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Resource specification and intelligent user interaction for federated testbeds using Semantic Web technologies

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ABSTRACT

In this paper we present the Testbed-as-a-Service with Ontology Repository (TaaSOR) platform that facilitates a community-based approach to building an infrastructure for the management and federation of heterogeneous networking testbeds in a bottom-up fashion. This platform provides semantically annotated services and experiments with automated transformation from other semi-structured data sources and a set of tools that enables a community of developers and experimenters to develop and modify ontologies which constitute the foundation of the platform. The platform also includes an ontology repository that enables persistence, publishing and management of the accumulated semantics in a transparent way based on ontologies and Linked Data represented in standardized formats. Positive feedback loops engineered in the platform lower the barrier for testbed operators for participation in a federation, reduce the barrier of entry for experimenters without expert domain knowledge, lower operational overhead for developers, and streamline operation for system administrators. As a proof of concept, the TaaSOR instance is applied to the ORBIT testbed and the corresponding OMF management framework to test the proposed platform in an environment used by a large number of researchers worldwide.

1. Introduction

Modern information and communication technologies (such as networks, devices, applied methods and algorithms) are highly sophisticated and as such they inevitably grow inner complexity that as a consequence requires increasingly more effective research for future advancement. This is true for the theoretical research, based on pure mathematical models and simulations, as well as for the research based on experiments, engineering and development. On the other side, there is an evident pressure towards an end-user value generation including commercial effects. Due to the increasing complexity, the risk of failure to generate value for an end-user within a production system is high and growing in the case when we rely on theoretical research only. This uncertainty can be significantly reduced through experimental research conducted by means of large scale testing and trials. Consequently, it is of the crucial importance to offer to researchers, developers, system architects and professionals powerful software tools and physical large scale testbeds to benchmark, tune, and optimize their applications and services [1]. With a goal to foster the emergence of the Future Internet, several global initiatives (FIRE in Europe [2], GENI in US [3,4], Japan's Akari [5], AsiaFI [6]) are working towards open, general purpose, sustainable large-scale shared experimental facilities in the form of open multi-user experimental testbeds.

With growth in the number of specialized experimental testbeds and increased interest in creating large, geographically distributed and functionally diverse experimental capabilities, the basic challenge for future experimentation

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infrastructure management is that of a *testbed federation*. The testbed federation should include heterogeneous resources while providing users with seamless access to the integrated experimental facilities. While interoperability between heterogeneous testbed installations at the lower technology levels is necessary, it is only the first step towards a successful federation. The ultimate "holy grail" is to achieve total system scalability and abstraction that would enable researchers to seamlessly conduct their experiments regardless of the testbed management framework, type and location of the physical infrastructure, nature of the experiment, and amount of required resources. An experimenter should be able to specify experimental requirements in simple (preferably human language) terms and obtain a collection of resources (configurations, hardware, policy, network and software) necessary to perform the experiment.

The crucial success factor for systems with inherent high complexity, such as the testbed federations, would be removing the high cognitive barrier to entry and steep learning curve for new users. Since the cognitive load must be minimized in order to foster the users' community growth, supporting software tools should deal with semantics and be capable of reasoning. The technologies that make a strong promise to successfully address such problems are currently under intensive development and include: ontologies [7], Semantic Web [8] and Linked Data [9]. The common ground for the converging technologies is formal representation and publishing of semantics such that computers are capable of processing them and reasoning about them. In this way, interaction between the experimenter and the system can be structured in a more user friendly way. In addition to the value proposition for end users, the semantic technologies can also provide support to system operators and developers by enabling structured management of a large set of distributed heterogeneous resources that is of crucial importance for federated systems as well as increasing utilization through better sharing of experimental substrates. Publishing resources in a consistent way on the Web, like Linked Data suggests [9], may enable more effective functionalities of high practical importance, such as semantic resource description, publishing and search as well as management of otherwise hard to deal with abstract resources such as topologies and interference.

In this paper we propose the Testbed-as-a-Service with Ontology Repository (TaaSOR) platform that facilitates a novel approach to testbed federation development by means of semantic technologies and the users' community. The approach is based on collecting relevant data from participating testbeds, publishing data as Web resources using Linked (Open) Data and facilitating seamless consumption of the published resources, providing interoperability and reasoning. While TaaSOR can be applied to any experimental facility, in this paper our focus is on a federation of wireless testbeds, particularly community support for publishing resources such as Linked Data and developing resource description as well as resource discovery. It is important to note here that the proposed TaaSOR platform does not replace but complements and facilitates use of the ontologies developed for wired testbeds and enables the community to adopt as well as extend them as needed. It provides a set of tools to foster community collaboration and federation-based growth including Web applications for semantic enrichment of the service descriptions as well as semantic annotations of mappings between different service entities.

The paper is organized as follows: in Section 2 we provide background information and existing work. In Section 3, we introduce basic concepts and design principles that influence the overall architecture while in Section 4 we describe the service design and demonstrate, as a proof of concept, the TaaSOR application for ORBIT testbed. We describe how relevant data is collected from the participating testbeds and later published as Web resources using Linked (Open) Data to facilitate seamless consumption of the published resources, providing interoperability and reasoning. In particular we focus on wireless aspects of the testbed, with added complexity with respect to wired testbeds with the two new challenging aspects: importance of physical location (i.e. spatial topology) and the presence of the interference in the shared RF space. We conclude in Section 5 by outlining a set of possible TaaSOR extensions.

2. Background

2.1. Testbeds

Networking testbeds have been a topic of intensive research work on a few large initiatives, most notably on the European FIRE initiative [2] and the US NSF-funded GENI initiative [3,4] with several highly visible projects such as PlanetLab [13,14], Emulab [15], Federica [16,17] and ProtoGENI [18]. They provide a controlled environment for execution of repeatable experiments featuring constraints, conditions and characteristics close to a real application deployment environment. The value proposition comes from a somewhat surprising fact that the gap between theoretical (especially with advancements that have resulted in a fairly sophisticated simulation and analysis tools) and experimental results is still large [19]. The experimentation on the required scale is crucial for success of end user applications. Testbeds also provide experiment repeatability while making it capable of altering specific settings such as protocols, end user behavior datasets, metrics, network traffic patterns and link reliability. Controllability provided by testbeds is the most promising approach to addressing inconsistencies between different results which happens due to experimental factors that cannot be controlled in experimentation in real network deployments nor taken into consideration during data analysis.

Networking testbed virtualization is a logical consequence of the global virtualization trend as described earlier in this section. It promises not only better utilization of resources and improved flexibility in resource provisioning but also the capability to provide a substrate for experimenting with radically new networking technologies and different topologies [20]. Virtual testbeds consist of a set of physical resources (including links, hosts, routers, etc.) and a substrate consisting of a set of dedicated but