Tutorial: Colosseum, the World's Largest Wireless Network Emulator

Tommaso Melodia, Stefano Basagni, Kaushik R. Chowdhury,
Abhimanyu Gosain, Michele Polese, Pedram Johari, Leonardo Bonati
Institute for the Wireless Internet of Things, Northeastern University, Boston, MA, U.S.A.
E-mail: {t.melodia, s.basagni, k.chowdhury, a.gosain, m.polese, p.johari, bonati.l}@northeastern.edu

ABSTRACT

Practical experimentation and prototyping are core steps in the development of any wireless technology. Often times, however, this crucial step is confined to small laboratory setups that do not capture the scale of commercial deployments and do not ensure result reproducibility and replicability, or it is skipped altogether for lack of suitable hardware and testing facilities. Recent years have seen the development of publicly-available testing platforms for wireless experimentation at scale. Examples include the testbeds of the PAWR program and *Colosseum*, the world's largest wireless network emulator. With its 256 software-defined radios, 24 racks of powerful compute servers and first-of-its-kind channel emulator, Colosseum allows users to prototype wireless solutions at scale, and guarantees reproducibility and replicability of results. This tutorial provides an overview of the Colosseum platform. We describe the architecture and components of the testbed as a whole, and we then showcase how to run practical experiments in diverse scenarios with heterogeneous wireless technologies (e.g., Wi-Fi and cellular). We also emphasize how Colosseum experiments can be ported to different testing platforms, facilitating full-cycle experimental wireless research: design, experiments and tests at scale in a fully controlled and observable environment and testing in the field. The tutorial concludes with considerations on the flexible future of Colosseum, focusing on its planned extension to emulate larger scenarios and channels at higher frequency bands (mmWave).

CCS CONCEPTS

• **Networks** → **Wireless access networks**; **Data center networks**; **Mobile networks**; **Ad hoc networks**.

KEYWORDS

Experimental wireless research, wireless channel emulation.

ACM Reference Format:
Tommaso Melodia, Stefano Basagni, Kaushik R. Chowdhury, Abhimanyu Gosain, Michele Polese, Pedram Johari, Leonardo Bonati. 2022. Tutorial: Colosseum, the World's Largest Wireless Network Emulator . In *The 27th Annual International Conference on Mobile Computing and Networking (ACM MobiCom '21), January 31–February 4, 2022, New Orleans, LA, USA.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3447993.3488032

ACM MobiCom '21, January 31–February 4, 2022, New Orleans, LA, USA

ACM ISBN 978-1-4503-8342-4/22/01…$15.00
https://doi.org/10.1145/3447993.3488032

Figure 1: Colosseum at its Northeastern University location.

1 INTRODUCTION

Large-scale experimentation is a core component of wireless research. They ensure that solutions are apt to work on actual devices operating in real-world environments. However, experimental capabilities are as effective and useful as their ability of capturing diverse wireless environments and conditions realistically, in a controlled environment that is highly accessible, programmable and where experiments can be repeated for fair and informative comparison among solutions. Up until now, the research community lacked widespread access to testbeds offering such critical capabilities, especially at scale. This is changing: the past few years have seen the emergence of larger testing facilities enabling repeatable wireless experimentation at scale. Examples include the testbeds of the U.S. National Science Foundation (NSF) Platforms for Advanced Wireless Research (PAWR) program and *Colosseum* that, with over 65k wireless emulated channels, is hailed as the world's largest wireless network emulator.[1]

Colosseum is a massive Radio Frequency (RF) and computational facility comprising 24 server racks—for a total of more than 170 servers—divided into four quadrants. The instrument is currently hosted at the Northeastern University Innovation Campus (Figure 1). It enables large-scale experiments through a pool of 128 USRP X310 Software-defined Radios (SDRs) controlled by dedicated and remotely accessible host computers called Standard Radio Nodes (SRNs). It emulates wireless signals traversing space and reflecting off multiple objects and obstacles as they travel from transmitters to receivers, through its Massive Channel Emulator (MCHEM) that consists of an additional array of 128 SDRs and 64 FPGAs [2]. As such, Colosseum can create *virtual worlds*, as if the radios are operating in an open field, downtown area, shopping mall, or a desert, by generating more than 52 terabytes of data per

[1] https://www.colosseum.net

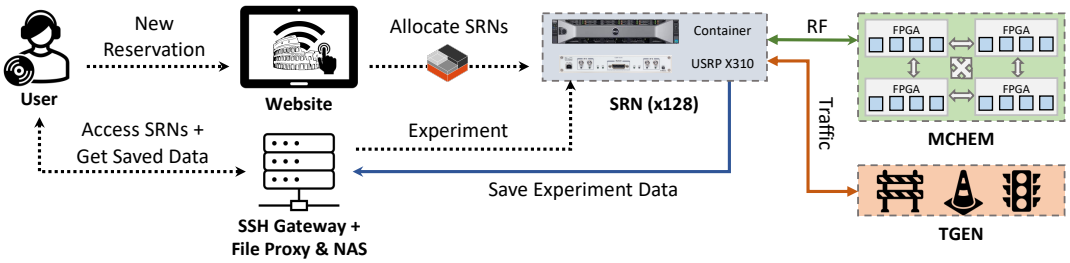

Figure 2: Workflow of an interactive experiment on Colosseum.

second. Traffic flows between any pair of SRNs can be emulated through the Colosseum Traffic Generator (TGEN).

Originally built by DARPA for the Spectrum Collaboration Challenge [3], Colosseum is now operated and maintained by the Institute for the Wireless Internet of Things[2] at Northeastern University. The instrument is currently available for free to anybody in the U.S.-based research community with an active grant on wireless research. This tutorial on Colosseum aims at providing a comprehensive introduction on how to access the emulator, and how to run repeatable wireless experiments at scale on it, emphasizing its capabilities of modeling a vast variety of scenarios, channel conditions, traffic and mobility patterns. Particularly, we will show how to use Colosseum in a set of scenarios relevant to most wireless research: local area networking (e.g., Wi-Fi-based networks), cellular networks, and wireless ad hoc scenarios for aerial or vehicular networking. Our tutorial will further emphasize that since Colosseum experiments are run in the form of Linux Container (LXC) instances, they can be ported to other real-world wireless testbeds including the PAWR platforms [1]. This facilitates full-cycle experimental wireless research: design, experiments and tests at scale in a fully controlled and observable environment, and testing in the field. Finally, we will discuss planned extensions of Colosseum.

2 TUTORIAL STRUCTURE

In this tutorial we explain the fundamentals of wireless network emulation, its use for experimental wireless research and how Colosseum does it at scale and with hardware-in-the-loop. We describe the Colosseum architecture and MCHEM, and discuss how RF and traffic scenarios in Colosseum are designed to capture realistic wireless environments and conditions.

After the initial overview of Colosseum, attendees are guided to the usage of the emulator: how to access it and on how to run experiments. Particularly, we explain the Colosseum containerized system and detail how to use containers on Colosseum. We then show how to run actual experiments in Colosseum and how to use its channel emulation system. Practical demonstrations are given of Colosseum use cases, including Wi-Fi and cellular networking and multi-hop ad hoc networks. These experiments run on customized containers for Wi-Fi and LTE applications that are prepared by the organizers' team at Northeastern University and are accessible to the Colosseum users.

Finally, the attendees learn how to export containers from Colosseum, e.g., how to transfer Colosseum-based experiments onto other testbeds for experiments in the field.

[2]https://www.northeastern.edu/wiot

3 COLOSSEUM USAGE: AN OVERVIEW

Figure 2 depicts the workflow of interactive experiments on Colosseum. First, users submit a new reservation through the Colosseum website. This triggers the allocation of LXC containers on the SRNs, either spawned from base container images provided by Colosseum or from images uploaded by the users. Then, users log into the containers through the Colosseum SSH gateway. From here, they can control the SDR connected to each SRN, and start RF and traffic scenarios. This can be done through the Colosseum Application Programming Interface (API) toolkit, namely `colosseumcli`. At the end of the experiment, the data and log files generated during the experiment are saved on the Colosseum Network Attached Storage (NAS). Users can retrieve them by logging into the Colosseum file proxy server for offline processing.

4 NRDZ AND AI-JUMPSTART EXTENSIONS

Future extensions of Colosseum include the integration of state-of-the-art NVIDIA GPU servers (through the MassTech Collaborative AI-JumpStart program) and new wireless emulation capabilities through the NSF National Radio Dynamic Zone (NRDZ) program. NRDZs are meant to be *safe* platforms for wireless experiments, i.e., platforms that would not generate harmful interference toward incumbent users. (Because of the interested frequencies and their extent, such platforms would not be allowed under Federal Communications Commission (FCC) spectrum regulations.) Colosseum is naturally positioned to implement an NRDZ as, by being an emulator, it avoids any interference to real devices and enables testing on multiple scenarios, different protocol stacks and different traffic patterns. To support NRDZs, MCHEM will be extended to emulate scenarios covering an area of up to 100 km^2, and a new quadrant will be added to emulate large-bandwidth, directional communications in the spectrum above 6 GHz.

ACKNOWLEDGMENTS

This work was partially supported by the U.S. National Science Foundation under grant CNS-1925601.

REFERENCES

[1] Leonardo Bonati, Salvatore D'Oro, Stefano Basagni, and Tommaso Melodia. 2021. SCOPE: An Open and Softwarized Prototyping Platform for NextG Systems. In *Proceedings of ACM MobiSys*. Virtual Conference.
[2] Ashish Chaudhari and Martin Braun. 2018. A Scalable FPGA Architecture for Flexible, Large-Scale, Real-Time RF Channel Emulation. In *Proceedings of IEEE ReCoSoC*. Lille, France.
[3] DARPA. 2016. Spectrum Collaboration Challenge. https://www.darpa.mil/program/spectrum-collaboration-challenge. Accessed September 2021.