not occupy any sub-band at all. We can look at this as an OFDM system with one user per carrier and dynamic allocation of the users on the carriers based on the instantaneous frequency responses of the users in each subband. We illustrate this in Fig. 3 for $K = 4$ and $N = 8$, where we see that at a particular time it is possible that a particular user occupies more of the available bandwidth than the others. This would be to take full advantage of the strength of the channels at a particular time. Such a scheme may be very appropriate for high speed wireless data networks.

1995!

The bandwidth of each of the smaller bands is $W_s = W/N$. If N is large enough, the sub-bands $[-W/2+mW_s, -W/2+(m+1)W_s]$, $n = 0, 1, \ldots, N-1$, can be considered as being frequency-flat (i.e. $W_s \ll 1/T_m$). This reduces the problem to one with N statistically identical, but not independent, parallel chan-

Why should some academics get involved?

- Most of our PhD students will not get academic jobs
  - Training on the standards process (in particular 3GPP) and IPR management
    => extremely useful (for us, postdocs, PhDs, research engineers) alongside fundamental research
- A few essential patents can be extremely lucrative for a research organization => help support more fundamental research
- Canonical examples
  - Turbo codes (IMT-Atlantique)
  - Polar codes (Bilkent University initially and others later)
  - MPEG source codecs (many non-industry contributions)
- Thing to avoid
  - Publishing great ideas and having them “stolen” and finding them slightly modified in patents and standards (3GPP) documents.

How to get involved

- 5G Standardizaion has lots of possibilities for “academic” contributions

  Example from Release 16 New Radio (too late)

  - 38.825 Study on NR industrial Internet of Things (IoT)
  - 38.812 Study on Non-Orthogonal Multiple Access (NOMA) for NR
  - 38.824 Study on physical layer enhancements for NR ultra-reliable and low latency case (URLLC)
  - 38.855 Study on NR positioning support
  - 38.874 NR; Study on integrated access and backhaul
  - 38.885 Study on NR Vehicle-to-Everything (V2X)
  - RP-190149 NR eMIMO WI
- Very similar to research publications, but less academic
  - Can even be derived using results from a research publication
  - BUT: these studies usually have patents behind them

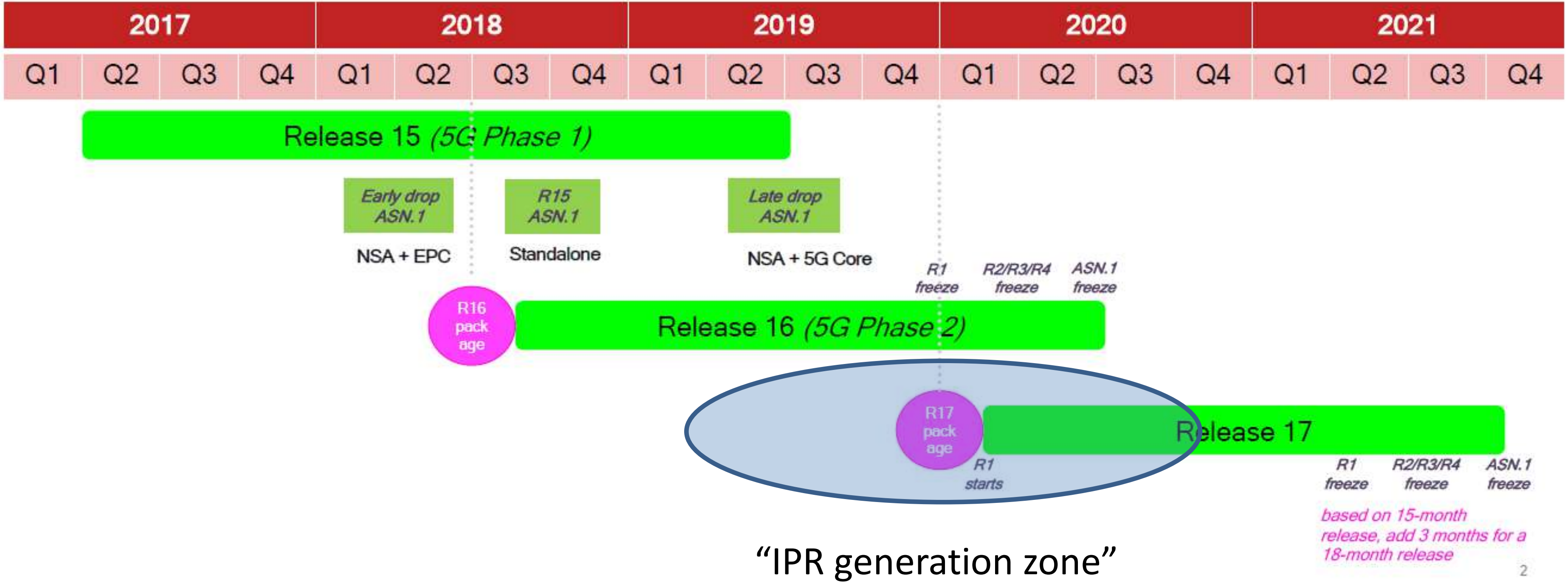
Areas Envisaged for Release 17 (Comm/DSP related)

- Release 17 will probably be called "5G+" on your future phones and should provide mechanisms for even more vertical use-cases
- 3GPP has 16 "shortlisted" areas for investigation (starting now) and standardization in 2021
- Some that may be appropriate for Comm/DSP communities
  - "NR-Light" => low SNR/spectral efficiency, short packets
  - "Small_data" => short/sporadic packets
  - "Coverage_enh" => low SNR/spectral-efficiency, multiple-access channel
  - "IIoT_URLLC_enh" => short packets for Industrial IoT
  - "MIMO-enh" => yes MIMO is still going strong, especially high mobility scenarios
  - [Non_Terrestrial_Networks] => positioning aspects
  - [Positioning_enh] => Factory/campus positioning, IoT, V2X positioning, 3D positioning, cm level accuracy, incl latency and reliability improvements
  - [NR_above_52.6 GHz] => waveforms and propagation related studies

How can we get involved

- In your collaborative projects with 3GPP industry (H2020, FP9 etc.)
  - Try to generate some “systems” patents (with or without your 3GPP partners) and propose study items with your partners
  - If your institute is a 3GPP member, go yourself
    - If you’re credible, the project framework should pay for the resources to do standardization like they do to industry
  - If your idea is truly good (essential) there will be a commercial opportunity for your institute

Timing is critical



Some Areas at EURECOM

- Target Release 17 contributions for new vertical use-cases (Industrial IoT, dense sensor networks, vehicular)
  - “Low-hanging fruit”
  - Massive random-access (uplink)
  - mMTC (coding for coverage extension)
  - NR-V2X (evolution of Release16 V2X)
- Release 18 and beyond (6G)
  - More fundamental ideas
  - Machine-learning tools applied to cellular networks

Open-Source (code) Models

- Means to share an implementation openly (e.g. linux kernel, GNUlib)
- Coupled with a community
  - User community (always)
  - Developer/contributor community (sometimes)
- Can be coupled with a community testing framework
  - Essential if there is a developer/contributor community
- Like a standard, but collaboration on code/documentation related to an implementation
- If there's a community then there are licenses and agreements
  - Critical to the collaboration model
  - Defines use of implementation
  - Defines legal framework for contributors

Prototyping with open-source

- A demo speaks a lot about an idea/patent, even more so if you can show some sort of interoperability with industrial systems
- If you're not Ericsson or Nokia, today several open-source solutions for 4G/5G radio signal processing and protocols exist for prototyping by researchers with commodity hardware (PCs + USRPs)
  - OpenAirInterface
  - srsLTE
- Even if you are Ericsson or Nokia these tools are still pertitnent!
- Problem
  - open-source (OSI license : GPL,Apache) kills a patent if contributed by the owner. Traditional open-source communities are not good for 3GPP patent holders
  - OpenAirInterface License protects the IPR like the ETSI/3GPP standard (FRAND)
- A word of caution
  - Avoid contributing potentially essential IPR into a 4G/5G open-source project
  - File patent and use OAI or keep closed and use a compatible open-source project (i.e. not GPL/AGPL)

Major Challenges (non-technical)

- Have open-source community working alongside 3GPP in synergy
  - If 3GPP players in OS community => implicitly influence the standard
    - Example : O-RAN industry group
  - Reference implementation for testing process (for development of the standard and standardization of testing procedures) : think of MPEG or IEEE 802.14
  - Make 3GPP integration easier for SMEs (e.g vertical use-cases)
- We strongly believe that OpenAirInterface License will allow for this
  - Major players also do, but are still skeptical to contribute 3GPP essential IPR today
  - We need to understand this process better => high potential for rapid technology transfer between academic and industrial labs

Major Challenge (technical)

- Methodologies for community-based development of *real-time signal processing*
  - DSP software is complex (algorithms and their computational optimization)
  - Generally-speaking, bridging two communities (computer scientists and DSP/Comms) is challenging
  - Interaction with real-time hardware
  - Testing with commercial devices remotely

OpenAirInterface

- Open-Prototyping activity that started ~1997 (3G era)
- Idea (initial) was to allow DSP/Comms researchers to experiment with real-time HW
  - Array processing, cross-layer scheduling, MIMO-OFDM receivers, mesh/relay topologies etc.
- Quickly we also aimed at end-to-end integration in order to test applications
  - Synergy with networking communities
  - Addition of core network components
  - Embraced more modern software methodologies
- ~2010 had partial 4G compliance to interoperate with commercial devices (a couple of years after commercial networks were first deployed)
  - Target was a reference implementation of 4G for research purposes
  - This got major industry interested (Alcatel-Lucent, Orange, etc.)
- 2014-15 :OpenAirInterface Software Alliance founded, License drafted (finalized later)
- 2018/19/20
  - Cloud-based Radio DSP and Protocols
  - 5G partial compliance
  - Network deployments for research (outdoor)
  - Embryonic commercial use-cases

OAI Community (Alliance)

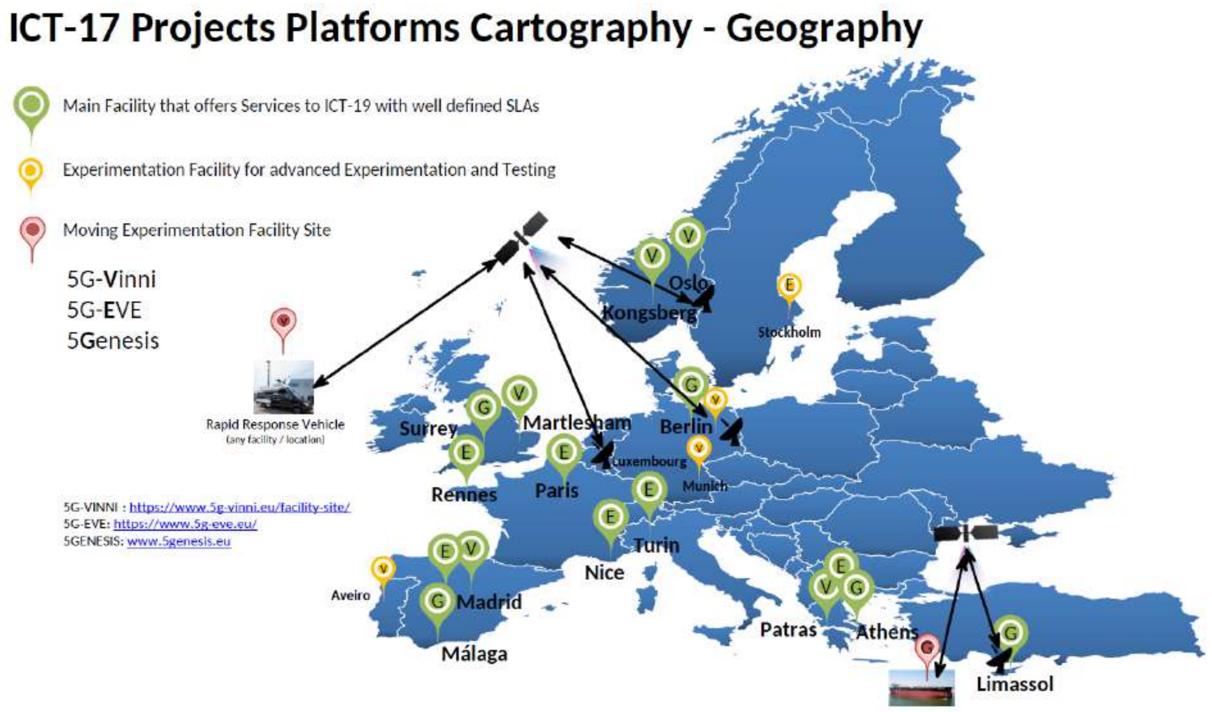
- Founded in 2014 as a “Fond de Dotation”
- 3GPP “strategic” members in 2015-2019 (Orange Labs, TCL 5G Lab, Nokia Bell Labs, Fujitsu, InterDigital, **PAWR**)
- Many associate members (RedHat, Cisco, Samsung USA, Renault, Kyocera, Viettel, Blackned, B-COM, INRIA, Fraunhofer, Rutgers WINLAB, U. Utah, BUPT, etc.)
- Non-membership donations : Facebook
- Donations are to maintain a engineering support team for
  - CI/CD
  - Community management/building
  - Industry relations

  ⇒ Industry is more comfortable and researchers can focus on features and architecture enhancements
- Organization of workshops
- Coordination of Technical and Strategic governance

CI/CD

- CI = continuous integration
  - Community pushes software enhancements (features, bug-fixes, etc) and tests are run automatically. If tests pass, code modifications are accepted (preferably automatically)
  - Key thing is that the tests are representative, if not exhaustive, of the use-cases of the software
  - OAI currently has 3 CI sites
    - EURECOM
    - Fujitsu (Tokyo)
    - Nokia Bell Labs (France) : soon
  - Includes both pure software testing (simulators, code quality indicators) and tests with hardware and real-devices (smartphones, IoT modules, etc.)
- CD = continuous delivery/deployment
  - Software is regularly pushed onto a deployed (production) system/network
    - EURECOM network (5G-EVE / OPNFV site)
    - INRIA R2LAB
    - US PAWR Sites
    - B-COM (France)
    - Orange Labs (PlugIn Network and 5G-EVE Site)

European 5G/B5G Experimentation Landscape



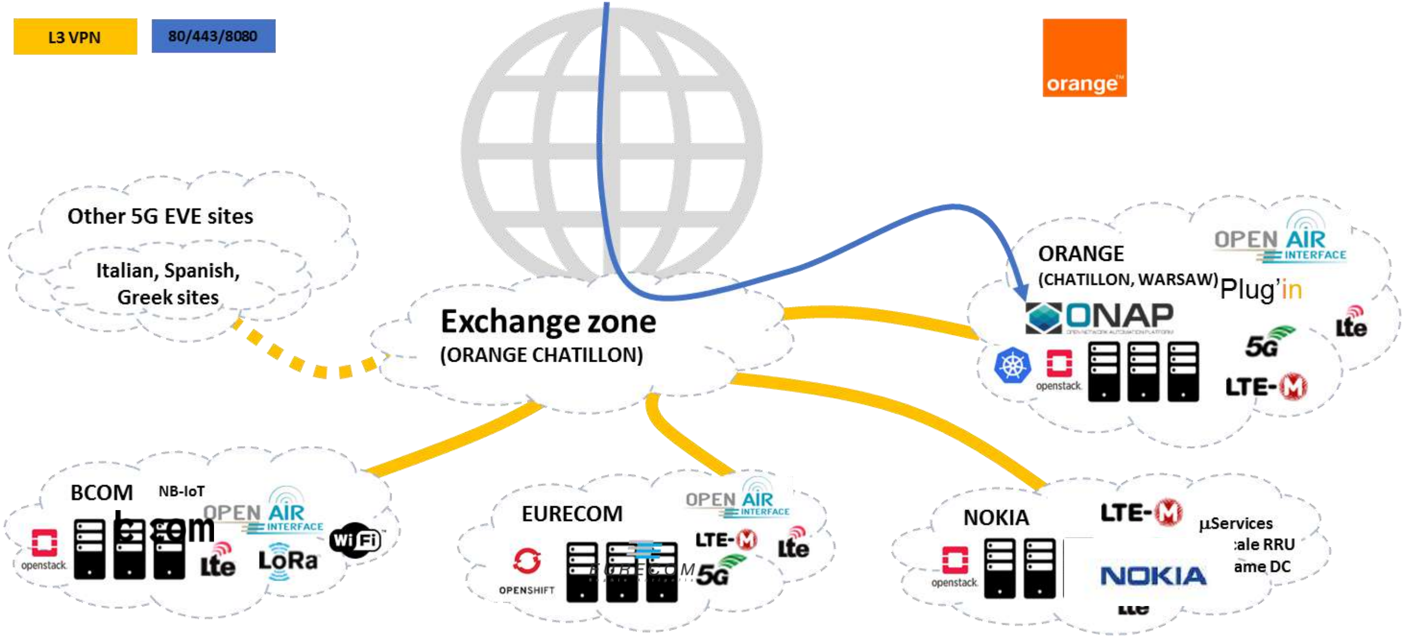
INSTITUT CARNOT Télécom & Société numérique

EURECOM

Various EU Objectives and Platforms (2019-2023)

- E2E pre-commercial “experimental” networks (€€€€)
  - Test integration of vertical services (SMEs, industrial IoT, major utilities, etc.) => upper-layer service paradigms
  - Use commercial 5G equipment (Nokia, Ericsson, Huawei, Samsung), no “under-the-hood” access
  - Orchestration (ONAP)
  - Data-center technologies
  - Major industry on the “bottom”, some academics and SMEs “over-the-top”
- Experimental networks (€)
  - Using open-source solutions (OAI, srsLTE, OMEC, Magma) or affordable commercial SW (Amarisoft,Open5GCore) and off-the-shelf HW (USRPs, IRIS, LimeSDR, etc.)
  - Test lower-layer components (full “under-the-hood” access)
    - Scheduling (e.g. URLLC)
    - Physical-layer technologies (massive antenna processing, DSP on x86, etc.)
    - Integration of some service architectures
    - Innovative use of data-center technologies (Kubernetes for RAN)
  - Academics/SMEs “on the bottom” and mix of academia/industry “over-the-top”

French H2020 5G Sites (5G-EVE)

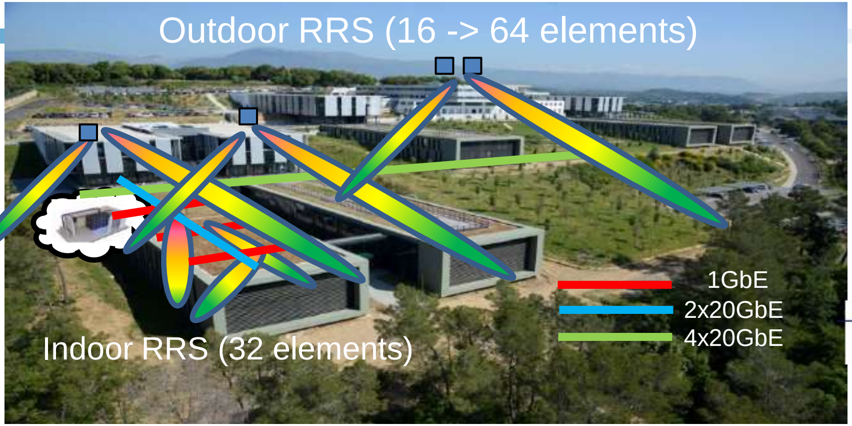


Main target: Testing of new vertical use-cases enabled by 5G

OPNFV VCO 3.0

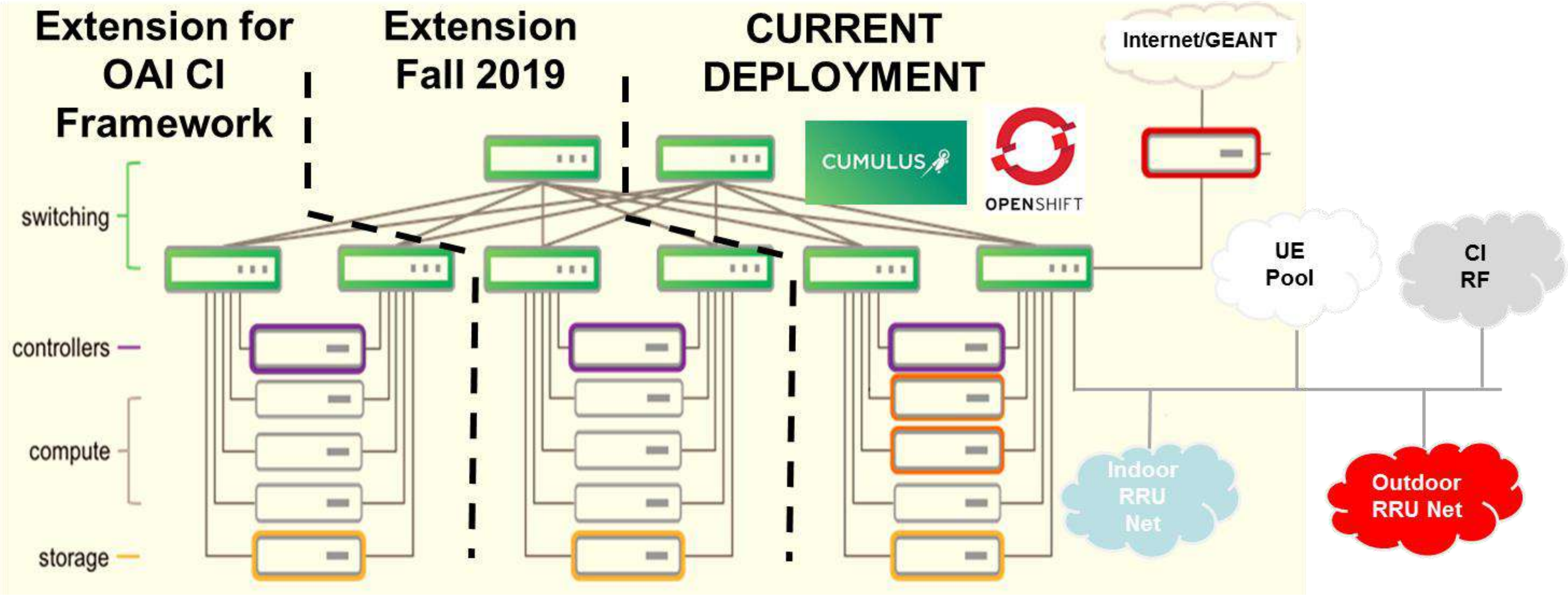
- Managed by Linux Foundation and RedHat
- Objective: Full 5G, Cloud Native, and Edge
- 2 test sites
  - EURECOM in Sophia Antipolis
  - Kaloom in Montreal
- Please visit: https://wiki.opnfv.org/display/OSDD/VCO+Demo+3.0+Home
- **Important message**: EURECOM site for Radio DSP and Protocols uses a modern data center architecture

EURECOM 5G Test Site



- Indoor/Outdoor deployment of 5G-NR Radio units (+LTE-M/NB-IoT)
- Frequency allocations in place / pending
  - 3600-3680 MHz TDD (61 dBm EIRP, NR band 78) => 5G eMBB/URLLC
  - 2580-2610 MHz TDD (61 dBm EIRP, LTE band 38) => 4G
  - 703 – 713/758 – 768 (57 dBm EIRP, NR band 28) => 5G (Orange license)
  - 698 – 703/753 – 758 MHz FDD (LTE band 68) => IoT / ProSe
  - 733 – 736/788 – 791 MHz FDD (LTE band 28) => IoT / ProSe
- Experimental Playground for OAI
  - Target scenarios : eMBB, URLLC, mMTC, D2D

Physical Architecture

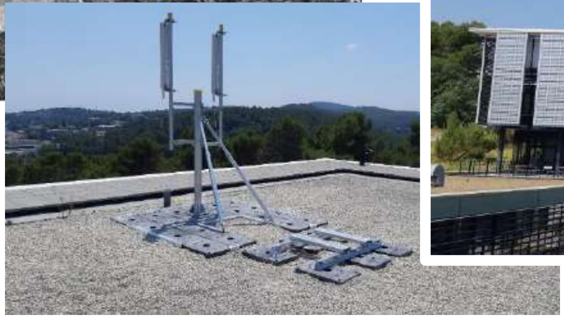


- Platform gateway
  - 1x Xeon E5-v3
- Switching Fabric
  - 3x EdgeCore 54-Port 25G/100G Ethernet Switches
- Intel Xeon servers
  - 4x Xeon Gold 6154
  - 1x Xeon Silver 4114
  - 2x Xeon E5-v2
- 5G RRUs (in server room for testing)
  - 2x USRP N310

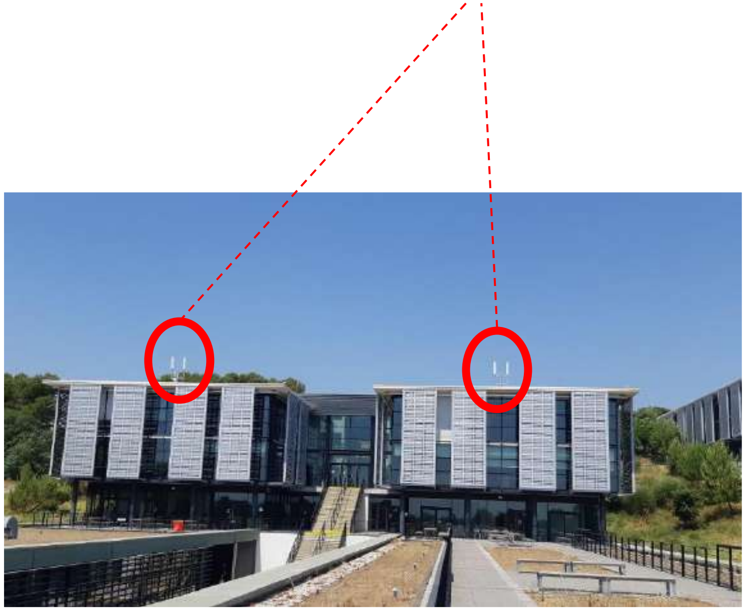
Technologies at EURECOM Site

- OpenAirInterface and Mosaic5G
- commercially-available RF and computing equipment
  - USRP B2x0, N3x0 + “Home-integrated” RF
  - Will use one commercial eCPRI RRU
- 3GPP technologies
  - 3GPP 5G NR (including RU,DU and CU node functions)
  - 3GPP 4G LTE (including RU,DU-LTE and CU-LTE node functions)
  - 3GPP 4G LTE-M
  - 3GPP 4G NB-IoT
  - 3GPP 4G LTE-Sidelink (ProSe / V2X)
  - 3GPP Rel 15 EPC (MME,HSS,S+PGw)
  - 3GPP Rel 15 5GC (Q1 2020)

Outdoor Components (Geography)



4G/5G Radio Site



Conclusions

- Allow academic (or non-profit) research institutes to be a direct part of 3GPP and not just a source of ideas for the patent holders!
- Learning from industry partners on
  - Harnessing commercial impact from our results
  - Tecnico-legal aspects and synergy with open-source community
- Better understanding of using modern software methodologies for
  - Implementing signal processing systems
  - Testing real-time signal processing systems
  - Integration of DSP with networking protocols and applications