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PREFACE

The workshop on Disruptive Information and Communication Technologies for Innovation and Digital transformation, organized under the scope of the DISRUPTIVE project (disruptive.usal.es) and held on June 18, 2021 in Porto, aims to discuss problems, challenges and benefits of using disruptive digital technologies, namely Internet of Things, Big data, cloud computing, multi-agent systems, machine learning, virtual and augmented reality, and collaborative robotics, to support the on-going digital transformation in society.

The main topics included:

- Intelligent Manufacturing Systems
- Industry 4.0 and digital transformation
- Internet of Things
- Cyber-security
- Collaborative and intelligent robotics
- Multi-Agent Systems
- Industrial Cyber-Physical Systems
- Virtualization and digital twins
- Predictive maintenance
- Virtual and augmented reality
- Big Data and advanced data analytics
- Edge and cloud computing
- Digital Transformation

The workshop program included 9 accepted technical papers and 1 invited talk. This volume contains 9 of the papers presented at the Workshop on

Disruptive Information and Communication Technologies for Innovation and Digital Transformation.

This workshop was organized by GECAD (Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development) and mainly supported by the European Regional Development Fund (ERDF) through the Interreg Spain-Portugal V-A Program (POCTEP) under grant 0677_DISRUPTIVE_2_E (Intensifying the activity of Digital Innovation Hubs within the PocTep region to boost the development of disruptive and last generation ICTs through cross-border cooperation).

June 18, 2021
Porto

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A MACHINE LEARNING BASED FRAMEWORK FOR PDM

UN MARCO BASADO EN EL APRENDIZAJE AUTOMÁTICO PARA PDM

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Abstract: The need for adaptation led the industry to evolve into a new revolution, where connectivity, amount of data, new devices, stock reduction, personalization and production control gave rise to Industry 4.0. Predictive maintenance is based on historical data, models and knowledge of the domain in order to predict trends, patterns of behavior and correlations by statistical models or Machine Learning to predict pending failures in advance. This paper presents a review of most applied machine learning techniques, comparing different authors' approaches used in predictive maintenance. Also, a conceptual machine learning framework is proposed to tackle various predictive maintenance challenges such as failure forecast, anomaly detection and Remaining Useful Life prediction.

Keywords: predictive maintenance; industrial maintenance; machine learning.

Resumen: La necesidad de adaptación llevó a la industria a evolucionar hacia una nueva revolución, donde la conectividad, la cantidad de datos, los nuevos dispositivos, la reducción del stock, la personalización y el control de la producción dieron lugar a la Industria 4.0. El mantenimiento predictivo se basa en datos históricos, modelos y conocimiento de el dominio con el fin de predecir tendencias, patrones de comportamiento y correlaciones mediante modelos estadísticos o aprendizaje automático para predecir con antelación los fallos pendientes. Este artículo presenta un estudio de las técnicas de aprendizaje automático más aplicadas, comparando los enfoques de diferentes autores utilizados en el mantenimiento predictivo. Además, se propone un marco conceptual de aprendizaje automático para abordar varios desafíos del mantenimiento predictivo, como la previsión de fallos, la detección de anomalías y la predicción de la vida útil restante.

Palabras Clave: mantenimiento predictivo, mantenimiento industrial, aprendizaje automático.

1 Introduction

The Industry 4.0 is the emergence of the «smart» factory, which means smart grids, mobility, flexibility of industrial operations and its interoperability, integration with customers and suppliers and the adoption of innovative business models [21]. The 4th industrial revolution focuses mainly on creating a digital representation of physical processes to gain better insights into what is happening in physical processes [10].

In addition, in the last decade the industry has adopted information and communication technologies in most of its activities, but especially in logistics and production operations. This evolution together with the Industrial Internet of Things (IIoT) has changed the way systems can interact, monitor, control and administer. Therefore, facilitating the integration of processes and systems between sectors and technologies contributes to better communication and cooperation with each other in a new intelligent way, revolutionizing production, logistics and resource planning more effectively and economically [5, 28].

According to Vanson Bourne's 2017 global survey, sponsored by ServiceMax, GE Digital, a provider of software and industrial services, identified that 82% of companies had at least one unplanned downtime in the three years prior to the study, lasting average of four hours. These outages cost about 260,000 dollars an hour across all businesses, with two episodes of downtime lasting 4 hours each equating to more than 2 million dollars. The cost, causes and repercussions of unplanned downtime are driving investments in digital tools, such as Machine Learning, mobility tools, IoT platform, Digital Twin [33, 32].

Machine downtime has a direct impact on production costs and is directly related to companies' ability to be competitive in terms of cost, quality and performance.

To this end, data is the key to this new generation of information that can anticipate or collaborate in making predictive decisions. Predictive maintenance (PdM) is based on the early detection of equipment problems, leading to maintenance being performed based on the actual condition of the machines. In this way, the repair or replacement of components is only carried out after detecting a certain level of deterioration, instead of being carried out after the failure occurs or at a predefined time. By preventing serious failures, predictive maintenance reduces unexpected failures and maximizes the mean time between failures (MTBF), in addition to reducing work accidents and their severity. In this way, it allows a reduction in the average time of repair (MTTR) and extends the useful life of the equipment. All of this results in increased revenue, lower maintenance and production costs, transformed into a competitive advantage for the company [21, 22, 26].

This work aims to review the most used machine learning techniques in *PdM*. We also present a conceptual framework for machine learning models used for forecasting and detecting failures and predict the remaining useful life of industrial equipment.

2 Machine Learning in predictive maintenance

In recent years, the fourth industrial revolution has attracted worldwide attention leading to a transformation of traditional production into factories equipped with intelligent sensors where technology is ubiquitous. Leading to produce huge amounts of data. One application that can benefit of this large amount of data is predictive maintenance, which consists of using historical data in predictive algorithms to identify trends in order to detect when the equipment will need repair, maintenance or replacement. This approach allows the industry to predict the degradation of machine performance and autonomously manage and optimize service needs on the equipment. Thus, predictive maintenance in production environments brings several benefits that are extremely strategic [18].

In this way, Machine Learning is the main asset capable of detecting and predicting failures, such as estimating the remaining life of equipment [25], in addition to being used to diagnose failures [1]. Second, Machine Learning allows to be adjusted to new changes in the factory plant, providing stakeholders with visualization of the results of the changes made. Finally, Machine Learning algorithms can identify which variables are important in the performance, deterioration and life cycle of the equipment, which is really powerful to support decision making. In this way, it can lead to major cost reductions, greater predictability and availability of systems.

Due to all these aspects, in the last years machine learning has achieved a great growth in the publications of studies related to the application of techniques for predictive maintenance in the most varied sectors. At the same time, several researches and literary reviews appear with explicit methodologies to classify and present the studies carried out [37, 36, 8].

ML techniques have been increasingly applied and have shown improved performance over conventional approaches. In practice, the application of ML techniques is not easy due to the lack of efficient procedures for obtaining training data and specific knowledge necessary to train the models. However, a factor worth mentioning is that most articles use real data instead of synthetic data, thus bringing the results closer to the real application [8].

In an overview, the techniques most frequently used for PdM are Random Forest (RF), Artificial Neural Networks (ANN), Support Vector Machines (SVM) and K means with a focus on applications of fault diagnosis and RUL prediction tasks. For this purpose, are used signals that: include acoustic emission, electrical signature parameters (current and voltage), temperature, pressure, rotation speed and vibration [36, 8].

In the Table 2, several applications of Machine Learning in predictive maintenance over the past few years are presented, providing an overview of the existing literature.

2.1 Random Forest-based approaches

In Wu et al. 2016 [34], the authors obtained an excellent performance in indus- trial PdM using the parallel Random Forest (PRF) technique. In this experiment, they collected signals from three sensors (ie, cutting force, vibration and acoustic emission) to create a seven-channel data acquisition system in order to extract 4 resources from each channel. In this way they were able to predict tool wear with an accuracy of 99.20% through the use of 28 dimensions.

Following an approach based on Random Forest to generate predictive models dynamically, Canizo et al. 2017[7] proposes an improvement of the paper from Kusiak & Verma 2011[19], where wind turbines are monitored. These models are designed using status data (alarms activated and deactivated) and operational data on the performance of wind turbines. In this way, the authors obtained an accuracy of 82.04%, achieving an improvement of 5.54% compared to the previous work.

More recently, Ayvaz & Alpay 2021[4] carried out a study with several ML techniques in order to forecast and detect failures using data generated from IoT sensors in a production line. The results of the comparative evaluations of the ML algorithms indicated that RF models obtained the best score achieving a value of 0.982 for R2, followed by the XGBoost method with 0.979.

Table 1. Studies related to PdM using Accuracy for classification and MSE for regression

References	Techniques	Results	Data
(Wu et al. 2016)[34]	PRF	99.20%	DR
(Durbhaka & Selvaraj 2016)[12]	K-means	81.80%	DR
	K-NN	87.00%	
	SVM	78.80%	
	CRA	93.00%	

References	Techniques	Results	Data
(Canizo et al. 2017)[7]	RF	82.04%	DR
(Kanawaday & Sane 2017)[15]	NB	96.61%	DR
	SVM	95.52%	
	CART	94.46%	
	Deep Neural Network	98.69%	
(Aydin & Guldamlasioglu)[3]	LSTM	85.00%	DS
(Zhang et al. 2017)[35]	DNN	100%	DL
(Mathew et al. 2017)[24]	SVR proposto	0.5522	DS
	SVR padrão	0.7322	
(Eke et al. 2017)[13]	K-means	-	DR
(Amihai et al. 2018)[2]	RF	-	DR
(Kolokas et al. 2018)[16]	RF	99.25	DR
	NB-G	98.00%	
	NB-B	98.50%	
	MLP	99.10%	
(von Birgelen et al. 2018)[31]	SOM	-	DL
(De Benedetti et al. 2018)[11]	ANN	90%	DR
(Huuhtanen & Jung 2018)[14]	CNN	-	DR
(Lasisi & Attoh- Okine 2018)[20]	SVM	97.62%	DR
	RF	92.86%	
	LDA	90.48%	
(Uhlmann et al. 2018)[30]	K-means	-	DR
(Bruneo & Vita 2019)[6]	LSTM	99.88%	DL
	SVM	97.82%	
	DNN	98.57%	
(Kumar et al. 2019)[17]	HMM + Regressão Linear	0.7261	DR
	HMM + Regressão quadrática	pura 0.7561	

References	Techniques	Results	Data
(Wo Jae Lee et al. 2019)[23]	SVM	89%, 80%, 91%	DR
	RNN	97%, 89%, 93%	
	CNN (Time history data)	78%, 90%, 85%	
	CNN (Spectrum Data)	99%, 95%, 99%	
(Cheng et al. 2020)[9]	ANN	96.422%	DR
	SVM	96.547%	
(Ayvaz & Alpay 2021)[4]RF	RF	0.9821	DR
	XGBoost	0.9791	
	Gradient Boosting	0.7761	
	MLP Regressor	0.6751	
	SVR	0.3471	
	AdaBoost	0.3381	

1. The values presented refer to R2
2. The values presented refer to the root mean square error of reconstruction (RMSE)
DR – Real data
DL – Literature data
DS – Synthetic data

2.2 Approaches based on Neural Networks

Neural networks are one of the most common and applied ML algorithms, and have been proposed in several industrial applications, including soft sensing [29] and predictive control [27].

In these related projects, one of the selected articles is Aydin & Guldamlasioglu 2017 [3] that implemented LSTM networks to predict the current condition of an engine using Apache Spark's large-scale data processing framework. The data was obtained through sensors collecting temperature data, engine pressure, fuel and coolant bleeding. In this way, the authors were able to obtain an accuracy of 85.00% in the forecast of the estimated remaining service life (RUL) of the engine. Using a simpler ANN structure, Kolokas et al. 2018 [16] compared the use of an MLP with other ML algorithms for the detection of failures in equipment in the aluminum industry, using data from nine months of operation. In this experiment, the author managed to obtain an accuracy of 99.10% in the MLP, surpassing the accuracy obtained in the comparative algorithms of Gaussian Naive Bayes (NB-G) with 98.00% and Bernoulli Naive Bayes (NB-B) with 98.50%. On the other hand, the DT and RF algorithms used for comparison stood out slightly better than the neuronal network, achieving accuracy of 99.25% and 99.25%, respectively.

Using a data set from the literature provided by NASA, Bruneo & Vita 2019 [6] presented an ML approach based on LSTM to demonstrate that these structures can be considered viable techniques for the analysis of historical data in order to predict RUL. The authors, to prove their approach, compared the intended technique with other algorithms such as SVM and DNN (Deep Learning Network). In the experiments carried out, the LSTM managed to excel, obtaining the highest precision with 99.88%, thus surpassing the DNN with 98.57% and the SVM with 97.82%.

2.3 Support Vector Machine based approaches

SVM is another ML method widely used and known to perform classification and regression tasks, due to its high precision. In Mathew et al. 2017 [24], the authors used a type of SVM for regression purposes called Support Vector Regression (SVR). In this work, a modified regression kernel is proposed for forecasting problems in order to determine the remaining useful life (RUL). The tests are performed with a simulated set of time series, and have shown that the proposed SVR has surpassed the standard SVR model, improving the RMSE (mean square error of the reconstruction root) from 0.732 to 0.552.

Lasisi & Attoh-Okine 2018 [20] compared the technique of SVM, RF and Linear Discriminant Analysis (LDA) to detect defects in rail geometry. This study used real data from a first-class railroad in the USA. Of the models used, the SVM managed to stand out by ranking with a 97.62% accuracy rate, followed by the RF with 92.86% and finally, the LDA with 90.48%.

2.4 K-means based approaches

The k-means model is a popular clustering algorithm that uses an unsupervised strategy to determine a set of clusters. In Durbhaka & Selvaraj 2016

[12] they analyzed the behavior of wind turbines using vibration signal analysis. In this work, the kNN and SVM algorithms are compared with K-means to classify types of failures in wind turbines. In conjunction with the comparison, the authors proposed a collaborative recommendation approach (CRA) method to analyze the similarity of all ML algorithm results in predicting the replacement and correction of deteriorating turbines to avoid sudden breakdowns. Individually the ML models were able to obtain an accuracy of 81.80% for K means, 97.00% for kNN and 78.80% for SVM. However, the proposed CRA approach was able to obtain an accuracy of 93.00% when analyzing the similarity of all the results of the models.

2.5 Other approaches

In Kanawaday & Sane 2017[15] they proposed a two-phase approach to predict low-quality production cycles, in order to enable the necessary measures to be taken to avoid the low-quality cycle. The first phase of the proposed architecture was the use of ARIMA models to predict the values. of the parameters for the rest of the production cycle, later these values are supplied to the supervised models for the classification of the production cycles. In this study, four classification techniques were evaluated (Naive Bayes, Support Vector Machine, CART and Deep Neural Network), with DNN obtaining the best result achieving an accuracy of 98.69%, followed by NB with 96.61%. The rest, SVM and CART, achieved 95.52% and 94.46%, respectively. The authors concluded the study with the indication that machine learning techniques are a fundamental part of predictive maintenance.

3 Machine Learning Framework Architecture for PdM

We propose a conceptual framework to be developed as an API service in future work. This framework will allow to apply several machine learning models presented in the literature for different predictive maintenance approaches.

The component diagram represented in Figure 1 shows the architecture of what the framework needs to have in order to offer fault prediction and detection. In this way, the components called «Data Repository», «Data Extraction» and «Preprocessing» are specific components related to the storage and data processing used to feed the machine learning models. The «Data Segregation» component is responsible for dividing the data into two subsets in order to enable training and evaluation of models. Regarding the «Model Training» component, it has several subcomponents representing the different approaches to predictive maintenance that can be implemented. The "RUL forecast" uses regression models in order to estimate the remaining useful life of the equipment. The "Failure Prediction" and "Failure Detection" components uses anomaly/outlier detection techniques for classification and forecasting techniques for regression. The «Model Repository» component stores the models created by the «Model Training» component with the respective evaluation produced by the «Model Evaluation» component. The component responsible for forecasting and failures, called the "Failure Prediction Service" receives the data through HTTPS and uses the existing models in the "Model Repository" to infer the arriving data.

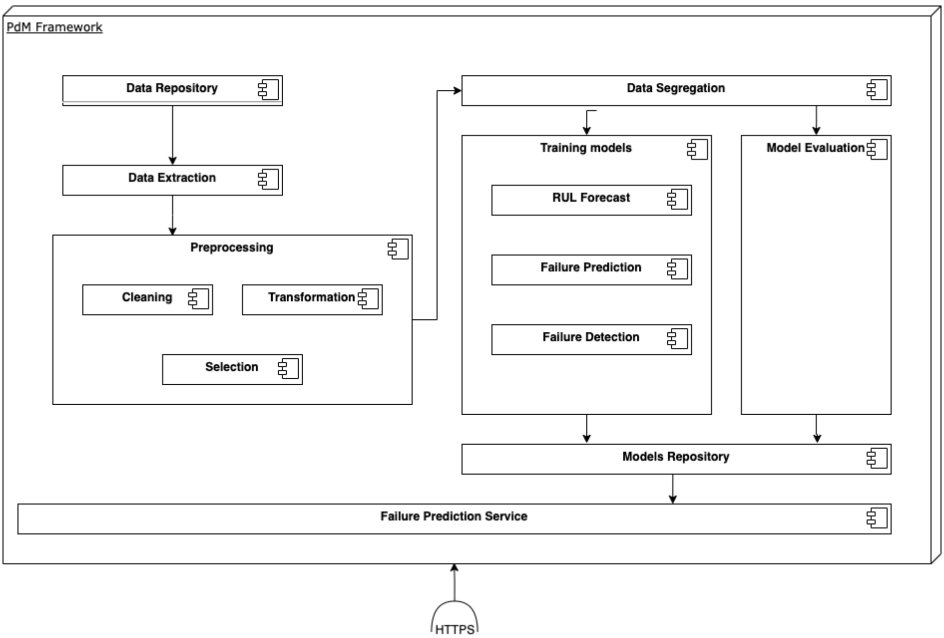

Fig. 1. Component diagram representing our PdM Machine Learning proposal framework.

4 Conclusions

The growing digitalization of companies marks the beginning of a new era for industrial maintenance. A new generation of smart sensors appeals to an increasing number of manufacturers who wish to improve their maintenance methods. Ongoing research into predictive maintenance techniques discussed in this paper promises to deliver technologies that may improve equipment reliability. Integrating our proposed framework for predictive maintenance will allow to predict equipment's RUL and failures before they occur, enabling plants to avoid unnecessary equipment replacement, save costs, and improve process safety, availability, and efficiency.

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TECHNOLOGICAL APPLICATIONS FOR SUSTAINABLE AGRICULTURE : A TRINOMIAL

APLICACIONES TECNOLÓGICAS PARA LA AGRICULTURA SOSTENIBLE: UN TRINOMIO

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ABSTRACT: In recent years, technological development has made it possible to implement sustainability-oriented solutions in the agricultural sector, leading to significant improvements. The practical application of information and communication technologies and of blockchain technology in agriculture, gives a deeper digital meaning to agricultural challenges and possibilities. This article addresses the trinomial: technology, agriculture and sustainability. The present research reviews some examples of the application of those technologies in real-world scenarios, as well as their evolution and contribution to agricultural sustainability.

KEYWORDS: agriculture; iot; Edge computing; sustainability; blockchain.

RESUMEN: En los últimos años, el desarrollo tecnológico ha hecho posible la aplicación de soluciones orientadas a la sostenibilidad en el sector agrícola, lo que ha dado lugar a importantes mejoras. La aplicación práctica de las tecnologías de la información y la comunicación y de la tecnología blockchain en la agricultura, da un sentido digital más profundo a los retos y posibilidades agrícolas. Este artículo aborda el trinomio: tecnología, agricultura y sostenibilidad. La presente investigación revisa algunos ejemplos de la aplicación de dichas tecnologías en escenarios reales, así como su evolución y contribución a la sostenibilidad agrícola.

Palabras clave: agricultura, IoT, Edge computing, sostenibilidad, blockchain.

1 Introduction

Optimal agriculture is fundamental if the human civilization is to continue prospering. This is because farming must meet the basic needs of daily life. The agricultural industry must adapt to the current market, using resources efficiently and respecting the environment. This study reviews different state-of-the art technologies that are being applied on the agricultural market and analyzes the environmental effects of those technologies.

As [10] indicates, the Food and Agriculture Organization of the United Nations estimates that between 20 % and 40 % of world crop production is lost each year due to pests and diseases, despite the application of about two million tons of pesticides. Intelligent devices, such as robots and drones, could allow farmers to reduce agrochemical use through the early detection of crop pests, enabling the accurate application of chemicals or the elimination of pests.

This document is structured as follows: Section 2 describes different state-ofart technologies that are being used in agriculture, Section 3 presents sustainability implications, Section 4 is a discussion on the topic and Section 5 draws conclusions.

2 Technological advances in Agriculture

Thanks to technological advances, farms in developed and developing countries can benefit from the application of low-cost technologies. In this regard, the internet of things (IoT) and, more specifically, the industrial internet of things (IIoT), is presented as a key enabling technology for implementing and monitoring resource management solutions in various scenarios in industry 4.0, including smart agriculture environments [14].

IoT can be used in combination with other technologies such as *cloud computing*, *big data*, *AI*, or *distributed ledger technologies* (e.g. blockchain) to implement solutions that improve the traceability and productivity of industrial processes [18]. However, when trying to transmit data to the cloud, several challenges arise regarding the privacy of the data, power consumption or costs associated with the use of cloud services [2]. In this regard, service providers charge fees based on the amount of data that is transferred, stored and processed in the cloud [16]. By using *edge computing* technologies, it is possible to reduce the volume of traffic transferred between the IoT layer and the cloud [1]. Edge computing offers a potentially manageable model for smart farming integration. As mentioned above, in addition to the importance of transferring data efficiency to the cloud, another very important aspect is the immutability of the data. The use of blockchain technology as an upgrade of electronic agriculture, organically combined with information and communication technologies, means that the benefits of both technologies can be enjoyed at the same time [4].

The increasing demand for food in terms of quality and quantity has increased the need for industrialization and intensification in the agricultural field. Internet of Things (IoT) is a very promising technology that offers many innovative solutions to modernize the agricultural sector. For a clearer contextualization of the following concepts, Figure 1 presents an schema of how they can interact.

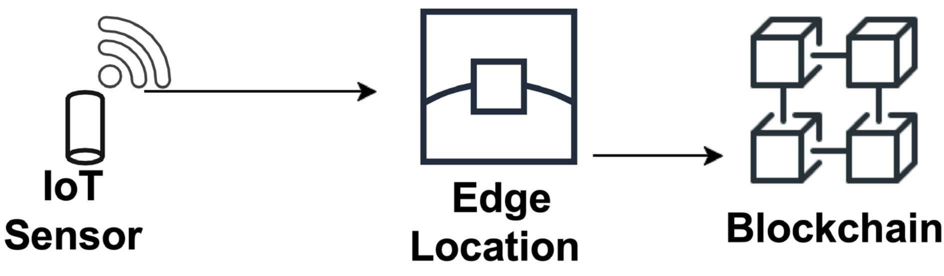

Fig. 1. Interaction diagram.

2.1 IoT

The concept of IoT was coined by a member of the development community of radio frequency identification (RFID) in 2000, and has recently gained more

importance in the real world. This is largely due to the increase in mobile devices, integrated communication and ubiquitous, cloud computing and data analysis [12].

Internet of things (IoT) refers to the general idea of connected things, especially everyday objects which are readable, recognizable localizable, addressable by a detection device and / or controllable via the Internet, regardless of the media. In the literature there are multiple IoT models oriented to the monitoring of the environmental conditions of a farm through a series of deployed sensors. All these models require, for correct operation, robust transmission on which to later be able to develop predictive artificial intelligence models.

IoT offers many solutions for each of its application areas. Some of the most important functions are: management of multiple communication protocols, data processing, information and response in real time, big data storage, security and data privacy [14] or data visualization [5].

However, the implementation of these functions entails a series of challenges that must be solved: the heterogeneity of data sources, security, privacy, latency, real-time response and the use of shared computing resources. While using IoT data ingestion layers can solve the problem of heterogeneity, other issues need to be addressed. One of them is the high volume of data that can be transmitted to the IoT platform by hundreds, thousands or even millions of devices. In this regard, solutions such as the *edge computing* paradigm have emerged in response to the need to reduce the amount of data traffic between the IoT layer and the cloud.

2.2 Edge Computing

Edge computing allows for the execution of machine learning models on the edge of the network, reducing the response time and providing a certain level of service even if the communication with the cloud is interrupted. This is commonplace in scenarios where Internet connectivity is limited (for example, rural agricultural environments) [2].

Different applications of edge computing were reviewed [15] and it was concluded that many applications had a very high potential in the agricultural industry. Moreover, [2] presented a platform oriented to the application of IoT, edge computing, artificial intelligence and blockchain techniques in smart farming environments, through the new global edge computing architecture. It was designed to monitor the status of dairy cattle and feed grain in real time, as well as ensure the traceability and sustainability of the different processes involved in production.

2.3 Blockchain

The emergence of blockchain comes from the latest advances in information and communication technology. This progress has promoted the traditional computeraided industry towards data-driven decision-making. Blockchain is a digital tech-

nology that is helping the smart industry evolve. Some authors see blockchain as an agent of change for the use of technology in agriculture.

When agricultural electronic systems are built with blockchain infrastructure, they are immutable and distributed systems for ledger management, the integrity of agricultural environmental data is safeguarded for those involved in transparent data management.

Although there are many applications based on blockchain in agriculture, their use is not worldwide. China is definitely the leader in the application of blockchain technologies, as evidenced in the reviews conducted in [3] and [17].

Some case studies presented in the literature, such as the one in [8] proposed a blockchain-based fish farm platform to ensure the integrity of agricultural data. In the case presented by [8], the designed platform aims to provide fish farmers with secure storage to preserve large amounts of agricultural data that cannot be manipulated. Various processes on the farm run automatically through the use of the smart contract to reduce the risk of error or tampering.

Some authors examined the impact of blockchain technology on agriculture and the food supply chain, [9] presents existing projects and initiatives underway, and discusses the overall implications, challenges, and potential, with critical insight into the maturity of these projects. Their findings indicate that blockchain is a promising technology towards a transparent food supply chain, with many ongoing initiatives on various food products and food-related issues, but there are still many barriers and challenges hindering its popularity among farmers and systems.

3 Sustainability implications

Sustainable intensification of agricultural systems offers synergistic opportunities for the co-production of agricultural results and natural capital. Efficiency and substitution are steps towards sustainable intensification, but redesigning the system is essential for optimal results as ecological and economic conditions change. Information Technologies can contribute to the transition of agri-food sustainability by increasing the productivity of resources, reducing inefficiencies, reducing management costs and improving coordination of the food chain [6]. Moreover, [11] explored how current social trends in the agri-food system offer new opportunities for pulses, and how simultaneous changes in both production and consumption can facilitate this double transition.

Food sustainability transitions refer to the transformation processes that is needed to move towards sustainable food systems. Digitization is one of the most important ongoing transformation processes in global agriculture and food chains. Crop diversification can improve the sustainability of western agriculture. In particular, legumes can help both agriculture and the food industry to be more environmentally friendly, as they reduce greenhouse gas emissions and help reduce the consumption of meat.

4 Discussion

Regarding agricultural production, the disparity between developed and developing countries is narrowing, as the market is increasingly globalized and more competitive. The Common Agricultural Policy (CAP) [7] provides and manages the resources of the EU budget, providing support to the countries of the European Union (EU), in the form of income to farmers, market orientation and environment. The CAP also regulated the evolution of quotas for agricultural industries. Although quotas have been eliminated, there is great concern among agricultural lobbies about the real effects of quotas over time, as well as their economic impact on a market, over the years. In addition, the challenges facing the European dairy industry are also applicable to dairy farmers around the world: the need to increase resource efficiency, to be more environmentally friendly and to apply the latest technological trends that allow to offer detailed information to the final consumer, while guaranteeing the safety and quality of the final product.

5 Conclusions

The transformation of the agricultural sector is becoming a reality; the technology being used in production is gradually becoming more advanced, as are the challenges faced by producers [13]. CAP's most recent scope of work includes water resources and effective water management. Thanks to the progress of science and technology, the practical application of information and communication technologies and blockchain in agriculture, digital agricultural democratization is possible.

In the coming years, IoT, edge computing and blockchain will play a fundamental role in the development of a more sustainable agriculture. Blockchain is a promising technology and will help us progress towards a transparent food supply chain, with many ongoing initiatives on various food products and foodrelated issues, but there are still many barriers and challenges hampering its increased popularity among farmers and the systems.

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A BRIEF REVIEW ON MULTI-AGENT SYSTEM APPROACHES AND METHODOLOGIES

BREVE REPASO A LOS ENFOQUES Y METODOLOGÍAS DE LOS SISTEMAS MULTIAGENTE

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Abstract: Agents are understood by definition as entities that interact with their environment and also with other agents. Thus, when two or more agents are able to work together in order to solve a common problem, they form a multi-agent system (MAS). MAS are systems that integrate a set of agents that interact, communicate and coordinate to achieve the established objectives. MAS are designed to meet a set of objectives according to a set of rules and standards. This article briefly summarizes different MAS classifications and methodologies that have been extensively used in the literature.

Keywords: multi-agent systems; MAS methodologies; MAS classification.

RESUMEN: Los agentes se entienden por definición como entidades que interactúan con su entorno y también con otros agentes. Así, cuando dos o más agentes son capaces de trabajar juntos para resolver un problema común, forman un sistema multiagente (SMA). Los SMA son sistemas que integran un conjunto de agentes que interactúan, se comunican y se coordinan para alcanzar los objetivos establecidos. Los SMA se diseñan para cumplir una serie de objetivos de acuerdo con un conjunto de reglas y normas. Este artículo resume brevemente las diferentes clasificaciones y metodologías de los SMA que se han utilizado ampliamente en la literatura.

PALABRAS clave: sistemas multiagente, metodologías SMA, clasificación SMA.

1 Introduction

An agent is a computer system located in some environment that is capable of acting autonomously in an environment to meet its design goals. Autonomy is a difficult concept to define as it is very broad but in this context, it refers to a system's ability to act without the direct intervention of humans (or other agents) and to control its own actions and internal state [20]. Agents can be defined as intelligent entities with social skills (interaction, collaboration, communication, coordination, competence, negotiation, intelligence) that encapsulate a functionality to solve a problem [32, 19].

The agent paradigm emerged to satisfy the deficiencies that classical software engineering had when modelling complex software systems. In this sense, according to [9, 18, 32], the agent paradigm can be applied to three main types of systems:

- **Open systems**: These systems are able to change dynamically, because their components are not known a priori and are highly heterogeneous (different entities, implementations and techniques, etc.). Negotiation and cooperation techniques are necessary to solve this type of systems, the basis of which is part of multi-agent systems [1].
- **Complex systems**: They are related to large and unpredictable systems, whose approach is the use of abstraction and modularity techniques. Both characteristics are an intrinsic part of MAS, since

the notion of an autonomous agent is itself an abstraction of a module that encapsulates procedures and data (objects) that allow to solve a problem autonomously [17].

- **Ubiquitous systems**: This type of systems enhance the use of a computer system by utilizing the computational power of a physical environment, usually distributed, but somehow abstracting its complexity away from the end user. The system must cooperate with the user to achieve the desired objectives.

In sum, agents must be able to interact, negotiate and coordinate to achieve the common goal.

The remainder of this study is structured as follows: Section 2 presents the most widely used MAS classifications found in the literature, Section 3 presents MAS methodologies, Section 4 the communication between agents and finally, the last section presents the conclusions drawn from the review.

2 MAS Classifications

The other major focus of interest has been the classification of agents according to different criteria [26, 23, 4, 11, 30]. Nowadays, in the literature there are different classifications of agents, highlighting mainly the following taxonomies:

- Classification of the type of agent implementation [26]. According to this classification, the following four types of agents are distinguished, which are presented in order of complexity: simple reflex agent, reflex agent with internal state, goal-based agents and utility-based agents.
- Classification according to the type of agent attributes [23]. For instance, [23] makes a complex classification of agents, distinguishing agents according to different characteristics. Thus, according to :
  - Mobility, there are static and mobile agents.
  - According to internal reasoning model, there are deliberative and reactive agents.
  - Attributes such as autonomy, cooperation and learning, there are collaborative, interface, collaborative learning and smart agents.

- The union of characteristics of these types of agents gives rise to a new type of agent, called a hybrid agent.

- Classification according to the conceptual design. Taking into account the conceptual design of the agents, there are interface, search and information agents.
- Classification according to the architecture [30]. The last classification to be presented in this paper is based on the internal architecture of the agent. Following this criterion, reactive, deliberative and hybrid architectures are distinguished.

Within these classifications of agents, [30] classify according to the architecture of the agent, since it determines what the agent's main components are, and how they interact with each other to achieve the final mission. If an agent is considered to be a complex system, the architecture should describe the internal structure of the agent, explaining how the agent is decomposed into independent modules that interact to achieve the required functionality. In this sense [30] proposes three classic architectures.

- Reactive architectures in which the agent lacks both reasoning and the ability to represent its environment, and its actions are modelled by basic rules [22].
- Deliberative architectures where the agent is able to maintain a symbolic representation of knowledge and plan the set of actions to be taken to achieve its goals.
- Hybrid architectures, which is a model of architecture that combines the characteristics of the two aforementioned architectures.

The most widely studied and extended deliberative architecture is the BDI (Belief, Desire, Intentions) model [13], which has been the most widespread among reasoning models, since it combines a philosophical model associated with human reasoning and a considerable number of implementations [12]. Intelligent agents have different roles, as outlined below [3]:

- **Beliefs**. Related to the set of propositions that the agent accepts as true. That is, the agent's view of the environment and the state of the other agents.

- **Desires or goals or objectives**. Refer to the set of properties that the agent tries to make true.
- **Intentions**. Associated with the set of planned actions that allow it to reach a desired state.

These agents provide solutions in dynamic and uncertain environments. Moreover, they are capable of dealing with real-world problems, even when they have only a partial view of the problem and a limited number of resources.

In addition, most software systems existing today are highly complex (such as Cloud Computing environments), since they are usually concurrent systems, interacting with each other and with other external systems [33].

1.1 Multi-Agent Systems and Optimization

An optimization problem consists in finding the best solution, according to a set of criteria, within a set of possible solutions. Optimization algorithms are general procedures that solve a problem by producing feasible solutions through problem contextualization. Optimization algorithms can be seen from two different viewpoints, they are exact if they find the optimal solution or heuristic if the solution is not necessarily optimal.

The ideal would be to obtain an optimal solution, however, in problems where the human factor exists, it is necessary to apply heuristic methods to adapt them to the needs or characteristics that the user desires. To apply these methods, it is necessary to:

1. Identify the problem.
2. Define and present the problem.
3. Explore viable strategies.
4. Advance the strategies.
5. Achieve solutions and evaluate the effects of the application of these solutions.

3 MAS Methodologies

In recent years, the rise of organizational concepts has undergone a process of rapid development. Thus, a great variety of models and methodologies for their development can be found in the state of the art, some of them based on artificial societies. The development of these methodologies, whose objective is to facilitate agent-based software design tasks, has also led to the evolution of Agent Theory itself [32]. Some of the most common methodologies used for multi-agent systems are described in the Table 1.

Table 1. Multi-agent methodologies

Name	Methodology Description		Authors
GAIA	Provides a set of models that are used in the analysis and design stages of multi-agent system development and evolve throughout that process	Environmental Preliminary role Preliminary interaction Organizational rules	[31, 34]
INGENIAS	Is based on the well-known and established software development process; the unified process. It is based on the definition of a set of meta-models that describe, from various points of view, the elements that make up a multi-agent system	Organization environment task/goals agent interacion	[25]
MASE	Uses a series of graphic models to describe system objectives, behaviors, agent types and agent communication interfaces. It uses most of the Unified Modelling Language (UML) diagrams and makes some improvements to fit the MAS domain	Capturing Goals Applying the use cases Refining roles	[8]
TROPOS	Agent-oriented software development methodology, based on two key features: (1) the notion of agent and the associated mentalist notions (e.g. objectives and tasks) (2) the analysis of the requirements and the specification of the system to be analyzed with respect to its intended environment	Early requirements analysis late requirements analysis Architectural Design Detailed design Implementation	[5, 14]

Name	Methodology Description		Authors
PROMETHEUS	Specifically aimed at the construction of intelligent agents	System Specification Architectural Design Detailed design	[24]
PASSI	Step-by-step methodology for designing and developing multi-agent partnerships. Integrating design models and concepts from software engineering approaches using the UML notation	Domain Description Agent Identification Role Identification Task specification	[6]
DECAF	Flexible multi-agent system, which is a set of software tools for rapid design, development and execution of intelligent agents for complex software systems	Distributed Environment Centered Agent Framework	[15]
RETSINA	The agents of the system must form a community of peers who are committed to peer-to-peer relationships. The structure of the community of actors must emerge from the relationship between the actors rather than be imposed by the infrastructure. It does not employ any centralised control, implements distributed infrastructure services that facilitate the relationships between agents	operating environment communication infrastructure ACL infrastructures MAS management services Performance Services security	[27, 28]

As seen in the Table 1, GAIA [31] is undoubtedly one of the main MAS development methodologies and has been widely used in different studies and contexts. After its emergence, the methodology was revised to include organizational concepts, the notion of environment, and a set of tools and techniques to facilitate its use in open environments; this revision has been called GAIA II or GAIAexOA [34]. In recent years, organizational concepts have undergone a process of rapid development. Thus, a great variety of models and methodologies for their development can be found in the state of the art, some of them based on artificial societies. The development of these methodologies, whose objective is to facilitate agent-based software design tasks, has also led to the evolution of Agent Theory itself [32, 18].

The design process of a networked system or a Cloud Computing (CC) environment, requires the study of the design methodologies of the Virtual Organizations (VO) themselves. This is so because each methodology includes its own tools, techniques and models for modelling, but in most cases these methodologies have numerous common features; different authors have defined them as the meta-model of the multi-agent paradigm [7, 2].

3.1 MAS methodologies analysis

Once the main methodologies for the design and (in some cases) development of MAS have been presented, it can be seen at a glance that all of them have a set of common features; features that have evolved as they have been revised over time. Thus, the classical methodologies have a clear design approach focused on the agent itself, while revisions of these methodologies have evolved to an organizational design model.

In the organizational systems' meta-model, there are two key concepts, the role and the organization (or group), in addition to the agent concept itself. It is common to divide the study of organizational systems into two levels of abstraction [31]; the structural (or macro) that takes into account the dynamic and organizational aspects (roles and groups); and, the concrete (or micro) level that shapes the low-level definition of the agents (tasks, plans, etc.).

4 Communication between agents

Over the years, the different types of communication between agents have been studied. Some of them are defined below:

- Speech act: An agent can act as a speaker (S) who produces an utterance to change the beliefs of the hearer (H) [21].
- Message: Agents use point-to-point or broadcast communication to talk to other agents. In the former, agent A can talk directly to agent B if it knows the agent's address.
- Blackboard: In this communication method, agents can collaboratively share data with each other using a central repository called Blackboard.

Nevertheless, the definition of the concept of organization is much more complex. First, the organization has to describe the objectives for which it has been designed, bearing in mind that these objectives have to be aligned with those of its members (roles or suborganizations) and that to some extent they provide rationality to the system as a whole. This design, although it has different nomenclatures depending on the methodology, it tends to include social, communicative, interactive and normative aspects [9]. Each of these is described below:

1. Social aspects refer to the description of the set of roles, groups (role associations) and the relationship between them. Regarding the existing relationships between roles and groups (recursively), some authors have defined a set of social structures that allow to model the interactions between members. Among the main structures, the following stand out: hierarchies, coalitions, teams, congregations, societies, federations, markets, matrixes and composite organizations. Some studies have simply defined possible relationships between members [9] such as dependency, hierarchy, use, etc.
2. The communication aspects refer to the means or language that makes the exchange of information possible. That is, a knowledge representation language (usually represented by an ontology) and a communication language. The communication sequence between two agents is called illocution [10], communication act [9] or link [16], and can have different purposes depending on the philosophy of the message [9]: representation, prohibition, permissions, declaration, expressive, commitment or directive.
3. Interaction aspects refer to how roles collaborate to achieve common goals. That is, given that there may be objectives that cannot be achieved individually, and that require the combination of several agents for achievement, it is necessary to describe an interaction structure that allows to articulate or regulate the achievement of individual sub-objectives that in turn make the achievement of higher-level objectives possible. It should be emphasized that these interaction sequences evolve as the relationships between roles and groups progress.
4. Normative aspects, it should be noted that this is one of the main pillars of organizational MAS, and there is even a methodology based on this concept HARMONIA [29]. Norms (or institutional patterns

[34] make it possible to establish a relationship of trust between the members of an organization, since they limit the free will of individual agents. Any external agent, who wishes to be part of an organization, must comply with the standards. In short, they formally define the obligations, prohibitions and permissions of the members and of the communications between them.

In addition to the concepts that have just been presented (role, organization, norms and social structures), organizational MAS routinely include another key concept; environment. Agent theory traditionally conceives the agent as an entity that plans its actions based on its perception of the environment. However, the increasing complexity of the environment itself in the context of open systems (dynamic, heterogeneous and unpredictable) can not only make the MAS unpredictable, but also difficult to interact with.

5 Conclusions

Despite their broad applicability, MAS still face a number of challenges, such as coordination between agents, security and tasking. This study provides a comprehensive analysis of all aspects of MAS, from definitions, characteristics, applications, challenges, and communications to evaluation. A classification of MAS applications and challenges is provided along with references for further study. We hope that this paper will serve as an insightful and comprehensive resource on MAS for researchers and practitioners in the field.

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REVIEW ON THE APPLICATIONS OF MULTI-AGENT SYSTEMS IN AGRICULTURE

ESTUDIO SOBRE LAS APLICACIONES DE LOS SISTEMAS MULTIAGENTES EN LA AGRICULTURA

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Abstract: Recent technological advances have led to the development of numerous platforms for precision agriculture, which help farmers access detailed information and make the right decisions regarding the management of their farm. Adapting the application of chemicals to crop demands or estimating optimal irrigation duration, are just some possibilities offered by multi-agent systems. Numerous multi-agent systems have been developed for use in precision agriculture. This article reviews state-of-the-art multi-agent systems and their uses in agriculture.

Keywords: multi-agent systems; agriculture; precision agriculture.

Resumen: Los recientes avances tecnológicos han propiciado el desarrollo de numerosas plataformas para la agricultura de precisión, que ayudan a los agricultores a acceder a información detallada y a tomar las decisiones correctas sobre la gestión de su explotación. Adaptar la aplicación de productos químicos a las demandas de los cultivos o estimar la duración óptima del riego son algunas de las posibilidades que ofrecen los sistemas multiagente. Se han desarrollado numerosos sistemas multiagente para su uso en la agricultura de precisión. Este artículo repasa los sistemas multiagente más avanzados y sus usos en la agricultura.

Palabras clave: sistema multiagente; agricultura; agricultura de precisión.

1 Introduction

Today, there are an increasing number of systems and architectures in the agriculture industry that take advantage of technology to increase the efficiency of farm resources [14, 2, 15]. The advent of decision support systems (DSS) in precision agriculture (PA) has been made possible thanks to the continuous progress of information technology.

Traditionally, field management consists of visually inspecting the development of crops to arrive at a diagnosis with which farmers make decisions and act by giving different treatments to their crops. In places where technology has not yet arrived, this approach is still used. It is based on the farmers' experience in the field and their observations.

Crop management started evolving when the first PA technologies began emerging some thirty years ago, but it has undoubtedly been transformed with the current age of digital information.

1.1 Precision Agriculture

Precision agriculture is a term that has been coined in recent years. It refers to the concept of using new technologies to increase the yield and profitability of crops while reducing the resources needed for cultivation [22, 25]. One of the main goals of PA is to improve agricultural sustainability and to optimize crop growing decisions, taking into account field variability and site-specific parameter values. Raw measurements of key crop parameters need to be processed efficiently so that numbers or images become unambiguously valuable information. Therefore, PA involves the use of geospatial techniques and sensing applications to observe, measure, and respond to interfield and intrafield variability in crops.

Technical and cost-related limitations hamper the deployment of PA infrastructures as decision support systems in smallholder settings. As a result, there has been an upsurge in applications, systems and architectures that aim to reduce costs. One of the fundamental aspects of PA is monitoring sensors' measurements [9] as well as cloud-based systems for data collection, processing and storage. On the basis of this data, predictions may be made. Lately, the implementation of edge architectures has become a popular solution in the field of precision agriculture [21, 2].

Current advances in data management are making PA grow exponentially, as data has become the key element of modern agriculture, helping growers make critical decisions. Figure 1, shows some of the aspects that are usually tracked in PA.

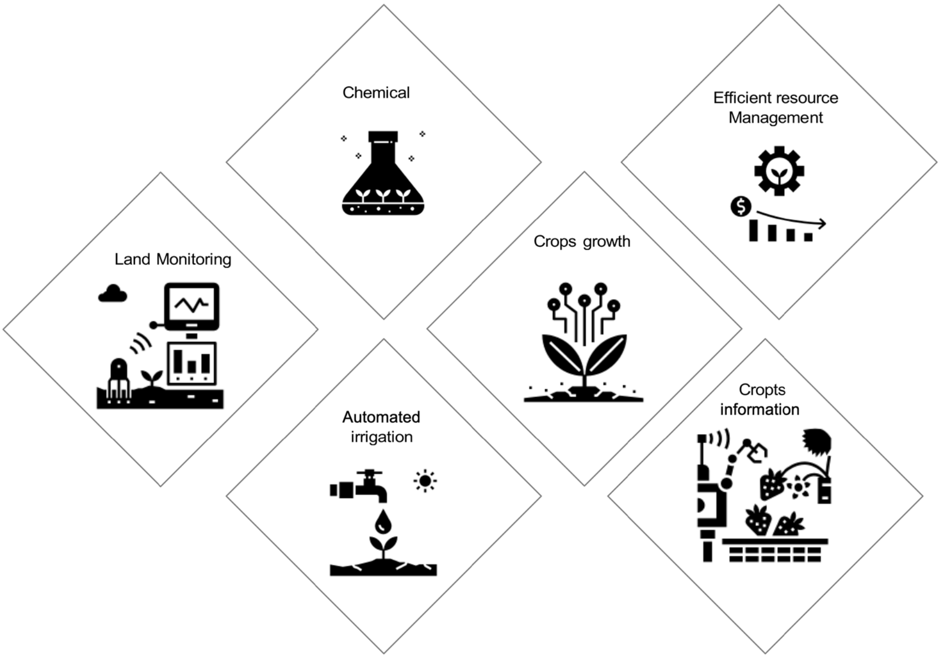

Fig. 1. Precision Agriculture Diagram.

Although many technologies have been developed for precision farming, in this case we have focused on multi-agent systems that have been developed for monitoring agriculture.

This article is organized as follows: Section 2 describes the state of the art of multi-agent systems in agriculture as well as different use cases, section 3 includes the discussion and draws the conclusions.

2 Multi-Agent Systems in Agriculture

Throughout the years, different authors have provided different definitions of multi-agent systems. Nevertheless, [24] gathered the main definitions and what was common to all of them is that multiple agents act autonomously to overcome complex problems that a single agent would not be able to solve. Figure 2 represents a general MAS architecture, in which agents are interconnected in a changing environment.

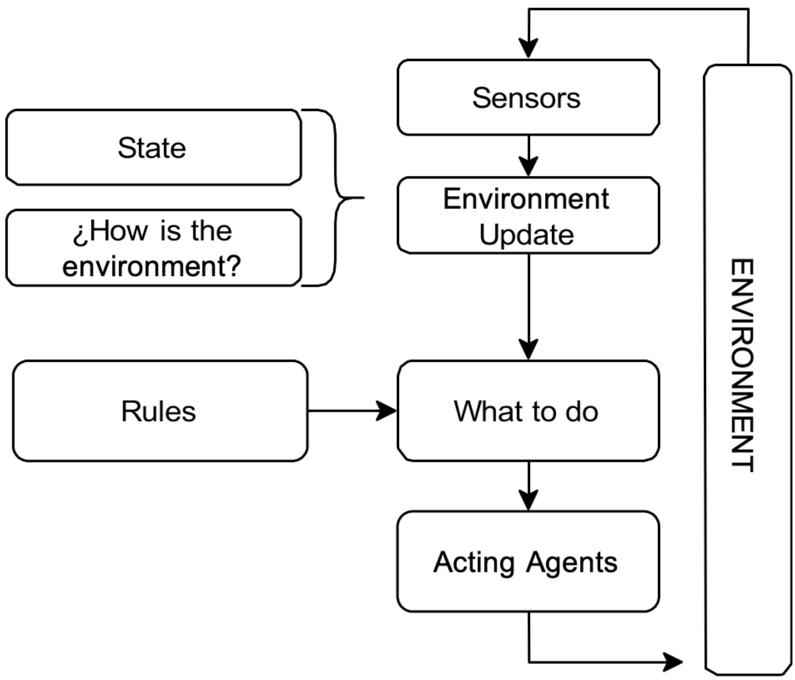

Fig. 2. Multi-agent Architecture.

Different studies have been carried out to implement multi-agent systems in different sectors. For instance, in the supply chain sector, in which there are many interconnected variables, numerous MAS applications have been proposed [11]. Regarding the applications of MAS in PA, the information provided by crops only becomes beneficial when managed efficiently. The multi-agent systems that improve the decision-making of the field management nodes, save resources at the farm level while increasing the income. They achieve this through optimal water and fertilizer use and through respecting the environment and the consumer. Some authors have presented complete systems regarding the management of resources in agriculture, however, others focus on each of the phases of precision agriculture. Although it is true that there are some multi-agent systems that cover a wide spectrum of possibilities, such as the case of [20], where a review has been conducted of the data processing methods in crop management. The platforms developed in recent years allow farmers to access knowledge that can help them make the right decisions when implementing PA management actions [3]. Some examples of different applications are described below.

2.1 Landscape

Nowadays, different systems have been developed for the study of land and crop location through models of multiagent land use change and land cover systems [10] did a review of the application of multi-agent models in agriculture and land use modelling. Agricultural landscape modelling can make a key contribution to design, but it still has to overcome several difficulties to offer reliable tools to decision makers [16, 13] presented a model which offered a promising new tool of land cover phenomena that focus on human-environment interactions.

2.2 Irrigation

Water is an essential natural resource for social, economic and environmental development [12]. Among the multiple sectors using water, agriculture is the largest consumer of this resource, accounting for approximately 70 % of total freshwater consumption [1]. That is why different authors have proposed multiagent systems, specially oriented to this end [3] developed a platform based on MAS that integrates the use of a soft computing technique based on expert knowledge. It was designed for when limited data precludes the ability to develop accurate empirical models. Moreover, [6, 5] presented other use cases in which multi-agent systems were developed to reduce water consumption and to determine the relationship between water and the type of soil.

In the case of [6], the author proposed an architecture that was tested in an agricultural environment to optimize the irrigation of a corn crop. Thanks to the wireless sensor network (WSN) it was possible to obtain information on the crop's terrain and its climatic conditions, extracting information on the needs of the cultivated corn and making efficient irrigation decisions based on these needs, reducing water consumption by 17.16 % compared to traditional automatic irrigation.

2.3 Energy Consumption

The use of wireless sensor networks is essential for the implementation of information and control technologies in application areas such as precision agriculture [19] designed a system with the objective of achieving energy efficiency during the awakening synchronization, exchanging the energy consumed in the receiver for that of the transmitter [7] presented the results obtained from the simulation of a system that allowed to reuse the energy of a power plant. They showed how the agents that make up the system communicate with sensors and actuators and how data analysis algorithms are applied to allow for the use of this energy in greenhouses, providing a reduction in the energy they need without the system [18] conducted a review of the state-of-the-art applications in the energy sector, as in the case of the electricity grid, in which a multi-agent system became the best option.

2.4 Pesticides

It is important to reduce the consumption of pesticides [8] or instead prevent fungi [4], since fungal diseases have been underestimated worldwide, but constitute a substantial threat to various plant and animal species, and to public health. In the case of [8] they built a new model based on Mathematical Programming-based Multi-Agent System (MPMAS). It is a multi-agent system that allows an ex-ante evaluation of the impact of alternative strategies to reduce the use of pesticides, including a series of taxes on pesticides, the introduction of integrated pest management, a price premium for safe agricultural products and grants for biopesticides.

3 Discussion and Conclusions

An advantage of multi-agent systems is that they allow solving problems or situations in which a single agent would not be able to perform the task by itself. As evidenced by this article, multi-agent systems have been used over the last few years to facilitate different agricultural processes. Thanks to multiple agents, a large amount of information can be obtained and parallel processes, in which the agents exchange information, can be executed. Moreover, they perform prediction tasks and incorporate artificial intelligence techniques.

Nevertheless, other disruptive technologies may be applied in the field of agriculture in conjunction with multi-agent systems. For example, blockchain to keep a record of territories or track manufactured products, as [23] poposed, which is a system that uses smart contracts and blockchain technology to eliminate intermediaries and streamline logistics activities. As in the case of the solution proposed in [17], which was implemented on a mixed farm.

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ROUTE OPTIMIZATION FOR A BEER DELIVER DECISION SUPPORT SYSTEM

OPTIMIZACIÓN DE RUTA PARA UN SISTEMA DE APOYO A LA TOMA DE DECISIONES EN LA DISTRIBUCIÓN DE CERVEZA

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Abstract: In this paper we present a brief literature review on routing problems and decision support systems for fleet management. Problems such as the Travelling Salesman Problem and the Vehicle Routing problem are presented along with their most common solution methods. We also propose a decision support system prototype for the fleet management of a beer delivery organization.

Keywords: travelling salesman problem; vehicle routing problem; decision support systems.

Resumen: En este artículo se presenta un breve repaso de la literatura sobre problemas de enrutamiento y sistemas de apoyo a la toma de decisiones en la gestión de flotas. Se presentan problemas como el Problema del Vendedor Viajero y el Problema de Enrutamiento de Vehículos junto con sus métodos de solución más comunes. También proponemos un prototipo de sistema de apoyo a la toma de decisión para la gestión de flotas de una organización de reparto de cerveza.

Palabras clave: problema del vendedor viajero, problema de enrutamiento de vehículos, sistema de apoyo a la decisión.

1 Introduction

Nowadays, the fleet management systems incorporate a wide variety of integrated technologies to potentiate an extensive set of functionalities, such as, operations planning, routing, scheduling, tracking, diagnosis, management and many others. The response to transportation requests made by a fleet of vehicles are wellknown problems in the literature. These kind of problems usually fit in one of two large groups: Vehicle Routing Problem (VRP) and Arc Routing Problem (ARP). The first group, VRP, represents the problems of traversing a set of specific points, which means that the demand is spread along the nodes of a graph [12]. The second, ARP, represents the problem of traversing several arcs of a graph [12]. In this paper we will focus our study on the Travelling Salesman Problem (TSP) and VRP. We will also present a Decision Support System prototype to the fleet management of a beer delivery organization.

The VRP was first introduced in the literature under the name Truck Dispatching Problem by Dantzig and Ramser (1959) [3] in the context of the optimization of the gasoline delivery, made by a fleet of homogeneous trucks, between a terminal and several service stations. In that paper, the problem was presented as a generalization of the classical TSP, therefore it makes part of the NP-Hard problems, in terms of computational complexity. In the past 50 years enterprises and academy gave an increasing attention to these kind of problems. A lot of effort was made to approximate the theoretical concepts to the real world problems, resulting in a wide range of solution methods applied to a lot of variations of the original VRP. The following sections of this article are organized in the following way: A brief review of the TSP and

Multiple Travelling-Salesman problem (mTSP); the VRP; Decision support system prototype architecture, usability and results.

2 Routing Problems

2.1 Travelling salesman problem

Conceptually, the TSP is the problem of finding the shortest route that visits once, and only once, a set of cities, given the distance between each pair of cities and returns to the origin city [7]. It was first formulated in 1800 by the mathematician William Rowan Hamilton in the context of the Hamiltonian cycle a cycle in a graph that visits each vertex exactly once. The general TSP mathematical formulation was first presented in 1930 by Merrill Flood on his work to solve the school bus routing problem. A mathematical formulation for the TSP is presented on equation 1. Cities are identified with the numbers $1, \ldots, n$ where x_{ij} is the path from a city i to city j if $x_{ij} = 1$ and $c_{ij} > 0$ is the distance from city i to city j.

$$
\begin{aligned}
\text{Minimize} \quad & \textstyle\sum_{i \neq j} c_{ij} x_{ij} \\
\text{subject to} \quad & \textstyle\sum_{j=1} x_{ij} = 1 \quad i = 1, \ldots, n \\
& \textstyle\sum_{i=1}^{n} x_{ij} = 1 \quad j = 1, \ldots, n \\
& \textstyle\sum_{i,j \in S}^{n} x_{ij} \leq |S| - 1, \\
& S \subset V,\ 2 \leq |S| \leq 2 - n, \\
& xij \in \{0, 1\}, \\
& i, j = 1, \ldots, n,\ i \neq j
\end{aligned}
\qquad (1)
$$

The mTSP is a generalization of the TSP problem and is defined by Bektas [2] as follows: Given a set of nodes and m salesmen located at a single depot, mTSP consists of finding tours for all m salesmen, who all start and end at the depot, such that each node is visited exactly once. This generalization makes the problem more similar to the VRP. A mathematical formulation for the mTSP is presented on equation 2.

Minimize

$$\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij}$$

subject to:

$$\sum_{j=2}^{n} x_{1j} = m, \qquad (2)$$

$$\sum_{j=2}^{n} x_{j1} = m,$$

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j = 2, \ldots, n$$

$$\sum_{i=1}^{n} x_{ij} = 1, \quad i = 2, \ldots, n$$

+ subtour elimination constraints,

$$x_{ij} \in \{0, 1\}, \forall (i, j) \in A,$$

Given the importance and the complexity of the problem, the TSP was the target for an enormous number of different solution methods over the past 60 years. These methods can be classified as exact methods and heuristic methods. The exact methods lead to the optimal solution, but are more expensive in terms of time and computational resources, on the other hand, the heuristic methods (non-exact) are solution methods that lead to a sub-optimal solution but require less time and computational resources. It is important to remember that the TSP is an NP-Hard problem where the number of possible solutions has the order of $n!$ (where n is the number of cities) so, for a large number n, the computation of all possible solutions is practically impossible. Exact methods:

- Brute-Force: Consists on the computation and evaluation of all the possible solutions for the problem. It has a running time of $O(n!)$, so if we have 20 cities, we will have to evaluate approximately $2.4329\ 10^{18}$ solutions, which turns out to be almost impractical.
- Dynamic programming: The Held-Karp method [5] decreases the running time to $O(n^2.2^n)$. Considering the exponential part of the previous expression, the computation of all the solutions will turn out to be impractical for $n = 50$ there will be $2.814\ 10^{18}$ solutions.
- Branch-and-bound, Cutting-plane and branch and cut methods: these are, by far, the best methods to solve the TSP. A branch-and-cut method was able to solve an instance with 85,900 cities Applegate et al. [1].

Heuristics and Meta-heuristics:

- Simple heuristics: The number of simple heuristics, usually based on the concept of greedy algorithms, are found in the literature. Examples are the heuristic for the Nearest Neighbor heuristics, Insertion heuristics and the Christian Nilsson heuristic [9];
- Tabu search: A largely used meta-heuristic applied to the TSP [11];
- Ant colony optimization: A meta-heuristic based on a cooperative learning method presented by Dorigo [4] in the context of the TSP and lately used by a large number of researchers to solve a large variety of problems. Is able to give fast and good solutions, if implemented correctly.

2.2 The Vehicle Routing Problem

VRP is an important problem in the fields of transportation, distribution and logistics. The VRP can be described as the problem of finding a plan for the following task: Determine a set of vehicle routes to perform all (or some) transportation requests with the given vehicle fleet at minimum cost; in particular, decide which vehicle handles which requests in which sequence so that all vehicle routes can be feasibly executed [12]. A way to formulate, mathematically, the one of the variants of VRP is depicted on equation 3. In this formulation c_{ij} represents the cost of going from node i to node j, x_{ij} is a binary variable that has value 1 if the arc going from i to j is considered as part of the solution and 0 otherwise, K is the number of available vehicles and $r(S)$ corresponds to the minimum number of vehicles needed to serve set S. Finally 0 represents the depot node.

$$\text{Minimize } \sum_{(i,j)\in A}^{n} c_{ij}x_{ij}$$

Subject to

$$\sum_{j\in \delta+(i)}^{n} x_{ij} = 1, \quad \forall_{i} \in N,$$

$$\sum_{j\in \delta-(j)}^{n} x_{ij} = 1, \quad \forall_{j} \in N,$$

$$\sum_{j \in \delta-(0)}^{n} x_{0j} = |K|,$$

$$\sum_{j \in \delta-(0)}^{n} x_{ij} \geq r(S), \quad \forall_{S} \subseteq N, S \neq \emptyset$$

$$x_{ij} \in \{0,1\}, \forall (i,j) \in A$$

Given the potential of the problem to real world applications, several variants of the problem emerged on the literature over the past 50 years [6, 10, 13] to fit better in the real problems specific constraints. Some of those constraints are:

- Capacity constraints: The total packages demand of the locations cannot exceed the vehicles carrying capacity;
- Time/distance constraints: the duration/length of each route cannot have a fixed bound;
- Maximum number of locations that each vehicle can visit;
- Time windows: each location must be serviced within a time window and waiting times are allowed;
- Precedence relations between pairs of locations: for example, location *j* cannot be visited before location *i*.

3 Decision Support System for Beer Delivery

Decision Support Systems (DSS) related to routing problems provide enormous gains to the companies, reducing transportation costs and increasing profitability. There are several examples of such systems in the literature, namely the ASICAM developed in the context of the forest wood transportation and the DSS developed by Weintraub, Andres [14] to solve the general VRP.

In this Section we present our DSS prototype proposal for the fleet management of a beer delivery organization.

3.1 Application Architecture

Beer deliver decision support system (DeliBEERy) was built with Django, a high-level Python free and open source Web application framework. DeliBEERy provides a friendly user interface, where its possible to create, save and optimize routes with vehicles capacity restriction. To execute this operations, is important to manage the users and routes saved in the database with back-office platform. This platforms (Front-office/Back-office) communicate with SQLite database through python.

It was configured an open-source JavaScript library for mobile-friendly interactive maps in Front-Office platform and also configured with Gurobi, an optimization engine. This engine will provide DeliBEERy with the best optimized route to deliver their beer. To proceed to the optimization route calculation method, Gurobi needs the distance matrix data. DeliBEERy communicates via javascript with an open source routing machine (OSRM) providing the distance matrix data to Gurobi. After computing the routes, the solution is sent to OSRM in json format. OSRM will respond with the drawn map solution. For a best understanding of the process, see the Figure 1.

3.2 Usability

The first thing to start using DeliBEERy is authenticate in the application. When logged in, the application redirect the user to the home page, represented in Figure 2. There are several options in the left menu where each one has is specific function.

Start with **Save Instance**, after click in it, will save the distance matrix provided by OSRM in the database along with the attributes tables. **Calculate Route** will ask to first indicate the capacity of vehicles needed if the respective field is empty, then Gurobi will optimize the route using the vehicles capacity and the distance matrix provided by OSRM for the given set of clients. The VRP is often defined under capacity and route length restrictions, when capacity constraints are present, as in this case, the problem is denoted as Capacitated vehicle routing problem (CVRP). For our problem resolution we will follow the approach by Maes [8].

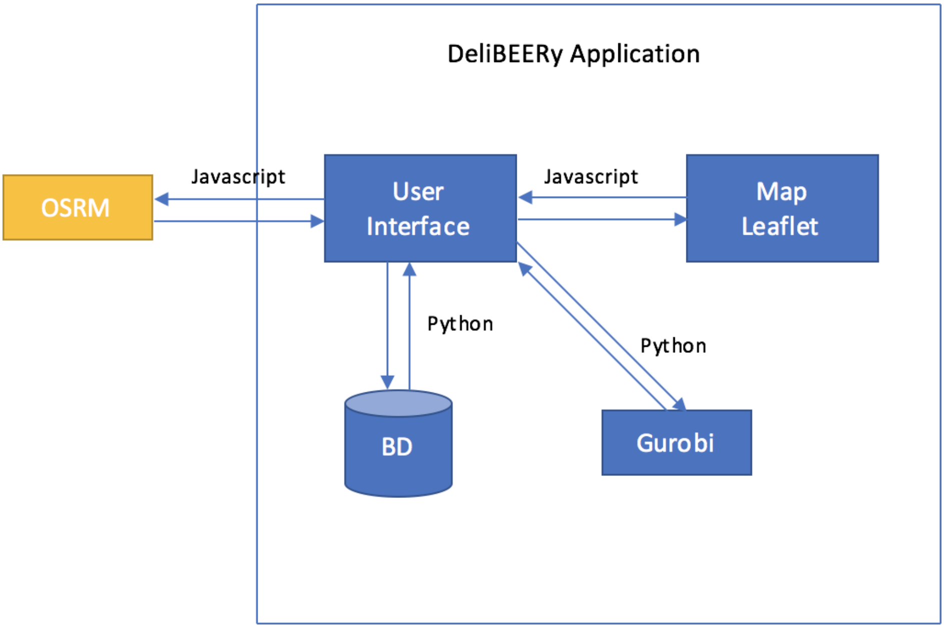

Fig. 1. Decision support system architecture.

Still in the left menu there is a table with information about the markers location. With the buttons **New Attribute** and **Remove attribute** the user can add or remove attributes to the table. It is listed also in another table, the historical of the saved set of clients location by date. To view a specific set of clients location, the user click in the required date indicated in the row, then DeliBEERy will load the saved set of clients location. To remove a specific saved set of clients locations, the user need to make the same procedure but clicking instead in the **X** in the required row.

Show Route, it will open a new window with the route solution showed in Figure 3. Where it's possible to visualize the solution drawn by OSRM.

4 Results

As showed in Figure 3 the results allows to obtain optimized routes minimizing the number of vehicles used and the costs associated to the beer delivery. Its possible to have a general view about the transportation planning, the route for each associated vehicle and also the client characteristics.

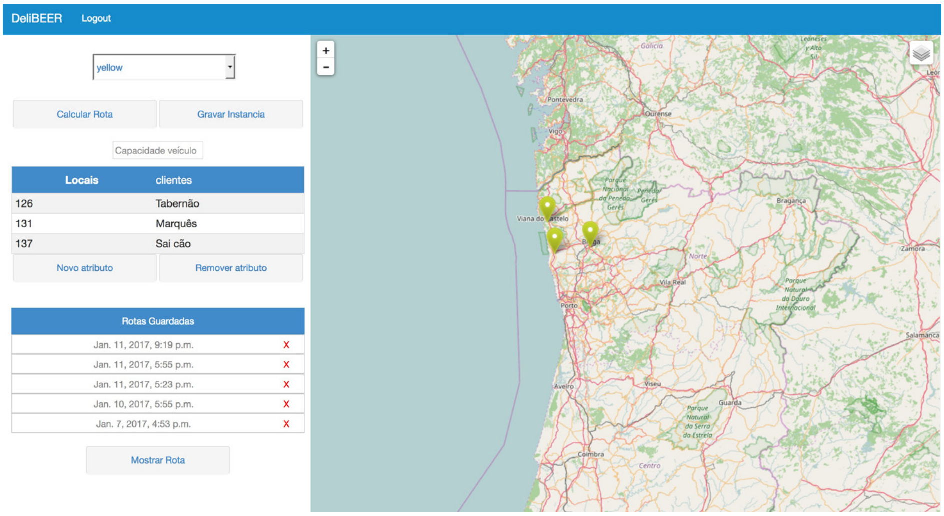

Fig. 2. DeliBERRy home page.

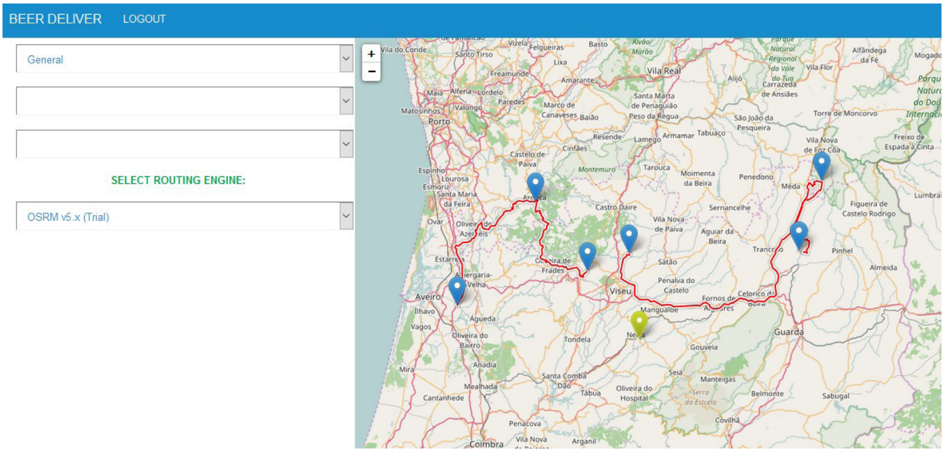

Fig. 3. DeliBERRy route solution page.

5 Conclusions

This work results from a thorough and broad review of literature, concerning Optimization routing problems. Over the past 60 years a lot of research was made in the definition of problems such as TSP, VRP and their variants, to incorporate the specific features of the real world problems. There are a wide variety of solution methods that encompass exact and non-exact approaches that are capable of solving the TSP and VRP for significantly large instances. In this paper was presented a quickly and simple solution to an CVRP approach with the help of open source tools. Regardless of the scientific improvements, a lot of work is still necessary to develop Decision Support Systems that fit the majority of the users' requirements.

6 Acknowledgements

This work has been partially supported by the European Regional Development Fund (ERDF) through the Interreg Spain-Portugal V-A Program (POCTEP) under grant 0677 DISRUPTIVE 2 E (Intensifying the activity of Digital Innovation Hubs within the PocTep region to boost the development of disruptive and last generation ICTs through cross-border cooperation).

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THE ROLE OF DIHS IN THE IMPLEMENTATION OF THE EUROPEAN AND NATIONAL DIGITALISATION PROGRAMMES

EL PAPEL DE LOS DIH EN LA IMPLEMENTACIÓN DE LOS PROGRAMAS DE DIGITALIZACIÓN EUROPEOS Y NACIONALES

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Abstract: Digitalisation is key to increase competitiveness. This paper surveys the Digital Europe Programme as well as the Portuguese and Spanish national strategies. The role of the Digital Innovation Hubs to support the digital transition, as orchestrators and access points for the latest digital capacities, and the process to establish the European network of hubs is addressed. Finally, two case study of DIH are presented, PRODUTECH DIH and DIGIS3.

Keywords: digitalization programmes; EDIH; DIH; digital innovation Hub.

Resumen: La digitalización es clave para aumentar la competitividad. Este documento analiza el Programa Europa Digital, así como las estrategias nacionales de Portugal y España. Se aborda el papel de los Digital Innovation Hubs para apoyar la transición digital, como orquestadores y puntos de acceso a las últimas capacidades digitales, y el proceso para establecer la red europea de hubs. Por último, se presentan dos casos de estudio de DIH, PRODUTECH DIH y DIGIS3.

Palabras clave: programas de digitalización; EDIH; DIH; digital innovation hub.

1 Digital Europe Programme (DIGITAL)

1.1 Overview

Within the Multiannual Financial Framework a proposal was made to establish the Digital Europe Programme (DIGITAL) for the period 2021-2027 that was adopted on June 2018 by the European Commission. In march 2021 the Council adopted the Programme and on the 29th of April [1] it was adopted by the European Parliament. On the occasion of the adoption by the Council, Pedro Nuno Santos, Portuguese Minister for Infrastructure and Housing and President of the Council, stated at that date that *«The Digital Europe Programme is part of the EU's strong push to make the most of digitalisation for the benefit of its societies and economies, increase its autonomy in key technologies and bolster its competitiveness. It will help us build high-performing and secure state-of-the-art digital services for all citizens and businesses across the Union».*

DIGITAL will start retroactively from 1 January 2021 and run until 2027. It was assigned a budget of €7 588 million. Nevertheless, DIGITAL will not stand alone, but rather complement other EU programmes, such as the Horizon Europe programme for research and innovation and the Connecting Europe Facility for digital infrastructure.

The general objectives of DIGITAL are to support the digital transformation of industry and to foster better exploitation of the industrial potential of policies on innovation, research and technological development, for the benefit of citizens and businesses across the Union, including its outermost regions and its economically disadvantaged regions. Furthermore, also aim to better align Union, Member State and regional policies, and to pool private and industrial resources in order to increase investment and develop stronger synergies.

The Digital Europe programme lies on 5 interlinked specific objectives that reflect key policy areas: High Performance Computing (~29% budget); Artificial Intelligence (~27%); Cybersecurity and Trust (~22%); Advanced Digital Skills (~8%); and Deployment and Best Use of Digital Capacities and Interoperability (~14%).

The general objective of supporting the industry digital transformation will have a strong focus on small and medium-sized enterprises (SMEs).

The Digital Europe programme is covered by several work programmes, each one dedicated to one or more specific objective(s) funded by the programme: DIGITAL Europe Work Programme 2021-2022; DIGITAL Europe - European Digital Innovation Hubs Work Programme 2021-2023; and, DIGITAL Europe –Cybersecurity Work Programme 2021–2022.

In this paper the focus is on the European Digital Innovation Hubs, as orchestrators and access points for the latest digital capacities, that were given a central role in the implementation of the Programme.

1.2 European Digital Innovation Hubs

European Digital Innovation Hubs (EDIH) should act as single-entry points for companies to access tested and validated technologies but also to promote open innovation. In addition, it will be their role to foster advanced digital skills. The network of EDIHs will share best practices and specialised knowledge and will be able to support companies and public administrations in any region and economic sector, thus also following the objective of a more cohesive, resilient and competitive EU.

The Programme will finance a network of European Digital Innovation Hubs that should ensure broad geographical coverage across Europe and should contribute to the participation of the outermost regions in the Digital Single Market.

Potential candidate EDIH to the initial network will be proposed by each Member State following a national open and competitive process.

The workprogramme of Digital Europe Programme is under development but a draft working document, developed by The European Commission, on the European Digital Innovation Hubs in Digital Europe Programme is public and its version of 25 of January 2021 allows the sum-up that follows [2]. This document explains how European Digital Innovation Hubs will be implemented in Digital Europe Programme, how it will be complemented in the support to digital transformation of the economy by other EU programmes, and how it contributes to building a successful network of hubs covering all regions of Europe. A schematic overview of the role of EDIHs in Digital Europe Programme is presented in Figure 1.

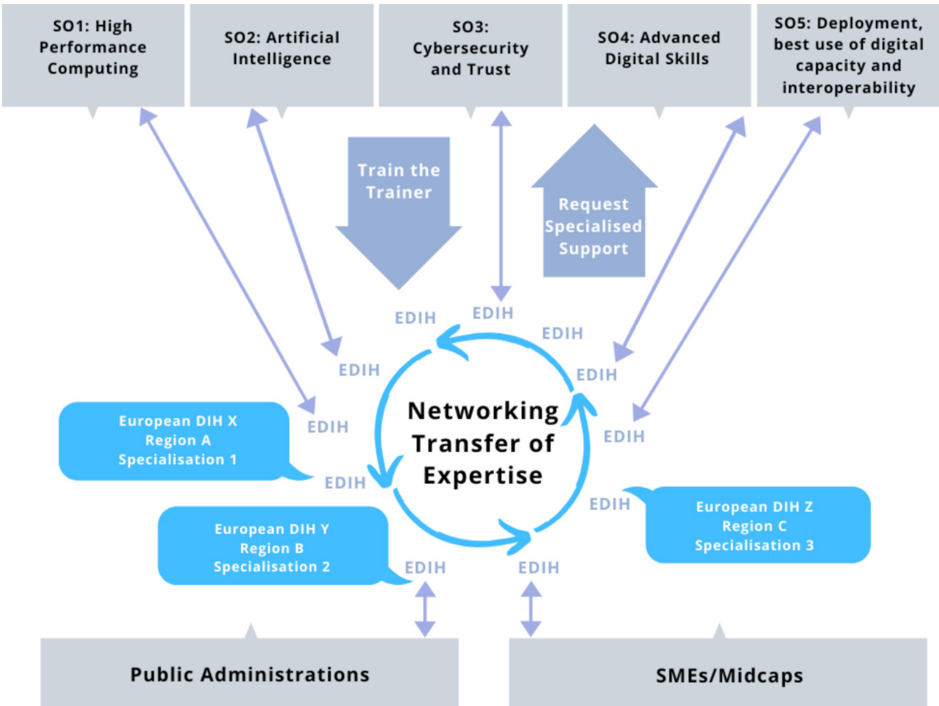

Fig. 1. Schematic overview of the role of EDIHs in Digital Europe Programme SOURCE: «European Digital Innovation Hubs in Digital Europe Programme Draft working document 25 01 2021» [2].

EDIH: Organisation, Knowledge transfer and Services [2]. A EDIH can be a single legal entity or a consortium of legal entities, governed by a consortium agreement or similar, with complementary expertise and with a not-for-profit objective.

The organisation, composition, and governance structure of the EDIH is defined by the partner entities but should cover at least the technology side and the business development side, and be capable of doing effective outreach. They should also have appropriate links to companies and/or public sector organisations.

European Digital Innovation Hubs will work closely with the relevant specialised centres or consortia responsible for the different Digital Europe Programme (DEP) projects to make sure that companies and public administrations are aware of the developed knowledge and technology and can experiment with those technologies and apply them according to their needs. Special horizontal support activities are foreseen to support the necessary knowledge transfer from the DEP Specific Objectives towards the EDIHs and vice versa.

EDIHs shall support companies – especially SMEs and mid-caps – and/or the public sector in their digital transformation, and for such offer services such as:

- Test before invest: including awareness raising, digital maturity assessment, demonstration activities, visioning for digital transformation, fostering the integration of various technologies, testing and experimentation with digital technologies, knowledge and technology transfer.
- Skills and training: namely training, boot-camps, traineeships and job placements.
- Support to find investments: in particular, access to financial institutions and investors, supporting the use of InvestEU and other relevant financing mechanisms.
- Innovation ecosystem and networking: serve as brokers and matchmakers between e.g. end-users (private or public) and potential suppliers of technological solutions for e.g. experimentation and testing or solutions co-creation.

EDIH network: Selection process. The funding of the selected EDIH will be in the form of grants, and is expected to reach 100-200 EDIH in the first year. Each Member State has launched a national open and competitive process that will result in a list of designated hubs in each Member State, that should have geographical coverage of the country and respond to the demand of industry and public sector while taking into account existing assets of the country. The designated potential hubs will be invited by the European Commission to respond to a restricted call for proposals with a certain deadline. The eligible proposals will be evaluated by external experts and all of those above threshold will be ranked, and Member States will endorse the ranking of the proposals. Finally, the selected proposals will get a grant from the European Commission. If after this process there are still gaps in the coverage of the network of EDIHs, open calls may further complement the network. It is expected that the EDIHs will start working in early 2022.

A table with the foreseen distribution of funding of Digital Europe Programme for EDIHs in all MS was presented, but for the purpose of this article only data for EU, Portugal and Spain, the 2 countries involved in the DISRUPTIVE Interreg project, are presented (Table 1).

Table 1. Number of hubs foreseen for each country SOURCE: Adapted from «European Digital Innovation Hubs in Digital Europe Programme Draft working document 25 01 2021» [2].

Country	Projected budget (1000€)	Min # of hubs	Max # of hubs (recommended)	NUTS regions
Portugal	22,251	3	6	7
Spain	62,515	9	18	19
Total EU	747	107	211	240

At the time of this paper, May 2021, 330 entities were self-registered on the European Commission's S3 platform as candidate EDIHs [3].

2 Portuguese and Spanish national Digital Strategies

2.1 Portugal's Action Plan for Digital Transition

Portuguese digital journey aims to converge with Europe and as such was reinforced as a strategic priority and essential vector of the country's economic growth. On April 2020 the Council of Ministers approved the «Action Plan for the Digital Transition» [4] assumed as the country's transformation engine, aimed at accelerating Portugal, leaving no one behind, and projecting the nation in the world.

The structure of the Plan has 3 main action pillars and an added cross-cutting catalyst dimension that is an accelerating instrument for the digital transition:

- Pillar I – Capacity building and digital inclusion.
- Pillar II – Businesses' digital transformation.
- Pillar III – Public services' digitalization.
- Catalysation of Portugal's digital transition.

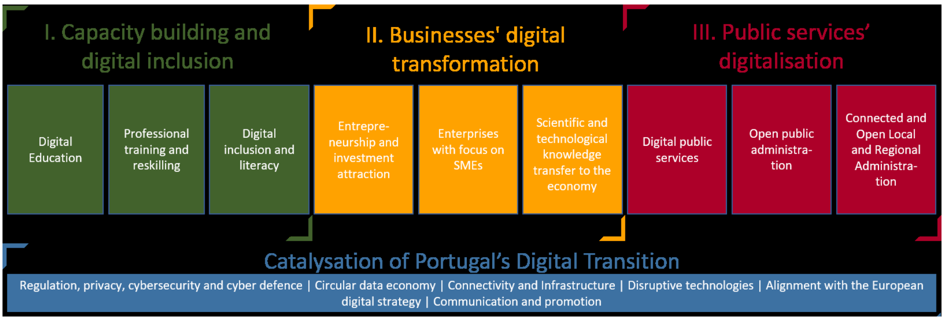

Fig. 2. Portuguese Action Plan, fundamental pillars, sub-pillars and cross-catalyst dimension. SOURCE: Adapted from «Presentation Portugal Digital – março 2021» [5].

The global coordination of the Action Plan belongs to «Portugal Digital Mission Structure», that is responsible for ensuring the links with the different structures involved in the measures, their implementation and results reporting, as well as promoting the Action Plan.

Digital Innovation Hubs for Entrepreneurship (measure 8) are integrated in pillar 2, sub-pillar scientific and technological knowledge transfer to the economy.

Given the significant differences in digitisation levels, both regionally and sectorally, building a network of Digital Innovation Hubs is key to ensuring that all businesses can take advantage of digital opportunities. The aim of this measure is to stimulate a national network of Digital Innovation Hubs to be developed in connection with the competitiveness clusters and technological interface centres. This network will be interconnected with the European network of hubs to be boosted by the European Commission in the scope of the European framework programmes for 2021-2027.

The Portuguese network of DIHs: the recognition process. In December 2020 the Regulation on the Process of Recognition of the Digital Innovation Hubs and Access to the European Network was published under Order nr. 12046/2020 [6]. It is expected that the applicant consortiums present projects aligned with the pillars of the national strategy and contribute to an adequate territorial and sectoral coverage avoiding overlapping and maximizing synergies and complementarities. Those DIHs aiming at integrating the EDIH network have to demonstrate their added value at European level and have competences in the key digital technologies of DIGITAL presented in Figure 1. The open call for the selection process was published in mid-December 2020 with due date in February 2021. The evaluation of the applications is, at the date of this paper, ongoing. 10 DIH will be selected for national recognition, nevertheless at this stage, in the EC S3 platform, 28 Portuguese DIH have registered as EDIH candidates [3].

2.2 Spain's Agenda for Digital Transition

Spain Digital 2025, presented in July 2020, will focus its objectives on promoting the country's digital transformation as one of the fundamental levers to relaunch economic growth, reduce inequality, increase productivity and take advantage of all the opportunities offered by new technologies, with respect to constitutional and European values, and the protection of individual and collective rights [7]. The agenda consists of 50 measures structured around 10 axis:

1. Digital connectivity
2. 5G technology
3. Digital skills
4. Cybersecurity
5. Digitisation of Public Administrations

06. Accelerate the digitization of companies
07. Digital transformation driving projects
08. Spain as a European audiovisual platform
09. Data economy and Artificial Intelligence
10. Digital rights

Fig. 3. Spain Digital 2025 – the 10 axis SOURCE: Adapted from «España Digital 2025» [7].

The Government has created the Consultative Council for Digital Transformation, which will have a public-private nature and will facilitate dialogue and participation of the different economic and social agents for the digital transformation of the country.

The SMEs Digitization Plan, 2021-2025, includes a Support Programme for Digital Innovation Centres (CID), developed by the General Secretariat for Industry and SMEs with an investment of EUR 42m for the development of

CID and these can provide information, services and facilities to successfully address SME digital trans-formation projects.

The Spanish network of DIHs: the application process. In October 2020 the Spanish Ministry of industry, trade and tourism opened in October 2020 a public call for expression of interest [8]. This call for expression of interest (EOI) was made with a dual purpose: on the one hand, to identify national candidates interested in joining the European Network of DIH promoted by the Commission, and on the other, to know the current status of their potential applications. This EOI featured a preliminary element and aimed not only to facilitate and speed up the national pre-selection procedure but also to promote the submission of quality proposals taking into account the characteristics of the national ecosystem.

In February 2021, all the applicants who had submitted the mentioned EOI, a total of 40, were informed on their official approval by the Ministry as Spanish EDIH candidates.

3 DIH Case studies

3.1 PRODUTECH DIH

PRODUTECH is currently host of 2 Digital Innovation Hubs, PRODUTECH DIH Platform [9] and iMan Norte Hub[10]. Within the framework of the Portuguese DIH recognition and access to the EDIH network process a single proposal consolidating the track record of this 2 DIHs was submitted. At the date of submission of this article, the evaluation process is still ongoing.

Although nowadays independent in their work, the initiatives have different «geometries» (members), geographical scope and focus, nevertheless, and due to PRODUTECH hosting of both, synergies are explored within its articulated operation.

PRODUTECH DIH Platform is a national DIH encompassing the relevant stakeholders, namely competence centers and labs, R&D organizations, sectoral technology centers, industry associations, production technology providers, leading users from the manufacturing industry, education/training centers and other stakeholders. It has a multi-sectorial coverage (via the technological centers comprised by the cluster) and has as intervention domain the Manufacturing Industry as a whole.

iMan Norte Hub focuses on cyber-physical production systems and robotics, gathers a consistent set of stakeholders with track record in supporting the digitalisation of companies and as the Norte region of Portugal as intervention domain. It has its genesis within the scope of the EU project BeinCPPS. iMan Norte Hub is operationalized by a Memorandum of Understanding established between its members and is co-coordinated by PRODUTECH, INESC TEC, UPTEC and 4 sectorial technological centers (CTCOR, CATIM, CITEVE and CTCP).

The relevance of both initiatives has been recognized nationally and internationally, notably, just to cite some examples:

– PRODUTECH DIH Platform is one of the selected DIHs of AI DIH network [11];
– Both DIHs are mentioned in the JRC Technical Report on «Digital Innovation Hubs in Smart Specialisation Strategies» [12] and in the document sponsored by the Portuguese Government «Portugal INCoDe.2030- AI Portugal 2030» [13].

The success of the initiatives can also be measure by the participation in European projects:

– PRODUTECH DIH Platform, via PRODUTECH, is part of DISRUPTIVE (INTERREG-POCTEP), DIH2 (H2020) and DIH4CPS(H2020) [14];
– iMan Norte Hub takes part in SmartEes (H2020), via CENTI, AgROBOfood, SmartAgriHubs and i4MS, all latter 3 are H2020 and participates via INESC TEC.

3.2 DIGIS3

The general objective of the Digital Innovation Hub DIGIS3 [15] is to ensure the Intelligent and Sustainable Digital transformation mainly of SMEs and the public sector of Castilla y León, with an urban and rural territorial scope fo-cused on cohesion.

The key is comprehensive support for users, facilitating their access to specialized technical knowledge and experimentation environments, in a one-stop-shop service whose central core of knowledge and training is structured around Artificial Intelli-gence and Supercomputing, complemented by others support technologies in digitiza-tion such as IoT, Big Data, Blockchain and Robotics among others.

This support is carried out through a portfolio of services and suitable digitization itineraries, according to the level of digital maturity of the users, and which also takes into account the specific needs of the sector and the geographical environment.

This regional digitization initiative is aligned with the priority sectors of the RIS3 of Castilla y León and has a focus on 4 application domains: Industry 4.0; Agro smart; Smart Territories, Smart Administration and establishes 4 Strategic Pillars: Global Sustainability; Skills; Capillarity; Cooperation-Networks.

DIGIS3, led by the Institute for Business Competitiveness of Castilla y León (ICE), has emerged as a result of the continuous growth of the existing DIHs in the region and is formed by the following entities:

– The AIR Institute technology center, as a center of competence in Artificial Intelligence of IoT DIH, Digital Innovation Center focused on the use of IoT technologies in production processes, products and services of companies.
– The DIHBU association, Digital Innovation Center expert in Industry 4.0, formed by industrial companies, knowledge centres, and developers in Industry 4.0 solutions in Castilla y León.
– The DIH-LEAF association, Digital Innovation Center oriented to the lives-tock, environmental, agricultural and forestry sectors, involving, among others, universities and technology centres, companies and producer associations, in order to respond to the challenge of digitization and technological innovation of this broad productive sector.
– The Castilla y León Supercomputing Center Foundation (SCAYLE), as an expert partner in supercomputing.
– The University of León as an expert partner in supervision, control and automation of industrial processes and critical infrastructures as well as in Industry 4.0, Internet of Things, Data Science, Artificial Intelligence, Computer Vision, Robotics, Additive Manufacturing or Aerospace Technology.

The main stakeholders who are collaborating in this initiative are:

- Collaborating Entities: Group of entities committed to participating in its promotion and in the actions carried out in the Action Plan: clusters, tech. companies, industrial associations, chambers of commerce.
- Advisory Group: Relevant entities that provide a very important external point of view when defining and implementing the DIH strategy.

4 Conclusions

The digital transformation of the economy is key for Europe to remain competitive internationally. Four years after the launch of the Digitising European Industry Strategy and the eGovernment Action Plan, the European economy has made significant progress, but the level of digitalisation however remains uneven, depending on the sector, country and size of company: only 20% of SMEs in the EU are highly digitised. The Digital Europe Programme aims to support and accelerate the digital transformation of the European economy, industry and society, and to improve the competitiveness of Europe in the global digital economy.

EDIHs will play a central role in the Digital Europe Programme implementation, will have both local and European functions and will have their capacities increased to cover activities with a clear European added value and promoting transfer of expertise.

Finally, the COVID-19 pandemic clearly demonstrated how digital technologies enable resiliency for the society at large and will have a significant role in the economic recovery as there will be near future opportunities to integrate digital technologies and the know-how to make the best use of them. A working network of European Digital Innovation Hubs will be an important success factor.

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(POCTEP) under grant 0677_DISRUPTIVE_2_E (Intensifying the activity of Digital Innovation Hubs within the PocTep region to boost the development of disruptive and last generation ICTs through cross-border cooperation).

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ENSINO DE ROBÓTICA MÓVEL ATRAVÉS DA REALIZAÇÃO DE UM HACKATHON EM ROS

TEACHING MOBILE ROBOTICS THROUGH A HACKATHON IN ROS

ENSEÑAR ROBÓTICA MÓVIL A TRAVÉS DE UN HACKATHON EN ROS

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Abstract: A robótica móvel é um campo que vem crescendo constantemente nos últimos anos, possuindo aplicações em diversas áreas como a indústria, agricultura, medicina, entre outros. Sendo o ROS uma das principais plataformas de desenvolvimento de softwares desta área e visando a disseminação do conhecimento destas tecnologias, foi proposto um hackathon para fomentar a aprendizagem em ROS e robótica móvel. A decisão por essa abordagem foi devido à dificuldade de novos usuários no primeiro contato com a plataforma, por possuir conceitos complexos e ausência de front-end, o primeiro contato com ROS é difícil, levando os novos usuários a desistência. Com isso, o ensino foi feito por meio deste evento - que é uma atividade imersiva e intensa para a solução de problemas na instância tecnólogica, principalmente em programação. De forma, que as primeiras barreiras fossem quebradas, o processo de aprendizagem facilitado e estimulasse os participantes a seguirem essa linha de pesquisa. O público alvo são estudantes de engenharia eletrotécnica, computação, mecânica e entusiastas em robótica. Neste paper será apresentada a estruturação do Hackathon, que compreende um nivelamento dos estudantes, para capacitá-los a programar as funcionalidades essenciais de um robô móvel e, por fim, o desafio robótico proposto. As etapas iniciais foram elaboradas com dificuldades que aumentaram progressivamente, iniciando com tarefas de controlo básico de um robô simulado até o desafio de desenvolver uma navegação autónoma em um ambiente de simulação buscando uma fonte de gás cuja posição é desconhecida.

Keywords: robotics; ROS; digital technologies.

Abstract: Mobile robotics is a field that has been growing steadily in recent years, with applications in several areas such as industry, agriculture, medicine, among others. Since ROS is one of the main software development platforms in this area and aiming at the dissemination of knowledge of these technologies, a hackathon was proposed to promote learning in ROS and mobile robotics. The decision for this approach was due to the difficulty of new users in the first contact with the platform, because it has complex concepts and lack of front-end. The first contact with ROS is difficult, leading new users to give up. With that, teaching was done through this event - which is an immersive and intense activity for solving problems in the technological instance, especially in programming. Therefore the first barriers were broken, the learning process was facilitated and the participants were encouraged to follow this line of research. The target audience are students of electrical engineering, computing, mechanics and robotics enthusiasts. In this paper, the structuring of the Hackathon is presented, which comprises a leveling of the students, to enable them to program the essential functionalities of a mobile robot and, finally, the proposed robotic challenge. The initial stages were elaborated with difficulties that progressively increased, starting with tasks of basic control of a simulated robot until the challenge of developing an autonomous navigation in a simulation environment looking for a gas source whose position is unknown.

Keywords: robotics; ROS; digital technologies.

Resumen: La robótica móvil es un campo que no ha dejado de crecer en los últimos años, teniendo aplicaciones en diversos ámbitos como la industria, la agricultura o la medicina, entre otros. Siendo ROS una de las principales plataformas de desarrollo de software en este ámbito y teniendo como objetivo la difusión del conocimiento de estas tecnologías, se propuso un hackathon para fomentar el aprendizaje en ROS y la robótica móvil. La decisión de este enfoque se debió a las dificultades que tenían los nuevos usuarios en el primer contacto con la plataforma, pues al tener conceptos complejos y ausencia de front-end, el primer contacto con ROS es difícil, llevando a los nuevos usuarios a desistir. Con esto, la enseñanza se hizo a través de este evento - que es una actividad inmersiva e intensa para la solución de problemas en el ámbito tecnológico, principalmente en la programación. En cierto modo, al romperse las primeras barreras, el proceso de aprendizaje facilitó y estimuló a los participantes a seguir esta línea de investigación. El público objetivo son los estudiantes de ingeniería eléctrica, informática, mecánica y aficionados a la robótica. En este trabajo se presentará la estructuración del Hackathon, que comprende una nivelación de los alumnos, para que puedan programar las funcionalidades esenciales de un robot móvil y, finalmente, el reto robótico propuesto. Las etapas iniciales se elaboraron con dificultades que fueron aumentando progresivamente, comenzando con tareas básicas de control de un robot simulado hasta llegar al reto de desarrollar una navegación autónoma en un entorno de simulación en busca de una fuente de gas cuya posición se desconoce.

Palabras clave: robótica; ROS; tecnologías digitales.

1 Introdução

A robótica móvel é um domínio que vêm expandindo rapidamente nos últimos anos uma vez que suas aplicações tornaram-se de suma importância em inúmeros setores, como na automação industrial, agricultura, comércio, assistência médica, exploração espacial, serviços pessoais, segurança, pesquisa e desenvolvimento, entre outros [1]. Os robôs autónomos podem ser caracterizados por sua habilidade de locomoção de forma autónoma em um ambiente, sendo capazes de tomar decisões de acordo com sua percepção do espaço, executando tarefas sem que seja necessária uma constante interferência humana [2].

Certamente um dos assuntos mais discutidos na atualidade sobre a robótica móvel são os veículos autónomos que prometem revolucionar a forma como as pessoas se locomovem, garantindo mais conforto, o aumento das capacidades das estradas e a redução de impactos ambientais [3]. Por mais que os carros autónomos ainda estejam sendo testados para poderem se tornar parte do quotidiano, há inúmeras aplicações já consolidadas dos robôs móveis.

Na indústria os robôs móveis estão presentes em operações intralogísticas estabelecendo o fluxo de materiais-primas e produtos entre máquinas, postos de trabalho, de recepção e de expedição, armazéns e outros. Tais tarefas podem ser executadas por veículos auto-guiados (AGVs) que se movimentam em um caminho determinado seguindo uma marcação, fios, ou fitas magnéticas, ou ainda por robôs móveis autónomos (AMRs) que são mais flexíveis que os AGVs. Os AMRs podem se locomover de forma autónoma em uma área predefinida não estando presos à rotas definidas, além de serem empregados em sistemas assistivos interagindo com pessoas e outros robôs [4]. A Amazon por exemplo, possuí um avançado sistema de robôs móveis atuando em suas *warehouses*, em 2017 a empresa já contava com mais de 15000 robôs, que possibilitam a execução de tarefas como separação e reabastecimento de produtos simultâneamente, algo que possibilitou uma maior escalabilidade em vendas com maior agilidade no envio dos produtos [5].

Na agricultura robôs móveis são utilizados na realização de atividades de plantio e irrigação, além de monitoramento de plantio através de drones [6]. Outra área de atuação é exploração espacial, onde pode-se citar os *rovers* espaciais, como o Curiosity que encontra-se em missão em Marte desde 2012 e o Perseverance que chegou ao planeta vermelho em Fevereiro de 2021 [7]. Eles podem ser caracterizados como robôs móveis semi-autónomos por suas rotas serem definidas e controladas por um operador na Terra, além de possuírem a capacidade de evitar obstáculos de forma autónoma [8]. No setor médico, principalmente devido ao cenário da pandemia de Covid-19 robôs móveis vêm sendo aplicados na limpeza de edifícios hospitalares, na desinfecção de salas através de luzes UV-C, para o transporte de medicamentos e alimentos, e na comunicação e monitoramento de pacientes por meio de dispositivos de telepresença acoplados aos robôs [9].

Levando em consideração o grande número de aplicações as quais a robótica móvel está sujeita fica claro o quanto essa área têm um impacto funcional e econômico, e a tendência é que cresça cada vez mais. De acordo com relatórios recentes divulgados durante a pandemia da Covid-19, o mercado da robótica móvel deve crescer a uma taxa de 24% ao ano, passando do valor de U$19 bilhões em 2018 para U$23 bilhões em 2021 e U$54 bilhões em 2023 [10]. Isso mostra o quão grande será a demanda na área de pesquisa e desenvolvimento de robôs móveis, logo a capacitação de novos profissionais se faz necessária.

Existem inúmeras ferramentas que possibilitam o desenvolvimento de novas aplicações em robótica como é o caso do Sistema Operacional de Robôs (ROS), um *open source framework* que conta com um amplo acervo de drivers para leitura de sensores, envio de dados para actuadores e motores, algoritmos e bibliotecas que possibilitam a construção de mapas, manipulação de objectos, navegação, entre outras funcionalidades. O ROS se tornou uma importante ferramenta na pesquisa e desenvolvimento na área da robótica, tendo forte presença em companhias de tecnologia e uma forte comunidade pesquisadora que proporciona troca de experiências e apoio no desenvolvimento de projectos [11].

Tendo em vista a crescente demanda da robótica móvel e a importância do ROS como ferramenta de desenvolvimento nesta área, pretende-se a realização de um Hackathon para introduzir aos participantes conceitos básicos do ROS e de sua utilização no controle de robôs móveis, a fim de instiga-los a realizar pesquisas no ramo da robótica móvel. O presente artigo tem por objectivo demonstrar um novo método de introdução do assunto para os estudantes, de forma a facilitar o primeiro contato deles com a *framework*. Como resultado espera-se uma aprendizagem prática e rápida dos conceitos fundamentais do ROS aplicado a robótica móvel e evitar desestímulos pela dificuldade de realizar as tarefas mais básicas.

Após esta breve contextualização apresentada nesta secção, a secção 2 representa a parte dos trabalhos relacionados, aplicações de ROS e seu uso como aprendizagem de robótica móvel. A secção 3 faz a descrição sobre um hackathon e o motivo de ter utilizado esse método. Na secção 4 estão detalhadas as datas de realização e como foi feita a organização do evento, assim como as descrições de cada etapa. Na secção 5 são expostos os resultados esperados após a realização do evento baseado em actividades anteriores. Finalmente a secção 6 apresenta as conclusões deste trabalho.

2 Trabalhos Relacionados

Aprender a utilizar o ROS é uma difícil tarefa, sobretudo para pessoas que não possuem experiência em programação, computação distribuída, sistema operacional Linux, *multithreading*, programação orientada e outros conceitos essencialmente ligados ao funcionamento do ROS. Sem uma concepção básica dos tópicos citados, o aprendizado do ROS apresenta uma curva não muito amigável para os novos usuários, pois demoram a compreender os conceitos fundamentais dessa plataforma, bem como tirar proveito de algoritmos já existentes [11]. Tendo isso em mente nesta secção será brevemente apresentada a plataforma ROS, as suas aplicações na robótica e algumas estratégias criadas para a melhora de seu aprendizado.

2.1 Introdução ao ROS e Aplicações em Robótica

O ROS é um sistema operacional de robótica, *open source*, formado por bibliotecas e ferramentas úteis para simplificar a tarefa de criar comportamentos complexos e robustos em aplicações de robôs. Para isso possui uma arquitetura simples, que permite uma rede com máquinas executando ROS, sendo um deles o *master*, que estará a rodar o «roscore», responsável por inicializar os serviços necessários para as comunicações entre os nós.

Com esse sistema é possível que a arquitetura do processamento de dados seja feita de modo paralelo. Por exemplo, é possível utilizar um outro PC com maior capacidade de processamento para fazer processamento de imagem caso o embarcado não seja suficiente. Além disso, a comunidade do ROS conta com muitos pacotes já desenvolvidos, então não é necessário a cada aplicação reinventar o que foi feito, é possível partir do ponto que já está consolidado e avançar em pesquisas e desenvolvimento. Por exemplo, como definido no próprio site do ROS, um grupo tem como especialização realizar mapas, outro a navegação e outro visão computacional para reconhecer pequenos objectos. Com isso, um grupo pode utilizar as informações do outro para melhorar sua aplicação.

Além das características citadas, o ROS apresenta ainda outras vantagens, nomeadamente [12]:

– Ponto-a-ponto: um sistema ROS distribuído em hospedeiros é ligado em tempo de execução do sistema, seguindo uma topologia ponto-a-ponto;
– Multi linguagens: actualmente o ROS tem suporte a linguagem C, C++, Python e LISP, o que facilita pois nem sempre as pessoas tem a mesma facilidade em todas as linguagens;
– Baseado em ferramenta: para gerenciar a complexidade do ROS, um grande número de pequenas ferramentas são utilizadas de forma a executar vários componentes ao invés de apenas um sistema;
– Leve: por utilizar um sistema modular, usando o CMake5, e bibliotecas independentes, o sistema caracteriza-se como leve;
– Grátis e Open-Source: o sistema tem todo seu código fonte disponível, permitindo desenvolver projectos comerciais e não comerciais.

Porém, o ROS também tem alguns pontos fracos. Entre eles está a ausência de suporte para alguns pacotes, que podem ter sido desenvolvidos em alguma actividade de investigação e após o término, foi abandonada, sem corrigir todos os erros e fazendo com que em alguns meses passe a ser obsoleta. Outro ponto negativo é o suporte a sistemas embutidos.

Entre as principais empresas que estão a utilizar ROS hoje pode-se destacar a ABB, Clearpath, Doosan, Amazon, Fanuc, Fetch, Locus, Turtlebot, Universal Robots e Yaskawa.

2.2 Aprendizagem de ROS

Existem inúmeras formas para aprender a utilizar o ROS, nomeadamente o website ROS Wiki conta com diversos tutoriais introdutórios práticos que permitem o entendimento dos conceitos básicos de utilização do Sistema Operacional, além da documentação de pacotes disponíveis para as diferentes distribuições do ROS [13].

Alguns livros como Programming Robots with ROS [11] e ROS By Example [14] apresentam de forma didática as principais ferramentas e simuladores presentes no ROS, além de diversos algoritmos em linguagem Python que auxiliam no desenvolvimento de programas para controle e navegação de robôs.

Há ainda várias plataformas educacionais baseadas em robótica móvel que possuem alguma integração com o ROS, como [15]:

- O iRobot Create, uma plataforma circular baseada no aspirador de pó Roomba, contando com sensores de telêmetro a laser 2D;
- O Mindstorms NXT da Lego, um kit de robô educacional equipado com motores de accionamento e sensores como acelerômetro, luz, som, ultrassom e sensores de toque;
- O Pionner 3D-X, uma plataforma de driver que conta com oito sonares e um microcontrolador integrado de alto desempenho baseado em um microprocessador RISC Renesas SH2-7144 de 32 bits;
- O STAGE, um simulador 2D desenvolvido para aplicações de SLAM (Navegação e Mapeamento Simultâneos) que possibilita a criação de ambientes com objectos simples que actuam como obstáculos a serem identificados por sensores Lidar (detecção de luz e alcance) [11].

As didáticas apresentadas consideram que o novo usuário do ROS possui conhecimentos prévios necessários para instalar, configurar e utilizá-lo. O que acaba por desestimular quem não possui estas competências, pois constantemente precisará resolver problemas que muitas vezes será incapaz de discernir.

Tendo por objetivo facilitar o primeiro contato com ROS de estudantes que tenham interesse em robótica móvel, foi proposto a realização de um hackathon para a introdução de forma dinâmica dos conceitos básicos do ROS, a fim de guiá-los organizada e progressivamente, através de um ambiente ROS disponibilizado e com o acompanhamento de investigadores especializados no assunto.

Deste modo, os participantes não precisam se preocupar com a tarefa de instalação e configuração do framework. Ademais, dada a competitividade e dinamismo de um hackathon, e mesmo a oportunidade de aplicar o ROS na solução de problemas robóticos reais, essa didática acaba por estimular um maior interesse no participante em continuar a desenvolver trabalhos na área após o Hackathon.

3 Especificação do Hackathon em ROS

O «Hackathon em ROS - Um desafio na robótica móvel» foi desenvolvido, no âmbito do projeto DISRUPTIVE financiado pelo programa POCTEP, com o intuito de despertar nos participantes o interesse em tecnologias disruptivas com aprendizados multidisciplinares através de atividades intensas e imersivas que possam mostrar habilidades no tema.

Hackathon surge da união das palavras *hack* e *marathon*, ou seja, este tipo de desafio visa a resolução de problemas de programação de forma criativa e intensiva em um curto período de tempo. Onde os participantes trabalham em equipes normalmente multidisciplinares, trocando ideias e experiências [16].

Para a presente competição, espera-se que os integrantes a finalizem com um conhecimento dos fundamentos do ROS, sendo capazes de realizar um controle simples do robô em um ambiente de simulação, entender os parâmetros apresentados e necessários para o movimento do mesmo, saber como ler e publicar as mensagens no ambiente ainda que seja elevada a complexidade.

Sendo o público-alvo estudantes de cursos de graduação e mestrado de áreas tecnológicas, com um conhecimento breve em linguagem Python e em Linux, a aprendizagem em ROS é esperada ao desenvolver fases onde o nível de dificuldade aumenta na medida em que as fases do hackathon avançam. Deste modo, pode-se instruir a partir de conceitos mais básicos e todos os participantes progredirem sincronicamente, para ao final todos atingirem o nível esperado para o evento. O conhecimento na linguagem de programação é importante por evitar a necessidade de explicar conceitos básicos que divergem da temática planeada. Para o uso da linguagem Python em ROS é utilizada a biblioteca «rospy», que possui comandos relativos ao ambiente e as comunicações possíveis/necessárias. Para o uso do sistema operacional, apesar de ser melhor um conhecimento prévio, todos os comandos necessários e úteis serão disponibilizados em um guia que está entre os materiais de apoio do evento.

As atividades serão realizadas de forma remota durante 5 dias, em um ambiente desenvolvido em uma máquina virtual à qual cada participante poderá baixar e executar em seu próprio computador. Essa máquina virtual é composta por um ambiente com o sistema operacional Linux Ubuntu 16.04, onde está instalado ROS e também os ambientes do simulador Stage desenvolvidos e instalados no ambiente ROS disponibilizado. Para facilitar o acesso e utilização, cada comando de inicialização foi inserido como um atalho, assim, é possível iniciar o simulador de cada fase através de um comando simples, sem a necessidade de escrever todos os comandos do ROS. Como o arquivo de instalação da imagem possui 5,4 GB e ainda é necessário o download do programa que a executa, essas informações serão disponibilizadas três dias antes do início, para que todos possam realizar o download, instalação e ter tudo pronto para o início das atividades do hackathon.

Após a instalação os usuários e participantes do evento, já teriam os requisitos necessários para participar do evento e dar início as fases planejadas.

4 Calendarização das Fases de Implementação do Hackathon

Para a realização do hackathon, foi definido uma separação em etapas. Entre as etapas estão as partes introdutórias e as fases que foram feitas com níveis de dificuldades sequenciais, fazendo com que os participantes conseguissem iniciar em um nível básico e chegarem à fase final em um mesmo nível de conhecimento para que fosse possível desenvolvê-la.

Foram desenvolvidas três fases, que serão posteriormente melhor detalhadas, onde na primeira o objetivo é entender o simulador, como fazer as comunicações para movimentar o robô. Na segunda fazer o robô se mover de modo autónomo, entendendo como desviar de obstáculos. E na terceira e última fase o robô teria que encontrar uma fonte de gás desconhecida no simulador, portanto o robô iria navegar no ambiente, desviando de obstáculos e ainda se deslocar até o ponto de objectivo.

As etapas foram organizadas da forma como apresenta a Figura 1:

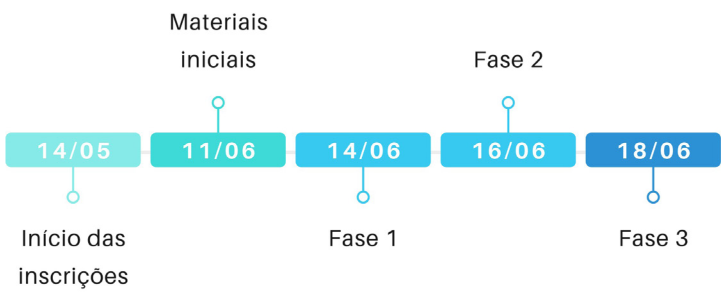

Fig. 1. Cronograma do hackathon em ROS.

– 11/06, às 18:00: Disponibilizado aos grupos a máquina virtual, como fazer a instalação e algumas informações básicas para os grupos se familiarizarem com a ferramenta;
– 14/06, às 18:00: Primeira fase, que deve ser finalizada até as 18:00 do dia 15/06;
– 16/06, às 18:00: Segunda fase, que deve ser finalizada até as 15:00 do dia 18/06;
– 18/06, às 15:00: Última fase do evento, com duração de 3 horas.

Ao início de cada uma das fases será feito por uma chamada no Zoom, onde elas serão explicadas e os organizadores estarão disponíveis para tirar dúvidas dos grupos por até uma hora.

Os desafios serão realizados no simulador STAGE que é representado na Figura 2.

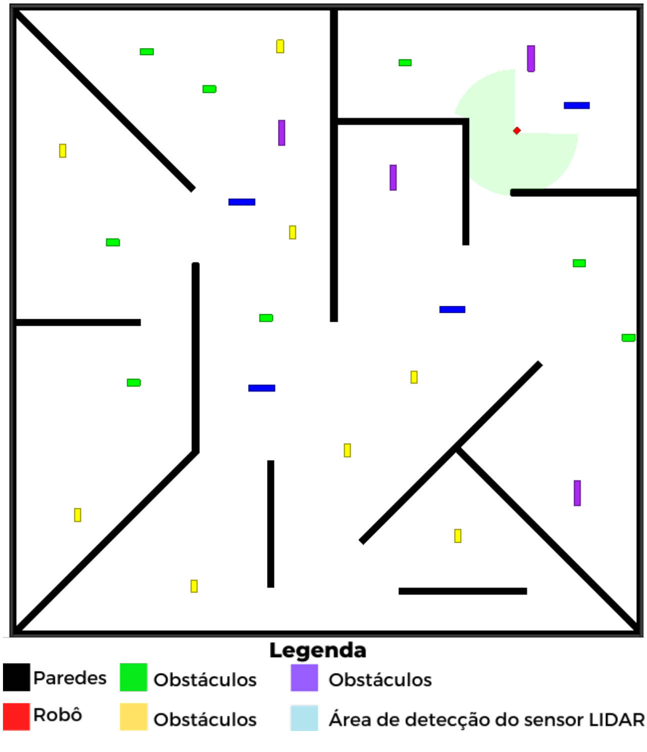

Fig. 2. Exemplo de cenário usado no Hackathon no simulador STAGE.

Esse é um dos exemplos utilizados durante o evento. A dimensão do ambiente simulado é de (iniciando em -25 até 25 em cada eixo) e as barras pretas representam paredes e as coloridas obstáculos desconhecidos.

4.1 Fase 1

A primeira etapa do Hackathon têm por objectivo introduzir aos participantes o ROS, de modo a possibilitar a compreensão de seus conceitos básicos de nós, tópicos e mensagens, além de apresentar o ambiente de simulação STAGE que será utilizado para o desenvolvimento de todos os desafios propostos.

Como primeiro desafio os participantes deverão desenvolver um algoritmo Python que permita o controle de um robô móvel presente no ambiente de simulação, realizando a sua locomoção entre pontos distintos do ambiente. Para tal tarefa, é necessário que os participantes inicializem um nó para o processo, em que possam realizar a leitura do tópico de odometria do robô, afim de, terem acesso a posição do robô no ambiente para determinar a distância que o robô está em relação ao ponto de destino e possam calcular a velocidade linear e angular do robô realizando sua publicação no tópico de velocidade.

4.2 Fase 2

Nesta etapa as equipes terão a tarefa de controlar o robô do ambiente de simulação STAGE, de tal maneira que ele possa caminhar livremente pelo espaço sem que colida com nenhum obstáculo.

O robô conta com um sensor Lidar que permite medir com precisão a distância entre o robô e os obstáculos presentes no ambiente através da medição da luz reflectida pelos objectos. O sensor possui um alcance de varredura de 5 metros e um ângulo de varredura de 270°, sendo assim, ao realizarem a leitura do tópico do sensor laser, é possível determinar a qual distância e posição em relação ao robô os obstáculos se encontram, e a partir deste dados implementar o algoritmo de desvio.

4.3 Fase 3

Como desafio final do Hackathon os participantes terão como proposta, controlar o robô realizando uma varredura no ambiente em busca de uma fonte de gás.

Em um tópico estará sendo publicado um valor correspondente a concentração de gás relativa a actual posição do robô dentro do ambiente, ou seja, quanto mais próximo o robô estiver da origem do gás, maior será o valor da concentração retornado pelo tópico. A distribuição do gás no ambiente é modelado a partir de uma função gaussiana. A fim de aumentar a dificuldade da tarefa, existe um ruído na função de concentração que a faz variar entre entre -1.5% e 1.5% do valor real ao longo do tempo.

A função de distribuição do gás (Equação 3) publica um valor que varia de 0 a 100. Esse valor varia de acordo com a distância do robô ao gás, sendo 100 quando estivesse junto à fonte. Na Equação 1 as variáveis GasX e GasY são as posições X e Y da fonte, enquanto que RobotX e RobotY são as posições do robô lidas pelo código, fazendo com que a variável «dist» seja atualizada conforme o robô se movimenta. Essa distância é calculada de acordo com o teorema de Pitágoras, encontrando a distância em linha reta entre os dois pontos.

A Equação 2 é a distância ao quadrado dividida 100. Portanto, quando menor a distância, menor o valor dessa expressão. Essa divisão é feita para atenuar o valor da exponencial, diminuindo a taxa de decaimento.

$$dist = \sqrt{(RobotX - GasX)^2 + (RobotY - GasY)^2} \tag{1}$$

$$aux = \frac{dist^2}{100} \tag{2}$$

$$gas = \alpha * e^{-aux} \tag{3}$$

Com isso, a função do gás é α multiplicado pela exponencial negativa da Equação 2. Com $\alpha = 100$, o valor irá aumentar até 100 conforme a distância diminui até 0. Sendo a distância a linha reta entre os dois pontos, os pontos que estão a uma mesma distância representam uma circunferência, logo cada circunferência terá um valor de leitura do gás que varia conforme o raio, como é possível ver nas Figuras 4 e 3.

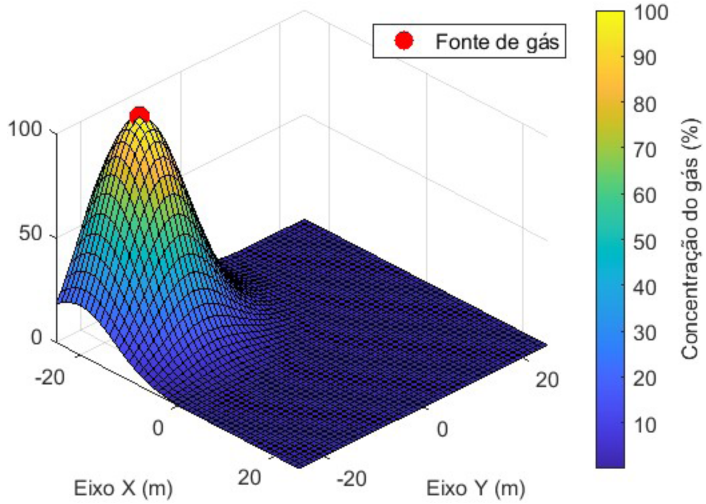

Fig. 3. Vista da distribuição de gás no ambiente.

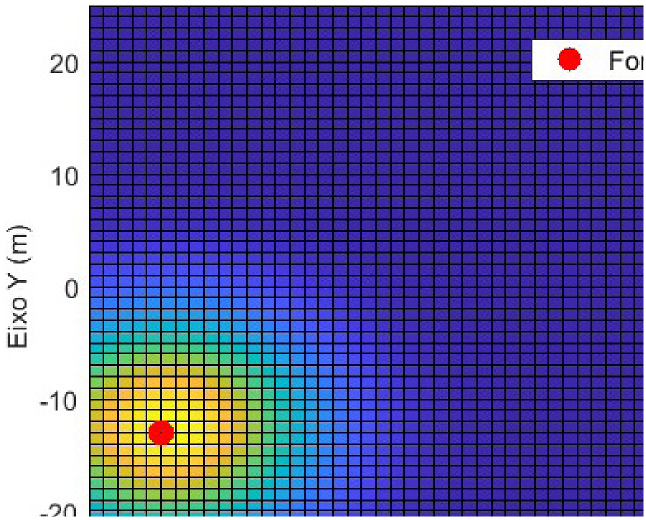

Fig. 4. Vista de topo (2D) da distribuição do gás no ambiente.

Na imagem a fonte de emissão de gás está posicionada na posição (10, -15) e em um raio superior a 25 metros o valor é zero.

Para a publicação do valor do gás no ambiente, foi utilizado um ruído gaussiano de forma que essa indicação possuísse uma variação de -1.5 até 1.5% e fosse publicada somente em um raio de 23 m de distância. Esse ruído é aplicado de forma a dificultar a localização da fonte de emissão de gás. Uma vez que sem a presença do ruído, o valor de leitura simplesmente aumentaria em proporção a distância do robô e da fonte.

5 Resultados Esperados

Anterior à realização do hackathon, foi elaborado um workshop de introdução à ROS, que visa trazer para grande parte dos participantes um primeiro contacto com a *framework* e uma aprendizagem básica através de aula teórica e uma aula prática de desenvolvimento dos códigos e uso da plataforma em conjunto com os participantes, e também estimulá-los na área da robótica. O curso utilizou a mesma máquina virtual do hackathon e teve uma participação de 21 pessoas de um total de 40 inscritos (representando 52,5%). Com isso, também espera-se uma frequência semelhante nesse evento, visto que ambos possuem o mesmo perfil de participantes, sendo estudantes de licenciatura e mestrado, professores e trabalhadores da indústria.

Foi feita uma pesquisa ao término do curso para obter uma avaliação dos participantes e com algumas perguntas sobre a participação deles. Entre elas, destacam-se duas que eram a respeito do conhecimento prévio na plataforma e do nível de aprendizagem acerca das atividades do curso. Dos 21 participantes, 13 responderam e as Figuras dos gráficos das respostas são apresentados, respectivamente, nas Figuras 5 e 6. As opções de respostas das perguntas eram distribuídas em uma escala entre as possíveis opções. Para a primeira pergunta, as seleções iam de «Não conhecia» até «Utiliza sempre». Já para a segunda pergunta, relacionada ao aumento do conhecimento em ROS após a participação no curso, as alternativas compreendiam de «Não aprendeu» à «Aprendeu muito».

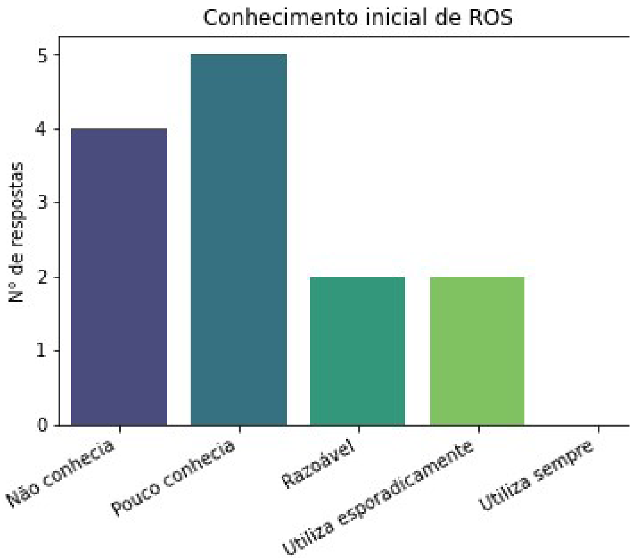

Fig. 5. Conhecimento em ROS antes do curso.

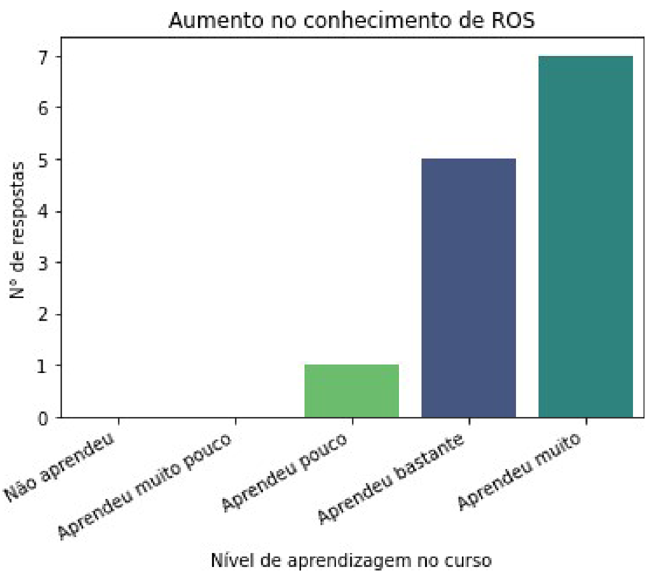

Fig. 6. Conhecimento após aprendizagem no curso.

Com isso, percebe-se que mesmo com um conhecimento prévio baixo da maioria, o nível de aprendizagem em uma atividade prática, desenvolvida em conjunto, foi bastante significativo, gerando estímulos e interesse na área, o que também pode ser comprovado quando os integrantes informaram na pesquisa que todos desejam continuar a trabalhar com ROS, sejam em estudos, investigação, trabalho ou *hobby*.

Além disso, após a realização do hackathon, é esperado que os participantes tenham a capacidade de:

- Compreender o ROS e sua importância;
- Perceber os conceitos básicos da plataforma;
- Possuir a capacidade de desenvolver uma aplicação capaz de controlar o robô no simulador;
- Despertar o interesse para na realização de pesquisas no âmbito de ROS e robótica móvel.

6 Conclusões

Dado o crescimento do uso da robótica móvel e suas tecnologias associadas, perceber seu uso e saber utilizar é de grande importância no desenvolvimento de pesquisas na área e para empresas. Uma das plataformas mais utilizadas hoje é o ROS e, de forma a estimular o aprendizado de maneira lúdica, didática e interativa, foi utilizado um hackathon para introduzir esse assunto.

O hackathon visa introduzir o tema e instigar os participantes a desenvolverem atividades de pesquisa no tema com métodos de imersão intensa no assunto.

Como trabalho futuro, o hackathon vai ser finalizado no dia 18 de Junho de 2021, e após a sua implementação, vai ser realizada uma análise do seu impacto através da análise do feedback dos participantes.

Agradecimentos

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GESTIÓN INTELIGENTE DE RED CUÁNTICA

INTELLIGENT QUANTUM NETWORK MANAGEMENT

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Resumen: Las redes cuánticas materializan el cambio de paradigma provocado por el agotamiento de la computación clásica. Hasta ahora, se han construido redes cuánticas agrupando repetidores cuánticos confiables unidos por redes de fibra óptica. La necesidad de construir redes robustas y resilientes ante ataques se hace fundamental en el diseño del futuro Internet cuántico. Proponemos un método de gestión de la red que permita a esta adaptarse en tiempo real y protegerse frente a sabotajes o accidentes que inutilicen parte de la red o de sus nodos.

Palabras clave: QKD; quantum key distribution; quantum network; intelligent quantum network; dijkstra algorithm.

Abstract: Quantum networks materialize the paradigm shift caused by the exhaustion of classical computation. So far, networks have been built Quantum Clustering Reliable Quantum Repeaters Linked by Fiber Networks optics. The need to build robust and resilient networks against attacks becomes fundamental in the design of the future quantum Internet. We propose a method of network management that allows it to adapt in real time and protect itself against sabotage or accidents that disable part of the network or its nodes.

KEYWORDS: quantum key distribution; quantum network; intelligent quantum network; dijkstra algorithm.

1 Introducción

La aparición de la computación cuántica impulsa la necesidad de un cambio de paradigma. La comunicación cuántica podría proteger datos sensibles y la infraestructura digital en los próximos años. Para ello, es necesario diseñar e implementar redes cuánticas que sirvan a este respecto.

Existen numerosos experimentos exitosos sobre comunicación cuántica en distancias por encima de 100 sobre canales de fibra óptica como entre otros los que encontramos en [6]. No obstante, tratando de poner un enfoque realista orientando a una implementación comercial en condiciones reales, se han considerado distancias por debajo de 50 basándonos en las experiencias [8] que consigue demostrar que en esas distancias con equipos comerciales actuales como los fabricados por la empresa *ID Quantique SA* se consiguen resultados destacables. Este dispositivo [9] permite intercambiar del orden de 20000 claves cuánticas en una hora.

Podemos encontrar metodologías para diseñar redes cuánticas comerciales mediante la distribución de repetidores cuánticos como la que se propone con detalle en [7].

1.1 Retos, alcance y contribuciones

La implantación de redes cuánticas sobre redes comerciales de fibra óptica lleva acompañada la necesidad de la gestión de las mismas. En un escenario de explotación comercial, surgen las necesidades de disponibilidad de la red, garantía de calidad de servicio y capacidad de recuperación frente a incidencencias sobrevenidas.

Este artículo pretende dar respuesta a las necesidades derivadas del uso de las redes de fibra ópticas comerciales para su uso en la creación de una red cuántica. Parte de la base de trabajos previos para el diseño de la red, centrándose en métodos para ser resiliente frente a ataques o degradaciones por su uso o provocados por accidentes.

Proponemos un método para conseguir dar robustez y fiabilidad a nuestra red cuántica. Ante un posible sabotaje de alguno de los nodos o de alguno de los canales, introducimos un método de gestión de la red que permita su continuidad con el menor impacto posible.

Proponemos un método para conseguir dar robustez y fiabilidad a nuestra red cuántica. Ante un posible sabotaje de alguno de los nodos o de alguno de los canales, introducimos un método de gestión de la red que permita su continuidad con el menor impacto posible.

1.2 Organización

El resto del artículo está organizado del siguiente modo. En la sección segunda se muestra el esquema de distribución de los nodos en la red. En la sección tercera se presentan cuestiones fundamentales sobre seguridad en la red cuántica, así como sus posibles ataques. En la sección cuarta introducimos la línea de trabajo sobre el sistema de gestión de red basándonos en trabajos previos relacionados.

Por último, en la sección sexta se indican las principales observaciones de este documento y las correspondientes recomendaciones.

2 Distribución de los nodos de la red cuántica

Para construir una red que conecte todos los municipios entre sí, se debe diseñar una red distribuida de repetidores. Para realizar dicho reparto, se utiliza una metodología basada en agrupación de municipios, a través de un algoritmo de k-medoides como se realiza en el trabajo previo [7]. Este algoritmo ayudará, dado un conjunto de municipios, a seleccionar aquellos que se encuentran físicamente cerca entre ellos. Después, el algoritmo facilitará la selección del municipio más céntrico, dentro del conjunto de municipios cercanos. Este municipio será considerado como candidato, dentro del conjunto, para albergar un repetidor. La metodología, finalmente, tratará de conectar los posibles repetidores entre ellos para generar una red de distribución.

2.1 Red de Repetidores

Para poder garantizar que cualquier municipio dentro de la red pueda comunicarse con cualquier otro, es necesario establecer una red de repetidores basada en los municipios representativos seleccionados en el paso anterior. Esta red se definirá de la siguiente manera:

1. Cada municipio representativo se conectará con todos los municipios de su clúster. De este modo, todos los municipios de un mismo clúster podrán intercambiar claves cuánticas utilizando el repetidor. En el paso anterior se garantiza que el repetidor queda a una distancia menor que D respecto a cada municipio de su clúster.
2. Cada repetidor se conectará con todos los repetidores de su entorno que se encuentren a una distancia menor D. De este modo, si hay más de un repetidor cerca de otro, se podrán utilizar distintos enrutamientos para reducir la saturación de la distribución de claves.

Estos criterios a la hora de crear la red no sólo facilitan la consecución de un mejor enrutado, sino que además permite fácilmente identificar posibles regiones aisladas de la misma. Para poder encontrar estas regiones, basta con calcular el número de componentes conexas de la red. Formalmente, la red es un grafo G no dirigido, dividido en vértices V, que representan los municipios, y aristas E que representan aquellos municipios que, o bien se encuentran dentro de un clúster y están conectados a su repetidor, o bien son repetidores a una distancia menor que D, entre ellos. De esta forma, el número de componentes conexas del grafo se puede calcular de varias formas, donde las más representativas son la multiplicidad de sus autovalores, o la estimación utilizando caminos aleatorios [14]. Si el número de componentes conexas del grafo es al menos uno, la red es totalmente conexa.

3 Seguridad en comunicaciones cuánticas

Como se ha mencionado en las secciones anteriores, la seguridad de los canales sobre los que se implementan los protocolos de comunicación cuántica reside en las propiedades de la mecánica cuántica –siempre y cuando esta se comporte como dicen los postulados que la definen [5]–. Atendiendo a dichos principios, cuando un atacante denominado Eve interacciona con la clave que se distribuye provoca una perturbación en la comunicación que podría ser detectada por Alice y/o Bob.

Para que la comunicación sea segura, Eve no debe tener acceso a los dispositivos que Alice y Bob utilicen para el intercambio de claves cuánticas. Además, hasta ahora se ha supuesto que el canal clásico era autenticado además de que Alice y Bob eran realmente quién decían ser. A continuación, se introducen algunos de los ataques al canal cuántico que deben considerarse.

3.1 Ataques individuales

En los ataques que se describen a continuación Eve ha tomado muestras individuales de cada qbit y las va midiendo una tras otra.

Ataque de divisor de haz

Conocido como *Beam splitting attack* este ataque es probablemente el más dañino que se pueden realizar a los sistemas de distribución de claves cuánticas sobre fibra óptica. Como se describía, existen unas pérdidas asociadas con el propio canal. En este ataque [2] se utiliza esa circunstancia para mediante un acoplador óptico sobre el canal cuántico extraer parte de la clave sin que Bob se percate de la presencia de Eve.

Ataque de división de número de fotones

Como se describe en [10] *Photon Number Splitting Attack, PNS*, Eve realizará una medida no destructiva del número de fotos en cada pulso. Si detecta más de un fotón en cada pulso, almacenará uno de ellos para medirlo. El resto lo enviará a Bob [1].

Ataque de interceptación y reenvío.

Por último, encontramos el ataque más sencillo que podemos realizar. En *Intercept and resend attack* [3] Eve intercepta los fotones, los mide utilizando una base aleatoria y reenvía a Alice los fotones.

4 Aproximación a un Sistema de Gestión de red

Los repetidores –los nodos de nuestra red– han de conocer la topología completa de la red, así como unas instrucciones para saber hacia dónde redirigir sus mensajes en caso de que no sean ellos mismos el destino final de estos.

Se ha diseñado una red conexa sobre el territorio objeto de estudio. Todos los repetidores están conectados entre sí de tal modo que se consigue dicho objetivo. El siguiente paso consiste en implementar la lógica que permita establecer el camino óptimo para que un mensaje llegue entre cualquier par de puntos de la red. Todo municipio debe poder comunicarse con el resto.

4.1 Topología de red

La primera de las características se basa en un mapa de topología de red. En dicho mapa se identifica la red completa, los distintos nodos de esta y las redes que relacionan dichos nodos.

La información de la red que hemos diseñado debe estar albergada en el elemento de gestión de cada nodo y en cada elemento final de la red. Podemos establecer una abstracción de la implementación física de la red, de tal manera que esta topología aún basándose evidentemente en la propia red de fibra y los repetidores, constituya una verdadera topología lógica que sirva a cada parte de la red.

Estos ficheros de topología darán las instrucciones necesarias para que un usuario final sepa a quién encaminar la petición en primer lugar. De igual manera en base a esos caminos definidos los repetidores cuánticos conocerán cuáles pueden ser los siguientes nodos –subsidiariamente qué redes– a los que transmitir la información.

4.2 Matriz de costes

El reparto poblacional en el territorio no es homogéneo. Se produce un efecto atomizador en los repartos demográficos. De tal manera que, en la aplicación del reparto de nodos, se han considerado exclusivamente criterios de distancia (si bien se ha partido de la premisa de municipios de más de 1000 habitantes basándose en el trabajo anterior referenciado [7]). Esto constituye una configuración no homogénea de la carga de la red.

Se define en un primer momento una matriz de costes atendiendo a la población objeto que da servicio cada nodo. De tal manera que cada nodo estará ahora señalizado por un identificador del nodo, y un número que podemos vincular con el grosor de población objeto de servicio. Añadimos complejidad a la matriz indicando la distancia entre cada uno de los nodos conectados. De esta forma hemos creado una primera matriz.

4.3 **Chequeo de sanidad del nodo y del canal**

Cada nodo podrá saber en todo momento su estado de saturación, las peticiones que está atendiendo y otras variables que pueden definirse vinculadas con su estado de salud puntual. Dicha información debería ser transmitida al resto de elementos de la red, consiguiendo así una información de estado global del sistema conocida por todos y cada uno de los elementos de este.

4.4 **En búsqueda del camino óptimo**

Vamos a tratar de introducir un elemento novedoso en la gestión de la red cuántica. Teniendo en cuenta por cada repetidor: su grosor (la población objeto de cada nodo), la distancia entre ellos y su salud instantánea se puede dotar de inteligencia al proceso de encaminado de los paquetes. Se trata de construir una matriz dinámica que pueda servir para un algoritmo de costes determine el camino óptimo para realizar la entrega de los mensajes en cada momento.

En el inicio del experimento los nodos parten de la topología de red definida y de la matriz de costes inicial. De tal manera que en el momento en que un usuario envía un mensaje a través de la red cuántica, el sistema es capaz de encaminar dicho mensaje.

Se define el envío automático de datos de calidad entre los nodos tal y como se describía en la subsección anterior. Esta información de salubridad de la red y de sus nodos va a modificar el encaminamiento del mensaje entre Alice y Bob. Se propone un método basándonos en el Algoritmo introducido por Dijkstra [4] some or all pairs of which are connected by a branch; the length of each branch is given. We restrict ourselves to the case where at least one path exists between any two nodes. We now consider two problems. Problem 1. Constrnct the tree of minimum total length between the n nodes. (A tree is a graph with one and only one path between every two nodes.. Si se detectan problemas en un canal, su peso aumentará. Por ello, al aplicar dicho algoritmo el camino se modificará consistentemente.

4.5 Justificación en base a investigaciones previas

Existen trabajos previos en los que se discute y se prueba la utilidad de la aplicación del algoritmo de Dijkstra para la gestión inteligente de redes de fibra óptica [12]. Encontramos comparativas de uso del algoritmo escogido –Dijkstra– versus otros –Heurísticos, Yen KSP y algunos otros– sobre grandes redes con pruebas de generación de nodos de forma aleatoria [11] resultando demostrado la prevalencia en el uso de Dijkstra. También se analiza su utilidad para garantizar la calidad del servicio prestado QoS en la gestión de la red [13].

5 Experimentación

Sobre nuestra red vamos a simular la inoperatividad sobrevenida de alguno de los nodos o bien la desconexión de una parte de la red por un problema en alguno de los segmentos de la red.

Partimos de una red ideal en la que los distintos nodos de la red y sus conexiones se muestran como en el gráfico que se muestra a continuación. Entendemos que el estado de partida en el que no tenemos saturación en ningún elemento de red. En esta representación de la red, los nodos –vértices– (marcados con círculos) son repetidores cuánticos. Tienen asignados unos números para identificar cada nodo. La red que une los nodos –aristas– tiene un peso asignado que como se decía es ideal e igual a 1.

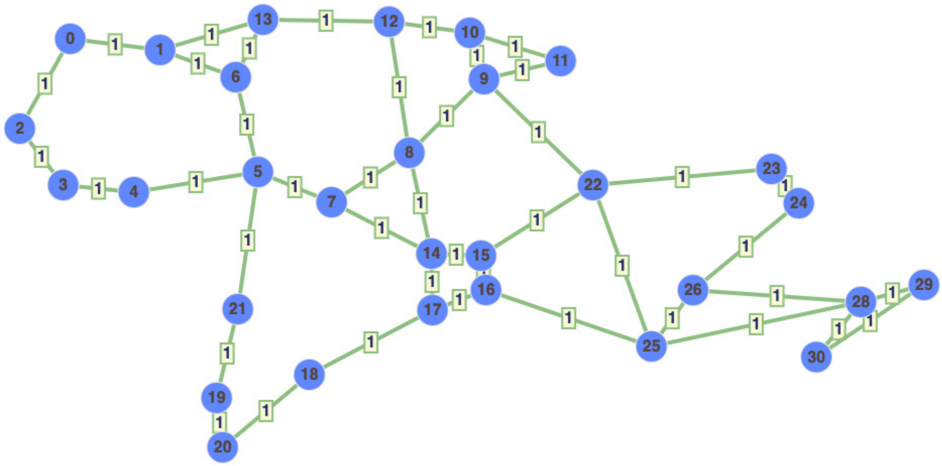

Fig. 1. Situación de partida de la red.

En nuestra simulación partimos del nodo identificado como 0 y nos dirigimos al identificado como 30. Aplicamos el Algortimo de Dijkstra para calcular el camino óptimo inicial:

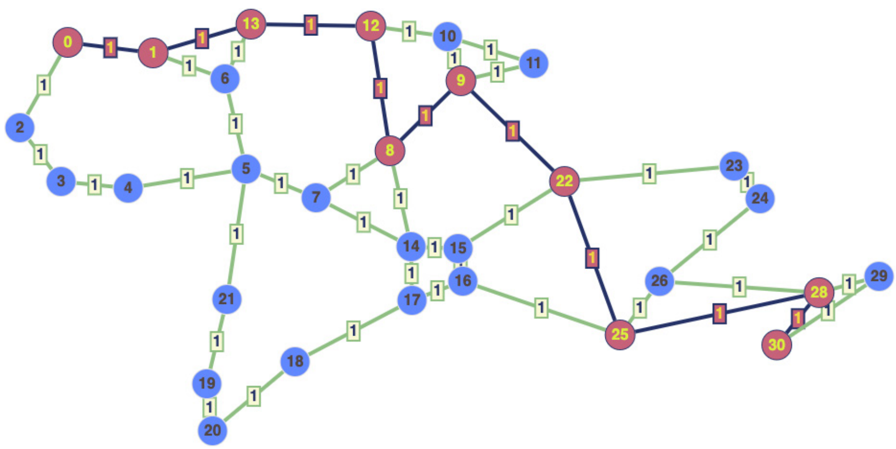

Fig. 2. Camino óptimo entre los nodos 0 y 30 tras aplicar el Alrgoritmo de Dijkstra.

5.1 Eliminación de un nodo

Al eliminar un nodo de nuestra red conexa, este no será capaz de mandar su estatus al resto de nodos, por lo que estos dejaran de tenerlo en cuenta para el reparto de paquetes. Se producirá consecuentemente una inoperatividad en dicho nodo y en aquellos canales que unan el nodo con sus vecinos, pero se podrán trazar caminos alternativos.

En el gráfico mostrado se elimina el nodo identificado con el 8 y se calcula de nuevo el algoritmo:

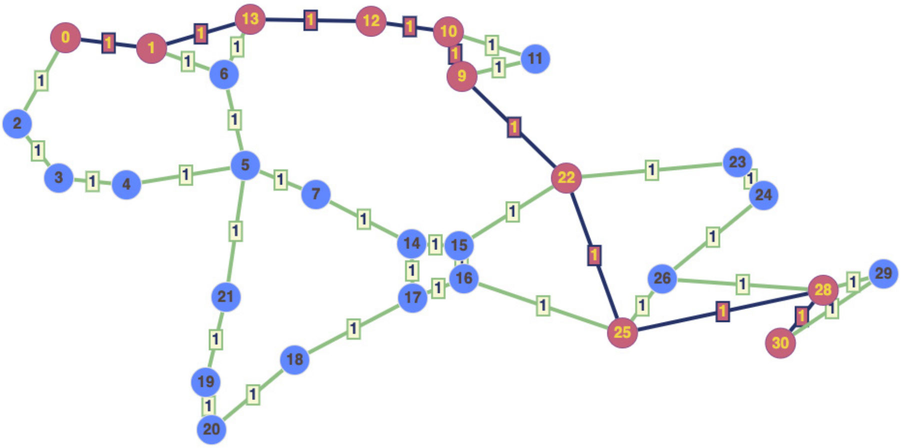

Fig. 3. Camino óptimo entre 0 y 30 tras eliminar el nodo 8.

5.2 Anulación de un segmento

Si un segmento que une una pareja de nodos queda inutilizado, los nodos dejarán de utilizar ese canal. Gracias al cálculo del algoritmo de Dijkstra se trazará un nuevo camino para poder encaminar los mensajes consecuentemente.

En el experimento se eliminó el segmento que unía el nodo 11 y el nodo 22:

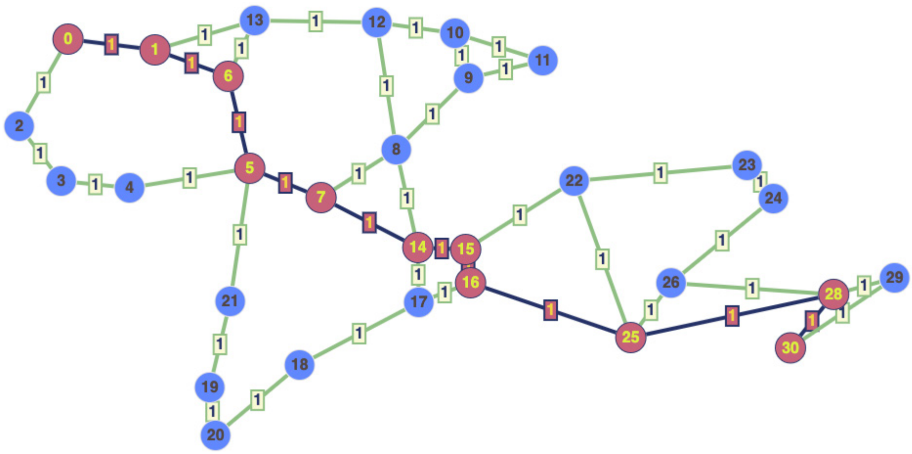

Fig. 4. Camino óptimo entre 0 y 30 tras eliminar el segmento entre el 11 y el 22.

6 Conclusiones

La aportación principal de este artículo consiste en el cálculo dinámico de las rutas óptimas en dos escenarios concurrentes:

1. en situaciones de saturación de un nodo y de un elemento de la red. En ese caso, el algoritmo creará dinámicamente una nueva ruta garantizando la entrega del mensaje.
3. en el momento en que se produzca el sabotaje o incidente que inutilice un elemento de la red cuántica, el algoritmo aislará el posible nodo atacado –o segmento de la red, según el caso– y reencaminará el tráfico utilizando rutas alternativas para garantizar el mejor funcionamiento posible de la red.

Conseguimos dotar a nuestra red cuántica de robustez y fiabilidad. Introducimos un método de gestión de la red que permita su continuidad -con el menor impacto posibleante un imponderable, bien sea voluntario o derivado del uso de los nodos y el canal.

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PROPUESTA DE POLÍTICA PÚBLICO-PRIVADA PARA EL DESPLIEGUE DE LA BANDA ANCHA EN ENTORNOS RURALES DE CASTILLA Y LEÓN

PUBLIC-PRIVATE POLICY PROPOSAL FOR THE DEPLOYMENT OF BROADBAND IN RURAL ENVIRONMENTS OF CASTILLA Y LEÓN (SPAIN)

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Resumen: Los nuevos servicios y aplicaciones disruptivas requieren la utilización de redes de comunicaciones de banda ancha. En el segmento de acceso, las redes de acceso ópticas pasivas (PON) se están consolidando como la mejor alternativa para este despliegue dado que las tecnologías de acceso tradicionales (cable coaxial, cobre) ya han dejado de ser capaces de soportar el creciente volumen de tráfico. Sin embargo, el despliegue actual de estas redes PON es muy desigual estando únicamente presentes en las áreas de mayor densidad de población donde el coste por conexión para los operadores se mantiene bajo. En este artículo presentamos una propuesta de política público-privada que permitirá incentivar a los operadores para el despliegue de redes PON en entornos de baja densidad de población (entornos rurales). Para demostrar su eficacia, se presenta un caso de uso en la provincia de Valladolid (Castilla y León, España). Los resultados de este estudio muestran que, gracias a la utilización de la política propuesta, los operadores pueden encontrar atractivo dar un servicio a todos los usuarios y poblaciones que lo deseen.

Palabras Clave: red de acceso; PON; *passive optical networks*; *long-reach* PON; despliegue; tecnologías disruptivas; entorno rural.

Abstract: Disruptive new services and applications require the use of broadband communications networks. In the segment of access, passive optical access networks (PON) are consolidating as the best alternative for this deployment given that access technologies traditional (coaxial cable, copper) are no longer capable of supporting the growing volume of traffic. However, the current deployment of these networks PON is very unequal, being only present in the areas of greatest population density where the cost per connection for operators is keeps low. In this paper we present a public-private policy proposal that will allow operators to be encouraged to deploy networks PON in low population density settings (rural settings). For demonstrate its effectiveness, a use case is presented in the province of Valladolid (Castile and León, Spain). The results of this study show that, thanks to the use of the proposed policy, operators may find attractive provide a service to all users and populations who want it.

Keywords: access network; passive optical networks; long reach; deployment; disruptive technologies; rural environment.

1 Introducción

Internet se encuentra en plena evolución hacia el denominado Internet de las Cosas (IoT por sus siglas en inglés, *Internet of Things*). IoT es un paradigma que permitirá interconectar una ingente cantidad de dispositivos con características heterogéneas. Gracias al desarrollo de esta tecnología, aplicaciones disruptivas de Industria 4.0, Realidad Virtual (VR), *Smart cities, Smart homes* o *Intelligent Transportation Systems* (ITS) se podrán llevar a la práctica. Cada uno de esos nuevos servicios requieren capacidades de red, computación y almacenamiento particulares, y las actuales infraestructuras de comunicaciones no pueden ofrecerlas.

Uno de los requisitos que caracterizan a todos estos servicios es la necesidad de disponer de una red de comunicaciones de gran ancho de banda, baja latencia, alta disponibilidad y alta seguridad [1]. En el segmento de acceso (la red que conecta al usuario final con la primera central de comunicaciones) la mejor alternativa como red fija son las redes ópticas pasivas (PON, *passive optical networks*). Las redes PON, ofrecen un gran ancho de banda y brindan dinamismo, escalabilidad y confiabilidad a un precio reducido [1]. Las redes PON se caracterizan por llevar una red de fibra óptica hasta el usuario final dando lugar al FTTH (*fiber to the home*). Una de las características principales es que no tienen elementos activos (aquellos que consumen energía) entre la central y el usuario final. La tecnología en la que se basan estas redes es suficientemente madura para que actualmente haya un despliegue importante de las mismas. En este sentido, el FTTH Council en uno de sus últimos informes, de diciembre de 2020, afirma que 202 millones de hogares pasarán a tener FTTH en 2026 en Europa, frente a 88,1 millones en 2019 [2]. Además, se espera que la penetración de FTTH sea del 73,3% en 2026 (43,3% en 2019). Las tecnologías PON se perfilan como predominantes en los próximos años, pasando del 48,4% en septiembre de 2018 al 73% en 2025 [3]. Este despliegue es sin embargo muy desigual dependiendo de los países y de la densidad de la población del área a cubrir. De esta forma, las redes PON están desplegadas en las grandes ciudades (entornos con gran densidad de la población) mientras que en entornos de baja densidad como en entornos rurales el grado de implantación es mínimo o nulo. Esto se debe a que los costes por conexión son mucho más reducidos en entornos de alta densidad debido a tener distancias reducidas (con lo que se reduce el coste del despliegue) y un gran número de conexiones.

Sin embargo, el despliegue de redes de acceso de gran ancho de banda es necesario para la implantación de servicios de IoT, Industria 4.0, VR o ITS en el entorno rural. En [4] se mostraron las diferentes aplicaciones de tecnología MEC *(multi-access edge computing)* en el entorno rural, y para ofrecer dichas aplicaciones son necesarias también redes de acceso de gran ancho de banda como las redes PON. En este artículo se presenta una propuesta de política público-privada para conseguir el despliegue de redes PON en entornos de baja densidad de población como es el medio rural. Mediante un caso de uso en la provincia de Valladolid (Castilla y León, España) se verán las ventajas de está política para todos los implicados: usuarios, sector público y operadores.

2 Redes Ópticas Pasivas

Las redes ópticas pasivas (PON) se están convirtiendo en la principal tecnología para las redes de acceso de banda ancha en todos los países, y tienen el potencial de alcanzar una alta penetración en el mercado a corto y medio plazo.

Las redes PON típicamente presentan una topología en árbol (Figura 1) entre un terminal de línea óptica (OLT, *optical line terminal*), situado en la oficina central y varios terminales de red óptica (ONT, *optical network terminal*) situados en las dependencias de los usuarios finales. La conexión entre el OLT y las ONTs se realiza mediante fibra y divisores ópticos, por lo que los elementos activos solamente se encuentran en los extremos de la red, mientras que el resto de la infraestructura es totalmente pasiva. Estas redes de acceso trabajan en dos canales diferentes con una longitud de onda distinta dedicada a cada canal. En el canal de bajada (desde la OLT hacia las ONTs), la conectividad es punto-multipunto y se utiliza una longitud de onda de 1490 nm para la transmisión. En cambio, en el canal de subida (desde las ONTs hasta la OLT) las arquitecturas PON presentan una conectividad multipunto, por lo que todas las ONTs comparten la misma longitud de onda, que es de 1310 nm. Por lo tanto, se requiere un protocolo MAC (*medium access control*) dentro de este canal para evitar colisiones entre los datos de diferentes usuarios (ONTs).

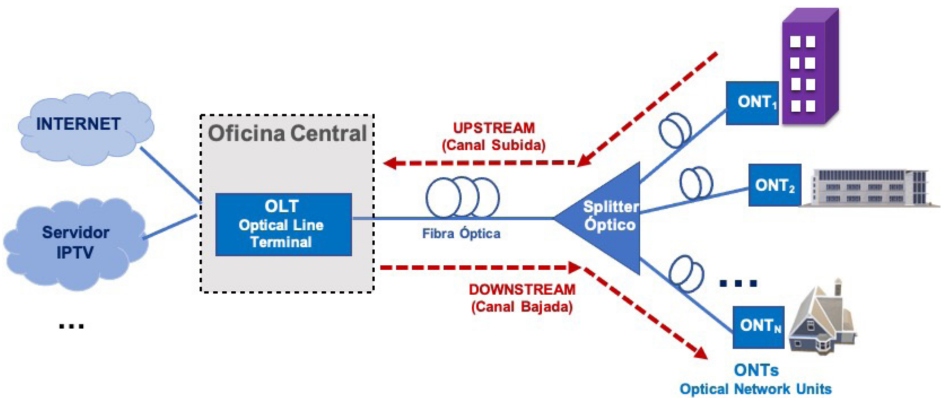

Fig. 1. Esquema de una red PON.

Actualmente existen fundamentalmente dos estándares PON: EPON (ethernet PON) [5] y GPON (gigabit PON) [6]. El estándar EPON soporta una tasa simétrica de 1.25 Gbps mientras que GPON presenta tasas de transmisión más flexibles, hasta 1.25 Gbps en el canal de subida y 2.5 Gbps en el canal de bajada. En ambos estándares, la distancia máxima entre la OLT y las ONTs es de 20 km. En España, los operadores han optado por el despliegue utilizando tecnología GPON.

Para conseguir aumentar la cobertura de las redes PON y hacerlas más rentables, se propusieron las redes ópticas pasivas de largo alcance (LR-PON, *long-reach* PON) [7]. Estas LR-PON amplían la cobertura de las redes PONs tradicionales desde 20 km hasta 100 km y combinan el segmento de acceso y la red metropolitana en un sistema integrado. De este modo, las arquitecturas LR-PON pueden simplificar la red, reduciendo el número de interfaces de equipos y elementos de red, lo que conlleva una reducción significativa de los gastos de capital (CapEx) y operativos (OpEx) de la red. La tecnología LR-PON ha sido pensada para su utilización en entornos de baja densidad con el objetivo de eliminar centrales y conseguir una gestión centralizada.

3 Despliegue de Redes PON en Entornos Rurales

Para el diseño de redes PON es necesario utilizar algoritmos de planificación que permitan determinar la posición óptima de las centrales con las OLT y los cables de fibra a establecer para conseguir una estructura en árbol que conecte las ONTs con las OLTs acorde con las características y restricciones de dichas redes. Estos algoritmos toman como entrada la distribución de la población en las localidades en las que se desplegará la tecnología y utilizan un modelo de costes para dicho despliegue. El coste por conexión depende claramente de la densidad de población del área de cobertura. Así en las áreas de gran densidad de población, los costes por conexión resultante son mucho menores que en las áreas con menor densidad de población. Esto hace que muchos operadores se planteen la conveniencia o no de llevar esta tecnología a zonas de baja densidad de población. Para evitar que haya poblaciones que no disfruten de un acceso a Internet de banda ancha, el sector público (gobiernos nacionales, regionales y/o locales) deben implantar políticas para conseguir que los operadores realicen dicho despliegue y las redes PON lleguen al mayor número de habitantes (preferiblemente a todos).

El modelado de costes de una red PON está compuesto por costes de instalación e infraestructura (CapEx, *capital expenditures*) y costes de operación y mantenimiento (OpEx, *operational expenditures*). En este estudio nos vamos a centrar en los primeros y en concreto en el despliegue de fibra necesario para llegar hasta las poblaciones con conexiones PON o LR-PON dependiendo de la distancia entre ONTs y OLT. Como se ha explicado en el apartado anterior, la topología más utilizada en redes PON es una topología en árbol desde la OLT a las ONTs. Por otro lado, las OLTs estarán conectadas al punto de acceso a la red de área extensa (WAN, *wide area network*) o red troncal. En este artículo supondremos un enlace punto a punto desde las centrales donde se ubican las OLTs a dicho punto de acceso. Cuando se trata de instalación de infraestructura de red PON, el coste principal es debido a la obra civil necesaria para la instalación de la fibra óptica. Esta instalación puede ser realizada de forma área, canalizada o directamente enterrada. Al ser grandes las distancias en el entorno rural, este coste va a ser muy elevado comparado con el resto de componentes de la red. Para conseguir abaratar costes, pueden plantearse varias políticas para el despliegue de redes PON:

- Modelo privado: toda la infraestructura es desplegada de forma privativa por cada operador de red. De esta forma, cada operador debe hacer frente todos los gastos de instalación. La consecuencia inmediata es que los operadores seleccionan las poblaciones a las que proporcionan acceso evitando aquellas en las que la rentabilidad no sea suficiente por su tamaño de la población. Intentan mantener el coste por conexión suficientemente bajo para mantener sus márgenes de beneficio.
- Modelo privado subvencionado: Al igual que en el caso anterior, toda la infraestructura pertenece al operador así como los costes de instalación. En este caso, el sector público subvenciona parte de la infraestructura para asegurar que la conexión llegue al mayor número de ciudadanos posibles o incluso a todos. En este modelo, si se desea que varios operadores desplieguen redes PON hasta todas las poblaciones para evitar monopolios y falta de oferta, el coste para el sector público de la subvención se multiplicaría, en principio, por el número de operadores.

– Modelo de compartición de infraestructuras: los operadores realizan acuerdos voluntarios entre ellos o con la ayuda de las administraciones públicas, con el fin de coubicar o utilizar de forma compartida elementos de red.
– Modelo público-privado: Esta es la propuesta que planteamos en este artículo. Para rebajar los costes del despliegue, el sector público hace la instalación y mantenimiento de parte de la infraestructura. En concreto, se encargaría de instalar los cables entre las centrales donde se alojan los OLTs y el punto de acceso WAN. Estas fibras se pondrían a disposición de los operadores de forma gratuita. Además, también pondrían a disposición de los operadores el espacio para alojar la central con los OLTs. A este respecto, conviene señalar que el sector público tiene espacios disponibles en todas las localidades para dicho cometido por lo que no le supone un coste a mayores. A cambio de la cesión de dicha infraestructura (centrales más fibra desde ellas hasta el punto de acceso WAN) los operadores se comprometerían a llevar redes PON a todas las localidades seleccionadas por el sector público. Una de las ventajas es que se puede ceder la infraestructura a varios operadores puesto que el ancho de banda de las tecnologías ópticas es tan elevado que permite multiplexar todo el tráfico en pocas fibras (normalmente una). Al asegurar que varios operadores dan servicio PON en todas las localidades, se evitan riesgos de monopolio. Por otro lado, la infraestructura pública es totalmente pasiva por lo que no tiene ningún coste de operación: lo que se cede son las fibras pero cada operador instalaría los transceptores en cada extremo dependiendo de sus necesidades. Además, los costes de mantenimiento son muy bajos dado que solo deberían ser arregladas las fibras en caso de corte de éstas. Por último, el sector público puede utilizar su propia infraestructura para dar servicio propio al sector público en estas localidades.

4 Evaluación de Modelos de Despliegue de PON

4.1 Definición de Caso de Uso: Provincia de Valladolid

En esta sección comparamos el modelo privado con el modelo público-privado descrito anteriormente. Para la comparación de los modelos se ha seleccionado la provincia de Valladolid (Castilla y León, España) como caso de uso debido a que su demografía es similar a gran parte de la región POCTEP (España-Portugal) con lo que los resultados pueden ser extrapolados. En concreto, tiene un núcleo poblacional con una población elevada (Valladolid, capital de la provincia y casi 300000 habitantes) con pocos pueblos con población media (de 1000 a 20000 habitantes) y muchos pueblos con baja población.

Se ha considerado un único punto de acceso a redes WAN situado en la capital de la provincia y se ha buscado mediante una formulación de programación lineal entera (ILP, *integer linear programming*) la localización óptima de los OLTs para reducir el coste del despliegue de los cables de fibra. Se ha limitado la distancia entre ONTs y OLT a 100 km (de acuerdo a las especificaciones de *long-reach* PON) y solo se ha considerado el despliegue de fibra hasta llegar al punto de acceso en cada población. En cada uno de estos árboles, se ha considerado un *splitting* de 64 usuarios por PON, ratio normalmente utilizada por los operadores en España. En cuanto a la fibra, se ha considerado un valor de 15000 €/km para la instalación de cables de fibra [8] y se utilizan cables de 12 fibras monomodo con un coste de 1000 €/km [9].

4.2 Análisis de los Resultados

En la figura 2 se puede observar la estructura en árbol diseñada por el algoritmo de planificación. Cada uno de los puntos rojos es una central donde se alojan OLTs. Esta central será el punto de acceso al municipio en estos pueblos desde donde se tenderán redes PON hasta los usuarios finales. El punto rojo central (donde van a parar todas las líneas rojas) es la capital de provincia y donde se encuentra el punto de acceso a la red WAN. Las líneas rojas entre las centrales y el punto de acceso WAN constan de un cable de 12 fibras. Los puntos azules son las poblaciones donde se da servicio, pero a diferencia de aquellas que tienen centrales con OLTs, en éstas no hay centrales para dicho propósito y sus redes PON son servidas por OLTs en otras poblaciones a las que están unidas por los cables representados en azul. Como se puede ver, en la figura 2, el diseño óptimo de la red genera pequeñas estrellas conectadas a la red WAN.

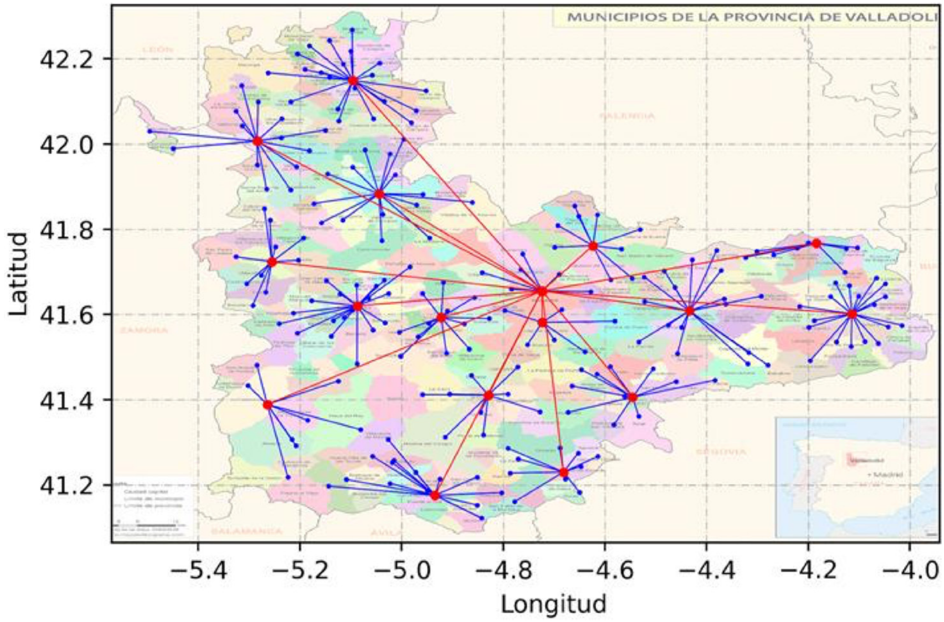

Fig. 2. Mapa con topología diseñada para el despliegue de red PON suponiendo llegar a todos los municipios de la provincia de Valladolid.

En la figura 3 se muestra el coste por conexión para el operador dependiendo del porcentaje de conexiones por habitante en cada localidad. Se muestran distintas alternativas: modelo privado llegando a todas las localidades, modelo privado llegando a todas las localidades mayores de 5000, 1000, 500, 200 y 100 habitantes y modelo público-privado llegando a todas las poblaciones.

Como se puede observar en la figura 3, el precio por conexión disminuye al aumentar el porcentaje de conexiones por habitante. Esto se debe a que el coste de la instalación de la red tiene una influencia muy pequeña respecto al número de conexiones dado que cada cable tiene 12 fibras y en cada fibra se puede establecer una PON con 64 usuarios por lo que tenemos una granularidad de 768 usuarios por cable. Además, como ya se ha visto, el coste fundamental es la instalación de la obra civil y esta no depende del número de conexiones (siempre que haya al menos una conexión).

Por otro lado, comparando las distintas opciones, se puede observar que los operadores podrían no estar interesados en la instalación de redes de banda ancha basadas en fibra a todas las poblaciones si no hay ningún incentivo público puesto que el coste por conexión crece considerablemente al llegar a municipios con menos población. Por este motivo, sin esos incentivos públicos es probable que solo den servicio a las poblaciones más grandes. Viendo los resultados de la gráfica, gracias a la utilización del modelo público-privado que proponemos, el coste para los operadores llegando a todas las poblaciones es similar al que tendrían si de forma privada solo atienden a poblaciones de más de 200 habitantes.

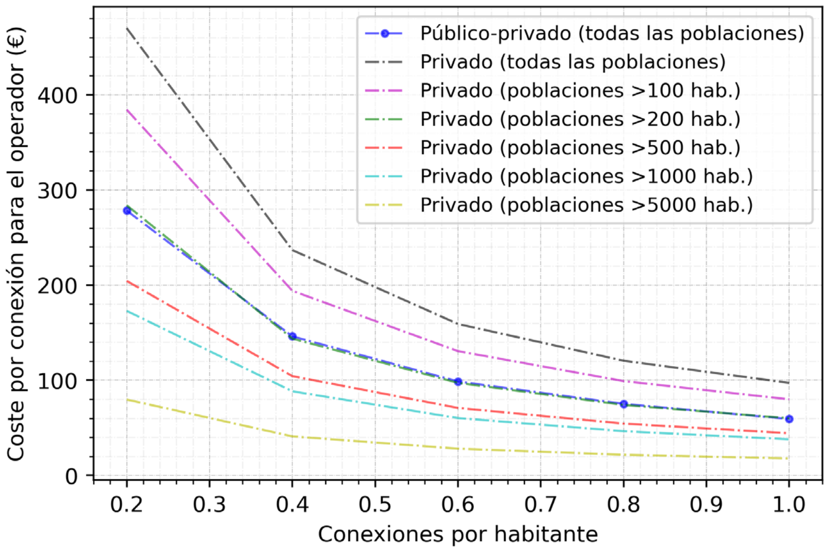

Fig. 3. Coste por conexión para los operadores dependiendo del número de conexiones por habitante y la política seguida.

Tabla 1. Porcentaje de población y número de municipios respecto al total de la provincia dependiendo del número de habitantes.

Poblaciones con tamaño superior a:	Porcentaje de población	Porcentaje de municipios
5000 habitantes	81.29 %	5.78 %
1000 habitantes	92.68 %	17.78 %
500 habitantes	94.62 %	24.44 %
200 habitantes	97.69 %	46.67 %
100 habitantes	99.29 %	72.89 %

A este respecto, en la Tabla 1 se puede observar el porcentaje de poblaciones con más de un determinado número de habitantes y el porcentaje de la población en dichos municipios respecto a los números totales de la provincia [10].

Como se puede observar, si los operadores solo llegan a poblaciones de más de 200 habitantes, el 97.69 % de los habitantes de tendrán la posibilidad de una conexión de banda ancha de fibra pero, en términos de municipios, solo 46.67 % tendrán acceso por PON. Estos números hacen claro la necesidad de implementar políticas públicas para conseguir acceso de banda ancha en todas las poblaciones que permita los nuevos servicios asociados al IoT. La ventaja de la política público-privada propuesta es que hace atractivo llegar a todos los municipios puesto que su coste de instalación por conexión no crece y el sector público asegura acceso de banda ancha a todos sus habitantes independientemente de donde se encuentre su municipio. Además, están las ventajas anteriormente descritas de la posibilidad de utilizar la infraestructura pública por varios operadores para reducir la posibilidad de monopolio y también el uso por parte del sector público de su propia infraestructura para dar acceso de banda ancha a sus servicios en los municipios.

Por último, en la figura 4 se muestra el coste por conexión para tanto para el sector público como para el operador dependiendo del porcentaje de conexiones por habitante en cada localidad. Los costes mostrados corresponden al modelo público-privado en el que se da acceso a todas las localidades de la provincia de Valladolid.

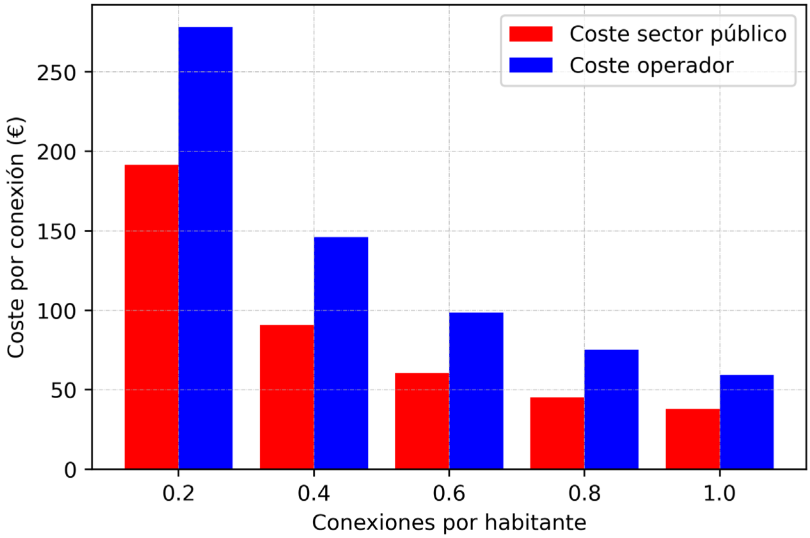

Fig. 4. Coste por conexión para el sector público y el operador dependiendo del número de conexiones por habitante siguiendo el modelo público-privado llegando a todos los municipios.

Como se puede observar en la figura 4, los operadores siguen asumiendo el mayor coste del despliegue pero este no es superior al que tendrían que hacer si solo llegasen a poblaciones de más de 200 habitantes. En cuanto al sector público, su coste es similar en el modelo público-privado o en el modelo privado subvencionado si asumimos que la subvención es la diferencia entre el coste por conexión llegando a todos los municipios y llegando solo a los mayores de 200 habitantes. El problema con el modelo subvencionado es que, en este caso, la infraestructura pertenece al operador y para hacer uso de ella el sector público tendría que pagar por su utilización. Además, el coste de la subvención tendría que multiplicarse, en principio, por el número de operadores que se instalan mientras que en el modelo público-privado ese coste no varía. Además, facilita que varios operadores decidan trabajar reduciendo el riesgo de monopolios y fomentando la competencia.

En cuanto a números totales, suponiendo una conexión por habitante, el gasto para el sector público sería de 37.89 € por habitante y en Castilla y León el gasto en comunicaciones del presupuesto para 2021 es de 54.66 € por habitante [11]. Teniendo en cuenta que es una infraestructura financiable y con gran periodo de amortización, puede ser un coste asumible para el sector público.

5 Conclusiones

En este artículo se ha presentado el problema del despliegue de redes ópticas pasivas como tecnologías para el acceso a Internet de banda ancha en entornos rurales de Castilla y León. Además, se ha propuesto una política público-privado que consigue hacer atractivo a ojos de los operadores de comunicaciones, el despliegue de redes PON a todos los municipios (incluso los pequeños en áreas de baja densidad de población). Gracias a la utilización de este modelo, el coste que asumirían los operadores para llegar a todas las poblaciones de la provincia de Valladolid (Castilla y León, España) sería el mismo que si lo hiciesen de forma privada solo a poblaciones de más de 200 habitantes. Sin embargo, gracias a ello, se puede atender a todos los habitantes de la provincia (frente al 97.69 % conseguido con el modelo privado) y llegar a todas las localidades (frente al 46.67 % de las localidades con el modelo privado).

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The exchange of ideas between scientists and technicians, from both academic and business areas, is essential in order to ease the development of systems which can meet the demands of today's society. Technology transfer in this field is still a challenge and, for that reason, this type of contributions are notably considered in this compilation. This book brings in discussions and publications concerning the development of innovative techniques of IoT complex problems. The technical program focuses both on high quality and diversity, with contributions in well-established and evolving areas of research. Specifically, 10 chapters were submitted to this book. The editors particularly encouraged and welcomed contributions on AI and distributed computing in IoT applications. The editors are specially grateful for the funding supporting by the project "Virtual-Ledgers-Tecnologías DLT/Blockchain y Cripto-IOT sobre organizaciones virtuales de agentes ligeros y su aplicación en la eficiencia en el transporte de última milla", ID SA267P18, financed by regional government of Castilla y León and FEDER funds.

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