Paving the Way to Society/Industry 5.0: The SmartMe.IO Experience

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Abstract

The social and economic cost of COVID-19 has revealed that prevention strategies are potentially very cost effective by comparison to coping with a pandemic. The actions by Public Administrations and businesses need new approaches in order to benefit in health and quality of life. As a consequence, the concept of Future Cities and Industries as human-centered realities that balance economic and technological advancement to solve society's problems is urgent. It represents a new vision for a resilient society where humans, nature and technology create a resilient and sustainable balance enhanced by data. This new digital transformation results in new resilient and sustainable environments permeated by a sustainable economy and the creation of products and services with low environmental impact and high social impact.

Keywords

Arancino · Artificial intelligence · Future cities · Industry 5.0 · Resilience · Neurobiologic · Smart cities · Society 5.0 · Sustainability

1 Introduction

COVID-19 was not just a rare event, but a symptom of ecological disruption and danger to human survival. COVID-19 has captured the attention of the planet towards the need to adopt new and more urgent measures to counter the pandemic. It almost seemed that the problems related to overheating, lack of food and water and other diseases already known and widely spread expired in the background. Most of these emerging diseases and practically all pandemics, including COVID-19, are caused by microbes in animals which spread rapidly after repeated contact between wildlife, livestock, and people. Combined with the technological reality of highly interconnected and globalized economies, rapid transport and increase in world population, this makes pandemics a rapidly growing risk.

For the next several millennia, cities and respective populations continued to grow in number. Towards the end of the century, the UN

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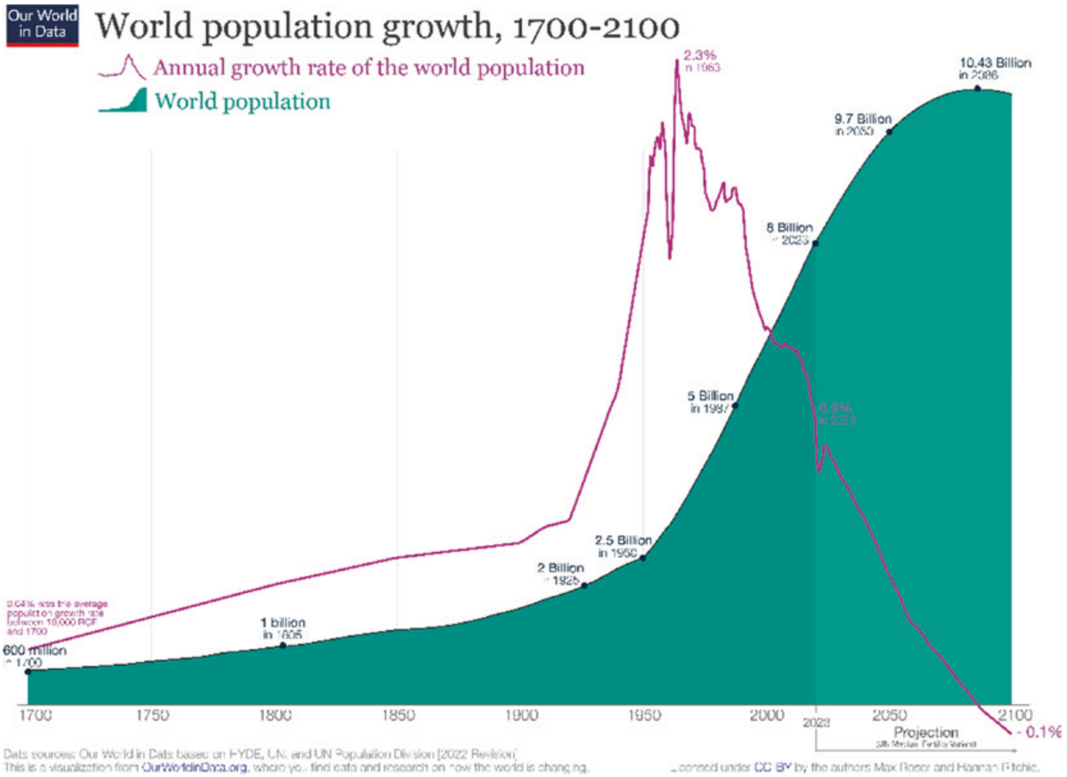

Data sources: Our World in Data based on HYDE, UN, and UN Population Division (2022 Revision)
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing. Licensed under CC BY by the authors Max Roser and Hannah Ritchie.

Fig. 1 World population growth, 1700–2100

expects the global population to reach its peak at around 10.4 billion[1] (Fig. 1).

Figure 1 highlights a comparison between the annual growth rate of the world population (i.e., the percentage change in population per year) and the world population. Since the peak in 1963 the increase of the world population has slowed and today grows by 0.9% per year. However, the growth of worldwide populations means the growth in the access to data and therefore to public and private services based on the use of information technologies.

Rapidly advancing innovation in digital technologies such as Artificial Intelligence (AI), Internet of Things (IoT), robotics, and blockchains, as well as biotechnologies provide augmented abilities to people enabling them to pursue their dreams. Figure 2 shows the growth of Big Data and Hadoop market size in the 2017–2022 time period. As a consequence, the concept of Future Cities as a human-centered reality that balances economic and technological advancement to solve society's problems is urgent.

SmartMe.IO is a company specialized in engineering and implementation of hardware and software systems based on Open Source IoT technologies for management and care of complex environments related to Industry and Smart Cities. The vision of SmartMe.IO focuses on collaborative industries, bioeconomic and creative products and services.

In this paper we present our neuro-biologic approach followed in designing the Arancino hardware stack, i.e., a family of Open Source IoT technologies designed for the production of modular and high customizable electronic

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[1] Source World Population Growth - Our World in Data, https://ourworldindata.org/world-population-growth last visited May 2023.

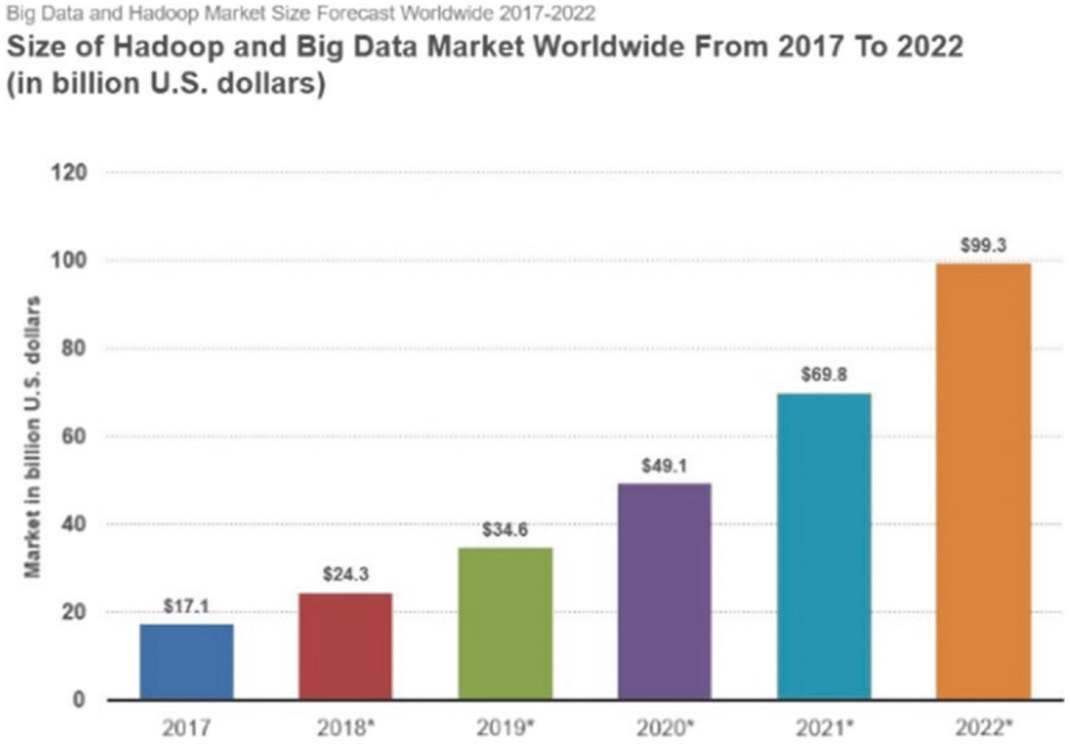


Fig. 2 The growth of big data and Hadoop market size in the 2017–2022 time period (*Source* statista.com)

devices with processing and communication capabilities at the edge of the IoT network.

We also present the Stack4Things® software framework, an evolution of OpenStack, to manage IoT devices (sensors and actuators) and collect and process data, both at the edge and the cloud. We will describe how a monitoring infrastructure based on Stack4Things® can be setup in a short time and with limited costs.

More specifically, Sect. 2 introduces the reader to the transition from Industry 4.0 to the concept of Society and Industry 5.0. In Sect. 3 we explain how the neuro-biologic approach has been implemented in analogy to the human brain in order to simplify cloud-IoT interaction. Section 4 reports related works concerning the state of the art near our vision in IoT-Cloud applications for Smart Cities and Industries, gaps in the existing approaches and complex challenges. Sections 5 and 6 detail the proposed Arancino – Stack4Things® ecosystem for Cloud-IoT integration in a continuum. In Sect. 7 we show the main steps for a fast deployment of monitoring infrastructures. Finally, use cases are presented and discussed in Sect. 8 and conclusions in Sect. 9.

2 From Industry 4.0 to Society/Industry 5.0

After the global financial crisis (2008), i.e., the most serious financial crisis since the Great Depression (1929), the most industrialized countries have oriented their policies towards a political-technological turning point named Industry 4.0. Businesses have focused their strategies on Industry 4.0 issues, with the aim of providing customers with Industry 4.0 compliant tools in order to improve both the safety of operators and the monitoring and control of machines and equipment. Worldwide use of sensors and actuators, both with the expansion of the 5th Generation technologies and the deployment of increasingly intelligent robots and machines, promised to transform Industries in a new advanced reality, as part of the smart city ecosystem. These types of scenarios have generally been identified as smart factories, the Industrial Internet of Things (IIoT), smart industries, or advanced manufacturing. Moreover, the term Industry 4.0 has been applied to a group of rapid transformations in the design, manufacture, operation and service of manufacturing systems and products.

Unfortunately, this historical passage coincided with the Great Lockdown [1]. As a consequence, the application of advanced technologies such as Artificial Intelligence, Machine Learning, Big Data, Cloud Computing, Internet of Things, Digital Twin, Augmented Reality has marked an acceleration, influencing not only the industrial world but also society and human relations. This new digital transformation results in new resilient and sustainable environments permeated by a sustainable economy and the creation of products and services with low environmental impact and high social impact.

Keidanren (Japan Business Federation), the most important Japanese business federation, presented the concept of Society 5.0: an emerging form of society characterized as “Creative Society” enabled by the digital transformation. Society 5.0 follows the societies in which humankind lived in the past: Hunting Society (Society 1.0), Agrarian Society (Society 2.0), Industrial Society (Society 3.0) and Information Society (Society 4.0). This evolution affects not only Future Cities but also Industries. Public Administrations and businesses need new approaches in order to create a resilient a sustainable balance of society for benefit in health and quality of life. Data can drive this process of “society evolution” because data are integral part of our reality and it is not possible to think of a society devoid of data and technology. We are therefore talking about a real new evolutionary phase of society characterized by a return to the centrality of the environment and people in the industrial processes. The vision of Society 5.0 seeks to balance economic development with the solution of socio-environmental problems, in which technologies are used not only for profit but in order to improve the quality of life of citizens.

Society 5.0 is a reality increasingly aware of the environment and the damage that human activities have caused or can cause. This awareness is slowly driving the world's population in correcting our mistakes and addressing environmental issues. We can use AI and IoT applications to help us achieve this.

Industry 5.0 is the title of the report that the European Commission published in January 2021. Subtitle: “Towards a sustainable, human-centric and resilient European industry”. For the European Commission, “Industry 5.0 recognizes the power of industry to achieve social goals beyond jobs and growth to become a provider of resilient prosperity, making production respect the limits of our planet and putting the well-being of workers at the center of the production process”. Two important qualities that must characterize the “daughter” applications of Industry 5.0 are thus highlighted: resilience and sustainability. Although the Industry 5.0 paradigm is new, the European Union defined the term resilience already in 2012 as the “ability of an individual, a household, a community, a country or a region to withstand, adapt and quickly recover from shocks and pressures in a manner that reduces vulnerabilities and risks”.

In the broadest sense, sustainability refers to the “ability to maintain or support a process continuously over time” and it is mainly based on three pillars: economic, environmental, and social. Sustainability is a priority objective for the European Union’s internal and external policies [2, 3]. The United Nations 2030 Agenda includes 17 Sustainable Development Goals (SDGs) intended to apply universally to all countries. The EU is committed to gradually decreasing its greenhouse gas emissions by setting a goal of zero net emissions by 2050. To achieve the goal, the EU must invest in new technologies. As a consequence, the European Commission estimates that Europe needs about €260 billion in extra investment every year over the next decade. On 11 March 2020, the Commission adopted a new circular economy action plan as part of the new industrial strategy. On the basis of the above considerations, it is not enough for Industry 5.0 to use the enabling technologies already present in Industry 4.0.

3 Neuro-Biologic Approach

Nowadays both industrial and ready-to-use systems [4] are increasingly made up of numerous subsystems, each with a specific task [5]. IoT devices may be equipped with a microcontroller unit (MCU) and/or a microprocessor unit (MPU). Sensors and actuators interact with each other and with the surrounding environment to achieve multiple purposes through the monitoring and control of natural, civil and industrial environments. The resulting complexity is therefore remarkable both for the monitoring and management procedures, and for the considerable amount of data to be managed. The aggregation of subsystems takes place at different levels, typically proceeding from the simplest ones (edge devices able to perform simple functions using local data), towards the more complex ones (complete subsystems with well-defined operating logics). The management of the single component, however well-structured and complete, is not sufficient to ensure the optimal functioning of the entire system, which instead requires interaction and coordination between its components.

SmartMe.IO has evolved its Arancino technology in a full-stack platform meeting several requirements and in particular resilience and sustainability [6]. This platform is based on the so-called transition technologies, i.e., machine learning, software engineering and partly based on the convergence of interdisciplinary subjects (energetics, problem solving, game theory, learning strategies).

The Arancino architecture, already in the course of its development oriented to the objectives of Industry 4.0, has been implemented in analogy to the human brain (Fig. 3) to simplify cloud-IoT interaction, thus facilitating the implementation of Cyber Physical Systems, exploiting edge and fog computing and adapting seamlessly to artificial intelligence and machine learning solutions.

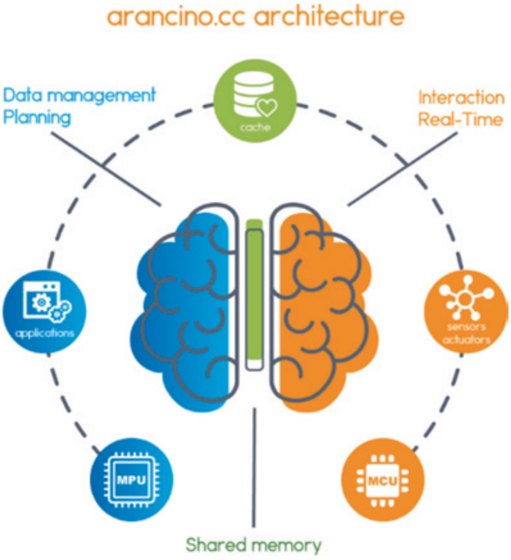
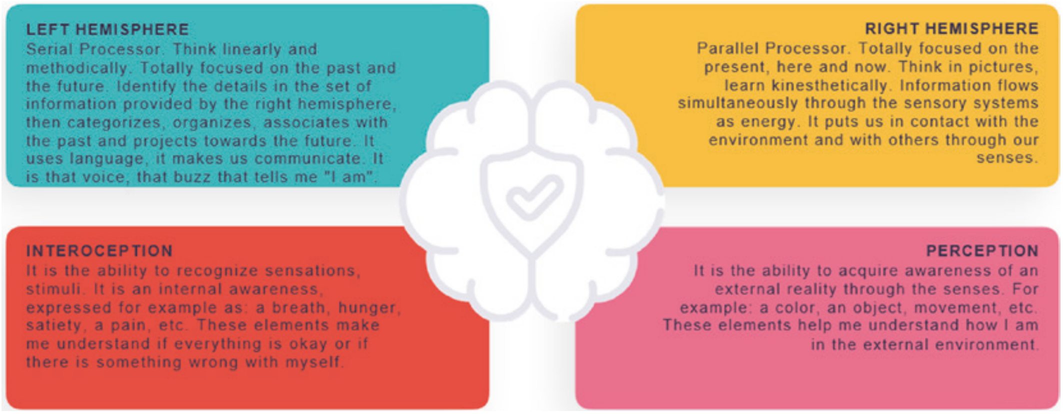


Fig. 3 Analogy between the Arancino architecture and the human brain

The human brain consists of two hemispheres (right and left) that communicate via the corpus callosum. The right hemisphere is specifically focused on the management of the present, collects the stimuli sent by the different subsystems (internal organs, the five senses etc.) and reacts promptly to the occurrence of events. The right hemisphere is dominant in its ability to recognize faces, spatial abilities, and images (Interaction, Real-time). The left hemisphere, on the other hand, maintains the memory of past experience, identifies and catalogs decision-making paths, constitutes the experience on the basis of which to evaluate optimal strategies, helps to create self-awareness, is aware of the state of well-being of the individual parts and plans how to achieve the objectives while minimizing the use of resources. The left hemisphere is therefore dominant for the functions of calculation and logical and mathematical ability (Data Management, Planning). The activity of the two hemispheres is coordinated thanks to the continuous exchange of information that takes place through the corpus callosum, the element that connects them (Shared Memory). The different



LEFT HEMISPHERE
Serial Processor. Think linearly and methodically. Totally focused on the past and the future. Identify the details in the set of information provided by the right hemisphere, then categorizes, organizes, associates with the past and projects towards the future. It uses language, it makes us communicate. It is that voice, that buzz that tells me "I am".

RIGHT HEMISPHERE
Parallel Processor. Totally focused on the present, here and now. Think in pictures, learn kinesthetically. Information flows simultaneously through the sensory systems as energy. It puts us in contact with the environment and with others through our senses.

INTEROCEPTION
It is the ability to recognize sensations, stimuli. It is an internal awareness, expressed for example as: a breath, hunger, satiety, a pain, etc. These elements make me understand if everything is okay or if there is something wrong with myself.

PERCEPTION
It is the ability to acquire awareness of an external reality through the senses. For example: a color, an object, movement, etc. These elements help me understand how I am in the external environment.

Fig. 4 Schema inspired by neuro-biologic systems between the Arancino architecture and the human brain

specializations of the two hemispheres allow them to work together more effectively.

The reference metaphor is that of a living organism, in which sufficiently autonomous functional organs collaborate with each other by exchanging signals through the nervous system, carrying out specific tasks, while being aware of being part of a single system in which collective well-being depends on the correct functioning of the individual components.

Arancino meets (i) resilience because it makes a system able to anticipate, react and learn timely and systematically from any crisis and thereby ensure stable and sustainable performance; (ii) sustainability because it makes a system able to maintain or support a process continuously over time. Moreover, Arancino implements the neuro-biologic approach as the process of self-control motivated and directed by the system itself, inspired by biological mechanisms.

The schema in Fig. 4 connects interoception and perception abilities respectively to the left and to the right hemisphere.

Left hemisphere: Serial Processor. Think linearly and methodically. Totally focused on the past and the future. Identify the details in the set of information provided by the right hemisphere, then categorizes, organizes, associates with the past and projects towards the future. It uses language, it makes us communicate. It is that voice, that buzz that tells me "I am".

Interoception: It is the ability to recognize sensations, stimuli. It is an internal awareness, expressed for example as: a breath, hunger, satiety, a pain, etc. These elements make me understand if everything is okay or if there is something wrong with myself.

Right hemisphere: Parallel Processor. Totally focused on the present, here and now. Think in pictures, learn kinesthetically. Information flows simultaneously through the sensory systems as energy. It puts us in contact with the environment and with others through our senses.

Perception: It is the ability to acquire awareness of an external reality through the senses. For example: a color, an object, movement, etc. These elements help me understand how I am in the external environment.

The concepts expressed so far can be extended to systems (sensors and actuators) deployed in the environment in order to protect it. This essentially means:

- Integrating Cloud and IoT in a continuum
- Fast deployment of monitoring infrastructures
- Specific applications related to new services deployment in peace operations.

According to the previous definition, this smart ecosystem must therefore be able to respond promptly (in some cases in real time) to both external and internal stimuli in order to adapt its functioning to achieve the sustainability and environmental protection goals. Such decisions may be taken, if necessary, by the subsystems independently. At the same time, systems applying the neuro-biologic approach will need to be able to learn from experience (i.e., through machine learning mechanisms). These mechanisms allow them to carry out planned actions and forecasting strategies at the general system level. The ultimate goal is to optimize resources, maximize efficiency, reduce costs considering both internal and external factors (such as environmental impact).

4 Related Work

Johnsen et al. [7] address a scenario where a medium sized smart city in an Alliance nation is struck by disaster. A small multi-national force is deployed to the city to provide relief. The work aims to demonstrate how the challenges could be addressed in IoT applications for a smart city defense operation.

Østergaard et al. [8] highlight the risk that Industry 4.0 would waste the creativity, problem solving and critical capacity of the human being. The consequence would be the failure of mass customization enabled by Industry 4.0 itself. Most importantly, for Østergaard Industry 5.0 represents the return of the human touch in production: the mass customization enabled by Industry 4.0 is not enough because consumers want mass personalization, which can only be had when the human touch returns to manufacturing.

Khare et al. [9] show how the Open Data platform of the #SmartME project has been revised and extended by including a trustless system engaging each stakeholder (the University of Messina, the Messina Municipality, etc.) in the data storage and protection duties. This has been obtained by introducing security features at different levels, and enabling multiple entities and groups to participate at all levels of the data processing and consumption pipeline.

Benomar et al. [10] introduce network virtualization as a fundamental enabler of infrastructure-oriented IoT deployments. The authors present a Cloud-based approach for network virtualization in an IoT context using OpenStack, the de-facto standard IaaS middleware, and Neutron, i.e., its networking subsystem. The authors demonstrate that an IoT deployment without networking resilience and adaptability makes it unsuitable to meet user-level demands and service requirements.

Tricomi et al. [11] focus on how to deal with the case of catastrophic (e.g., potentially disruptive) events. Specifically, they propose a novel software-defined approach for the adaptive management of a Smart Factory infrastructure, centered around business logic rewiring and reconfiguration at run-time across different factory domains.

Pereira Da Silva et al. [12] present a comprehensive understanding of the use of the Fog Computing paradigm in Smart Cities platforms. They provide an overview of the state of the art on this topic also identifying gaps in the existing approaches. Stringent requirements on latency and data processing are challenges in such a context and Fog Computing can support new applications thus increasing volume of IoT data and devices.

Along with its rapid adoption, IoT also creates complex challenges regarding the management of IoT networks due its resource limitations (e.g., computational power, energy, security, etc.). Siddiqui et al. [13] focus on SDN-based IoT management frameworks and provide a taxonomy based on specific categories (i.e., network function virtualization, middleware, OpenFlow adaption, blockchain-based management).

Task scheduling is a critical issue in distributed computing environments like Cloud and Fog in order to provide an optimal distribution of tasks among the resources. Singh et al. [14] presents a comprehensive taxonomic review and analysis of recent metaheuristic scheduling techniques using exhaustive evaluation criteria in the Cloud and Fog environment.

Puliafito et al. [15] discuss the challenges, the state-of-the-art, and the solutions to a set of currently unresolved key questions related to Cyber-Physical Systems and smart cities. The authors identify five main challenges and for each of them the relevant sub challenges and enabling technologies. In particular, the main challenge "human-centric solutions", that is really important for a Society 5.0 scenario, has the sub challenge "involving human-in-the-loop". This in turn requires, among others, the Internet of Skills (IoS) enabling technology.

IoS is introduced in [16] as the next-generation Internet: it combines advanced 5G networking, soft/hard robotics, and artificial intelligence technologies. In particular, artificial intelligence can introduce automation in the orchestration operations, especially at the edge of the network, by injecting intelligence even in the form of plugins or functions as described and supporting time-sensitive distributed decision making [17, 18].

In such a Society 5.0 scenario Cyber-Physical Systems promise to be human-centric, serve human needs, and lead to applications that increase social well-being [19].

5 Integrating Cloud and IoT in a Continuum

The traditional approach to the design and implementation of a system, whatever it is, focuses on the strictly functional aspects. The issues relating to what is "external" to the system or relating to "how" the system is created or its state during operation, are relegated to the application of shared standards or procedures such as general legislation, environmental impact, rules relating to the impact on health, quality assurance, product certification, sizing standards, etc.

An application area of the IoT paradigm is the preservation of environment and living organisms (e.g., bees). By implanting IoT devices, for example for the monitoring of the pollution level, decision makers can take better charge of preserving nature. IoT can be also used in waste management by preventing the abandonment and permanent accumulation of waste (for example bulky waste), as well as the spillage of industrial sewage thus helping us take better care of our environment. Neurobiologic approach activates a series of actions, specifically:

- Considering all the implications
- Comparing risks and opportunities
- Imaging alternative strategies
- Reacting to critical situations
- Introducing proactivity
- Continuous interaction with the environment.

Figure 5 shows the Arancino - Stack4Things® ecosystem integrating IoT and Cloud computing in a continuum. Physical or virtual sensors and actuators work at-the-edge of the entire network. End-nodes are connected by using one or more communication protocols or standards. Among these, MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT). It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. Cloud computing, i.e., hosting and provision of computational and / or storage services offered on request through the internet, is designed as a full-stack solution based on Stack4Things® technology. At the highest level of the architecture, Machine Learning algorithms and Telemetry are designed and provided as hyper-customized services (i.e., ad-hoc designed).

6 Stack4Things® Services

Stack4Things® is an OpenStack[2] based platform [20–22] that aims at extending OpenStack's capabilities to deal with IoT deployments. It is a cloud-oriented horizontal solution that provides virtualization, personalization and orchestration of IoT objects, offering an immediate experience on some of the most popular embedded and

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[2] OpenStack: https://www.openstack.org/.

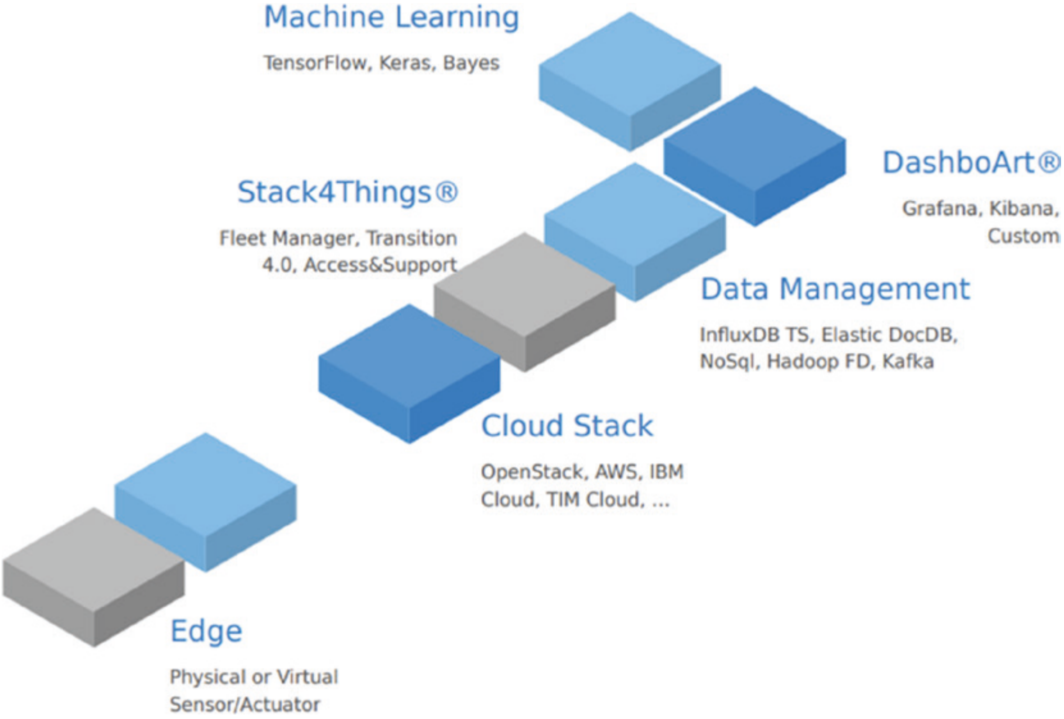


Fig. 5 Arancino - Stack4Things® Ecosystem integrating IoT and Cloud computing in a continuum

mobile systems. The platform allows to design cloud environments providing extreme versatility in cross-platform use, flexibility in data access (time-series and NoSql databases) and control of individual system nodes.

Stack4Things® allows the exchange of information with IoT devices regardless of their location, hardware, software and network configuration. The platform works only on Linux operating systems and has been released under the Apache license.

Figure 6 shows a block diagram in order to help the reader to understand its architecture. The design of Stack4Things® is split into two subsystems: the first is hosted in the Cloud, where a subsystem called **IoTronic** is deployed; the second subsystem is represented by a number of geo-distributed IoT devices that host the Stack4Things® device-side agents, named **Lightning-Rod (LR)**.

The communications between the Cloud-side, IoTronic, and its device-side counterpart, LR, are built exploiting a mechanism based on WebSockets with a reverse tunneling approach that is able to bypass firewall and NAT systems.

The compatibility of Stack4Things® with OpenStack makes the system able to interact with other (OpenStack) services to provide advanced user facing features such as virtual networking and containerized applications at the network Edge. In a nutshell, Stack4Things® provides the support of (among others):

1. **Authentication/authorization**: using the OpenStack identity service (i.e., Keystone), Stack4Things® can manage users' authentication. Besides, the middleware deals with authorizations to access/manage the (remote) IoT devices.
2. **Remote access and management**: using service forwarding through the Cloud, a user can access (e.g., using ssh or vnc) his/her IoT devices regardless of their localization or networking configurations using a (reverse) WebSocket tunneling mechanism.

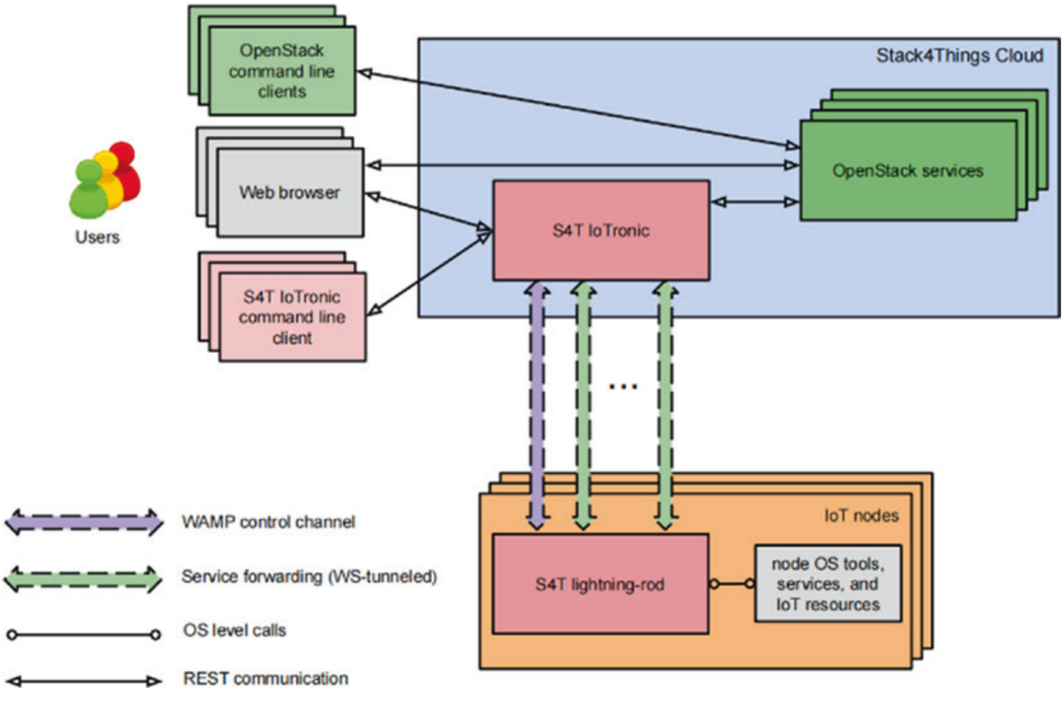


Fig. 6 Stack4Things® (S4T) IoTronic and Lightning-Rod (LR) agents

3. **Remote customization/contextualization**: through Stack4Things®, a user can define, on the Cloud, the application logic in form of functions and deploy them, still according to authorization and privacy policies, even at runtime, on the (remote) IoT devices. As runtime environments, the platform offers the choice between Python and Node.js.
4. **Networking as a service**: using the Neutron OpenStack project it is possible to provide networking as a service between interface devices managed by other OpenStack services. Innovative plug-ins are included in the main distribution and supported by the Neutron community.

6.1 Stack4Things® Virtual Networking

Stack4Things® is used to create virtual networks (i.e., overlays) between distributed IoT devices. Therefore, they can reach each other as if they were on the same physical network (i.e., LAN). To enable this capability, we integrated Neutron, the networking subsystem in OpenStack, with IoTronic. The Stack4Things® Cloud side networking system is illustrated in Fig. 7, which shows a block diagram with two main blocks: the Neutron server and the IoTronic APIs block. We extended the Neutron capabilities to provide networking services for instances (i.e., IoT devices) deployed outside the Cloud (the standard Neutron enables networking services for Cloud-based instances only).

In our approach, we are considering as binding-hosts, where the Neutron L2 agents are running beside software switches, nodes hosting the Stack4Things® WS tunnel agents while the instances are the remote IoT nodes. Consequently, Neutron ports are created and managed on these nodes (i.e., Stack4Things® WS tunnel agents hosts) along with their networking facilities (i.e., software switches).

In our design, the ports are created on the Cloud-side (i.e., WS tunnel agent hosts) yet, they will be attached to our approach instances, which are the remote IoT nodes located at the

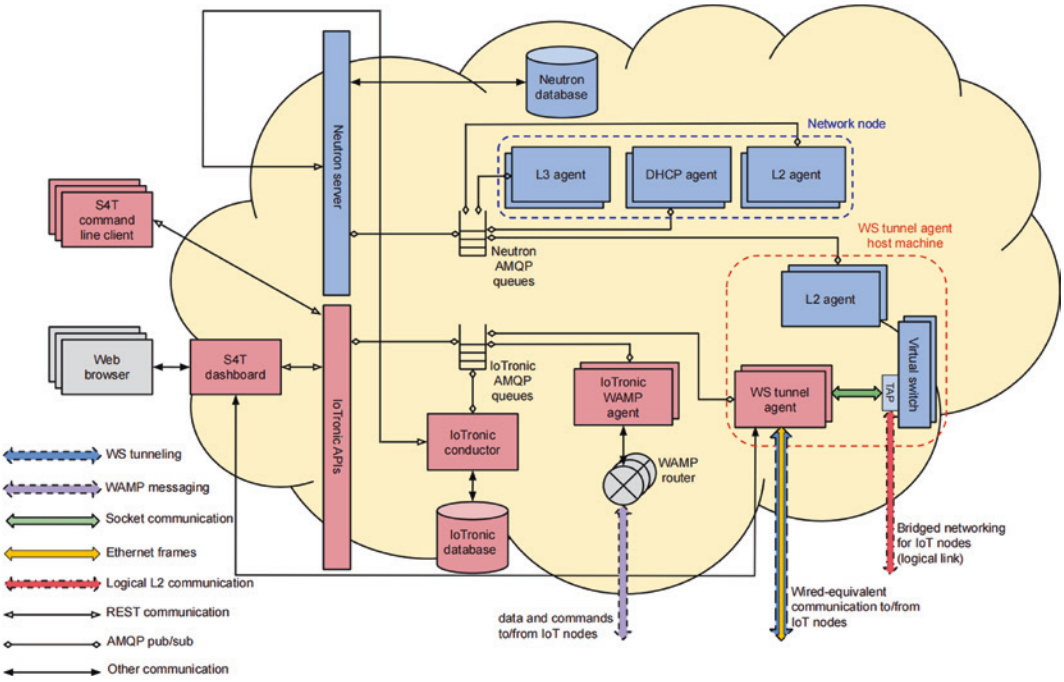


Fig. 7 The Stack4Things® Cloud-side networking system

edge of the network, where Virtual InterFaces (VIFs) get instantiated.

Stack4Things® design has been thought out considering the typical constraints of IoT environments, thereby making the approach versatile and scalable. On the one hand, the edge nodes are not involved at all in most of the network virtualization duties since they are totally unaware about Neutron involvement, thus making the overall footprint of the solution inherently lightweight for them. On the other hand, since L2 agents and switching platforms are running on the Cloud, the approach provides availability for mission-critical Neutron services and scalability for particular hefty configuration requirements.

The device-side architecture is highlighted in Fig. 8. Data and commands to/from the Cloud are exchanged (WAMP messaging) with the Lightning-Rod Engine by using the Stack4Things® WAMP library. The wstunnel plugin allows the wired-equivalent communication to/from the Cloud. Bridged networking for IoT nodes is implemented via Logical L2 communication and via socket communication with the wstunnel plugin. Data are collected from sensors or transmitted to actuators via General Purpose Input/Output (GPIO) hardware interface by OS level calls.

6.2 Stack4Things® Edge FaaS System

Serverless techniques, in particular FaaS (i.e., Function-as-a-Service: FaaS) approaches, can be easily exploited to create IoT slices. Stack4Things® extends the serverless paradigm to the network Edge using the OpenStack FaaS subsystem Qinling. In particular, in order to deploy functions at the Edge on top of IoT devices, Qinling uses IoTronic as the networking driver for the containers (created by Zun [23]). The architecture of the system is highlighted in Figs. 9 and 10.

Zun (ex. Higgins) is the OpenStack Containers service. It aims to provide an API service for running application containers without the need to manage servers or clusters.

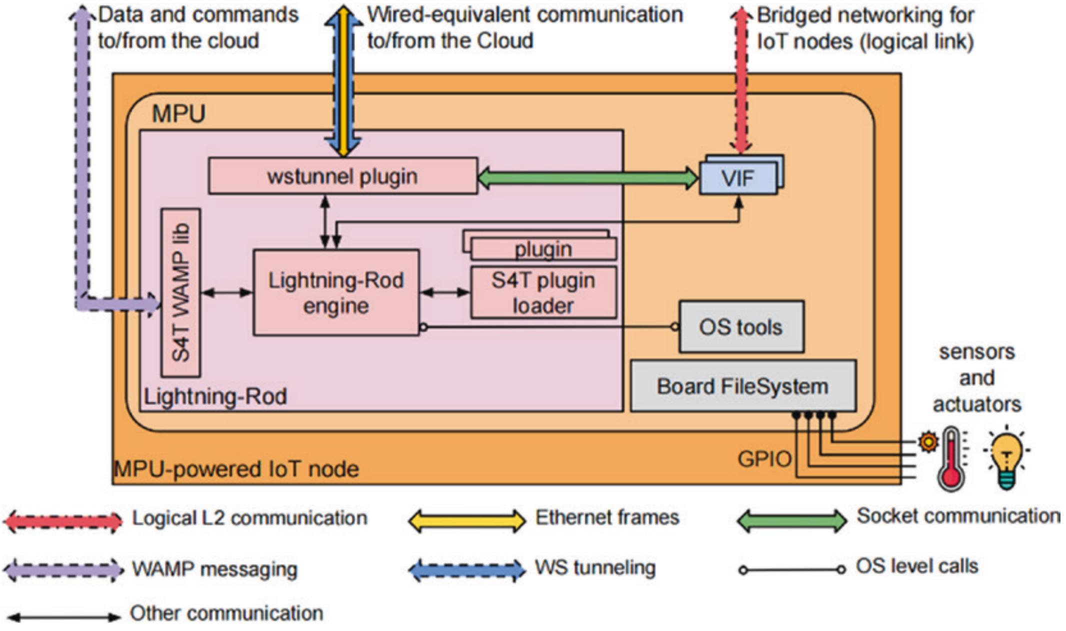


Fig. 8 The Stack4Things® device-side networking system

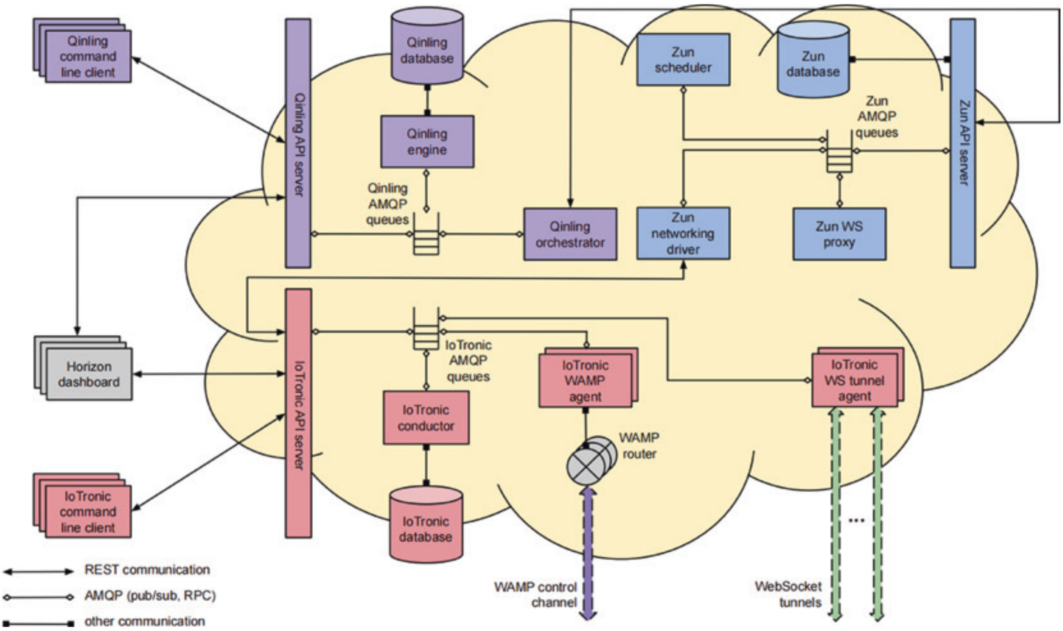


Fig. 9 The Stack4Things® Cloud-side FaaS system

A user, in order to deploy a runtime/function on a particular IoT device, interacts, through the dashboard or CLI, with the Qinling-API server that forwards the request to the Qinling orchestrator. This latter component cooperates with the Zun-scheduler to identify the IoT device where the runtime/function should be deployed; then, the Zun-API server sends a

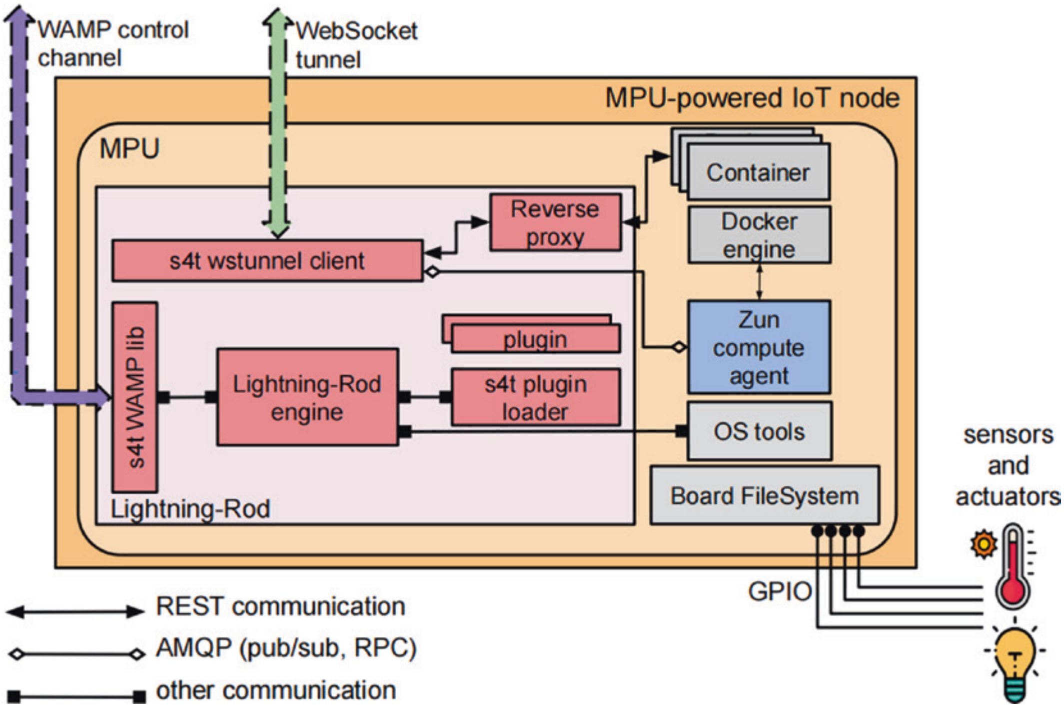


Fig. 10 The Stack4Things® device-side FaaS system

request to create, on this device, the containers needed (i.e., the capsule). To make users able to reach the capsule and in particular, the runtime container, IoTronic exposes it, on the Cloud side, using a public IP address and a port, then a WS tunnel is created between the Cloud and the IoT device. Hence, a request that reaches the Cloud on that IP address/port will be forwarded to the WS tunnel and reaches the device. On the device-side, the request is received through the Stack4Things® wstunnel plugin and forwarded to the reverse proxy that routes it to the correct runtime.

6.3 Stack4Things® Secure Web Services

To merge the cyber-world with the physical one and make IoT an integral part of the Internet, reusing existing Web technologies and standards is a suitable choice. In this case, IoT objects will not be only IP-based devices connected to the Internet, but they become able to communicate/cooperate using the same language. Therefore, they can interact among each other and with other components from the existing Web world. In such a homogeneous environment, smart objects will be able to offer their functionalities (e.g., sensed data) via RESTful Web services (also called Web Application Programming Interfaces (APIs)).

Figures 11 and 12 respectively show the Cloud-side and the device-side web services systems. For example, an embedded system with a temperature sensor that collects measurements from the physical world can provide its real-time sensed data as a smart object service (i.e., a Web service). Therefore, we can build an ecosystem where the smart objects can offer their functionalities as Web services that other entities (e.g., other devices, Web services, applications) can make use of to provide appealing services/applications.

At the MPU-powered IoT node (Fig. 12), data collected from sensors or commands sent

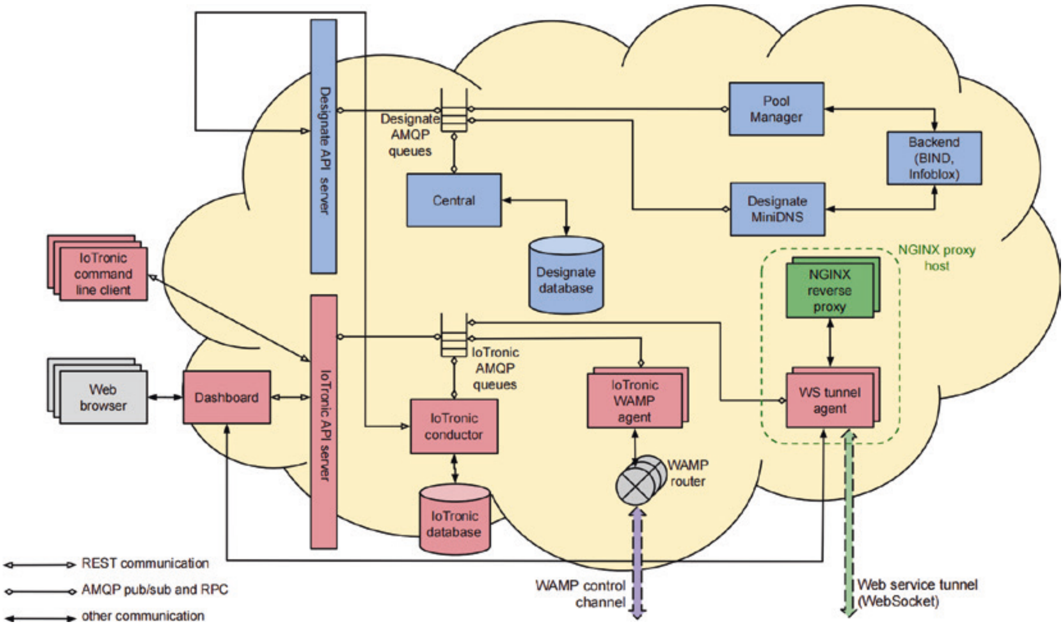


Fig. 11 The Stack4Things® Cloud-side web services

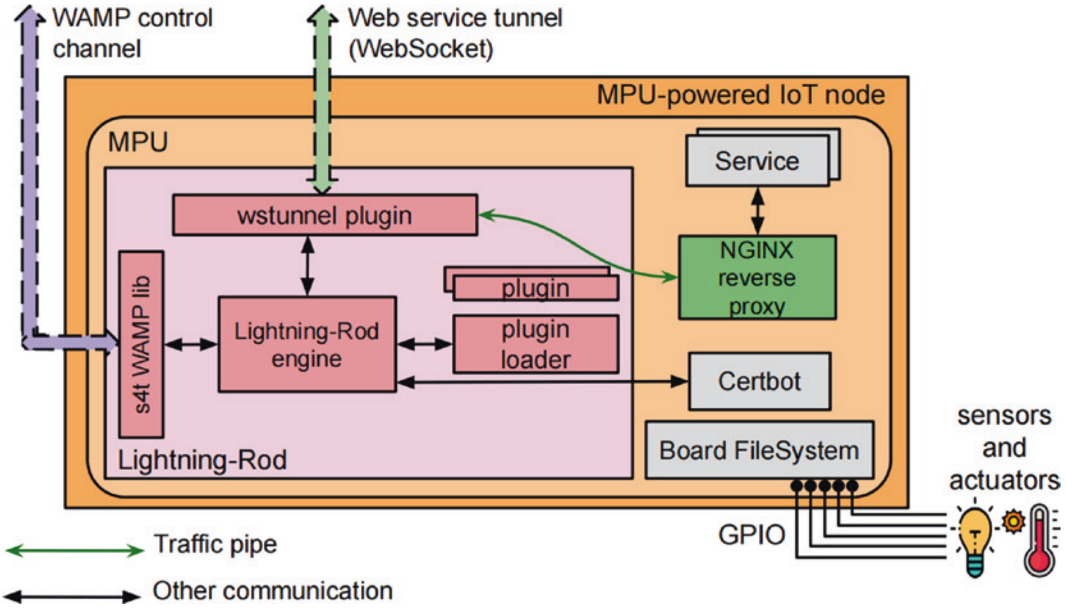


Fig. 12 The Stack4Things® device-side web services

to actuators are managed by the Lightning-Rod engine in form of automated tasks (Certbot). In order to enable secure communication (using HTTPS) between the services and clients, Stack4Things® integrates within the system an automated approach (i.e., without any human interaction) based on the ACME protocol for X.509 certificates issuance and validation. This approach used the Certbot agent with Let's encrypt Certification Authority (CA).

Stack4Things® through the S4T WAMP libraries provides users with the ability to expose services running on the IoT devices to the Web. This is achieved by integrating IoTronic (Fig. 11) with the DNS-as-a-Service system of OpenStack. This latter subsystem manages the records about the URLs associated with the services running on the IoT devices while IoTronic deals with their reachability (i.e., requests routing) by creating Websockets tunnels and configuring NGINX reverse proxies for traffic redirection/forwarding (traffic pipe).

7 Fast Deployment of Monitoring Infrastructures

Starting from the neuro-biological approach introduced in the previous Sections, we can resume the fast deployment of monitoring infrastructures in three main steps (Fig. 13):

- Deployment
- Collection
- Services.

The deployment step mainly consists in the technical setup of sensors and actuators physically placed in the monitored environment. Sensors and actuators are connected by i2c or serial interfaces (e.g., via usb) to the end-nodes at-the-edge of the IoT-Cloud network. End-node devices (e.g., the Arancino boards) are controlled by the on-board microcontroller unit (MCU) and are usually battery powered through low-energy applications (e.g., Bluetooth Low Energy) and low-consumption electronic circuits.

The collection step mainly identifies the communication of the IoT devices with the Cloud. Data collected in real-time from the end-nodes are transmitted through a multitude of wireless technologies (e.g., LoRaWAN™) or by a cabled infrastructure. At the highest level, services that need more computational resources than end-nodes capability are implemented.

Finally, advanced services are deployed on the Cloud so as to automatically provide a feedback to the system. Sensors can be virtualized and services orchestrated in order to optimize management of the computational resources

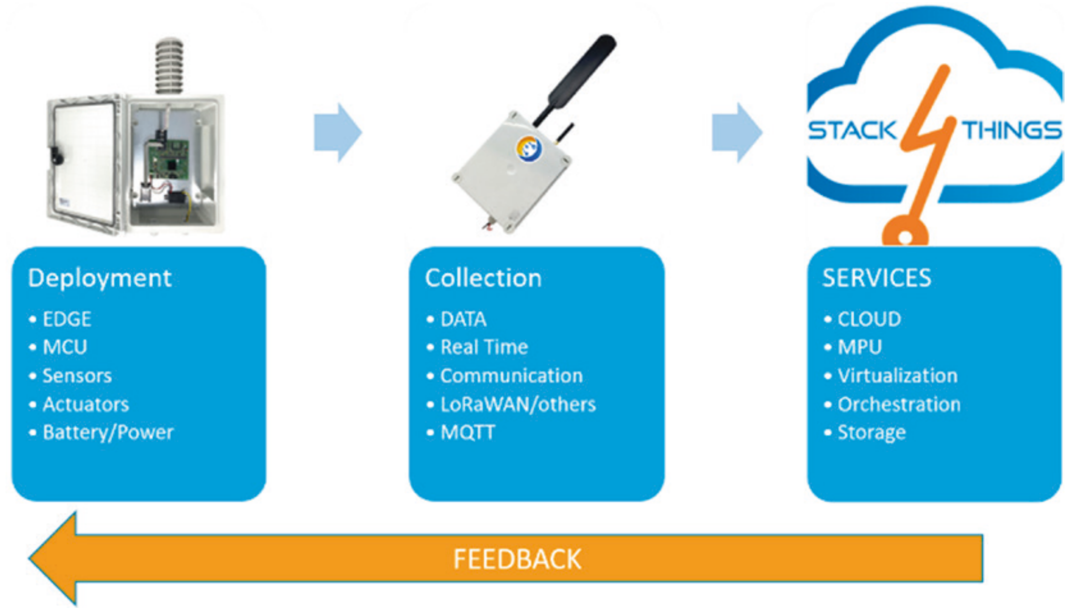


Fig. 13 Fast deployment and operational flow by using the neuro-biological approach

Fig. 14 AIR Environmental Station (SME-ES-02)

Fig. 15 Mobile Environmental Station (SME-ES-03)

(e.g., in terms of efficiency, sustainability and resilience to critical events).

Among the main devices used for the aforementioned purposes we mention the following, equipped with the open source operating system Arancino OS:

1. The AIR Environmental Station (SME-ES-02 in Fig. 14) allows the outdoor measurement of environmental, air quality and meteorological parameters. The relative data, i.e. temperature, humidity, pressure, UV power index and density, brightness, PM1 / PM2.5 / PM10, rain, wind speed and direction, are then transmitted for their visualization and analysis via WiFi mobile connectivity. and (on request) 3G /4G/LTE and/or LoRa® (LoRaWAN™ Class A). Moreover, it can be equipped with Smart Camera for Object counting applications.
2. The Environmental Station SME-ES-03 (Fig. 15) is a mobile monitoring station that allows the indoor measurement of environmental parameters such as Temperature and Humidity, Particulate (PM2.5 and PM10), NO2, O3 and SO2. LTE communication (10uA)+GPS, Expansion cards for sensor stacking. It is powered with a 5 V dc voltage with a customizable plastic encapsulation.
3. The picoGW device (SME-PGW-01) in Fig. 16 is a gateway that operates both on the cellular network (LTE / 4G via SIM and special communication module also equipped with a GNSS geolocation system) and on the LoRaWAN™ network. Its operation is based on the Arancino architecture that offers high availability and scalability at low prices.
4. The AI Smart Camera (SME-AI-01) is a device equipped by the Arancino.AI technology for artificial intelligence applications, including indoor minibox or housing with

Fig. 16 PicoGW device (SME-PGW-01)

IP protection rating for outdoor applications. It works “On the Edge”: all processing takes place on the smart device and no images are recorded or transferred. It has a vision system for the recognition of classes of objects (see Figs. 17 and 18 as an example of monitored pedestrian and vehicular flows). Each class of objects is recognized by its software package. Main characteristics are: Arancino.AI technology, Crowd detecting, Object Virtualization, Overlay networks of things, Remote control and customization, Device Fleet management and delegation, Fog orchestration, Software-defined, Customizable case.

8 Use Cases

In this Section we introduce relevant use cases, the implementation of which is characterized by the use of Arancino and Stack4Things® technologies. Each Use Case represents an experience from which we built the presented

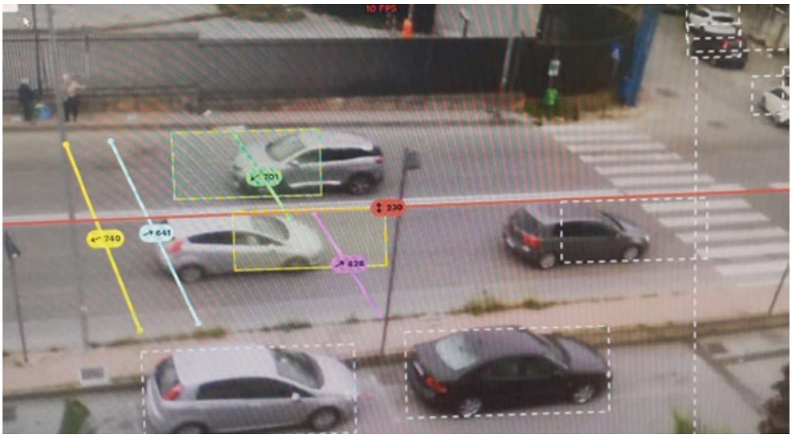


Fig. 17 Monitoring of pedestrian and vehicular flows

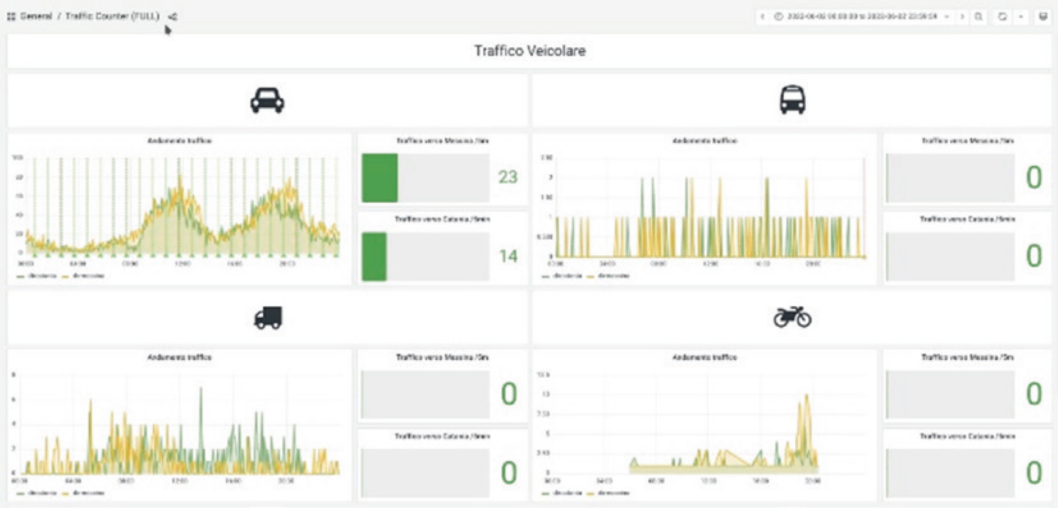


Fig. 18 Traffic counter dashboard reporting both numerical and graphical representation of four different typologies of vehicles

neuro-biologic approach. Specifically, we have overcome some limitations that we detected with a traditional approach to data collection and processing. Among these, the most important limit was recognized to be the focus on objectives concerning only the functionalities of the controlled system, with no consideration of its health and its interaction with the environment where it is located or where it operates.

8.1 USE CASE A: Monitoring of Electromagnetic Field Levels at Radio Base Stations

An interesting application case concerns the Monitoring of Electromagnetic Field Levels at Radio Base stations, in continuous mode and through systems of analysis and correlation of the measured data. The system allows to measure the values of the strength of the electric field E (V/m), in the range of frequencies used for mobile telephony. Low-cost probes are used positioned on the base station (SRB) system. Through correlation algorithms, the system allows to obtain an estimate of the strength of the electric field in sensitive points chosen far from the SRB. From a few measurements recorded at different moments of time, the field radiated in the time domain by the sensors near the base station is reconstructed at many sensitive points in the SRB coverage region. In addition to the recorded measurements, other ''a priori'' information on the plant is also used, such as the patterns of the transmitting antennas, orography of the terrain, urbanization around the SRB as well as the characteristics of the signal transmitted in the sub-band to be monitored.

The solution adopted for monitoring electromagnetic pollution is based on Arancino and Stack4Things® technologies. As shown in Fig. 19 the system involves a star architecture in which a collector (Arancino Gateway) node forms the center to which several end-nodes (Arancino RF Meters) are connected.

Each end-node is equipped with an RF Meter (Fig. 20) for electromagnetic monitoring, with a specific antenna for the frequency range of interest, then it is connected to the star center via a dedicated USB hub. Data acquisition takes place in a synchronized manner at regular intervals. The collector node can perform pre-processing directly on board, then transfer data and results to the Cloud for subsequent analysis.

The RF Meter sensor is a radio frequency power meter capable of covering a frequency range from 1 MHz up to 8 GHz over a range of about 60 dB. Through a suitable external antenna connected to the sensor, the radio signal is acquired and processed. On the collector node (i.e., the gateway) it is possible to read the data of the individual sensors that, with a software-configurable rate (> 0.1 s) perform the radio frequency measurement, apply the tag related to the timestamp, and make the data available to be processed locally to the gateway or send it to the cloud.

8.2 Lesson Learned

In this use case we have experienced the implementation of the above-mentioned neuro-biologic approach in which the microprocessor part was used in order to optimize the arrangement of the sensor nodes (microcontroller part) and a series of metrics such as:

- Number of sensors N or their optimal spacing
- Optimal dimensions in the case of sensors placed at different heights
- Optimal radius
- The number of polarizations to be acquired at each of the measuring points (replicating the sensor: RF meter + Arancino Mignon)
- The sampling time intervals between successive measurements
- The reception bands (filters on the antennas used by the sensor)
- Optimal antenna to use.

The above optimizations are an example of functionality closely linked to the interaction of the system with the environment in which it operates.

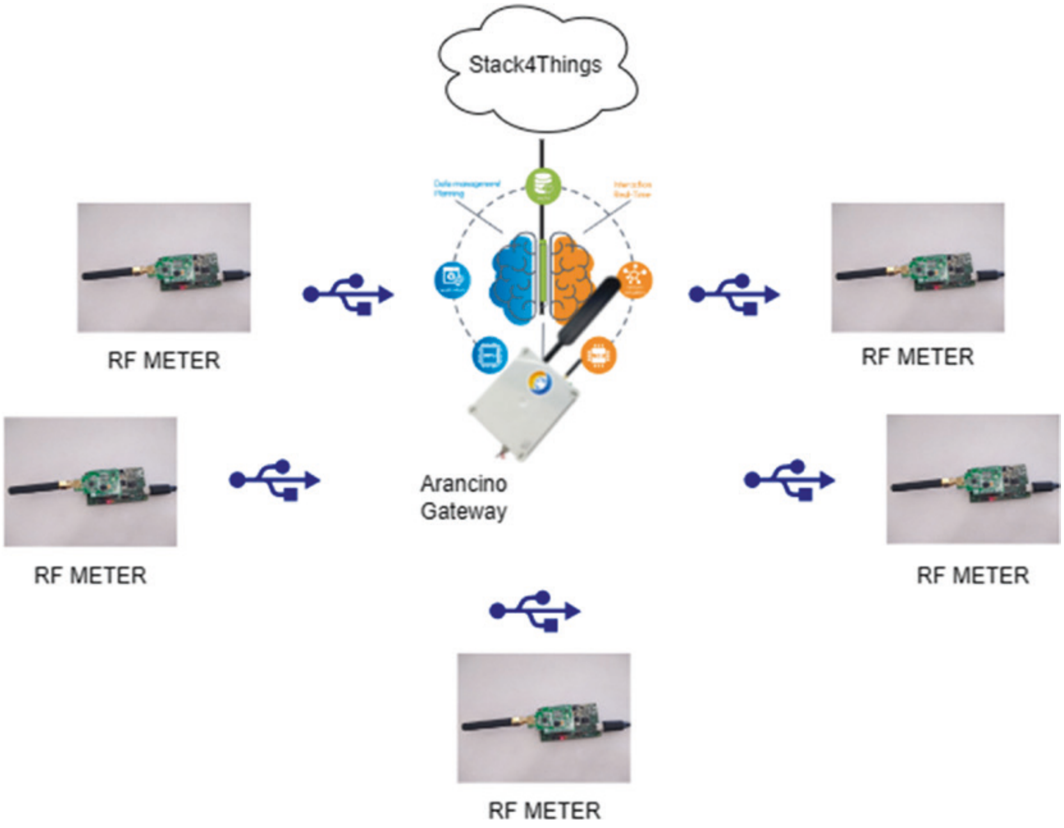


Fig. 19 Star architecture implemented for the EMF Monitoring

Fig. 20 Arancino Mignon end-node equipped with RF Meter sensor

8.3 USE CASE B: Realization of a Landslide and Rock Wall Monitoring System

An important application case is represented by the work carried out for the realization of a landslide and rock wall monitoring system. The system has been designed to identify in real time movements in progress and their space–time variation, as well as the dependence of the movements on the changing weather and hydraulic conditions of the area. The system allows the decision maker to evaluate the influence of external factors not directly attributable to landslide movement, for example microearthquakes. Data collected from sensors are transmitted via LoRaWAN Low Power, Wide Area (LPWA) networking protocol. The LoRaWAN protocol-based data collection device consists of a Transceiver module and a series of inclinometers and crack gauge sensors connected to it by RS485. The RS485 bus requires the sensors to be connected in a chain. Each crack meter is assigned a unique ID used during the data collection phase to send and receive commands. Each LoRa end-node periodically sends the request to each sensor and collects the received data.

Fig. 21 Lorenteggio area in Milan

8.4 Lesson Learned

The importance of this experience is mainly related to the use of LoRaWAN communication with our Arancino-Stack4Things® system. In particular, it was very useful to better understand the impact of the implementation choices in terms of energy consumption. The logic used is:

- To avoid statically associating sensors to nodes
- To reduce acquisition time, limiting it only to connected sensors

8.5 USE CASE C: Implementation of an Interoperability Platform for Future Cities

We present the design and implementation of an interoperability platform based on Arancino and Elastic Stack4Things® technologies.

Specifically, this use case is the application of the Ecosystem for the energy requalification of public lighting systems and related smart services in the Lorenteggio area in Milan (Fig. 21), with the aim of reducing the energy consumption of public lighting networks and installing different types of sensors and technologies typical of an intelligent district (Fig. 22).

Stack4Things® enabled remote device management via the cloud, maintenance, secure end-to-end communication and access to edge systems. The architecture is based on virtualizing the unused desktop resources also organizing them in order to serve the needs of big data processing. More specifically, the Elasticsearch-Hadoop (ES-Hadoop) connector has been implemented in order to get quick insight from big data and makes working in the ecosystem even better.

In particular, the platform implements:

- Intelligent lighting system that allows the adjustment of the intensity of public lighting. This is possible thanks to the combination of several parameters, monitored by the system itself, including traffic intensity, the presence of pedestrians and weather conditions. The adjustment of the light intensity can also take place remotely by the operators, through a dedicated dashboard that shows a summary view on the status of the equipment.

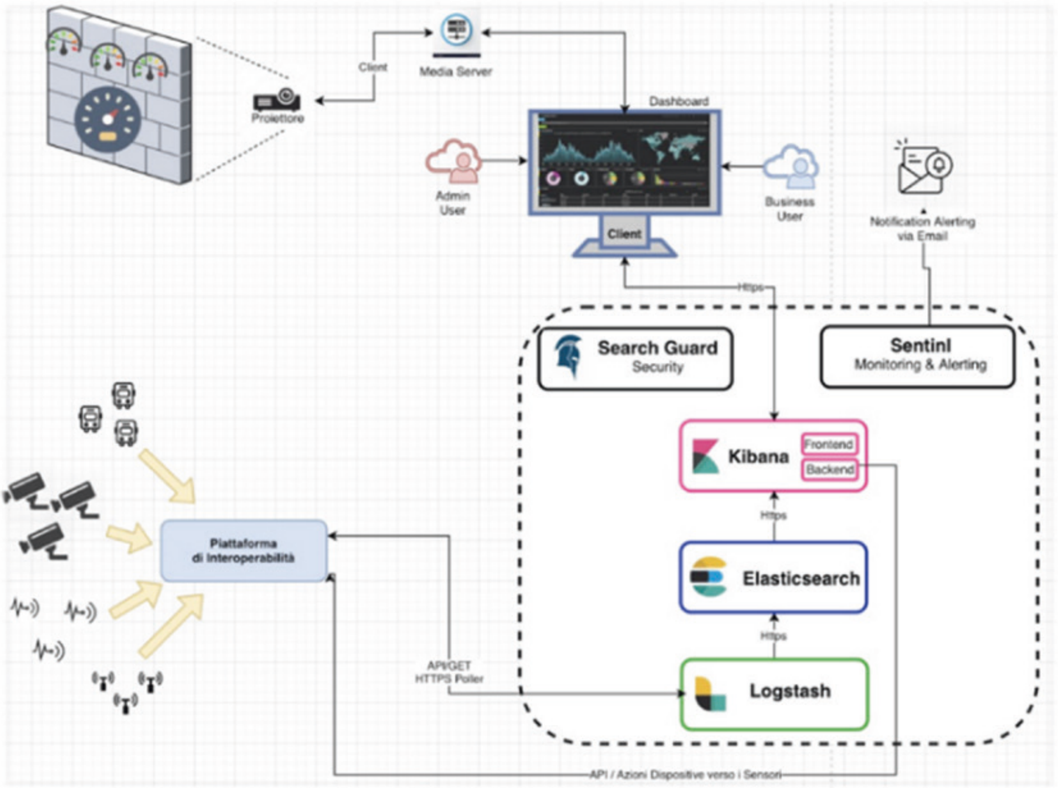


Fig. 22 Elastic Stack4Things® interoperability platform

- A system integrated in Open WiFi Milano for the public and free dissemination of the Internet signal.
- Cameras integrated with the city's video surveillance system, whose images are transmitted to the operations center of the Local Police.
- Smart cameras for video analysis.
- Environmental sensors for monitoring the level of electromagnetic emissions.
- Sensors for monitoring the status of parking spaces.
- Sensors for controlling the filling level of waste bins.
- Smart microphones for recognizing loud noises.

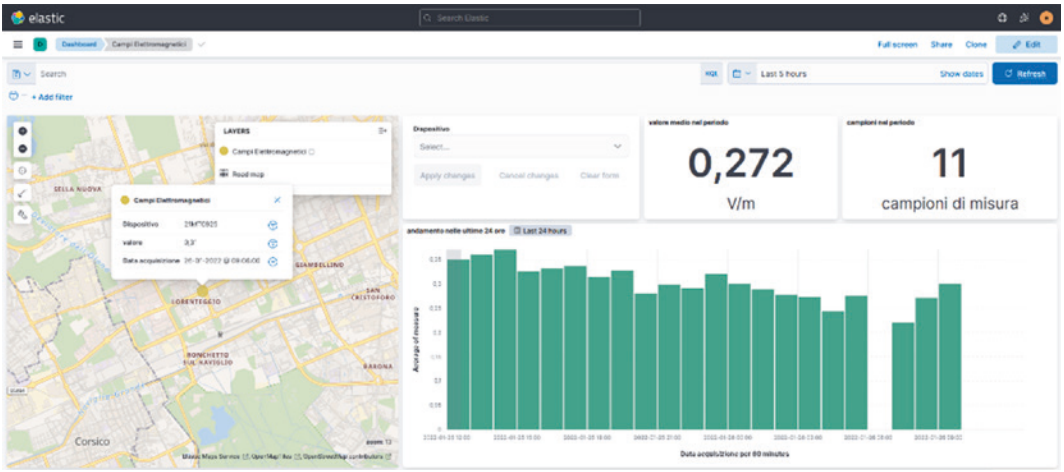
The information listed above is displayed on a single dashboard for use by operators and with specific views based on the profile. Figure 23 shows the dashboard for the monitoring of the level of electromagnetic emissions.

8.5.1 Lesson Learned

The above-mentioned use case is the first integration of Elastic and Stack4Things® technologies. With the final goal of further interconnecting People, Government, Businesses and Industry, the project introduces the role of interoperability to shape the Society 5.0 paradigm by enabling a human-centric and resilient society.

8.6 USE CASE D: Infrastructure Monitoring

A leading company in the field of technological innovation has developed an innovative system of diagnostics of stability and/or compliance with the architectural model of buildings, such



Last 5 hours

Dispositivo: Select...

valore medio nel periodo: 0,272 V/m

campioni nel periodo: 11 campioni di misura

Fig. 23 Elastic Stack4Things® Interoperability Platform

as roads, tunnels, bridges, pylons, antennas and other structures. As well as public and private buildings, rocks, soils and natural sites can be considered in order to identify any critical issues, in place or over time, about endurance and stability. SmartMe.IO has designed, developed and created the Gateway level of the system and the related interfacing modules for data processing and the Cloud.

8.6.1 Lesson Learned

The experience of SmartMe.IO in this field is very important: the development of new functionalities of the Iotronic platform, lightning-rod (LR), and the integrations to the Iotronic-dashboard (i.e., the main software components of Stack4Things®) are a clear example of software customization finalized to measure resilience in infrastructure in terms of both direct and indirect impacts. These include resilience to sudden shocks (e.g., disaster resilience) and to slow-onset impacts (e.g., climate change) and indirect impacts (e.g., pollution).

9 Conclusions

SmartMe.IO has focused its strategy on Future Cities and Communities issues, specifically in order to satisfy several objectives in terms of resilience, sustainability and creativity requirements. Prevention strategies are mandatory for Public Administrations and businesses in order to protect the health of citizens and to improve the quality of life. In such a context a fast deployment of monitoring infrastructures is mandatory and a human-centered approach is important to achieve a resilient society where humans, nature and technology create a resilient and sustainable balance enhanced by data. In this Paper, we introduced the SmartMe.IO vision. Specifically, we presented how SmartMe.IO has evolved the Arancino and Stack4Things® technologies by implementing the neuro-biologic approach. Specifically, we highlighted how IoT and Cloud can be integrated in a continuum to quickly deploy a monitoring infrastructure. Moreover, we presented the use cases that we consider the most important experience that drove us to adopt a new neuro-biologic approach to develop new proactive IT systems. Future works regards the research and development of new intelligent software agents to deploy customized solutions for both industries and smart cities contexts. The goal is to evolve the actual Arancino-Stack4Things® ecosystem as a common platform extended to new smart applications based on Artificial Intelligence and Blockchain technologies for predictive maintenance, traceability of products (especially in the agrifood chain), quality of production cycles and citizens' quality of life.

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