IoT Lab Crowdsourced Experimental Platform Architecture

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Abstract — **This paper presents the architecture of the crowdsourced experimental platform called IoT Lab. The platform will provide a new approach for experimentation by extending existing IoT FIRE testbeds, traditionally built from static sensor mote platforms, with crowd sourced resources and thus will enable richer and more distributed multidisciplinary experiments with more end-user interactions, flexibility, scalability, cost efficiency and societal added value.**

I. INTRODUCTION

Exploring direct interactions with the crowd through crowdsourcing and crowdsensing techniques while enabling the crowd to be at the core of the research cycle with an active role in research, from its inception to the results' evaluation, is the main motivation behind the development of the IoT Lab platform - testbed as a service (Figure 1) developed by IoT Lab European research project (www.iotlab.eu). This will provide a better alignment of the research with the society, end-users needs and requirements.

Crowdsourcing is recognised as a practice of obtaining needed services, ideas, or a content by soliciting contributions from a large group of people and especially from an online community, rather than from traditional employees or suppliers.

The crowdsourcing approach can apply to a wide range of activities including crowdsourcing of data, measurements, opinions, solutions and funding. The main focus here is on IoT-related, attractive types of crowdsourcing such as collection of data/measurements and user rates/opinions. IoT today regards every smartphone user as a source of data that is generated and shared via his/her device.

There are already a number of crowdsourcing platforms focusing on different ways to empower user participation in the IoT through their mobile phones. While some of the existing platforms might be too specific [1] and only support pre-defined tasks without a possibility to extend them due to the lack of open source code, others might be too general, like Ushahidi [2] that does not support the involvement of participants and only leverages on geo-localized data collection and visualization through maps.

Figure 1 IoT Lab 'Testbed as a Service'

Platforms like Phonelab [3], provide a model for crowd engagement in the IoT co-creation effort, but no actual application is provided to support this, while on the other hand custom applications are developed and distributed according to the selected use case.

There is a number of existing platforms that properly support user participations in IoT experimentation through mobile phones [4][5] but still lack the ability to fully support the IoT Lab envisioned models for participation and interaction between participants and investigators.

Supporting scripting and crowdsourcing on mobile phones is possible through APISENSE [6] but an integration with other IoT Lab provided tools is needed, such as Resource Management and Experiment Management. However, an official version of the platform has not been released yet.

Similarly, a set of other existing platforms, fulfilling different needs envisioned by the IoT Lab mobile app, will be investigated further in order to understand how and to what level they could be extended with other IoT Lab tools, so as to achieve a complete IoT Lab platform integration.

EpiCollect [7] can be useful for creating a survey and questionnaire, but the lack of open source code limits the possibility of extension and integration.

mCrowd [8] seems to better fit participatory sensing applications. However, the lack of APIs and only provided an iPhone version might limit the possibility of integration and extension.

Funf [9] and AmbientDynamix [10] represent good frameworks for crowdsensing and crowdsourcing. In particular, the capability of AmbientDynamix to adapt

its behaviour to context could allow support of different experiment participation models suitable for the end user perspective. The possibility to integrate it with other envisioned IoT Lab resources should be further investigated.

Together with AmbientDynamix, the scope of results is limited to the IoT Lab mobile application. McSense [11] seems to support all the basic functionalities envisioned in the IoT Lab mobile app (actuation and sensing), of which the IoT Lab platform should be comprised, and also includes tools for resource selection, task (and experiments) description and other useful functionalities. The possibility to integrate and extend it with other IoT Lab resources, such as integration with FIRE testbeds Profile Management and the Search and Communication tools, should be investigated further.

For all these reasons, the platforms that should be selected and further analysed to fully understand their potential integration with in the final IoT Lab platform are represented by AmbientDynamix and McSense.

None of the platforms actually foresees the possibility to integrate smartphones with existing FIRE testbeds or in general statically deployed IoT resources, such as smart power meters, home automation control systems and so on. Nonetheless, no effort has been put towards providing virtualization tools that enable heterogeneous IoT resources to be homogeneously available and interoperable with each other. To this purpose, the approach proposed by the IoT Lab platform is new and advanced with respect to existing crowdsourcing platforms.

The paper is organized as follows: Section II presents the IoT Lab vision and discusses the main challenges; Section III describes the architecture design approach whilst Section IV gives details about the architectural components. The sequences of using the services are given in Section V. The paper concludes in Section VI.

II. IoT Lab vision and key challenges

IoT Lab platform aims to enhance the existing IoT FIRE testbeds, traditionally comprising of static sensor mote platforms, by utilizing end-user participants' smartphones and relevant mobile/portable devices in order to achieve crowd participation in sensing and actuation operations and thus enable a wide range of multidisciplinary experiments.

To achieve this aim, the IoT Lab platform addresses the following objectives:

- Crowdsourcing & crowdsensing mechanisms and tools;

- Crowd-driven research;

- Virtualization of crowdsourcing and testbed components;

- Ubiquitous interconnection and cloudification of the testbeds' resources;

- Testbed as a Service;

- Multidisciplinary experiments;

- End-user and societal value creation;

Through these objectives the IoT Lab platform can achieve its goals in terms of (i) connecting and using existing IoT testbeds which increases the testbed economic sustainability; (ii) proactively involving participation of the public through crowdsourcing, as well as researchers taking part in the IoT experiments which provides closer interactions between experiments and society.

The platform also considers issues such as privacy and personal data protection through a 'Privacy by Design' approach and built-in anonymity.

There are various stakeholders identified for the IoT Lab "Testbed as a Service" platform with the main ones being: researchers/experimenters; testbed owners; crowd/media; EC; official authorities and potential private customers.

The expected IoT Lab impact is to support experimentally driven research, in particular to conduct multidisciplinary investigation of key techno-social-economic issues (i.e. Internet Science), to further exploit any relevant FIRE facilities, to consider benefits for citizens as well as to investigate ethical and self-sustainability aspects of experimental facilities.

The key challenge of the IoT Lab platform is to successfully attract researchers and the general public (crowd) into using the testbed facilities and joining the experiments respectively. A range of incentive and rewarding schemes has also been considered. Furthermore, a wider audience needs to be reached throughout the duration of the project both for IoT Lab sustainability reasons and in order to help the platform mature.

Additional technical challenges originate from the IoT Lab platform development process that needs to address heterogeneous identified requirements and to support challenging use cases proposed by the crowd.

III. Architecture design approach

The preliminary IoT Lab platform architecture design is addressing double challenge: On one hand, it has to integrate diverse IoT-related testbeds located in different regions of Europe. On the other hand, it has to integrate smart phones with existing FIRE testbed infrastructures, thus representing a novel approach with respect to existing crowdsourcing solutions. The key platform components have been identified and their functionalities, interaction patterns, interfaces and communication links described.

The derivation process followed an IoT-A methodology [12] to support interoperability and scalability and to enable use of a wide range of heterogeneous devices and testbeds from different application domains thus satisfying a high number of requirements.

An architecture generation process starts with the analysis of technical and end user related requirements derived from selected use cases. Two scenarios have been proposed. The first one is a "Game and Supermarket Marketing" - a smart city scenario in

which users can play a game and participate in experiments, for instance a market survey from a supermarket. The second scenario is "Energy Efficiency and User Comfort Hints" in which crowdsensing methods are used to adapt energy efficiency to human presence and behavior. Moreover, the users can provide feedback on the current devices' setup and set their user preferences representing a Physical Testbed Scenario. These two scenarios have been analysed using the IoT-A methodology and they are here represented using a general use case diagram shown in Figure 2.
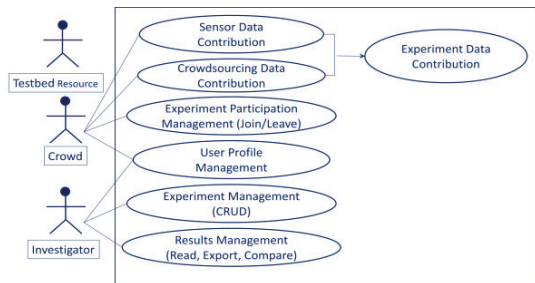

Figure 2 IoT Lab General Use Case Diagram

The analysis of the use cases provided a detailed list of requirements for the IoT Lab platform that can be summarised as follows:

- User profile management for both participants and investigators.

- Experiment Configuration – Investigators must specify a detailed description of their experiments, including needed resources, ethics and privacy concerns, timeline and overall objectives of the experiment.

- Testbed Resources Management – A simple and easy interface that allows testbed managers to configure and make their resources available for experimentation.

- Crowdsourcing and Crowdsensing provisioning – The platform must provide ways that allow both crowd and testbed resources to provide data which can be sensory data and/or crowd knowledge.

- Experiments Management – The system must provide ways that allow the users to browse and evaluate existing experiments and in the case of the investigators to manage their own experiments.

- Privacy and Ethics – Privacy by design concept is followed; users are requested minimal information and for each of the experiments a clear description of the required data (user and device) is presented. Experiments must be validated before being run.

- Support for incentives – Incentives scheme for crowd and investigators need to be included.

Development of the polyvalent and flexible IoT Lab platform 'Testbed as a Service' that can support a large set of IoT related experiments is guided by several considerations:

- Adopting a modular architecture, that will enable the evolution of individual components without impacting the whole architecture;

- Favouring generic enablers that can be easily used by different experiments;

- Aligning with main stream standards and solutions to ease the integration with third parties resources;

- Satisfying the requirements derived from the most up-voted use case scenarios proposed by the consortium and described above.

Selected real use cases for implementation identified several important experimental approaches including crowd sensing; data collection & processing from different IoT testbeds; the code execution on the participant side and completion of different questionnaires by participants.

The generic IoT Lab 'Testbed as a Service' enablers are illustrated in Figure 3.
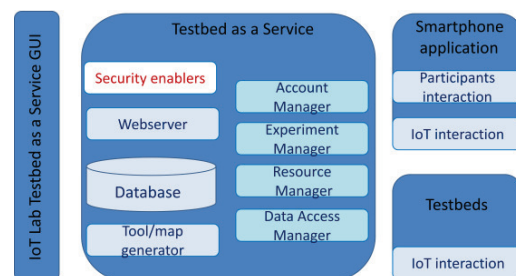

Figure 3 IoT Lab enablers – generic

IV. ARCHITECTURAL COMPONENTS

Main architectural components of the proposed IoTLab system are organised in four groups as shown in Figure 4: Account manager, Resource manager; Experiment manager and Web user interfaces.

A. Account Manager

The Account Manager group collects components related to different user accounts and assigned users' roles. Two main user categories are Investigators and Participants. Investigators use the IoT Lab platform and tools to set-up their investigations or experiments, recruit participants and collect and analyse results. Participants are all the actors involved in an experiment; i.e. people who use the IoT Lab product (application) and allow the experiment execution on their phones. Other users of the platform include: platform owners, researchers/students, testbed owners, customers, testbed service managers, and administrators, etc.

The IoT lab platform will collect different types of data and it will be designed to ensure the privacy and trust of the users. All users will have to be authenticated and appropriately authorised to be able to access the system functionalities. The platform will provide the option for data anonymisation as well as for generating identifiers for such accounts. Access to the platform functionality will be controlled by AAA (Authentication Authorization and Accounting) component. The Security component will control AAA mechanisms in the system. All accounts and roles will be persistently stored in a database.
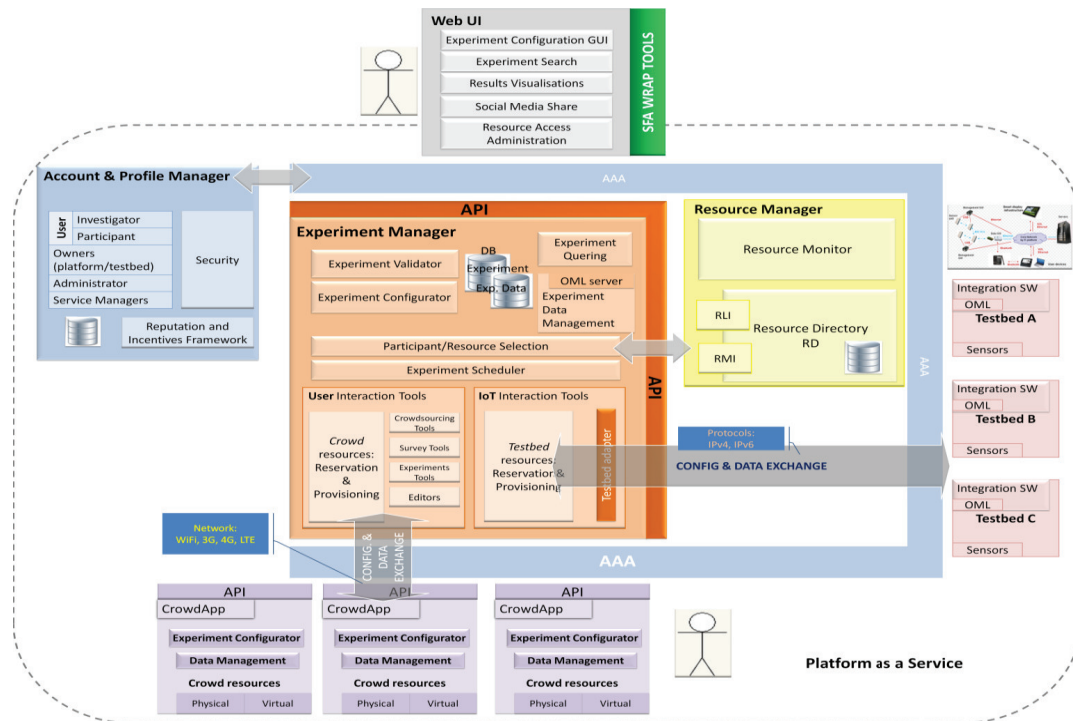
Figure 4 IoT Lab Architecture – A deployment view of the proposed concrete architecture

The function of the Reputation and Incentives framework component is to monitor the users' activity and then estimate the users' rating in a semi-automatic way as well as to apply incentives schemes for engaging different end users and crowdsourcing participants in experiments.

B. Resource Management

Resource Management Group monitors and collects information on available resources in the system. Resource Directory (RD) component provides a persistent storage of resources. It implements interfaces for the resource management by providing the CRUD functionality as well as the Resource Managing Interface (RMI) and Resource Lookup Interface (RLI) which are implemented as REST based web services. All resources available in the IoT system should be uniformly described. IoT testbed resources management interface uses Fed4FIRE enablers such as Slice-based Facility Architecture (SFA) Wrap and OML to enable interactions with IoT components from testbeds and smart phones in a unified way. SFA Wrap enables resource virtualization, federation and integration of testbeds. OML is responsible for data collection from testbeds and crowdsourced devices.

Resource Monitor Component manages resources in the RD by keeping the real time information on availability of resources in the system.

Testbeds should implement a resource discovery mechanism that will announce their available resources following the RSpec format of the SFA.

C. Experiment Manager

Experiment Manager Group aggregates components related to both the experiment management and the experiment data management. An API provides the standardised RESTful interface for component interaction. Several components take part in creating an experiment:

Experiment Validator Component receives a standardised abstract experiment representation and validates the experiment definition. Standardised experiment representation should result from consolidated analysis of use cases and additional user requirements. It can contain code segments that should be performed on the participants' devices involved in the experiment, or a definition of questionnaire forms that should be completed by every participant. All segments of an experiment should be verified and any detected irregularities should be reported before any further processing.

Experiment Configurator Component interprets the received validated experiment definition and stores the standardised experiment representation in an Experiment Database.

Participant/Resource Selection Component detects and selects available resources that match the experiment requirements. This component performs the appropriate query on the RLI interface and receives notifications on availability (and location) of Resources from the Resource Monitor component.

Experiment Scheduler runs the experiment on resources using the Reservation and Provisioning Components for appropriate testbeds.

Experiment Querying, through the Experiment Manager API, provides an access to stored experiments. All data provided by the experiment are collected by the Experiment Data Manager component. Testbeds provide streams of experimental data in the OML format.

Experiments are conducted on top of different testbeds. The process of an experimenter discovering, reserving and provisioning the available resources across all testbeds for his/her experiment will be conducted in a standardised way via the SFA Wrap tools and architecture (e.g. an SFA client will be running at the Web GUI). Then, the IoT Lab Experimenting Platform will take care of the particularities of each testbed and will interact with the resources according to the experiment scenario.

Crowd interaction management interface handles the interaction with the participants. Crowd based experimenting is focused on running the experiments on users' mobile devices. Again, these resources will be exposed by the IoT Lab Experimenting Platform in a standardised way via SFA Wrap.

User Interaction component aggregates components for experiments on top of crowdsourcing smart mobile devices. Several components for survey, crowdsensing and code script execution are involved in experiment execution.

IoT interaction tools control the experiment execution on federated testbeds. All components in the Experiment Manager are accessible through the Experiment manager RESTful API.

D. Web user interfaces

GUI access to the system is implemented through components grouped in the Web user interfaces.

The Experiment Configuration GUI provides the Web access for designing and initiating the experiment and it should be intuitive. The GUI communicates with the Experiment Manager through a corresponding API to provide the experiment description to the Experiment Validator. This also includes the access to the Survey and GUI editor so the experimenter can set up a specific survey and/or a specific user interface for his/her experiment on the smart phone application.

The Experiment Search Component provides an interface for the experiment querying. This component can query the resources in order to make the access easier for resources in different testbeds.

Results Visualisation Component provides the appropriate graphical interpretation of collected experimental data. It will include a maps and graphs generator based on main stream open source solutions, such as OGC SWE and Google maps. It will enable the platform to provide graphical representation and dynamic maps of the results as well as of the live data.

Social media will share components of the Web interface and enable different types of users to publish their experiments and related opinions on popular social networks.

The system management is provided through the Platform Administration Component which enables several functionalities including:

- User Account Administration for the users to log in and manage their personal account and profile.
- Data Access & Management for the experimenter to manage the collected data; delete unnecessary data sets; and/or retrieve filtered data sets.
- Filtering users' personal data in order to ensure full compliance with the personal data protection policy and obligations.

V. USE OF SERVICES

An overview of the usage of available services within the proposed IoT Lab platform described in the previous section is provided using the Sequence Diagrams, which illustrate three stages in the platform deployment:

- User registration Process (Fig.5)
- Experiment submission–Investigator side (Fig.6)
- Contribution from Crowd (Fig.7)

A. User Registration Process

Testbed Resources: All available individual testbed resources need to be stored in the Resource Manager following their announcement to the IoT Lab platform using a common description scheme. In this way, the IoT Lab platform will be able to leverage the available resources in a uniform manner.

Users of the platform (participants and investigator researchers) should be stored in a Resource Manager component following their registration in Account Manager, authentication through AAA and the role assignment again in Account Manager.
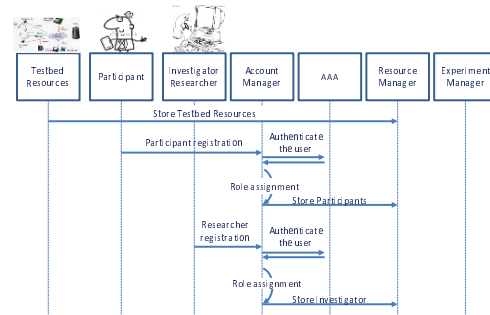

Figure 5: User Registration Process (Sequence Diagram)

B. Experiment Submission

Investigator/Researcher uses the Web UI to setup the experiment via Experiment Manager RESTful API.
The experiment is then validated based on standardized experiment representation, interpreted by Experiment Configurator and then stored in an Experiment Database. In addition to automatic validation, experiments are also physically validated as part of a review process involving human resources.

The Experiment Manager is then able to recruit the relevant participants and resources (testbeds) by

communicating the Resource Manager through Resource Lookup Interface (RLI). The experiment is then scheduled by Experiment Manager through reservation and provisioning of resources which includes: Testbeds - reserved through SFA WRAP and Crowd/mobile phones.
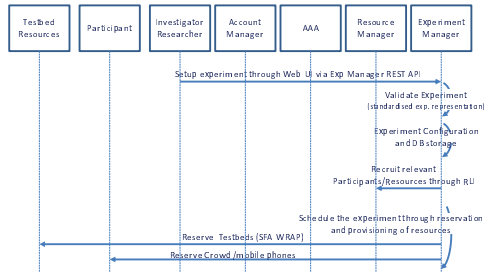

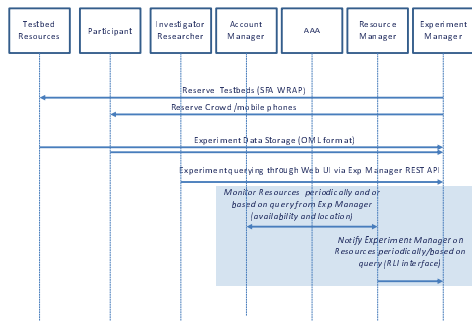
Figure 6 Experiment Submission (Investigator side)

Figure 7 Contribution from the Crowd/Testbed Resources

C. Contribution from Crowd/ Testbed Resources

The obtained experimental data from Testbeds and Participants is sent to the Experiment Data Storage within the Experiment Manager in an OML format.

An investigator researcher can send the query for experiments through the Web UI via the Experiment Manager RESTful API.

Monitoring the Resources and information about their availability and location should take place either periodically or based on the query from Experiment Manager between the Account Manager and the Resource Manager.

Resource Manager should notify the Experiment Manager on Resources periodically as well as based on the query through the RLI interface.

VI. CONCLUSIONS

In this paper are proposed the main components of the IoT Lab platform and described their identified functionalities, interaction patterns, interfaces and communication links.

The IoT Lab platform development focuses on:

- Enhancement of existing IoT FIRE testbed facilities which are traditionally built from static sensor mote platforms by including the participants' end user mobile phones and thus achieving a crowd participation in sensing and actuation operations.

- Solutions with built-in reputation and privacy mechanisms as well as procedures for dynamic selection of suitable crowd resources.

The derivation process followed an IoT-A methodology in order to support interoperability and scalability and to enable the use of a wide range of heterogeneous devices as well as the testbeds from different application domains, therefore, satisfying a high number of requirements. Integration of smartphones with existing FIRE testbed infrastructures or any general statically deployed IoT resources represents a novel approach with respect to existing crowdsourcing solutions.

The values that IoT Lab brings in comparison to other existing crowdsourcing solutions are numerous: IoT and crowd sourcing based research and development; access to distributed testbeds; economies of scale; access to innovative service oriented architecture (SOA) technology; a possibility to explore the future now; market insight; crowd interaction and access to wisdom of the crowd; experimental platforms; reduction of development time and time to market; capital expenditure avoidance; cost reduction; access to 'up to date' and evolving IoT services/infrastructures; new product experimentation on advanced IoT facilities.

Our further work will focus on the practical implementation of the proposed platform in order to test selected use cases in real situations and get a feedback from participants. Strategies for engaging as many participants as possible will be examined as well as the new components that provide reward mechanisms towards all participants and investigators.

VII. ACKNOWLEDGMENT

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