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Building a Sustainable, Energy-Efficient, and Secure European University using LoRaWAN: Protect your Digital Ecosystem and Enjoy!

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Abstract

This paper sheds light on integrating LoRaWAN technology—a Long-Range and Low-Power, wide-area networking protocol—within the Aristotle University of Thessaloniki (AUTh) to create a sustainable, energy-efficient, secure European multi-campus university ecosystem. The AUTh project advances asset management (especially the AV & IT) and surveillance practices through the IoT with LoRaWAN. This research articulates the project's lifecycle from design to operation, highlighting energy and cost savings alongside enhanced coverage. It emphasizes the system's scalability, with plans to extend the network across five campuses. AUTh showcases the substantial impact and positive outcomes such as increased safety, improved resource management, and alignment with European intelligent and eco-green standards for all HEIs. On the other hand, this case study provides detailed insights into the challenges, solutions, and best practices encountered, serving as a blueprint for educational institutions seeking to employ IoT technologies for enhanced asset management, security, and efficiency. Lastly, this study highlights the transformative impact of the project and, generally, LoRa technology in creating a connected, intelligent educational environment, setting a new standard for IoT applications in Higher Education inside and outside of Europe.

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1 Introduction

In the post-COVID era, the Aristotle University of Thessaloniki continues to pioneer IT Projects (Roussos et al., 2023) in Higher Education, advancing a project that employs IoT technologies for enhanced asset management and surveillance. By completing successfully a project integrating LoRaWAN—a cutting-edge, low-power, wide-area networking protocol—AUTh aims to facilitate real-time localization and monitoring of the high-cost Audio-Visual (AV) and Information Technology (IT) equipment across its campus.

Integrating LoRa[‡] technology in a European university (LoRa Alliance, 2021) offers profound benefits, enabling access to sophisticated tools and applications. This initiative responds to the ongoing need for advanced asset management solutions and a strategic move towards operational excellence and energy efficiency. The project's design is meticulously crafted to deliver an ecosystem that minimizes energy consumption and management overhead while providing robust coverage that transcends the limitations of traditional Wi-Fi networks. It underscores a commitment to extend the digital infrastructure to the farthest corners of the campus, ensuring that no asset is beyond the watchful eye of the network.

Beyond immediate utility, the AUTh project is built with scalability in mind—like most projects by the IT Center (Roussos et al., 2023)—paving the way for future expansion that could integrate with city-wide or national IoT networks. This foresight positions the university as a pioneer in the application of IoT within the educational sector, setting a benchmark for others to follow. As an introduction to our research, this paper will delve into the intricacies of deploying such a system, the challenges overcome, and the innovative solutions employed to realize a state-of-the-art asset management system (Hashim et al., 2021). Last but not least, this large-scale project (from design to final installation and testing) supported and continues to support educational goals both internally, through interdisciplinary learning between the different departments of the IT Center, encouraging exposure to different perspectives, as well as an institutional level, providing students with a live use case to get hands-on experience in LoRaWAN networks and data collection/data analysis. This approach not only enhances the utility and high impact of the project but also enhances the educational experience involved in these fields of research and study, offering students and faculty the opportunity to engage with cutting-edge technology in a real-world context.

2 Ensuring Protection and Security in a Digital Ecosystem Using LoRa Technology

The LoRa technology emerges as a crucial innovation, filling the gaps left by cellular, Wi-Fi, and Bluetooth Low Energy (BLE) networks, often constrained by their high power demands, limited range, and poor penetration in challenging indoor environments (Noreen et al., 2017). Its adaptability makes it ideal for many applications, ranging from urban to rural settings, encompassing intelligent cities, homes, buildings, agriculture, metering, and supply chain logistics (Devalal & Karthikeyan, 2018).

2.1 Why – The Need, Importance, and Benefits

Academic institutions are repositories of sensitive information and expensive equipment, making them prime targets for threats. Utilizing LoRa's low-power, long-range communication capabilities

[‡] LoRaWAN was officially approved as a standard by the International Telecommunication Union (ITU), the United Nations specialized agency for information and communication technologies (ICTs). The standard is titled Recommendation ITU-T Y.4480 "Low power protocol for wide area wireless networks" (LoRa Alliance, 2021)

allows for efficient, real-time monitoring and management of security devices without requiring extensive infrastructure or high operational costs. LoRa technology's utility is underpinned by several key attributes. Its long-range capability ensures connectivity over vast distances, reaching up to 50km in rural environments and penetrating dense or indoor urban areas. The low power requirement is another hallmark, significantly extending battery life and reducing replacement costs. Security is noticed, with end-to-end AES 128 encryption ensuring data integrity and confidentiality. The standardized nature of LoRaWAN networks facilitates device interoperability and enables swift global deployment of IoT applications. Additionally, its capacity for geolocation without GPS and its ability to maintain communication with mobile devices further enhance its application potential. The high message capacity per base station caters to extensive market needs while maintaining low operational costs (Cheng et al., 2018); (Augustin et al., 2016).

2.2 When – A 24/7 Intelligent Infrastructure

Deploying a LoRa network in an innovative European university is an ongoing, growing intelligent infrastructure that operates continuously. This uninterrupted service is a challenging tech step that consists of diverse smart IoT devices that establish a 24/7 intelligent infrastructure crucial for continuous security monitoring and robust digital ecosystem protection. This architecture's always-on functionality is vital for sustaining advanced data integrity and safety across campuses, characterized by its long-range communication capabilities and low power requirements, marking a new era for university security systems in the digital landscape (Gkamas, 2021); (Jaffar et al., 2020). This architecture is similar to the smartphone-based tracking systems, which use the 5G network and function by sending periodic signals to a monitoring system (Roussos & Nicopolitidis, 2023). The primary distinction is that LoRaWAN is better suited for applications requiring long-range communication of small messages without audio/video, with minimal energy consumption.

2.3 Where – Application Areas

LoRa technology's versatility technologically shines through its wide-ranging applications, from enhancing urban planning and smart agriculture to improving energy efficiency in buildings and streamlining supply chains (Augustin et al., 2016); (Chedaod et al., 2020); (Sanchez-Iborra et al., 2018). However, another beneficial application of this technology is in the educational sector. LoRa technology implementation within a university's digital ecosystem should prioritize coverage in areas critical for information security and operational efficiency, including data centers, offices, research labs, classrooms, and other areas where sensitive information is stored or transmitted, especially in high-cost devices like AR/ VR / IT / AV (Bouras et al., 2019); (Roussos et al., 2022). By extending LoRa's reach to remote campus areas not covered by traditional networks, universities can create a more comprehensive and secure network infrastructure, integrating connectivity into everyday operations and paving the way for a seamlessly connected future, avoiding the most common risks and threats (Gkamas, 2021); (Pocero et al., 2019); (Fargas & Petersen, 2017).

3 A Case Study: Implementing LoRa in the AUTh's Digital Ecosystem

The Aristotle University of Thessaloniki, one of Europe's leading educational institutions (Roussos et al., 2023), has launched a ground-breaking project to protect[§] and manage its assets through an

[§] The project as a proposal was initially designed and presented in early 2020 and completed in 2023 due to the pandemic advanced IoT network. This initiative positions AUTh as a pioneer among European universities, potentially the first to implement such a comprehensive IoT-driven asset management system at this scale. At the heart of this endeavor is deploying LoRaWAN technology, creating a real-time tracking system for monitoring AV and IT equipment.

3.1 Before Project: Rejected Technologies - Selection of LoRaWAN

Several ideas were explored during the project's planning phase but ultimately discarded. For instance, we examined the use of RFIDs for asset tracking; however, their shorter range and the necessity for close proximity scanning led to the selection of LoRaWAN, which offered broader coverage. Additionally, integrating Wi-Fi-based tracking was tested but rejected due to its high power consumption and infrastructure demands, which conflicted with our sustainability goals. We also examined the scenario of using ultrasonic sensors for indoor positioning, which provided high accuracy but were limited by their complex installation and maintenance requirements. These experiences underscore the importance of aligning technology choices with operational practicalities and project objectives, providing valuable insights for other institutions considering similar implementations.

3.2 Project's Technical and Organizational Prerequisites

Successful implementation required factors that must be considered by other institutions planning similar deployments. To deploy an IoT-based project like this, institutions should at least adhere to the following six essential prerequisites:

1. the existence of fully digitized buildings and floor plans, all integrated into an interactive mapping system;
2. a reliable campus-wide network and a robust IT infrastructure capable of supporting extensive LoRaWAN communications for seamless interaction between myriad devices distributed across vast areas. For optimal performance, the antenna should be positioned at a high point (at least 30m) to minimize obstructions and maintain a clear line-of-sight to the sensors, avoiding signal attenuation caused by buildings or trees.
3. a detailed and comprehensive project plan, including robust initial design and defined timelines to ensure alignment with institutional goals;
4. an accurate and extensive knowledge of the targeted assets, including a complete inventory, cost assessment, and mapping of all IT and AV equipment intended for monitoring;
5. a well-established organizational structure with clear responsibilities and committed stakeholder engagement to guarantee effective implementation and ongoing management;
6. adequate financial resources for initial setup, continual system maintenance, scalability, and proactive strategies for addressing potential IoT security vulnerabilities.

3.3 Project Overview: Enhancing Asset Management with LoRaWAN for Real-Time AV & IT Equipment Tracking

The Aristotle University's IT Center has spearheaded this project, reflecting its commitment to safeguarding its infrastructure and embracing a cutting-edge digital ecosystem. This implementation is being rolled out across AUTh's main campus and the Thermi Campus with plans to expand to another two or three campuses and other university sites, transforming it step-by-step into a multi-campus project.

In practice, the IT Center of AUTh has strategically installed an extensive array of BLE beacons, trackers, and LoRa gateways throughout the campuses. The precise numbers and locations of these devices are confidential, respecting the security protocols of the institution. However, it is essential to note that these devices are not limited to tracking capabilities; they are also equipped with sensors that measure environmental variables such as temperature and humidity, setting the stage for future sustainability and environmental monitoring applications. This comprehensive deployment underscores the necessity of meticulous, intelligent project planning and the establishment of clear, defined goals to ensure the success and effectiveness of such a sophisticated system.

Therefore, many goals were at the forefront of this project, each carefully selected to ensure the system's effectiveness in different aspects, including asset security, operational efficiency, technological integration, emergency response, and the broader vision of transforming the university into a leading digital academic ecosystem. Specifically, there were six principals as follows:

1. Protection and Security in a Digital Ecosystem: Ensuring the utmost protection and security of assets within AUTh's digital academic ecosystem, thereby fostering a safe and secure environment for learning and research and leveraging the data collected through the IoT system to inform strategic decisions and policies within the university. This goal utilizes real-time and historical data to improve campus operations, resource allocation, and emergency response strategies.
2. Real-Time Asset Localization: Implementing a system capable of providing precise, real-time locations for AV and IT equipment across multiple campuses, enhancing security and reducing the risk of loss.
3. Seamless Network Integration: Establishing a robust network capable of integrating LoRaWAN and Global Positioning System (GPS) technologies to maintain asset tracking both on-campus and in transit, ensuring continuous monitoring.
4. Sustainability and Efficiency: Designing a system with long-lasting battery life to minimize maintenance, reduce environmental impact, and streamline university operations.
5. Project Compatibility and Integration: Ensuring the LoRa system is fully functional, compatible, and can be integrated with other university initiatives, such as the AUTh's Panic Button project. This compatibility aims to enhance campus safety by preventing emergencies and safeguarding lives when university members are in danger.
6. Scalability and Adaptability: Creating an adequate infrastructure for current needs and flexible enough to incorporate future technological advancements and additional functionalities, such as environmental sensing and cultural heritage preservation.

3.4 Project Design: From Zero to One-Hundred

From defining processes and requirements to promoting the reliable performance of IoT and AV systems, standards can ensure a highly efficient outcome. To secure and efficiently manage its vast array of AV and IT equipment, the Aristotle University of Thessaloniki has set out to implement an IoT asset management system that is as pioneering as it is expansive. The initiative's overarching goal is to revolutionize asset tracking and security across its multiple campuses, harnessing the power of LoRaWAN technology for real-time equipment localization (Figure 1).

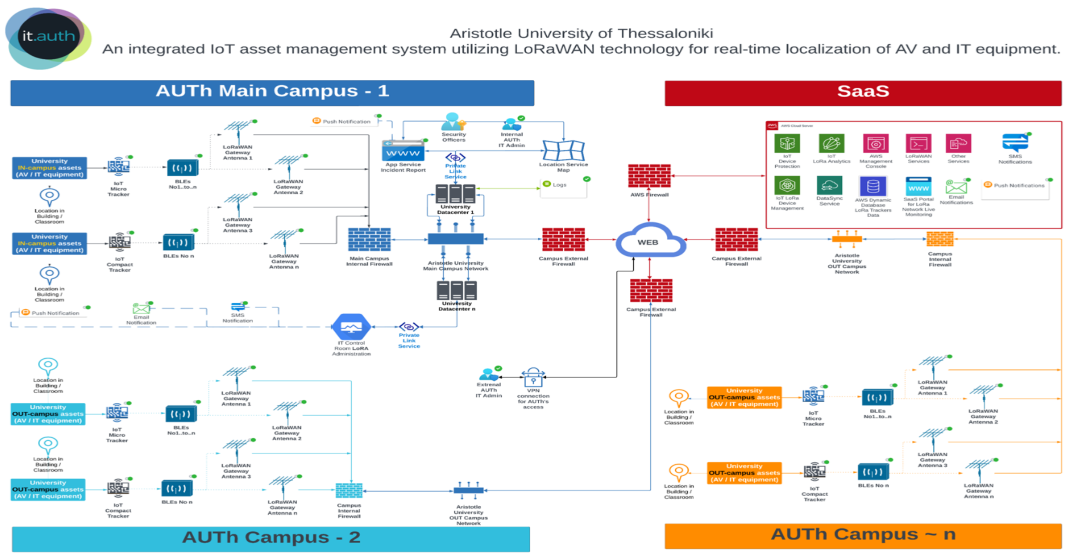

Figure 1 – Flowchart: A detailed view of AUTh's LoRaWAN project

This endeavor is about protecting and fostering an intelligent campus environment where technology and educational infrastructure merge seamlessly, as shown in the following figure, which is a way to give a graphic overview of the project.

Trackers, strategically placed throughout AUTh's premises, gather signals from BLE beacons to pinpoint the exact location of each asset within the diverse array of buildings and classrooms that span over 430,000 square meters of in-campus space. The captured data travels through a secure network, fortified by robust firewalls to preserve data integrity and protect against potential cyber threats.

The LoRaWAN network administration, centered at the university's IT Center combining Software as a Service (SaaS) and on-premises infrastructure, provides comprehensive oversight of asset statuses. Through secure VPN connections, IT administrators ensure system integrity and remote manageability. The network's fusion with SaaS platforms enhances incident reporting and asset management, all accessible via a streamlined web interface. AWS services underpin the system with robust data analytics, storage, and vigilant network monitoring. Immediate alerts are dispatched to security and university staff, enabling swift action when necessary. This initiative reflects AUTH's dedication to its vast educational community, encompassing over 90,235 students and 2,500 faculty members, highlighting the project's extensive impact (AUTh, 2024).

In addition, the system protects assets and is future-ready, equipped to integrate new sensors and trackers. It stands as a model for growth and flexibility, expanding with the university's needs. Coverage extends from bustling academic centers to remote campus areas, ensuring all assets are monitored. Implementing this plan involved setting up multiple BLE beacons and trackers linked to over six LoRaWan gateways to secure wide-ranging connectivity and real-time data transmission.

3.5 Project Challenges: Navigating Complexities Across Campuses

This chapter discusses the challenges encountered and addressed during the project implementation across different campuses. The implementation of AUTh's asset management system was a monumental task. A comprehensive study laid the foundation for a design meeting national and European legislative standards. The project demanded extensive clarification, documentation, and a rigorous approval process involving multiple university departments and public bodies.

Testing the LoRaWAN spectrum and ensuring campus-wide coverage required meticulous planning and execution (Figure 2). Interdisciplinary teams, including IT professionals, network engineers, programmers, civil and electrical engineers, and project managers, collaborated to bring this project to fruition. Each piece of equipment underwent thorough testing and cataloging before installation.

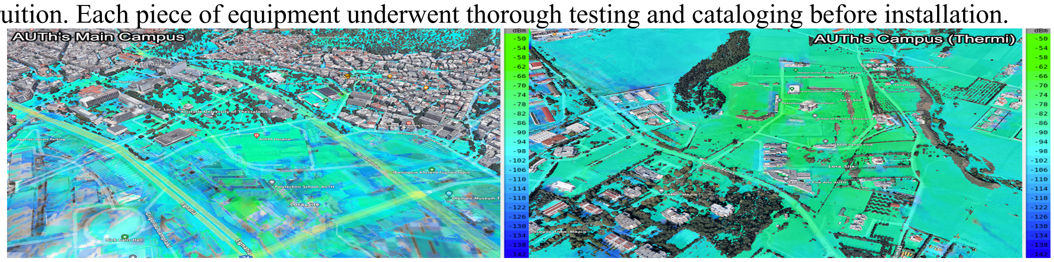

Figure 2 – Metering and Testing LoRaWAN spectrum at AUTh's city center and Thermi Campus

Moreover, another challenging part of the project was the installation phase, which saw antennas and IoT devices fitted across numerous buildings, floors, and halls, demanding countless connectivity and performance checks. Ensuring minimal energy consumption while maintaining optimal operation added another layer of complexity. Additionally, the university's security personnel required comprehensive training to manage the new system effectively. Some unforeseen issues were also software bugs within the tracking interface, which were mitigated through collaborative troubleshooting efforts between our IT team and the software providers. Also, the IT staff has tasked with handling hardware additions, and repairs, ensuring minimal downtime and efficient resource utilization.

3.6 The Project at a Low Level: The Procedure

The procedure begins with BLE beacons strategically placed throughout the area of interest. Each beacon emits a signal that contains a unique identifier known as a UUID (Universally Unique Identifier). These identifiers are designed to be distinct to each beacon, which is critical for distinguishing among multiple assets.

Trackers equipped with BLE technology scan for these beacon signals. Upon detecting a signal, a tracker captures the beacon's UUID, and this is the identification phase where the tracker recognizes which item it is in proximity to by the unique UUID it receives. Once the UUID is obtained, the tracker engages in the transmission phase. It leverages LoRaWAN technology, renowned for its long-range and low-power characteristics, to transmit the received UUID. This transmission is directed towards gateways that are part of the LoRaWAN infrastructure.

The gateways are the network's reception points that receive messages from multiple trackers. Upon receiving a LoRaWAN message containing the UUID relayed by the tracker, the gateway forwards this data to a centralized server. Then, the server represents the analytical brain of the operation. It has access to the location data of all the BLE beacons within the network. Using this data and the UUID from the gateways, the server employs algorithms to 'solve' the tracker's location. Finally, this is the computation phase, where the actual location of the asset is determined.

Upon successfully locating the item, the server then executes the notification phase. It informs the relevant university authorities or systems about the location of the asset. This is possible through the integrated SaaS management platform, the incident reporting system like the AUTh Incidents Reporting Portal (AUTh IRP), or other designated monitoring interfaces like the AUTh LoRa Dashboard for IoT Devices (AUTh LDIoT) since AUTh actively makes use of SaaS (Roussos et al., 2023). This procedure effectively combines BLE's proximity-based tracking capabilities with LoRaWAN's long-range network infrastructure to create a robust system for real-time asset location.

Moreover, the trackers exhibit an advanced failover feature to ensure continuous monitoring. When an asset equipped with a LoRa tracker moves beyond the campus boundaries, where LoRaWAN coverage may not be available, the tracker seamlessly transitions to GPS mode**. This functionality ensures that the asset remains within the monitoring purview of the university's tracking system. The system detects when an asset is being moved off-campus; at this point, the tracker activates its GPS functionality to transmit real-time location data back to the monitoring application. This dual-mode operation significantly enhances the robustness of the asset management system. Such a system is invaluable for asset management, security, and operational efficiency in various settings.

Last but not least, the energy longevity of the devices is noteworthy, with micro trackers boasting a battery life of up to three years and compact trackers extending that duration to five years. This durability is essential for maintaining a low-maintenance tracking infrastructure and ensures sustained operation without frequent battery replacements. This blend of extended battery life and dual-technology tracking positions the university at the leading edge of asset management and security within the academic sector.

3.7 The Project at a High Level: The Monitoring

The following screenshot (Figure 3) shows a web interface from a LoRaWAN network server's administration panel, the LDIoT.

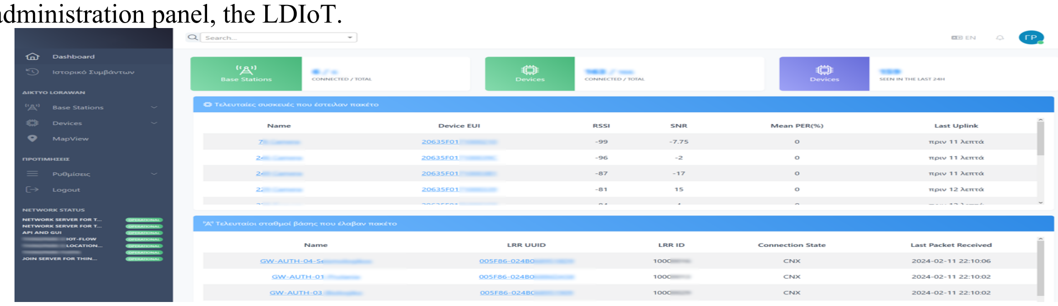

Figure 3 – Web interface of the of active devices in LDIoT (AUTh LoRa Dashboard for IoT Devices)

It features a dashboard providing an overview of connected devices and base stations. The dashboard displays device names, their unique identifiers (Device EUI), signal strength (RSSI), signal-to-noise ratio (SNR), packet error rate (Mean PER%), and the time of the last uplink.

The network status is on the left sidebar, indicating operational servers and interfaces. Some sensitive information has been blurred out to protect data privacy. In addition, the following screenshot (Figure 4) presents a map view from the same administration panel.

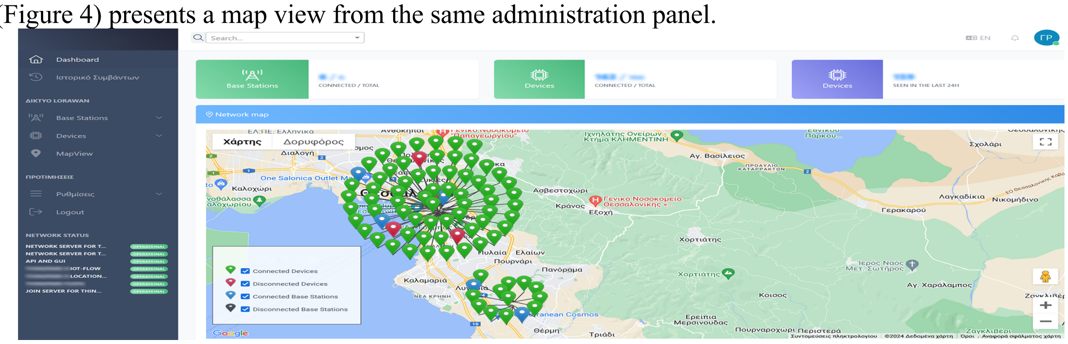

Figure 4 – Map view of the Web interface of the LDIoT (AUTh LoRa Dashboard for IoT Devices)

** For instance, if a high-cost device is slightly moved (minimal rotation of a few degrees) or subjected to significant vibration, an immediate signal is sent to the central monitoring system, indicating that the device has been disturbed. Should the device continue to move, it sends periodic updates every few seconds, maintaining constant communication about its status

It illustrates the geographical distribution of devices (representing IoT sensors or trackers) and base stations across a specific area, as indicated by the clustering of markers. Green markers also represent connected devices, and red markers represent disconnected ones. This map provides a real-time overview of network coverage and device status. Similar to the first image, specific data has been blurred to maintain confidentiality. Finally, AUTh's Incidents Reporting Portal (IRP) showcases the real-time positioning of IoT devices across the campus (Figure 5).

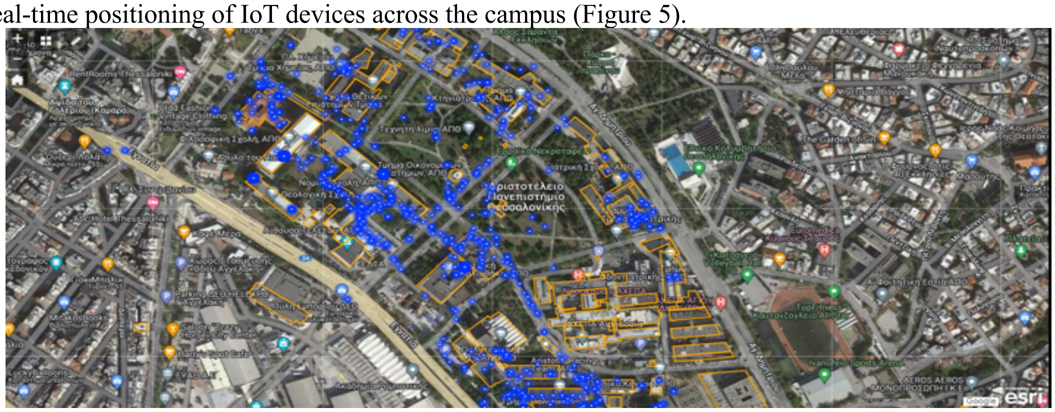

Figure 5 – Enhancing Campus Security: Integrating LoRa Technology into AUTh's IRP

3.8 Best Practices: Tackling Technical, Administrative, and Financial Challenges with Innovative Solutions

In deploying its IoT asset management system, the IT Center of Aristotle University of Thessaloniki adopted innovative solutions to overcome technical, administrative, and financial challenges. Adopting LoRaWAN technology was pivotal for the future of the university ecosystem, providing a cost-effective method for long-range communication with low power requirements, thereby addressing technical constraints. The project has adhered to best practices in project management, precisely scope, time, cost, and energy management, utilizing iterative and internal control processes. Since ITC is responsible for all the above, rules about management were settled.

Regarding the administrative part, many IT and Engineering science processes were also utilized to integrate and finally build a system for over a thousand IoT devices. This integrated method ensured that each device was efficiently incorporated into the system, aligning with the project's meticulous planning. Also, administratively, AUTh navigated the complexities of regulatory compliance and internal governance with a proactive approach, establishing clear protocols for obtaining necessary approvals, and our law and IT field science was required.

Regarding financial considerations, these were strategically managed through careful budgeting and cost-saving measures. Competitive procurement processes were used to maximize the value of financial investments in new technologies.

The technical installation involved comprehensive testing to guarantee extensive coverage, while the system's design focused on modularity and scalability. This foresight allows for future expansions and technological updates without requiring extensive modifications. As a model of best practices, AUTh's project is an exemplar for educational institutions embarking on similar technological endeavors.

4 Impact and Results

The Aristotle University of Thessaloniki's case for IoT asset management as an initiative for an innovative project leveraging LoRa technology and GPS tracking has redefined asset protection and operational innovation in academia. This endeavor secures the AV and IT equipment and lays the groundwork for future applications like cultural heritage preservation and protection, temperature monitoring, and other tech-efficient eco-green practices. The following table (Table 1) summarizes the impact and result according to Aristotle University's objectives and priorities for this project. These outcomes highlight the system's effectiveness and underscore its potential adaptability to other educational institutions seeking similar enhancements in asset management for educational spaces, whether we talk about single or multi-campus areas.

Project Objectives and Priorities	**Impact - Results**
Ed-Tech Approach, Pedagogy, Feedback	Improving data security and providing financial benefits to the university. Aligning with EU funding objectives for educational technology. Promoting respect for public supplies and promoting learning. Installing state-of-the-art AV and IT equipment in faculties leads to positive student and teaching staff feedback on technology use. Enhancing educational content with multimedia resources for student instruction.
Creativity, Innovation, Imagination	Introducing multi-campus IoT solutions, showcasing scalability. Expanding the university's technological horizon. Embodying a long-term vision for innovative university ecosystems. Pioneering creative problem-solving in asset management. Gaining recognition for innovative security approaches.
Advantages, Benefits, Rewards	Demonstrating cost and energy savings and improved asset utilization. Enhancing campus safety with real-time monitoring. Increasing the sense of safety among students and staff. Decreasing incident response times through real-time alerts. Receiving positive feedback from the HE community and National or European public sectors, including the government. Using eco-green practices aligns with EU standards for smart EU cities and sustainable EU campuses. Low overall campus crime rates regarding AV/IT equipment theft.
Sharing, Adoption, Transferability	Sharing knowledge and practices with other institutions Demonstrating versatility for different campus or multi-campus environments. Encouraging broader adoption of IoT standards.
Research, Collaboration, Synergy,	Engaging the public sector in collaborative smart city projects Boosting community awareness and involvement in campus security. Fostering a culture of shared research and development Encouraging student and staff participation in IoT initiatives.
Technology, Efficiency, Security, EU Comply	Utilizing LoRa for efficient campus-wide coverage and providing standards for data protection in the HE sector - Applying also AES 128-bit encryption Implementing SaaS solutions for efficient data management and showcasing the added value of SaaS in educational settings. Ensuring GDPR compliance in all data handling processes. Receiving positive audits on data management practices.

Table 1 - AUTh's Project Goals, Impact and Results

Moving on from the broader impacts and outcomes outlined in Table 1, we highlight a pivotal area of influence. From an educational perspective, involving both students and professors, one of the most crucial effects of this project is its tangible support of the educational process. The system fosters a more reliable and efficient learning environment by protecting/securing essential teaching resources, primarily AV equipment, as shown in (Figure 6), and ensuring their availability in educational spaces even under unexpected situations (theft attempt/loss/intentional damage).

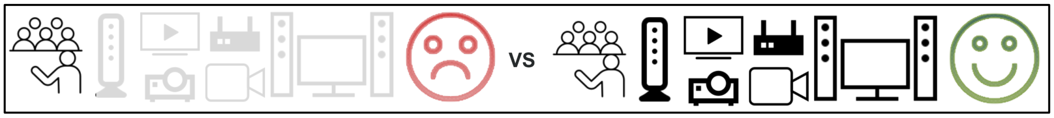

Figure 6 - The LoRaWAN project ensures an uninterrupted in-person/hybrid/virtual educational experience by empowering the availability of educational resources.

5 Discussion

This paper has highlighted the successful integration of the LoRaWan IoT asset management system across two AUTh campuses. The university plans to expand this project significantly, extending its reach to three additional campuses. This expansion will lead to a multi-campus system spanning five locations. This future step illustrates the project's scalability and success and AUTh's forward-thinking approach to leveraging technology efficiently across its digital ecosystem.

In conclusion, AUTh's project sets a new precedent for technological innovation in the HE and sets a positive example of a real case for other institutions. Through this initiative, AUTh demonstrates its capability to protect and manage its resources and its foresight in embracing the potential of IoT to create an interconnected, intelligent campus for the future. Finally, as a pioneering project in education, it underscores the university's leadership in smart multi-campus solutions, establishing AUTh as one of the biggest frontrunners in technological innovation within the Higher Education sector.

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