Enabling experimental research through converged orchestration of optical, wireless, and cloud domains

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***Abstract*—In this paper we present an overview of the FUTEBOL Control Framework (CF), which aims to enable experimentation at the boundary of wireless and optical networks by facilitating the composition and control of experiments through a comprehensive software-based toolkit. FUTEBOL CF integrates the optical, wireless, and cloud domains, allowing the advancement of telecommunications through experimental research on optical-wireless networks that comprise heterogeneous resources from federated testbeds under a unified CF.**

***Index Terms*—Wireless, Optical, Cloud, Fog, Testbed, Experimentation, Control Framework, Programmable networks**

I. Introduction

The FUTEBOL project[1] is establishing a set of federated distributed testbeds, between Europe and Brazil, suited for converged optical and wireless experimentation. However, raw infrastructure is not sufficient to fulfill the needs of the research community. Additionally, a control framework (CF) is necessary to allow experimenters to control and to coordinate their experiments. Such a CF eases the learning curve associated with the use of research infrastructure facilities and, in the case of FUTEBOL, coalesces the distinct and generally isolated domains of optical and wireless networking.

To this end, FUTEBOL developed a converged CF that integrates the provisioning, control, and orchestration of experiments across wireless and optical network domains. In addition, the FUTEBOL CF envisions the integration of cloud and edge computing infrastructures, and the adoption of Network Functions Virtualization (NFV), Software Defined Networking (SDN), and Software Defined Radio (SDR) paradigms in order to enable the creation of richer experimentation scenarios (e.g., Internet of Things, C-RAN, and other 4G/5G use cases) over the wireless, packet, and optical domains.

II. FUTEBOL Control Framework

The FUTEBOL CF achieves its goal by: (i) **uniformly provisioning heterogeneous resources** from the testbeds through Aggregate Managers that provide SFA interfaces with the Federation; (ii) **managing layer 2 inter-testbed connectivity**; (iii) **offering a service catalog** that provides virtual network functions (VNFs), services, and tools that facilitates converged experimentation; (iv) **orchestrating the experiments** by offering capabilities of inter-testbed live-migration, functional converged network orchestration, and networking and cloud convergence; (v) **controlling the resources** in clouds, wired networks, and wireless networks through Network and Cloud Controllers, which provide northbound interfaces for experiment orchestration and southbound interfaces for resource configuration; and (iv) **advancing network programmability** by extending the range of configurable physical parameters that are exposed to the Network Controllers for a large variety of resources (e.g., optical devices, IoT devices, and SDRs).

Figure 1 presents the FUTEBOL architecture, which aims to support various experimental use cases dealing with wireless, optical, and cloud convergence. The separation of the functionalities and components distinguishes between: (i) **service layer**; (ii) **experiment control and orchestration layer**; (iii) **testbed management layer**, represented vertically; (iv) **virtualization layer** and; (v) **converged physical infrastructure layer** (including optical, wireless, and cloud resources).

The next section will provide more details and examples on how experiments use FUTEBOL CF.

A. Orchestration and CF Toolkit

A fundamental concept of the CF is the converged experimentation slice that allows the experimenters to allocate heterogeneous converged resources, which are manageable units, with specific capabilities that, appropriately combined and orchestrated, meet the requirements of the experiment. The experiment uses the FUTEBOL CF in two main stages: a) the experiment provisioning stage, where resources are allocated and slices are provisioned, and b) the experiment control and orchestration stage, where the experiment resources are configured according to experiment requirements.

In the provisioning stage, the experimentation slice – including wireless, optical, and cloud resources from heteroge-

[1] www.ict-futebol.eu

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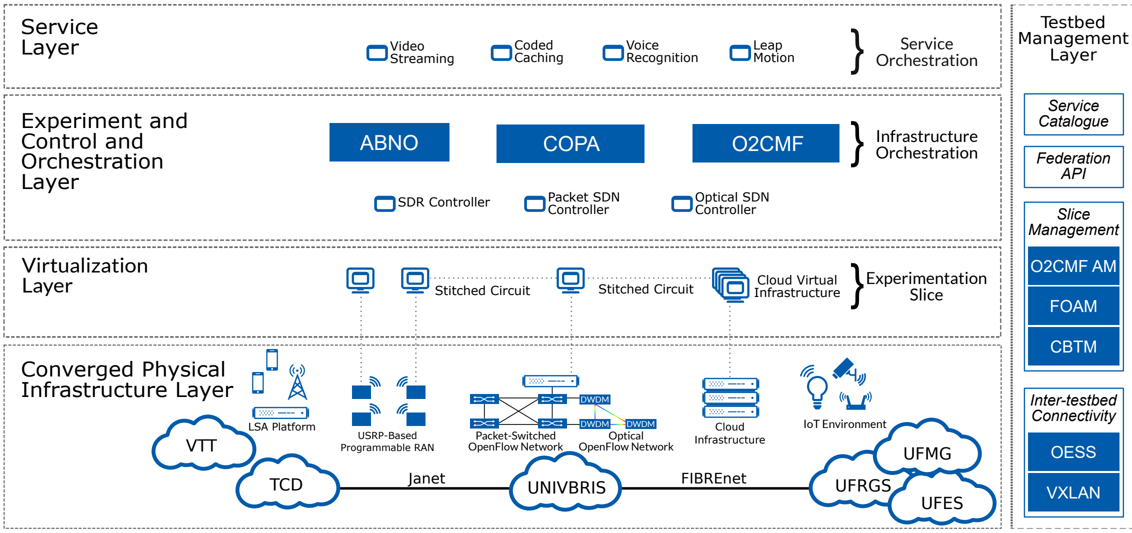

Fig. 1. FUTEBOL Control Framework

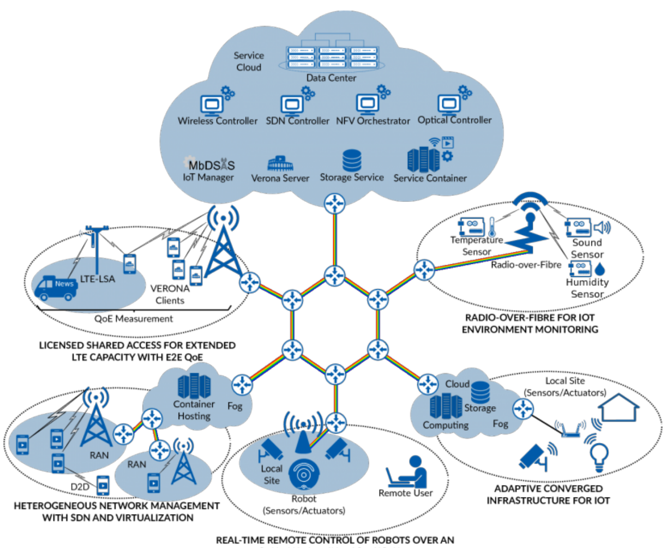

Fig. 2. Experiments enabled by the FUTEBOL CF

neous testbeds – is provisioned by the Aggregate Managers (*e.g.*, CBTM, FOAM, O2CMF) along with the necessary inter-testbed connectivity (*e.g.*, VXLAN tunnels or OESS stitched circuit). Each experiment can include an Orchestrator, which can be one of the following depending on experiment requirements: Application-Based Network Orchestrator (ABNO), Container Orchestration and Provisioning Architecture (COPA), and OpenStack and OpenFlow Control and Management Framework (O2CMF). The orchestrator is a VM or container that is hosted by one of the federated testbeds and has network connectivity with the involved testbeds. Besides, the experimenter can choose pre-built container/VM images from the service catalog of each testbed that contains VNFs, services, and controllers that enable converged experiments.

After the provisioning stage and during the orchestration stage, the experimenter interacts with the northbound interfaces of the instantiated orchestrator to perform orchestration tasks that trigger actions in the Network and Cloud Controllers. Finally, these actions are translated to commands that configure the physical resources.

III. Enabling Experimentation

Within FUTEBOL, the following five main experimentation areas [1] are being successfully tackled thanks to the CF (see Figure 2): i) Heterogeneous wireless/optical network management with SDN and virtualization, ii) Real-time remote control of robots over a wireless-optical SDN-enabled infrastructure, iii) LSA/SAS for extended LTE capacity with end-to-end quality of service, iv) Adaptive cloud/fog for IoT according to network capacity and service latency requirements, and v) Radio-over-fiber for IoT environment monitoring.

The FUTEBOL CF design is modular and each experiment can choose a subset of the available resources and tools depending on experiment requirements and the capabilities deployed by each testbed.

IV. Conclusion

Through the FUTEBOL CF we are able to orchestrate and to control heterogeneous wireless, optical, fog/cloud resources in a flexible and coordinated manner, enabling complex experimentation setups to the main challenges in this area.

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