IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom

Wi-SUN Network Implementation

by

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Project Report

MSc. AEIOT

IMT Atlantique, Rennes

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1 Introduction

The contemporary educational landscape is undergoing a transformative shift. The Internet of Things (IoT), a network of interconnected devices collecting and exchanging data, has emerged as a powerful tool for revolutionizing data collection and communication across various sectors. In the realm of education, IoT presents a wealth of possibilities to enhance learning experiences, optimize resource management, and foster a more efficient operational environment.

This project report delves into the implementation of a Wi-SUN network on the campus of IMT Atlantique Rennes (Ex. Télécom Bretagne). We will explore the deployment of the SiLabs Wi-SUN offering, a solution specifically designed to address the unique challenges and opportunities presented by IoT in educational institutions.

This project report meticulously dissects the implementation of a Wi-SUN network on the vibrant campus of IMT Atlantique. We will delve into the strategic deployment of the SiLabs Wi-SUN offering, a solution meticulously crafted to address the unique challenges and opportunities presented by IoT in educational institutions.

The Imperative for Transformation is that traditional methods of data collection and communication within schools often rely on outdated processes or technologies with limited range. This translates to inefficiencies and hinders the ability to gather real-time, data-driven insights. These insights are crucial for optimizing operations, personalizing learning, and fostering a dynamic educational environment. By embracing the transformative power of IoT, IMT Atlantique aspires to:

Revolutionize data collection through sensors and connected devices that will act as digital eyes and ears, gathering real-time data on various aspects of the school environment, encompassing classroom occupancy, environmental conditions, and even energy consumption. Learning experiences can be empowered via interactive learning tools and personalized learning platforms, powered by the harvested data, can be implemented to foster deeper student engagement, promote knowledge retention, and cater to individual learning styles. IoT-enabled systems will provide granular insights into areas like lighting and heating usage. This empowers data-driven decisions for optimizing resource allocation, reducing costs, and ensuring a sustainable learning environment. Tasks like automated attendance tracking or asset management can be streamlined through IoT solutions, freeing up valuable time for educators and administrators, allowing them to focus on more strategic initiatives.

2 Background

2.1 Limitations of Traditional Wireless Networks

Until recently, the primary methods for providing data access to devices involved either multihop mesh networks utilizing short-range communication technologies in the unlicensed spectrum or long-range legacy cellular technologies, predominantly 2G/GSM/GPRS, operating within licensed frequency bands. These traditional models have been disrupted by the emergence of a new type of wireless connectivity. This innovative approach is characterized by low-rate, long-range transmission technologies in the unlicensed sub-gigahertz frequency bands, which are used to create access networks with a star topology, known as low-power

WANs (LPWANs). Classical wireless technologies, primarily Wi-Fi, offer undeniable value in connecting devices. However, when considering large-scale deployments of battery-powered IoT devices in an environment like a school campus, several limitations come to light. This section dives deeper into these limitations and how Wi-SUN technology addresses them, making it a superior choice for this project.

- Range: Wi-Fi operates in the 2.4 GHz and 5 GHz bands. These high frequencies offer the advantage of high bandwidth, enabling faster data transmission rates. However, the flip side is that these frequencies are more susceptible to attenuation, which is the weakening of signal strength as it travels through distance or obstacles. Walls, furniture, and even human bodies can significantly weaken Wi-Fi signals, leading to:
  - Limited Coverage: In a sprawling school campus with multiple buildings and outdoor spaces, Wi-Fi signals may not reach all areas effectively. This creates connectivity gaps, hindering data collection from sensors in remote locations.
  - Signal Fluctuations: As users move around campus, they might experience frequent drops or fluctuations in signal strength as they transition between areas with varying signal coverage. This inconsistency can disrupt ongoing data transmissions and impact application performance.
- Wi-Fi's Power Hungry Nature: Wi-Fi modules require significant power to transmit and receive data packets. This is because they constantly listen for signals and transmit data at high speeds. For battery-powered IoT devices, like temperature sensors or occupancy detectors, this translates to:
  - Frequent Battery Replacements: The constant power consumption by Wi-Fi modules drains batteries quickly. This necessitates frequent battery replacements, which can be a significant burden on maintenance staff and disrupt ongoing data collection.
  - Limited Device Lifetime: The reliance on frequent battery replacements shortens the effective lifespan of battery-powered devices. This increases the total cost of ownership over time.
- Wi-Fi's Congestion Challenges: Traditional Wi-Fi networks are designed to handle a limited number of connected devices. As the number of devices trying to connect to a single access point increases, the network becomes congested. This congestion manifests in several ways:
  - Data Packet Collisions: With numerous devices transmitting data simultaneously, collisions can occur where multiple packets occupy the same channel at the same time. This results in data loss and requires retransmission, slowing down the overall network performance.
  -

2.2 The Advantage of IoT Wireless Networks

To address these limitations, this project explores the implementation of a Wi-SUN network. Wi-SUN, based on the IEEE 802.15.4e standard, offers several advantages:

- Long Range: Wi-SUN operates in the sub-GHz frequency band (typically between 600 MHz and 900 MHz). These lower frequencies have a distinct advantage in terms of range. They experience less attenuation compared to higher frequencies, offering several benefits:
  - Superior Penetration: Lower frequencies can effectively penetrate walls, floors, and other obstacles with minimal signal loss. This ensures reliable connectivity throughout the campus, even in areas with challenging signal paths.
  - Extended Coverage: Wi-SUN signals can travel longer distances without significant weakening. This allows for a single Wi-SUN network to cover a larger area compared to multiple Wi-Fi access points, simplifying network design and reducing infrastructure costs.
- Low Power Consumption: Wi-SUN devices are designed for extended battery life, ideal for long-term deployments with battery-powered sensors. The protocol incorporates several features specifically designed to extend battery life in IoT devices. Here are some key mechanisms:
  - Efficient Data Encoding: Wi-SUN utilizes advanced data encoding techniques that minimize the number of bits required to transmit information. This reduces the amount of power needed for transmission.
  - Optimized Sleep Modes: Wi-SUN devices can enter low-power sleep states when not actively transmitting or receiving data. This significantly reduces power consumption during periods of inactivity.
  - Targeted Messaging: Wi-SUN allows for targeted communication, where data is only sent to specific devices that require it. This eliminates unnecessary broadcasts and reduces overall power consumption in the network.
- Scalability: Wi-SUN is designed to handle a high volume of connected devices efficiently. The protocol employs techniques like:
  - Channel hopping: Devices can dynamically switch between different channels to avoid congested frequencies, ensuring smooth communication.
  - Frequency diversity: The protocol can utilize multiple frequency bands simultaneously, providing additional channels for data transmission and reducing congestion.
  - Media Access Control (MAC) layer techniques: Wi-SUN uses sophisticated MAC layer protocols to manage device access to the network, preventing collisions and ensuring efficient data flow.

This scalability makes Wi-SUN ideal for large-scale IoT deployments on campuses. It can effectively manage a multitude of devices, ensuring reliable and efficient data communication for various applications.

2.3 Project Goals

This project aims to:

- Understand the SiliconLabs Wi-SUN solution
- Evaluate the network's performance in terms of range, power consumption, and scalability.
- Identify potential applications of the Wi-SUN network to enhance campus operations and learning experiences.
- Design and deploy a Wi-SUN network on the IMT Atlantique Rennes campus utilizing SiLabs' Wi-SUN solution.

3 Implementation

3.1 SiliconLabs solution

The stack explored in the case of this project is provided by SiliconLabs. Wi-SUN, being an open standard based on IPv6 802.15.4g/e specifications, all members needs to adhere to the guidelines to help accelerate the implementation of the Field Area Networks (FAN) and the Internet of Things in general. This can be seen in 1

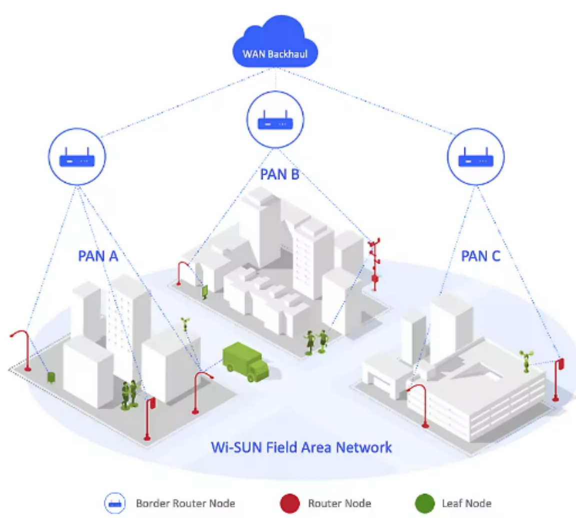


Figure 1: Wi-SUN Field Area Network

When it comes to the protocol stack employed by SiLabs, the physical layer is based on RAIL. SiLabs also ensures security using EAP-TLS. This can be seen in 2. As a developer, we have access to the top of the stack, which as a precompiled object-file, enabling connectivity. The Wi-SUN stack contains following blocks.[1]

- Wi-SUN stack – Wi-SUN functionality consisting of an IP stack, MAC layer, the routing protocol (RPL), and security manager.
- Wi-SUN RF test plugin – Optional software component to add an API to perform RF tests (for example, create an RF tone).
- Wi-SUN Util Functions – Optional software component to add helper functions to inform the application about the Wi-SUN PHY configured in the RAIL configuration file.

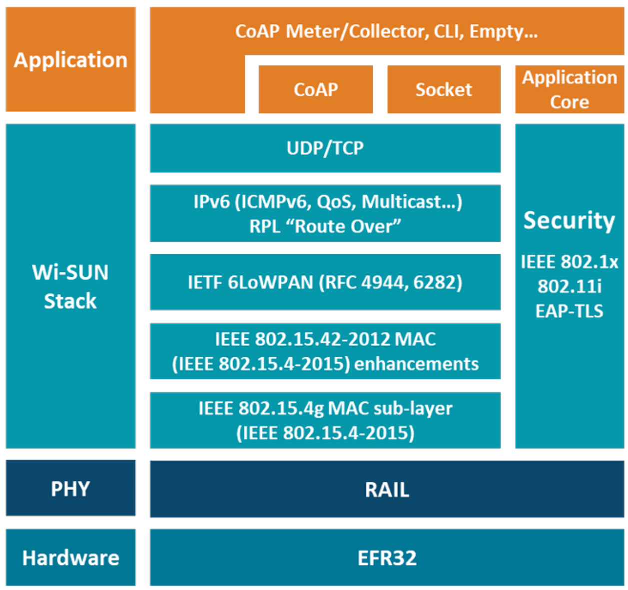


Figure 2: Wi-SUN Stack Architecture Block Diagram

There exists 2 versions of the SiLabs FAN; FAN1.0 and FAN1.1. The major difference between these two is the introduction of OFDM modulation in FAN1.1 and the ability to switch between FSK and OFDM depending on the use case.

3.2 SoC and Software

The EFR32FG25x Sub-GHz Wireless SoCs (EFR32FG25 Wi-SUN 863-876 MHz +16 dBm Starter Kit) as depicted in Figure 3 was obtained from the SiLabs team. This kit is specifically engineered to cater to IoT device requirements based on Sub-GHz Wi-SUN FAN (Field Area Networks). It comprises a radio board equipped with a matching network designed to transmit at +16 dBm and cover frequencies ranging from 863 to 876 MHz.

The main board, termed WPK, is furnished with an onboard J-Link debugger featuring a Packet Trace Interface alongside a Virtual COM port. These features facilitate seamless application development and debugging not only for the attached radio board but also for external hardware through an expansion header.

Furthermore, the FG25 Pro Kit furnishes developers with all essential tools required for the creation of high-volume, scalable Sub-GHz wireless IoT applications, ensuring comprehensive support throughout the development process [2].

To facilitate development, Simplicity Studio 5, Silicon Labs' core development environment, was utilized. Through this platform, the Software Development Kit (SDK) was downloaded, providing developers with an extensive suite of tools and resources necessary for efficient and streamlined development of Sub-GHz wireless IoT applications.

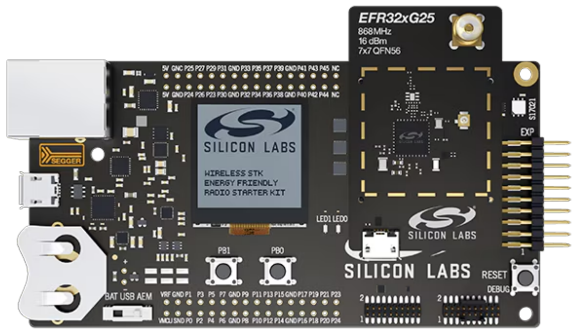


Figure 3: Example EFR32FG25x

3.3 Physical Setup

Figure 4: Physical Setup

Here, we can have an idea of the physical setup of the network. 2 SoCs are visible in the image (on the right, serving as the radio co-processor necessary for border router, and the other which runs the Node monitoring application).

3.4 Sample Applications

Silicon Labs provides a set of sample applications that can perform a range of operations, be it a simple ping application or a CoAP based application. They facilitate the process of understanding the capabilities of the solution. The following demo applications were used:

- Wi-SUN - SoC Ping
- Wi-SUN - SoC Border Router
- Wi-SUN - RCP
- Wi-SUN - SoC UDP CLient
- Wi-SUN SoC Network Measurement

3.4.1 Establishing Connections and First Pings

To start, the Wi-SUN Ping and Wi-SUN Border Router Applications were used. Both applications were flashed, one on each kit. The result of the code can be viewed in the figure 6 below.

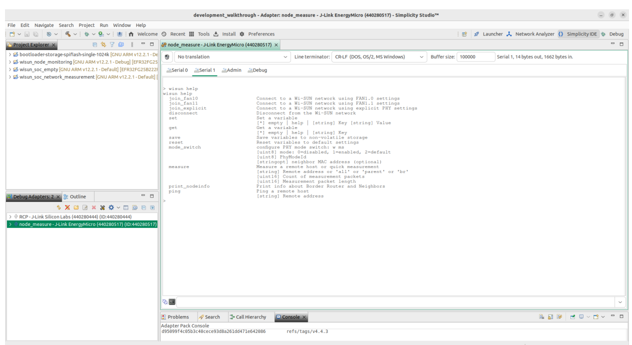
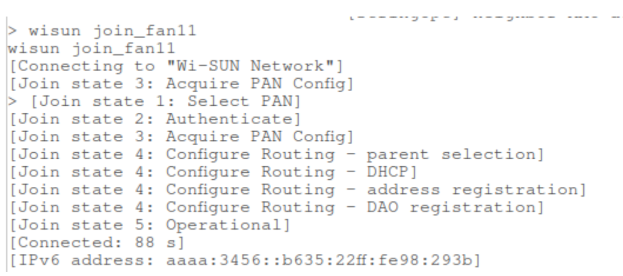


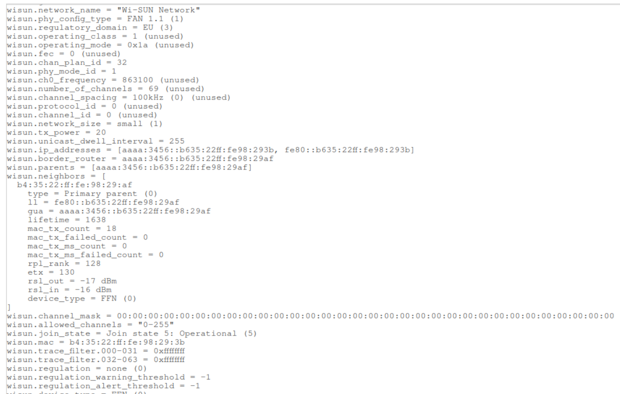
Figure 5: IDE running a basic application

In figure 5 the SimplicityStudio IDE can be seen.



```
> wisun join_fan11
wisun join_fan11
[Connecting to "Wi-SUN Network"]
[Join state 3: Acquire PAN Config]
> [Join state 1: Select PAN]
[Join state 2: Authenticate]
[Join state 3: Acquire PAN Config]
[Join state 4: Configure Routing - parent selection]
[Join state 4: Configure Routing - DHCP]
[Join state 4: Configure Routing - address registration]
[Join state 4: Configure Routing - DAO registration]
[Join state 5: Operational]
[Connected: 88 s]
[IPv6 address: aaaa:3456::b635:22ff:fe98:293b]
```

Figure 6: Simple connection via CLI



```
wisun.network_name = "Wi-SUN Network"
wisun.phy_config_type = FAN 1.1 (1)
wisun.regulatory_domain = EU (3)
wisun.operating_class = 1 (unused)
wisun.operating_mode = 0x1a (unused)
wisun.fec = 0 (unused)
wisun.chan_plan_id = 32
wisun.phy_mode_id = 1
wisun.ch0_frequency = 863100 (unused)
wisun.number_of_channels = 69 (unused)
wisun.channel_spacing = 100kHz (0) (unused)
wisun.protocol_id = 0 (unused)
wisun.channel_id = 0 (unused)
wisun.network_size = small (1)
wisun.tx_power = 20
wisun.unicast_dwell_interval = 255
wisun.ip_addresses = [aaaa:3456::b635:22ff:fe98:293b, fe80::b635:22ff:fe98:293b]
wisun.border_router = aaaa:3456::b635:22ff:fe98:29af
wisun.parents = [aaaa:3456::b635:22ff:fe98:29af]
wisun.neighbors = [
  b4:35:22:ff:fe:98:29:af
    type = Primary parent (0)
    ll = fe80::b635:22ff:fe98:29af
    gua = aaaa:3456::b635:22ff:fe98:29af
    lifetime = 1638
    mac_tx_count = 18
    mac_tx_failed_count = 0
    mac_tx_ms_count = 0
    mac_tx_ms_failed_count = 0
    rpl_rank = 128
    etx = 130
    rsl_out = -17 dBm
    rsl_in = -16 dBm
    device_type = FFN (0)
]
wisun.channel_mask = 00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00:00
wisun.allowed_channels = "0-255"
wisun.join_state = Join state 5: Operational (5)
wisun.mac = b4:35:22:ff:fe:98:29:3b
wisun.trace_filter.000-031 = 0xffffffff
wisun.trace_filter.032-063 = 0xffffffff
wisun.regulation = none (0)
wisun.regulation_warning_threshold = -1
wisun.regulation_alert_threshold = -1
wisun.device_type = FFN (0)
```

Figure 7: 'wisun get wisun' after established connection

3.4.2 WSBRD + Radio co-processor

The Wi-SUN Border Router application is a limited in its functionality. This is where the use of the linux wsbrd + radio co-processor configuration comes into play. This provides a number of advantages over the ready-to-use application, such as, efficient network management, enhanced performance, robust security, flexibility, interoperability and easy of deployment. It was particularly helpful in this project, to enable the use of a graphical user interface which enables a pictoral view of the mesh network. Take a look at this configuration at 8.

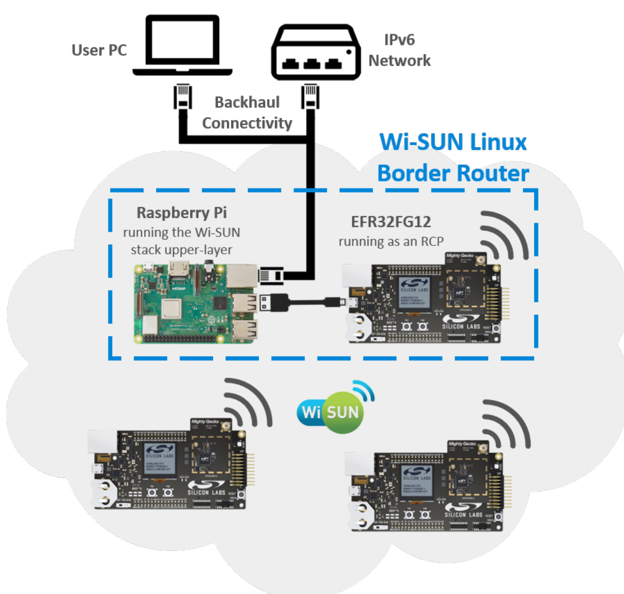
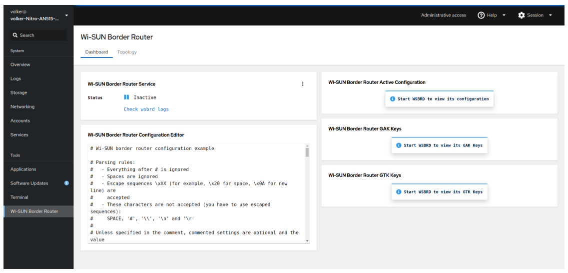


Figure 8: Wi-SUN Linux Border Router

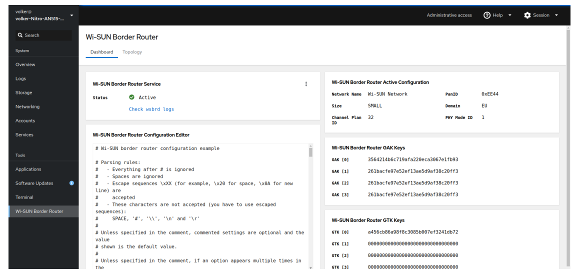
3.4.3 Graphical User Interface

This companion tool provides a means to perform remote border router configurations, as well as for the connected Wi-SUN devices to be represented visually. It runs on the wsbrd instance installed earlier, and as a plugin on Cockpit, which is a linux tool for web-based graphical interface for servers.

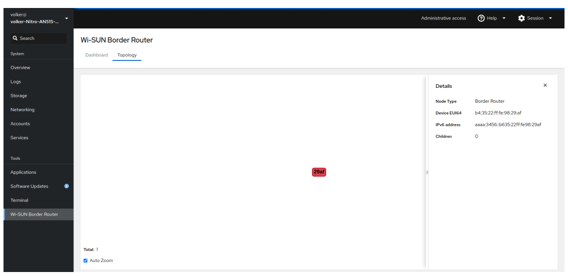
The multihop phenomenon can be viewed through this GUI in an easy manner 11b. The network automatically reselects parent nodes as per RPL protocol. In figure 11a for example, each node is connected directly to the border router.



(a) GUI via Cockpit

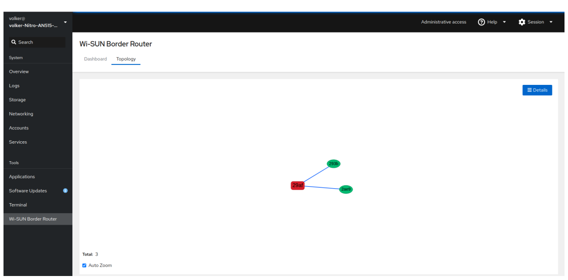


(b) GUI Active Router



(a) GUI Topology 1 Device

(b) GUI Topology 2 Devices



(a) GUI Topology 3 Devices

(b) GUI Topology 3-device multihop

3.4.4 Node Monitoring

This application provided a means to monitor the network, using the Wi-SUN linux border router, CoAP, and a UDP listener 12. For this setup to work, the following need to be ensured.

- A Linux Wi-SUN Border Router is set up and started, waiting for Wi-SUN nodes to connect.
- Convenience scripts are copied from linux_border_router_wsbrd to the user's home. Bash scripts are made executable using:

  - chmod a+x coap_all
  - chmod a+x ipv6s
  - chmod a+x *.sh

- The UDP notification receiver is started using

  ```
  python udp_notification_receiver.py 1237 " "
  ```

  waiting for messages from the Wi-SUN Nodes on port 1237.

- The application is built and flashed to all Wi-SUN devices.

Once the network has been setup, the node automatically tries to connect to the Wi-SUN network, given it is configured using the proper parameters such as network name and PHY.

It then sends an initial UDP connection message to the border router on port 1237. The messages can be viewed in figure 13 below.

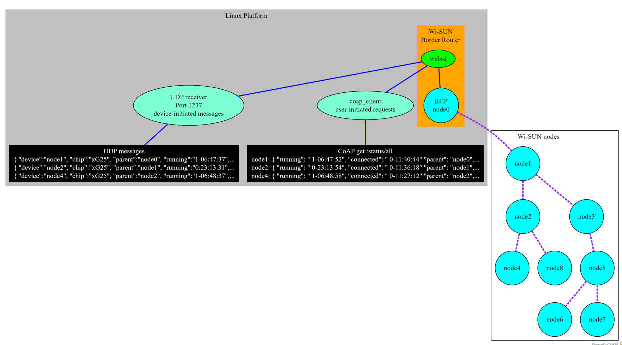


Figure 12: Node Monitoring
[3]

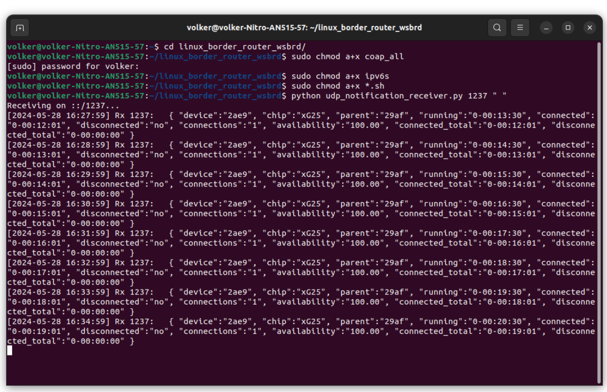


Figure 13: UDP Listener

4 Network Performance

An existing Wi-SUN Network Measurement Application [4] offers a user-friendly interface for conducting various performance evaluations. Through this application, users can easily assess critical network metrics such as packet error rate, average ping latencies, and more. This tool serves as a valuable asset for monitoring and optimizing the performance of Wi-SUN networks, enabling users to make informed decisions and ensure the reliability and efficiency of their deployments. Although these tests are performed before final deployment of the network, it provides an idea of the potential performance of this network.

Figure 14: Node Monitoring CLI

4.1 Range

For applications requiring communication across vast distances, traditional cellular networks and Wi-Fi often fall short. Here's where Low Power Wide Area Networks (LPWAN) technologies like LoRaWAN and Wi-SUN come in, offering significant advantages in terms of range.

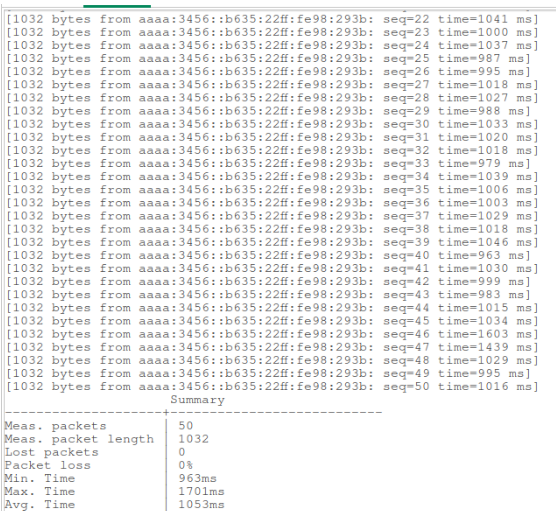
LPWAN technologies like LoRaWAN and Wi-SUN are specifically designed to prioritize long-range communication. They utilize lower frequencies and specialized signal modulation techniques to achieve extended reach, often exceeding 10 kilometers in rural environments and reaching several kilometers even in urban areas.

Wi-SUN can establish mesh networks, where devices can relay signals to each other, effectively extending the overall reach beyond the range of a single base station.

To test this, we simply position the devices at different spots on the campus. One device was placed in a TP lab at one end of the campus B00-133A and the border router at the other end of the campus. Multiple ping tests were run to ensure that they went through and this was a successful campaign.

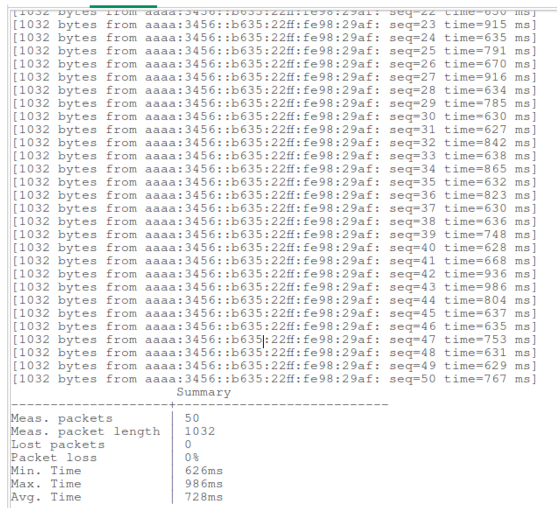
4.2 Ping Latency & Delivery Rate

To perform these tests, the devices are setup to ensure the links are tested to their full capacity. The `measure` command on the node (running Wi-SUN Network Measurement project), enables us to run a series of pings to a destination address. The figures below, show the results of pings from the wi-sun node as client, to its neighbour, and from the said node to the border router.



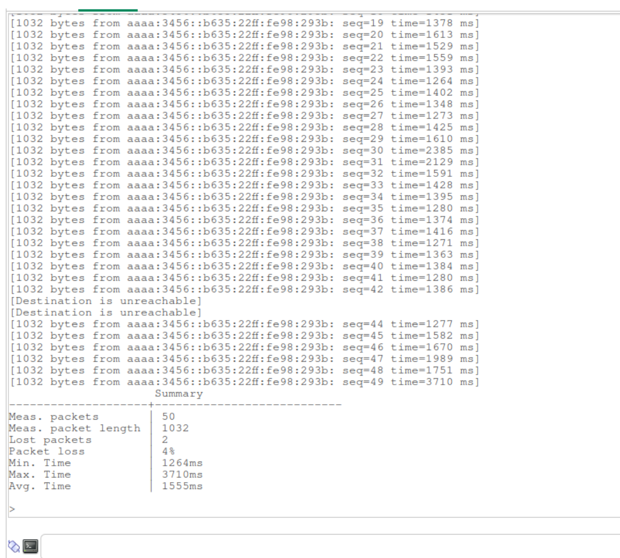
```
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=22 time=1041 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=23 time=1000 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=24 time=1037 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=25 time=987 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=26 time=995 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=27 time=1018 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=28 time=1027 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=29 time=988 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=30 time=1033 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=31 time=1020 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=32 time=1018 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=33 time=979 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=34 time=1039 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=35 time=1006 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=36 time=1003 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=37 time=1029 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=38 time=1018 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=39 time=1046 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=40 time=963 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=41 time=1030 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=42 time=999 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=43 time=983 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=44 time=1015 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=45 time=1034 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=46 time=1603 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=47 time=1439 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=48 time=1029 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=49 time=995 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=50 time=1016 ms]
                    Summary
--------------------+--------------------------
Meas. packets       | 50
Meas. packet length | 1032
Lost packets        | 0
Packet loss         | 0%
Min. Time           | 963ms
Max. Time           | 1701ms
Avg. Time           | 1053ms
```

(a) Node to Neighbour latency



```
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=23 time=915 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=24 time=635 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=25 time=791 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=26 time=670 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=27 time=916 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=28 time=634 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=29 time=785 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=30 time=630 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=31 time=627 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=32 time=842 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=33 time=638 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=34 time=865 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=35 time=632 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=36 time=823 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=37 time=630 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=38 time=636 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=39 time=748 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=40 time=628 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=41 time=668 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=42 time=936 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=43 time=986 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=44 time=804 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=45 time=637 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=46 time=635 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=47 time=753 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=48 time=631 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=49 time=629 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:29af: seq=50 time=767 ms]
                    Summary
--------------------+--------------------------
Meas. packets       | 50
Meas. packet length | 1032
Lost packets        | 0
Packet loss         | 0%
Min. Time           | 626ms
Max. Time           | 986ms
Avg. Time           | 728ms
```

(b) Node to BR latency



```
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=19 time=1378 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=20 time=1613 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=21 time=1529 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=22 time=1559 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=23 time=1393 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=24 time=1264 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=25 time=1402 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=26 time=1348 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=27 time=1273 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=28 time=1425 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=29 time=1610 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=30 time=2385 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=31 time=2129 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=32 time=1591 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=33 time=1428 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=34 time=1395 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=35 time=1280 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=36 time=1374 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=37 time=1416 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=38 time=1271 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=39 time=1363 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=40 time=1384 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=41 time=1280 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=42 time=1386 ms]
[Destination is unreachable]
[Destination is unreachable]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=44 time=1277 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=45 time=1582 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=46 time=1670 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=47 time=1989 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=48 time=1751 ms]
[1032 bytes from aaaa:3456::b635:22ff:fe98:293b: seq=49 time=3710 ms]
                    Summary
--------------------+--------------------------
Meas. packets       | 50
Meas. packet length | 1032
Lost packets        | 2
Packet loss         | 4%
Min. Time           | 1264ms
Max. Time           | 3710ms
Avg. Time           | 1555ms

>
```

Figure 16: Latency with higher range

In the first scenario considered, the nodes were placed in close proximity with each other, and the ping together with packet losses were compare.

For the node to border router, the average ping is 782ms, while for the node to other node ping is 1053ms. It is evident that the ping to the border router has a much lower latency.

However, this was performed in a point-to-point scenario. To get a better understanding of the performance in multi-hop, it would be essential to enforce a multi-hop topology using creative methods. In theory, we should expect a reduction in latency and throughput when in multi-hop.

A test was also conducted to evaluate these metrics in a quasi-real world scenario, that is, by having the nodes separated throughout the campus. This led to an increase in latency, and eventual packet losses in certain measurement campaigns (1555ms and 4% loss) 16. An important thing to note however, is that one of the nodes was configured to send udp packets to the border router every 60s, so this might have had an impact on the performance.

5 Potential Use-Cases

Implementing a Wi-SUN network on the IMT Atlantique Rennes campus can significantly enhance both operational efficiency and the learning experience. Here are some potential applications

- Smart Campus Infrastructure
  - Smart Lighting: Wi-SUN enabled smart lighting systems can automatically adjust based on occupancy and natural light levels, reducing energy consumption and enhancing safety.
  - Environmental Monitoring: Sensors can monitor air quality, temperature, humidity, and noise levels across the campus, providing real-time data for maintaining a healthy and comfortable environment.
- Energy Management
  - Smart Metering: Wi-SUN connected smart meters can monitor and report on electricity, water, and gas usage in real-time, enabling more efficient resource management and identifying potential savings.
  - Demand Response Systems: These systems can adjust power consumption based on the grid's status, helping to balance load and reduce peak demand charges.
- Safety and Security
  - Smart Surveillance: Wi-SUN networks can support connected cameras and sensors for enhanced security monitoring, providing real-time alerts and improving incident response times.
  - Emergency Response Systems: Integrating Wi-SUN with emergency alert systems ensures timely communication during critical situations, enhancing overall campus safety.
- Campus Navigation and Accessibility
  - Wayfinding Solutions: Wi-SUN can support indoor navigation systems that help students, staff, and visitors find their way around campus buildings.

  - Accessibility Support: Devices connected through Wi-SUN can assist individuals with disabilities by providing real-time location-based services and alerts.

- Sustainable Practices
  - Waste Management: Smart bins connected via Wi-SUN can monitor waste levels and optimize collection schedules, reducing costs and improving recycling rates.
  - Water Management: Sensors can monitor water usage and detect leaks in real-time, promoting efficient water use and reducing wastage.

The above mentioned use cases could potentially improve the overall learning experience of students and professors alike. As a school that prides itself on innovation and being forward-thinking, these would further solidify its claims.

6 Optimizing Wi-SUN Coverage: A Project for the Future

This project successfully addressed the initial objectives, getting familiarised with the SiliconLabs Wi-SUN solution, evaluating core network functionalities, and exploring its potential applications for the IMT Atlantique Rennes campus. However, the design and deployment of the Wi-SUN network on the campus were not accomplished due to several challenges, including logistical constraints, technical hurdles, and time limitations. This section outlines a roadmap for future students to achieve this objective successfully. This presents a valuable opportunity for a future student to take the project a step further and achieve comprehensive coverage evaluation.

6.1 Building on the Foundation

The groundwork has already been laid. The understanding of Wi-SUN technology and the initial evaluations of range, power consumption, and scalability provide a strong foundation. Additionally, the identification of potential applications guides the future network design towards practical campus needs.

6.2 Pre-Deployment Planning

- Stakeholder Engagement: Engage with campus administration, IT department, and potential end-users to gather requirements and secure necessary approvals.
- Site Survey: Conduct a thorough site survey to identify optimal locations for network devices and ensure robust coverage throughout the campus.
- Resource Allocation: Secure the necessary resources, including hardware, software, and technical support from SiliconLabs.

6.3 Design Phase

- Network Architecture Design: Develop a detailed network architecture plan that includes the placement of routers, endpoints, and gateways to ensure optimal performance.
- Simulation and Testing: Utilize network simulation tools to validate the design and make adjustments based on simulated performance metrics.
- Security Considerations: Implement robust security protocols to protect data integrity and privacy within the network.

6.4 Deployment Phase

- Pilot Deployment: Start with a pilot deployment in a small, manageable area of the campus to test the network's functionality and identify potential issues.
- Scaling Up: Based on the pilot's success, gradually expand the network to cover the entire campus, ensuring that each phase is thoroughly tested and validated.
- Training and Documentation: Provide training sessions for IT staff and end-users to ensure smooth operation and maintenance of the network. Develop comprehensive documentation for future reference.

6.5 Post-Deployment

- Monitoring and Optimization: Continuously monitor the network's performance and make necessary adjustments to optimize range, power consumption, and scalability.
- Feedback Loop: Establish a feedback loop with end-users to gather insights and address any concerns promptly.

While the deployment of the Wi-SUN network on the IMT Atlantique Rennes campus was not achieved in the current project phase, the groundwork laid and the insights gained provide a strong foundation for future efforts. By following the outlined roadmap, future students can successfully accomplish this objective, leveraging the knowledge and resources accumulated during this project to enhance campus operations and learning experiences.

7 Conclusion

The implementation of a Wi-SUN network on the IMT Atlantique Rennes campus represents a significant step forward in leveraging IoT technologies to enhance educational environments. This project successfully introduced the SiliconLabs Wi-SUN solution, evaluated critical network performance metrics, and identified potential applications that could transform campus operations and learning experiences.

Despite the achievements, the final goal of fully designing and deploying the Wi-SUN network on the campus was not realized due to logistical and technical challenges. However, this project has laid a solid foundation for future endeavors. The comprehensive understanding of Wi-SUN technology, coupled with the initial performance evaluations, positions future students to overcome these challenges and achieve comprehensive network deployment.

The project underscores the transformative potential of IoT and Wi-SUN technology in educational institutions. By providing a clear pathway for future students to follow, it ensures that the vision of a fully connected, smart campus remains achievable. Embracing these technologies not only optimizes campus operations but also enriches the learning experience, making IMT Atlantique a pioneer in educational innovation.

Through dedicated effort and collaboration, future students can build on the groundwork laid in this project, achieving the ultimate goal of deploying a comprehensive Wi-SUN network on the IMT Atlantique Rennes campus. This endeavor will undoubtedly set a precedent for other educational institutions to follow, showcasing the profound impact of IoT in transforming educational environments.

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