Smart-IoT Business Process Management: A Case Study on Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis

Patricia Gómez-Valiente, Jennifer Pérez Benedí, José María Lillo-Castellano, and Manuel Marina-Breysse

***Abstract*—Cyber–physical systems (CPS) and Internet of Things (IoT) systems are mainly in charge of sensing, acting, computing, communicating, managing, and evolving the software integrated in devices. The wide variety of technologies and devices that support IoT systems and the decentralization of services through infrastructures, such as fog or edge computing, has led companies to complex business models. These complex business models require decentralized and business-aware architectures driven by the business process management systems (BPMSs) that define the tasks involved in IoT workflows. Well-defined and established IoT business process management (BPM) are required for companies to remain competitive. However, there are still challenges that must be addressed to smoothly integrate IoT BPM and their architectures into a digitally native company's daily workflow. In this article, we present an IoT architecture to support a smart IoT BPM that focuses on addressing the challenges of scheduling, resource allocation, and state management of Smart IoT systems. In particular, the IDOVEN company's adoption of this Smart IoT BMP in an IoT system for remote digital early cardiac arrhythmia detection and diagnosis is illustrated which has been validated with 2188 patients across the seven continents.**

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I. INTRODUCTION

IN THIS era of high technology, the disruption of Internet of Things (IoT) technologies has had a strong impact in people's lives making them easier and more comfortable. IoT systems are composed by interconnected "things" in a distributed environment that makes feasible the data collection from anywhere at any time, analyzing it and acting accordingly in real-time thanks to the use of artificial intelligence (AI) techniques. In addition, IoT systems are supported by robust architectures that provide key capabilities, such as scalability, flexibility, availability, interoperability, remote, and real-time demands. There are many fields where IoT solutions require being applied to, such as healthcare, smart homes, smart energy/water grids, smart logistics, or smart cities [1], [2]. This widely extended IoT adoption requires the orchestration of these systems through complex business processes (BPs) to maximize the company benefits and user experience by digitizing a procedure.

Studies predict a significant growth of the IoT and its business value in the coming years. There will be more than 41 billion IoT devices by 2027, with an annual market growth of more than 2.4 trillion dollars [3]. In this scenario, a high number of business executives are interested in integrating the IoT devices into their BPs, known as IoT-aware BP. This combination gives the opportunity to these professionals to take advantage of the IoT technology in their processes obtaining an enrichment of the business performance and an achievement of the business competitiveness [4]. Thus, there has been continuous research to identify approaches and methods to integrate the IoT technology within the BP paradigm [4].

Schulte et al. [5] set the open challenges that business process management (BPM) should address. These challenges are scheduling, resource allocation, process monitoring and data collection, decentralized coordination for process enactment, and state management. In addition, it is important to consider that the common solutions of the IoT systems are mainly focused on the exploitation of the data generated by IoT devices through software platforms. However, the construction or acquisition of IoT devices is also important to guarantee their supply and maintenance, and by extension the correct execution of the system. This issue is especially critical because the device operation is degraded with the time and even, they break on and must be substituted. Therefore, it is necessary to provide solutions in which the acquisition, status evaluation, and renewal of IoT devices are part of the IoT systems through the automation of IoT devices' tracking services.

To deal with these challenges, this work presents the design of a complete BPM of IoT systems, addressing not only the development of the IoT system, but also the tracking and management of IoT devices. This BMP design is conceptualized by an architecture, called domain and platform independent IoT BPM architecture (DOMINIoT), and applied to a real industry case study, an e-Health IoT System for Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis, allowing a Device as a Point of Care (PoC) strategy. This article illustrates the real-world adoption of the architecture to this IoT system and the obtained results from its deployment in the IDOVEN company.

This article is structured as follows. Section II introduces the background about BPM and e-Health, Section III details the related work about processes, architectures, and solutions of IoT BPM, Section IV describes the Smart-IoT BPM defined in this work, Section V illustrates the adoption of the IoT BPM to a e-Health IoT System for Remote Digital Cardiac Arrhythmia Detection and Diagnosis, and finally, conclusions are presented in Section VI.

II. BACKGROUND

A. BMP

Processes are defined as a set of tasks performed in a determined order within or across companies or organizations [7]. BPM consists of defining a process and the set of tools and methods that allows to manage and analyze data and services to improve a company process [8]. The process of a company is constituted not only by the processes that conform the manufacturing of products or services, but also by those complementary processes that allow the development of the main manufacturing processes of the company, processes, such as acquisition, delivery, or manual tasks. The BPM lifecycle usually consists of four phases: 1) design and analysis; 2) configuration; 3) enactment; and 4) evaluation [9]. This work is focused on the design and analysis phase.

BPM is formally defined through models for monitoring, compliance validation, information storage, and improvement. Once a BPM model has been defined it can be instantiated to different specific models for the same company or different ones. A BMP model is composed by manual or automatic tasks executed by agents. These agents can be humans or devices [9], and the automation of task are called workflows [10].

But BMP models must change to deal with current society needs, since citizens and businesses require a wide range of smart applications and services for different purposes and domains [1], [2]. These applications and services must be properly orchestrated through a process to conform cyber–physical systems (CPS) that are in charge of sensing, actuating, computing, communicating, among others, software integrated in physical objects, through IoT [11] and cloud infrastructures [12], [13], [14].

B. E-Health

IoT plays a critical role in e-Health allowing remote and continuous care by integrating IoT devices in our lives. These new solutions where devices are becoming a PoC reaching the patient outside the walls of the hospital benefit not only patients, who obtain a more acute, fast and personalized healthcare service, but also the professionals, who count on a complete data gathered infrastructure to support their diagnosis procedure. With the goal to provide continuous monitoring, wearables represent the proper means to measure patients during their daily activities in a seamless way, complementing traditional stress tests, which only measure a specific interval of time in their lives, with real-life data. E-Health IoT systems manage these IoT devices and wearables, that are continuously monitoring data in quasi-real-time and allow extracting knowledge that may help with remote and digital early disease detection.

Cardiovascular diseases (CVDs) are the main cause of death in the world [15]. An arrhythmia is a CVD that encompasses an abnormality in the rhythm of the heart and if it is left untreated, it can put in danger the life of people [16]. However, an arrhythmia may not cause obvious symptoms, such as anxiety, blurred vision, chest pain, or fatigue among others, and they may have an intermittent nature, which leads to ignoring them.

Arrhythmias are usually detected through traditional tests, such as rest electrocardiograms (ECG), stress tests, or 24-h Holter monitors. However, in those tests, few heartbeats are monitored (around 2000 heartbeats in a stress test) and this quantity does not offer as much information as desired for a deep heart analysis. Additionally, patients must wait for an appointment with a health professional, go to the hospital and then, wait more time to get the results of the tests (∼1–4 months in Spain). As it can be denoted, these traditional practices demand to be face-to-face in a doctor's office and time to get a diagnosis, which may have an impact on the patient's health as the probability of an early detection decreases. From this scenario, IoT is a candidate solution to deal with the need of shooting down the distance and time factors to anticipate the arrhythmia diagnosis. Nowadays, wearable medical devices allow the remote, or even continuous, heart monitoring in a noninvasive way. Some of these devices vary in size, electrodes placement, number of leads, monitoring period, battery duration, user experience, need of healthcare staff to set up the device, open SDK for integration with third parties, or the quality of signal. These wearables are often provisioned with Bluetooth communication protocol to connect to a mobile application acting as gateways and to outsource the collected data so it can be consumed in real-time by other services such as a cloud-based platform for health professionals. These gateways can be used to receive alerts regarding the heart status, not constituting in any case the substitution of a doctor diagnosis. Therefore, in this work we define a BMP considering both, the IoT needs, and the support of the medicine professionals' tasks that must deliver a final diagnosis.

III. RELATED WORK

The integration of BPM and IoT is advantageous, as Maamar et al. [17] mention. There are different perspectives to address the integration needs of BPM and IoT: BPs modeling languages [18], [19], ontologies, architectures, algorithms, and technologies [4]. This work is focused on the architecture and technology issues. Regarding these issues, the work of Maamar et al. [17] identifies the integration needs and presents a generic framework to establish the required kind of modules for orchestrating the physical and cyber world. This framework defines the modules and communications to support a BP in IoT. In addition, the work of Fleisch et al. [20] refines the analysis of components defining six kinds of components that an IoT BPM should have, and the work of Pourmirza et al. [21] presents the reference architecture BPM system (BPMS)-RA by defining the main functions that BPM systems must implement from the literature analysis. Schulte et al. [5] took a step forward addressing both, the architectural and technological needs of this integration. They consider the value that the Cloud Computing provides to IoT BPM architectures [22]. As a result, the work of Schulte et al. [5] states the need of supporting BPM processes through elastic cloud structures to deal with the flexibility of the IoT infrastructures and the BPs. They define a high-level architecture to support the BPM system. They deploy the BMP system in a virtual machine (VM), where the process model is located, and which considers both manual and automated tasks. The process is supported by services located in servers that can be deployed for a specific system and configuration to be auto scalable. This architecture is presented as a metamodel for constructing a BPM that requires this elasticity. This architecture prescribes the components: workflow manager, scheduler, load balancer, and reasoner. The proposed architecture, presented in this work, to support the BPM process is based on this metamodel and components to address the pending challenges pointed out by Shutle et al., i.e., work scheduling, resource allocation, process monitoring, data collection, decentralized coordination for process enactment, and state management. In addition, the work of Schladofsky et al. [23] presents the required communication between the different BPM's stakeholders to enhance it and increase its value. This work has been considered in our proposal avoiding a silos communication among systems to maximize the BP value and including the BPM through the architectural components.

Different research works present architectures to support IoT BPM. The architecture LAURA integrates IoT and BPM by creating different layers [24]. As a result, IoT and BMP layers are in silos, and the generic BMP layer and its stakeholders are consumers of the lower layers of the IoT architecture. Our proposal takes a step forward providing a complete integration of BPM and IoT by identifying the common and required tasks of IoT BPM and prescribe them as modules of an architectural pattern to support the process. The proposal of Mass et al. [25] presents a workflow-based fog system architecture by hosting workflow managers on the edge devices. In this way, it is feasible the decentralized process execution avoiding the connectivity and efficiency problems that may present centralized BPMS architectures. These workflow managers are composed by the components: tasks, managers, schedulers, and executors. However, these architectures do not implement an IoT device state-aware process where the tracking and provisioning of devices are managed. The IoT-based business model specialized in vegetable greenhouses presented by Ruan et al. [26] identifies the business tasks of ordering, picking, packing, and delivering. However, as a difference from our work, they are presented from the final product perspective, i.e., the vegetables, instead of from the IoT devices, and they are not included as part of the IoT architecture, the architecture is defined from the physical viewpoint. Also, the work of Muhić et al. [29] presents the technical physical solution of the architectural model to support the business model for the Centre for digital communications with customers by considering Web and mobile application for customer's interaction. On the other hand, the work of Cheng et al. [30] states an execution environment based on the highly distribution that fog nodes provide and the easy integration that application programming interfaces (APIs) facilitate. Finally, it is important to emphasize the work of Serhani et al. [31], since it proposes an ECG monitoring architecture, as the case study of the present work. Serhani et.al illustrate the key layers of an ECG monitoring system, whose input is the raw data collected from ECG sensors and whose output is the visualization of the knowledge obtained after this raw data has gone through all the system layers, but it does not address the BPM.

From the related work of IoT BPM is possible to conclude that it is still necessary more research work. Specifically, it is required to provide traceability from the process to the IoT-BPM architecture considering all the stages of the value industry chain of the IoT-based business model, i.e., from the IoT devices manufacturing to the exploitation, analysis, and enactment of the IoT business system. In addition, there are no IoT BPM architectures that integrate these complete BP tasks as part of the solution through a software architecture configuration that can be used as a pattern for being specialized into different domains and technologies. Our proposal deals with these challenges being applied to an IoT system for Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis during four years in the IDOVEN company.

The main contributions of our research work regarding the state-of-the-art are the following.

1) Providing a BMP defining the scheduling, resource allocation, and state management of Smart IoT systems as mandatory activities, which are pending challenges in the area.
2) Providing a complete integration of BPM and IoT without being in silos to avoid this problem. They are smoothly integrated in modules that represent the common and required tasks of IoT BPM. This integration into modules allows to address the IoT and the BPM activities by easily using them as an architectural pattern to support the process.

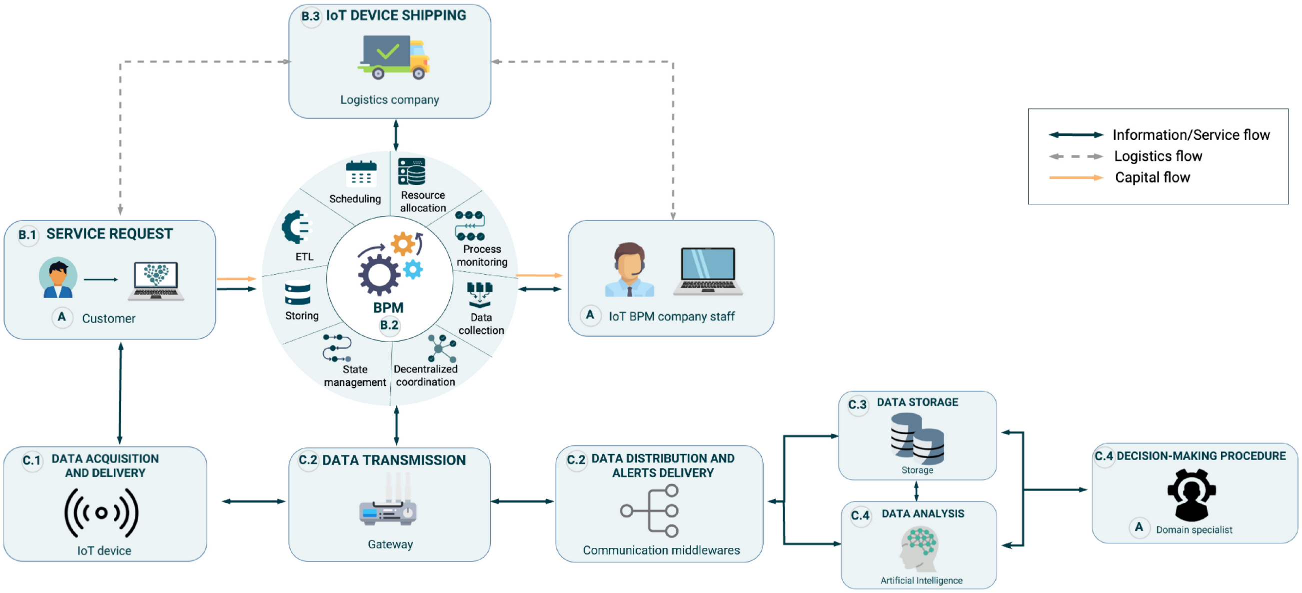


Fig. 1. DOMINIoT BPM architecture.

3) Providing an IoT BPM pattern with different levels of reusability by avoiding focusing on only one kind of solution as the presented related works; i.e., technology-agnostic, technology-dependent, or domain-dependent solutions. This work provides patterns to be reused and extended in different domains and technologies, as well as in the Google cloud platform (GCP) and the specific domain of Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis.

IV. SMART-IoT BUSINESS PROCESS MANAGEMENT

IoT technologies have had a strong impact in people's lives, and this has implied that IoT systems are not limited to the deployment of IoT devices in a controlled physical setting of an industry or institution. Currently, individual users may be part of IoT systems providing and acquiring data, and/or services from them. As a result, IoT systems are highly distributed and dynamic, and the maintenance of IoT devices is extremely complex. Therefore, the IoT BPM requires to control the IoT device lifecycle, from its order of manufacturing to its tracking analysis to know where it is, and how is it working for determining repairing or renewal tasks. As a result, in this work, the challenges of scheduling, resource allocation, and state management [5] are faced up to an IoT BPM architecture where the IoT devices are tracked by its architectural components and functionalities. This IoT BPM architecture implements a distributed workflow that is device state-aware and deals with the complete value chain of the e-business, from the service order to the service return of investment (ROI) (see Fig. 1). All these functionalities are aided by a continuous and decentralized process monitoring and data collection that are supported by AI techniques in order to improve the enactment of the BPM, the ROI, and the value chain [5], [26]. The IoT BPM architecture, called DOMINIoT, is defined as a generic architecture to be reused for any domain and technology.

Next sections detail how the architecture deals with: 1) the three main perspectives of the identified Information Technology-Influenced Business Model Patterns based on IoT of the study of Fleisch et al. [20], i.e., integration of users and customers, service orientation, and core competence analytics and 2) the Industry Chain of the IoT-based e-business model [26] in terms of information, capital, and logistics (see Fig. 1).

A. Users

Users are part of the value-creation chain of the IoT BP. The defined domain and platform independent IoT BPM involves three kind of users that interact in the required manual and automated tasks: 1) customers; 2) IoT BPM company staff; and 3) domain specialists (see A, Fig. 1). Customers are those that pay for an IoT solution to obtain an ROI from this payment. They can vary from a single user to a company or institution. The IoT BPM company staff comprises users that belong to the company whose main purpose is to deploy and/or manage the IoT system, each of them with different administrative roles. Thus, with different privileges depending on their tasks in the IoT system. This kind of user can be divided into two different ones when the company that deploys and maintain the IoT physical infrastructure is different to the company that manage the software IoT system. Finally, the domain specialists provide the knowledge to the BPM system, playing the decision making and analysis role, focused on the result and the final ROI to the customer.

B. Services

The defined DOMINIoT is characterized by the services that address the challenges of scheduling, supply chain, resource allocation, process monitoring and data collection, decentralized coordination for process enactment, and state management. These services are prescribed by the BPM service and the architectural components to guarantee the accomplishment of these challenges. In addition, the services are defined considering the value chain by explicitly, including the service request, and the information and logistics flows (see the legend box and arrows, Fig. 1). Next, the services are explained in detail.

1) Service Request: This service consists in offering the mean through which the customer can request the service itself, e.g., an online platform. The acquisition of the service is the key event that triggers the business model execution launching the BPM service (see the relationship with the BPM service, Fig. 1), and, as a result, the customer will receive the IoT devices to be deployed (see the relationship with the IoT device shipping service, Fig. 1), and the data results once they are being executed (see the relationship with the Data acquisition and delivery service, Fig. 1).

2) BPM Service: It represents the BPM and is composed of several subprocesses that are executed to deliver the service to the customer (see B.2, Fig. 1). These subprocesses range from noticing that there are new orders, preparing the IoT devices and other infrastructures that make possible providing the service, having an up-to-date inventory, and checking the IoT device status. To that end, these subprocesses require to be implemented through the following services.

a) Extract-transform-load service: It is intended to retrieve the submitted orders details from the online platform, to transform the information whether it is required, and to load them in the desired destination (see the relationship between the BPM service and the Customer, Fig. 1).

b) Storing service: It has the goal to store all the raw orders of IoT devices and deployments as well as the data that is generated along with its processing. This service specifically supports the storage of the gathered data from the BPM service, i.e., the data of the BPM and the IoT device state. As a result, the data of the deployment and BPM is not mixed with the data collected from IoT devices that provides the service to the customer.

c) State management service: It is used to track the IoT devices' lifecycle along their existence. To that end, we define two kinds of statuses, and each kind can take different states. Therefore, the system must tag the IoT device with the following statuses.

1) *A Processing Status Indicating the States:* The IoT device is free (free), or it is already in use (busy).
2) *A Maintenance Status to Indicate the States:* The device is correctly working (working), or the device has to be retired (damaged).

d) Decentralized coordination and BP monitoring services: With the mission to notify the IoT BPM company staff about new service requests, processing them for their shipment, and for managing their status. Therefore, the service has to implement different functionalities: 1) viewing incoming request; 2) editing any of the existing services details, allowing changes as required by customers; 3) associating IoT devices and infrastructures with pending services; 4) communicating with the logistics company for the shipment; 5) controlling and reconciling inventory, allowing increasing of the stock and deducting it as orders are shipped; and 6) managing the operating and reception status of the IoT devices. This orchestrator of the decentralized coordinator BP is necessary due to the distributed nature of the system and their functionalities and the services implementation. This orchestrator also allows the interaction between the state management and the storing services.

e) Data collection service: The management process and the tracking and monitoring of the IoT devices also demands collecting data for their storage. This data collection can be performed from the result of the execution of operations or automatic algorithms, and sometimes it is introduced manually, for example, updating the statuses of devices can be a task carried out by the staff of the IoT BMP company (see the relationship between the BPM service and the staff, Fig. 1).

f) Scheduling and resource allocation services: The system's computational resources must scale on-demand, releasing or acquiring new ones as needed. Also, a smart planning of inventory stock must be scheduled by the IoT BPM company staff in case demand pikes are expected during specific periods of the year.

3) IoT Device Shipping Service: To deploy the IoT devices and infrastructures of an IoT system, it is necessary to deliver them to the customer (see B.3, Fig. 1), requiring therefore the services of a logistics company. In those IoT systems that demand a complex deployment, this service will consist of not only the logistics support, but also the physical installation.

C. Core Competence Analytics Service

Core competence analytics is required because of the collection of data (see B.2, Fig. 1) from IoT devices with the aim to analyze them to provide valuable knowledge to the customer of the service, and a ROI from the provided services. To properly address these valuable data analytics, the IoT BPM architecture prescribes four services.

1) Data Acquisition and Delivery Service: The data acquisition is carried out by the IoT device which contains sensors to measure variables (see C.1, Fig. 1). Depending on the goal of the service, the IoT device can include sensors to measure temperature, humidity, pressure, proximity, acceleration, motion detection, or human body's variables such as vital signs. Also, sometimes correlating different sensors' data offers an understanding of the context that is being measured.

Data gathered by IoT devices must be outsourced through a communications protocol, typically a wireless one, such as WiFi, Bluetooth, ZigBee, LoRa, or NB-IoT. This communication allows the continuous monitoring of the variables stated previously and it can be continuous or discontinuous (event-based), depending on the requirements of the IoT system. As a result, this feature demands IoT devices to be connected to the power, include a charger or even replaceable batteries, as the energy of the device will drain along the duration of the service.

2) Data Transmission, Distribution, and Alerts Delivery Service: To transmit the data gathered by the monitoring device and send it to the data analysis services, there must be an intermediary between the device and the analysis platform, in a bidirectional way, and also, an intermediary between the different data services to distribute the data and deliver the knowledge to the customer (see the data transmission service and the data distribution and alerts delivery service, C.2, Fig. 1). The first intermediary is a gateway, which must meet several requirements to be integrated with the rest of the components of the architecture.

1) Allow continuous recording, especially in those IoT systems where IoT devices can be in movement.
2) Support the IoT communication protocols as well as be connected to the Internet;
3) Minimize resources, such as the battery usage and bytes consumption as much as possible.
4) Coexist with the IoT devices and its environment in a nonintrusive and seamless way.
5) Process the raw data coming from the device and transform it into an appropriate or aggregated data format to be ingested by cloud services.
6) In those IoT systems where customers are involved, notify them when the device is transmitting data and when there is new information to check.

3) Data Storage Service: The acquired data from IoT devices for data analytics must be stored in a specific and dedicated storage for its deep analysis (see C.3, Fig. 1). As a result, device data can rest there and be outsourced whenever a more in-depth and cold analysis is required.

4) Data Analysis and Decision-Making Procedure Services: To analyze the incoming data from the gateway in real-time for a fast and smart reasoning, it is necessary to implement an AI-based analysis procedure and if required, trigger an action (see C.4, Fig. 1). This analysis supports domain specialists' decision-making approaches, and this reasoning usually involves manual tasks performed by the specialist, who ensures the correctness and quality of the service and determines the best AI algorithms to apply depending on the task, moment, and IoT system. At the same time, not only the customer takes advantage of the service, but also domain specialists since the data analysis service provides a substantial amount of data and processing results that increase their knowledge.

D. Industry Chain of the IoT-Based e-Business Model

The architecture must include the flows that make feasible the value chain for the IoT BPM company and guarantee the ROI for the customer. These flows are the information and service flow, capital, and logistics (see legend box and arrows, Fig. 1) [26]. The information and service flows are the assets that the customer requires through the service request, which implies a payment. This payment is the capital gain of the IoT BPM company which oversees the process in terms of logistics and service. This service is supported by the information flow and communications, whereas the logistics plays a critical role to guarantee the delivery and deployment of IoT devices and infrastructures, as well as their tracking.

V. CASE STUDY: REMOTE DIGITAL EARLY CARDIAC ARRHYTHMIA DETECTION AND DIAGNOSIS

This section presents how the DOMINIoT architecture is positioned as a solution for constructing a specific domain and technology solution. Since the main purpose of this work is to illustrate in depth how to adopt the IoT BPM in order to be replicated and reused by the research community, this work has used the case study technique, whose goal is to search for evidence, gain understanding, or test theories by primarily using qualitative analysis [27]. As Clarke et al. state [28], to gain comprehension and illustrate a methodology or a process in detail is necessary to demonstrate one specific case in depth. As a result, to illustrate the advantages and completeness of the DOMINIoT architecture, this work has used an industrial case study that is being applied in real-world to be used as an exemplar case study for professional practice. Specifically, this IoT BPM has been adopted by the healthcare domain. In addition, to present this healthcare IoT BPM architecture and its results, this section describes in depth the traceability from the DOMINIoT domain and platform-independent IoT BPM architecture to its adoption to a specific domain and technological platform-dependent architecture, to illustrate how it can be reused is adoption to other domains and technological solutions.

A. Research Objective

The main goal of this case study is to illustrate the feasibility of deriving the GCP Solution of a Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis IoT-BMP architecture of an industrial IoT system from the DOMINIoT architecture. This main goal is decomposed into two objectives.

OBJ.1: To derive the required components of a Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis IoT-BMP architecture from the DOMINIoT IoT BPM architecture.

OBJ.2: To derive the required GCP components for implementing an industrial solution for a Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis IoT-BMP, from its technology-independent pattern.

B. Analysis and Methodology

In this case study, both quantitative and qualitative analysis were used to examine the case study. Qualitative analysis is performed by applying the defined methodology to conduct the case study. It consisted of applying the traceability of the elements and connections between models for illustrating in depth their specialization or refinement to allow the reusability of the adoption. On the other hand, quantitative analysis was performed by executing experiments to prove the correct execution of the resulting IoT-BMP system in a real setting. The results of the experiments are provided in terms of: 1) metrics related to the monitoring of the status of the IoT devices and 2) time metrics from the moment the service is requested until the patient receives a final report as well as their comparison with conventional diagnostic procedures in order to evidence the time reduction.

Finally, to evaluate the impact of this IoT BMP in our society, and specifically, in the healthcare domain, an approximation of the saved costs and time by the Spanish Health System has been calculated as well as the number of early diagnoses when using this service.

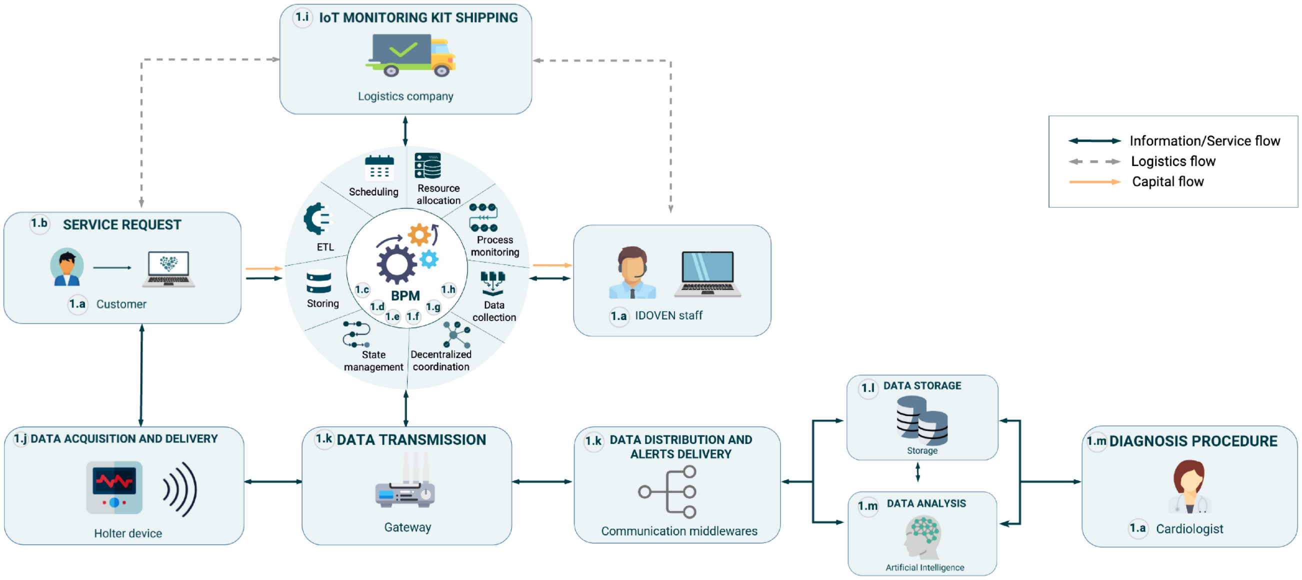


Fig. 2. Platform-independent IoT BPM architecture for remote digital early cardiac arrhythmia detection and diagnosis following a device as a PoC strategy.

C. Case Study Description

The healthcare field is one of the multiple domains that can benefit from IoT solutions. The case study of this research work is framed in this domain, and specifically in the remote digital early cardiac arrhythmia detection and diagnosis domain following a Device as a PoC strategy. This case study has been carried out in collaboration with the IDOVEN company.

IDOVEN is a European HealthTech startup company-based in Madrid leading a promising initiative that seeks to detect heart problems early to prevent diseases, such as myocardial infarction and sudden death. To do this, they are redefining the way cardiac arrhythmias are diagnosed by creating a platform that combines AI algorithms with wearable IoT medical devices and the expertise of cardiology professionals.

This case study is focused on the IDOVEN BP of Devices as a PoC business market, which provides a service that consists of recording the patient's heart for days or weeks using a wearable noninvasive IoT medical device for ECG monitoring, for instance, ECG event recorders, Holter monitors and ECG patches from different manufacturers, and analyzing this data with the IDOVEN's AI platform. In addition, the recorded heart activity signals during the monitoring days are analysed by the IDOVEN cardiologist team who, with the help of its AI algorithms, converts the millions of heartbeats patterns into clinically relevant medical information depicted in a medical report with the anomalies detected and customized recommendations. Specifically, this work is a proof of concept to test the feasibility of a service where patients can send continuously their electrical heart activity through a mobile application and receive alerts in real time in case an abnormal pattern is detected. These alerts do not constitute a medical diagnosis, just a notification to be assisted by a health professional. This case study fulfils the needs to adopt the DOMINIoT architecture, since it requires a scalable, real-time, and complex IoT architecture that guarantees the availability, feasibility, and correct execution of this IoT solution in a business context.

D. Case Study Execution

To address this case study, the DOMINIoT architecture was specialized in two steps: 1) the domain specialization (OBJ.1) and 2) the technology specialization (OBJ.2). The first step consisted in deriving a Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis IoT BPM architecture from the DOMINIoT architecture without considering technological solutions (see Fig. 1). As a result, this Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis DOMINIoT architecture can be used to be implemented with different technological solutions (see Fig. 2). And as a second step, the Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis DOMINIoT architecture was specialized for a specific technological solution, i.e., GCP (see Fig. 3). The results of these two steps are the following.

1) Domain-Dependent Architecture:

Remote digital early cardiac arrhythmia detection and diagnosis IoT BPM architecture

a) Users: The users of the system are: 1) the customers that want a runtime monitoring of their hearts in their day-to-day having not only a diagnosis by a cardiologist, but also runtime alerts if there is any sign of cardiac arrhythmia; 2) the IDOVEN company employees as the IoT BPM staff; and 3) cardiologists as domain specialists.

b) Service request: It consists in requesting IDOVEN's service which includes the monitoring kit composed of the ECG monitor IoT medical device or Holter monitor for continuous and remote heart monitoring to detect early cardiac arrhythmias through a shopping channel, for instance an e-commerce shop.

c) Extract-transform-load (ETL) service: It retrieves the submitted orders from the shopping channel and stores them in a desired destination.

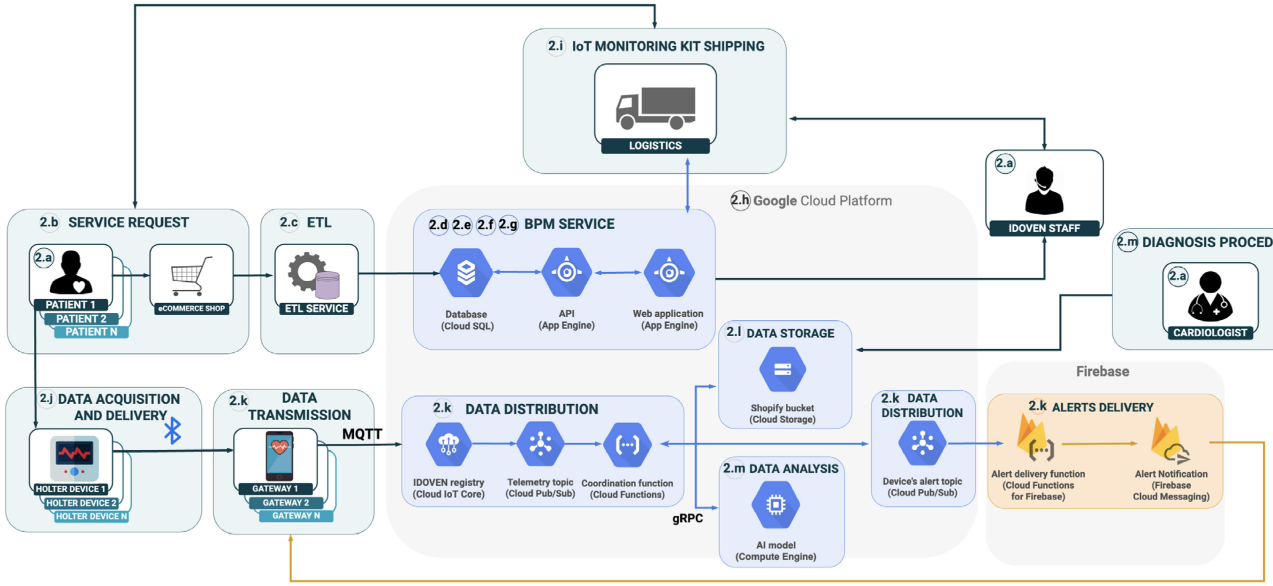


Fig. 3. Google Cloud IoT BPM architecture for remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy.

d) Storing service: It stores all the raw orders data as well as the data that is generated along with their processing.

e) State management service: It tracks the processing status by determining whether Holter monitors are free or busy. In addition, devices have the maintenance status indicating if they are enabled or damaged.

f) Decentralized coordination and BP monitoring services: They manage the orders and its assignment to Holter monitors, as well as controlling the status of the devices at any moment.

g) Data collection service: It collects data from the statuses of Holter monitors.

h) Scheduling and resource allocation services: They provide the required computational resources to scale on-demand as well as releasing or acquiring new Holter monitors, therefore this service could be supported by a cloud provider's services.

i) IoT monitoring kit shipping service: It oversees the delivery of the monitoring kit to the patient as part of the purchased service, and it is performed by a logistics company. Holter monitors are lent to patients so they can receive the service and should be returned to IDOVEN's facility also through the logistics company. In this case, this implies the famous "last mile" problem of home-delivery services because it includes logistics to deliver the IoT medical device at the client/patient/citizen home and reverse logistics to pick up the IoT medical device again.

j) Data acquisition and delivery service: It is carried out by the Holter monitor device that will record the patient's heart activity. This data is outsourced through the communication protocol the device supports. As the device will be continuously working, the patient must charge the device in case its battery drains.

k) Data transmission, distribution, and alerts delivery services: They follow the architecture DOMINIoT: 1) preserving the mobility of the patient and allowing the data recording and transmission in a nonintrusive and seamless way; 2) notifying patients if the Holter monitor is connected and if they are recording the heart activity signal; and 3) receiving alerts.

l) Data storage service: It stores the electrical heart activity.

m) Data analysis and diagnosis procedure services: They implement AI algorithms and use AI tools for detecting the presence or not of a heart arrhythmia using the gateway incoming data, and, if necessary, send alarms to patients. For the final patient's diagnosis report, these preliminary findings are presented as a clinical decision support system for the IDOVEN cardiology team. Thus, they also constitute consumers of the service as the Holter monitor has been continuously recording the patients' heart activity for a fair duration of time which allows to understand better the heart behavior as well as they can benefit from the findings of the AI techniques to accelerate and improve the accuracy of the diagnosis. In this way, this platform also acts as a decision support system.

2) Technology and Domain-Dependent Architecture: Google cloud platform remote digital early cardiac arrhythmia detection and diagnosis IoT BPM architecture

a) Users: The users do not vary from the same of the Domain-Dependent Architecture since they do not imply a technological change (see Section V-D1a).

b) Service request: The service request is served by an e-commerce shop built in Shopify platform which is connected to the ETL service. Fig. 4 shows the results of implementation of the e-commerce Web platform in Shopify to allow customers request IDOVEN's service.

c) ETL service: It is implemented with an ETL service and is connected to the e-commerce shop.

d) Storing service: It is implemented with the Google Cloud SQL storage.

Más de 10.000 personas ya confían en IDOVEN para el cuidado de su corazón

IDOVEN

Para hogar y familia

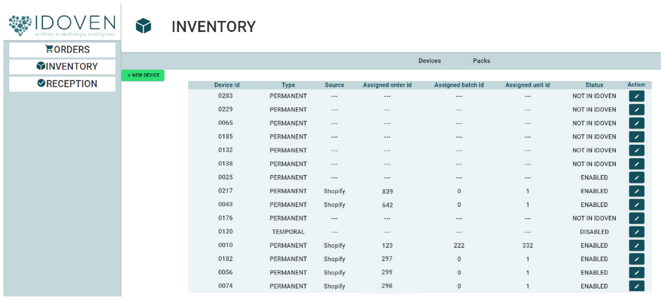
Conoce el estado de tu corazón desde casa sin visitar hospital o centro de salud. Con el mismo rigor médico. Comprueba si tu corazón está bien o conoce cuál es su evolución tras un episodio cardíaco.

Comprueba la salud de tu corazón desde casa

Conoce la evolución de tu corazón

Tarjetas regalo

Fig. 4. Catalogue of products for home monitoring.



INVENTORY

Device id	Type	Source	Assigned order id	Assigned batch id	Assigned unit id	Status	Action
0283	PERMANENT	---	---	---	---	NOT IN IDOVEN	✎
0229	PERMANENT	---	---	---	---	NOT IN IDOVEN	✎
0065	PERMANENT	---	---	---	---	NOT IN IDOVEN	✎
0185	PERMANENT	---	---	---	---	NOT IN IDOVEN	✎
0132	PERMANENT	---	---	---	---	NOT IN IDOVEN	✎
0138	PERMANENT	---	---	---	---	NOT IN IDOVEN	✎
0025	PERMANENT	---	---	---	---	ENABLED	✎
0217	PERMANENT	Shopify	839	0	1	ENABLED	✎
0043	PERMANENT	Shopify	642	0	1	ENABLED	✎
0176	PERMANENT	---	---	---	---	NOT IN IDOVEN	✎
0120	TEMPORAL	---	---	---	---	DISABLED	✎
0010	PERMANENT	Shopify	123	222	332	ENABLED	✎
0182	PERMANENT	Shopify	297	0	1	ENABLED	✎
0056	PERMANENT	Shopify	299	0	1	ENABLED	✎
0074	PERMANENT	Shopify	298	0	1	ENABLED	✎

Fig. 5. Web application tracking IoT devices statuses.

e) State management service: A Web application hosted in the Google application engine (GAE) helps IDOVEN staff to manage the state of the service and devices. This Web allows visualizing and updating the information stored in the database which supports the storing service, and uses as a backend a REST API (see Fig. 5), deployed also in the GAE service that exposes endpoints to be consumed by the application through HTTPS requests. This REST API allows the tracking and management of the IoT devices and is also integrated with the logistics company's API.

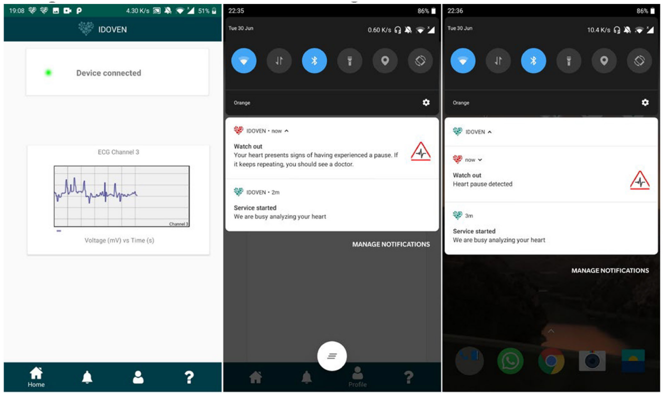
f) Decentralized coordination and BP monitoring services: The Web application, its API, and the SQL database help to carry out the management of the service request and connect with the logistics company's API.

g) Data collection service: A service provided through the Web application hosted in GAE allows IDOVEN staff to manually introduce the state of the Holter devices.

h) Scheduling and resource allocation services: The scalability and scheduling are achieved by using the GCP services.

i) IoT monitoring kit shipping service: The shipping of Holter monitors management and state control is performed by using the logistics company's API.

j) Data acquisition and delivery service: The Holter monitor, and the Android application play the sensor and gateway roles in the system, respectively. Holter monitors make possible the data acquisition and its transmission to the gateway via Bluetooth.



Device connected

IDOVEN • now

Watch out

Your heart presents signs of having experienced a pause. If it keeps repeating, you should see a doctor.

IDOVEN • 2m

Service started

We are busy analyzing your heart

IDOVEN

now

Watch out

Heart pause detected

3m

Service started

We are busy analyzing your heart

Fig. 6. IDOVEN mobile application.

k) Data transmission, distribution, and alerts delivery services: The Android application provides patients with the runtime information about the monitoring process and transmits the data via MQTT to the GCP (see Fig. 6), specifically to the data broker in Cloud IoT Core. The Cloud IoT Core service distributes data to the Cloud Function service through the Cloud Pub/Sub service. The Cloud Function service processes the telemetry data and serves its to the rest of cloud services. They are responsible for: 1) creating a storage bucket for each patient in order to store the telemetry data and AI results; 2) making a request to the Compute Engine about the AI analysis; and 3) publishing the result of the AI analysis to the device's alerts Pub/Sub topic to which it's subscribed to and which triggers the execution of the Firebase Cloud Function. Firebase is used to send messages from the GCP to the Android application in the form of "push notifications" when notifying a heart arrhythmia (see Fig. 6). Cloud Pub/Sub is a shared service between these two platforms, so it acts as a bridge between them.

l) Data storage service: The Cloud Storage stores the telemetry data.

m) Data analysis and diagnosis procedure services: The Compute Engine service to analyze the data through AI models.

E. Discussion and Results

The results of case study development have demonstrated the feasibility of deriving from the DOMINIoT architecture, the Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis domain-specific architecture (OBJ.1) and its GCP implementation (OBJ.2) (see Figs. 5 and 6). Specifically, this research work has created an IoT architecture to support IoT BPM, whose results address existing challenges in the area (see Section III). These results are enumerated as follows.

R1: An IoT-BMP architecture that integrates the BMP and IoT services in modules, such as IoT Shipping Device or BPM, with a decentralized orchestration and without being in silos (see Sections IV-B2d, V-D1a, and V-D2f).

TABLE I
DOMINIoT ARCHITECTURE APPLIED TO DIFFERENT DOMAINS

DOMAIN MAPPING		**DOMAIN**		
		Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis	**Smart Building**	**Blood Oxygen Level Monitoring System for Respiratory Disease Detection and Diagnosis**
Service request	**SW**	Continuous and remote heart monitoring through a shopping channel	Continuous and remote enviromental monitoring through a custom company-authored shopping service	Continuous and remote oxygen saturation monitoring through a custom company-authored shopping service
	HW	ECG monitor IoT medical device or Holter	Sensors (light, humidity, temperature, Co2, etc.) and/or actuators (power on/off, open/close blinds, air aconditioning on/off, etc.)	Oxygen saturation monitor IoT device or Pulse oximeter
BPM	**ETL**	Retriving the service orders from shopping channel and sending to the storing place	Retriving the service orders and sending to the storing place	Retriving the service orders and sending to the storing place
	State management	Holter: free or busy. Maintenance status: enabled or damaged.	Sensors and Actuators: There is in stock or not. Maintenance Status: Active, Slept, Damage, or Inactive. Concentrators to install the network of devices	Pulse oximeter: free or busy. Maintenance status: enabled or damaged.
	Decentralized coordination and business process monitoring	Management of the service request and communication with the logistics company	Management of the service request and communication with the logistics company	Management of the service request and communication with the logistics company
	Data collection	Storing all the raw orders data and their data processing	Storing all the raw orders data and their data processing	Storing all the raw orders data and their data processing
	Scheduling and resource allocation	Assignment of Holter monitors and controlling the status of the Holters	Assignment of sensors and actuators and controlling their status	Assignment of Pulse oximeter and controlling the status of the pulse oximeter
IoT device shipping		Logistics: delivery of the monitoring kit to the patient	Logistics: delivery of the sensors and actuators. Installation: physical deployment of the assigned sensors and actuators.	Logistics: delivery of the monitoring kit to the patient
Core Competence Analytics	**Data acquisition and delivery**	Holter records the patient's heart activity. This data is outsourced through the communication protocol the device supports.	Sensors send the environmental data acquired through the communication protocol the device supports.	Pulse oximeter records the oxygen saturation in blood. This data is outsourced through the communication protocol the device supports.
	Data transmission, distribution, and alerts delivery	Records and transmits data, notifies patients if the Holter monitor is connected and receive alerts.	Records and transmit data, notifies maintenance status, receive alerts to switch on/off the actuators, and send the actions to the corresponding actuator.	Records and transmits data, notifies patients if the Pulse oximeter is connected and receive alerts.
	Data storage	Stores the electrical heart activity	Stores environmental data	Stores the oxygen saturation level in blood
	Data analysis and decision-making	Implements AI algorithms and use AI tools for detecting the presence or not of a heart arrhythmia using the gateway incoming data, and, if necessary, send alarms to patients.	Implements decision-making systems based on statitistics to switch on/of actuators sending the alerts.	Implements AI algorithms and use AI tools for detecting descents in the oxygen saturation level using the gateway incoming data, and, if necessary, send alarms to patients.

TABLE II
PLATFORM-INDEPENDENT IoT-BPM ARCHITECTURE FOR REMOTE DIGITAL EARLY CARDIAC ARRHYTHMIA DETECTION AND DIAGNOSIS FOLLOWING A DEVICE AS PoC STRATEGY IMPLEMENTED WITH DIFFERENT CLOUD SERVICES

Technology Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis Mapping		TECHNOLOGY		
		Google Cloud Platform	Microsoft Azure	Amazon Web Services
Service request	SW	Continuous and remote heart monitoring through Shopify	Continuous and remote heart monitoring through a custom company-authored shopping service	Continuous and remote heart monitoring through a custom company-authored shopping service
BPM	ETL	Custom company-authored ETL	Custom company-authored ETL	Custom company-authored ETL
	State management	Google App Engine	Azure Cloud Services	AWS Elastic Beanstalk
	Decentralized coordination and business process monitoring	Google App Engine Cloud SQL	Azure Cloud Services Azure SQL Database	AWS Elastic Beanstalk Amazon RDS
	Data collection	Cloud SQL	Azure SQL Database	Amazon RDS
	Scheduling and resource allocation	Given by Google Cloud Platform's scalability capabilities	Given by Microsoft Azure's scalability capabilities	Given by Amazon Web Services's scalability capabilities
IoT device shipping		Logistics service selected by the company	Logistics service selected by the company	Logistics service selected by the company
Core Competence Analytics	Data acquisition and delivery	ECG monitor IoT medical device or Holter Bluetooth	ECG monitor IoT medical device or Holter Protocol communication the device supports	ECG monitor IoT medical device or Holter Protocol communication the device supports
	Data transmission, distribution, and alerts delivery	Android mobile application MQTT protocol Cloud IoT Core Google Cloud Functions Cloud Pub/Sub	Android mobile application MQTT protocol Azure IoT Hub, Azure IoT Edge, Azure IoT Protocol Gateway Framework Azure Functions Azure Service Bus	Android mobile application MQTT protocol AWS IoT Device Management, AWS IoT Core AWS Lambda AWS IoT Message Broker, AWS Messaging
	Data storage	Cloud Storage	Azure Blob Storage	Amazon Simple Storage (S3)
	Data analysis and decision-making	Compute Engine	Virtual Machines	Elastic Compute Cloud

R2: An IoT-BMP architecture that explicitly includes not only the service request flow, but also the information and logistics flows (see Section IV-D, Figs. 1 and 2).

R3: An IoT-BMP architecture that explicitly prescribes services for scheduling, resource allocation, and state management of Smart IoT systems as part of the BPM service, making mandatory the management of these services in any IoT system (see Sections IV-B2 and V-D).

In addition, the main goal of this research work is to demonstrate the feasibility of deploying this IoT-BMP architecture in a real setting and to illustrate how to adopt it at different levels of abstraction to promote its reusability in other domains and technological frameworks. This goal has been also achieved by the following results.

R4: A platform-independent IoT BPM architecture for remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy to be used as a pattern by those IoT companies that work in the same domain, and they want to deal with the challenges overcome by the results R1-R3 without changing their technological framework.

R5: A DOMINIoT to be used as a pattern to fulfil in the construction of any IoT system for dealing with the challenges overcome by the results R1-R3, the DOMINIoT architecture. At the same time, its abstraction provides the benefits of easily being specialized into the needs of a specific domain.

Table I has been defined to illustrate how to use the DOMINIoT architecture as a pattern at different domains: the domain used in this work to illustrate in depth the architecture remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy, the domain of smart buildings [extracted from SIoTCom (PID2020-118969RB-I00) and CROWDSAVING (TIN2016-79726-C2-1-R) projects of the Spanish Ministry of Economy and Competitiveness (MINECO)] and the healthcare domain, but within the respiratory disease detection and diagnosis.

R6: A Google Cloud IoT BPM architecture for remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy to be reused as it is described in terms of components and connections with the endorsement of its deployment in a real setting (see Table II). Table II has been

TABLE III
DATA FEED FROM THE HOLTER

Metric	Value
Number of Bluetooth frames delivered by the Holter	13,692
JSON messages sent to the Cloud	131
Average size of JSON message (Bytes)	31,758
Maximum network rate when sending (KB/s)	120
Maximum network rate when receiving (KB/s)	3.3
Average number of bytes sent to the cloud	4,160,298
Battery usage	Light

TABLE IV
DATA SENT TO THE CLOUD WITH DIFFERENT MONITORING SERVICES

Metric	Value
Number of JSON messages sent in 1 hour	319
Number of bytes sent in 1 hour	10.130.802
Number of Megabytes in 24 hours	243,14
Number of Megabytes in 7 days	1.701,97
Number of Megabytes in 21 days	5.105,92

created to illustrate how to adopt the platform independent IoT BPM architecture for remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy as a pattern to different technologies: the GCP used in this work to describe its implementation in detail, Microsoft Azure and Amazon Web Services (AWSs).

In addition to the presented qualitative results from the conduction of the case study, it is important to generate quantitative results. To that end, a set of experiments and analysis were conducted (see Section V-B).

One of the most important issues of the developed IoT solution for remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy, specifically, the heart arrhythmias, is to guarantee a continuous data feed from the smartphone to the cloud to execute an early analysis of the data received. To that end, an experiment was conducted which consisted of checking the number of bytes that the smartphone of a patient would have to send to the cloud during the service. The experiment consisted in running the Holter for 24 min. The metrics obtained are illustrated in Table III.

In addition, we measured the average number of Megabytes sent to the Cloud depending on the service purchased by the patient, i.e., being monitored for 24 h, 7 days, or 21 days. The obtained results are described in Table IV. From these data, it is possible to derive the following result.

R7: The data feed and the services worked as expected. Therefore, the good results imply that the presented Google Cloud Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis IoT BPM architecture is deployed to support the IDOVEN services.

The development of this study depicts the IoT infrastructure built following a lean design methodology [32] for four years to create a new clinical workflow that allows cardiologists to diagnose patients remotely outside the hospital while being able to guarantee a medical grade quality. This platform and workflow have been validated in the last two years with 2188 patients from 338 different zip codes in 31 different countries (see Fig. 7) across the seven continents and diagnosed over 80 different cardiac conditions to this date, deriving the result.

Fig. 7. Map with the locations where IDOVEN has monitored patients.

TABLE V
METRICS RESULTED FROM THE CONTINUOUS TRACKING OF THE STATUS OF IoT DEVICES

Average number of times a Holter device was used	Percentage of devices that resulted damaged	Percentage of devices that were in a good operating status
7.78	3.4%	96.6%

R8: The deployment of the DOMINIoT architecture using GCP in a real IoT System as the Remote Digital Early Cardiac Arrhythmia Detection and Diagnosis IoT system of the IDOVEN company which has been validated with 2188 patients across the seven continents.

In addition, the decrease in time to diagnosis was analyzed. Fig. 8 depicts time metrics from the moment the patient requests the 7-day service until it receives a final report. These times were calculated as the median for each monitoring order, and they included weekends, bank holidays, and the additional courtesy days added to make sure the patient completes properly the monitoring period and to adjust with the logistics workflow. Results showed the successful execution of the BPM as: 1) it takes 2.2 days to receive the monitoring kit at home from the moment it is requested, in comparison with the 1–4 months it takes in Spain to get a first appointment with a cardiologist which means a time reduction up to 98.2% and 2) it takes 4.6 days to receive the report from the moment IDOVEN gets the Holter device back, in comparison to the two weeks to up to eight months that a current patient would have to wait for results from a traditional Holter monitoring, meaning a time reduction up to 98.1%. These reductions of time give the patient peace of mind and help professionals to act early, increasing the quality of patient's life in the long term.

R9: The implementation of the BPM shows a time reduction of up to 98.2% for a patient to get recorded with a Holter monitor and a time reduction of up to 98.1% to receive the results of the monitoring.

Regarding the analysis performed about the tracking of the status of each Holter IoT device with the Web application, the results depicted that only 3.4% of devices were damaged and therefore, substituted, and the remaining 96.6% continued to be available for giving service (see Table V). This helped to maintain the quality and to acquire more stock if necessary.

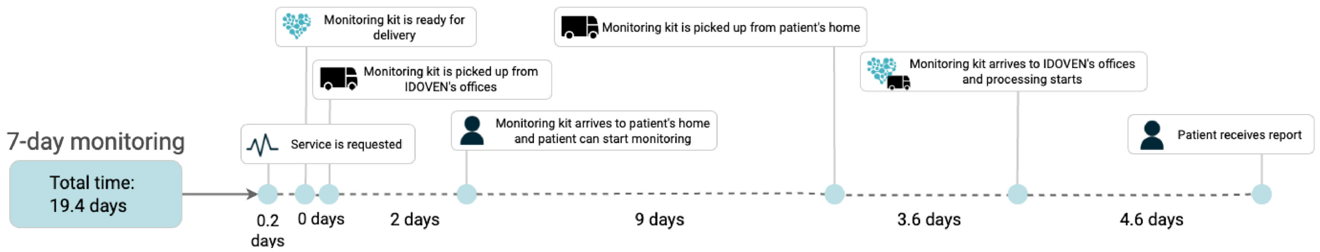


Fig. 8. Time metrics of the IDOVEN's remote digital early cardiac arrhythmia detection and diagnosis following a device as a PoC strategy service.

R9: Metrics related to the tracking of IoT devices and their status to ensure a correct performance throughout the BPM execution that showed that 96.6% of devices maintained their operating quality and 3.4% resulted damaged.

Finally, to show how our contribution can speed-up the diagnostic process while saving costs for public health systems, an approximation of the avoided cost was calculated in terms of avoided appointments and medical tests performed at primary care centers and hospitals in Spain when IDOVEN's Google Cloud IoT BPM architecture for remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy services were used.

Typically, when patients suffer symptoms, they must go to the primary care center and get recorded an ECG that suggests the patient needs a more in-depth review at the hospital. There, the cardiologist prescribes the Holter monitor, and then, the cardiologist and nursery team analyze their heart signal and either make a final diagnosis or require more complementary tests. With the presented solution, a healthy patient, who does not have to go through complementary tests, does not need these appointments and tests and thus, it incurs zero costs for the Spanish Health System. However, if the results given by IDOVEN indicates that it is necessary to perform complementary tests, the patient only needs to get an appointment at the primary care center and get another appointment with the cardiologist at the hospital where the professional could take IDOVEN's report as an appropriate starting point for the final diagnosis.

Particularly, in a sample of 846 patients analyzed by IDOVEN with 24-h, 7-day, and 21-day monitorings, 102 patients were recommended to go to the hospital for complementary tests due to minor and major findings in their ECGs. For this case, the solution helped the Spanish Health System to save €375 518.01 per 846 patients (see Table VI). This was calculated using the available data of the appointments and medical tests published by several Spain's regions [32], [33], [34], [35], [36].

In addition, not only the costs are avoided due to the number of appointments and medical tests. There are important savings in number of hours that health professionals invest during these processes and more importantly, in the heart signal analysis itself. Moreover, the detailed review of the ECGs is a highly tedious and repetitive task which induces fatigue and lack of productivity, increasing the probability of making mistakes and consequently, worsening the diagnosis. So, this architectural pattern solves this through its decision support system based on AI.

TABLE VI
COST AND TIME OF CONVENTIONAL APPOINTMENTS AND MEDICAL TESTS AT THE HOSPITAL IN COMPARISON TO USING IDOVEN'S SERVICES AND AI PLATFORM AND THE AVOIDED COST AND HOURS FOR THE SPANISH HEALTH SYSTEM

	744 patients not needing complementary tests		**102 patients needing complementary tests**	
	Cost (euros)	**Time (hours)**	**Cost (euros)**	**Time (hours)**
Conventional appointments and medical tests at the hospital	349,850.38 €	2,035.44 h	48,915.27 €	271.48 h
With IDOVEN's services and AI platform	0 €	0 h	23,247.64 €	68 h
Avoided cost and time with IDOVEN per patient group	349,850.38 €	2,035.44 h	25,667.63 €	203.48 h
Total avoided cost and time with IDOVEN	375,518.01 €	2,238.92 h		

With IDOVEN's analysis and remote patient monitoring service and its AI platform, the Spanish Health System saved 2238.92 h per 846 patients (see Table VI), helping to significantly reduce the waiting lists.

In addition, it is important to emphasize that out of the 102 patients that had to get complementary tests, 89 patients did not know they had any heart condition, and 13 patients had an existing heart condition that they were already aware of. In this way, it is evident that the solution contributes to the early detection of heart diseases, which in the long-term decreases the possibility of having a more severe disease which may incur in hospitalizations and other costs that were not considered in this study.

R10: The study of a sample of 846 patients demonstrating that the execution of this BPM: 1) saved the Spanish Healthcare System €375 518.01 and 2238.92 h in terms of time invested by health professionals and 2) helped to detect in 102 patients major and minor findings.

F. Limitations

The results of this case study developed has demonstrated the expected results by adopting the DOMINIoT architecture from the domain and technology perspectives in an industrial setting. It is reusable due its independence of domain and technology, and it can be extended or specialized to different domains and technologies to guarantee the fulfillment of a decentralized communication and the scheduling, resource allocation, and state management of IoT devices. However, it cannot be defined as a reference IoT-BPM architecture with all the required components and optional components of any IoT BPM system. To that end, it is required to adopt DOMINIoT to other domains, case studies, and technologies to ensure that other domains or technologies would not need optional components specifically tailored for them. Therefore, in this work, DOMINIoT is presented as a first step to this reference architecture with its core components and it is provided as a pattern to be reused, extended and/or tailored by other IoT BPM fields. In addition, some presented services still require human intervention and for automating them, it would be necessary to gather enough experience to design the best solutions, and to perform a study to demonstrate that the prescribed interconnections can be automated via technology. On the other hand, the experiments are dependent of the Google technology, the providers and the Holter's manufactures, more experiments with other technologies and hardware should be performed to consolidate the quantitative results.

VI. CONCLUSION

This article presents the DOMINIoT architecture, which supports a smart-IoT BPM that address the challenges of scheduling, resource allocation, and state management of Smart IoT systems. In addition, it has the advantages of being domain and platform independent. This article illustrates how this architecture can be derived to a domain and technology dependent architecture preserving the traceability of services, users, and IoT devices. As a result, it is presented as a pattern that can be reused by different domains and technological platforms providing a guidance with two tables for its adoption and replication in other domains and technologies. This article presents the results of the successful adoption by the IDOVEN company in an IoT system for remote digital early cardiac arrhythmia detection and diagnosis following a Device as a PoC strategy, which has been implemented using GCP services.

As future work, it is planned to implement the automation of some manual services, the adoption of other domains and technologies, and to include patterns to other quality attributes as security and sustainability.

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