Testbed Facilities for Multi-faceted Testing throughout the Service Development Lifecycle

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Abstract: This paper gives a general overview of the ITIL service lifecycle and problems addressed by experimenters in the different phases of such a process. To address these needs, the ongoing FP7-ICT project TEFIS (*Testbed for Future Internet Services*) is described and how it seeks to support the requirements of an experimenter by giving access to different testbed-facilities and support tools for test management and planning. Three test scenarios are explained to demonstrate the benefits of the TEFIS mulit-faceted testing facility. The question for TEFIS is whether we can support and satisfy the user requirements of service experimenters via a single access point. Finally, suggestions for future extensions and enhancements of the platform are discussed to allow experimenters to design effective tests which involve different resources independent of place and across the entire service development lifecycle.

Keywords: Service development lifecycle, Iterative service development, Experimental testing Facilities, Testbeds, Living Labs, Experimentation.

1. Introduction

This paper studies emerging insights and experiences regarding the use of experimental facilities in the service development, experiment and testing lifecycles. It presents the TEFIS project [1], whose mission is to build a multi-faceted testing facility that supports service researchers and engineers in testing and experimentation with new service technologies. This is achieved by offering access to testbeds specialising in different aspects of service knowledge, allowing such testbeds to be used together, encouraging sharing of experience and expertise in respect to service strategy within academia or industry both in terms of experimental approaches and lessons learned. Offering such a platform for Future Internet service testing to the European Internet of Services research community we envisage the acceleration and dramatic improvement within the design and evaluation phases of the service lifecycle. The paper describes the added value of the facility by exploring three reference use cases and shows how these uses cases benefit from the initial set of connected testbeds.

2. Background

2.1 State of the Art

There have been a number of initiatives across the world in recent years with a view to providing support and resources for experiments in and around the Future Internet. For instance, the FIRE initiative [1] in Europe is a cross-cutting approach in support of all ICT Challenge 1 providing facilities for other Future Internet projects. In PanLab [2], a common access broker and resource model (Teagle) has been developed in support of service and network experiments based on heterogeneous computer and networking resources. OneLab2 [3] provides an open, general purpose experiment facility for innovation and performance testing, using PlanetLab Europe (PLE) [4] for services and NITOS [5] for sensor network facilities, as well as other federated testbeds. Although PLE is based on proprietary tooling and interfaces, NITOS has aligned itself with the OMF from GENI [].

Winlab [6] provides intelligent wireless network experimental facilities, while Wisebed [7] began with a federated network of wireless test facilities and has now developed further to support SmartSantander and other smart city environments with the addition of semantics and a service delivery platform [8]. Finally, BonFIRE [9] seeks to support the Internet of Services community with federated clouds. Unlike Europe, GENI (the Global Environment for Network Innovations) [10] is very focused on networking research and so adopting a bottom-up approach. It explores networks of the future through the creation of a virtual Internet-scale laboratory and is generating specifications for testbed management. There are other, similar initiatives in Brazil, China and Japan.

Along with FIRE for computional resources, the European Network of Living Labs [11] provides an alternative, complementary approach to Future Internet experimentation. A Living Lab allows for the measurement of aspects which had not necessarily viewed by experiments: user motivations and a real-world environment, identifying real and practical demand for systems and the services running on those systems. Combining FIRE and the Living Labs would provide powerful and multi-faceted testing capabilities. TEFIS [12] attempts to do just that. Like BonFIRE, TEFIS seeks to support the Internet of Services community, but it focuses on providing testbeds which can support the entire service lifecycle, including user behaviour, scale, performance and SLA compliance. It brings together FIRE-type test facilities for traditional, IT-based testing, with Living Labs (Botnia [13]) to offer a full range of experimental capabilities. The combination of testbeds offered by TEFIS allows a broad range of service characteristics to be explored including functionality, performance, scalability, usability, maintainability, user experience/acceptability, and standards compliance.

2.2 Service Lifecycle

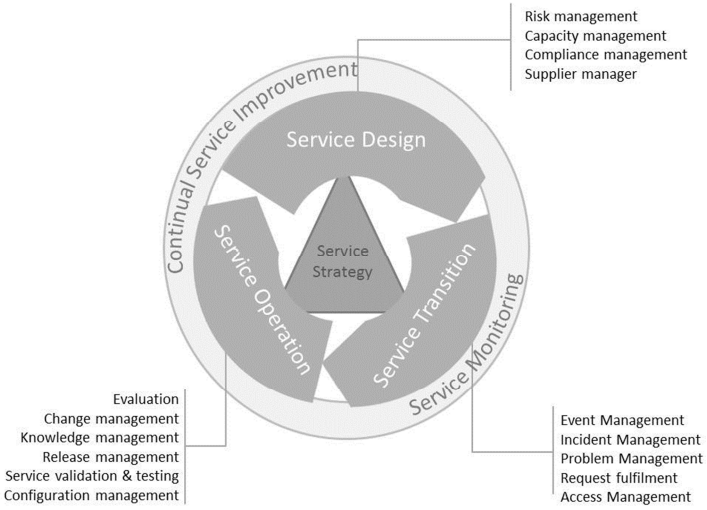


Figure 1: The ITIL Service Lifecycle

The Information Technology Infrastructure Library (ITIL) Service Lifecycle [12] (see Figure 1) defines a set of phases including Service Design, Service Transition and Service Operation. At each of these phases, different types of support are required to ensure that the service as delivered is appropriate and performs well. Verifying and validating that a service can deliver the desired behaviour is achieved through a series of experiments that measure service outputs for a given set of input conditions. Each ITIL phase contributes in some way to the verification and validation of service. A suitable test facility needs to be able to support investigation for each phase of the Service Lifecycle. The TEFIS platform allows each of the Service Lifecycle phases to be validated as illustrated below with reference to the initial use cases.

2.3 Service Testing Objectives

Table 1 below summarises the testing objectives and how they relate to the ITIL Service Lifecycle. In supporting experimentation with a view to improving services, all of these requirements need to be catered for,

Table 1: Service Testing Objectives

Objective	ITIL Service Lifecycle Phase(s)	Requirements
Functional	*Transition*	Validate that all function is available and works as expected
Performance	*Design; Transition*	Validate that the service continues to operate during all predicted loads; validate that configuration recommendations are appropriate.
Scalability	*Design; Transition; Operation*	Validate that the service continues to operate in the same way at different levels of load; validate that all requirements for deployment scenarios can be met.
Usability	*Transition*	Validate that users are able to access and use the functions offered.
Maintainability	*Transition; Operation*	Validate that the service can be deployed and continue to run in the operational environment.
Acceptance	*Transition*	Validate that users are comfortable with the design and how to use the service.
Standards Compliance	*Design*	Validate that all appropriate standards or regulations have been met.

Individually, the testbeds made available to experimenters can be expected to be able to provide support for these objectives. However, it is not necessarily the case that all of these objectives will be met by a *single* test facility. This is a major contribution of TEFIS: managing access to a range of different testbeds which can support all of these objectives within a single experiment and testrun or across multiple experiments and testruns.

2.4 Experiments and Testruns

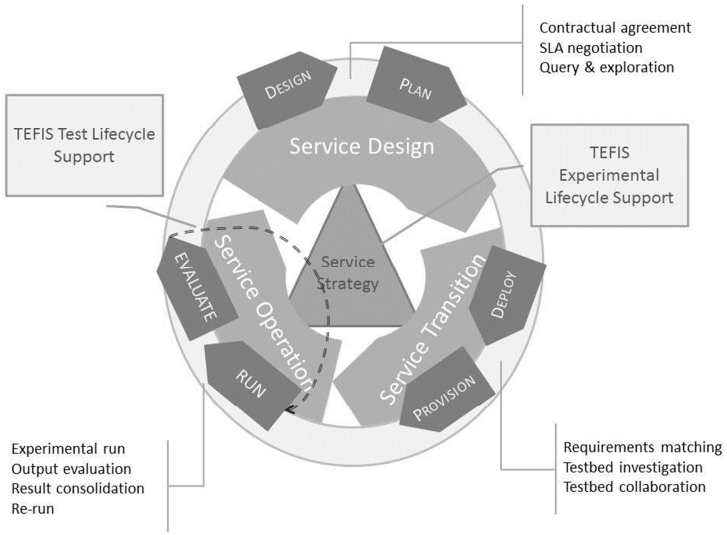
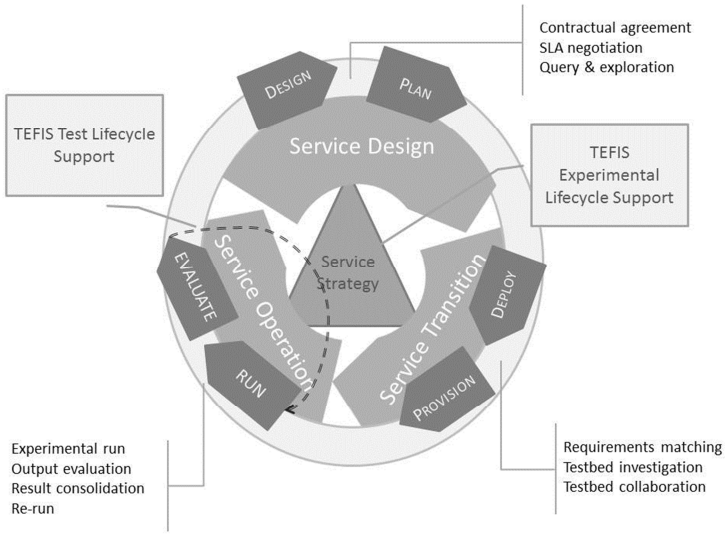


Figure 2: Experimental Phases

Moving now to specific experiments, we can think of a single experiment as a service in its own right, and a set of experiment phases can be defined. **Error! Reference source not found.** shows these experimental phases in much the same way as the Service Lifecycle. The complete cycle from design and plan to run and evaluate constitutes an experiment. When an individual instance of an experiment, or *test*, is run, then it generates output for evaluation. The combination of a single test and evaluation of results, is a *testrun*.

Experiments and Testruns



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summarises the various stages of an experiment, with a brief description of what is required. For each of the experiment phases, an experimenter will benefit from different types of support. Consider each of the stages identified:

- *Plan*: it would be helpful to be able to identify similar experiments within a given subject domain, see how the experiment was run and what the outcome was. It may help the experimenter to be able to discuss with other experimenters, or at least to be able to learn through inspection from the experiences of others. *An experimenter needs access to an archive of experiments; an experimenter needs to be able to participate in a community.*
- *Request*: once the test has been designed, the experimenter may need additional resource temporarily to be able to meet the execution requirements of the tests they have decided to run. *An experimenter needs access to resource on demand, which can be reserved for a limited period.*

- *Provision*: knowing that the resource is appropriate to the needs of the test, and that it is available is not enough. *An experimenter needs support through the configuration and initialisation of test resource which they may only need for a limited period and which they may never have used before*.
- *Deploy*: once resource is in place, and the experiment has been designed, it needs to be implemented: what steps need to be run (a workflow) and what, if any, are the dependencies between those steps? *An experimenter needs to be able to design the execution steps of an experiment to be run on the resources identified and then have it managed through execution.*
- *Run/Re-run*: once an experiment has been initiated, the steps to be run need to be managed and monitored; a single experiment may be sub-divided into multiple runs, each one with slightly modified settings; each test run needs to be monitored during execution. *An experimenter needs to be able to watch and control the instantiation of their experiment, including possible slight modification for individual test runs.*
- *Evaluate*: once run, an experimenter needs to be able to access any and all test data, including monitoring reports and specific application-generated log files, which may include test user input. *An experimenter must have complete access to all data generated and associated with their experiment, and to store and process any such data.*

Table 2: Requirements during each of the Experimental stages

EXPERIMENTAL PHASE	DESCRIPTION OF EXPERIMENTAL REQUIREMENTS
Plan	The experiment needs to be designed, taking into account any target requirements and a suitable set of exit criteria identified.
Request	A suitable environment to run the experiment must be found. Whatever contractual arrangements need to be put in place if necessary.
Provision	The environment needs to be reserved and appropriate configuration and initialisation settings explored and validated.
Deploy	The workflow for test execution needs to be drawn up and submitted to the environment to be run.
*Run (*and *re-run)*	The test needs to be executed and monitored either (workflow) step by step or as a complete instance or run. In response to any initial findings or the outcome of a complete test run, the test may need to be modified and re-presented for execution.
Evaluate	Final or interim results need to be checked. Some analysis may be done immediately; otherwise, processing may be done off-line. In either case, a re-run (*q.v.*) may be required.

3. The TEFIS Facility

In this Section we describe the TEFIS facility, the platform architecture including the tools and services that support the experimenter undertaking tests and the different testbeds including their characteristics and potential for contribution to service knowledge and strategy.

3.1 Platform Architecture

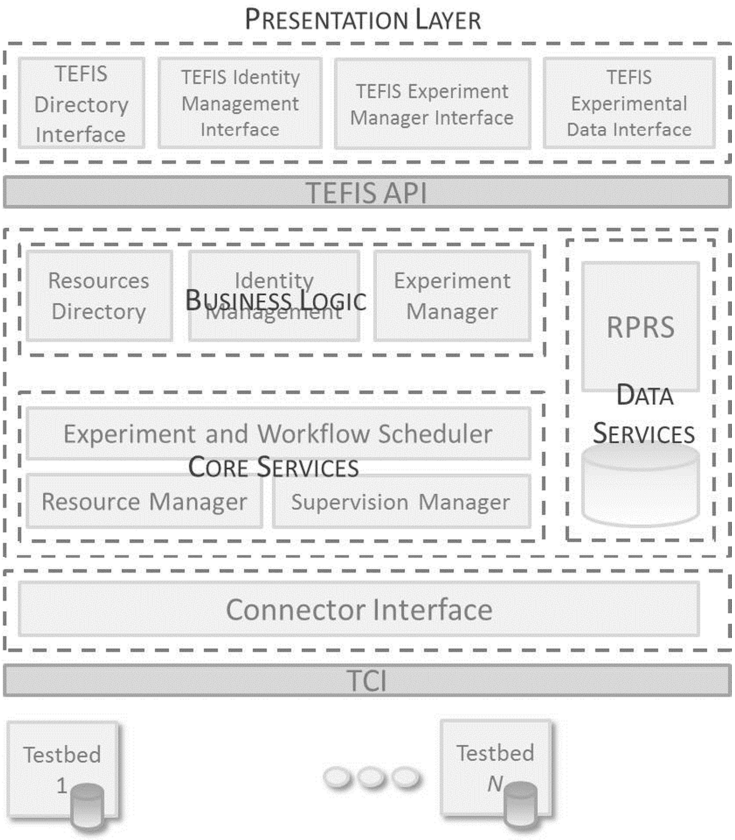

Figure 3: The TEFIS Platform

TEFIS, a *Testbed for Future Internet Services*, provides a single access point to a set of federated testbed resources supporting all phases of the experiment. Figure 3 shows the TEFIS infrastructure from experimenter (top) out to the federated testbeds (bottom). The platform itself in made up of five basic components: the *presentation* layer, the *business logic* supporting that presentation layer, the *core services* supporting overall operation and control, the *data services,* and a *connector interface* to communicate with the federated testbeds.

The Presentation Layer is the main access point for the user to create an account (the *TEFIS Identity Manager Interface*), to search for resource (the *TEFIS Directory Interface*) and to design the workflow for their experiment (the *TEFIS Workflow Manager Interface*). Each of these is supported by a corresponding component within the Business Logic (the *Identity Manager*, the *Resource Directory* and the *Experiment Manager*, respectively). In addition, the *TEFIS Experimental Data Interface* allows the experimenter to search any existing experiments to locate those with similar goals or set-up to what they are proposing, as well as to interact with monitoring data and experimental results once the experiment or an individual run completes.

The Core Services manages the whole platform and the execution of the experimenter's test runs. The *Experiment and Workflow Scheduler* takes the workflow created by the experimenter and presents it for execution to the appropriate test resource. The *Resource Manager* interacts with the resources to reserve and initiate them. The *Supervision Manager* handles all monitoring activities, checking performance within the TEFIS environment itself as well as communicating with the testbeds to retrieve monitoring output from them.

The Connector Interface provides a specification for communication onto and from the testbeds and allows for the implementation of site specific adaption layers. It is a significant benefit of TEFIS that it can offer support to experimenters. But also out to testbed providers: both users (experimenters) and providers (testbeds) are essential participants in the TEFIS platform and vision. It is the *Connector Interface* that provides the mechanism for that community to co-operate.

The Data Services support the other TEFIS components as well as experimenters and testbed providers with all of the data needs associated with an experiment. The TEFIS data filesystem holds all data and information necessary for the satisfactory execution of an experimental test run, as well as providing storage for output data from each workflow step. Through the experimental metadata we have defined, experiments can be tracked and browsed in support of experimenters within the community wanting to find or review related work.

3.2 Testbeds

As a research platform initially, TEFIS supports a number of various testbeds providing different types of capabilities in support of the exploration of service knowledge and strategy. It is a significant advantage to experimenters using the TEFIS platform that a single testrun can seamlessly execute across different test facilities, including testbeds dedicated to network performance, grid infrastructures and living labs. The current testbeds are described below:

3.3 PlanetLab

Available in both Europe and the US, the *PlanetLab* testbed [4] was created for large-scale distributed system and network research, built as it was on the Internet. It offers a set of geographically disparate nodes controlled from a centralised (sub-)authority and currently supports in the region of 5000 users and more than 1000 nodes. Each user may deploy and run experiments on an independent network overlay between selected nodes. The facility is particularly useful for the test and validation of network protocols and large-scale distributed systems under real-life conditions. This large-scale, real-world environment is particularly attractive to TEFIS users.

3.4 PACA Grid

The objective of PACA Grid [16] is to provide computational resources to the scientific community, academia as well as enterprise, to explore and evaluate a range of scientific applications, including though not confined to resource-hungry scenarios such as the development of algorithms, exercising financial computations, handling image processing and the like. It is installed within the INRIA Sophia Antipolis network and offers a grid of multiple clusters of machines, which can support a range of software packages and environments. The benefits forTEFIS users is the availability of flexible resource for computationally intensive experiments, performance and larger scale testing.

3.5 ETICS

To provide enhanced support for the software development lifecycle, the ETICS (eInfrastructure for Testing, Integration and Configuration of Software) [17] platform was designed with a view to improving the quality, reliability and interoperability of distributed complex systems. ETICS provides support for different user communities, and offers these facilities to all TEFIS users for the development, testing and release of software. Developers are provided with facilities to build and check software quality, as well as to automate any of the build and test processes; release managers can configure and integrate different components for each unique project release cycle, with appropriate repository and management facilities; and project managers can maintain a view over the entire process as it is being executed. The benefits for TEFIS users are managed processes for software build, the assessment of software quality metrics and an overall view of the status.

3.6 IMS

The IMS (IP Multimedia Subsystem) [1818] test facility provides resources for telecommunications operators as well as service providers to validate and test their applications prior to release. For the operators, IMS allows them to check for functional as well as regulatory compliance, but also to verify network and resource load. Service providers by contrast benefit from the opportunity to be able to establish that their services meet all compliance requirements and standards as well as interoperate appropriately within the network and as predicted. The benefits to TEFIS users have access to standardised multimedia capabilities for application functional and performance testing and regulatory compliance.

3.7 BOTNIA Living Lab

As a Living Lab, Botnia [13] provides facilities and access to end-users to encourage and enable innovative design and research within an overall user-centric context. ICT services can be developed and tested in a real-life environment and with the support and involvement of real end-users. As such they can be developed, tested

and validated in tandem with the exploration of innovative ways to engage potential customers. The benefits to TEFIS users is the ability to combine user-centric methodologies, with real end-users to gain understanding of aspects such as usability, user acceptance and quality of experience.

3.8 KyaTera

As a test facility still under extension and development, KyaTera [19], a high-performance fibre-optic network, grew out of an original effort to support collaboration between different members of the scientific community for the development of the science, technologies and applications appropriate to the Future Internet. It provides the capability to evaluate the quality of the network, especially when complex objects, such as multi-media data, need to be transmitted to a specific level of quality. The different parameters affecting quality of service can be identified and explored. The benefit for TEFIS users is advanced and controlled network capabilities to be able to investigate all aspects of transmission and quality of service.

4. TEFIS Use Cases

The TEFIS platform has examined a number of representative Future Internet scenarios, including e-Commerce, multimedia services and e-Health. The scenarios provide a powerful demonstration of the benefits of TEFIS in each requiring multiple test facilities to be managed as a single, complete test entity for various stages of the specific tests.

Table 3: TEFIS Use Case Summary

Test Case	ITIL Service Lifecyle Stage	Description	Testbeds Used	Benefits
eCommerce	*Design*: performance and capacity planning *Transition*: validation, change management, service validation *Operation ;* incident and problem management	For complex services which dynamically aggregate functions from different SOA-type components, there is a basic requirement to be able to validate performance in different environments and within strict SLA-terms. This use case investigates optimal service creation and performance. Requires multiple operational environments.	➢ ETICS: to build the application(s) and check functional coverage ➢ PACA Grid and PlanetLab: to evaluate performance in different client environments	TEFIS provides a single access point for all test stages. TEFIS provides the seamless integration and management of test steps across different environments, including the automatic transfer of appropriate data from output of one process to input of another. TEFIS can be used to generate simulated load to drive stress testing.
Multimedia services	*Design*: investigation of business model *Transition:* evaluation, service validation and testing *Operation:* none	A mobile network operator wants to offer a new IMS service to its customers. Before deployment in the live network, they want to ensure that: • The user experience is positive; and • The best business model	➢ The IMS platform is used to provide the infrastructure where the tests are to be run ➢ BOTNIA living lab will provide the end-users to interact with the service for evaluation	TEFIS manages all stages of the experimental design and execution as well as each of the test roles. TEFIS provides a single access gateway to the different stakeholders as well as the different sets of data required as input and generated

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		is chosen. The test is to be run in a number of stages including usability, end-user testing, and the evaluation of the business model. The test includes the operator, the application developer, as well as end-users.		as output from the experiment.
eHealth	*Design*: Service level, risk, capacity management *Transition*: Evaluation *Operation:* access and event management	For a multi-disciplinary medical team, especially when working in different locations including the patient's home, it is important to be able to make medical records available to all team members as quickly as possible. As multi-media records, these are large data objects; as personal data, they are also sensitive. This is based on the GIMED project.	➢ KyaTera: will provide the ability to transmit, store, search and recover multimedia information or an electronic PMR (Patient Medical Record). ➢ ETICS: provides measures of software quality for the utilities used to manage and access the data. ➢ PACA Grid: supports the simulation of geographical distribution and processing as well as to generate a suitable stress test for the eHealth system.	The TEFIS platform provides the management of the test across different environments. The TEFIS platform will also generate mock-up PMRs for use during the tests, since real data would be very sensitive.

Table 3 summarises an initial set of use cases that will prove the capabilities of the TEFIS platform in enabling complex testing across the various ITIL Service Lifecycle phases. The three initial tests for eCommerce, Multimedia services and eHealth exploit the different test facilities available within the TEFIS platform. For the experimenter in each case, the TEFIS portal provides the appropriate support for the design and execution of the various tests using different facilities as described in the table. In addition, TEFIS would allow the experimenter to search for and review related experiments that have been run previously on the platform. This is an important feature in support of experiment definition. In the next section, such features of the TEFIS platform which are intended to support all testing activities are summarised and described in more detail.

5. TEFIS: the Added-Value for Multi-faceted Testing

The TEFIS platform is able to support varied application scenarios, supporting testing different service characteristics, brokering resource for different stages of the experiment with different resources, and seamlessly managing the workflow associated with the experimental test run. At this stage, we should review the experimenter requirements that we outlined in the Service Development Lifecycle section above. In so doing, it becomes apparent that TEFIS has much to offer to a range of different and varied experiment types.

An experimenter needs access to an archive of experiments	The TEFIS platform provides the experimenter with the ability to search for existing experiments that have already run, along with the associated results and configuration settings[1]. Searching is done on keywords, but also against a free-text description of the experiment to maximise the coverage and potential to find matching experiments.
An experimenter needs to be able to participate in a community	TEFIS provides an environment for users to communicate and exchange information about their experiments. In allowing access to experimental description and output, an experimenter is already offering support to other experimenters, which is a good basis for the creation of a user community.
An experimenter needs access to resource on demand, which can be brokered for a limited period	The TEFIS platform manages all aspects of the execution of an experiment, booking and managing resource as and when required by the user. As is evident from the initial use cases outlined in Table 3, the TEFIS platform is designed to handle seamlessly an experiment workflow that spans resources from different testing facilities.
An experimenter needs support through the configuration and initialisation of test resource which they may only need for a limited period and which they may never have used before	The TEFIS portal provides all the tools necessary to be able to review and configure any and all resources recommended to support the experiment proposed. There is no prior knowledge of the resources necessary, since the Resource Repository provides all the appropriate templates to guide the user through selection and configuration.
An experimenter needs to be able to design the execution steps of an experiment to be run on the resources identified and then have it managed through execution	The TEFIS platform supports the experimenter through the creation of a suitable workplan, defining how an experiment is to be run, as well as a workflow for the individual execution steps expected to be invoked to complete the experiment. Once defined, these are used by the TEFIS Core Services to manage the experiment through its execution and evaluation.
An experimenter needs to be able to watch and control the instantiation of their experiment, including possible slight modification for individual test runs	In TEFIS, the experimenter is provided with the monitoring capabilities to be able to check the status of an experiment in execution, as well as to be able to access and begin to process whatever results are available. As the experimenter goes through this review process, they may decide that they need to modify the original experiment. TEFIS maintains all the data and information needed for the experimenter to be able to revisit an experiment or individual testrun.
An experimenter must have complete access to all data generated and associated with their experiment, and to store and process any such data	The TEFIS platform allows the experimenter access to all data associated with their own experiment, and any others they may be authorised to. Data may be transferred on demand from the platform itself or any temporary storage on the testbed facility.

By way of summary, then, TEFIS provides:

[1] This depends on the access permissions granted by the experiment owner.

- *Faster experiment development* in supporting review and searching of previous and related experiments, as well as supporting experimenters through the various stages of preparation, workflow definition and execution.
- *Brokerage of test resources*; testbed providers are given access to a wider potential user audience through a common and experimenter-supportive interface; and experimenters can submit a single experiment to be run across as many testbeds as are appropriate to satisfy their test requirements.
- *Multiple test facilities*. The TEFIS platform provides access to different facilities offering different services and capabilities, from large, computer clusters to highly distributed systems and network simulators. A significant benefit that TEFIS currently provides is the availability of a Living Lab (Botnia) within the current test facilities that may be federated.
- *Community Support*, through the facility to be able to share results as well as set up. TEFIS may also enable the exchange of information and data between experimenters with similar goals and aspirations.

6. Future Developments and Research Issues

The TEFIS platform as described in the preceding sections provides a number of capabilities to allow experimenters to design effective tests which involve different resources and which can make use of the design and results of previous work, assuming appropriate levels of access have been assigned. As TEFIS moves forward, it also begins to allow for future extension and enhancement in a number of areas.

- Building a community: sharing experimental outcomes and set-ups between different experiments does in itself promote a sense of community. But over time and with the co-operation of its users, the TEFIS platform can offer more, not only as a portal to access different facilities and review other experiments. As experiments are run and information about them (experimental metadata) becomes available, then it will be possible to profile experiment types, usage patterns, and even begin to categorise experimental domains entirely on the basis of real experience. Such information will help the community of TEFIS users directly as they run their own experiments, but will also provide valuable insights for the community at large.

- A Portal to Federated Testbeds: As usage patterns begin to emerge and experiments can be typed on the basis of real experience, testbeds can be positioned to support more potential use areas than previous envisaged. Experimenters will be able to benefit from enhanced predictive capabilities from TEFIS: when they request resource in one environment, on the basis of the experiment they have defined, they can be helped towards consideration of using a second environment which experience has shown is typically used in conjunction with the first.

- Searching the way Experimenters do: the development of usage patterns and predictive deployment is a benefit that will accrue overtime. However, the TEFIS platform already provides simple and intuitive search capabilities whereby the user can match against free text descriptions of experiments.

    - User-centric searches and support: an experimenter can simply look to match vague descriptions to try to locate similar work.
    - User alert rather than full review: when experiments are not available for searching as the result of access permission setting, it is possible to initiate contact between searcher and experiment owner. This back-up behaviour will also help support the development of a TEFIS user community.
    - What to match in a search: standard matching is done against keywords; in TEFIS as stated, there is also the ability to match against free-form text. It is possible though to search not only the description of the experiment as it is defined by the experimenter and in relation to resource configuration, but also in terms of results, either monitoring output or application data. Allowing other experimenters to search for similar work on the basis of what the

outcome was enhances the potential for a match and can encourage collaboration in the TEFIS community.

- The TEFIS platform has defined a *test_profile* to contain all information relating to an experiment. Identifying common features to such profiles will again enable experiments to be characterised and modelled.

- Autonomic testing: with the potential to characterise experiment types, establish usage patterns and identify predictive behaviours to experiment design, then it will become possible to develop self-healing capabilities within experiment execution. This will allow for enhanced test handling. It will also offer experimenters further guidance and support in designing error-free experiments.

The TEFIS platform already provides full test lifecycle coverage. As the project moves forward and as a result of platform use, the enhancements outlined in this section will offer a complete range of experiment handling from inception to execution and beyond.

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