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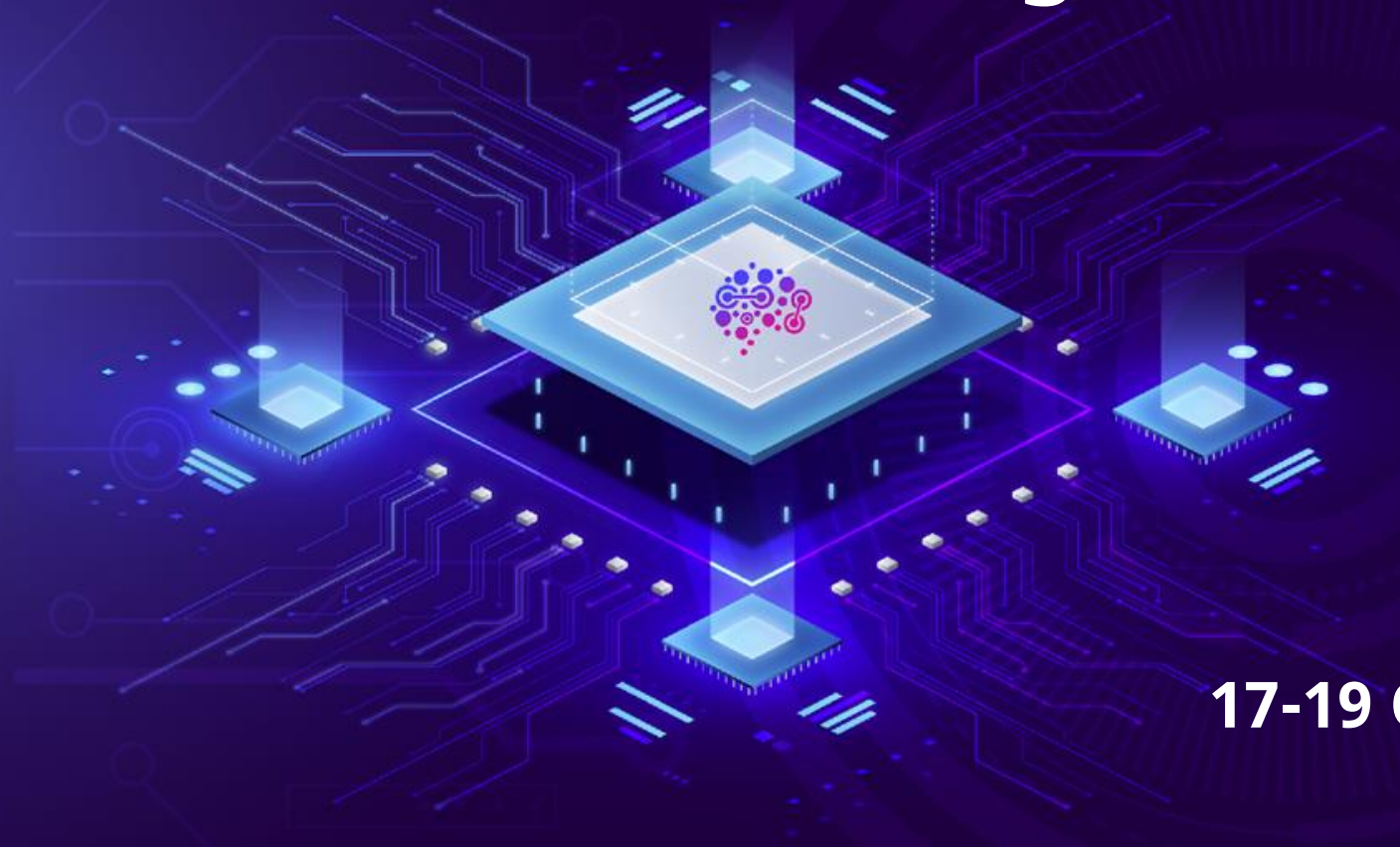

Advancing emerging edge AI technologies and driving next generation intelligent applications.

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Roadside Perception Units (RSPU) Connected with a LoRa 2.4 GHz Mesh Network

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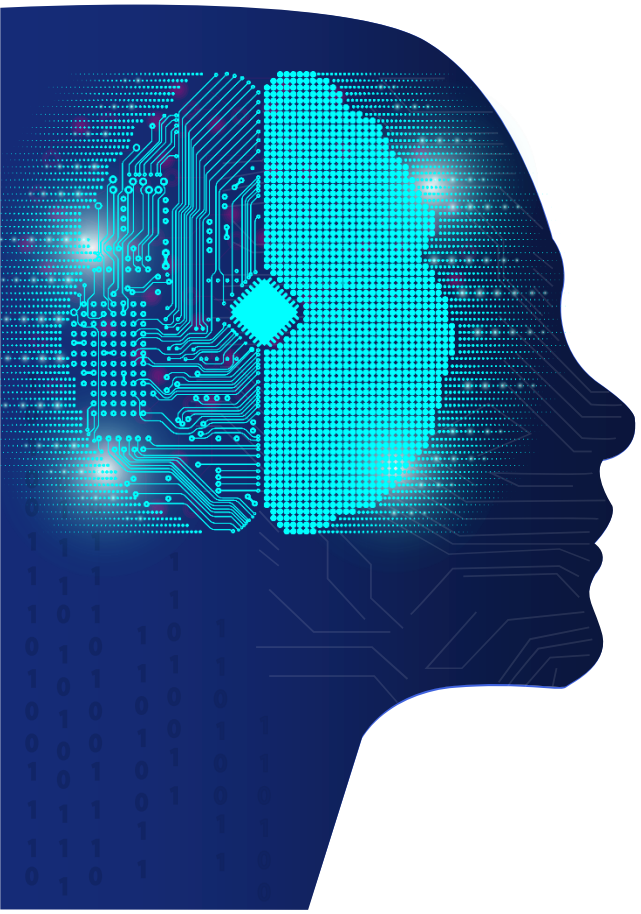
Presentation Outline



- Introduction
- State-of-the-art
- Research Goal
- Methodology
- Design and Implementation
- Experimental Results
- Future Research
- Conclusion

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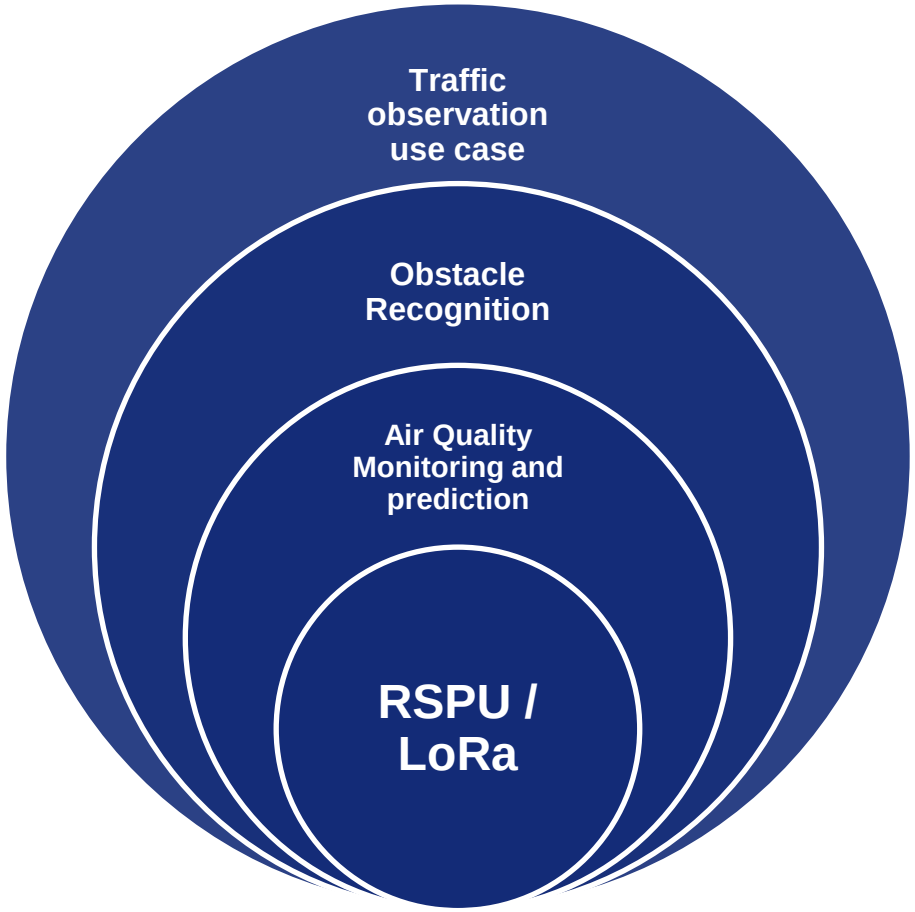
Introduction

An urban environment is comprised of :

- Large and heavy traffic loads
- Multiple vehicle interactions
- Increased population density
- Industrial activities:
    - Manufacturing
    - Construction
    - Waste Management & Recycling

Our main focus is a well-rounded infrastructure that aims to:

- Enhance the perception field
- To mitigate air pollution
- Tackle the traffic jam problem



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State-of-the-art

Why LoRa network:

- Cover urban area with larger distances
- Support battery powered devices
- Interconnect RSPU's directly
- Lower latency
- Better privacy
- Increased flexibility
- Eliminating wired backbone communication

Utility tools:

- Platforms : Jetson Orin, Tensorflow Lite, Kafka
- Frameworks: Tensorflow, PyTorch, Docker
- Technologies: YOLOv8, YOLOLite, Gradient Booster

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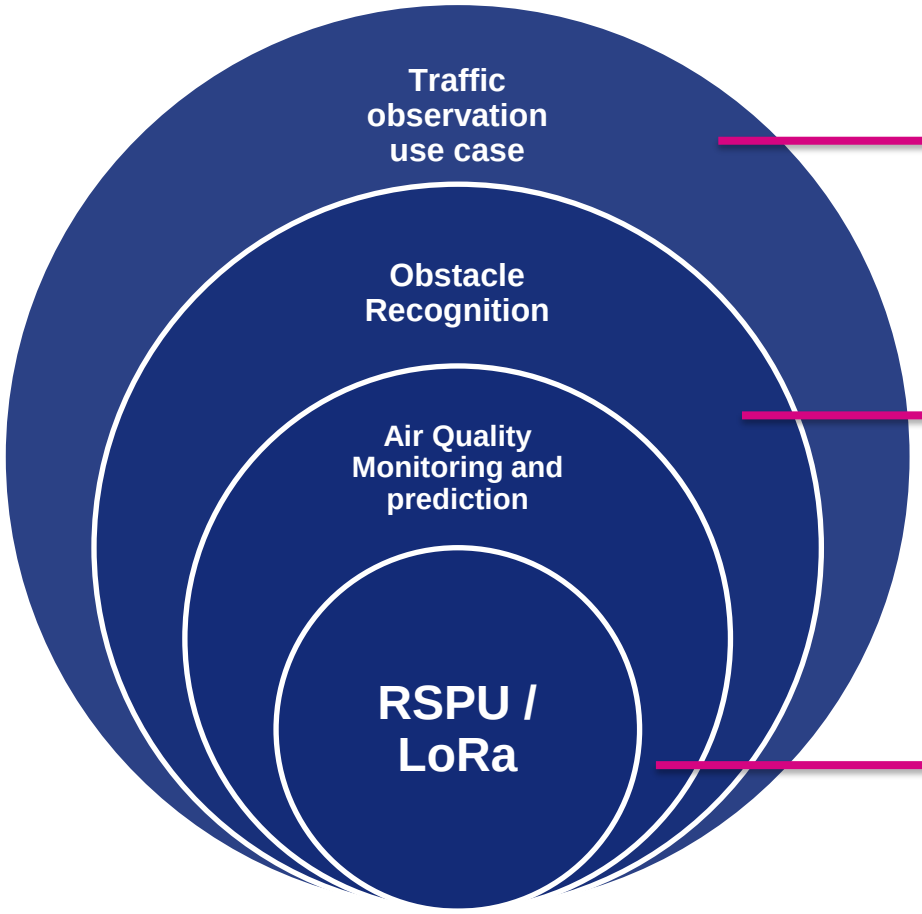
Research Goal

Through the implementation of the Use Cases:



- Capture general movement and typical routes taken by vehicles
- Enable optimal decision making in the route selection process

- Monitor the environment of an intersection filled with vehicles, in real-time
- Recognize potential emergencies a priori, improving transportation quality

- Provide a holistic perspective on the air quality conditions
- Informed decision-making and proactive interventions mitigating air pollution, creating a cleaner, safer urban environment

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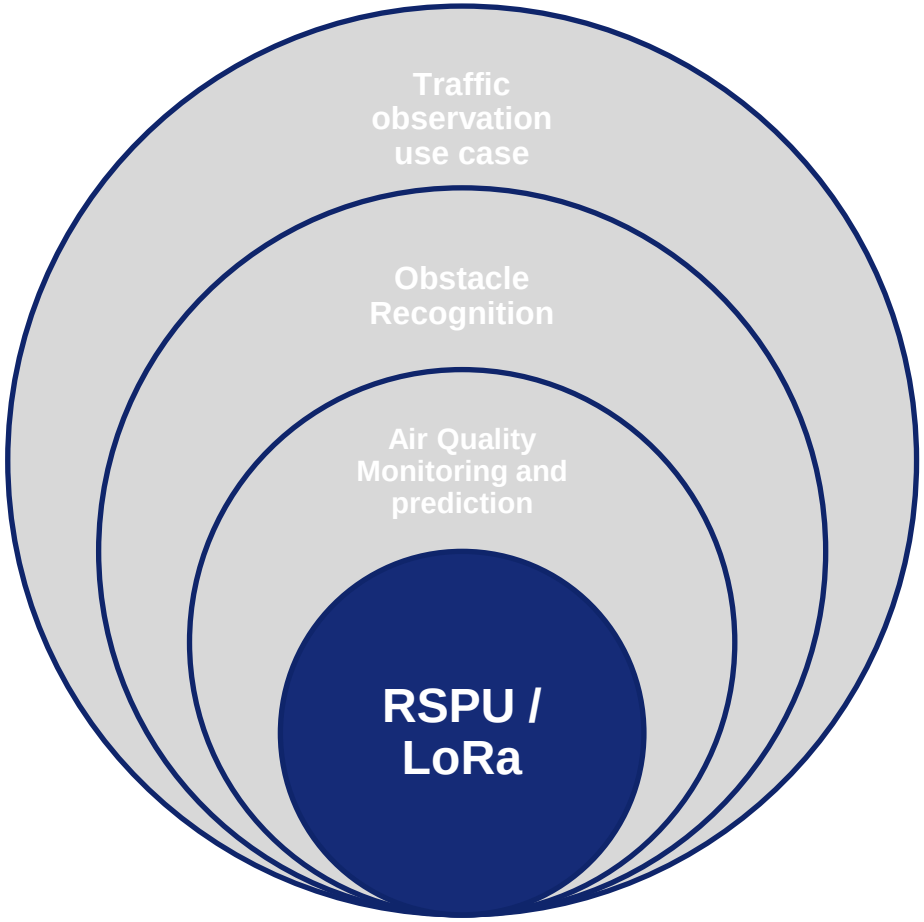
Methodology



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Methodology

The 2.4 GHz LoRa Mesh Network will be designed and implemented to transmit various types of non-critical and non-safety-relevant information between multiple RSPUs and sensor devices

- LoRa Mesh Router (R):
  - Facilitate data routing throughout the entire network
  - Establish communications among routers and nodes
  - Efficiently relay of data packets to their intended destinations

- LoRa Mesh End Nodes (E):
  - Transceivers with power saving features when integrated into battery powered devices
  - Can communicate with each other using the routers

- LoRa Mesh Coordinator (C):
  - Manages and organizes the LoRa Mesh network
  - Responsible to allocate network resources

- LoRa Mesh Access point (AP):
  - Bridge connecting the LoRa Mesh Network with other networks
  - Functions both as router and optionally as coordinator

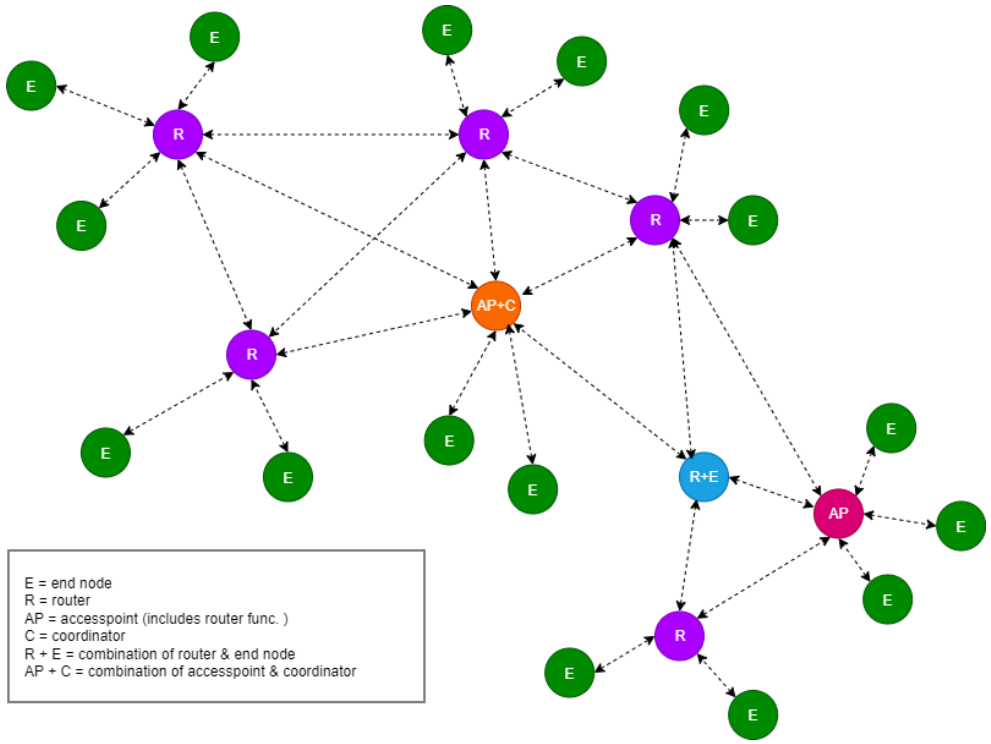

Figure 1: Illustration of the network architecture /Example topology

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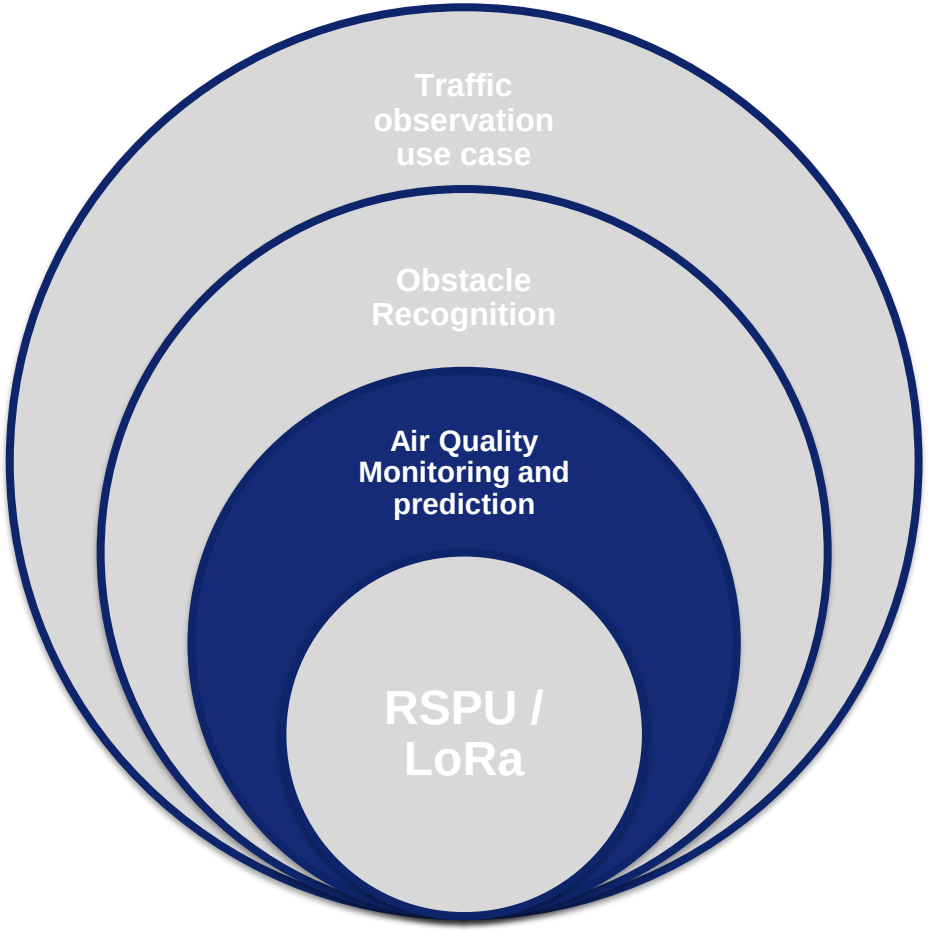
Use Case 1 :



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Design and Implementation

Air quality monitoring and prediction

Goal: system which offers precise, real-time air quality monitoring, enabling data-driven solutions for urban environmental improvement

- Sensor nodes, placed strategically on city intersections continuously collect data for temperature, humidity and pollutants to compute Air Quality Index (AQI) in real time.

Pollutants:

1. Particulate Matter 2.5 (PM2.5)
2. Particulate Matter 10 (PM10)
3. Nitrogen Dioxide (NO2)
4. Ozone (O3)
5. Sulfur Dioxide (SO2) Sensor

AQI Breakpoints:

POLLUTANT	INDEX LEVEL *(based on polluant concentrations in µg/m3)*					
	1 Very good	2 Good	3 Medium	4 Poor	5 Very Poor	6 Extremely Poor
Ozone (O_3)	0-50	50-100	100-130	130-240	240-380	380-800
Nitrogen dioxide (NO_2)	0-40	40-90	90-120	120-230	230-340	340-1000
Sulphur dioxide (So_2)	0-100	100-200	200-350	350-500	500-750	750-1250
Particules less than 10 µm (PM_{10})	0-20	20-40	40-50	50-100	100-150	150-1200
Particules less than 2.5 µm ($PM_{2.5}$)	0-10	10-20	20-25	25-50	50-75	75-800

Note: PM10 and PM2.5 values are based on 24-hour running means

European Air Quality Index Calculation, ECMWF Projects [Online]. Available: https://ecmwf-projects.github.io/copernicus-training-cams/proc-aq-index.html [Accessed: 17 October 2023]

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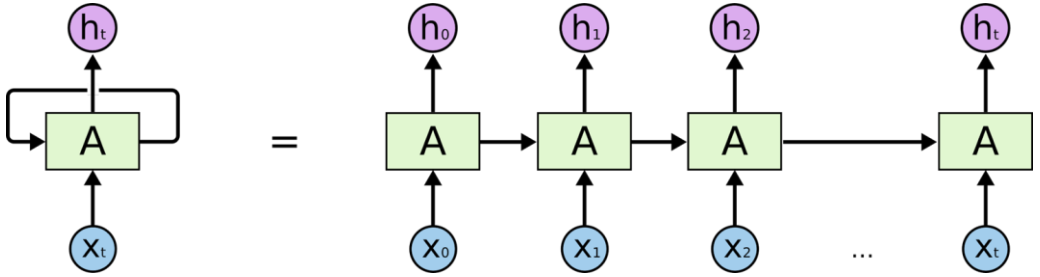
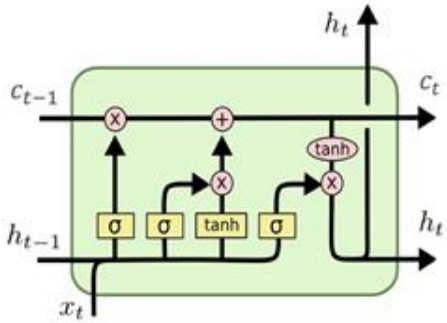
Design and Implementation

- The sensor nodes use the LoRa module to transfer data from each sensor node to an RSPU
- Each RSPU, leverages timeseries ML technologies to analyze data and predict AQI
- For example, Long Short-Term Memory (LSTM) will be used to learn complex temporal patterns and predict future AQI levels. Its main advantage lies in its ability to capture long-term dependencies and adapt to changing conditions, making it suitable for real-time predictions





C. Olah, “Understanding LSTM Networks,” (2015) [Online]. Available: https://colah.github.io/posts/2015-08-Understanding-LSTMs/. [Accessed 17 October 2021].

- An efficient Federated Learning (FL) approach will synchronize all RSPUs for re-training the ML models
- This format with the new incoming data will be able to continuously improve the model's performance

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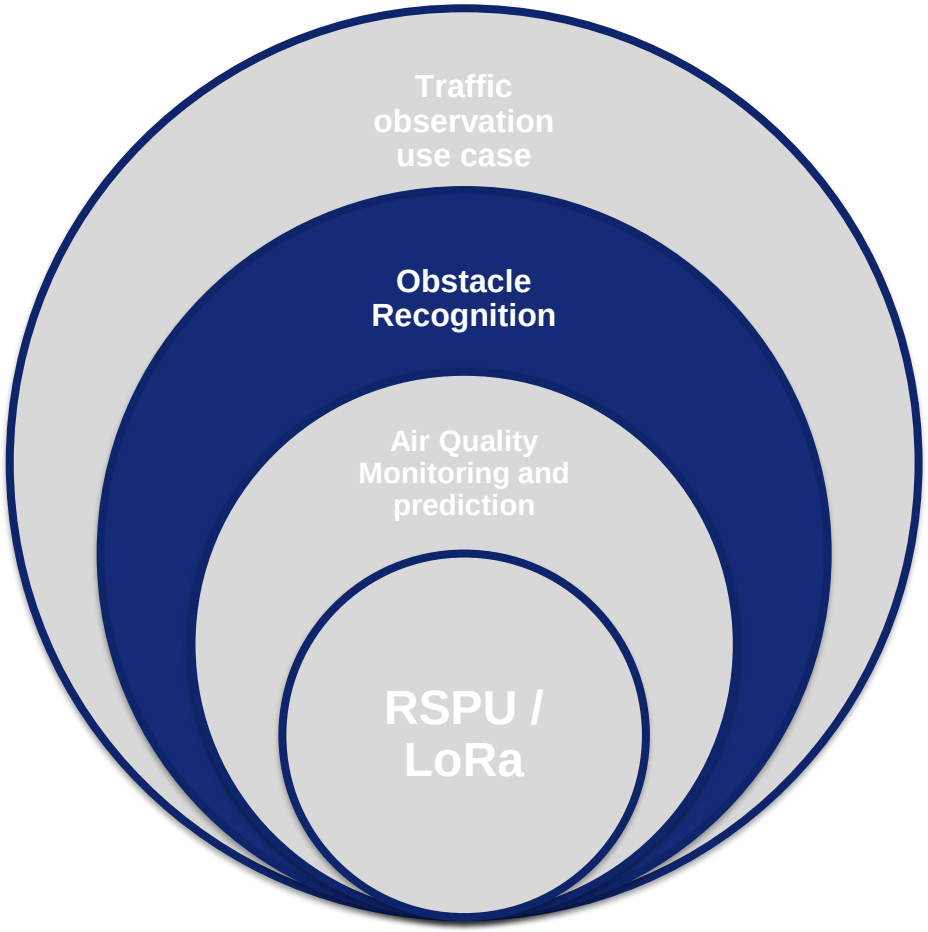
Use Case 2 :



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Design and Implementation

Obstacle Recognition

- Each RSPU is equipped with camera sensors to capture real-time data and to secure full coverage of all possible sides of the intersection
- The central interface of the RSPU will supply the captured data to an ML model
- This model will be implemented using tiny ML frameworks to be compact in size. This model will be trained offline with a reference dataset then fine-tuned, quantized and finally deployed to the RSPU.
- This model will recognize potential obstacles, improving thus the total transportation quality in real-time by detecting the location of each object recognized, classifying all objects captured
- Such a system must be robust and ought to almost never be retrained and therefore precision/accuracy is a necessity

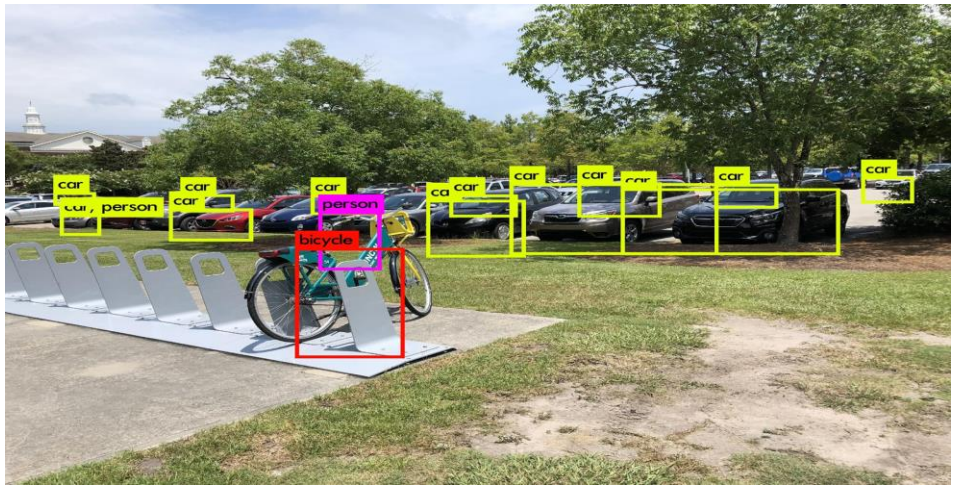

Figure 2 :Example of the result contributed by the tinyML model. [Source: YOLO Lite]

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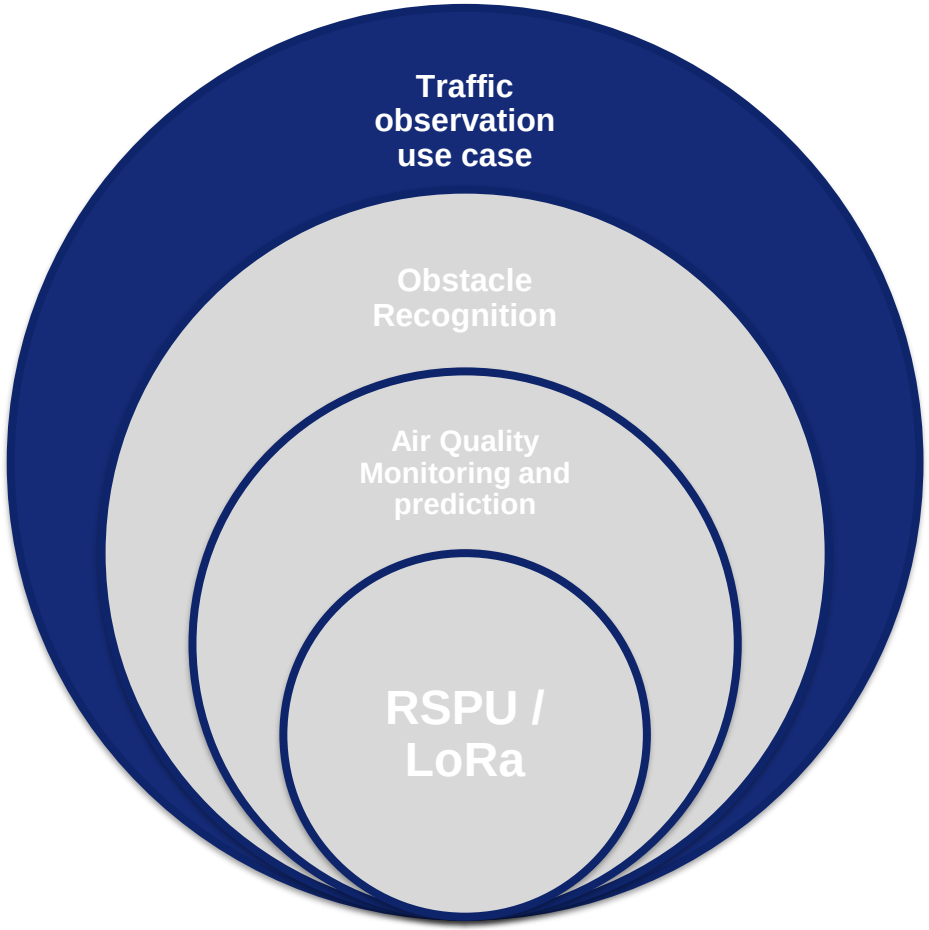
Use Case 3 :



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Design and Implementation

Traffic Observation

- The primarily focus of this use case is to optimize the traffic flow and secondary to inform affected users with actual road situation, enabling optimal decision making when selecting the route.
- This use case relies on a 360-degree camera located at the centre of an intersection
- This sensor will recognize and track the movement of individual vehicles, keep track of the number of vehicles on the surveying intersection and the number of vehicles leaving it
- This resulting information in each RSPU, contains the dataset of known vehicles and the length of traffic jams in all directions.
- Descriptive vectors for each vehicle and traffic jam length will be transferred between the RSPUs, using the LoRa Mesh network, synchronizing the dataset of known vehicles and traffic jams. .
- Such a system disregards any use for cloud applications thus improving the reliability of the system as well as decreasing the delay

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Design and Implementation

The network, in order to be able to cover the requirements and the necessities dictated by the use cases must:

1. Cover an urban area with larger distances (up to several kilometers)
2. Take into account obstacles such as buildings to consider communication hence line of sight is not guaranteed
3. Offer reliable data transmissions between network nodes
4. Support battery-powered sensor devices
5. Devices must function both as routers and sensors or actuators simultaneously

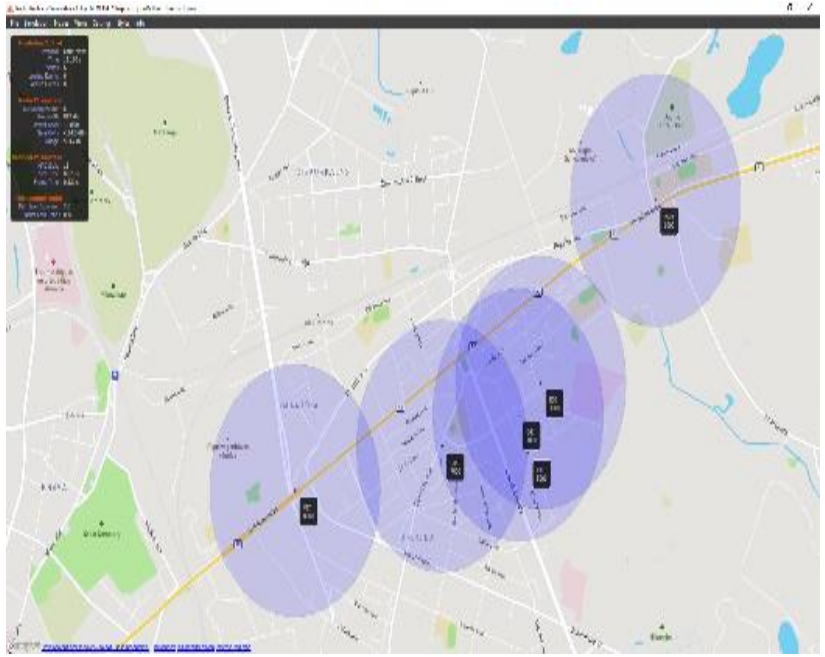

Figure 3: RSPU locations, 2.4 GHz LoRa eLOS-coverage@SF8, 812kHz. TP =+10dBm

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Experimental Results

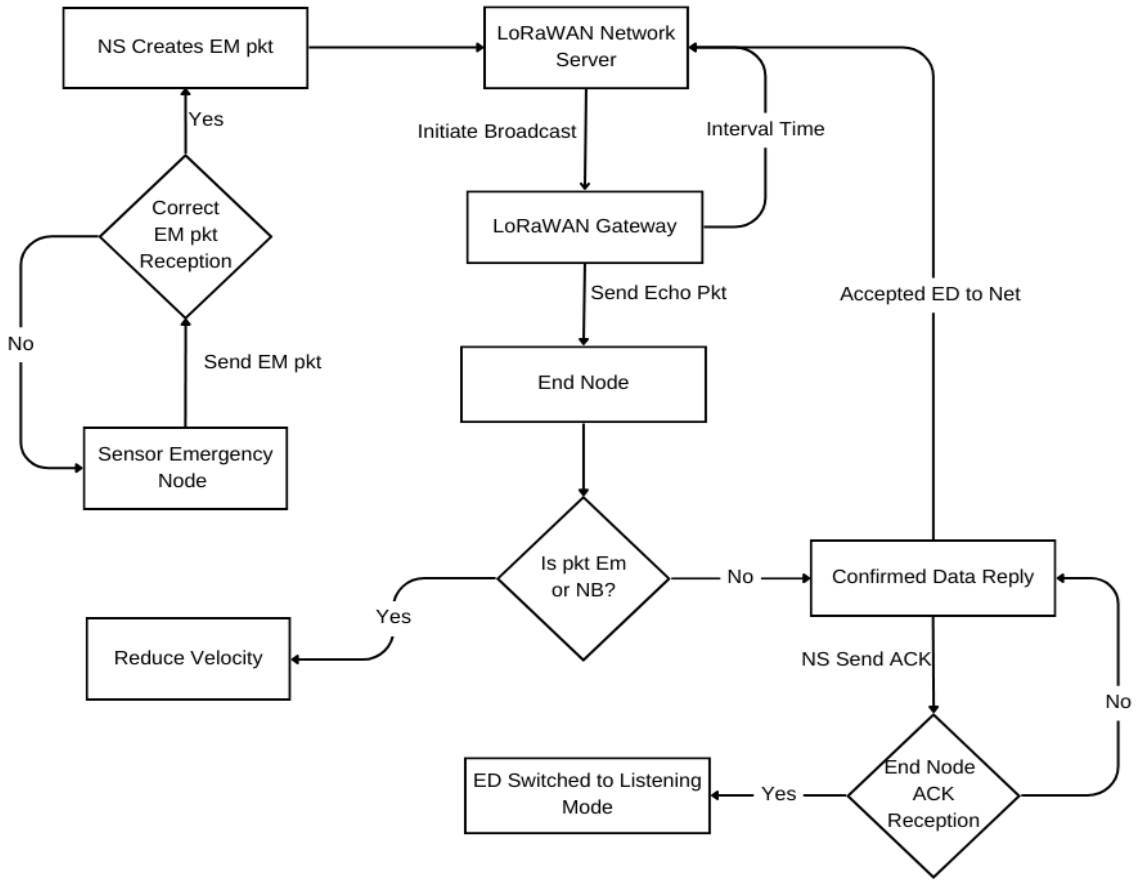

Figure 4: LoRaWAN: Simulation Flow Chart

LoRaWAN experimentation

- Simulation system to test the capabilities of LoRaWAN network
- Examine, scalability, adaptability and performance of the networks
- Investigate the reaction of the network when an emergency broadcast is necessary

Simulation Configuration (NS3, LoRaWAN for ns3):

- NS Periodic Broadcast Transmission
- Class C EDs listening in 2nd RX window
- Confirmed Data Traffic & ACK reply
- Outside Sensor Informs the NS about emergency
- NS Emergency Broadcast Transmission
- Dynamic Addition/Creation of Nodes during execution

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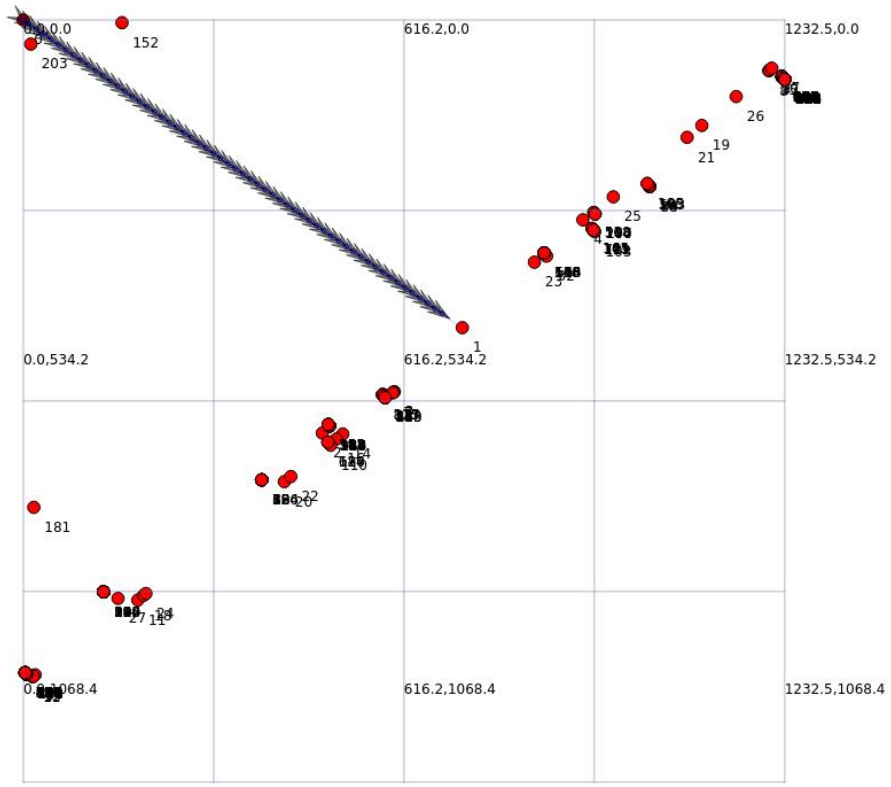
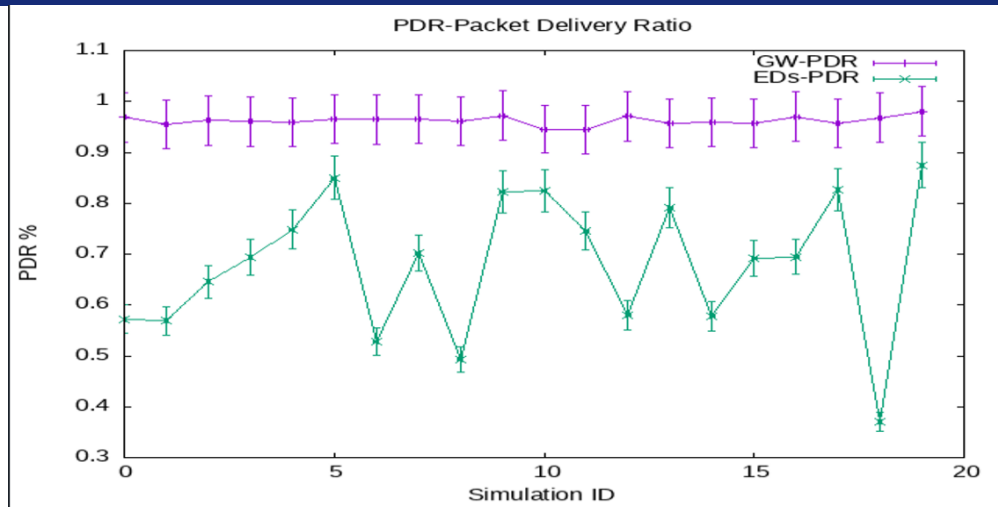
Experimental Results





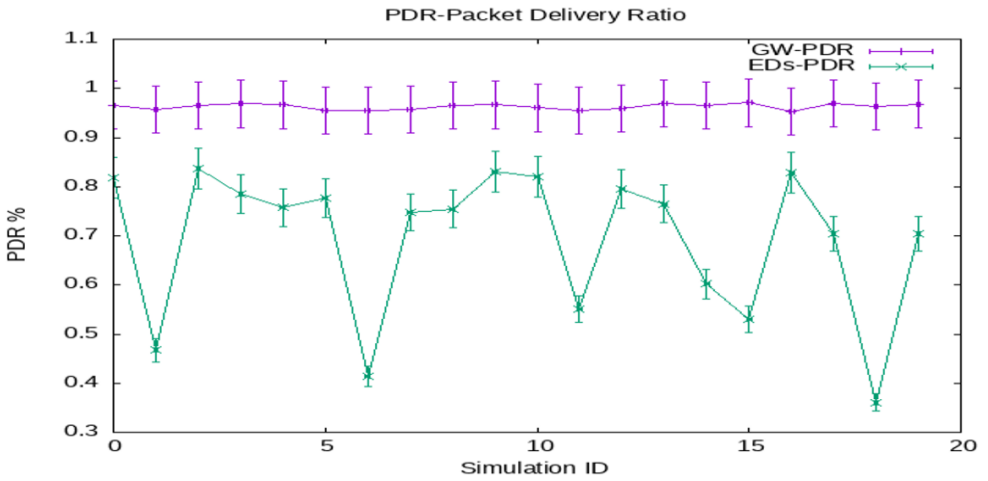


Figure 5,6,7: ***Environment represented with NS3: Broadcast signal from the NS to Eds & PDR for GW and Eds for different time periods***

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Future Research

Regarding the Experimentation:

- Aspire to optimize the routing of UL and ACK packets so that the system is even more scalable while minimizing the number of retransmissions required
- Enhance the scalability of the network by optimizing the geocasting techniques while increasing the GW availability and multitude
- Examine the energy efficiency performance of the system when ADR and power saving features like Deep Sleep are applied to the end nodes

Regarding the use cases:

- Enhancing each component within the system to ensure the attainment of both precision and real-time standards
- Minimizing the size of each module implemented for easier integration and inference to an embedded system

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Conclusion

- LoRa protocol is ideal for covering larger distances, with reliable connections and efficient approach for a battery-driven device/ resource restricted systems

- The use cases demonstrate how the integration of technology can have a transformative impact on urban living. By prioritizing clean air, safety, and efficient transportation, cities become better equipped to meet the needs and expectations of their citizens.

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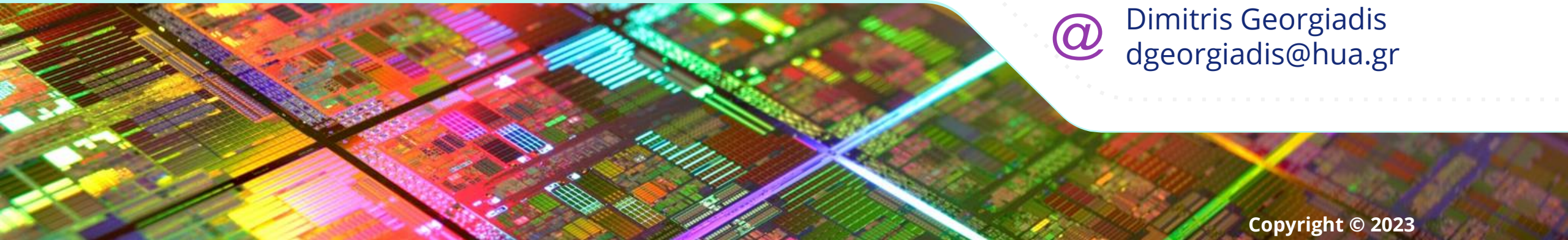
Thank You

For your attention



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