An Open Virtual Neighbourhood Network to Connect IoT Infrastructures and Smart Objects – VICINITY

IoT enables interoperability as a service

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***Abstract*— The lack of interoperability is considered as the most important barrier to achieve the global integration of Internet-of-Things (IoT) ecosystems across borders of different disciplines, vendors and standards. Indeed, the current IoT landscape consists of a large set of isolated islands that do not constitute a real Internet, preventing the exploitation of the huge potential expected by Information and communications technology (ICT) visionaries and unfolding business opportunities facilitated by digitalization and automation. The VICINITY project will build and demonstrate a platform linking various ecosystems providing "interoperability as a service" for infrastructures in the IoT. The approach is bottom-up, decentralized, user-centric and standards-based without relying on a single standard.**

***Index Terms*—Virtual neighborhood, interoperability as a service, IoT, ontologies, IoT enabled value-added services.**

I. Introduction

Nowadays various Internet-of-Things (IoT) networks are being deployed for sensing, measuring, controlling and business process optimization purposes while various IoT platforms are emerging on the market to manage these networks. Nevertheless, these infrastructures are mostly acting as isolated islands in the global IoT landscape while inter-connection of these islands might bring significant value-added. Exploitation of these benefits is however inhibited by various interoperability barriers that are present in the current IoT ecosystems [1]-[3]. Such barriers are:

- Lack of IoT protocol interoperability,
- Interconnected smart objects of different owners require data sharing that raises serious privacy issues,
- IoT component vendors might be reluctant to share interface specifications,
- Large-scale integration imposes rules that are disadvantageous for particular participants.

Therefore, the present IoT landscape rather looks like a set of isolated islands shipped by different vendors serving different domains. VICINITY will provide an IoT platform that can connect isolated islands, and will allow integration of end-users and creation of new business models. VICINITY will pave the way for large-scale demonstration of the applicability of the solution in different use cases that implement and demonstrate different value-added services facilitated by VICINITY platform.

- VICINITY presents a virtual neighborhood concept. A decentralized approach resembling a social network will be used. The users are allowed to configure installations and integrate standards according to the preferred services, as well as being able to fully control their privacy.
- Data exchange between different devices is handled through the VICINITY open interoperability gateway, which reduce the need for having a technical background in order to exploit to the VICINITY ecosystem.
- An application programming interface (API) will allow for easy development of an adapter to the platform.
- Connecting to detect IoT infrastructures is handled by the open VICINITY auto discovery device. The device will automatically discover the smart objects.

The paper is organized as follows. Section II introduces VICINITY concept requirements, barriers and opportunities. Section III analyzes the standardisation context. Section IV introduces the main goal - interoperability as a service. Section V presents the VICINITY ontologies. Section VI explains the significant value-added services brought by VICINITY. Section VII introduces the integrated IoT infrastructures. Sections VIII and IX illustrate VICINITY IoT test-labs and IoT use-cases separately. Section X concludes the paper.

II. VICINITY CONCEPT REQUIREMENTS, BARRIERS AND OPPORTUNITIES

VICINITY was envisioned as a way to innovate options to solve semantic interoperability issues that hinder development of connected services and further business models automation can unlock within buildings, energy systems, mobility and healthcare domains. The challenge is deeply technical, but it interfaces with even more issues, which are not technical in nature. While trying to classify the non-technical issues the ecosystem stakeholders are facing, the two categories became prominent internal and external factors driven.

It was observed during the site visits and stakeholders interviews that Internet of Things enabled solutions, which are novel to the user and operator communities across all the domains and are not fully understood by them. These systems and solutions involve multiple stakeholders, which are defined as ‘ecosystems of stakeholders’.

Understanding stakeholders’ real needs and expressed needs is challenging in the cross-domain environments, where benefits of an overall system are distributed across the ecosystem participants. The ecosystem approach is one of the methods adopted to facilitate the operational requirements solicitation and use cases definition for VICINITY. Prioritization of IoT initiatives, dissemination of the best practices and development of the related methodologies in support of the public sector rollouts is needed.

Deep concern for ethics and privacy considerations, new General Data Protection Regulation (GDPR) compliance preparations introduces additional complexity in projects development. Collaboration challenges coupled with organizational challenges and systems users concerns regarding “big brother” phenomena frequently voiced by elder people in assisted living environments or collection of aggregated information expressed by employees in commercial buildings, pose additional acceptance challenges, beyond technical interoperability. Fig. 1 outlines the main challenges identified during the system requirements gathering phase. Moreover, the end-users prefer simple, easy to use services and devices hiding complexity of the decision-making and choices generated within a system. The four domains are being directly affected by the ongoing new market design in energy sector, new models introduction through digitalization in health and building domains and related customers’ requirements driven changes in transport domain.

Cross domain data-driven services offered to business-to-consumer (B2C) and business-to-business (B2B) end-users in the field of energy consumption with demand side management including renewable energy sources and energy storages, buildings environment quality supporting health assistance services, advanced parking services considering drivers and vehicles profiles and parking purpose.

Interoperability in IoT opens potential to integrate more clean energy production and allows for further optimization of all the resources consumed. Understanding how energy and resources among which: electricity, water, heating and cooling, building rooms occupancy, parking space are produced and consumed or used creates potential in dynamic pricing, better

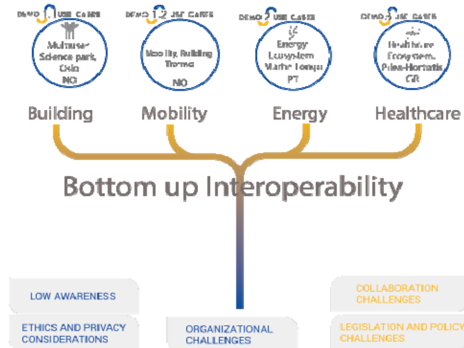

Fig. 1. Ecosystem Bottom up Interoperability.

invoicing and optimal use.

Caring for an aging population is one of the major challenges for future healthcare system. An important step is the need to move from institutional care to assisted living at home and the related services provision enablement, in particular for elderly people living alone and people with long-term needs and chronic illness. Digitized and automated medical care services enable these people to obtain a better quality and longer independent life environment.

III. STANDARDIZATION ANALYSIS

Standards are crucial to the effective deployment of the IoT in order to ensure that the IoT devices, gateways, platforms, servers and applications all work together seamlessly and can pass data between them. At the recent ETSI IoT/M2M standardization workshop it was stated that using open standards in IoT deployments would accelerate growth of the IoT by 27% and reduce deployment costs by 30% [4]. The problem is that there are many standards relevant to the IoT and a plethora of standards bodies developing them. Which ones should VICINITY choose?

VICINITY has undertaken a thorough review of all existing standards and platforms, selecting those that are needed to build a service or to create some interoperability among different standards and platforms. It has identified at least 20 organisations developing standards that will have a direct impact on VICINITY architecture and services. The Alliance for Internet of Things Innovation (AIOTI) has gone even further and identified nearly 100 bodies developing standards that are in some way relevant to the IoT and its domains [5]. VICINITY is participating directly in the AIOTI Working Groups in order to monitor and contribute to these.

At the communication level there are a limited number of standards, including WiFi and ZigBee, and exchanging data between IoT devices at this level is not the problem. The problem is the discovery and classification of services and the communication at the semantic layer that is summarized under the term Machine to Machine communication (M2M). Achieving interoperability and establishing services at this level is more challenging and requires semantic knowledge from different domains and the ability to discover and classify services of things in general. This is difficult to standardize as it changes rapidly and is dependent on particular applications, locations and use cases. Important standards groups in this area include the ETSI SmartM2M Technical Committee. Here

VICINITY partners have been developing specific ontologies for the Building and Energy domains as extensions to the Smart Appliances REFerence ontology (SAREF) [6]. The VICINITY ontologies will also be implemented in the W3C Web Ontology Language standard (OWL) – for more information see V.

IV. Interoperability as a Service

The H2020 project VICINITY aims at providing “Interoperability as a service” and not to define yet another standard whose main architecture is shown in Fig. 2. From the hardware point of view, the architecture consists of a gateway or a mobile device which are connected to a VICINITY neighborhood manager in the cloud (higher layers). From a logical point of view, the user defines – like in social networks – access rights to data from its “things” at the neighborhood manager. On the (local) side gateway, agents share the data in a peer-to-peer (P2P) way only with those external partners that have permission – without replicating data in other locations. The agent also takes care of enriching data with semantic information, or implements value-added services that are based on the user’s data and the data from its digital vicinity.

The main challenges in achieving VICINITY objectives are the lack of an IoT protocol for interoperability (which can support avoiding vendor locks in the current IoT ecosystems) as well as dealing with security and privacy issues. The current lack of interoperability is mainly due to the heterogeneity of IoT ecosystems, which are built on different, often proprietary, standards. However, aiming to transform such ecosystems toward new standards requires significant change management efforts regarding IoT users and operators. Therefore, a main idea in our approach is to allow IoT operators and users to continue using their tools, specifications and processes and to set the conditions of their collaboration upon their interests.

Furthermore, aiming for a decentralized network enables achieving P2P security (because the P2P configuration naturally supports end-to-end encryption of communication between the different peers and no third party has access to user data) and privacy (because nodes keep ownership over their data, control access to such data, and only metadata is interchanged in the platform level).

Additionally, VICINITY infrastructure is going to achieve decentralized interoperability between integrated IoT infrastructures and value-added services through a P2P network of VICINITY Nodes, where the infrastructure and/or the service managers can share the access to their IoT objects without losing control over them.

By setting up partnerships between organizations and sharing access rules by managers, a social network (called virtual neighborhood) of organizations, integrated IoT infrastructures and value-added services is created.

In this ecosystem, managers can set-up the sharing access to value added services and IoT objects of their integrated for their partnered organizations using the VICINITY Cloud.

The **VICINITY Cloud** is the infrastructure that provides

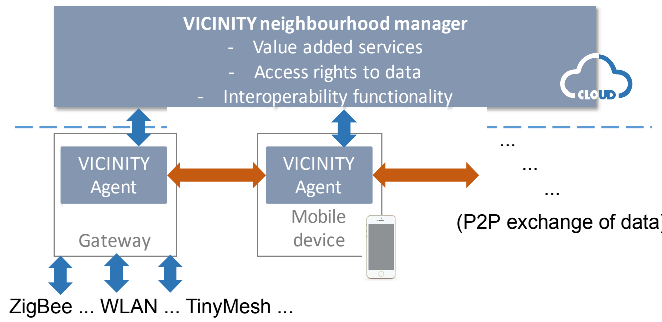

Fig. 2. The VICINITY architecture providing Interoperability via agents.

Interoperability as a Service itself, by providing services that enable:

- Configuring the virtual neighborhood of integrated infrastructures and value-added services (including set-up sharing access rules of any IoT objects).
- Semantic search (discovery) of IoT objects in the virtual neighborhood composed by VICINITY Nodes.
- Characterization of new IoT objects and generation of the necessary thing descriptions (following the Web of Things approach) based on the VICINITY ontologies.
- Configuring the VICINITY Nodes based on IoT object description (such as data-integration and privacy services), sharing access rules (for accessing IoT objects in the P2P network), and configuration of the communication with the integrated infrastructure or value-added services (such as encryption and data integrity features).
- Auditing changes and events in the virtual neighborhood (such as new integrated infrastructure request, change of sharing access rules, new device or service in virtual neighborhood events) including user notification of such important events.

The **VICINITY P2P Network** provides a closed and secure common communication network for the VICINITY Nodes and VICINITY Cloud to exchange user data between the Nodes based on the share access rules defined in the Cloud services, and control and configuration messages between the Nodes and Cloud.

The **VICINITY Nodes** are the set of software components providing different services to integrate IoT infrastructures and/or value added services into the VICINITY Cloud, such as:

- Remote IoT object semantic discovery to look-up for the objects provided by other integrated infrastructures and/or value-added services.
- User data forwarding within the P2P network according to the share access rules defined in VICINITY Cloud.
- Encryption and data-integration services for forwarded user data to ensure secure transmission of the data within VICINITY P2P Network.
- Configurable of auditing and logging of exchanged user data.

V. The VICINITY Ontologies

The presented interoperability approach relies on ontologies (i.e., semantic data models) that will be exploited throughout the VICINITY infrastructure. We refer to ontologies as "formal, explicit specifications of a shared conceptualization" [7]. The VICINITY ontologies will be formal in the sense of following Description Logics and being implemented in the W3C Web Ontology Language standard OWL [8]. The conceptualization to be shared among the VICINITY components and plugged systems will cover different domains of interest ranging from horizontal domains like time and space to specific definitions need within the VICINITY ecosystem. For this reason, the VICINITY approach is based on a modular ontology network in which existing standard ontologies will be reused whenever possible. In summary, the ontology network will be composed by: 1) cross-domain ontologies (horizontal domains) addressing the modeling of general concepts like time, space, web things, among others, that would be reused and probably extended by 2) the VICINITY platform oriented ontology that will represent the information needed to exchange IoT descriptor data between peers and that would be extended by 3) domain oriented ontologies that would cover vertical domains such as health, transport, buildings, etc.

Apart from the domain-specific ontological requirements, the VICINITY ontologies development is based on the following non-functional requirements:

- *Reuse*: existing ontologies or standard models will be reused when possible increasing interoperability with external systems that might be already using such ontologies. This point is also applied at a meta-level by using standard technologies to implement the ontologies themselves.
- Modularity: the ontology should be designed as a network in which modules might be interconnected and refer to others.
- *Extensibility*: the ontologies should allow the development of third-party extensions.
- *Good practices*: the ontologies will be developed following methodologies and best practices commonly used in ontological engineering in order to address ontology development activities such as design, implementation, evaluation, publication, and documentation, among others.

As a result, a network of ontologies is being developed within the project and it is published at http://vicinity.iot.linkeddata.es. The ontologies being developed so far are: 1) an ontology for describing Web of Things (http://iot.linkeddata.es/def/wot/); 2) a core ontology for the model underlying the VICINITY use case (http://iot.linkeddata.es/def/core/); and 3) a mapping ontology to represent mappings between web resources and RDF models in order to allow interoperability in an IoT context based on VICINITY technical solutions (http://iot.linkeddata.es/def/wot-mappings/).

VI. Value-added services

Value-added services provide advantages for both the customers and the service providers. While, customers will have opportunity to receive certain added value, providers can benefit from increased rapport with their clients generating additional revenue for them. Value-added services over IoT complete the services loop in the global software services industry. However, these offerings do not succeed in isolation and need to have a robust foundation.

VICINITY interoperability platform will provide such foundation through making feasible the connection of diverse intelligent entities and IoT ecosystems that sense and transmit a broad array of data. This data cloud and globally accessible network of things, users, and consumers, enables a global infrastructure to generate new services, allowing anyone (e.g. service providers, application developers) to create content and applications for global users that would not be obvious without the level of connectivity and interoperability provided by solutions such as VICINITY.

Furthermore, VICINITY concept enables the development of new business models, exploiting the unleashed volume of semantically enhanced information, stemming from the emerging IoT ecosystems connected to the VICINITY interoperability platform.

VII. Integrated IoT infrastructures

Important features expected from an IoT Software Platform as they are listed in [9] and more detailed in [10] are device management, integration support, information security, protocols for data collection, types of data analytics and support for data visualizations.

IoT Platform maintains a list of devices and key metadata information about them to offer data streams for IoT applications. It also enables to configure these devices, change operational settings, upgrade their software remotely, querying the status and support reporting of any error conditions [10]. Key features of IoT platform (control & data access) should be made available to outside world via APIs – nowadays is common to use REST APIs. Protocols used by IoT Software Platforms could be distinguished per [10] as application protocols (e.g. RTPS), payload container protocols (e.g. CoAP, SOAP), Messaging Protocols (e.g. AMQP, MQTT, XMPP, JMS) and Legacy Protocols (e.g. BACnet or UPnP). Type of data analytics used in IoT are real-time, batch on an accumulated set of data, predictive and interactive.

Per Saverio Romeo, Principal Analyst at Beecham Research, there are more than 300 IoT platforms today [11]. One of the recent surveys of the IoT middleware platforms that focuses on the usability and evaluates representative sample of 39 such platforms can be found in [9]. The candidates of IoT platforms that are about to be integrated via VINCINITY approach are AWS IoT platform [9], LinkSmart, OpenIoT [12] and FIWARE.

VIII. IoT test-labs

In order to integrate developed components forming server and client infrastructures, deploying the first VICINITY prototype and to implement control and energy management systems, including advanced smart metering infrastructure (AMI) and demand response, four IoT test laboratories will be established for testing and validating the integrated solutions.

A. AAU Microgrid IoT Laboratory

The AAU IoT Laboratory [13] is located in Aalborg University, Denmark. It will integrate developed components, smart devices, advanced control, and energy management systems according to different VICINITY IoT use-cases with various domains, such as e-health, transport, buildings and energy.

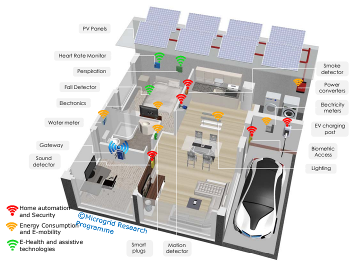

Fig. 3. AAU microgrid IoT laboratory.

A Home Energy Management System (H-EMS) will be implemented in addition with the integration of smart devices which will allow the user to have full-access and controllability to the system's information, and also provides the user the option to remotely control the system. Smart devices will work and provide valuable information to the H-EMS as described, to manage efficiently the microgrid. It is expected that the H-EMS together with the current smart devices will enhance the overall system performance and user's comfort levels, reaching new ways of flexibility, controllability and efficiency.

B. ATOS IoE Laboratory

The IoE lab addresses technological contributions in the scope of IoT components, connectivity, platforms and services integration, fostering the usage of open and standard technologies, while also ensuring wider adoption and implementation of the IoT paradigm. The laboratory is moreover composed by a multidisciplinary technological team targeting embedded systems, sensorized devices, open web technologies and the application of best-practices, agile developments and continuous integration through a self-designed platform and integration services.

C. UNIKL Test Laboratory

It is desirable to validate the correct behaviour of the VICINITY before deploying it in the field. For this purpose, a model-based development process is reasonable.With the Test Lab at University of Kaiserslautern (UNIKL), this will be met to an extent, that "virtual" devices are connected to the VICINITY Server. Those way real use-cases can be simulated, analyzed and the correct behavior can be validated during early stages of the development process.

A network Simulator is directly connected to the VICINITY-Cloud on one side, and to a variety of real and simulated devices on the other side. The devices themselves are communicating via different Network Gateways. They can be pure virtual devices/gateways or real existing ones. Both are integrated seamlessly into the VICINITY, enabling the simulation and evaluation of any possible IoT Scenario. Performance, scalability and runtime behavior will be evaluated with the ultimate goal of simulating a "virtual Oslo".

D. CERTH Test Laboratory

CERTH Test laboratory comprises the Institute's main offices and a dedicated experimental Smart House. Both buildings are equipped with numerous IoT sensors and automation infrastructure to facilitate the experimentation and test operation of the VICINITY framework at the early stages of its development. In particular:

- The offices building comprises of offices where CERTH personnel work and interact during their every-day operations. Most areas are fully equipped with IoT oriented devices and sensors allowing real-time monitoring of environmental, energy and consumption related information, further allowing interaction and control at device level. This building will be the primary test bed infrastructure for the VICINITY platform.

Fig. 4. IoT monitoring sensors deployed at CERTH building.

- The Smart House is a real house simulation building, equipped with a vast variety of sensors, actuators and smart devices and intelligent robots, being capable to provide an useful test bed for the experimentation of all foreseen use case scenarios.


Fig. 5. Smart house of CERTH test laboratory.

IX. IoT USE-CASES

A. Intelligent Building System

This use case will target the interconnection of smart objects under a "virtual neighbourhood" of intelligent buildings, addressing both geographic proximity as well as the use of energy profiles. These will allow neighbourhoods to negotiate as a group their potential forecast energy flexibility within a Smart Grid ecosystem, allowing the realisation of dynamic Demand Side Management (DSM) strategies. The use case will be deployed and demonstrated at Oslo Science Park consisting of four semi-independent buildings, as well as a basement parking garage, for a combined area of 55,000 square meters. The use cases at Oslo Science Park will have three main focuses. First, a use case is on energy flexibility in buildings in a smart neighbourhood. The second use case is about Smart Parking/Booking/ Electric Vehicle (EV) charging and optimizating this across a local grid. The third use case is


Fig. 6. Intelligent building system in Norway.

a Smart Grid use case to optimize local energy flexibility in a smart urban neigbourhood.

B. Smart Parking

The Smart parking demonstration is located in Tromsø, Norway offering an extendable service for sharing available parking space. The initial test site is located in a newly constructed cluster of a living community for residents, elderly and young people, some of them requiring health and assistive service from the municipality. The area consists of apartment buildings, offices, theater and amusement activities with less and less outdoor parking space.

Fig. 7. Smart parking use case.

C. Smart Energy System

The DEMO site is focused on transversal energy domain and municipal buildings management. Energy generating and consuming components could potentially form a municipal-scale smart-grid enabled by VICINITY. It aims to demonstrate value added services that could be enabled through the VICINITY framework based on renewable energy generation infrastructure.

Fig. 8. Smart energy system in Portugal.

The Use Case in Alcoutim, will target collaborative management of a community-scale energy ecosystem linking the Solar Lab, Demonstration Platform, Weather Station and a cluster of Municipal buildings. This energy ecosystem will form a data exchange with flows from both the Generation and Demand sides. Data will be obtained from sensors and build information models that will allow for information to be generated upon which an environmental quality service can be provided for the Municipal Building Smartgrid environment including the Public School, Swimming Pool with Sports center and the Retirement Home.

D. eHealth and Assistive Living Home

This Use Case will demonstrate how sensors, actuators and integrated communication devices installed at home can provide assistive living to elderly people and people with long terms needs, allowing remote monitoring of end-users' health parameters and providing them direct means of communication with a 24-hours call center with specialist staff in case assistance is needed.

Fig. 9. eHealth/assistive living home.

X. Conclusions and Future Work

The VICINITY project is divided into five phases, covering the following topics: Definition of Requirement, Standard Analysis & Framework Design, Platform Implementation, System Integration & Lab Testing, Pilot Installation, Demonstration & Evaluation, and horizontal activities. By now, phases 1 and project activities have started to be conducted. VICINITY project will finally provide the owners of connected IoT infrastructures with decentralized interoperability. It connects different smart objects into a "social network" called virtual neighbourhood where the infrastructure owners may control their shared devices and data. The project supports IoT interoperability by offering a generic IoT API based on widely accepted standards. VICINITY will also explore and demonstrate value-added services in renewable energy generation and consumption spectrum, AI-based services within health data analysis and the transport domain, and invites to extend the business and technology scope of value added services beyond the capabilities of the consortia through open call application.

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