Web-based management for Internet of Things ecosystems

Paraskevi Doulgeraki[1], Effie Karuzaki[1], Eirini Sykianaki[1], Nikolaos Partarakis[1], Maria Bouhli[1], Stavroula Ntoa[1], and Constantine Stephanidis[1,2]

[1] Institute of Computer Science, Foundation for Research and Technology—Hellas (FORTH), 70013 Heraklion, Crete, Greece;
[2] Computer Science Department, School of Sciences & Engineering, University of Crete, 70013 Heraklion, Crete, Greece

{vdoulger, karuzaki, eirinisi, partarak, bouhli, stant, cs} @ics.forth.gr

Abstract: In this paper, we present a front-end User Interface for a secure Internet of Things platform that provides management features as a service on top of heterogeneous Internet of Things ecosystems. The proposed platform is capable of monitoring all the connected devices at various levels, such as remaining energy, uptime, network statistics, quality connection, routing protocol statistics, software bugs, maximum bandwidth, and communication delay.

Keywords: Internet of Things, Management as a service, Service based architectures, Sensor networks

1. Introduction

The Internet-of-Things (IoT) refers to the interconnection of hundreds of smart devices including sensors, smart mobile phones, home appliances, etc. IoT can support a large number of applications, such as environmental monitoring, e-health services, smart agriculture, etc. Its rapid development has led to the creation of various architectures with the contribution of research institutions, but also high-tech companies. This has contributed to their maturation and improvement, but it has also created serious technological fragmentation with isolated platforms that in many cases are incompatible both in terms of software and hardware.

Modern Information Technology (IT) platforms also include other more sophisticated devices, in terms of processing power and available memory, usually referred to as "Gateways", to hyper-connect smart devices to the supporting infrastructure responsible for storing and processing the collected data. Therefore, a modern IT platform includes a large number of heterogeneous hardware devices and software programs. The heterogeneity also extends to the network level, since it is common to use different technologies in different parts of the same platform (WiFi, Zigbee, etc.). Also, devices are often placed in difficult-to-reach locations, and as a result, in the event of a breakdown, it is laborious to locate and repair them. In addition, due to the overconcentration of wireless devices, interference is often created which significantly affects the quality of communication.

IT platforms are often the target of successful cyberattacks due to insufficient protection, due to both the lack of knowledge of the relevant personnel and the low computing power of these devices, which make it impossible to use strong cryptographic algorithms [1-3].

Aiming to address the aforementioned challenges, the purpose of the EPOPTIS project [4] is to design, implement and evaluate an interoperable IT architecture that will offer "Management as a Service" to monitor all involved devices in an IoT ecosystem. This service consists of appropriate hardware and software to monitor parameters at various levels 1) remaining energy, 2) uptime, 3) network statistics (e.g. lost packets per protocol), 4) connection quality, 4) routing protocol statistics, 5) software bugs, 6) maximum bandwidth, 7) communication delay, etc.

This paper described the design and implementation of the frontend platform to visualize the devices connected to the IoT ecosystem and their data to present a comprehensive picture of the state of the network and devices. The platform enables monitoring and management using different technologies in a uniform and transparent way to the user.

2. Background and related work

2.1 Data visualization

An integral part of an IoT management system is considered the capacity to sufficiently visualise the infrastructure data, states and alerts. In this context, the term data visualization refers to the representation of data using graphics, animation, 3D rendering, and other multimedia tools [5] to communicate the results of data analysis clearly and efficiently to end users [6]. It has multi-faceted benefits, as it can not only present a wide range of information concisely and understandably but also reveal correlations and patterns between data that are almost impossible to detect otherwise. Essentially, data visualization helps to "make sense" of data and allows the immediate and effective treatment of errors and malfunctions.

In the field of the Internet of Things (IoT), data concerns measurements taken from a large number of sensors and interconnected devices [7-9]. Visualizing them is extremely useful, as it helps to analyze and understand the data collected, which would otherwise have no meaning [10], especially given the endless flow of information collected by smart systems and sensors [11]. In addition, visualization is a cornerstone for IT management and supervision, as it enables the immediate identification of patterns that occur over long periods (e.g. temperature variation in an area) but also the immediate identification of the spatial and temporal points of origin of various malfunctions [12]. For example, through a map, it will be possible to spatially locate the IT points [13] where faults are detected, while through time-based visualizations it will be possible to locate the moment when a fault started.

2.2 Data visualization for IoT ecosystems

Visualization tools are instrumental in making IoT network management decisions, as they provide a visual analysis of the data retrieved from the network and highlight patterns that would otherwise remain hidden [7]. Many systems that promise data visualization have been developed and are available today. Among them, some systems support the immersive visualization of data [14] and IoT ecosystems [15]. From a more administrative perspective on the management of IoT ecosystems, several commercial and free systems have become available. For example, CloudRadar is a commercial system for monitoring an IT infrastructure, in which users can monitor data collected by web services [16]. It mainly aims to monitor the performance of these services through predefined metrics, such as the memory they occupy, the CPU load, etc. Another commercial program is Domotz [17], a service for monitoring and managing networks and devices, and notifying users when something does not work properly, enabling remote updates, backup, rebooting and configuring of these infrastructures and devices. One of the most popular commercial platforms for managing and visualizing data received from IT networks is IBM's Maximo platform [18]. Through this platform, the user can monitor the operation of the network, receive notifications when something goes wrong and perform some actions to solve any problems that arise. Google IoT Core [19], in combination with other services on the Google IOT platform, provides solutions related to the collection, processing, analysis and visualization of data resulting from connected IT. Apart from commercial platforms, there are also free ones, such as Freeboard [20], which provides a dashboard in which the user can define what data will be displayed while defining the position, size and title of each element of the dashboard as well as whether it needs one of the predefined display formats (e.g. chart). Contus [21], ThingSpeak [22], TheThings.io [23], and DataDog [24] are among the platforms focusing on data visualization.

2.3 Contribution of this research work

Our contribution is summarised as the provision of management as a service on top of heterogeneous IoT ecosystems. In this work, we design and implement a UI that plugs into a service-oriented API that in turn supports the interconnection with various IoT ecosystems through well-defined semantics. Thus, in this work, the heterogeneity of technologies and the plethora of IoT vertical implementations remains hidden under a unique UI layer. Thus, by leveraging existing standards and by supporting API-based integration of IoT ecosystems, this work proposes a platform front-end for basic but important IoT management operations. This is considered the main advantage of this work in conjunction with existing commercial systems and the implementation of this UI is the main contribution of this work.

3. System Overview

The platform supports 3 levels of access for users. These levels are: 'Visitor', 'IoT ecosystem administrator' and 'General administrator'. Visitors can view the devices connected to the respective ecosystem, their position within it as well as the measurements taken from the sensors. They have access to technical features of the ecosystem (e.g. the number of ports, network statistics, etc.) but cannot see potential failures or receive notifications about them.

IoT ecosystem administrators can monitor the state of their assigned ecosystems. In addition to visitors, they can see the status of the ecosystem as well as receive notifications about its smooth functioning and manage the gateways and devices connected to it through a graphical environment. This management includes: (a) editing the elements of an ecosystem (e.g. name, map, etc.) (b) importing/deleting sensors and gateways, (c) processing the technical characteristics of sensors and network gateways, such as name, IP address, communication and data security protocol, and (d) user management.

Their home screen with the control panel is divided into three zones (see Figure 2). The first is the general information zone where the IoT ecosystem administrator can, in addition to visitors, see how many gateways are down, as well as the number of users who have access to the ecosystem. The second is the notification zone, in which IoT ecosystem administrators can see messages about the operation of the ecosystem at various levels, such as at the level of measurements taken from the sensors, at the network level (faults) and also at the device level (faults and software errors). Finally, the third zone at the base of the page is the monitoring zone of all the portals that belong to the ecosystem as well as the statistical data concerning its operation and the operation of the network. In this zone, the IoT ecosystem administrator can see the map showing the locations where the gateways of the ecosystem are placed. Figure 3 presents the dashboard of an ecosystem and analysis of different information panels.

General administrators have access to all the information of every IoT ecosystem as well as the functions that the IoT ecosystem administrators have, while in addition, they bear the responsibility of managing the platform as well as the users who benefit from the service offered by this system.

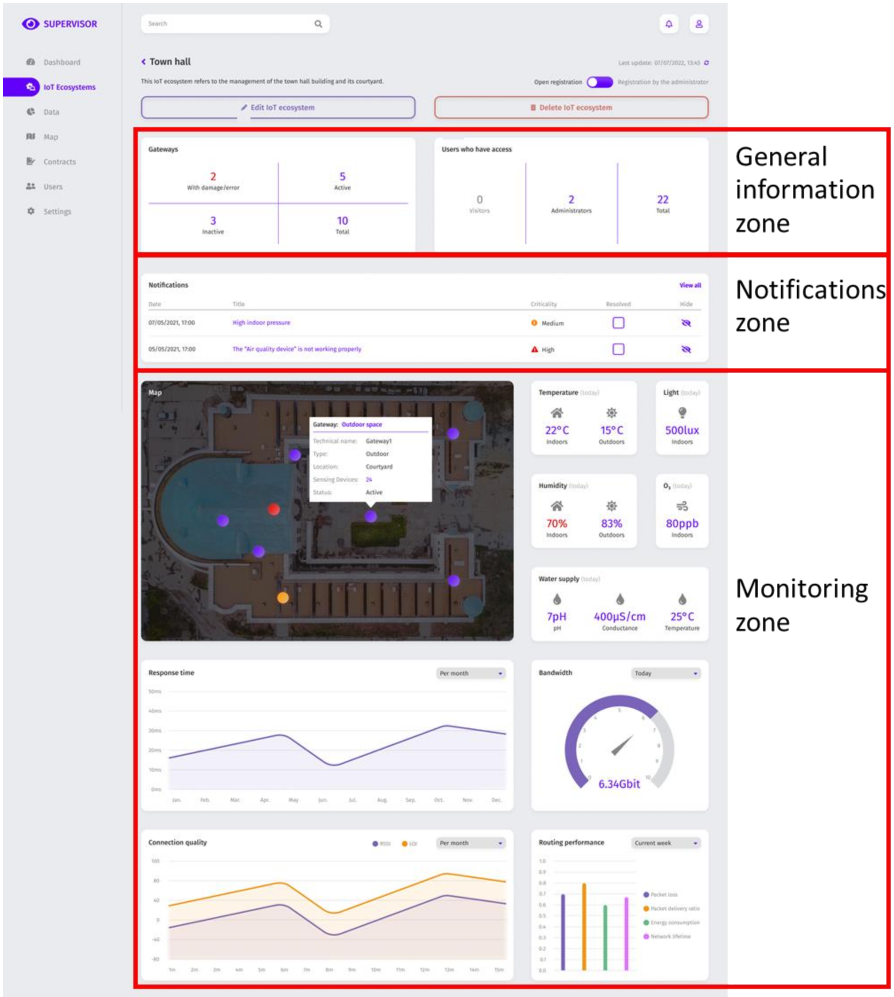

Figure 1. Supervisor's home page

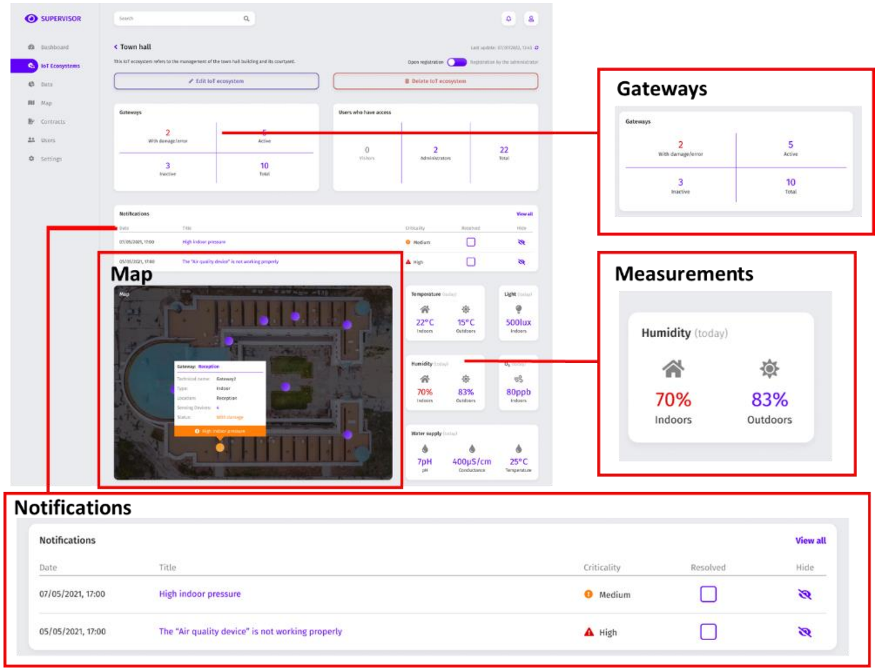

Figure 2. Analysis of an ecosystem's dashboard.

4. Implementation

For the design of the EPOPTIS platform interface for the visualization of the measurements collected by IoT ecosystems, an iterative design process was followed aiming to improve the user experience following expert-based evaluation [25-27]. The iterative design was conducted in the form of evolving interactive prototypes to achieve high-quality user interfaces. In this respect, the iteration cycle involved the following phases: (i) problem definition, ideation, and requirements specification; (ii) design of prototypes (evolving from low fidelity to high fidelity mockups, and eventually to functional prototypes); (iii) expert-based evaluation. Evaluation of each prototype was conducted with the participation of domain and usability experts, resulting in identifying problems that should be solved and improvements that should be pursued in the next prototype iteration. The implementation of the system was initiated after concluding the UI design.

The presented platform acts as the front end of a very complex system that integrates IoT monitoring functionality over cloud-based distributed architectures. In this paper, we will analyze the data model and the UI implementation. Graphically, the data model structure is depicted in Figure 1. At the application level, measurement data is obtained from all sensors participating in the IoT. At the hardware level, data is received from the gateways (which aggregate the information of the individual sensors connected to them) and at the network level, information is received from both the gateways and the individual sensors connected to them. Finally, gateways can detect faults in sensors, which are submitted for visualization.

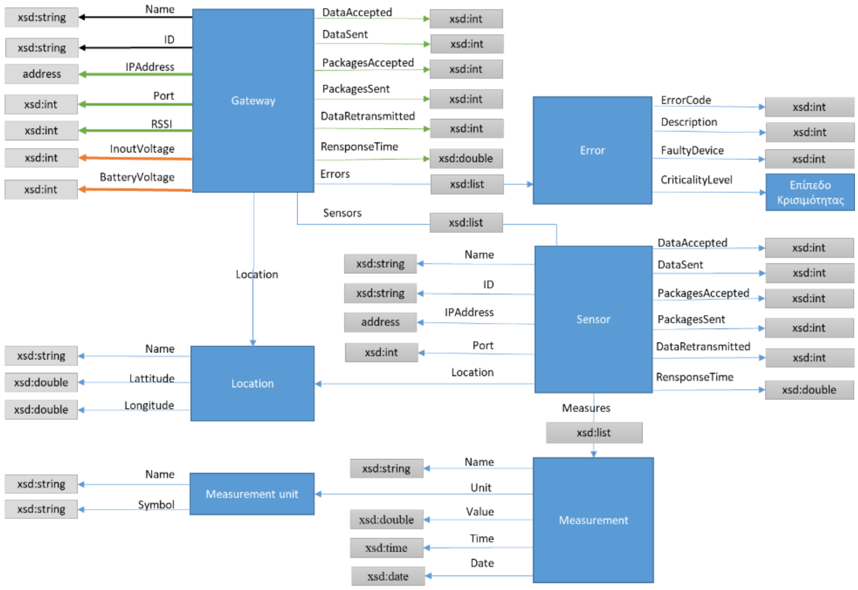

Figure 3. Data model structure.

For the implementation of the user interface, the Angular development platform and framework have been deployed. Angular is an open-source, component-based framework for building scalable web applications, which is supported by Google and a large community of volunteers and companies. Frameworks like Angular allow the fast development of web applications by providing mechanisms to manage and present the data coming from the system's respective data provider. In addition, they ensure high performance and security in applications. The main programming language used in the angular framework is Typescript, an open-source language developed by Microsoft. It is a superset of JavaScript, providing a syntax that allows the optional declaration of variable types, while providing elements of object-oriented programming, such as classes, interfaces, etc. Essentially, Typescript allows for better code organization, better code control for developers, faster performance and better error prevention and handling, making it an ideal choice for large-scale applications as in the case of the EPOPTIS project.

Finally, the HTML5 language and the Bootstrap 5 framework were used for the implementation of the web pages. Bootstrap, being the most popular framework for developing responsive websites, provides mechanisms that control how the web page elements will be shown, rearranged or hidden according to the screen size, ensuring that optimal user experience and usability is offered on all screen sizes (computer screen, tablet, mobile phones). Finally, to control the appearance of web pages, the SCSS language is used - a superset of CSS that offers variables, and nesting features among others to allow better code organization and fine control of the appearance of the interface elements.

5. Conclusion

Summarising this work, we have presented the design and implementation of platform-agnostic web-based management as a service solution for IoT ecosystems. The novelty of this work regards its pluggability to different IoT architectures through a device-agnostic approach that is based on a data model and a generic UI implementation. The proposed solution has been implemented and tested in the context of the research project EPOPTIS financed by the European Union and Greek national funds and has reached a significant level of maturity within the project. The next steps include a user-based evaluation, aiming to assess the usability and usefulness of the proposed solution, with a representative user sample.

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References

1. Kim, S. H., Wang, Q. H., & Ullrich, J. B. (2012). A comparative study of cyberattacks. Communications of the ACM, 55(3), 66-73.
2. Liu, S., & Cheng, B. (2009). Cyberattacks: Why, what, who, and how. IT professional, 11(3), 14-21.
3. Bout, E., Loscri, V., & Gallais, A. (2021). How Machine Learning changes the nature of cyberattacks on IoT networks: A survey. *IEEE Communications Surveys & Tutorials*, *24*(1), 248-279.
4. EPOPTIS project. Available online: https://www.epoptis-project.gr/en/home/, accessed on 03-05-2023
5. Post, F. H., Nielson, G., & Bonneau, G. P. (Eds.). (2002). Data visualization: The state of the art.
6. Vitsaxaki, K., Ntoa, S., Margetis, G., & Spyratos, N. (2022). Interactive visual exploration of big relational datasets. International Journal of Human–Computer Interaction, 1-15.
7. Protopsaltis, A., Sarigiannidis, P., Margounakis, D., & Lytos, A. (2020, August). Data visualization in internet of things: tools, methodologies, and challenges. In *Proceedings of the 15th international conference on availability, reliability and security* (pp. 1-11).
8. Kalaitzakis, M., Bouloukakis, M., Charalampidis, P., Dimitrakis, M., Drossis, G., Fragkiadakis, A., ... & Stephanidis, C. (2019). Building a Smart City ecosystem for third party innovation in the City of Heraklion. *Mediterranean Cities and Island Communities: Smart, Sustainable, Inclusive and Resilient*, 19-56.
9. Zidianakis, E., Partarakis, N., Antona, M., & Stephanidis, C. (2014). Building a sensory infrastructure to support interaction and monitoring in ambient intelligence environments. In *Distributed, Ambient, and Pervasive Interactions: Second International Conference,*

DAPI 2014, Held as Part of HCI Interational 2014, Heraklion, Crete, Greece, June 22-27, 2014. Proceedings 2 (pp. 519-529). Springer International Publishing.

10. Allam, S. (2017). Exploratory Study for Big Data Visualization in the Internet of Things. Sudhir Allam," EXPLORATORY STUDY FOR BIG DATA VISUALIZATION IN THE INTERNET OF THINGS", International Journal of Creative Research Thoughts (IJCRT), ISSN, 2320-2882.
11. Il-Agure, Z., & Dempered, J. (2022, May). Review of Data Visualization Techniques in IoT Data. In 2022 8th International Conference on Information Technology Trends (ITT) (pp. 167-171). IEEE.
12. Yao, L., Sheng, Q. Z., & Dustdar, S. (2015). Web-based management of the internet of things. *IEEE Internet Computing*, *19*(4), 60-67.
13. Karim, F., & Karim, F. (2017). Monitoring system using web of things in precision agriculture. *Procedia Computer Science*, *110*, 402-409.
14. Teras, M., & Raghunathan, S. (2015). BIG DATA VISUALISATION IN IMMERSIVE VIRTUAL REALITY ENVIRONMENTS: EMBODIED PHENOMENOLOGICAL PERSPECTIVES TO INTERACTION. *ICTACT Journal on Soft Computing*, *5*(4).
15. Bouloukakis, M., Partarakis, N., Drossis, I., Kalaitzakis, M., & Stephanidis, C. (2019). Virtual reality for smart city visualization and monitoring. *Mediterranean Cities and Island Communities: Smart, Sustainable, Inclusive and Resilient*, 1-18.
16. Cloudradar. Available online: https://www.cloudradar.io/, (accessed on 10-01-20223)
17. Domotz. Available online: https://www.domotz.com/, (accessed on 10-01-20223)
18. Maximo. Available online: https://www.ibm.com/products/maximo, (accessed on 10-01-20223)
19. IoT-core. Available online: https://cloud.google.com/iot-core, (accessed on 10-01-20223)
20. Freeboard. Available online https://freeboard.io/, (accessed on 10-01-20223)
21. Contus. Available online: https://blog.contus.com/iot-data-visualization-for-iot-platforms-applications/, (accessed on 10-01-20223)
22. Thingspeak. Available online: https://thingspeak.com/, (accessed on 10-01-20223)
23. Thethings. https://thethings.io/, (accessed on 10-01-20223)
24. Datadoghq. https://www.datadoghq.com/product/, (accessed on 10-01-20223)
25. J. Nielsen, "Iterative user-interface design," Computer, vol. 26, no. 11, pp. 32-41, 1993.
26. J. Nielsen, "The usability engineering life cycle," Computer, vol. 25, no. 3, pp. 12-22, 1992.
27. T. Brown, "Design thinking," Harvard business review, vol. 86, no. 6, p. 84, 2008.