Towards the Future Internet
G. Tselentis et al. (Eds.)
IOS Press, 2009

doi:10.3233/978-1-60750-007-0-67

Control of Resources in Pan-European Testbed Federation

Anastasius GAVRAS [a], Halid HRASNICA [a], Sebastian WAHLE [b], David LOZANO [c], Denis MISCHLER [d], Spyros DENAZIS [e]
[a]*Eurescom GmbH, Germany,* [b]*Fraunhofer FOKUS, Germany,* [c]*Telefonica I+D, Spain,* [d]*Thomson, France,* [e]*University of Patras, Greece*

Abstract. The Pan-European laboratory – Panlab – is based on federation of distributed testbeds that are interconnected, providing access to required platforms, networks and services for broad interoperability testing and enabling the trial and evaluation of service concepts, technologies, system solutions and business models. In this context a testbed federation is the interconnection of two or more independent testbeds for the temporary creation of a richer environment for testing and experimentation, and for the increased multilateral benefit of the users of the individual independent testbeds. The technical infrastructure that supports the federation is based on a web service interface through which available testing resources can be queried, provisioned and controlled. Descriptions of the available resources are stored in a repository, and a processing engine is able to identify, locate and provision the requested testing infrastructure, based on the testing users' requirements, in order to dynamically create the required testing environment. The concept is implemented using a gateway approach at the border of each federated testbed. Each testbed is an independent administrative domain and implements a reference point specification in its gateway.

Keywords. Testbed, Federation, Federated Testbeds, Reference Point, Resource Control, Panlab, Teagle

Introduction

The Pan-European laboratory – Panlab – is based on federation of distributed testbeds that are interconnected, providing access to required platforms, networks and services for broad interoperability testing and enabling the trial and evaluation of service concepts, technologies, system solutions and business models. In this context a testbed federation is the interconnection of two or more independent testbeds for the temporary creation of a richer environment for testing and experimentation, and for the increased multilateral benefit of the users of the individual independent testbeds.

Rapid development of Information and Communications Technologies (ICT) in the last decades has been ensured by significant efforts performed by the corresponding research community world-wide. Both theoretical research, e.g. based on mathematical analysis and simulations, and research based on experiments contributed significantly to the recent technological developments. Meanwhile, the complexity of ICT systems, for example networks, devices, applied methods and algorithms, has increased in order to ensure their proper operation. Therefore, to be able to develop and asses new concepts and achievements in complex environments, researchers and engineers are increasingly looking for opportunities to implement their concepts in testing systems and in this way obtain quickly the solutions and optimizations that can be implemented in production systems. Thus, with the recent developments in the ICT area, the necessity for experimental research carried out in the form of large scale experiments and testing is significantly growing among the research and engineering communities. On the other hand, in the ICT area, as the main driver of common global developments, there is a need to ensure world-wide experiments and testing ensuring that developed solutions can be applied anywhere as well as empowering wider groups of researchers to have access to various experimental and testing facilities at a global scale.

In order to meet the requirements – enlarged experimental opportunities and remote testing – the Panlab concept [1] has been created in Europe to form a mechanism that enables early-phase testing and interoperability trials as widely and deeply through the layers and players of telecommunications, as possible. In order to boost European testing, we must have the means to dynamically provision testbeds according to customer requests. This can be achieved by means of a new functionality capable of composing, managing and refining testbed resources. This constitutes the primary objective of the pan-European laboratory for networks and services, which implements the Panlab concept [2].

The entire mechanism, the rules and procedures of how to achieve the effective testing collaboration, have been developed in the Panlab project at a high abstraction level. The considered mechanisms include legal and operational requirements on the Panlab concept as well as requirements on technical infrastructure to be established in order to realize the Panlab concept, as summarized in [3].

In this paper, we describe how the technical infrastructure controls the distributed testing resources in the Pan-European laboratory federation in order to dynamically create appropriate testing environments. It is organized as follows: First, Sec. 1 presents the Panlab concept, including an introduction of the Panlab roles and the integration of testbeds, as well as Teagle as the main collaboration tool. Sec. 2 presents the seven operational stages of the Panlab concept. The enabler functionalities of the technical infrastructure of the federation are described in Sec. 3, while Sec. 4 describes the reference points for partitioning the identified responsibilities of the different administrative domains. Sec. 5 presents the main components responsible for configuration, control and interconnection of components across multiple administrative domains. Finally in Sec. 6, the conclusions of the paper are presented.

1. General Panlab Concept

1.1. Components and Roles within the Panlab Concept

The Panlab infrastructure has to ensure interconnection of different distributed testbeds to provide services to its customers, in order to do various kind of testing. Coordination of the testing activities, for example infrastructure configuration, ensuring necessary interconnection of customers and testbeds, and the overall control and maintenance of the environment, is ensured by the so-called Panlab Office. Thus, we can outline the following main roles of the Panlab concept, as is presented in figure 1:

- Panlab Partner – an entity that participates in Panlab activities by providing infrastructural elements and services necessary to provide testing services. Panlab partners are connected to the Panlab Office for offering functionality to the customers.

- Panlab customer – an entity that uses a service provided by the Panlab office, typically to carry out R&D activities, implement and evaluate new technologies, products, or services, benefiting from Panlab testing offerings.
- Panlab Office – an entity that realizes a brokering service for the test facilities, coordinating and supporting the Panlab organization It is responsible for coordinating the provision of the testing infrastructures and services, partly by using tools and, when possible, web interfaces, but also directly coordinating the Panlab Partner test-sites and the communication path between them and customers.

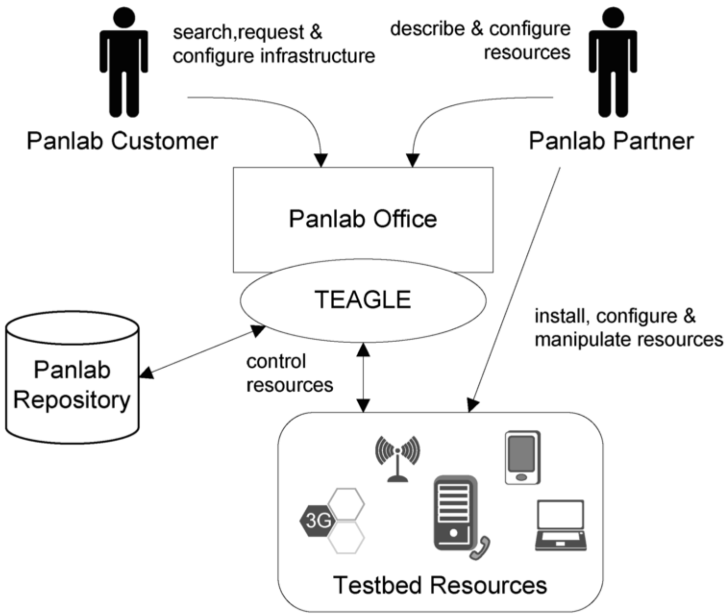

Figure 1. Panlab components and roles

In addition to the roles defined above, the Panlab architecture relies on several other architectural components that will be introduced in the course of the following sections. Among those are the Panlab search and composition engine "Teagle" and a Panlab repository that stores testbed descriptions and testing results.

In a first phase of Panlab operation, various operational steps, ensuring the creation and realization of testing projects, are executed manually by personnel of the Panlab Office and involved partners and customers. Thus, the testbed metadata held in the Panlab repository is entered manually as well as testing configurations, etc. In order to achieve a near to full automation of all Panlab related processes, the so-called Teagle tool will be developed, in order to offer, (among other functionalities) an online form where the testbed representatives can enter the relevant data describing the testbed [4] and its resources, Panlab customers may then search the Panlab repository to find suitable resources needed for doing their tests.

1.2. Integration of Testbeds

In a general use case applied to the Panlab architecture, two or more Panlab components have to be interconnected in order to ensure realization of a particular testing project (figure 2).The established connection between the different testbeds must serve a specific objective, i.e. it must serve the interactions between (i) applications, (ii) signalling control and service support, or (iii) user data transport. Connections can be requested to serve one or more of these objectives.

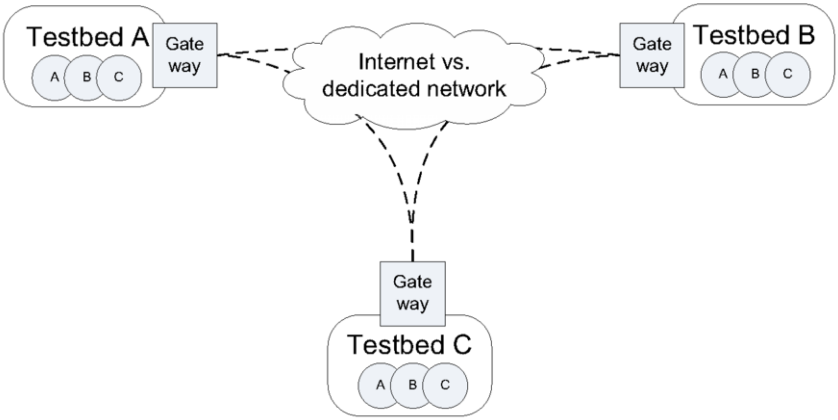

Figure 2. Gateway concept

One of the tasks of the gateways is to match property requirements to the connectivity service with the properties of the available connectivity. In many cases, Virtual Overlay Network (VON) technologies can be used to connect resources and sites with a common set of connectivity properties. Especially Virtual Private Network (VPN) or Virtual LAN (VLAN) technologies are well established means to create a logically dedicated network for a specific purpose. From the federation point of view, a logical connectivity support function must be implemented, which is able to control the gateways, located at the edge of the individual testbeds, to establish the requested connections to the peer site or sites. Thus, interconnection of Panlab components is ensured by establishing connections among gateways of respective individual components representing separated administrative domains, where all other interconnection functions remain under control of these components.

1.3. Teagle Tool providing Search & Match Functionality

As mentioned before, the Panlab architecture relies on a tool called "Teagle" which is a web instance that provides the means for a customer to express the testing needs and get feedback on where, how and when testing can take place. Teagle enables finding a suitable site for one's testing needs within a database of partner testbeds (the Panlab repository). The objective of Teagle is to manage the complete set-up of a desired infrastructure. This includes necessary resource reservations and interconnection of elements to serve a specific testing need. Thus, by using Teagle, the customers can select desired technologies and features for a test configuration to be set up. Functionalities of Teagle tools are described in [3] and further specific details can be found in the documents available at [1].

2. Operational Stages of the Panlab Concept

This section aims at exemplifying key operational aspects as they emerge from the overall Panlab concept and use cases. To this end, we have identified seven operational stages, the purpose of which is to provide the context that specific operations are defined and executed in:

1. **Customer Interaction:** This stage comprises the interactions between a customer requesting the provisioning of a testbed and the corresponding tests to be carried out when the testbed has been provisioned. This interaction takes place through the Teagle and may formally end with a Service Level Agreement (SLA). This SLA can then be used by Teagle to analyse customer requests and then to find the proper testbeds in the Panlab repository that match the customer request. Then this SLA becomes a binding contract.
2. **Testbed Discovery:** This stage may well be seen as a precursor of the previous stage or as a distinct part of customer interaction. In the former case a customer before interacting with Teagle may search on his own the testbed repository in order to find for himself what is available in Panlab. This means that proper Graphical User Interfaces (GUI) guide the customer through the Panlab offerings and/or provide examples of the available technologies. In the latter case, Teagle simply searches through the Testbed repository in order to find, with or without customer's collaboration, suitable technologies.
3. **Testbed Provisioning:** This stage starts when the customer and the Panlab office have both agreed on the SLA, and Teagle can now initiate the provisioning of the testbed environment before it is delivered for use to the customer. This is an entirely Panlab office responsibility. Provisioning is carried out through a number of interfaces implemented by the Panlab control architectural elements. One major aspect of testbed provisioning is the wide variety of configuration operations that may need to be performed on testbed components. Therefore, configuration critically depends on control interfaces available in the testbed devices and they raise problems of interoperability for controlling these devices. Resolving them requires that the testbed components implement open or standard interfaces for their configuration. In case of proprietary control interfaces, there must be functionality in place that performs mappings of configuration operations on to the proprietary control interfaces. This description gives rise to one of the main architectural components of the Panlab architecture, namely, the PTM. Finally, all these operations are performed in a secure environment.
4. **Usage and Management of Testbed by the Customer:** When entering this stage, the testbed has been configured, deployed and handed over to the customer and his users or test suites for its actual use. This means that a number of management interfaces may be exported to the customer so that he can further tune the testbed internal operations according to user needs or test requirements. At this stage the testbed operations pertaining to specified tests and users' requirements, become the responsibility of the customer whereas the overall welfare (security, fault tolerance, SLA conformance etc.) remains at Panlab's office responsibility. Any additional operation that falls outside the scope of the contracted SLA must be re-negotiated and re-provisioned.
5. **Monitoring and Collection of Test Data:** Monitoring services and collection of test data represent an important part of the overall Panlab services as it

provides the means to process and analyse the behaviour of the product for which the customer has requested the testbed in the first place. Monitoring in Panlab may be carried out either by the customer by deploying monitoring mechanisms customised for his proprietary tests, or on behalf of the customer when he needs common monitoring mechanisms e.g. packet traces, sampling etc. In the former case, we assume that monitoring functionality is part of the components contributed to the testbed by the customer whereas, in the latter case, the monitoring mechanisms form an integral part of the testbed offering and as such they also undergo deployment and/or configuration during the provisioning stage. The same mechanisms may also be used for other activities, e.g. Quality Assurance or SLA conformance. Finally, there are proper interfaces, protocols and resources, for the collection and transport of monitoring data to repositories either in the customer or Panlab premises, so that they may become available for further processing and analysis.

6. **Processing and Accessing Test Data:** After completing the tests, data should be collected and stored in repositories for further processing by the customer or on behalf of the customer according to his needs. Access to these data may be controlled by certain policies. To this end, a customer may decide to make the collected data publicly available or keep them for his own purposes. In due course, we expect that the collected data will become a valuable asset of the Panlab office and as such it is envisioned that these data should become available to other customers even if they do not require the deployment of a testbed. This involves the definition of common formats to read the data as well as tools for carrying out analysis e.g. statistical, anomaly detection etc. Accordingly, the Panlab office through Teagle may consider this stage as an additional service to testbed provisioning and a distinct service on its own.
7. **Quality Assurance:** This stage comprises a series of Panlab functionalities running at the background of any testbed operations and aiming at guaranteeing the welfare operation of the testbed infrastructures and conformance to contracts by both sides, namely, customer and Panlab. Such functionality ranges from security to monitoring as well as proofs of conformance to contract terms.

3. Federation Enablers

For federating different testbeds residing in autonomous administrative domains and provide composite infrastructures using resources across the boundaries of the domains, three major blocks of functionality need to be provided:

- Resource Description,
- Service Exposure, and
- Service Composition.

These functionalities are considered the enablers for the federation, since they represent essential capabilities of the technical infrastructure of the federation.

3.1. Resource Description

Whatever is offered by a testbed towards the federation must be described according to a common information model in order to allow Teagle to understand the functionality of resources, offer them towards external users and provide compositions of distributed functionalities. This means that Panlab Partner resource offerings become services to be consumed by the costumer. The services need to be described uniformly to allow Teagle as a broker residing between the customer and the resource, to match requests to concrete functionalities. The TMF SID [8] provides a good starting point for a common information model that might need to be extended to meet the Panlab requirements and to deal with the high heterogeneity of Panlab Partner testbed resources.

3.2. Service Exposure

The basic service exposure mechanism foreseen for the Panlab architecture is shown in figure 3. A1 and A2 are functionalities that are offered by testbed A towards the federation. As is described above, the PTM provides the mapping from federation level commands to resource specific commands and the IGW is responsible for providing and controlling connectivity to other administrative domains.

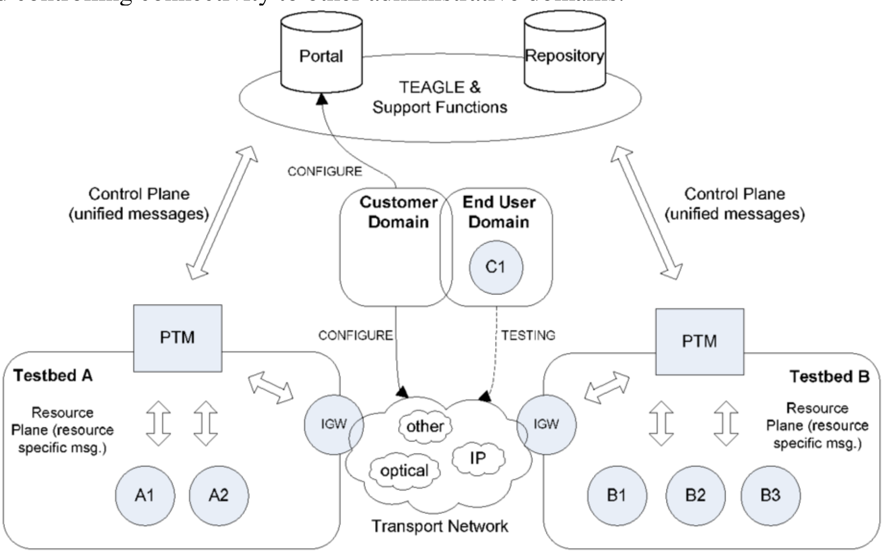

Figure 3. Service exposure

The PTM exposes the functionalities A1 and A2 as services to the federation. As an example consider A1 to be an application server and A2 a web service that allows to send IMS instant messages. The PTM would then expose a service that allows the set up and configuration of A1. Also the PTM would expose the web service which simply results in exposing the endpoint of A2.

The testbeds shall encapsulate functionality in atomic building blocks that can then be used in a combinational manner across the entire federation. This means that functionalities offered by the individual testbeds are represented as atomic components that act as building blocks during the composition of a testbed. In this context, a testbed instance acts as a container of the selected building blocks. Accordingly, different combinations of building blocks may result in different testbed instances dictated by customer requests. This is in line with the general concept of Service Oriented Architectures (SOA) and shall ultimately lead to a service market. However, in contrast to open, "internet-style" service markets, the principle demonstrated here relies on centralized support functions and legal entities that ease the establishment of business relationships between multiple stakeholders. For example the negotiation of Non-Disclosure Agreements (NDA) and contacts is simplified through agreed templates and a trusted relationship between the Panlab Partner and the Panlab Office.

3.3. Service Composition

Teagle shall offer a service composition functionality that allows the orchestration of (atomic) building blocks offered by different testbeds. In order to do so, as stated above, it requires a solid description on what is available. A repository shall hold descriptions of the available resources in the federation and instructions on how to invoke them. Teagle displays the content to the customer, provides user accounts and offers a search tool for browsing federation resources. Once the customer has looked up and identified interesting functionality to be provided by the federation, a composition tool shall provide a workflow that defines how to provision the desired virtual environment as a composition of building blocks from different testbeds. In this regard several aspects are important:

- Pre- and post-conditions of building blocks,
- Timing across the entire workflow (which operation goes first, second, etc.),
- Dynamic probing of availability.

The field of service orchestration is still subject to extensive research boosted by the success of service oriented architectures. Panlab will make use of current state of the art technologies in this area and seeks to contribute with scientific results to this important field of research. However, first Panlab implementation stages are foreseen to rely on many manual processes while fully automated service composition remains the grand vision to be achieved in later concept implementation stages.

4. Reference points

The infrastructure supports network agnostic service provisioning by separating the testing service logic from the underlying networking infrastructure. It identifies and defines the necessary interfaces for resource negotiation at the technology and administrative domain borders. It defines the necessary messages at the federation level that are mapped via a Panlab Testbed Manager (PTM) to intra-testbed messages to automate provisioning (figure 4). The messages defined at the federation level are based on the New Generation Operations Systems and Software (NGOSS) [5] framework. Reference Points (RP) mark an interface specification between Panlab entities.

Each participating testbed implements at its border the necessary functionality in the PTM, to be able to receive and interpret control messages from the federation. The PTM is responsible for the clear separation between the mechanisms for services provisioning at the federation level, from the mechanisms needed to map these services onto the network infrastructure.

Furthermore, each participating testbed implements an Interworking Gateway (IWG) for the technologies it supports at the testing usage level (figure 5). The IWG covers only the protocols and technologies that are meaningful in the context of usage of its own components and resources.

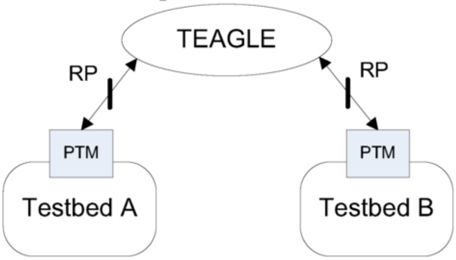

Figure 4. Gateway concept implementation – PTM

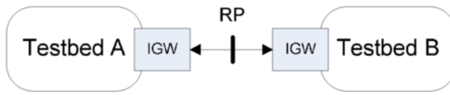

Figure 5. Gateway concept implementation – IGW

The concept of reference points is essential for partitioning the responsibilities that each administrative domain has to fulfil. Each RP has to satisfy a number of well identified requirements that are related to the technical or business relationship manifested by each RP. The figure 6 below identifies the complete set of reference points that are related to control and usage of a resource inside a testbed as seen from outside a testbed (administrative domain). From this perspective the relevant actors are the federation domain, represented by Teagle, the End-User domain, the customer domain, as well as the neighbour testbed domain, represented by the shaded IGW in figure 6. For completeness the internal reference points from the PTM to testbed components are also illustrated. The main reason for this is that the PTM component maybe a generic component provided by the federation.

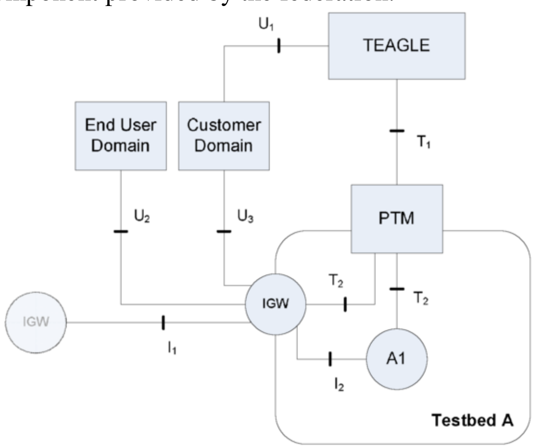

Figure 6. Reference points

T1 - Teagle to PTM – This RP refers to the common control plane that is established across the entire federation and is based on SOAP Web Services. Via this reference point, the configuration of resources (A1) is passed to the PTM.

T2 - PTM to Testbed Components – The PTM is responsible for managing all exposed components inside its testbed. It does so by applying a device driver concept. A device driver for a component is usually implemented by the testbed provider according to the functionality the component exposes to Teagle. Device drivers are translating the Teagle operations and executing the operation on the associated testbed component (A1). This is an internal RP.

U1 - Costumer to Teagle – This RP provides customer access to Teagle services, such as searching for specific functionality, setting up a desired testbed, configuring the testbed for a specific test case, retrieving test results etc. This RP will be implemented as a web interface and is not used during the test execution phase.

U2 - End-User Domain to IGW – This RP provides End-User access to a configured testbed and the services that are subject to test. This RP is in the usage plane and is not used for configuration, control or management.

U3 - Costumer Domain to IGW – This RP provides customer access to a configured testbed during the execution phase of a test. This is necessary when adjustments are needed to a provisioned testbed after its initial configuration.

I1 - IGW to IGW – This RP interconnects two neighbour testbeds at the usage plane. Over this RP usage testing data are transported. The implementation of this RP depends on the requested testbed.

I2 - IGW to Testbed Components – This RP interconnects the testing service component with the IGW. The implementation of this RP depends on the requested testbed. This is an internal RP.

Although the concept of RPs is defined for the administrative domain borders, i.e. between the testbeds, or between the testbeds and the federation, the internal RPs T2 and I2 are also identified, because the PTM and IGW can be generic components that may be provided by the federation infrastructure. This can be the case if for example T2 has to implement a standard SNMP interface and the IGW is a standard VPN endpoint.

5. Resource Configuration and Control

5.1. Panlab Testbed Manager

The most important component for the implementation of the infrastructure is the Panlab Testbed manager (PTM) that has been presented in the previous section. It is implementing the interactions at the control layer between the set-up and configuration requests by Teagle and the components in the testbed it manages. The PTM is therefore capable to interact with these functions in a web service client/server way and to adapt commands received as web services into control commands applicable to the testbed component. Control commands can be of 2 types:

- Generic commands such as “create entity” which is the command to instantiate and make resource reservation of the component to which the command is addressed.
- Specific commands such as “include profile data into data base” which is a command to a database to declare new users.

The PTM is also interacting with the IGW in order to prepare the connectivity with other components. It is part of the adaptation process of the initial web services command to issue the right control commands to the gateway to allow the interconnection between several components. This can include simple address set up but also pin-holing through a firewall, or parameter setting for other address translation operations.

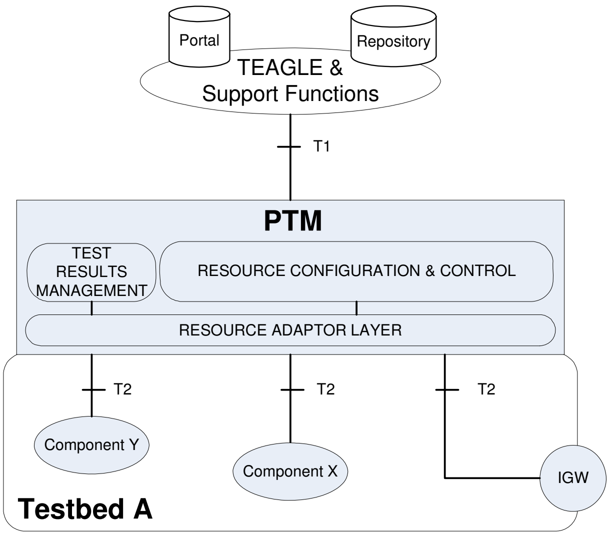

Figure 7. Panlab Testbed Manager

Testbed components may implement heterogeneous technologies at different levels. Although there are no requirements on specific technologies for testbed components, any testbed component must be individually controllable by the PTM. This means that, apart from the functionalities it provides at the usage plane, any testbed component needs to:

- Be individually identifiable, addressable and reachable from the PTM
- Provide booking, provisioning and configuring means to control its operation at the usage plane level.
- Optionally provide monitoring capabilities both to inform the PTM about its current state and to deliver data on test results towards the PTM.

5.2. Interconnection gateway

The main requirement for interconnecting testbeds is to ensure that only the nodes configured as part of a testbed are allowed to communicate. Furthermore it is necessary to hide the internal network topology reducing complexity and allowing the partners to dynamically provision multiple overlay networks if so requested. This is the responsibility of the Interconnection Gateway (IGW).

The main purpose of the IGW is to interconnect testbeds and components inside the testbed with the peers that are part of the configuration. Technically seen this component is a border gateway function and policy enforcement point for each testbed. For the IP layer the IGW acts as a dynamically configurable entity implementing:

- L2 connection/isolation of testbed devices
- multi-VPN endpoint and link to central VPN concentrator
- firewall and filter
- application proxy and/or network address translation

6. Conclusions

The work presented here is a summary of the conceptual design of the technical infrastructure to prove that federation is a model for the establishment of a long-term sustainable large scale and diverse testing infrastructure for telecommunications technologies, services and applications in Europe. Beyond the demonstration of the technical feasibility of the service related mechanisms described in this paper, the future work includes research towards the fully automated provisioning of composite testbeds across the whole infrastructure.

To support the long-term sustainability of the federation, future work will develop and elaborate on the mechanisms to combine and accommodate potential clean slate approaches. In particular the work is focused on the architectural requirements to facilitate the separation of the "provisioning platform" from the underlying infrastructure as a means to accommodate approaches based on different architectural mindsets.

Acknowledgements

Parts of this work have been developed within the Panlab Specific Support Action and have received funding by the European Commission's Sixth Framework Programme. The authors of this paper would like to thank the Panlab Consortium partners for the good collaboration. Also parts of the work presented here are early achievements of the Project PII which receives funding from the European Commission's Seventh Framework Programme. The mechanisms described are being implemented in the course of the PII project. The authors thank the PII partners for the fruitful discussions and cooperation. The work of PII is aligned with the objectives of the Future Internet Research and Experimentation (FIRE) initiative [10].

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