Enabling interoperability-as-a-service for connected IoT infrastructures and Smart Objects

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Abstract. 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 non-interoperable infrastructures 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 is building and demonstrating 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.

Keywords. Virtual neighborhood, interoperability as a service, IoT, ontology, IoT-enabled value-added service, microgrid energy management, assistive living.

1. 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 vendor-specific platforms 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: a) lack of IoT protocol interoperability, b) interconnected smart objects of different owners require data sharing that raises serious privacy issues, c) IoT component vendors might be reluctant to share interface specifications, and d) large-scale integration imposes rules that are disadvantageous for particular participants.

Therefore, the present IoT landscape rather looks like a set of non-interoperable infrastructures shipped by different vendors serving different domains. VICINITY will provide an IoT platform that can connect infrastructures 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 standardization 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.

2. 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 invoicing and optimal use.

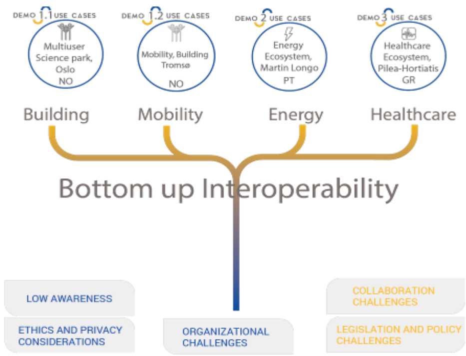

Figure 1 Ecosystem Bottom-up Interoperability

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.

3. 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 organizations 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 Wi-Fi 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 Environment 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.

4. 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, the 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.

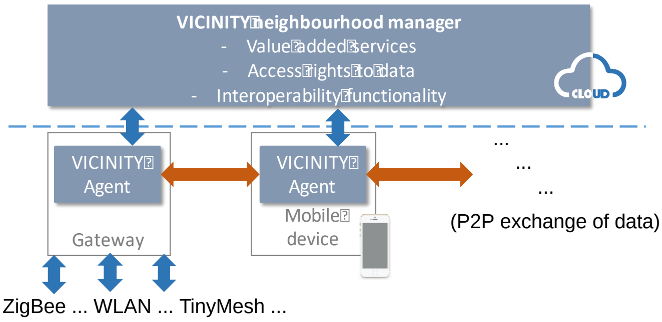

Figure 2 The VICINITY architecture providing interoperability via agents

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

5. 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.

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) a core ontology for the model underlying the VICINITY platform (http://iot.linkeddata.es/def/core/); 2) an ontology for describing things in the Web of Things (http://iot.linkeddata.es/def/wot/); 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 the VICINITY technical solutions (http://iot.linkeddata.es/def/wot-mappings/).

As mentioned above, this ontology network will be extended for the different domains that are relevant in the project use cases. For the health domain, different standards are relevant, such as the ISO 13606[1] (Health informatics — Electronic health record communication) that focuses on the interchange of part or all of the electronic health record (EHR); the CEN ISO/IEEE 11073[2] (Health informatics - Medical/health device communication) that enables communication between medical, health care and wellness devices and with external computer systems; or the Health Level-7 (HL7) focused on the exchange of medical data in the area of healthcare and that includes standards focused on interoperability, such as FHIR[3] (Fast Healthcare Interoperability Resources).

Largely adopted are also a set of international classifications and terminologies such as SNOMED Clinical Terms[4] (SNOMED CT) or those maintained by the World Health Organization[5] (WHO): the International Classification of Diseases (ICD) that covers epidemiology, health management and clinical purposes, the International Classification of Functioning, Disability and Health (ICF) that covers health and health-related domains, or the International Classification of Health Interventions (ICHI) that covers health interventions.

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[1] http://www.en13606.org/
[2] http://11073.org/
[3] http://hl7.org/fhir
[4] https://www.snomed.org/
[5] http://www.who.int/classifications/en/

Other initiatives to be taken into account are community-driven efforts such as OpenEHR[6] or the Personal Connected Health Alliance[7] (PCHAlliance).

Not all of these initiatives are directly focused on semantic interoperability. However, over time different ontologies have been developed for some of those standards, terminologies and classifications, or have been inspired by them. Relevant ontologies can be found in the two main ontology catalogues that are devoted to the collection of biological and biomedical ontologies, namely the Open Biological and Biomedical Ontology (OBO) Foundry[8] and BioPortal[9], which also includes the OBO ontologies in its catalogue.

6. 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.

7. 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.

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[6] http://www.openehr.org/
[7] http://www.pchalliance.org/
[8] http://www.obofoundry.org/
[9] http://bioportal.bioontology.org/

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.

8. 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, IoT test laboratory University of Aalborg (AAU) has been established for testing and validating the integrated solutions.

8.1. Residential Microgrid Energy Management System in AAU IoT-Microgrid Laboratory

With the rapid development in sensing, measuring, networking, controlling, renewable energy generation, ambient intelligent technologies, and business process optimization, smart residential microgrids (RM) get a lot of attention in terms of the provision functions, such as energy scheduling optimization, energy cost reduction, energy efficiency improvement, and living quality enhancement.

By means of the smart sensors and devices, the residential activities can be automatically detected and identified. By comparing these sensing data with the recorded behavior patterns, many services and controls can be achieved, such as accident notification, health emergency detection, and comfort/cost optimization, thereby helping the residents live independently and comfortably. This is so-called Ambient Assisted Living (AAL).

A. Residential microgrid energy management system in AAU Lab

The RM established in AAU IoT-Microgrid Laboratory is an integrated smart house and microgrid system that includes renewable energy resources, power converters, smart household appliances, IoT sensors, gateways, and devices. Several PV panels which power capacity is around 2 kWp and a 2 kW wind turbine are connected to the RM. Inside the smart house, both water and electrical-based underfloor heating systems are installed. The temperature of the smart house can be independently controlled per room wirelessly. Electronic appliances, including laptops, cell phones, LED lights, home entertainment systems, and white goods are also installed in the living area and kitchen area of the RM. In order to detect activities and conduct reactivations, a set of sensors have been deployed inside the RM, for instance, door/window sensors, motion sensors, smart wall plug, environment sensors, gateways, a Gorenje smart oven and a Gorenje smart refrigerator.

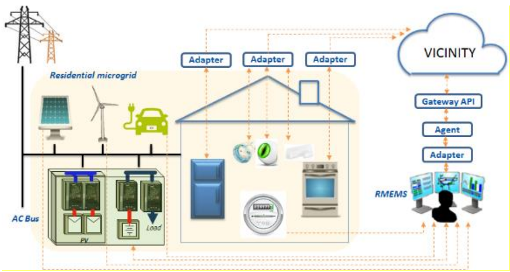

Fig. 3. Integration overview of VICINITY and RM in AAU IoT-microgrid laboratory.

A LabVIEW-based RM energy management system (RMEMS) is developed to achieve monitoring, high-level regulation, and to provide optimal solutions for fulfilling residents' requirements in terms of energy cost reduction and living quality improvement. The REMES covers from low-level data acquisition by sensors, middle-level data integration and up to high-level optimal decision-making. It can be divided into five stages: raw-data collection, sensor data processing to get context information, activity recognition, optimal decision-making and value-added service providing. By means of the RMEMS, the RM is fully integrated into the VICINITY infrastructure by using VICINITY adapter, VICINITY gateway API and VICINITY node, therefore participating in VICINITY Neighborhood, as shown in Fig. 1.

B. Case study – An integrated optimization for indoor temperate and energy costs.

This study case focuses on an integrated optimization process for indoor temperate and energy costs by taking into account the indoor comfortable temperature range, solar irradiation, and variable electricity tariff.

Support vector machine (SVM), which can construct a hyperplane or a set of hyperplanes in a high- or infinite-dimensional space, is used for temperature and irradiation short-term prediction with limited historical data. The particle swarm optimization (PSO) method is adopted in this study to obtain the optimal operation point to ensure the comfortable indoor temperature, meanwhile reduce the energy costs as much as possible. Optimization constraints for power converters and energy storage systems (ESS) are shown as follows:

$$\begin{cases} -P_{ESS}^{\max} \le P_{ESS}(\mathrm{t}) \le P_{ESS}^{\max} \\ 0 \le P_{PV}(\mathrm{t}) \le P_{PV}^{\max} \\ 0 \le P_{WT}(\mathrm{t}) \le P_{WT}^{\max} \\ SoC_{ESS}^{\min} \le SoC_{ESS}(\mathrm{t}) \le SoC_{ESS}^{\max} \\ T_{house}^{\min} \le T_{house}^{real}(\mathrm{t}) \le T_{house}^{\max} \\ 0 \le P_{heat}^{avg}(\mathrm{t}) \le P_{heat}^{\max} \\ P_{PV}(\mathrm{t}) + P_{WT}(\mathrm{t}) + P_{ESS}(\mathrm{t}) - P_{heat}^{avg}(\mathrm{t}) + P_{grid}(\mathrm{t}) = 0 \end{cases} \quad (1)$$

where $P_{ESS}^{\max}$ is the maximum active power of ESS, $P_{PV}^{\max}$ and $P_{WT}^{\max}$ are the power limitations for PV and wind turbine respectively. The state-of-charge constraints ($SoC_{ESS}^{\min}$ and $SoC_{ESS}^{\max}$) are preset against deep-discharge and over-charge of ESS. $T_{house}^{\min}$ to $T_{house}^{\max}$ are the indoor comfort temperature limitations. $P_{heat}^{\max}$ and $P_{heat}^{avg}(\mathrm{t})$ represent the maximum and average heating power. $P_{grid}(\mathrm{t})$ is the active power exchange between RM and utility.

The optimal operation point can be obtained by means of the penalty function as follows:

$$f_{penalty} = \alpha \sum_{t=1}^{N} p_{elec} P_{grid}(\mathrm{t}) \Delta t + \beta \sqrt{\frac{1}{N} \sum_{t=1}^{N} (T_{house}^{ext}(\mathrm{t}) - \frac{T_{house}^{\max} + T_{house}^{\min}}{2})^2} \quad (2)$$

where p_{elec} is the electricity tariff, α and β are weight coefficients for the cost and temperature variables.

The study case will be further extended for e-vehicles charging and service for sharing available parking space for testing in a living community for residents, elderly and young disabled persons, some of them requiring health and assistive service from the municipality. Further enhancements will be to 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-hour call center with specialist staff in case assistance is needed.

9. 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&2 are finalized and project activities in the other phases are progressing. 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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