# Portfolio

## Innovative Smart System

**VASSEUR Cyril**
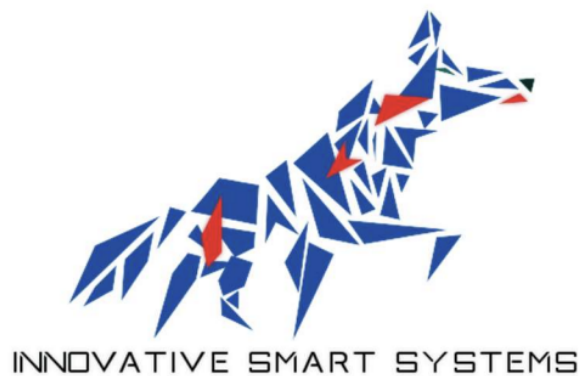

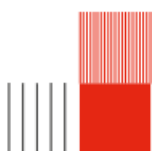
INNOVATIVE SMART SYSTEMS

**Institut National des Sciences Appliquées de Toulouse**

January 6, 2025

**Abstract**

This portfolio was prepared as part of the second year of a Master's program in Innovative Smart Systems (ISS) at INSA Toulouse. Its purpose is to provide a comprehensive overview of my academic year, detailing the skills and knowledge I gained, along with my reflections on each course taken during the program. Within this portfolio, you'll find summaries of each course, including insights on the topics covered and my personal assessments. Additionally, it includes reports from practical sessions (laboratory work) and project-based exercises that allowed me to apply theoretical concepts in real-world contexts.
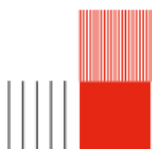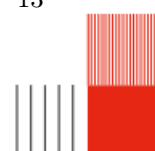
# Table of contents

# Chapter 1   : Introduction

Dans le cadre de ma 5 ème Annéeà l'INSA Toulouse, j'ai eu l'occasion de me spécialisé dans le domaine de l'innovative smart system. Dans la première partie vous retrouverez des informations sur ma scolarité, ainsi que mon CV qui vous informerons un peu mieux sur qui je suis.
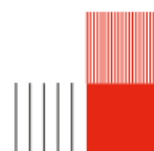
# Chapter 2  : General Information

## 2.1. Presentation of MS Innovative Smart System

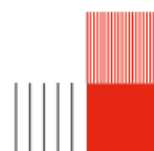The **Internet of Things (IoT)** is expected to grow rapidly in the coming years. Often described as the fourth industrial revolution, IoT is a promising field, with over 20 billion smart devices projected to be connected by 2020. However, achieving this scale will involve overcoming several challenges at multiple levels.

The **Innovative Smart Systems Master's Program** aims to prepare young engineers to understand and tackle these challenges by developing innovative solutions. IoT systems consist of multiple layers, each with its own focus:

- Perceptual Layer

- Network Layer

- Support Layer

- Application Layer

Each of these layers has specific challenges, addressed by different training units in the program:

- Designing smart devices: *Smart Devices Training Unit*

- Connecting devices: *Communication Training Unit*

- Processing data within the network: *Data Processing Training Unit*

- Providing services for network interaction and data access: *Middleware and Services Training Unit*

This master's program addresses these challenges through a variety of courses, bringing together students from diverse fields, including Electronics, Telecommunications, Computer Science, and Physics. By combining these skills, students can collaborate to solve the complex problems involved in developing IoT networks and systems.
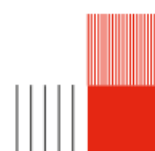
## 2.2. Curriculum

### 2.2.1. Student Profile

**Personal information :**
Surname: VASSEUR.
First name: Cyril.
email: vasseu@insa-toulouse.fr.

### 2.2.2. Curriculum Vitae



**Figure 2.1:** Curriculum Vitae
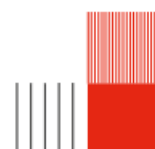
### 2.2.3. Background

Before entering INSA for my third year of higher education, I completed a two-year technical diploma (DUT) in Electrical Engineering and Industrial Computing at IUT of Béthune. I then pursued an engineering degree at INSA Toulouse, where I began a Master's in Automation and Electronics through an apprenticeship program. My first year was spent with Plastic Omnium, where I worked on developing a test bench for heavy vehicle batteries used in trains and trucks. For my second year, I moved to Thales Alenia Space, drawn by my interest in the space sector, where I became a software apprentice specializing in satellite navigation. After completing my Master's, I continued at Thales Alenia Space to pursue my second Master's in Innovative Smart Systems (ISS).

## 2.3. Training units

Below, you can find the overview of the various courses completed in the ISS program.

| | AE | Evaluation method |
|---|---|---|
| Discover methods to validate and prioritize innovations and market targets | 3 | portfolio |
| Know the points to work to offer value and build a good business model | 3 | portfolio |
| Define if an idea is patentable and carry out a search of anteriority | 3 | portfolio |
| Define your financing tool according to your needs and adapt | 3 | portfolio |
| set goals in line with your means, discover and select digital and traditional commercial actions | 3 | portfolio |
| recuit, manage and organise a startup | 3 | portfolio |
| make a pitch | 3 | presentation |

**Figure 2.2:** Business Startup Unit

| Software Engineering | AE | Evaluation method |
|---|---|---|
| Define the different phases in software development | 3 | Project |
| know the different project management methods | 3 | Project |
| Apply one of these methods a project | 3 | Project |
| | | |
| Processing Semantic Data | AE | Evaluation method |
| design and understand a model for an application | 3 | TP Report |
| Know how to infer new knowlegde from a knowledge base | 3 | TP Report |
| Be able to enrich data with semantic meta-data | 3 | TP Report |
| | | |
| Data Processing and Analysis: Big Data | AE | Evaluation method |
| Know how to explore and represent data sets | 3 | TP Report |
| Master R | 3 | TP Report |
| Master complexity associated to statistical data processing and know the techniques to be used to minimise them | 3 | TP Report |

**Figure 2.3:** Analysis and data processing, business applications Unit

| Protocols and communication | AE | Evaluation method |
|---|---|---|
| Understand the major development phases for mobile communications and development of the associated technology | 4 | |
| Understand the impact of new mobile technology | 4 | |
| Be able to analyse and evaluate optimal wireless network technologies | 4 | |
| Be able to suggest optimal technological solutions for IoT networks | 4 | |
| Understand and master optimisation of communication protocols for IoT with respect to energy limitations | 4 | |
| Understand and master optimisation of communication protocols with respect to security concerns | 4 | |
| Know the main processing techniques used for digital communication and know how to explain the basic structure of digital | 4 | |
| Mastering the architecture of an energy management system, simple storage, energy recovery, know how to size the storage el | 4 | |
| | | |
| Security for IoT networks | AE | Evaluation method |
| Understand the fundamentals of security | 4 | TP Report |
| Be able to identify security weaknesses in an IoT architecture | 3 | TP Report |
| Be able to assess the impact of exploiting a security vulnerability in an IoT architecture | 3 | TP Report |
| Be able to propose adequate security counter-measures | 3 | TP Report |

**Figure 2.4:** Communication Unit
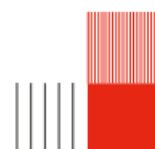
| Manage an innovative project: | AE | Evaluation method |
|---|---|---|
| Solve a problem in a creative way | 4 | |
| Develop the first stage of innovation | 4 | |
| Understand production, validation, distribution, acceptability, and aftermath of innovation | 4 | |
| structure and lead an innovative project | 4 | |
| | | |
| Learn teamwork | AE | Evaluation method |
| Multi-disciplinary students work as a team | 4 | |
| | | |
| Be convincing: present and defend an idea | AE | Evaluation method |
| express and exchange hypotheses | 4 | |
| Suggest a strategy to solve the problem identified | 4 | |
| Suggest a model | 4 | |
| choose, design and / or justify a protocol or an experimental prototype | 4 | |
| | | |
| self evaluation with portfolio | AE | Evaluation method |
| Reflect upon my training process and methods | 4 | report/WEB |
| Be able to put forward my training experiences, whether they be explicit or implicit | 4 | report/web |
| Be self-sufficient and responsible towards my education | 4 | report/WEB |

**Figure 2.5:** Innovation and humanity Unit

| | AE | Evaluation method |
|---|---|---|
| Analyse a real-life problem | 4 | report/presentation |
| Suggest a technological solution to a problem | 4 | report/presentation |
| Implement a prototype to solve the problem | 4 | prototype |
| Present and debate (in English) the technical choice made | 4 | presentation |
| Produce a report (in English) for the developed project | 4 | report |

**Figure 2.6:** Innovative project Unit

| Service Oriented Architecture | AE | Evaluation method |
|---|---|---|
| Know how to define a Service Oriented Architecture | 4 | Project |
| Deploy an SOA with web services | 4 | Project |
| Deploy and configure an SOA using SOAP | 4 | Project |
| Deploy and configure an SOA using REST | 4 | Project |
| Integrate a process manager in an SOA | 4 | Project |
| | | |
| Middleware for the Internet of Things | AE | Evaluation method |
| Know how to situate the main standards for the Internet of Things | 4 | TP Report |
| Deploy an architecture compliant to an IoT standard and implement a sensor network | 4 | TP Report |
| deploy and configure and IoT architecture using OM2M | 4 | TP Report |
| Interact with the different resources of the architecture using REST services | 4 | TP Report |
| Integrate a new technology into the deployed architecture | 4 | TP Report |
| | | |
| Adaptability: Cloud and Autonomic Computing | AE | Evaluation method |
| Understand the concept of cloud computing | 3 | TP Report |
| Use a IaaS-type cloud service | 3 | TP Report |
| Deploy and adapt a cloud-based platform for IoT | 3 | TP Report |

**Figure 2.7:** Middleware and Service Unit

| Skills | AE | Evaluation method |
|---|---|---|
| Introduction to Sensors | | |
| Understand basic notions of sensors, data acquisition: physics, electronics and metrology point of view | 4 | Exercise of application by project group to be inserted in the portfolio |
| Be able to manufacture a nano-particles sensor using micro-electronics tools: chemical synthesis, assembly, | 4 | Cleanroom training |
| Be able to design the datasheet of the sensor manufactured | 4 | Datasheet inserted in portfolio |
| | | |
| Microcontrollers and Open Source Hardware | | |
| Understand microcontroller archictecture and how to use them | 4 | Portfolio |
| Be able to design data acquisition system (sensor, conditioner, microcontroller) with respect to the application | 4 | Portfolio |
| Be able to design the electronic circuit of a sensor's signal conditioner (design + simulation) | 4 | Portfolio |
| Be able to design a shield to accommodate the gas sensor | 4 | Portfolio |
| Be abe to design the sofware to use the gas sensor and its HMI | 3 | Portfolio |
| Be able to combine all of the above mentioned components into a smart device | 4 | Portfolio |

**Figure 2.8:** Smart devices Unit
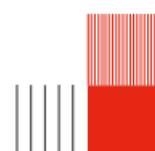
| | AE | Evaluation method |
|---|---|---|
| Knowing the main issues in security for IoT | 3 | report/presentation |
| Understand the terminology of security | 2 | report/presentation |
| Being able to have a critical look at the design of a system from a security point of view | 2 | report/presentation |
| Being able to understand a scientific article that explains a weakness or a security solution and to explain it | 2 | report/presentation |
| | | |
| | | |
| | | |

**Figure 2.9:** Security Unit

## 2.4. Apprenticeship

### 2.4.1. Why did I choose an apprenticeship

During my years at INSA, I chose to pursue an apprenticeship, which is a way to combine academic studies with practical work in a company that finances both the training and the apprentice. This arrangement benefits the company by allowing it to train a future employee in advance so that they are operational immediately upon graduation.

In my first year at INSA, I was employed by Plastic Omnium. The department where I worked had recently been acquired, leading to significant changes in company policies. Consequently, most engineers who had transitioned into the new structure eventually decided to resign, including my former supervisor and my manager. After spending several months in this uncertain environment, I was offered the opportunity to leave the company to seek a more stable situation.

My decision strongly inclined toward Thales Alenia Space (TAS), primarily due to the nature of its activities and its reputation, which I heard about through word of mouth. I applied for several positions and was ultimately accepted for one as a Satellite Navigation Software Apprentice Engineer. I joined TAS in September 2023, allowing me to start the new academic year with peace of mind. I have remained with TAS since then, completing my final year of studies alongside my work with them.

### 2.4.2. My sector of activities with Thales Alenia Space

GNSS systems transmit information about the position and clock bias of each satellite, enabling users to locate themselves in the Earth-centered WGS 84 reference frame. However, the accuracy of GNSS navigation data is only guaranteed for a maximum of six hours, meaning there is a possibility that a satellite may broadcast erroneous positional information. While such errors usually do not affect non-critical systems, GNSS systems are not recommended for life-critical applications, such as guiding aircraft during airport approaches.

To address this limitation, the concept of an augmentation system was introduced. This system has two primary missions. The first is to calculate correction messages that allow aviation users relying on single-frequency GNSS signals to achieve precise localization. The second mission involves real-time monitoring of GNSS navigation data to detect anomalies and alert aviation users within a timeframe compatible with their flight phase.

Given that the requirements of civil aviation often cover extensive areas, using a geostationary satellite emerged as an obvious solution. Such an augmentation system is known as SBAS (Satellite-Based
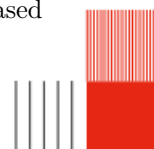
Augmentation System). An SBAS broadcasts a signal containing information about the reliability and accuracy of positioning signals from GPS and Galileo. This signal is designed to be processed by users without requiring major modifications.

The role of an SBAS is to analyze the various elements contributing to measurement errors and then broadcast dedicated augmentation messages containing corrections for each of these elements. User receivers recompose these corrections based on their geographic position, enhancing positioning accuracy and mitigating sources of error related to satellite clocks, positioning, and ionospheric effects.

### 2.4.3. My mission and the final project

My apprenticeship at Thales Alenia Space has been a defining and enriching experience, filled with diverse assignments and stimulating responsibilities. From the beginning, I benefited from a structured onboarding process that allowed me to master the tools and workflows essential to project execution.

Working in a collaborative environment with open spaces that encourage communication and quick problem resolution, I discovered the importance of high-performance equipment. For instance, I worked with a workstation equipped with 92 cores and 256 GB of RAM, which enabled me to run complex simulations, process large datasets, and maintain high levels of efficiency.

Agile methodology was at the heart of my activities, where I participated in daily meetings, sprint planning, and retrospectives. This approach allowed me to efficiently plan tasks and collaborate seamlessly with my team. It was particularly valuable for software development projects, where I used tools like Git to manage project lifecycles—from branch creation to pull requests—ensuring the quality of the produced code.

During this period, I used various programming languages, primarily Python and C. With Python, I developed analysis scripts and optimized existing tools to reduce execution times. I also worked on graphical representations to facilitate result interpretation and improve collaboration. In C, I designed features such as a stack trace to secure program execution, addressing complex issues related to compilation configurations, such as managing warnings and improving code flexibility.

A key mission was ensuring the quality of non-regression tests for SBAS scenarios. I updated outdated configurations and developed simulation scenarios covering diverse use cases. This involved managing massive datasets, ensuring traceability of changes, and maintaining reliable reference outputs. I also worked on enhancing scenario configurability, making the system more adaptable to new requirements.

Additionally, I contributed to resolving over 3,000 warnings during the compilation process—a challenge requiring a structured and collaborative approach. I developed automation tools to classify issues and proposed tailored solutions that balanced efficiency with compliance with company standards. These activities helped me develop a critical perspective and an analytical approach to complex technical problems.

In conclusion, my year at Thales Alenia Space allowed me to solidify my technical skills, immerse myself in a high-tech environment, and make meaningful contributions to the company's projects. This experience motivates me to pursue a career in software engineering, tackling increasingly ambitious challenges.
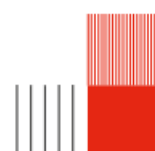
# Chapter 3 : Communication unit

## 3.1. Energy For Connected Oject

### 3.1.1. Overview of the Energy for Connected Objects Course

As part of the Innovative Smart System specialization in the 5th year, the course titled Energy for Connected Objects focuses on energy solutions for connected objects (IoT), addressing innovative techniques such as ambient energy harvesting and wireless energy transfer. The objective of this course is to provide students with an in-depth understanding of modern methods for managing and generating energy for connected objects. These systems are crucial in a context where energy autonomy and sustainability are essential for the development of the Internet of Things.

The course is structured with a combination of lectures and practical work. The four theoretical sessions cover topics ranging from electricity generation and storage to ambient energy harvesting techniques (such as light, vibrations, and electromagnetic fields) and advanced wireless energy transfer methods (including near-field and far-field electromagnetic solutions). These concepts help to understand how to power connected objects wirelessly and without batteries, by exploiting available energy sources in the environment.

The two practical sessions allow students to apply these concepts by designing an emulator for connected objects and characterizing an electromagnetic energy harvesting system. Evaluation is based on a group lab report and an in-depth study of energy autonomy options for an innovative project. This study includes exploring battery-free power supply possibilities, paving the way for sustainable IoT projects. Additionally, the course provides a series of academic resources to further knowledge in energy harvesting and wireless transfer, which are essential for developing efficient and environmentally responsible IoT devices.

### 3.1.2. Technical Foundations of Energy-Autonomous IoT Systems

The technical dimension of this course focuses on two key areas: ambient energy harvesting and wireless energy transfer, with particular attention to practical aspects and technical challenges in designing energy-autonomous IoT systems.

Ambient Energy Harvesting This technique involves capturing energy from the environment and converting it into electricity to power connected objects. Ambient energy sources include:
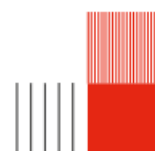
- Light: primarily through photovoltaic cells that capture both solar and artificial light.

- Mechanical (kinetic): using electromagnetic, piezoelectric, or electrostatic transducers capable of converting vibrations or motion into electrical energy.

- Thermal: using thermal transducers like thermoelectric devices, which generate electricity from temperature gradients.

- Electromagnetic: using capacitive and inductive transducers to capture ambient electromagnetic fields.

This approach allows for continuous power, although it depends on the proximity of field sources. Each type of energy harvesting presents challenges related to availability, stability, and energy efficiency. Optimization techniques such as using hybrid transducers or transducer networks (series/parallel topologies) can improve the efficiency of energy collection for low-power IoT devices.

Wireless Energy Transfer This field covers methods that enable the transmission of energy without cables, focusing on powering connected objects via dedicated energy sources, which are often more reliable and predictable than ambient sources. The main wireless energy transfer techniques include:

- Optical (light): using lasers or infrared for long-distance transfers, requiring a direct line of sight.

- Acoustic: using ultrasound, especially for specific applications and short-range transfer.

- Electromagnetic: which is divided into near-field transfer (capacitive or inductive coupling, suitable for short distances with high efficiency) and far-field transfer (radio or microwave waves), enabling longer ranges but typically with lower efficiency.

To maximize the energy efficiency of these wireless systems, devices like rectennas (rectifying antennas) are used, converting RF waves into DC current. Optimal rectenna design involves selecting an appropriate frequency, using impedance matching circuits, and carefully configuring the rectifier to minimize losses. Signal modulation techniques, impedance management, and waveform optimization are essential to reduce energy dissipation and meet the power and autonomy requirements of connected objects.

This course provides a technical understanding of energy management solutions for autonomous IoT systems, covering the design of autonomous sensors, reducing energy consumption, and best practices to optimize the efficiency of energy harvesting and transfer devices. These skills are crucial in the development of sustainable IoT applications, ranging from smart homes to industrial sensor networks.

### 3.1.3. Reflections and Applications of Wireless Energy Transmission

The Energy for Connected Objects course was highly enriching, even though the foundational knowledge was already familiar to most students. The real value lay in connecting various building blocks of knowledge in a coherent and practical way.

Prior to this course, I had never implemented wireless energy transmission in either my personal or professional life. Thanks to the lectures and hands-on practical sessions, I now feel confident in designing
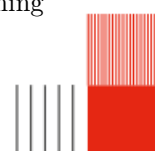
and implementing such systems. The practical exercises were well-aligned with the course content and enabled me to achieve my first successful wireless energy transmission.

While I do not currently plan to work in this specific field, as my professional interests lean more toward software development in the aerospace sector, I can already envision potential applications for this technology. For example, wireless energy transmission could be used within satellites to reduce weight by eliminating cables. However, further research would be needed to determine if this approach is viable in the vacuum of space.

This course provided valuable general knowledge that could be applied to personal projects and opened new opportunities for my future job search.

I will now proceed to self-assess my performance on the key aspects of this course :

- Mastering the architectures of an energy management system, simple storage, energy recovery, know of to size the storage capacity: 4

- understand and Master optimization of Communication protocols for IoT with respect to energy limitations: 4

## 3.2. Wireless Sensor Network

### 3.2.1. Course Structure: Theory, Research, and Practical Work

The course Towards Internet of Things (IoT) and Wireless Sensor Networks (WSN), led by Professor Daniela Dragomirescu, aims to equip students with the necessary skills to design, implement, and deploy wireless sensor and actuator networks. These networks are critical to the development of IoT systems, focusing on aspects such as energy efficiency, robustness, and ease of deployment.

Wireless communication technologies, including GSM, GPRS, EDGE, and UMTS, have paved the way for the emergence of IoT and related systems like WSN, Ambient Intelligence, and Cyber-Physical Systems. This course explores the architectural and operational principles of IoT and WSN, emphasizing:

- Designing energy-efficient systems.

- Developing protocols for enhanced reliability, synchronization, and localization

- Exploring the challenges of real-world deployment, including battery constraints and security.

The course combines theoretical lectures with practical assignments:

- Theoretical Lectures: Cover IoT architecture, challenges in WSN, and cross-layer optimization.

- Research Work : Students worked on group and individual projects analyzing various protocols, such as LoRa, Sigfox, ZigBee, and BLE. Tasks included examining physical and MAC layers, energy consumption, and specific use cases.
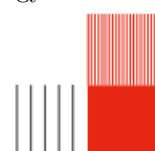
- A pratical work to define the specification and a simulation of hand made MAC protocols with physical layer.

This course bridges academic learning with practical applications, highlighting use cases in fields such as aeronautics, healthcare, and smart infrastructure. It offers insights into the real-world challenges and opportunities presented by IoT technologies, preparing students for diverse professional paths.

### 3.2.2. Energy-Efficient Strategies in Wireless Sensor Networks

The IoT ecosystem integrates sensing, data collection, analysis, and actionable insights. A typical IoT architecture involves:

- Sensors and Actuators: Gather physical data and initiate actions.

- Wireless Communication: Ensures seamless data transfer.

- Internet Connectivity: Enables remote monitoring and control.

- Data Analysis: Derives meaningful insights from collected data.

Wireless Sensor Networks play a pivotal role in this architecture, addressing challenges like energy autonomy, synchronization, and data routing. ne of the major challenges in deploying WSNs is the reliance on batteries. The course introduces energy-harvesting techniques such as solar and thermal harvesting. The main objective witt the energy is to made a energy-efficient erotocols with MAC and routing layers designed to minimize power consumption.

The course delves deeply into protocols optimized for WSN, emphasizing their MAC and physical layers. Key considerations include:

- Synchronization: Ensures data consistency and reduces latency.

- Localization: Provides spatial awareness for sensor nodes.

- Security: Implements measures to safeguard data integrity..

Protocols like ZigBee and BLE were analyzed in assignments for their trade-offs in power consumption, range, and data rates, providing insights into their suitability for different applications. Our groupe has to made research about BLE, you can find our work in the annexe part.

The second assement made a focus on MAC protocols, during our research we gain a better understanding of different type of access: explores several MAC protocols designed for wireless sensor networks (WSN) and the Internet of Things (IoT). Traditional approaches such as FDMA, TDMA, and CDMA divide resources by frequency, time, or codes. While straightforward, they face limitations in synchronization and energy efficiency. Contention-based protocols like CSMA/CA, S-MAC, and T-MAC use mechanisms to avoid collisions, with improvements such as programmed sleep cycles to conserve energy. Energy-optimized protocols, including B-MAC and L-MAC, focus on managing active and passive periods to reduce consumption but are less suited for mobile environments. Advanced protocols like GAF

incorporate location-based management, dividing the network into cells to activate only necessary nodes, optimizing energy while supporting mobility. Each protocol addresses specific needs, from energy stability to flexibility for dynamic IoT applications.

### 3.2.3. Reflections on the Impact of the WSN Course

The WSN (Wireless Sensor Networks) course was one of the most impactful courses of the year for me. It stood out as one of the classes that introduced the most new information and concepts. The workload for this course was notably higher compared to others, largely due to the novelty of the material. However, I found it invaluable, as it significantly enhanced my understanding of the processes involved in information transfer.

This course was particularly important because it served as a central pillar for the year, especially within the communication module. The knowledge gained here was directly applied in other courses, such as those on 3G to 6G technologies and energy systems. It also played a key role in the Innovative Project, which was multidisciplinary in nature and required a synthesis of skills and knowledge from various domains.

The assignments and deliverables were especially critical, and active participation during lectures was essential for grasping and applying the course concepts effectively.

Although I have not yet had the opportunity to apply the knowledge gained in a professional setting due to the software-focused nature of my apprenticeship I recognize the immense potential of WSN protocols. While I plan to continue in the software field, I believe exploring WSN applications after my studies could open up exciting opportunities given the vast range of possibilities these technologies offer.

I will now proceed with my self-assessment.

- Be able to analyse and evaluate optimal wireless network technologies: 4

- Be able to suggest optimal technological solutions for IoT networks: 3

- Know the main processing techniques used for digital communication and know how to explain the basic Structure of digital: 4

- Understand and master optimisation of communication protocols with respect to security concerns: 3

## 3.3. 5G technologies

### 3.3.1. Evolution of Mobile Networks: From 3G to 6G

The course titled "From 3G to 6G," taught by Professor Étienne Sicard at INSA Toulouse, delves into the evolution of mobile technologies, from their inception to the cutting-edge advancements shaping the future. Aimed at fifth-year students, this course provides a comprehensive understanding of the technical,
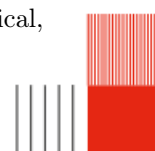
economic, and environmental aspects of mobile networks. It highlights the major technological transitions that have defined each generation and explores innovations paving the way toward the 6G era.

The course covers several key themes. The first section focuses on the miniaturization of electronic components, discussing advances in transistor design, including the shift from traditional MOSFETs to modern architectures like FinFETs and Nano-Sheet FETs. This evolution is framed within the broader context of the global transformation of the electronics industry and its impact on mobile network performance.

The second section revisits the history of mobile generations, from 3G to 6G, emphasizing key technological milestones and applications associated with each era. The 3G era, marked by the introduction of UMTS, was pivotal in enabling mobile data services. Subsequently, 4G introduced LTE, revolutionizing multimedia applications by providing significantly higher bandwidth. The 5G era brought the integration of the Internet of Things (IoT) and the utilization of millimeter-wave frequency bands, dramatically enhancing network capacity and speed.

Lastly, the course reflects on emerging technologies and the future of telecommunications, particularly through the roadmaps toward 6G outlined by industry leaders like Nokia, Huawei, and Orange. These roadmaps introduce transformative innovations such as Zero-Energy Devices and cyber-physical systems, which are poised to redefine connectivity.

A critical part of the course involved group presentations. Our group chose to focus on the topic of Starlink, an innovative satellite internet system by SpaceX. This project was pivotal in contextualizing the theoretical knowledge gained during the course, linking it with real-world applications.

### 3.3.2. Scientific Foundations and Innovations in Mobile Telecommunications

The technical aspect of the course immerses students in the scientific foundations and innovations underpinning mobile telecommunications. A major focus is on technological miniaturization, which has revolutionized electronic device design over the years. With the continuous reduction in transistor size, evolving from traditional MOSFETs to FinFETs and Nano-Sheet FETs, the performance of electronic chips has greatly improved. These advances have enabled the production of more compact and energy-efficient devices capable of handling increasingly large volumes of data.

The course also explores the evolution of mobile generations, shedding light on the bandwidth requirements and modulation technologies specific to each generation. The 3G era marked the advent of mobile internet with UMTS, while 4G, through LTE, revolutionized the use of multimedia applications with higher data speeds. The 5G era introduced millimeter-wave frequencies (26 GHz) and advanced technologies such as massive MIMO and beamforming, paving the way for sophisticated applications like autonomous vehicles and connected healthcare. Looking ahead, 6G, anticipated by 2030, aims to exploit even higher frequencies, exceeding 100 GHz, enabling ultra-fast data rates and minimal latency. However, these advancements come with significant technical challenges, including signal attenuation at high frequencies and increased energy consumption.

The exploration of ultra-high frequencies (UHF and beyond) is a central theme of the course. While 5G primarily operates between 3.4 GHz and 26 GHz, 6G aims to expand into frequencies exceeding 100 GHz, encompassing the W and D bands (130–174 GHz). This transition toward higher frequencies unlocks unique opportunities for applications such as augmented reality, telemedicine, and global connectivity via

satellite constellations. However, it also introduces challenges related to wave propagation and the need for more efficient antenna designs.

Our group presentation on Starlink tied into the technical elements of the course by examining its use of low Earth orbit (LEO) satellites operating at frequencies between 10.7 GHz and 12.7 GHz. We analyzed the implications of satellite constellations for global connectivity and their technical challenges, such as frequency interference and latency. Additionally, we highlighted the role of innovative technologies in overcoming deployment hurdles and meeting the increasing demands for broadband access. This project served as a practical extension of the course's technical content, allowing us to apply theoretical knowledge to a real-world case study.

### 3.3.3. Reflections on the Course and Professional Insights

I perceived this course as a valuable addition to my general knowledge, as it did not present significant challenges in terms of comprehension. Delving deeper into the history of mobile technologies provided me with a clearer understanding of the future implications of this field, along with the technical challenges it poses for the environment and end users.

One of the standout aspects of this course was the freedom and variety of topics available for presentations. This flexibility allowed us to conduct research on subjects we were passionate about, making the work both engaging and enjoyable. Personally, I greatly appreciated this approach, as it encouraged active participation and made the learning experience more meaningful.

From a professional perspective, I have already had opportunities to explore and gain insights into the mobile technology sector. However, my focus has primarily been on GNSS (Global Navigation Satellite Systems) technologies. While the mobile technology field is a rapidly growing industry with promising career opportunities, I currently do not envision it as my primary career path. Nevertheless, the knowledge and insights gained from this course remain highly relevant and valuable for my broader professional development

I will now proceed with my self-assessment.

- Understand the major development phases for mobile communications and development of the associated technology: 4

- Understand the impact of new technology: 4
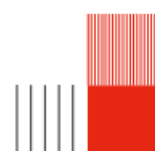
# Chapter 4  : Middleware and service unit

## 4.1. Cloud and Edge Computing

### 4.1.1. Conceptual Foundations of Cloud and Edge Computing

The Cloud and Edge Computing course, taught by Dr. Sami YANGUI, explores key concepts and technologies related to distributed computing, cloud computing, and edge computing. This course is essential for students specializing in Innovative Smart Systems, as it covers the fundamentals needed to understand how Internet of Things (IoT) systems interact with cloud and edge architectures, thus optimizing data processing and management.

Key concepts include:

Distributed Computing: This approach uses multiple interconnected components to work together in a single environment, with coordinated actions to achieve common goals. These systems help optimize communication and resource sharing within IoT applications.

Cloud Computing: This model relies on access to a vast pool of virtualized resources, available on demand, with a "pay-as-you-go" billing model. The cloud offers great flexibility for IoT infrastructure and applications, reducing operational costs.

Edge Computing: This technique brings data processing closer to the sources, reducing latency and enabling real-time processing. Edge computing is especially relevant for IoT applications requiring high responsiveness, such as predictive maintenance, fleet management, or autonomous navigation systems.

The course also covers virtualization and the role of hypervisors in enabling the simultaneous operation of multiple operating systems on a single physical infrastructure, which is crucial for resource management in cloud and edge environments.

### 4.1.2. Technical Architectures and Practical Applications

Technically, the course delves into the architectures needed to set up cloud and edge systems suitable for the constraints of IoT applications. The concept of virtualization is central, particularly with the use of type-1 (bare-metal) and type-2 (hosted) hypervisors, which allow for flexible and efficient resource allocation. These hypervisors also ensure process isolation, reducing the risk of conflicts and optimizing
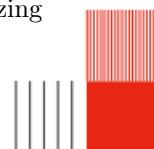
security.

One key technical aspect of the course is cloud federation and the portability of applications between different environments. Through federation, multiple cloud services can collaborate to better manage load spikes. For example, in fleet management applications, a hybrid cloud infrastructure can dynamically distribute tasks between the centralized cloud and edge nodes to ensure continuous availability and low latency.

The practical work allows to deepen the use of containers (such as with Docker) and cluster management via Kubernetes. As part of the lab project, we set up a hybrid cloud-edge architecture capable of handling the mobility and dynamic availability of edge nodes. The goal is to maintain reliable service throughout a journey by replicating services across the network and migrating services between nodes when necessary.

Finally, the course covers deployment models, such as IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service), which offer varying levels of control and flexibility. We learned to choose the appropriate model based on the specific needs of IoT applications, as well as how to design scalable and autonomous services to optimize costs and performance.

### 4.1.3. Insights and Practical Reflections

This course was entirely new to me, despite having previously used virtual machines (VMs) during my apprenticeship. In that context, I only interacted with pre-configured VMs and had no experience setting them up. Learning about the underlying techniques of virtualization and containerization was particularly fascinating and, I believe, invaluable for both my professional and personal development. These technologies offer the flexibility to create different environments, which can be essential for various scenarios, such as testing, development, or running specific applications.

The practical sessions, which involved setting up and using VMs and containers, significantly enhanced my understanding of their purpose and functionality. These exercises provided a hands-on experience that bridged the gap between theoretical knowledge and real-world applications, reinforcing the importance of these techniques in modern computing.

I also think introducing this course at the beginning of the academic year was a strategic choice. The principles learned here became foundational, as we applied them in several other courses and within the innovative project. This integration highlighted the interdisciplinary nature of cloud and edge computing, making the course not just a standalone module but a cornerstone of the curriculum.

- Understand the concept of cloud computing: 3

- Use a IaaS-type cloud computing:3

- Deploy and adapt a clou-based platform for IoT: 3

Overall, this course provided me with a solid introduction to virtualization and containerization, tools that I am now confident will play a significant role in my future projects and career path.
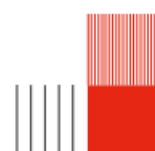
# 4.2. Service Oriented Architecture and Software Engineering

## 4.2.1. Foundations and Practical Applications of Service Architectures

The Service-Oriented Architecture (SOA) and Microservices course provided an in-depth understanding of modern distributed application architectures. It began with the foundational principles of SOA, highlighting how business functionalities are encapsulated into services to enable modularity, reusability, and interoperability across diverse platforms. The course then transitioned into Resource-Oriented Architecture (ROA) and RESTful web services, showcasing their advantages in simplicity and scalability over traditional SOA methods like SOAP.

This course emphasized the evolution from monolithic to microservices-based applications, which split large applications into smaller, independent units. Through this approach, services could be scaled and maintained independently, fostering resilience and flexibility. Cloud-native practices were also introduced, covering deployment on platforms like Microsoft Azure.

Practical sessions involved implementing RESTful microservices. In one lab, we developed a simple microservice that adhered to CRUD (Create, Read, Update, Delete) operations using REST APIs. Another practical task focused on deploying an application to Microsoft Azure, where continuous integration and deployment (CI/CD) practices were demonstrated through GitHub Actions. These hands-on activities enriched the theoretical learning, bridging the gap between conceptual understanding and real-world applications.
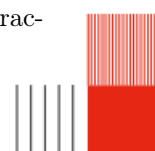
## 4.2.2. Architectural Principles and Implementation Techniques in SOA, ROA, and Microservices

ervice-Oriented Architecture (SOA) SOA organizes business functionalities into services that communicate using standardized protocols like SOAP. SOAP employs XML-based messaging, defined by WSDL (Web Service Description Language), which outlines operations, data formats, and endpoints. While robust, SOA's complexity and high resource demands make it less suitable for lightweight applications, but it remains essential in enterprise environments requiring interoperability.

Resource-Oriented Architecture (ROA) ROA adopts the REST (Representational State Transfer) style, simplifying interactions via HTTP methods such as GET, POST, PUT, and DELETE. RESTful services use stateless communications and commonly exchange data in JSON or XML, with JSON preferred for efficiency. Resources are accessed through unique URIs, offering scalability and flexibility, making ROA ideal for web and mobile applications.

Microservices Architecture Microservices build on SOA and ROA by decomposing applications into independent, focused services. Each microservice manages its own database and lifecycle, communicating via RESTful APIs. This architecture enhances scalability, resilience, and flexibility. Containerization with Docker ensures consistent deployment, while orchestration tools like Kubernetes manage clusters, handling scaling, load balancing, and service discovery.

Development and Deployment The course emphasized building and deploying distributed systems. Prac-

tical sessions focused on creating RESTful microservices with CRUD operations, then deploying them on Microsoft Azure using CI/CD pipelines. Docker was used to containerize applications, and GitHub Actions automated the workflow, from building to deployment. These exercises provided hands-on experience in creating scalable, cloud-native applications.

### 4.2.3. Reflections on Learning and Practical Challenges in Service Architectures

The Service Architecture course introduced me to new concepts, yet I realized that I had unknowingly implemented a REST-based service in the past. As part of the innovative project, I developed a RESTful web application for monitoring our sensors. This course allowed me to better understand the principles behind what I had previously built and provided valuable insights to improve it.

Delivered as a MOOC (partially online course), this format offered a flexible and enriching learning experience. I found the MOOC approach particularly beneficial, as it allowed us to progress at our own pace through the various modules that comprise the course. This flexibility was key to absorbing the technical aspects of the material.

The practical sessions, however, presented a significant challenge due to the workload exceeding the allocated time in the schedule. While the tutorials were conducted during class sessions, the mini-projects in the practical assignments (TD) had to be completed entirely on our personal time. While this workload was necessary to grasp the course concepts, I believe the scheduled time was insufficient to address all aspects comprehensively. Additional TD hours would have been beneficial to manage the work more effectively. That said, completing these assignments prepared us to tackle the larger group project (BE) with relative ease.

In my apprenticeship, service architecture is not a focus, and I do not foresee pursuing a career in this field. Nonetheless, the course remains highly valuable, as the knowledge gained is applicable to personal projects and potentially other professional contexts.

- Know how to define a Service Oriented Architecture: 4

- Deploy an SOA with web service: 4

- Deploy and configure an SOA using SOAP: 3

- Deploy and configure an SOA using REST: 4

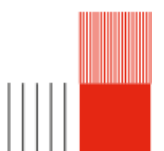- Integrate a process manager in an SOA: 4
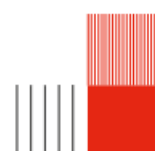
## 4.3. Middleware for IoT

### 4.3.1. Descriptive

### 4.3.2. Analytical

### 4.3.3. Technical

# Chapter 5  : Smart device unit

## 5.1. Sensor Introduction

### 5.1.1. Descriptive
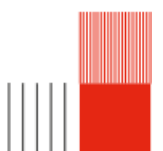
### 5.1.2. Technical

### 5.1.3. Analytical

## 5.2. Microcontroller and open source hardware

### 5.2.1. Descriptive

### 5.2.2. Technical

### 5.2.3. Analytical

## 5.3. Annexes

The annex is not included in this document but can be accessed via the link below:

- Annex 1: Cloud and Edge computing report (PDF).