# A European Testbed for Spectrum Sharing Studies Based on AI/ML Techniques

EuCNC 2021 Workshop on Spectrum sharing for the digital ecosystem towards 6G

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# Outline

- Testbed rationale
- CEPT/ECO perspective
- JRC perspective
- About the Testbed evolution

# The European Spectrum Sharing Testbed Initiative

- A joint initiative by
  - Joint Research Centre of the European Commission
  - European Communications Office of CEPT
- Aims
  - Support needs of regulatory studies on **dynamic spectrum sharing** in the **next 10 years**
  - Promote rapid flow of **European R&D knowhow** into the regulatory process

# Why Testbeds are Important for Spectrum Sharing

- Complex and unpredictable nature of interference
- Complexity of use cases, especially in 5G and more in 6G
- Need to test the performance at the different layers
- For AI/ML use, trustworthy data is key

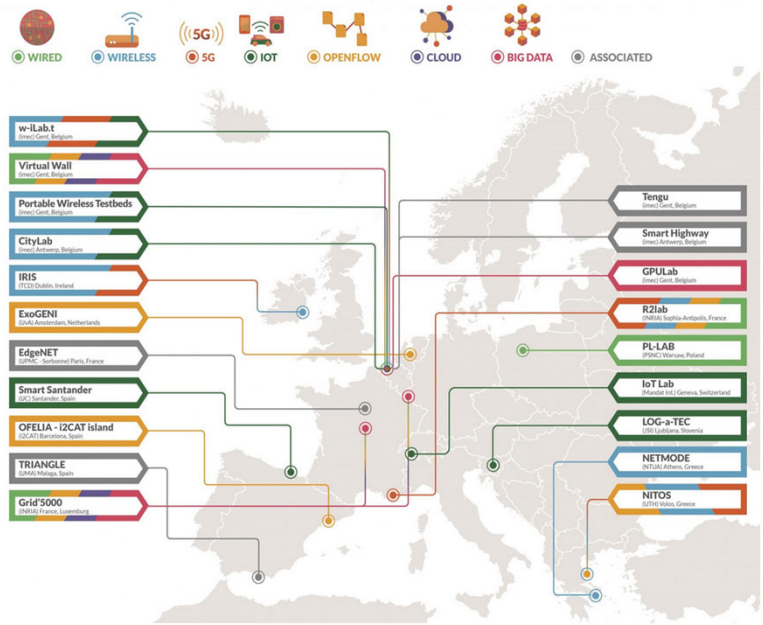
- The recent technological developments require more realistic tests and new use cases to be validated in real conditions. The consequence is that the testbeds are more important.

# EU 5G Testing Platforms

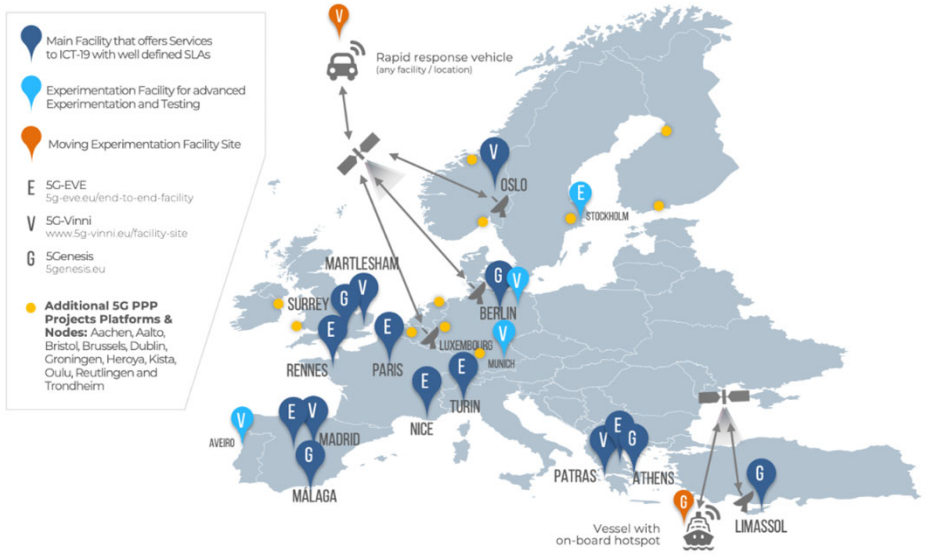
- Testing as a service

Fed4Fire+ testbed facilities across EU

→ SLICES testbed




5G Infrastructure Public Private Partnership (5G PPP): 5G-EVE, 5GENESIS and 5G-VINNI




- ETSI TR 103 761 V0.0.5 (2021-04) Core Network and Interoperability Testing (INT) Methodologies for E2E Testing & Validation of Vertical Applications over 5G & Beyond netwo

# Some Relevant EU Projects in Spectrum Management and Sharing

- 5G ALL-STAR: 5G Agile and flexible integration of satellite and cellular (2018-21)
  - Spectrum sharing between cellular and satellite access
- 5G-Enhance: EU-JP 5G Enhanced Mobile Broadband Access Networks in Crowded Environments (2018-21)
  - Enhanced spectrum resource management.
- COHERENT: Coherent control and spectrum management for 5G heterogeneous radio access networks (2015-18)
  - Spectrum sharing strategies in the context of heterogeneous mobile networks
- S3ISE: Spectrum Sharing Systems for Improving Spectral Efficiency: (2012-16)
  - Integrate spectrum sensing into other upper layer functionalities such as power and rate control, and resource scheduling
  - Exploiting inherent dynamics in a spectrum sharing environment
- ACROPOLIS: Advanced coexistence technologies for radio optimisation in licenced and unlicensed spectrum (2010-13)
  - Cooperative and cognitive communications paradigms that support advanced coexistence technologies for radio optimization
- CREW: Cognitive Radio Experimentation World
  - Open federated test platform, which facilitates experimentally-driven research on advanced spectrum sensing, cognitive radio and cognitive networking strategies

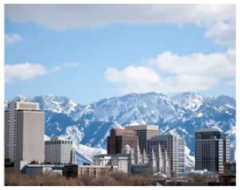
# Some Relevant Collaborative Results on AI and Spectrum Sharing

- SCATTER: Dynamic and Collaborative Spectrum
  - Demonstration of AI-Based incumbent protection system for collaborative intelligent radio networks
    - Partners: Ghent University., ….
    - Two-step AI-based algorithm that recognizes, learns, and proactively predicts the incumbent's transmission pattern
- Licensed shared access field trial and testbed for satellite-terrestrial communication
  - Partners: VTT, ESA…

# Relevant Spectrum Sharing Activities Worldwide

- US: NIST, PAWR platforms

PAWR platforms were chosen to be geographically diverse and research focus independent



**POWDER**
Salt Lake City, UT
Software defined networks and massive MIMO
**AVAILABLE TODAY !!**

**COSMOS**
West Harlem, NY
Millimeter wave and backhaul research
**AVAILABLE TODAY !!**

**AERPAW**
Raleigh, NC
Unmanned aerial vehicles and mobility

**Rural Broadband Platform**
TBD
*Coming late 2020*

**Colosseum** – *World's largest RF emulator, located at Northeastern University in Boston*
**AVAILABLE TODAY !!**

- UK: 5G RuralFirst, Birmingham City

# Directions for Future EU Testing Platforms in 5G and beyond

- Leveraging the ongoing initiatives:
  - **Artificial Intelligence**: European Network of AI Excellence Centres with 5 projects
  - **5G and beyond Testbed**: Scientific Large Scale Infrastructure for Computing/Communication Experimental Studies (SLICES)
  - **Standardization**: testbeds federations for 5G and beyond:
    - ITU-T – ETSI and IEEE FUTURE Networks are collaborating for defining Interoperability, Standardization, Reference Model and APIs



Disclaimer: a selection of the most relevant projects, and testbeds are cited in these slides. Others may exist.

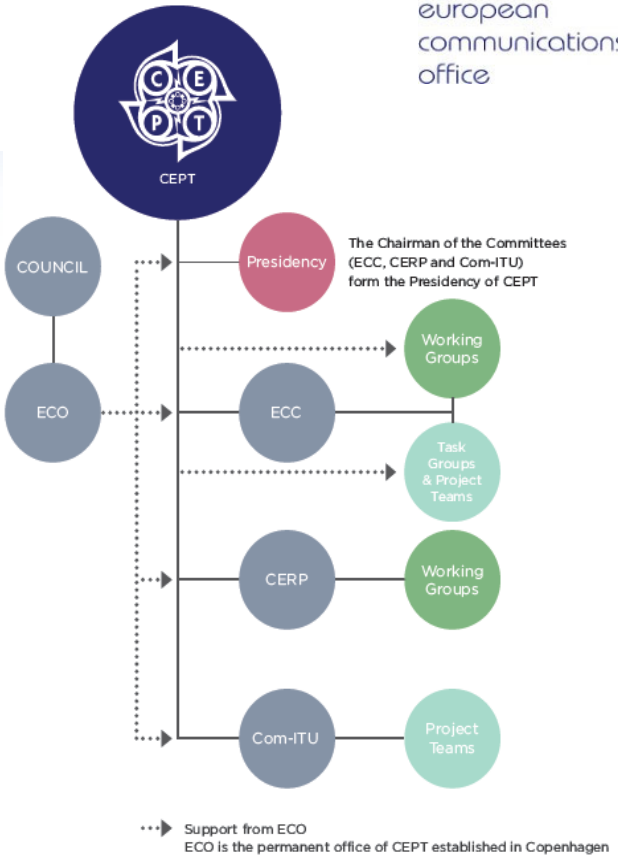
# Spectrum Sharing Field Tests

- OFCOM TV White Space
- Finnish LSA Trials
- Italian LSA Field Pilot
- … See the presentation by Heikki this morning

ECO
european communications office

# CEPT: European Conference of Postal and Telecommunications Administrations

- **CEPT**: Organisation of regulators and policy makers from 48 European countries
- **ECC**: Electronic Communications Committee – main body with responsibility for spectrum and telecommunications
- **ECO**: European Communications Office – CEPT Permanent Office




EU Member States – blue
Other CEPT members - green



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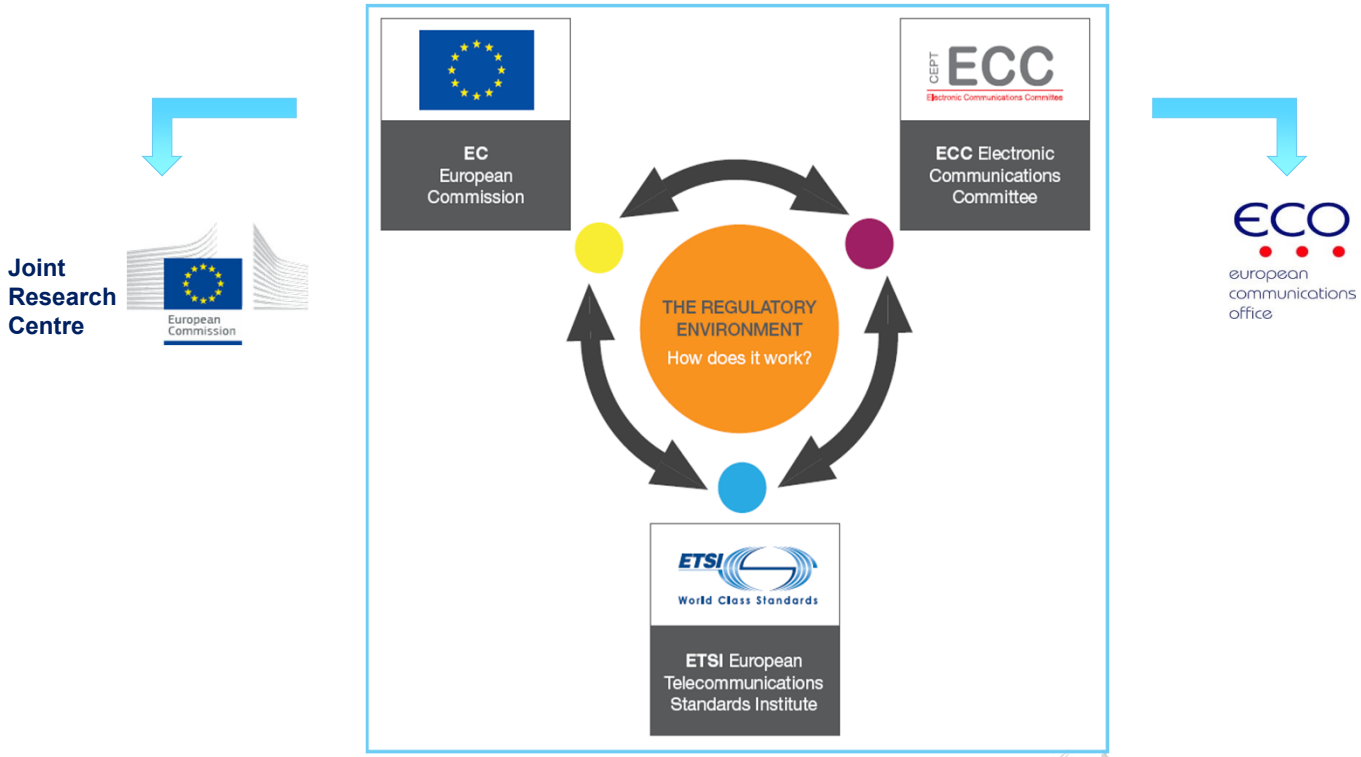
# ECC: Electronic Communications Committee

- Primary objective is to harmonise the efficient use of the radio spectrum, satellite orbits and numbering resources across Europe
- Reduce spectrum scarcity and improve sharing and access to spectrum to enable the introduction of new technologies, whilst protecting existing ones
- Develop common policies and regulations in electronic communications and related applications for Europe
- Provide the focal point for information on spectrum use in Europe (EFIS, ECODocDB, etc.)
- Active in representing European interests in the ITU and other international organisations
- Applies expertise in partnership with all stakeholders, the European Commission and ETSI to facilitate the delivery of technologies and services for the benefit of society.

# European regulatory framework for radio spectrum

Developing and exploring relationships with universities, scientific institutes and European research programmes is strategic for the ECC

- ECO and JRC have been working together on spectrum matters of common interest.



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# ECC strategic plan for 2020-2025

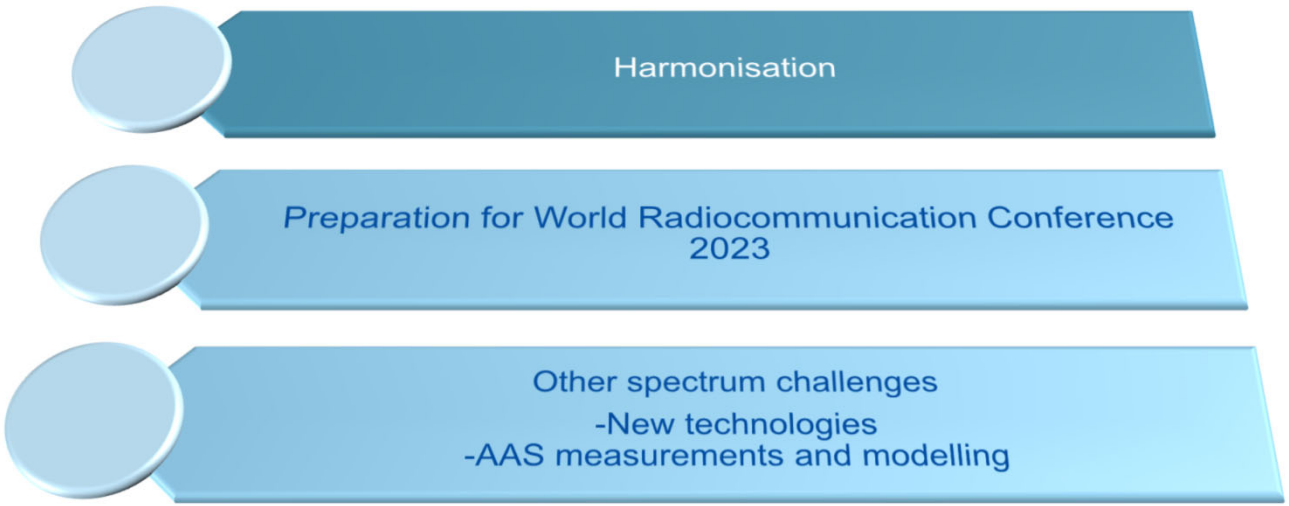
- The ECC Strategic Plan for 2020-2025 identifies skills and actions to be developed in:
  - Expertise in managing scarce resources
    - Spectrum management
    - Numbering and resources
  - Europe wide forum for the work in ITU
  - Cooperation with the European Commission, ETSI, others…
  - Focal point in Europe for information on electronic communication
- Major spectrum challenges
  - Spectrum sharing
  - Receiver parameters
  - Promote use of higher frequencies

# Major topics in 2020-2025

1. Review the 470-960 MHz band
2. Wireless broadband and connectivity
3. General authorisation and licence exempt use of spectrum
4. Next generation satellite systems, including mega NGSO constellations and short duration satellites.
5. New business models and applications, including small cells and backhaul infrastructure
6. Number portability, ease of switching, end-user protection, public safety

# The CEPT Roadmap for 5G and beyond

The new roadmap for 5G and beyond builds on previous and existing activities on spectrum harmonisation for 5G. It looks towards future developments, also addressing techniques such as artificial intelligence and blockchain.



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**SEAMCAT** is the common CEPT software tool for coexistence studies

SEAMCAT
Spectrum Engineering Advanced Monte Carlo Analysis Tool

https://www.seamcat.org/

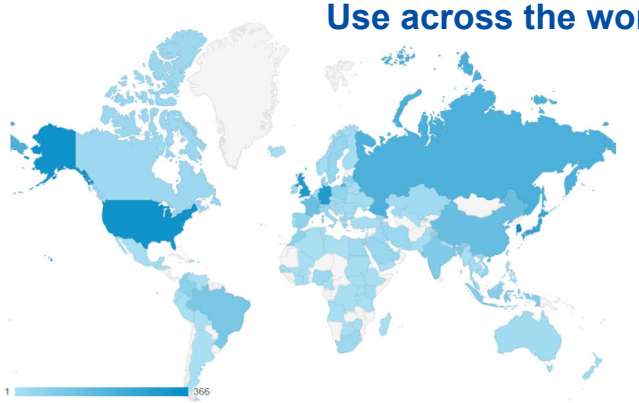
The tool is **Open Source** and **free of cost**

- Based on the Monte Carlo simulation method for statistical modelling of interference scenarios between radio communication systems

The **SEAMCAT Technical Group** (STG) provides in CEPT technical support on the development of SEAMCAT

ECO organises regular training workshops

## Use across the world




| Country | Acquisition: Sessions |
|---|---|
| | 3,671 (% of Total: 100.00% (3,671)) |
| 1. South Korea | 366 (9.97%) |
| 2. United States | 342 (9.32%) |
| 3. United Kingdom | 310 (8.44%) |
| 4. Germany | 304 (8.28%) |
| 5. Japan | 253 (6.89%) |
| 6. Russia | 204 (5.56%) |
| 7. China | 148 (4.03%) |
| 8. France | 142 (3.87%) |
| 9. Brazil | 106 (2.89%) |
| 10. India | 89 (2.42%) |

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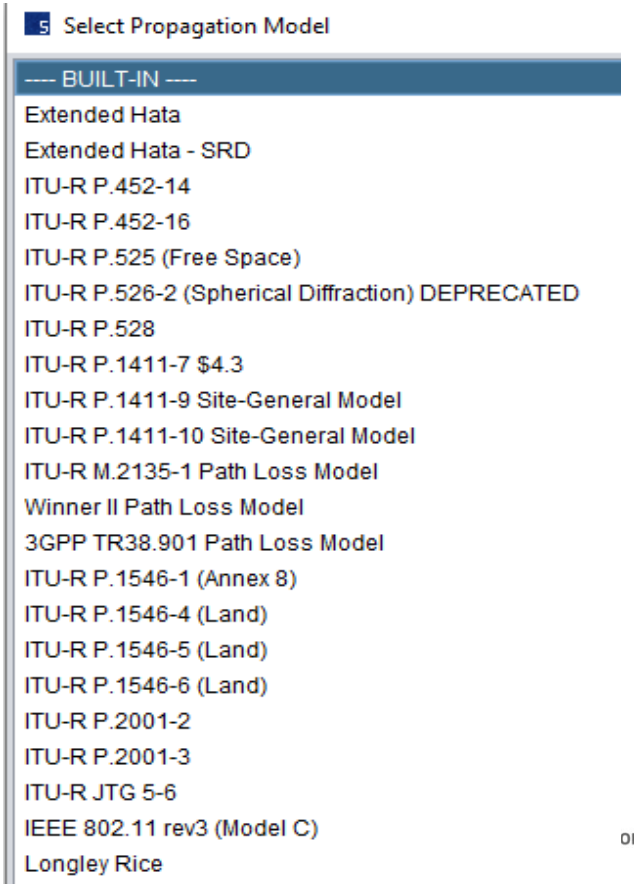
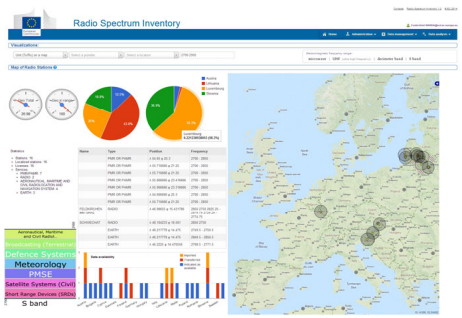
# Built-in propagation models in SEAMCAT

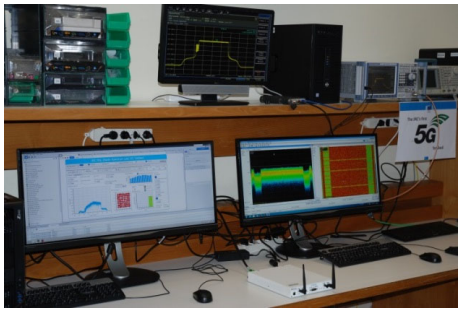
- Several pre-defined propagation models (with some variants) are available in the library
- Users can also develop plugins to be used by SEAMCAT. This provides additional flexibility.
  - For instance, an external Propagation Model Plugin has been recently developed for studies on SRD in the 900 MHz. This extends the site-general propagation models from Recommendation ITU-R P.1411-10 with the statistical functions for LoS probabilities from Report ITU-R M.2135-1

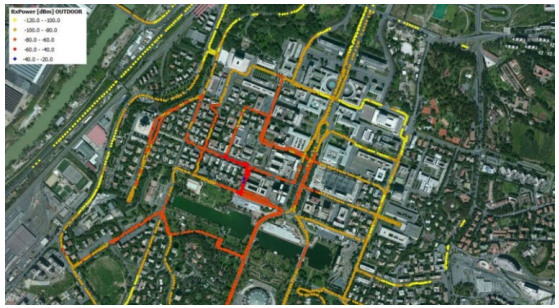


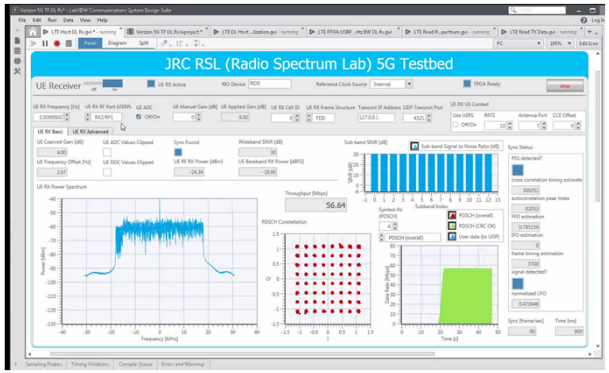
# JRC on Spectrum

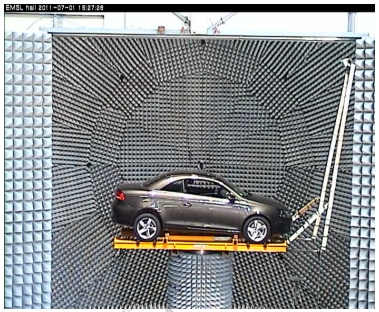
- Supports EU spectrum policy (RSPP)
- JRC-ECO collaboration on Radio Spectrum Inventory
- Radio Spectrum Laboratory for conducted and radiated tests for coexistence and compatibility studies (CEPT, ETSI, ITU-R)
- Italian regulatory pilot on LSA in 2.3 GHz LTE-TDD
- OFCOM pilot on TV White Space









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# Horizon Prize 2016
# **Collaborative Spectrum Sharing**
# KCL + TUAS + Fairspectrum + QMU + JRC

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# Policy Context

- Radio Spectrum Policy Programme (RSPP): "… to foster the collective use of spectrum as well as the **shared use of spectrum**".

- RSPP: "… to foster the development of current and new technologies, for example in **cognitive radio**, including those using white spaces".

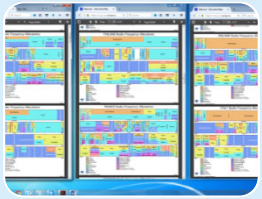
- **Spectrum sharing technologies dynamically** take advantage of the geographical, the frequency and the time dimension of the radio spectrum.

- To foster **dynamic spectrum access** in the EU, we need a regulatory environment for the internal market that enables shared spectrum access.

- **Reassurances to encourage greater and more efficient sharing of spectrum**

# Coexistence & Compatibility Studies

## Today – Static spectrum sharing



| Incumbents + Secondary users | Simulations<br>SEAMCAT<br>MATLAB<br>Monte-Carlo<br>MCL … | Experimental validations<br>Conducted and Over-the-Air (Limited) |
|---|---|---|

## Tomorrow – Static & Dynamic spectrum access

- Growing need for sharing

**Sharing schemes**

**RF Emulation**

- Radios
- DSS algorithms

- Hybrid RF environment
- In-field pilots

**Field Test**



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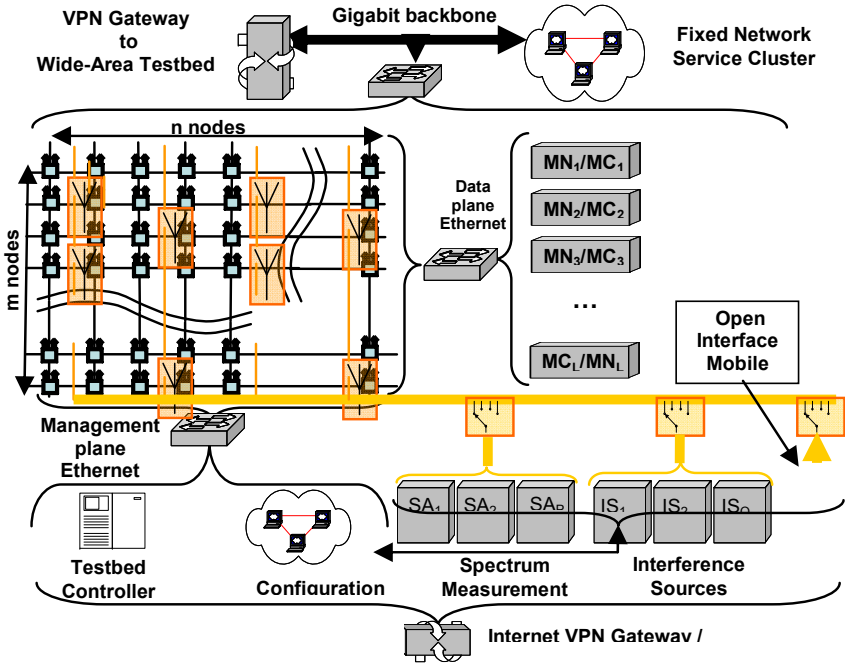
# Radio Spectrum Emulation Platforms: State of the Art (1)

- **ORBIT Radio Grid** (Rutgers University)
- NSF Research Testbed programme 2003 onwards
- Focus: New radio network architectures, protocols, middleware and applications
- 400 radio nodes -> Software defined radios
- Multiple simultaneous experiments
- Experiments as a Service
- Complementary field-test facility
- [http://www.winlab.rutgers.edu/projects/Orbit.html](http://www.winlab.rutgers.edu/projects/Orbit.html)



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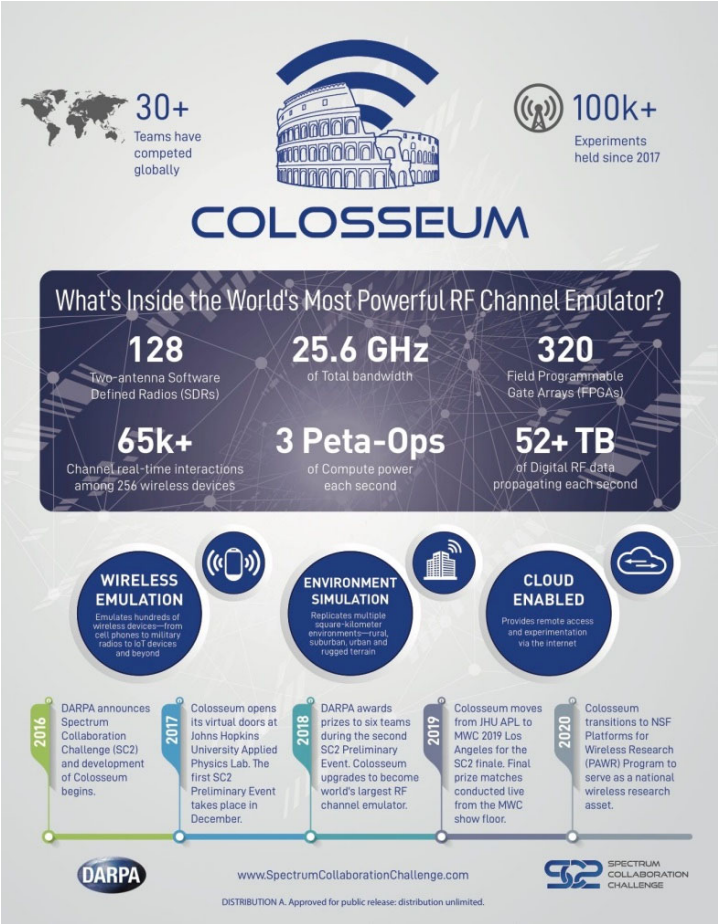
# Radio Spectrum Emulation Platforms: State of the Art (2)

- **Colosseum Testbed**
- DARPA challenge **SC2** (2016-2019)
- The first of its kind collaborative machine learning environment to overcome scarcity in RF spectrum
- Dynamic spectrum sharing – AI & ML
- Massive RF channel emulator (256x256) 65,000 simultaneous channel interactions
- 2019+ NSF national wireless research asset
- Spectrum Efficiency, Security, …
- https://archive.darpa.mil/sc2/



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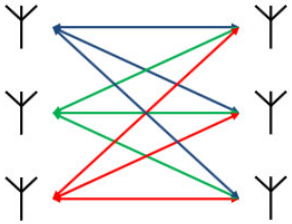
# Concept of DARPA RF Emulator

## Colosseum Introduction

- World's largest wireless testbed
  - 256 x 256 100 MHz RF channel emulation
  - Capable of being subdivided for running multiple simultaneous scenarios
- 128 Standard Radio Nodes
  - Configured as 2x2 MIMO
  - Compute resources
- Access control and scheduling infrastructure
  - Supports remote access for scrimmages and competitions
- Scoring infrastructure
  - Runs automated scoring algorithms for rewarding optimized collaborative behavior
- Automated match initialization
  - Deployment of performer nodes
  - Configuration of RF environment



*Unique channel emulation along every TX/RX path*

https://commons.wikimedia.org/wiki/File:Lightmatter_colosseum.jpg

Email questions to darpa-baa-16-48@darpa.mil

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## What can Colosseum do as an RF Testbed

- Make the radios believe they are operating in a 1 sq. km open field, a dense urban city, a suburban shopping mall, a desert, or anything in-between
- Multipath and fading effects will be simulated with high-fidelity ray-tracing

[redacted]



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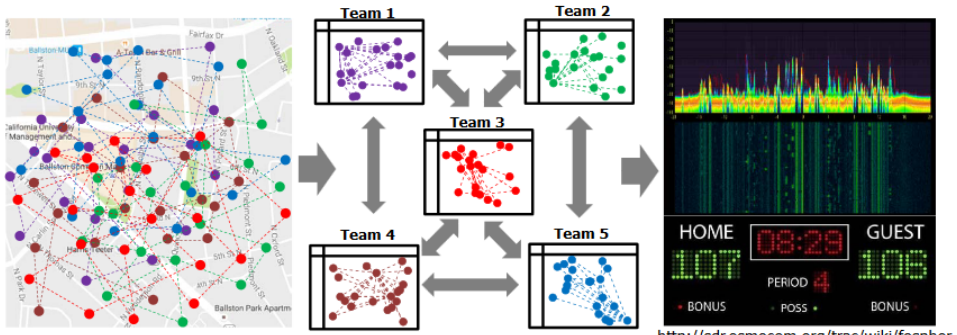
# Framework & Architecture

## What can Colosseum do as a Competition Framework

- Allow multiple teams to timeshare resources of the system to evaluate and debug their radio network designs using a large numbers of radio nodes
- Automate the execution of complex scripted scenarios involving multiple teams
- Visualize and Score the decisions, actions, effects and performance of multiple radio networks interacting in real-time

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http://sdr.osmocom.org/trac/wiki/fosphor

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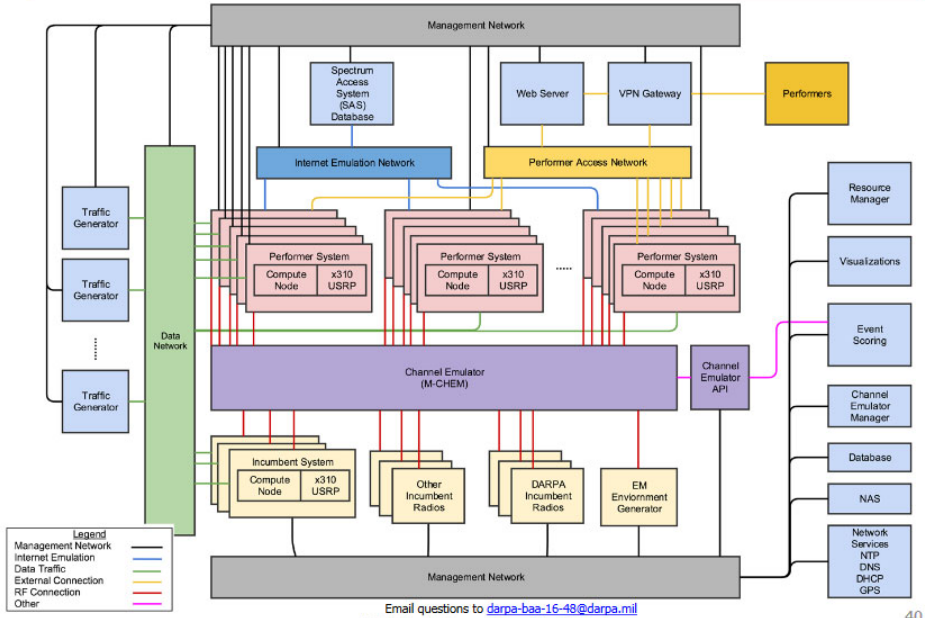
## Colosseum Block Diagram

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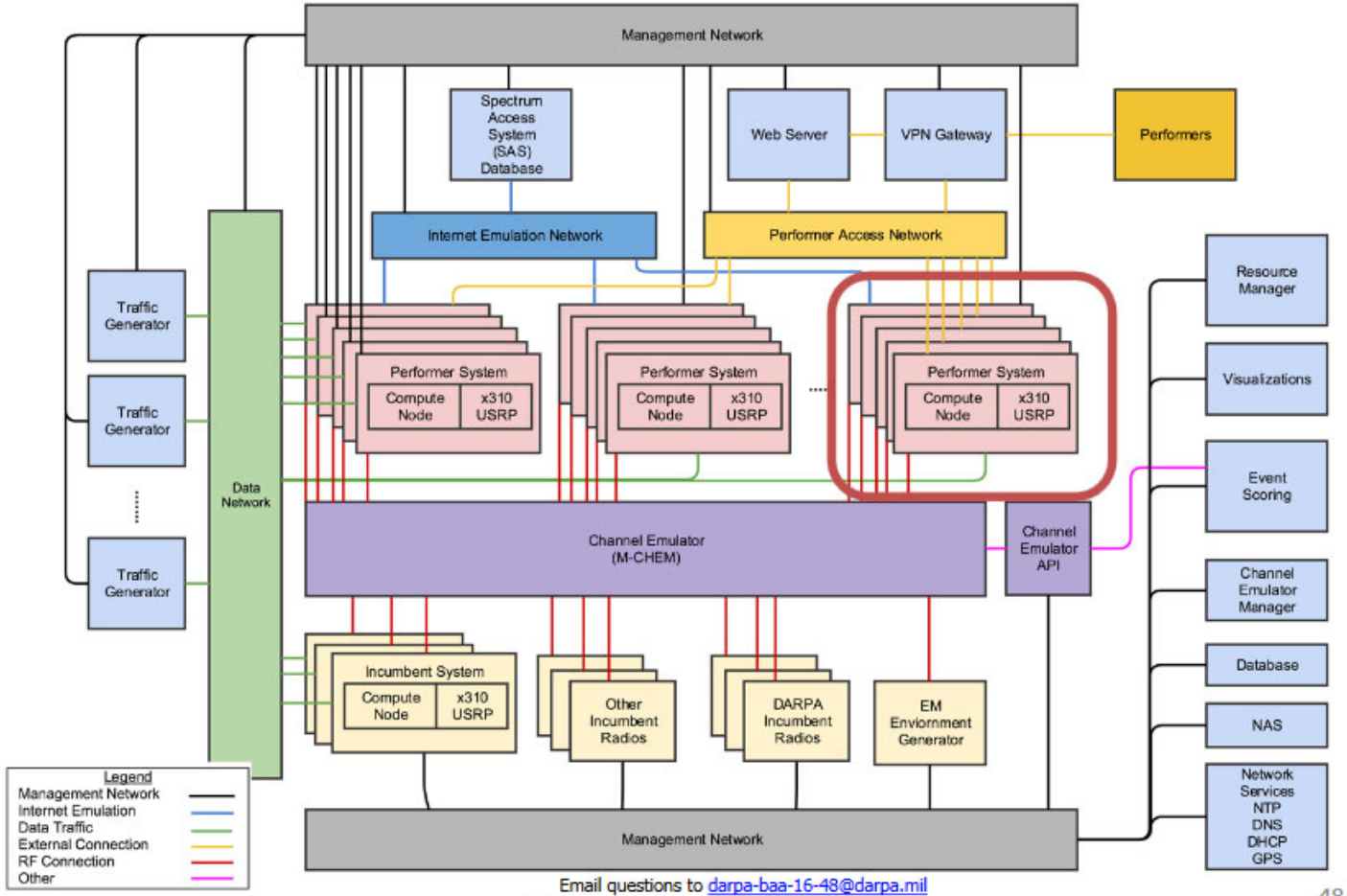
# Colosseum Standard Radio Nodes

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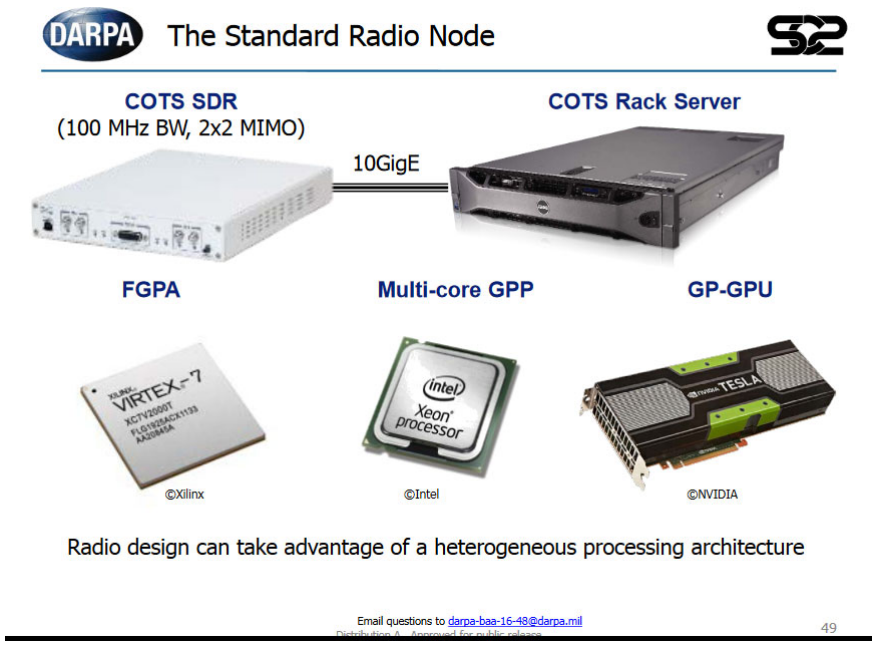
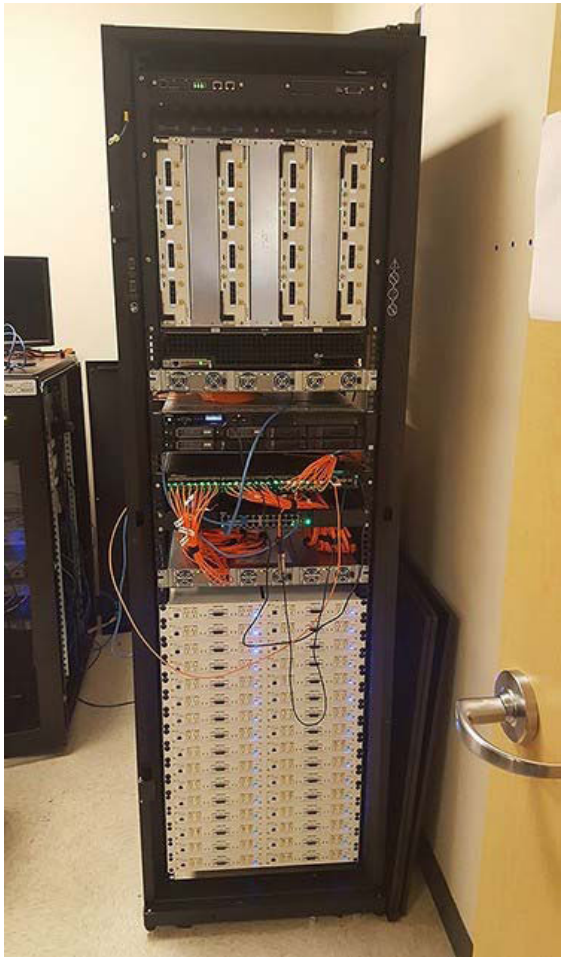
# Radio Node Hardware





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# Scenario Development Process

Evaluation Hypothesis ⇨ Test Conditions ⇨ Use Cases ⇨ Scenarios

Machine learning algorithms are stressed when their RF environment information has higher uncertainty

Greater uncertainty results due to:

- Higher collaboration channel latency
- Reduced SINR
- …

- Positions
- How many nodes
- Physical environment
- …
- High Latency
- Low Latency
- High SINR
- Low SINR

*For every radio…*

- *Channel definition*
- *Motion*
- *IP traffic*



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# RF Channel Modeling

Largescale RF channel modeling is considered to be the most challenging part of the scenarios modeling task

- Full-mesh modeling of MIMO radios (2-4 antenna elements per radio)
- Incorporating complex physical environments such as buildings
- Accounting for indoor-to-outdoor modeling and related permutations
- Accounting for stochastic motion of the wireless environment (e.g., a non-mobile radio wouldn't realistically see a stationary channel)
- The ability to represent models as a time-varying, complex, tapped delay-line model, with the ability to scale the output to a variable number of taps
- Processing complexity of a large-scale scenario (10s of minutes long, with 128 radios, with 2-4 antennas each, notionally distributed across a square km in an urban setting)

Example: An incomplete approach to RF channel modeling

- Using ray tracing alone, a static node would end up seeing a constant phase and amplitude fade to another node
- This doesn't match reality due to the unmodeled phenomenology present

Approaches must create *realistic* channel propagation conditions

# The JRC-ECO Spectrum Emulator

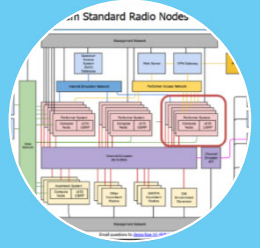
**Phase 1**
- Clarify requirements, added value over SEAMCAT
- Single incumbent, single secondary, known scenarios

**Phase 2**
- Single incumbent, multiple secondary
- Static bands, complex scenarios

**Phase 3**
- Multiple incumbents, multiple secondary
- Dynamic spectrum access, spectrum sensing, AI/ML

# Platform Architecture & Development

Hardware



Architecture & Middleware

Domain knowledge



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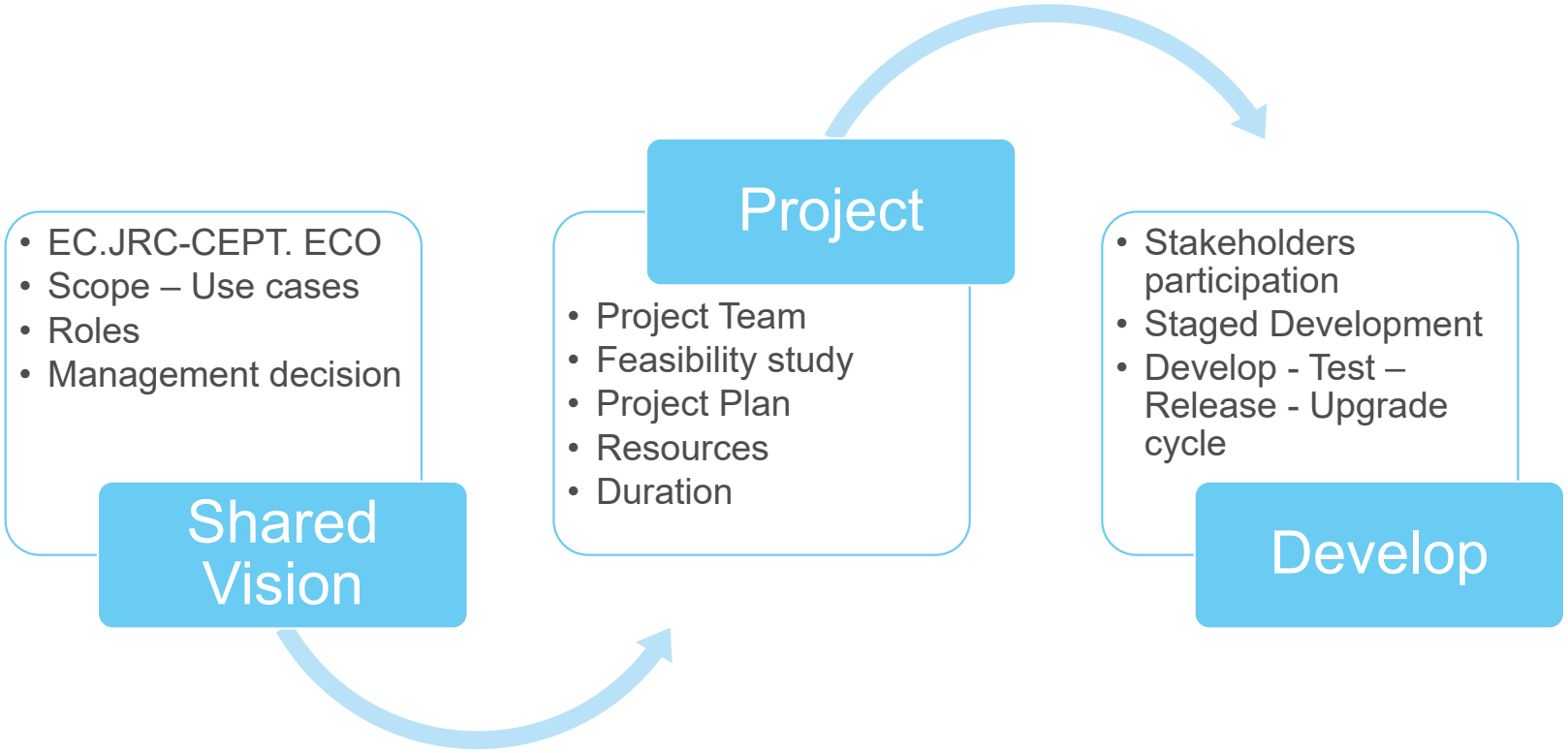
# Project steps



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# The JRC-ECO Spectrum Sharing Testbed

**Phase 1**
- Clarify requirements, added value over SEAMCAT
- Single incumbent, single secondary, known scenarios

**Phase 2**
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- Static bands, complex scenarios

**Phase 3**
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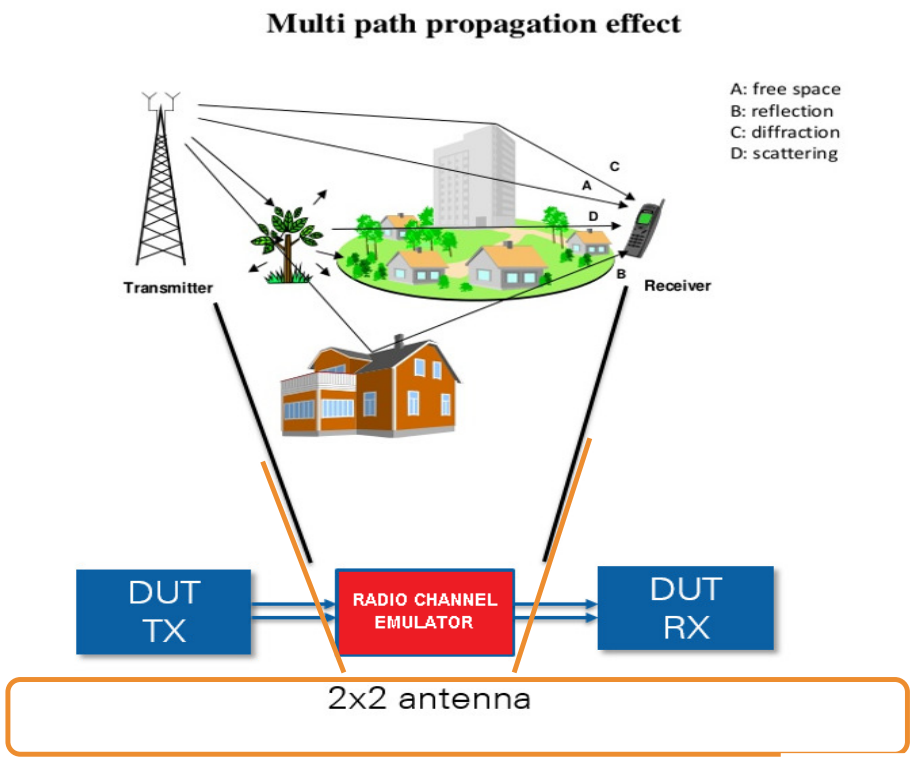
- Dynamic spectrum access, spectrum sensing, AI/ML

# Radio Channel Emulator




Replace the real-world radio channel between two or more radio transmitters and receivers by providing a faded representation of a transmitted signal to the receiver's inputs



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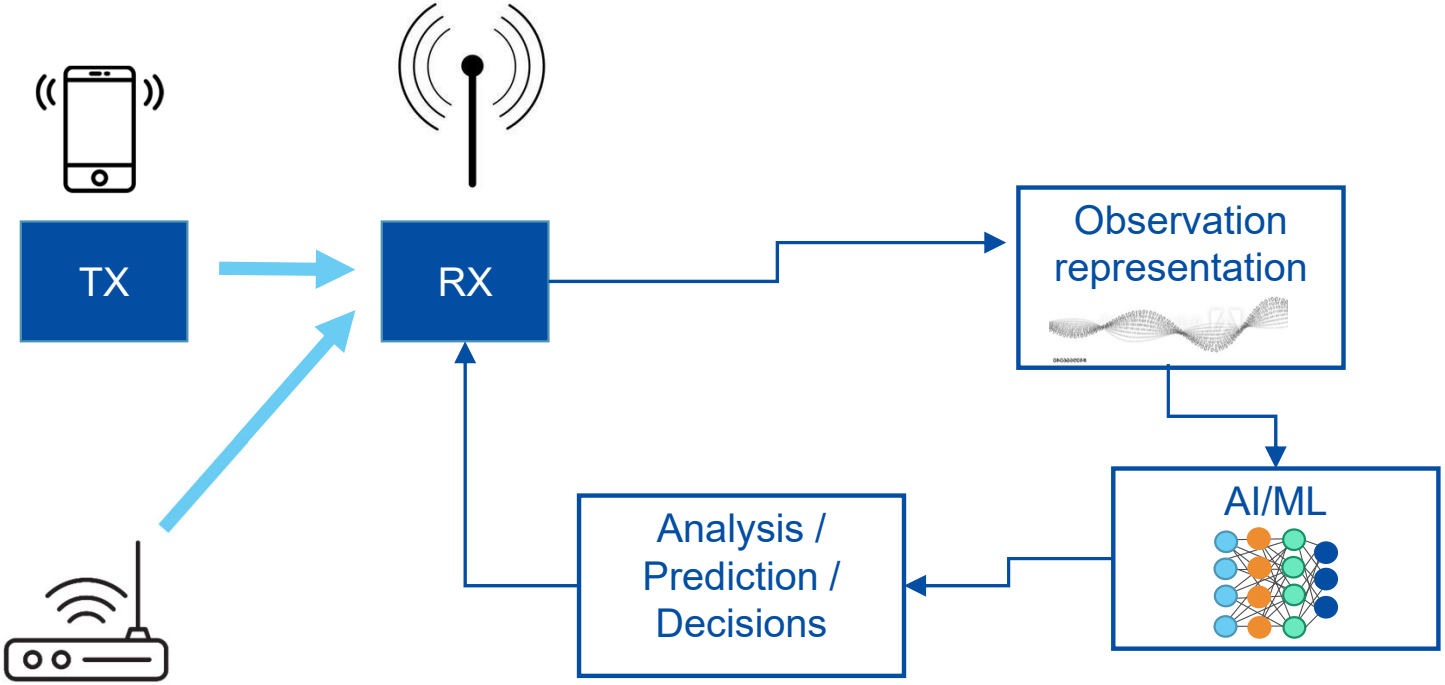
# AI/ML Implementation at the Receiver



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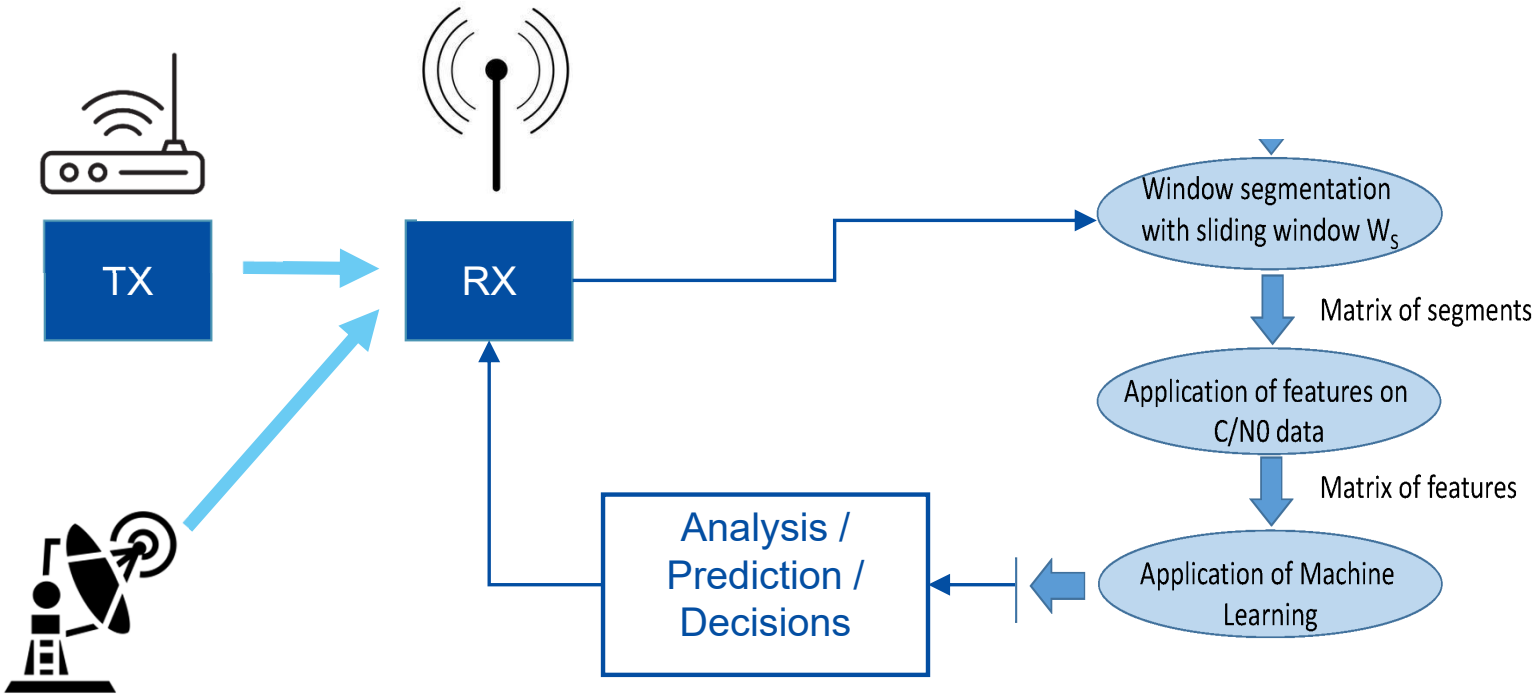
# Current Implementation at the Receiver



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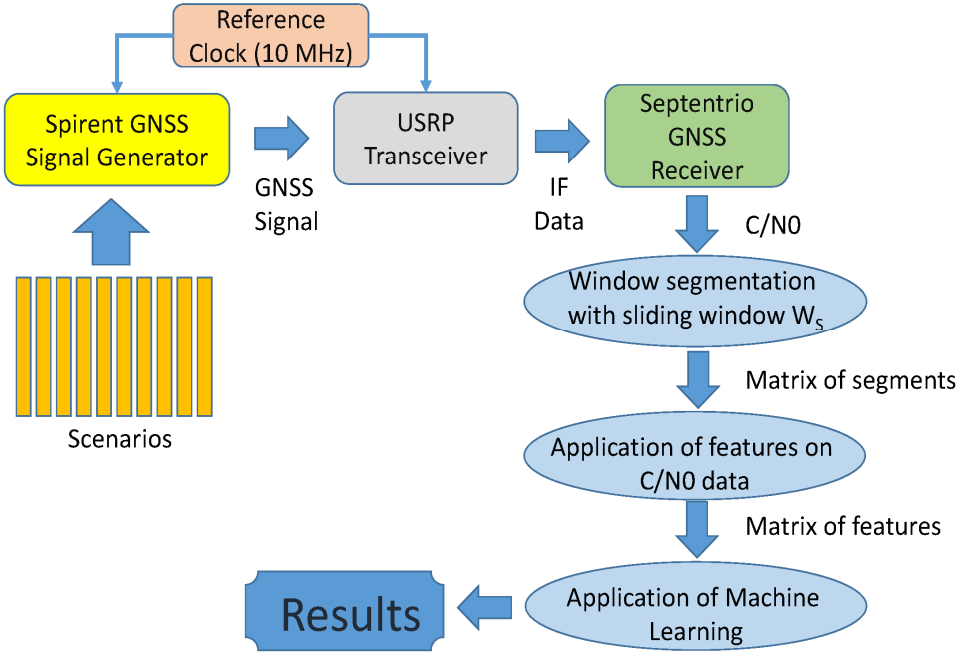
# Overall schema for GNSS scenario classification



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# Discussion – Testbed requirements

- Regulatory requirements
- Industrial requirements
- R&D requirements

# Thank you

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