Real-Time and Near-Real-Time Services in Distributed Environment for IoT – Edge – Cloud Computing Implementation in Agriculture and Well-Being

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Abstract. Well-being and agriculture works of people living not only in villages but also in towns nowadays, the healthy living environment at home, in the park, in the sports center, at work, local and remote monitoring of different parameters of the body, house, garden, the greenhouse is a matter of increased interest from families. Regardless of the size of the family, garden, villas, and fields, there is a need for support of integrated smart services in real-time and near-real-time forming an adaptable family software-defined Personal Enhanced Living Environment 4.0 network configurable on the top of the existing public and private infrastructure. The scale of the network, the variety of Internet of Things parts, and the distributed edge and cloud computing services that are fragmented nowadays need to be integrated. The raw data created, data storage and data processing require a common edge-to-dew-to-fog-to-cloud approach and clear correlation to the related sectors such as water, land, house, factory, environment, parks, and infrastructure management. In this paper, an integrated approach toward services for different types of users based on the previously defined scenarios is presented. The services are software-defined and use existing infrastructure orchestrated resources that are unified, and allocated appropriately to support the functional and non-functional requirements. Private and public parts of the data, data flows, data space, and capacity for processing are considered.

Keywords: Sensors · Data sharing · Edge · Dew · Fog · Cloud computing technologies · Smart agriculture · Smart cities · Smart home · Smart well-being

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1 Introduction

Nowadays the work of the so-called smart systems is specific with its fragmentation. Regardless of using cloud services and the Internet of Things (IoT), devices the applications are separated and do not exchange data with few exceptions. The requirements of the market for an integrated simple and highly customizable service for a Personal Enhanced Living Environment are high. However, the Personal Enhanced Living Environment 4.0 should be integrable, sharing, importing, and exporting data with a clear view of the privacy of the data. It is also expected to be distributed by nature and uses: 1) local, smart dust level computing facilities like gateways and controllers for different sensor devices at home, park, field, and factory; 2) dew computing level facilities such as home computers, tablets, smartphones; 3) fog computing facilities formed by the regional data centers; 4) cloud computing facilities formed by the global data centers [1]. In many papers, the smart dust and dew computing levels are covered by the common term edge computing. In some papers, even fog computing infrastructure is considered as part of the edge. The distribution of the data, data flows, clear identification of the private and public data, resources to be used at different computing levels, and orchestration and sharing of these resources are a matter of intensive development [2]. The new paradigm of distributed resources orchestration is expected to allow fully distributed processing of the data and better utilization of the network nodes.

Well-being is a term that is considered often to be related to the Body Area Networks and body monitoring in general. However, in the context of this work, the term is enhanced with new features related to the living environment, and many things known as home automation, building automation, and smart agriculture. Smart environments and smart cities influence the complexity of the services prepared for the well-being platforms. Very often such platforms are also considered to be data-driven [3, 4], i.e., changing behavior depending on the data.

Another important point in the creation of the services for the Personal Living Environment 4.0 is the distinction between the real-time and near-real-time services for the customers. The term real-time is tricky and is interpreted by different authors differently. In this paper, there is a definition of services based on a clear explanation of the real-time requirements with a limit of round trip delay of 150 ms. This is the perception of the human beings for the delay. One could say that a service is offered in near-real-time when the round trip delay is close to 150 ms, i.e. up to one second. All services with a round trip delay bigger than one second are considered to be working in non-real-time.

Finally, the new services could not be developed without the digitalization of sectors that feed the Personal Enhanced Living Environment 4.0 with multidisciplinary data. However, many of the sectors are still too fragmented and use proprietary technology solutions.

The structure of this paper contains a literature review of the recent papers in the field, a clear classification of the end-users of the platforms and expected services, classification of the services based on the functional and non-functional requirements and scenarios investigated, possible network architecture and technologies to be implemented and preliminary results in the controlled and real environment.

2 State of the Art

The new term Personal Enhanced Living Environment 4.0 that is proposed in this paper is an extension of the previously well-defined platforms for Enhanced Living Environment, Ambient Assisted Living, and Personal Defined Networks. Many details of such a platform are already defined and worldwide experimented. However, the existence of a sustainable and customizable integrated solution is still missing. The main problems are the fragmentation of the business, different levels of digitalization of the sectors, the use of too many proprietary solutions, and the lack of appropriate data sharing rules between systems and platforms.

In this paper, there is a trail to integrate different proprietary and non-proprietary solutions, create circumstances for data sharing, distributed resource orchestration, and allocation, and distributed data storage and processing.

The integration of the agriculture and living environment will require the use of short-range and long-range sensor technologies. Data collected is often missing, corrupted, or late and appropriate processing could suffer from the lack of data and processing capacity.

The existence of Long Range (LoRa) sensor technology is already proven to be implementable in the open space environment like sea coast, crop fields, meadows, forests, rivers, and smart cities [5]. The range of the technology is about 40 km. However, the limits in the power of transmission have happened to shorten this distance. This is the case in Europe. To avoid the development of infrastructure in rural places or in places where installation is almost impossible, part of the equipment and especially the gateways and controllers are developed to fly on drones or be carried by mountain vehicles, or transported by boats, or trucks.

The efficiency of the sensor implementations in agriculture is of vital importance as it reflects the water use and reuse, smart ways to grow crops and manage the production, prediction of possible disasters, and ways to avoid disasters, i.e., making the agriculture more sustainable [6, 7]. A rich analysis of the possible scenarios in smart agriculture could be seen in [8]. The work combines the use of different fixed and mobile approaches for data collection, the possibility to monitor different parameters of the crops, and has an implementation of artificial intelligence in data processing. The proposed in this paper modular approach to making the gateways interoperable with multiple sensor technologies at the same time is more universal. A similar approach toward smart agriculture is also presented in [9].

A rich analysis of the climate influence on smart agriculture is presented in [10]. The vast implementation of artificial intelligence in data processing and data correlation is well demonstrated.

The problems in the typical living environments seem not to be similar to the ones in smart agriculture [11, 12]. In many cases, the sensors are working in short range and the transmission power could be limited easily. However, when the Personal Enhanced Living Environment 4.0 is distributed towards the parks, public transport, yards, and shops the problem with infrastructure interoperability, the distance of the transmission and collection and sharing of different types of data is again a matter of high importance. The aim is also to go further and create a cooperative solution for living and working environments as they could not be separated so easily during the last pandemic years because most of the people work from home.

The problems in urban environments as in smart cities [13] are in the existence of too many and highly dependable parameters of different systems that could be analyzed. This creates circumstances for the use of multiple often diverse solutions. An approach to the data analyses is presented in [14]. The approaches require often the processing of the images obtained from different sources and careful correlation between the data obtained from the image analyses as seen in [15].

Work with medical devices, the necessity to use the network for healthcare is analyzed in many papers over the last decade such as [16]. Implementation of machine learning in activity recognition is demonstrated in [17]. Enhanced Living Environment platform architecture and testing could be seen in [18] and [19]. General approaches to the definition of IoT scenarios are taken into consideration in [20].

3 Users' Requirements

The requirements of the users towards their personal defined network are usually high and depend very much on the culture, background, traditions, and habits of the people. The living and working environment is always expected to be comfortable and to consider additional features of life and work. The personal environment is part of the living and working environment of the people in the house and colleagues in the office. Therefore, data sharing and data correlation between different parameters need special consideration. The idea for Enhanced Personal Living Environment 4.0 is presented in Fig. 1. The proposal is to create a circumstance for the use of the integrated approach from any place and at any time, i.e., transparent in space and time.

Recently, thanks to the vast digitalization of different sectors and increased use of IoT and cloud computing in houses, companies, parks, and factories it is possible to define and specify the requirements and main functions of platforms such as Living Environment 4.0, Working Environment 4.0, Personal Living Environment 4.0. The requests from the market for such a service are high. However, the solutions offered are still fragmented and proprietary by design without an appropriate level for data sharing and data correlation.

Many of the services in the Personal Enhanced Living Environment 4.0 have to work in real-time, while quite a big amount of services also work in near-real-time. The meaning of these terms depends very much on the context to be implemented. For example, the alarms for falling, fires, floods, and high personal temperatures are expected to be created and processed in real-time. Parameters like temperature in the garden, soil humidity, and particle matters in the room and street might be detected and monitored in near-real-time. It is important to mention that in many cases the limit of 150 ms is relaxed. There are many examples such as Voice over IP communication, sensors-to-cloud communication, sensor-to-server communication where the limit could be up to 5 s, and even more. Many IoT implementations when the sensors are sleeping exchange the data within the intervals of 5 s due to the specific features of the technology.

Fig. 1. The idea of the enhanced personal living environment 4.0.

All services need to be supported transparently in space and time using standard interfaces, protocols, and data formats, i.e., Wi-Fi, 3G, 4G, Ethernet, 5G interfaces, MQTT (Message Queuing Telemetry Transport), or similar protocols, and JSON (JavaScript Object Notation) or other similar data formats.

4 Primary, Secondary, and Tertiary Users

The classification of the users is an important issue as they will require different functionality and be implemented over different infrastructure facilities and resources. From the point of the service use, one may distinguish three types of users: primary, secondary, and tertiary.

Primary users are direct users of the services provided. These are people and their living and working environment. They also have:

- Their own Personal Enhanced Living Environment for the body
- Optional Personal Enhanced Living Environments of their relatives/ patients for the doctors and caring people, customers for management of specified part of the data
- House living environment access
- Garden living environment access
- Working living environment access
- School/shops, other public places living environment access
- Car/ infrastructure living environment access

Primary users could support:

- Partial orchestration of resources
- Import of common data
- Export of part of their private data

Secondary users have the same functionality as the primary users having additionally the possibility to extend the monitored devices and persons such as family members, colleagues, places, environment, and devices. Secondary users have:

- Their Enhanced Living Environment
- Personal Enhanced Living Environments of their relatives/ patients for the doctors and caring people, customers for management of specified part of the data
- House living environment
- Working living environment
- Car/public transport infrastructure living environment

Secondary users should support also data sharing on their data and the data of the monitored people and network places.

Tertiary users have additional roles in configuration management, support, insurance management, social analyses, medical data analyses, and public services analyses made for the communes, governmental and non-governmental organizations. Their network should support;

- Their Enhanced Living Environment
- Personal Enhanced Living Environments of their customers for configuration, statistics, management, monitoring of part of the data
- Infrastructure use and resources orchestration
- Infrastructure development
- Definition and specification of policies for infrastructure development and use of data

Tertiary users share data on the infrastructure, many types of publicly available data for the climate, infrastructure, facilities, utilities, community policies, etc.

5 Scenarios Implemented at IoT Level

Last decade many scenarios on the IoT level have been implemented in diverse fields and sectors. In [21] and [22] there is a detailed scenarios' specifications for the home, person, and garden management. All scenarios are explored in a real environment. Scenarios are classified here for simplicity and used for the service creation process as well.

Groups of scenarios to be implemented in the Personal Enhanced Living Environment 4.0 platform are classified shortly in next sections.

5.1 House Automation Management, Office/ Factory Building Automation Management, Crops Management in the House, in the Greenhouse

Common devices to be implemented in the house and garden could be summarised as doors and windows guarding, security systems, and utility devices for electricity, water, and gas supply. The results expected are data and appropriate visualization of the data for monitoring and management as well as setting of appropriate alarms for power failures, fire, flooding, gas leakage, etc. Implementation of the machine learning on the data collected at dew, fog, and cloud computing level could lead to the prediction of alarms and raising/decreasing of alerting level to the end-users.

Many parts of the rooms in the houses and offices and halls in the factories could be a matter of passive and active monitoring and management as lamps, recuperators, heaters, coolers, humidifiers, dehumidifiers, purifiers, curtains, windows, doors, sockets, air quality sensors, and many others.

5.2 Crops Management in the Yard, in the Park, in the Fields

People in the villages, people living in the houses with yeards grow different crops. The Personal Enhanced Living Environment 4.0 implementation needs to be extended by IoT solutions for crop management in short and long distances. The water supply system may work depending on the environmental conditions such as sunlight, rain, the humidity of the air, soil, type of the soil, type of crops, and many others. Water sources need additional management for the levels, capacities, number of pumps, electricity supply, type of sensors and actuators implemented, etc. Additionally, the monitoring services could be optimized based on machine learning and passive/active on-site experiments. The aim is to optimize the use of energy, water, and electricity and reach an efficient and sustainable solution that is specific for every customer and climate zone.

5.3 Healthcare Scenarios

Scenarios for healthcare implement sensors for both parameters measurements and management as well as the definition of different levels of notifications, messaging, alarms, and reports of the person under care. Types of the sensors could be classified into sensors for the body parameters (blood sugar, temperature, skin resistance, activity) and actuators for management such as panic cords, voice commands, noise sensing, alert levels, etc.

6 Functional and Nonfunctional Requirements of the Personal Enhanced Living Environment 4.0

The data collected from different parts of the distributed environment could be a matter of additional analyses and additional functions could be defined accordingly.

The main functional requirements of the Personal Enhanced Living Environment 4.0 could be summarized as:

- measuring data
- monitoring data
- reporting data
- storing data
- processing data
- correlation of data
- visualization of data
- export of data
- import of data
- transformation of data
- verification of data
- validation of data
- comparison of data
- prediction of events
- analyses of events
- creation of alarm
- notification
- acknowledgment requests
- request for data
- hiding private data
- sharing public data
- collection of resources
- orchestration of resources
- allocation of resources
- unification of resources
- release of resources

Non-functional requirements could be summarised as making the Personal Enhanced Living Environment 4.0:

- adaptable and scalable
- identifying resources
- having policies for resource allocation and release
- keeping the performance parameters

- identifying the missing data, missing parameters, and missing parts of the infrastructure
- being capable to perform a self-test of the infrastructure
- having self-configuration capabilities.

7 Services for Primary, Secondary, and Tertiary Users

Services for the primary, secondary, and tertiary end-users are different. While the basic services are directly related to the functional requirements the added value monolithic services are combining many features and functions with the data from the existing infrastructure. Therefore, some additional services could be defined as additional functions of the platforms such as:

- Analyses of the efficiency of the electricity use
- Redistribution of the electricity using predefined algorithms or machine learning algorithms
- Security smart service
- Added value smart service for the garden and crop fields that are specific to the crops and environment
- Additional services for the thermal comfort of the crops in the greenhouses
- Value-added service for the light control
- Value-added service for the air quality
- Smart care adaptable services controlling medicines, body parameters, additional prescriptions, activities, training, dietary prescriptions
- Value-added multicast services for alarms and alerts
- Services for the control of the swarm behavior

In Fig. 2 the main menu for the main agriculture management service is shown. There are submenus for the management of the greenhouse, irrigation system, water supply basin, greenhouse heating system, environmental parameters for the yard, and the technical parameters of the sensor IoT network. In the figure, the Signal-to-Noise Ratio (SNR) and Received Signal Strength Indication (RSSI) are related to the quality of wireless connection to the sensors.

In Fig. 3 the submenu for the greenhouse is presented with measurements of the temperature and relative humidity (SM or soil moisture in the figure).

Services for the secondary users are enhanced by possibilities to:

– add additional persons for monitoring
– drop persons for monitoring
– add a place for monitoring
– drop a place for monitoring
– activate/ deactivate service
– share data

- define policies for data sharing
- import data
- perform additional data visualization and analyses
- manage alarms and events
- implement machine learning for the prediction of events

Services for the tertiary users are mostly related to the:

- data visualization
- data correlation
- data collection
- data analyses
- policy definitions
- policy implementation
- data validation
- data sharing
- correlation between the data and legislation
- service adaptivity and sustainability
- service scaling

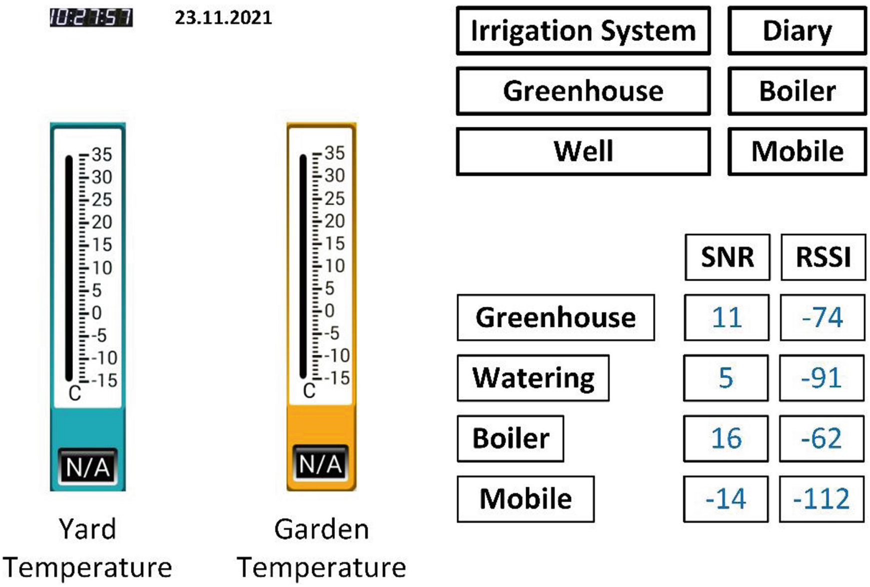

Fig. 2. The main menu of the greenhouse IoT system management.

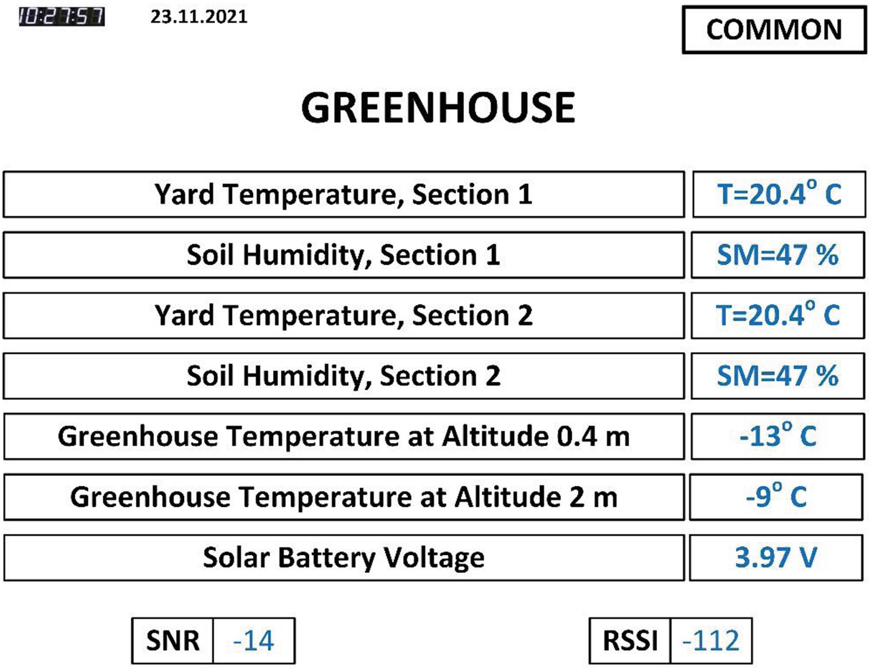

Fig. 3. Greenhouse submenu.

8 Network Architecture

The network infrastructure is heterogeneous and supports both functional and non-functional requirements for the services. The adaptivity and the performance of the services depend very much on the existing infrastructure. The main home implementation with ZigBee and EnOcean sensors is presented in Fig. 4.

The edge/smart dust-to-dew-to-fog-to-cloud computing is presented by sensors, gateways, controllers, local servers, and Internet connectivity.

The software-defined and personal-defined networks on the top of the existing infrastructure have an interface locally or through the Internet using fixed or mobile devices. Data flows, data storage, and data processing are distributed among network devices.

Figure 5 presents an automation infrastructure for the greenhouse, water irrigation, water supply, boiler for water heating, and mobile computing devices.

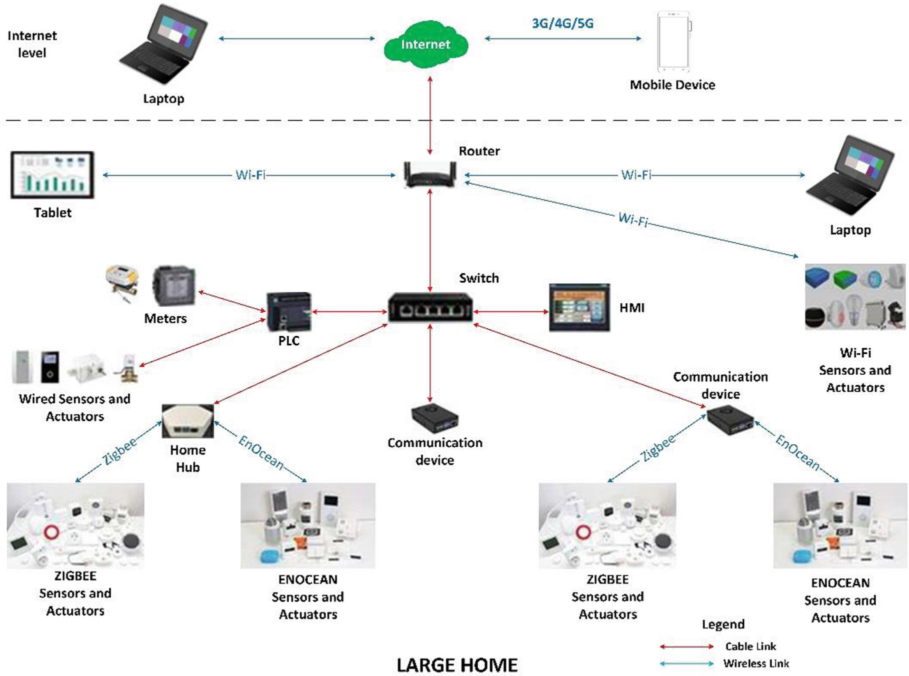

Fig. 4. Home automation infrastructure (PLC - Programmable Logic Controller, HMI – Human-Machine Interface),

The presented Personal Enhanced Living Environment 4.0 platform has currently more than 500 sensors of different types and technologies, fixed and mobile gateways, some of them flying on a drone, controllers, and local and remote servers for data storage and processing. It is capable to raise alarms, uses the algorithms with the parameters obtained by the machine learning algorithms, monitors the infrastructure for its performance parameters such as batteries levels, link quality (Fig. 6), telegrams delays, telegram losses, validates the vitality of the data collected and is capable to predict some events as increased consumption, non-typical behavior, the necessity for reaction, lack of notifications and many others.

There is a need to mention explicitly that the validity of the data from sensors and removal of the outliers in the time series obtained from the sensors is also an important topic. It is expected that the data acquisition algorithms and machine learning classification algorithms could support the creation of a valid data sets at the edge. Creation of ontologies like SAREF (Smart Applications REFerence) and woking on a common data representation formats like JSON (JavaScript Object Notation) aim to support the standardization process of the data representations, flows and storing and enforce the data sharing.

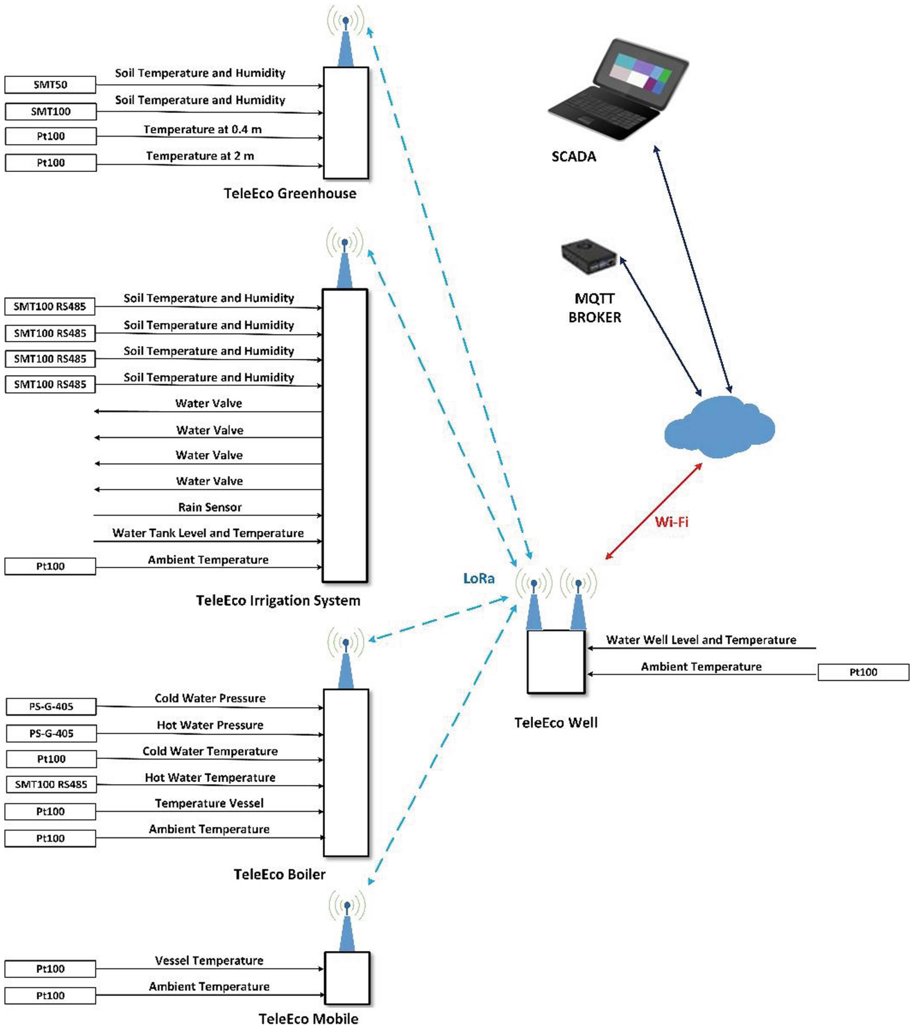

Fig. 5. Garden automation (SCADA - Supervisory control and data acquisition).

Reservation of the connections is another important issue in the technologies presented. Most of the sensors are working in multicasting mode or in a mesh retransmission mode. This is the natural sensor technologies way to support connectivity reservation. Some of the sensors are working in point-to-point mode. There is no reservation in the connections in these cases. However, the variety of the sensors, the multivariate analyses, the data dependencies and/or machine learning and data acquisition algorithms are capable to solve the problem of missing data.

There is yet another way to support data reservation on the fly using so-called peer ports at application layer. The technology is implementatble at the edge, fog of cloud computing level.

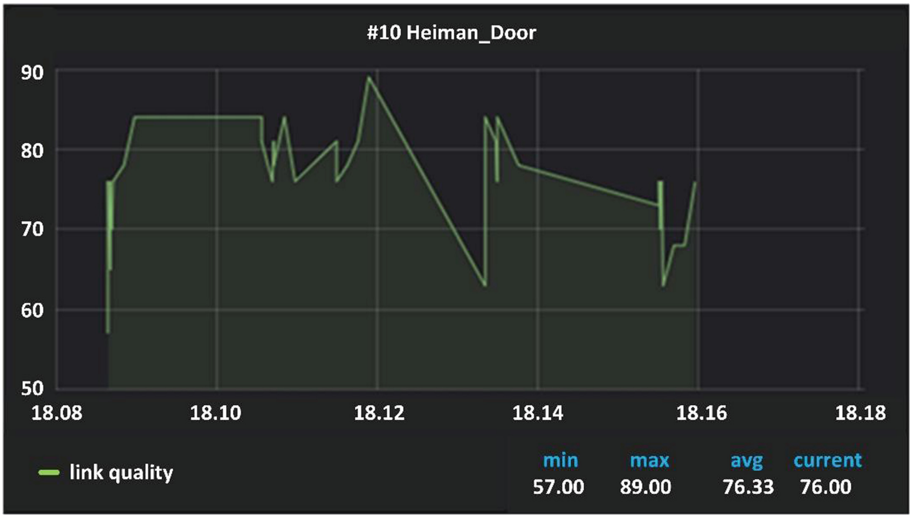

Fig. 6. Link quality to the sensor of a door, SNR between 6:08 and 6:18 pm.

9 Conclusions and Future Work Plans

Services in the Personal Enhanced Living Environment 4.0 have been highlighted and classified towards primary, secondary, and tertiary end-users, real-time and non-real-time performance, and distributed orchestration of the data at the smart dust, dew, fog, and cloud computing. All services are based on the experimented scenarios and added value services have been identified based on the results from real environment implementations. The aim is to create more smart services based on machine learning algorithms that could predict events and manage risks in the distributed environment and implement also the distributed resource orchestration.

The analyses continue with a more accurate estimation of the storage capacity, data flows and traffic of data flows, data processing requirements at edge/fog/cloud level and possible mapping to the resource allocation algorithms to make the services more sustainable.

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