Enabling SDN Experimentation with Wired and Wireless Resources: The SmartFIRE Facility

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Abstract. Over the last few years, several experimentation platforms have been deployed around the world, providing to the computer science research community a way to remotely perform and control networking experiments. Most of the platforms, called testbeds, offer experimentation as a service. However, each testbed is specialized in a specific technology: wired, wireless or cloud. The challenge for experimenters is thus to combine different technologies in order to tackle the research questions they address. Therefore a federation framework has been developed thanks to several projects, including SmartFIRE. SmartFIRE is an intercontinental federation of SDN, wireless and cloud testbeds, aiming at providing experimentation services with resources from these various networking fields. This federation framework enables easy experimentation with the heterogeneous resources that the individual testbeds provide. In this article, we present our contributions towards the extension of the state-of-the-art control and management framework, in order to orchestrate the federated SmartFIRE facility. As a proof of concept, we demonstrate several use cases that take advantage of our contributions, providing the availability of experimentation on novel architectures.

Keywords: SDN · Wireless · Cloud · Testbed experimentation

1 Introduction

The main goal of SmartFIRE [1] is to provide a large-scale intercontinental SDN-based testbed with wireless, and wired packet switching, providing a

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federated facility that includes many smaller-scale testbeds in Europe and South Korea. The South Korean testbeds bring powerful experience in the OpenFlow connections, especially in the utilization of their outstanding capabilities for information-centric experimentation, while the European testbeds offer their knowledge in the wireless connections, enabling the perspective for enhancing OpenFlow experimentation with wireless connectivity.

SmartFIRE is the first intercontinental testbed, spanning multiple small-scale testbeds in South Korea and Europe. It exploits the building blocks of an OpenFlow-based infrastructure, wireless and cloud resources in order to construct an experimental federated testbed for researchers. The control and management of SmartFIRE is able to allow authorized and authenticated experimenters to allocate resources, run experiments and collect measurements in a given facility and across heterogeneous facilities. SmartFIRE adheres to ongoing parallel processes for improving the state-of-the-art cOntrol and Management Framework (OMF) [2], exploiting the experience and the feedback of its usage and improving its deployment in previous testbeds. Moreover, it contributes with new requirements and framework extensions as a result of its supported pilots.

2 Testbeds and Interconnections

The following subsections present the individual facilities that are federated in SmartFIRE and illustrated in Fig. 1.

2.1 South Korean Testbeds

The South Korean testbeds provide enriched experimentation in the field of SDN. The following paragraphs present their structure and their experimentation capabilities.

Fig. 1. The SmartFIRE federation of European and South Korean testbeds.

Gwangju Institute of Science and Technology (GIST) offers OF@TEIN, which is an aggregated OpenFlow island consisting of 7 racks, located over 7 international sites. In the OF@TEIN testbed, similar to the GENI racks, a unique rack is designed and deployed to promote the international SDN research collaboration over the intercontinental network of TEIN. OF@TEIN aims at (a) the design and verification of the racks (with domestic-vendor OpenFlow switch), (b) the site installation and verification of the OF@TEIN network, and (c) the design and development of the OF@TEIN experimentation tools. GIST has recently deployed a cloud service based on OpenStack, offering virtualized resources.

Korea Institute of Science and Technology Information (KISTI) offers an emulation based network testbed in the KREONET [3] domain. It is called KREONET-Emulab and provides the opportunity for evaluation of several network protocols. Many network protocols, which cannot perform over KREONET due to unexpected hazard, can be freely tested in KREONET-Emulab. It consists of 42 powerful servers, each of them equipped with 5 network interfaces, one for the control and four for the experimentation. Each server can work as a router with 4 paths, and each network interface can be configured up to 1 Gbps.

Electronic and Telecommunications Research Institute (ETRI) proposes the network architecture of MOFI (Mobile Oriented Future Internet) [4]. Following a completely different approach from the current IP networking, MOFI enables the development of networks with Future Internet support of mobile intrinsic environments. The evaluation of the MOFI architecture relies on the OpenFlow-based mobility testbed of ETRI. The mobility testbed is an aggregation island, consisting of four interconnected South Korean domain networks. Their interconnection is based on the KOREN [5] networking infrastructure.

Seoul National University (SNU) proposes the C-flow architecture [6], as a result of the research on the development of content delivery networks with use of SDN. In particular, C-flow is the architecture for the development of ICN-based networks using OpenFlow. It provides functionalities for caching contents at specific cache servers or caches collocated with switches, as well as for their name-based forwarding. Additionally, SNU operates the C-flow testbed which enables the experimentation on ICN.

Korea Advanced Institute of Science and Technology (KAIST) provides a wireless mesh network, named OpenWiFi+, which is a programmable testbed for experimental protocol design. It is located at the campus of the KAIST University and it consists of 56 mesh routers, 16 of them being deployed indoors and 40 outdoors, each of them equipped with three IEEE 802.11 b/g/n WiFi cards. Moreover, 50 sensor nodes are deployed at the same campus.

2.2 European Testbeds

The European testbeds share fruitful experiences in the experimentation in SDN and wireless networking. Their capabilities are presented below.

University of Thessaly (UTH) provides the NITOS facility, which is open to the research community 24/7 and it is remotely accessible. The testbed consists of 100 powerful wireless nodes, each of them equipped with 2 WiFi interfaces, some of them being 802.11n MIMO cards and the rest 802.11a/b/g cards. Several nodes are equipped with USRP/GNU-radios, cameras and temperature/humidity sensors. The nodes are interconnected through a tree topology of OpenFlow switches, enabling the creation of multiple topologies with software-defined backbones and wireless access networks [7]. The testbed features programmable WiMAX and LTE equipment, fully configurable with an SDN backbone [8].

iMinds supports the generic and heterogeneous w-iLab.t facility. It consists of two wireless sub testbeds: the w-iLab.t office and w-iLab.t Zwijnaarde. The w-iLab.t office is deployed in a real office environment while the testbed Zwijnaarde is located at a utility room. There is little external interference at the Zwijnaarde testbed as no regular human activity is present and most of its walls and ceiling are covered with metal. The majority of devices in w-iLab.t are embedded PCs equipped with WiFi interfaces and sensor nodes. Since the Zwijnaarde testbed was deployed more recently, the devices in this testbed are more powerful in terms of processing power, memory and storage.

Universidad de Murcia (UMU) offers the research and experimentation infrastructure of GAIA. GAIA comprises several network nodes interconnected with different technologies. On the one hand, they are connected to the campus network through Gigabit Ethernet switches and thus they form the point of attachment to the Internet. On the other hand, they are connected to a CWDM network, which acts as backbone/carrier network and can be adapted to different configurations, depending on the specific requirements of each experiment. GAIA has also a wide wireless and WiMAX deployment along the campus. This, together with other smaller wireless deployments, allows the experimentation with many local and wide-range wireless technologies, including mobility and vehicle (V2V) communications.

2.3 GEANT and KREONET/KOREN Interconnecting Networks

The European testbeds are interconnected through the GEANT [9] network, which is the fast and reliable pan-European communications infrastructure, enabling data transfer speeds of up to 10 Gbps. The South Korean testbeds are interconnected with the same speeds via KREONET [3] and KOREN [5].

3 Experimentation Framework and Federation Architecture

3.1 Users Management and Resources Reservation

SmartFIRE provides a web portal (http://portal.eukorea-fire.eu/) allowing experimenters to register. A distributed Public Key Infrastructure (PKI) based authentication provides users access to the different federated testbeds through a single account. The reservation of the resources is done through a GENI adopted architecture named Slice-based Facility Architecture (SFA) [10]. The goal of SFA is to provide a minimal interface, a narrow waist, that enables testbeds of different technologies and/or belonging to different administrative domains to federate without losing control of their resources. It succeeds in combining all available resources. As the name suggests, SFA is built around the central notion of a slice, which is the basic element for mapping experimenters to resources.

3.2 SFA Aggregate Manager (AM) for SmartFIRE Federation

As you see in Fig. 2, there are SFA Aggregate Manager (AM) components for each testbed. This architecture allows testbed providers to write their own driver code. A driver is responsible to translate the SFA AM calls into the specific testbed configurations. As part of the SmartFIRE project an OpenStack driver has been developed by UPMC with external partners such as KulCloud and Telecom Paris Sud. This development enabled GIST to deploy its own OpenStack instance as part of the SmartFIRE federation. The other SmartFIRE testbeds use the OMF Broker [11] developed by UTH or the Emulab framework in order to become members of the SmartFIRE federation.

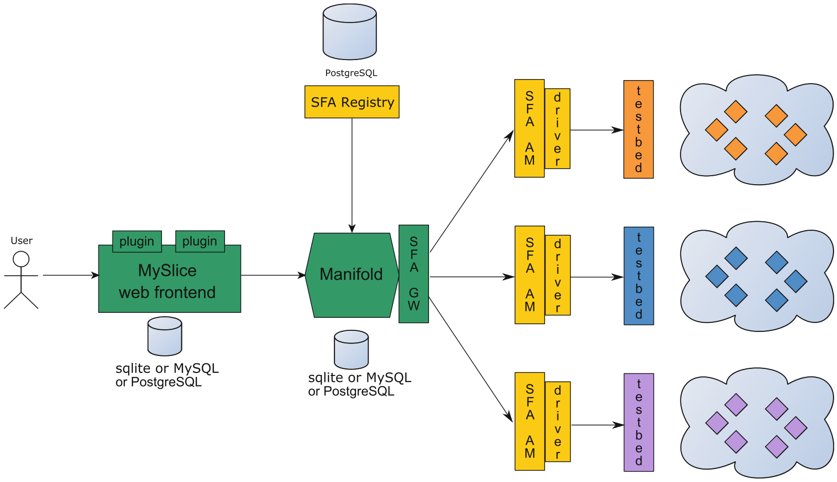


Fig. 2. SmartFIRE portal architecture.

3.3 Experiment Control: OMF

As we already mentioned, the main purpose of SmartFIRE is to extend appropriately the state-of-the-art framework of OMF [2], in order to create a unified platform that consists of multiple testbeds and is controlled from a single framework. OMF was originally created in the Orbit [12] testbed, and soon became the most widely used tool for experiment control among the majority of the testbed frameworks worldwide. OMF enables the experimenter to automate an experiment instead of setting up everything manually by logging into each node to configure/control its operation. The concept is similar to network simulators where the user describes a topology along with the applications that run during the simulation. The difference is that the topology consists of physical nodes on which OMF runs applications like a traffic generator. Also, the measurements are automatically collected with the help of the OMF Measurement Library (OML). The configuration and control of node operation occurs through specific properties, which are part of formal resource descriptions, and can be done not only at experiment setup but also during experiment runtime.

The basic components of the OMF framework are the Experiment Controller (EC) and the Resource Controllers (RCs). The role of the EC is to orchestrate the execution of the experiments, written in the OMF Experiment Description Language (OEDL). The EC interprets OEDL and sends appropriate messages to the corresponding RCs. In turn, each RC is responsible for abstracting and controlling one or more underlying physical or logical resources. It basically converts the messages received from the EC into resource-specific commands, and relays the response back to the EC. It is important to note that the message exchange between the EC and the RCs is performed using a publish-subscribe mechanism, assuming a stable and reliable communication. Thus, in case of network problems, the messages published by the EC and/or the RC are dropped.

The measurements produced by an experiment on the SmartFIRE platform are stored directly on an OML server, without any involvement of the EC. Given that several experiments can run at the same time, a separate database is maintained for each experiment. The user can inspect and retrieve the results of his experiment at any point in time. The OML software enables distributed real-time collection of data in a large-scale testbed environment, which is contextualized per experiment. While OML has been developed in the context of OMF, it has been spun out as an independent project and has already been deployed in non-OMF testbeds. It is also now being increasingly adopted for monitoring operational network and service deployments. OML is further developed to be able to collect measurements for the use cases that will be performed for the evaluation of the SmartFIRE objectives. Part of the SmartFIRE OMF and OML extensions are presented in [13,14].

4 Experimentation Capabilities Provided by SmartFIRE

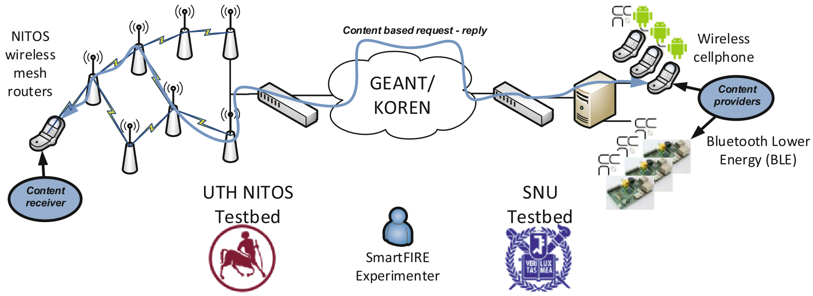
4.1 ICN Experimentation

In SmartFIRE, an architecture for ICN experimentation is implemented using wireless and SDN technology. As it is depicted in Fig. 3(a), wireless devices laying on UTH (NITOS) are connected to ICN-enabled nodes on SNU, where the IP addressing scheme is replaced by a novel one based on content identifiers. The utilized resources are interconnected including Layer 2 intercontinental virtual links, based on the GEANT/KOREN services. The goal of this innovation is to use identifiers that specify only the content and not the location of this content, as the IP addresses do. Each content is cached on multiple sides on the SNU testbed, while the ICN architecture aims at forwarding the content from the most appropriate side to the wireless device that requested it. The streaming over the wireless mesh is based on a Backpressure routing scheme.

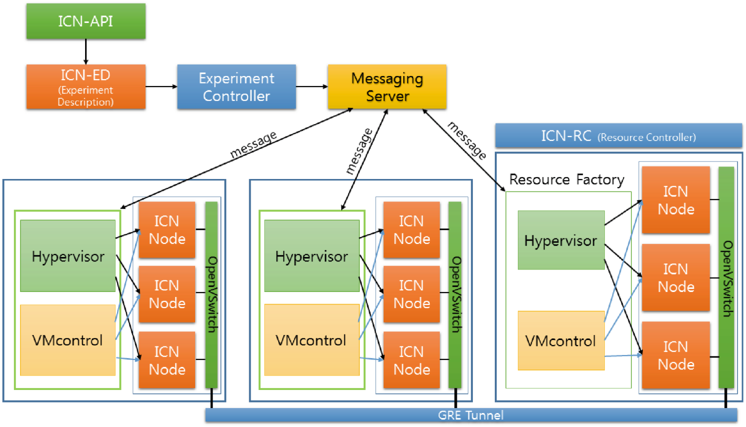
Many researchers try to replace the location-based host access with an ICN approach, where the contents are distributed and retrieved by their name, while the location of the content is not considered. Their target is the contents to be accessed not by “where”, but by “what”. The C-flow [6] offers the way for experimentation on ICN, using the virtual machines with the CCNx [15], the most widely known tool for ICN experimentation. More specifically, there are three entities - a publisher, a router, and a subscriber - and two types of packets - an interest-packet for the content request and a data-packet for the content encapsulation. When the subscriber broadcasts the interest-packet with the name of the wanted content, the matching data-packet is returned from the cache of an intermediate router or the repository of the publisher.

The routing over the wireless mesh is based on the Backpressure algorithm [16]. Backpressure is a throughput-optimal scheme for multihop routing and scheduling. The implementation of this scheme is not straightforward in practice, especially in the presence of 802.11 MAC, mainly because of its requirement for centralized scheduling decisions that is not aligned with the aspects of CSMA/CA. In [17] we present a novel scheme that is compatible with the decentralized operation of WiFi networks and efficiently utilizes the benefits of Backpressure, combining throughput optimality with load balancing. This scheme is implemented relying on the Click Modular Router [18] framework for routing configuration, which is another long established tool for SDN development.

SmartFIRE gathers the experience of SNU and UTH and develops the appropriate extensions of the OMF framework, supporting the experimentation in heterogeneous topologies, with information-centric data retrieval over the wired networking and load balancing schemes over the wireless access. One of the outcomes of these efforts is the ICN-OMF framework [13]: a Control and Management Framework for scalable, configurable and low-cost testbeds, that enables the experimentation with C-flow. The extended framework is able to control and manage globally dispersed ICN nodes (i.e. publishers, subscribers, or routers). The C-flow testbed architecture is depicted in Fig. 3(b), including the main OMF ICN-EC and ICN-RC components, which are extended versions of the aforementioned OMF EC and RC ones. The other outcome of SmartFIRE is the OMF support for Click Router development and experimentation [14].



(a) The C-flow Experimentation Topology



(b) The C-flow Architecture

Fig. 3. The information-centric Communication Scheme.

4.2 MOFI Experimentation

The MOFI [4] architecture is an outcome of the long-time Future Internet research in ETRI. MOFI is an identity-based network architecture that supports an environment for mobile-oriented experimentation. In MOFI, the network consists of multiple domains and multiple communication entities, having one or more global unique identifiers, named Host Identifiers (HIDs). MOFI uses an HID to identify an entity in the network, which is globally unique on the Internet. We consider the 128-bit HID format for compatibility with IPv6 application. The Locator (LOC) of each entity is used for the delivery of the data packets. In MOFI, the LOC is defined as a locally routable IP address that must only be locally unique in the concerned network. The end-to-end communication between two hosts is performed with HIDs, whereas LOCs are used for packet delivery in the access and backbone networks.

Each domain has a lot of Access Routers (ARs) enabling HID-based communication, and one or more Gateways (GWs) that interconnect the domain

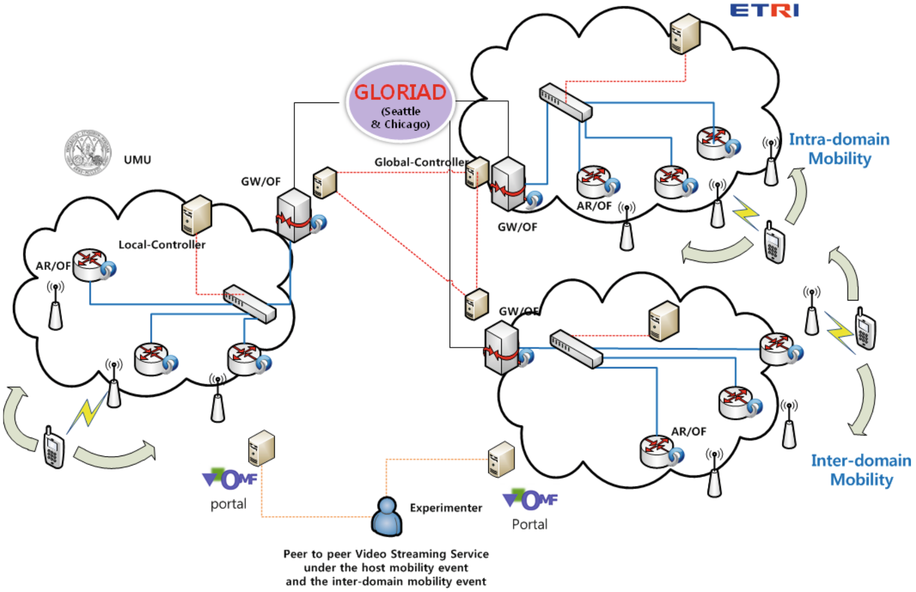


Fig. 4. The Identify-based Communication Scheme.

networks. MOFI performs better than the existing schemes for a variety of mobile network environments, in terms of signaling delays required, data transmission throughput, number of signaling messages, and handover delay. The HID-LOC mapping control is done in the distributed way, in which each AR performs the HID-LOC mapping control operations. We consider that the mapping control may be different across different network domains.

ETRI has developed an MOFI testbed over an OpenFlow-based and Linux platform, in order to evaluate the efficiency of the MOFI's architecture. This testbed is a federated facility, since it uses KOREN in order to interconnects four major South Korean domain networks. ETRI has built two MOFI-domain networks, which consist of two ARs (developed with use of virtual OpenFlow switches), a GW and an OpenFlow controller. Moreover, ETRI and UMU have developed demonstrations that showcase the capabilities of their joint experimentation, using both domain networks of ETRI and the one domain network provided by UMU, as it is depicted in Fig. 4. The experimentation on MOFI is orchestrated by the OMF framework, which is another significant contribution of SmartFIRE.

5 Conclusion

SmartFIRE can be considered as a very important complement to current available testbeds, providing considerable added value through an increased level of heterogeneity in the federated SDN-enabled infrastructure, and also through an enriched, intercontinental multi-domain, multi-layer experimental platform. The experimental facilities, which are developed in South Korea, on the one hand, and the enhancement to the experimental facilities in Europe, on the other, increase the number of involved technologies and also the level of heterogeneity. The final product is an experimental facility that provides multi-layer (layer 1 & 2), multi-domain and multi-technology testbed.

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