Proceedings of the 2014 26th International Teletraffic Congress (ITC)

FIRMA: A Future Internet Resource Management Architecture

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***Abstract*—The Internet is broken and there are several approaches to fix it. In order to validate the different attempts, they need to be evaluated within large-scale environments involving numerous heterogeneous resources. As a result, several testbeds have been established along with a number of competitive mechanisms to federate them. Since most of these protocols try to address similar issues, combining and unifying them is subject of current research. This leads to a complex environment for testbed owners and developers. Furthermore, it is foreseeable that even more federation approaches in different application domains will emerge in the future. Therefore, we propose an extensible architecture that allows to be federation protocol agnostic. The fundamental idea is to allow interoperability on the level of a semantic information model and to separate delivery mechanism specific implementations from a common core. The requirements for such an architecture have been extracted from latest European Future Internet research projects and its practicability is being evaluated by an initial implementation.**

***Index Terms*—Future Internet, Testbed, Management, Federation, Experimentation, Provisioning**

I. Introduction

motivation The Internet is broken[1] and there are several approaches to fix it. New developments need to be evaluated against specific requirements derived from Future Internet use cases. Given the nature of the Internet, scalability and support for a wide range of heterogeneous resources are of particular interest. Therefore, various Future Internet experimental facilities have been established to enable experimenters creating their own environments, which can be used to evaluate the according system under test.

complexity In order to improve the reasonability and scalability of experiments, testbeds get federated and as a result their visibility and usefulness compared to isolated facilities get increased. As a result, current research discusses architectures to interconnect different testbeds with each other in a standardized manner. Since in particular reproducibility is needed to gain scientific knowledge, this standardization involves all areas of the experiment life-cycle[2].

existing work In the last years a variety of frameworks, protocols, and architectures have mainly been designed for these purposes in the Future Internet Research and Experimentation (FIRE) and Global Environment for Network Innovations (GENI) initiatives. Currently, particular attention is being paid to the Slice-based Federation Architecture (SFA) for resource provisioning, the Federated Resource Control Protocol (FRCP) for experiment control, and the OML Measurement Stream Protocol (OMSP) for experiment measurement and resource monitoring.

bigger picture Notwithstanding the above, the federation of facilities is also subject in similar contexts. In particular within the Future Internet Public Private Partnership (FI-PPP) the federation of nodes is also envisaged based on Future Internet Core Platform (FI-WARE) components. Another example is the IEEE group Standard for Intercloud Interoperability and Federation[1] (P2302) that is focusing on technologies to interconnect cloud environments.

main issue However, these mechanisms have been mainly designed independently from and therefore are not closely linked with each other. This leaves the experimenter and testbed owner, that might even be part of multiple federations, to cope with all the variations with respect to tools and protocols.

contributions The main contribution of this paper is the definition of a notably reusable and extensible architecture for federated provisioning, orchestration, monitoring, and control of heterogeneous Future Internet resources resting upon a semantic Linked Data[3] driven information model.

structure The remainder of the paper is structured as follows. In Sec. II relevant work by others and the most important stances in the literature are presented. Based on this knowledge the treated research gap is shortly summarized in Sec. III and the proposed architecture is presented in detail. In Sec. IV a short evaluation of the current implementation is being presented. Finally, we close giving some conclusions and outline future work in Sec. V.

II. Related Work

big picture A number of research activities worldwide are focusing on the definition and the development of Future Internet architectures. The major Future Internet programs are the GENI program in the United States, the European FIRE and FI-PPP initiatives.

SFA Within GENI different competing testbed control frameworks are under development. A comparison between these control frameworks has been published earlier [4]. Therefore, the need to federate several testbeds that are controlled by the different competing control frameworks has been identified already 2010[5]. As a result, the Slice-based Federation Architecture (SFA) was defined and is still under revision

[1] http://standards.ieee.org/develop/project/2302.html

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to allow federation across facilities. SFA aligned testbeds can be controlled by various SFA compliant user tools. Resources are described using so called Resource Specifications (RSpecs), predefined XML schemas that allow arbitrary extensions for specific resources.

OMF

While SFA mainly addresses issues regarding the description, discovery and provisioning of resources, mechanisms are also needed to describe experiments and to control and monitor resources accordingly. For these purposes the cOntrol and Management Framework (OMF) has widely been adopted. It takes an experiment description file as an input to orchestrate experiments on OMF enabled testbeds. The underlying architecture has now been refactored to a federation-enabled version using the Federated Resource Control Protocol (FRCP).

OMSP

Furthermore, for experiment measurements the OML Measurement Stream Protocol (OMSP) is generally being used to collect and push monitoring information. One implementation is the ORBIT Measurement Library (OML), which enables experimenters to instrument their application by defining measurement points inside their application source code.

Teagle

Within the FIRE context the need to conduct experiments over federated testbeds has been identified as well. Starting with the PII project, possible heterogeneous resource federation scenarios in large scale experimental facilities had been analyzed and the Teagle[6] federation architecture was proposed.

standardization

Subsequently, the OpenLab and Fed4FIRE projects have been established to address compatibility and standardization[2] between FIRE and GENI facilities. It has been identified, that federated testbeds must support all the functions of the experiment life-cycle: resource description, resource discovery, resource requirements, resource reservation, resource provisioning (direct or orchestrated), experiment control, facility monitoring, infrastructure monitoring, experiment measuring, permanent storage, and resource release; as well as federated identity management, authorization, and Service Level Agreement (SLA) management. Based on identified characteristics[2], the heterogeneous federation approach was recognized to be the most suitable one for the Future Internet experimentation facilities under evaluation. In this architecture all testbeds run their native testbed management software.

EIT ICT

Furthermore, within the European Institute of Innovation and Technology Information and Communication Technology Labs[3] (EIT ICT Labs) context federation is also perceived as a catalyst to increase the utility of a testbed. In particular within the Fanning out Testbeds-as-a-Service for the EIT ICT[7][4] (FanTaaStic) project new ways of creating a sustainable business model, including an operational concept for the implementation, are getting explored.

FI-PPP

In parallel, within the FI-PPP context, the Experimental Infrastructures for the Future Internet (XIFI) project establishes a sustainable pan-European federation of Future Internet test infrastructures. This federation is technically based on Generic Enablers (GEs) developed by the FI-PPP project FI-WARE and not interoperable with the FIRE/GENI developments.

Inter-cloud

Analog to these efforts, current research also strives to federate resources within single administrative domains in a related context: In 2009 a “Blueprint for the InterCloud”[8] was published to define protocols and formats for Cloud Computing interoperability and different Standards Developing Organizations (SDOs) are working on according documents. One example is the IEEE project P2302.

III. Own Approach

bottom line

We have shown that several approaches to manage resources across multiple administrative domains already exist. It becomes apparent that on the one hand, a single federation mechanism can’t be used within every context and more fields of application emerge. On the other hand, most of them share many similar concepts and manage information about the very same resources.

research scope

This leads to a wide range of interesting research questions, in particular with reference to the experiment life-cycle and beyond. Within the scope of this paper, we’ll restrict the research topic to two major aspects: First, an underlying concept to allow interoperability independent of specific protocols by focusing on managing a representing information model based on Linked Data[3]. Second, an architecture that is extensible enough to abstract from resources and federation mechanisms, while at the same time support in principle all aspects of the experiment life-cycle.

A. Semantic Information Model

main issue

Current implementations of SFA, FRCP, OMSP and Teagle related interfaces do not specify a formal information model at the present time (following the terminology given in RFC 3444). Therefore, the combination of and handovers between different protocols is laborious, although identical resources are being managed. This is aggravated by the fact that applying arbitrary models makes it difficult for developers to parse and work on data, for users to find resources, and finally prevents the envisioned interoperability between testbeds and implementations.

approach

The most common approach to avoid such data silos, is the application of Linked Data. By using a formal, linkable semantic representation of resources and messages, algorithms are capable of reasoning about them partly independent of the underlying protocol implementation while referencing to identical resources using the same identifiers. It is envisioned to apply this approach to each step of the experiment life-cycle by exploiting the expressiveness of the Resource Description Framework (RDF), the RDF Schema (RDFS) and the Web Ontology Language (OWL). Concrete examples are: description of testbeds within SFA `GetVersion` calls by publishing JavaScript Object Notation (JSON) serialized meta-data; discovery, selection, reservation, orchestration and provisioning of resources within according SFA calls by using XML serialized

[2]http://open-multinet.info
[3]http://eitictlabs.eu
[4]http://testbeds.eu

RDF data; control of resources by adopting the same XML serialized RDF data within FRCP messages; monitoring of resources by publishing accordingly annotated OMSP streams or SFA related resource descriptions; authorization of resource control by incorporating authorization related attributes to the according resources; and the publication of available resources in form of a SPARQL endpoint.

existing work

Listing 1 illustrates an excerpt of a potential request (bound and unbound provisioning of a virtual machine). It is part of a larger set of proposed ontologies that are under discussion for further standardization[5] and replacement of current XML-based SFA RSpecs.

Listing 1. Excerpt of a Provisioning Request

```
:message rdf:type geni:Message ;
      geni:type geni:Request .

:boundvm1 rdf:type indl:VirtualNode ;
        nml:implementedBy fusecoplayground:vmserver1 .

:unboundvm1 rdf:type indl:VirtualNode .
```

B. Architecture Overview

main issue

In order to cover the whole experiment life-cycle, related work focuses on loosely combining existing developments. While this approach reuses already established software components, it also introduces complexity including duplicated functionalities, synchronization overheads and resource mapping issues. Therefore, the goal is to identify shared functionalities of existing mechanisms in order to define an extensible architecture with a protocol and resource agnostic core.

achievements

As a main achievement, Fig. 1 shows the proposed architecture from a very abstracted high level point of view. It is deployable as a single testbed management as well as a federation wide brokering system. It is based on the established Entity, Boundary, Interactor (EBI) and Data, Context and Interaction (DCI) architectural design patterns to separate concerns and allow the reusability of the developments.

C. North- and Southbound Modules

north/-south

The implementation of the above referenced federation protocols is located in the northbound interface. They are treated as exchangeable Delivery Mechanisms (DMs) required in specific application domains only. This includes native APIs as well as SFA, FRCP, OML or GEs. Overlapping functionalities and cross cutting concerns (in particular the management of resource information) are pushed into lower core modules.

Resources, on the other hand, are interfaced by the southbound interface. An adapter is responsible for describing, provisioning, controlling and monitoring a single or multiple resources and their instances by publishing, receiving and subscribing to semantically annotated information. A resource in this context can be a physical or virtual resource as well as a service or testbed (e.g., with another internal/external API) or another whole federation.

[5]https://github.com/open-multinet/playground-rspecs-ontology

Fig. 1. FIRMA Architectural Overview

D. West and Eastbound Modules

west-/east

The core functionalities, such as a semantic resource repository, reservation management, orchestration, elasticity or authorization decisions are located in the westbound area. Requirements for theses modules are derived by identifying common functionalities needed in the northbound interfaces.

Finally, the integration of existing services is located at the eastbound area. This includes services such as billing, accident reporting or Customer Relationship Management (CRM) systems for enhancing the trustworthiness and inclusion in commercial offerings.

E. Message Bus

loose coupling

The modules are loosely interconnected with each other using publish/subscribe DMs and they exchange semantically annotated messages and events in an asynchronous, bidirectional manner. This allows to potentially distribute several components and therefore scale the architecture as the demand raises or to add and remove components without interfering with the running system.

IV. Evaluation

Lst. 2

In order to show the practicability of the proposed semantic model and architecture, an initial Java framework is been implemented. An example query about testbed meta-data and its result is shown in Lst. 2.

Listing 2. Query Meta-Data

```
Query:
SELECT ?label ?url ?image ?lat ?long ?amendpoint ?
     amversion WHERE {
?testbed rdf:type omn:Testbed ;
             rdfs:label ?label ;
             foaf:depiction ?image ;
             foaf:homepage ?url ;
             foaf:based_near [
                geo:lat ?lat ;
                geo:long ?long
             ] .
```

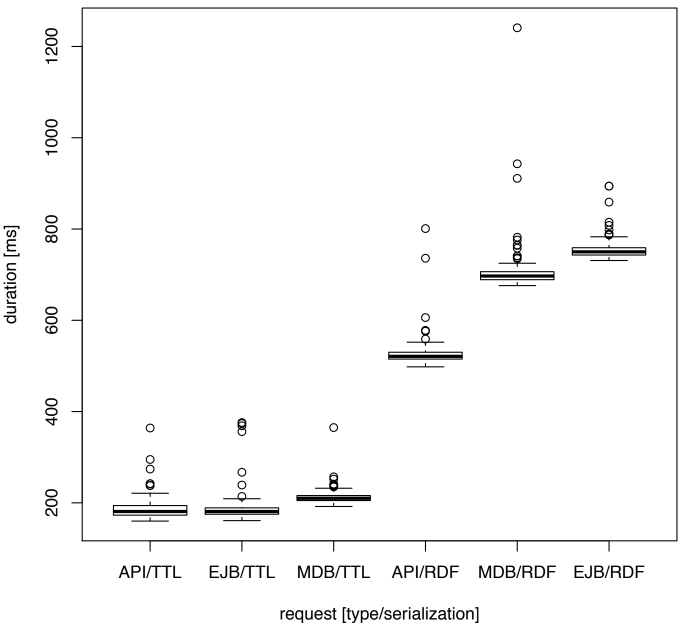

Fig. 2. Query for SKOS concepts in 112.846 triplets based on [9]

```
?am rdf:type geni:AggregateManager ;
      omn:partOfGroup ?testbed ;
      omn:endpoint ?amendpoint ;
      omn:version ?amversion .
}

Result:
label,url,image,lat,long,amendpoint,amversion
FUSECO Playground,http://fuseco-playground.org,http://
     www.fokus.fraunhofer.de/en/fokus_testbeds/
     fuseco_playground/_logos/FUSECO_Playground_Logo.
     jpg,52.5258083,13.3172764,https://fuseco.fokus.
     fraunhofer.de/api/sfa/am/v3,3.0
Time: 0.152 sec
```

Fig. 2

In Fig. 2 a short performance evaluation of querying resource information via a native interface is depicted: Data: 112.846 triples based on [9]; Query: Resources that are Simple Knowledge Organization System (SKOS) concepts; Result: 6.334 triples (200 repetitions); Software: Oracle Java 8, WildFly 8.1, Apache JENA 2.11.2; Serializations: Turtle (TTL) and RDF/XML; Internal Query: as direct Java API, Enterprise Java Bean (EJB) or Message Driven Bean (MDB) using the Java Message Service (JMS).

V. Conclusions and Future Work

results

We have given a brief overview of the current experimental Future Internet research landscape. Based on this, we have identified research gaps with respect to the support of the whole experiment life-cycle by existing solutions. As the main contribution, a semantic model and management architecture was introduced and shortly described. The architecture is currently being implemented[6] and preliminary results are encouraging.

who profits

As a result of this research, developers could use this architecture for implementing and linking federation mechanisms within a single framework, testbed owners could provide resources using different interfaces at once to increase their sustainability, researchers would have an instrument to directly compare different protocols.

further work

The short-term goals include the implementation of plugins for selected SFA, Teagle, OMSP, FRCP and related GEs functionalities. The medium-term planning treats the international standardization of the proposed semantic model and the integration of the architecture in commercial contexts. Finally, the long-term objectives comprise the extension of the architecture's applicability from heterogeneous resource federation to generalized service life-cycle management.

Acknowledgments

This work was carried out with the support of the European Fed4FIRE (Grant No. 318389), OpenLab (Grant No. 287581) and FanTaaStic (Activity 13200-A1300) projects.

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