# Experimenting in a Global Multi-Domain Testbed

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***Abstract*—Upcoming AI-based and 5G applications are demanding new network management approaches that are capable to cope with unprecedented levels of flexibility, scalability and energy efficiency. In order to make these use cases tangible and feasible, network management solutions aim to rely on multi-domain, multi-tier architectures that permit complex end-to-end orchestration of network resources. However, current research on scheduling functions and task-offloading algorithms often focus on one single-domain, and the exploration of large-scale inter-operable solutions becomes a challenge. Fortunately for the networking research community, a number of available testing facilities deployed at different geographical location along the world can be integrated to be used as a single joint multi-domain infrastructure. In this demo paper, we present a hands-off experience of how to integrate different high-performance testbeds, located in USA, Belgium and The Netherlands, in order to enable multi-domain large-scale experimentation. We demonstrate end-to-end performance characteristics of the testbed integration and we describe the main takeaways and lessons learned to drive researchers towards successful deployments in such end-to-end global infrastructure.**

***Index Terms*—Orchestration, Control, Monitoring, Experimentation, Network Programmability, SDN, Industrial IoT**

## I. Introduction

Current trends on network programmability are enabling a number of new applications such as AI-based autonomous driving or haptic sensing. These new use cases require complex orchestration that must carefully decide where and when to execute a given task, allocating the required computing power while keeping low latency communications, and at the same time, minimizing the energy consumption. Sometimes such orchestration is required to span over large, multi-domain networks, i.e., smart city, edge, cloud, etc. In order to support researchers, testbeds facilities can be integrated in a global end-to-end architecture to test and reproduce new orchestration approaches in a flexible and scalable manner.

The demo presented in this work, experimentally shows the realization of such integration, interconnecting the Chameleon [1], Virtual Wall [2] and Citylab [3] testbeds to deploy an end-to-end experiment. We present a technical description of the deployment and interconnection, and we report results on link performance and computing capabilities when the three testbeds are jointly integrated.

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Finally this demo provides insights and takeaways to help researchers to design and deploy their orchestration experiments over such multi-domain global testbed infrastructure.

## II. Interconnecting testbeds across the globe

We consider a Smart City use case to characterize the performance of the integrated multi-tier testbed (see Figure 1). The architecture consists of 3 heterogeneous domains:

- **Citylab**[1] is federated within Fed4FIRE+ and it is intended for wireless networking experimentation in the unlicensed spectrum and for Smart City edge computing deployments [3], [4]. Located in Antwerp (Belgium), it covers an area of about 0.5 x 0.5 $Km^2$. Citylab nodes can receive data streams from multiple sensors in 32 locations (+22 planned), using different wireless technologies, i.e., WiFi, 6TiSCH, DASH7, Zigbee and Bluetooth, and offloading task to higher the cloud when CPU intensive tasks are required.
- **Virtual Wall:**[2] is also federated within Fed4FIRE+. The testbed consists of more than 550 servers to be used as bare metal hardware or as virtual resources, i.e., XEN virtual machines or docker containers. Located in Ghent (Belgium), we use it as a tier-2 cloud center whose nodes are interconnected through a SDN network composed by OpenVSwitch switches and controlled through OpenFlow by an ONOS controller.
- **Chameleon**[3] consists of two operating sites: University of Chicago (UC) and Texas Advanced Computing Center (TACC). It also supports both bare metal instantiation or virtualization, and has more than 15000 cores of numerous hardware flavors. This demo uses Chameleon as tier-1 testbed because of its large-scale and high-performance characteristics [5].

The connection between Chameleon and Virtual Wall is done with layer-2 stitched links [6]. This means that resources are privately allocated to the experiment through VLANs. However the connection between Virtual Wall and Citylab is done with shared IPv6 GRE tunnels.

[1]https://www.fed4fire.eu/testbeds/citylab/
[2]https://doc.ilabt.imec.be/ilabt/virtualwal
[3]https://www.chameleoncloud.org/

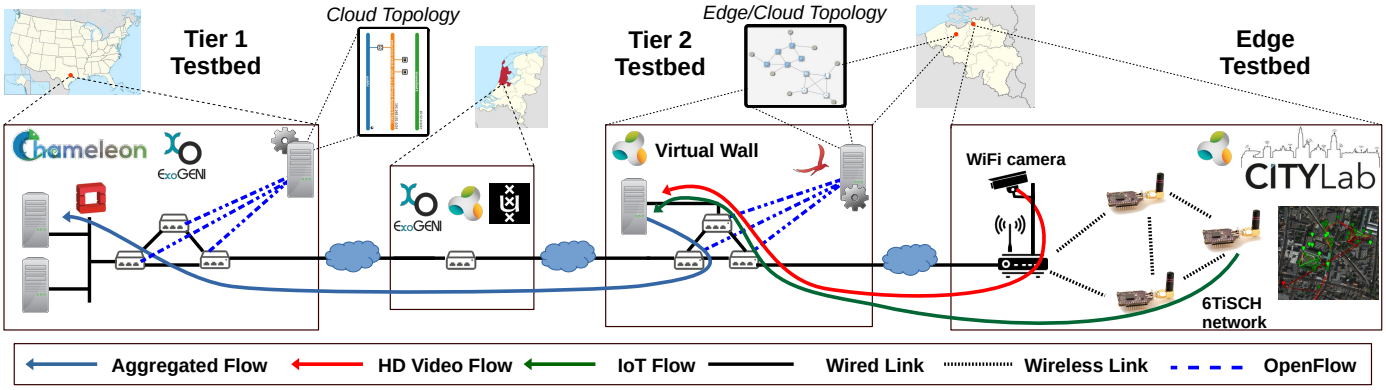


Figure 1: Smart city use case example with a multi-tier architecture.

Table I: Link characterization.

| Link | Type | Bandwidth (UDP) | Bandwidth (TCP) | Latency (round-trip) | Jitter |
|---|---|---|---|---|---|
| Citylab - Virtual Wall | IPv6 GRE link | 864 Mbps | 756 Mbps | 3.01 ms | 28 us |
| Virtual Wall - Chameleon-TACC | L2 Stitched link | 938 Mbps | 926 Mbps | 140 ms | 22 us |
| Virtual Wall - Chameleon-UC | L2 Stitched link | 954 Mbps | 936 Mbps | 115 ms | 21 us |
| Citylab - Chameleon-TACC | End-to-End | 862 Mbps | 724 Mbps | 144 ms | 19.9 us |
| Citylab - Chameleon-UC | End-to-End | 861 Mbps | 725 Mbps | 118 ms | 22 us |

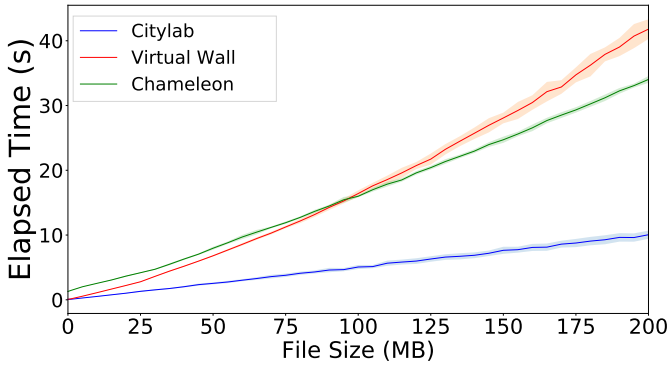


Figure 2: End-to-end latency when file processing is needed.

## III. Demo

The demo consist of two parts. First we demonstrate how to instantiate, configure and interconnect a multi-domain testbed as presented in Figure 1. Secondly, we do performance experiments on connectivity and task-offloading.

Connectivity results for stitched/GRE links and end-to-end links are given in Table I. In order to assess the performance in a task-offloading context, we also execute data stream parsing tasks that require a significant amount of sourced data (JSON files), and results in terms of overall elapsed time are given in Figure 2. These tasks involve transmitting data streams to be executed, and according to the link characterization presented in Table I, the execution at the edge is preferable to avoid transmission delays. However scenarios with CPU intensive tasks will benefit from the offloading to the cloud [7].

## IV. Conclusion

In this demo we show the integration at transatlantic scale of three different testbeds Citylab (wireless, edge), Virtual Wall (cloud) and Chameleon (cloud), located in Belgium and USA (connected via The Netherlands), to experiment with a multi-domain, multi-tier testbed.

Within a Smart City use case, we present results on node and link performance. We also discuss the technical challenges and main takeaways that may help researchers when designing and deploying orchestration experiments at this global scale.

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