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Implementing A Sensor Network With Mesh Technology

Metropolia University of Applied Sciences

Bachelor of Engineering

Electronics

Bachelor's Thesis

June 2020

Metropolia
University of Applied Sciences

Author Title Number of Pages Date	Roshan Dangal Implementing a sensor network with mesh technology 26 June 2020
Degree	Bachelor of Engineering
Degree Programme	Electronics
Professional Major	
Instructors	Anssi Ikonen, Senior Lecturer

The aim of this thesis work was to develop and build a functional sensor network system which takes environmental measurements with three end nodes and collects the data to gateway node to be published to a selected cloud service for further analysis and monitoring. This thesis work was commissioned by Metropolia University of Applied sciences, Department of Electronics Engineering located in Myyrmäki, Vantaa Finland.

Particle mesh was used to create and implement a sensor network and various mesh network technologies were studied. The project was based on the fully integrated IoT kit particle Argon. The measurement is taken by three end nodes which collect the data to gateway node to be published to a selected cloud service for further analysis and monitoring. The Particle Argon is equipped with the Nordic nRF52840 and Espressif ESP32 processors as its brain and Espressif ESP32-DOWD 2.4 GHz Wi-Fi coprocessor as its connection to the internet. Thus, the device operates entirely under Wi-Fi network.

This thesis can be used to create a small area sensor network which can take environmental measurements using particle mesh. The IoT hardware Particle Argon has its own IoT Device Cloud and IoT apps platforms. These IoT Cloud and IoT Apps are safe and operated platform delivers the visibility and command over the model. The entire code for various sensor circuits was written in C++ programming language in particle Web IDE. The measurement values can be monitored in mobile devices using particle application.

Keywords	Sensor, Mesh Technology, Particle Argon, Particle IDE, IoT

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List of Abbreviations

AP	Access Point
BSS	Base Station System
IP	Internet Protocol
IoT	Internet of Things
BLE	Bluetooth Low Energy
IPv6	Internet Protocol Version 6
VDC	Voltage Direct Current
ZCL	ZigBee Cluster Library
OS	Operating System
IDE	Integrated Development Environment
PCB	Printed Circuit Board
OTA	Over The Air
NLOS	Non-Line Of Sight Propagation
OSI	Open Systems Interconnection
AES	Advanced Encryption Standard
IEEE	Institute of Electrical and Electronic Engineers
LiPo	Lithium Polymer
DC	Direct Current

AC	Alternating Current
RP-SMA	Reverse Polarity Sub Miniature
SWD	Serial Wire Debug
iOS	iPhone Operating System
CLI	Command Line interface
QR	Quick Response
LED	Light Emitting Diode
URL	Uniform Resource Locator
HTML	Hyper Text Markup Language
GPIO	General Purpose Input Output

1 Introduction

Small area sensor networks are greatly in use for monitoring various environmental measurements like temperature, humidity, proximity, sound, vibration, pollution and pollutants. The constant monitoring of these parameters in the field of electronics, biomedical, pharmaceutical, and agricultural industries is crucial. The application of wireless sensor networks is critical in many fields such as area monitoring, health applications, transportation, environmental sensing, industrial monitoring, agricultural sector and many more.

By implementing wireless sensor networks these parameters can be observed and analyzed through the network remotely, the base station or a sink performs as an interface between the users and the network. All the required data can be retrieved for the network by injecting queries and gathering results from the sink. Mostly a wireless sensor network contains various sensor nodes. The sensor nodes can communicate among themselves using radio signals. Every single node has a fixed communication bandwidth, processing speed and storage capacity in a wireless sensor network.

Considering the importance of measurement and control of various environmental measurements the goal of this project was to develop a functioning sensor network and implement using Particle mesh technology. The measurement is taken by three end nodes which collects the data to gateway node to be published to a selected cloud service for further analysis and monitoring.

The Particle Argon is equipped with the Nordic nRF52840 and Espressif ESP32 processors as its brain and Espressif ESP32-DOWD 2.4 GHz Wi-Fi coprocessor as its connection to the internet. Thus, the device operates entirely under Wi-Fi network. The IoT hardware Particle Argon has its own IoT Device Cloud and IoT Apps platforms. These IoT Cloud and IoT Apps are safe and operated platform that delivers the visibility and command over the model. This feature improves with the functionality to evaluate and monitor the device remotely.

The aim of this thesis work was to develop a functional sensor network using Particle IoT device Argon, along with study the Particle mesh technology, study of particle mesh protocol and comparing its protocol with other mesh technologies like ZigBee and BLE. Moreover, this technology is widely implemented in the areas like medical, industrial, military, and many more.

2 Theoretical Study on Wireless Sensor Networks

The tiny computers which works jointly to create a network are called nodes. A sensor network includes a large number or sensor nodes, these networks cover a wide range of spatially distributed embedded devices which receive, process and transfer the data to the users. The network of nodes covers a large number of embedded devices which are connected to collect, process and transfer the data to the user. The ability to processing and computing are also controlled.

2.1 Particle Mesh Technology

In this chapter an overview of particle mesh is explained, along with a short description of wireless mesh technology. Particle Mesh is a wireless mesh technology was established on the Thread networking protocol which have intention to connect the spacing among Wi-Fi and Cellular arrangements with the help of local networks.

Particle mesh is cost effective, safe and trustworthy. Most of the current IoT networks cannot connect all portions of the curious places and spaces to which users want to connect with. Hence, there is a necessity of new system which have better connectivity to reach places like remote pipelines without available Wi-Fi infrastructure, subterranean systems where cellular signals cannot reach. Particle Mesh is designed for cellular or Wi-Fi connected equipments which can achieve advantage by adding sensors or add-ons. Giving all the added sensors an independent internet connection might cost high amount, for this purpose particle mesh creates a path for the secondary product line to be easily available to the system connected through a local network to the central device.

The Wi-Fi sometimes is consuming power in high amount and Bluetooth is less efficient but can be great in point to point and data flow between a distributed network system. Those hard to reach places can be reached by the mesh radios, which enables building a local network wherever and whenever needed.

Thread is a protocol to easily and safely connect various home appliances. It seems complicated but still is user friendly. Thread has solved the connectivity issues that IP based protocols have. Some of the main advantages of wireless mesh networks are as follows:

1. Simple installation: Mesh nodes are very simple to operate and assemble, hence users can easily add new nodes to extend the ability and coverage of wireless network.
2. Cost-effective: In mesh systems the wire cables are used in minimum amount, which removes the huge cost of cables and installment procedure.
3. Non line of sight (NLOS): Wireless mesh technology has huge application in outdoor and public places because NLOS configuration is easily used
4. Adaptable and stable structure: Since devices are sharing the same Access points, when multiple devices use the same network the system will slow down. But the devices can be connected from different nodes and system have very minimum chance to slow down and data delaying because of router failures.
5. High bandwidth: Bandwidth is many times a problem in a system. The strength of signal is directly proportional to the transmission distance and the coverage area of single center mode is limited. Since the non-line of the sight transmission of the wireless mesh network is improved the network strength is also improved, the summed bandwidth is easy to increase. The power requirement in wireless mesh system is minimum which promotes energy saving. Figure 1 explains the OSI layers of Thread protocols and properties of thread protocol.[2]

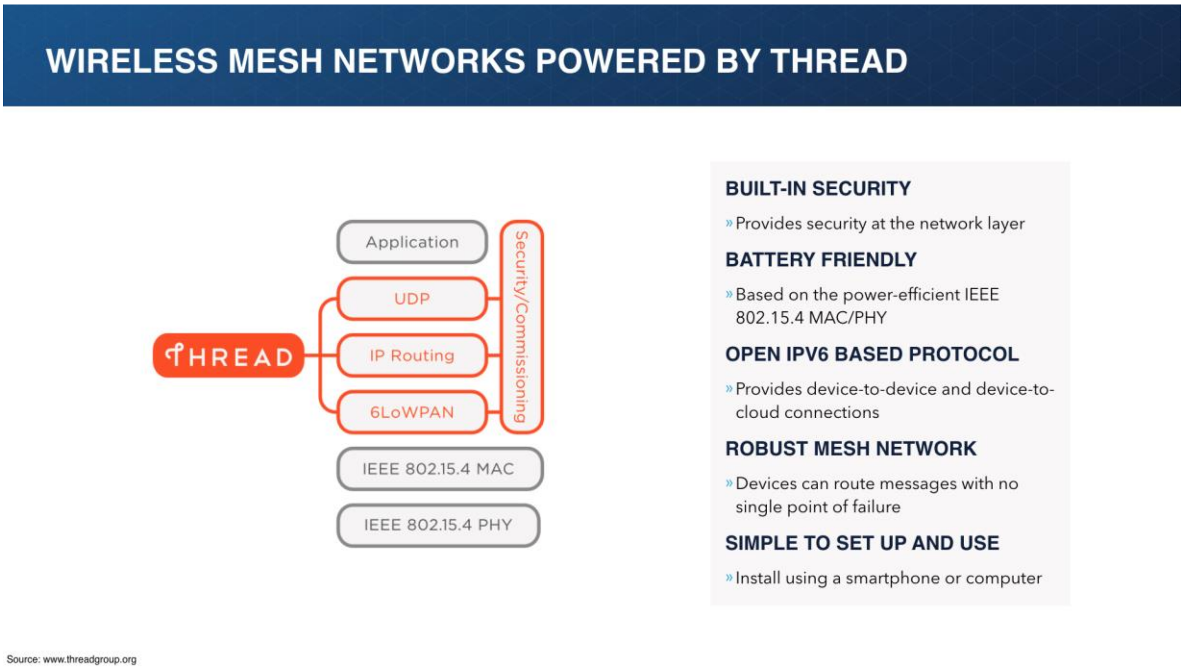


Figure 1. OSI layers of Thread Protocols [2]

Particle Mesh network is composed of three components, which are Gateway, Repeater and Endpoint. Passing of data over network is allowed by border routers which are the devices with additional connections over mesh and are gateway. The data forwarding is performed by routers which is not designed to sleep as it is a part of mesh network foundation. End devices do not route data for other devices in mesh network and are mesh only devices. They may go to sleep mode because they have minimum networking duties to perform. Since end devices can go to sleep, they are economic in terms of battery saving and they are suitable for battery powered nodes and sensors. Below the Figure 2 explains various components of mesh network.

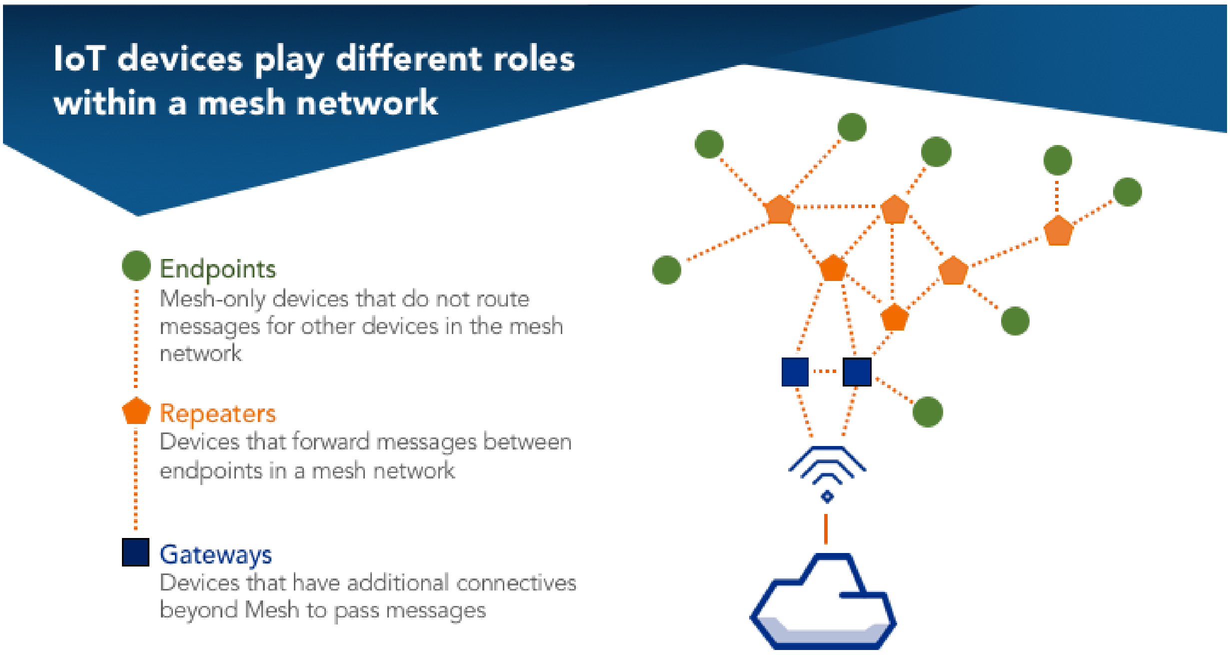


Figure 2. Components of mesh network [2]

2.2 Common Protocols for Local Area Sensor Network

There are various protocols which can be used to establish a connection in the internet. Protocols defines the characteristics of a connection. Protocols can be termed simply as a set of rules. They define conventions and rules for the communication. They combine all process requirements and implement communication between servers, routers, computers, and other internet connected devices.

2.3 Thread

At particle mesh Open Thread is implemented because of its flexibility. Open thread is one of the most used thread implementations. It is suitable for IoT developers. With thread IoT devices can communicate through radio frequencies, power lines or combination of both. Thread is the only mesh technology which is based on IPv6 which enables addressability and end routing across the networks or on the same network.

Some of the key points to implement Open Thread in particle mesh are network deployment, secure by default and local management. Only authorized devices can be connected in open thread. There is an extra layer with extra security until cloud. It provides APIs to set mesh networks commission equipments and handle local network communication. The state of the local network and the way local network report their network are specified in open thread. Because of these characteristics the state of the network system can be observed from anywhere.

2.4 Zigbee

Zigbee is ideal for home automation, data collection in medical gadgets as it gives up blueprint for standard local area network using low power and small digital radios. Zigbee is an IEEE 802.15.4 standard. Mostly ZigBee can be placed as a bridge among installed sensor and control system for communicating. Zigbee is usually used in short range data flow as its typical range is 10-100 meters.

Generally, ZigBee has three parts, which are coordinators, routers and end device. The equipments like actuator and sensor which are in the system are end devices. The base and the bridge of the network system is coordinators. There needs to be at least one coordinator in the network system. The storage and data transfer operation is also done by coordinators. The Routers helps coordinator for transferring messages among coordinator and end devices. The implementation of the system can be star or mesh as per the situational demand. [3]

The figure 3 below shows how ZigBee nodes are implemented in mesh network.

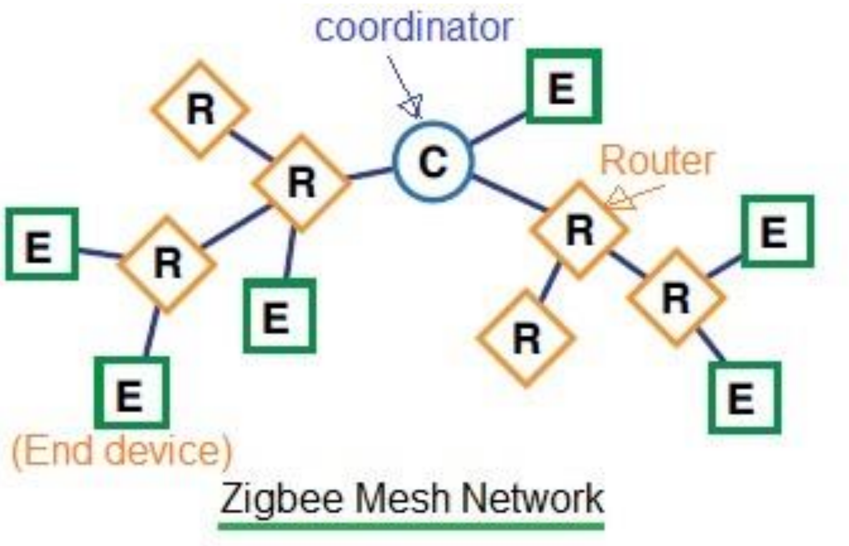


Figure 3. Zigbee mesh network[3]

2.5 Bluetooth Mesh

Bluetooth mesh was officially made available in market by July 2017[3]. It plays an important role in IoT connectivity space. Bluetooth have wide range of application. Mainly it has been implemented is consumer electronics like tablets, laptops and mobile phones. Bluetooth is leading the short-range technology in order to connect nodes within capillary network. Low power sensors are enabled to communicate with the remote capillary gateways because of the addition of mesh in Bluetooth. The local area network which uses short radio access technologies to provide a set of equipment with broad area connectivity is called capillary networks. The figure 4 below presents the concept of Bluetooth capillary gateway [9]

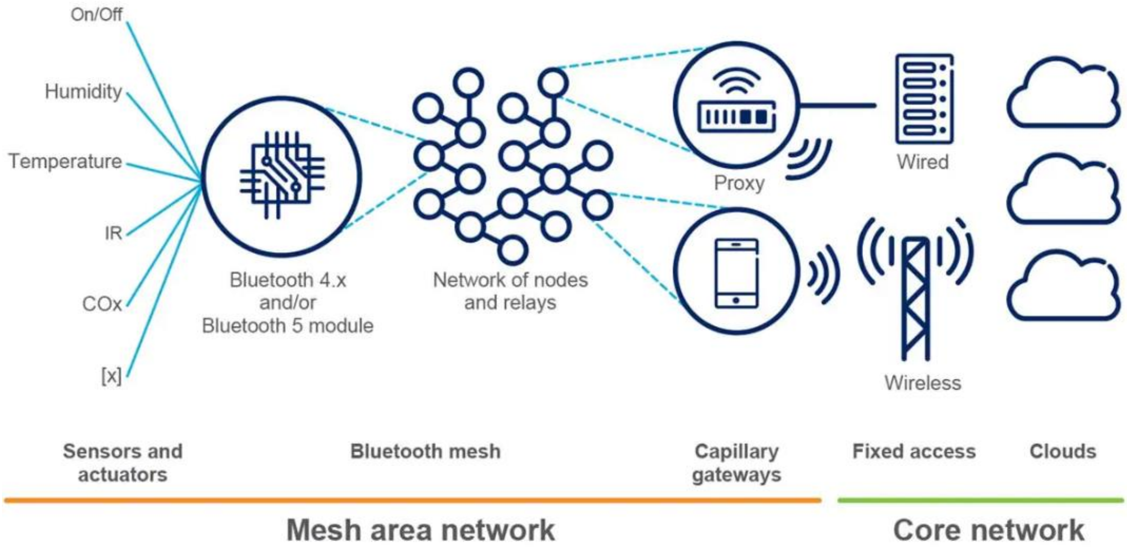


Figure 4. Bluetooth mesh network capillary gateways [9]

The multiplicity of user situation which needs sensing and actuation command for constraint nodes are standardized by Bluetooth as a capillary radio. The communication between nodes which are not within radio reach of each other are also enabled by the relaying of these commands over multiple hops in the mesh.

2.6 Comparison Of Protocols

Every protocol has been designed with its own set of unique character and purpose, depending on the case scenario and operational necessity. Every protocol succeeds in the main areas of its own like throughput, power consumption, security and scalability. Thread, Bluetooth and Zigbee mesh works similar within small payloads. When throughput and payload need to increase Zigbee and Thread can be used. Latency might increase for all three protocols when network size expands but Bluetooth have the biggest rise. Optimization of larger Bluetooth mesh networks can be done by using relay optimization. The best situation of Bluetooth mesh application is when short messages are used, mainly in multicast messages. As matter of fact, no mesh protocol is winning, performance differs as per the situational demand.

As a conclusion of mesh performance study, the network size, reliability, required latency, desired throughput are the vital factors choosing the appropriate protocol. Table 1 below shows the comparison of various mesh technologies.

Table 1. Comparison of various mesh technologies

	Particle Mesh (Thread)	**Bluetooth Mesh**	**Zigbee**
Application Layer	Flexible support for IP based application layers like dotdot, OCE and Nest weave	Native Mesh model	Comprehensive Zigbee Cluster Library (ZCL)
Market focus	Commercial	Lighting and home automation	Home Automation, Lighting and metering
Maturity	Established in 2015	Established in 2017	Established in 2003
IPv6	Yes	No	No
Cloud Connectivity	Border Router Gateway	Smartphone Gateway	Gateway
Security	AES symmetric encryption	Mandatory Security	AES 128 bit symmetric encryption
Ecosystems	Nest	None	Amazon, IKEA Philips HUE, Samsung Smart things, Lowes Iris, WinCox, Rogers, Deutsch Telekom and others
Routing	Full Routing	Managed Flooding	Full Routing
Frequency Band	2.4 GHz	2.4 GHz	2,4GHz
Max number of devices in each mesh Network	32	Over 1600	6500

Range	More than 100 meters	Around 100 meters	10-100 meters
Data rate	250 kbps	Up to 1 Mbps	250 kbps

3 Introduction To Hardware Used In Platform Development

The hardware from Particle, Argon and Xenon which were used in this thesis are explained below.

3.1 Particle Argon

In this chapter overall details of the particle Argon are explained. The Argon acts as a standalone Wi-Fi endpoint of Wi-Fi enabled gateway in particle mesh and is a rigid Wi-Fi enabled development board. It is based on the Nordic Semiconductor nRF52840 SoC. It has built in battery charging system, easy to connect a LiPo and deploy the local area network Connecting ongoing projects to the Particle Device cloud or as a gateway to connect a whole group of local endpoints have been very simple by the help of Argon.

The Argon has on board a microcontroller, which is a small, low-cost, low-power computer that can run a single application. The microcontroller runs the show; it runs your software and tells the rest of the Argon what to do.

Microcontrollers are particularly good at controlling things, hence the name. They have a set of “pins” that are called GPIO (General Purpose Input and Output) pins, or I/O pins. They can be hooked to sensors or buttons to listen to the world, or they can be hooked to lights and motors to act upon the world. These microcontroller’s pins have been directly connected to the headers on the sides of the Argon, specifically, the pins labelled D0 to D7 and A0 to A5 are hooked directly to the microcontroller’s GPIO pins. The Argon has 24 pins that can be connected in a circuit. These pins are:

- VUSB: For powering the Argon off an unregulated power source with a voltage between 3.6V and 6V. When powering the Argon over USB, this pin can be used as 5V V-Out to power external components. Powering the Argon via USB and V-in at the same time should be avoided.

- Li+: This pin is internally connected to the positive terminal of the LiPo battery connector
- 3V3: This pin will output a regulated 3.3V power rail that can be used to power any components outside the Argon
- GND: These pins are your ground pins.
- RST: Argon can be reset (same as pressing the RESET button) by connecting this pin to GND.
- D2 to D8: GPIO (General Purpose Input/Output) pins. They're labelled "D" because they are "Digital" pins, meaning they can't read the values of analog sensors.
- A0 to A5: These pins are 6 more GPIO pins, to bring the total count up to 16. These pins are just like D2 to D8, but they are "Analog" pins, which means they can read the values of analog sensors (technically speaking they have an ADC peripheral). As with the Digital pins, some of these pins have additional peripherals available. A0-A5 are PWM-able
- TX and RX: These pins are for communicating over Serial/UART. TX represents the transmitting pin, and RX represents the receiving pin.
- SDA & SLC: Primarily used as data pin and clock pin for I2C, but can also be used as a digital GPIO.
- MO, MI & SCK: Primarily used as SPI interface pins, but can also be used as a digital GPIO.

Figure 5 shows the block diagram of Argon.

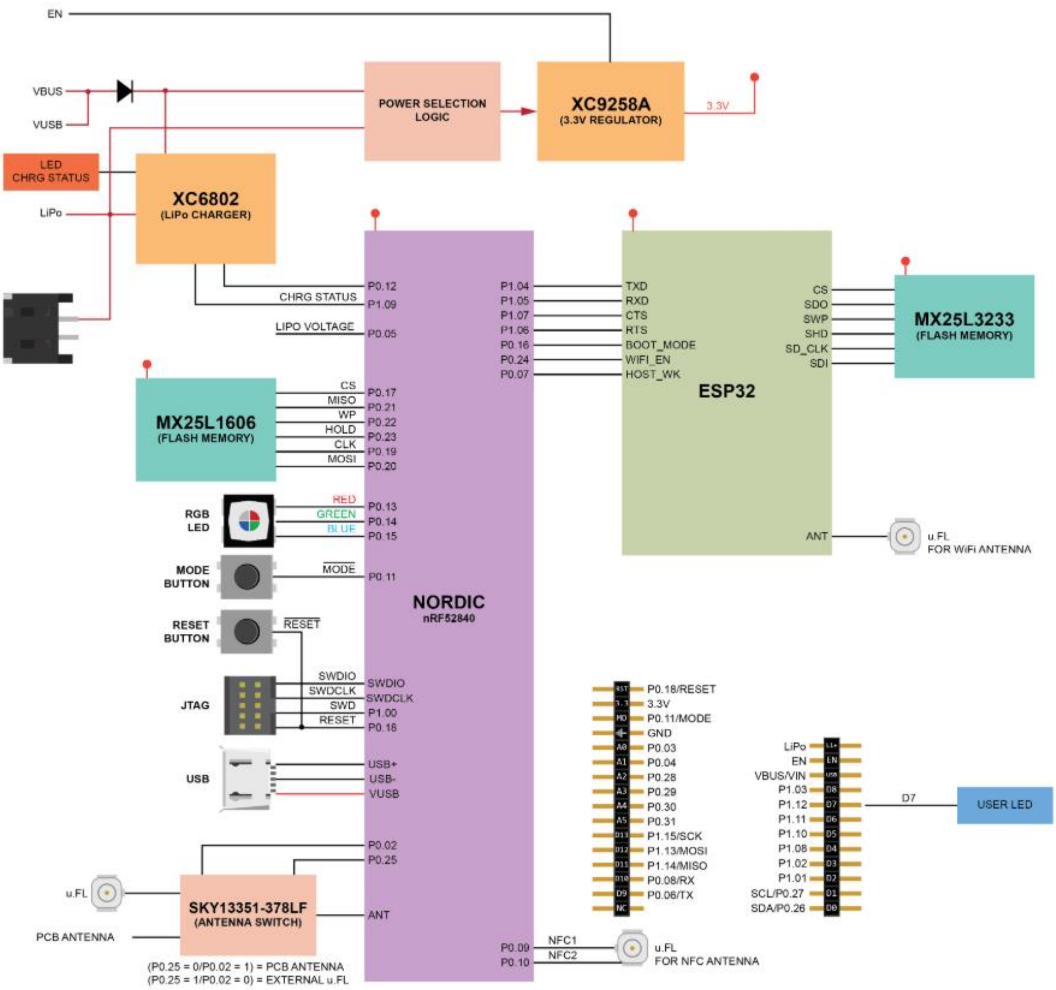


Figure 5. Block diagram of Argon[4]

Power to Argon can be provided in various ways. The easiest way is via USB port which can provide a minimum of 500mA. The step-down regulator will maintain power from the USB down to 3.3V by on board Torex XC9258A.Other ways to provide power are VUSB pin, LiPo, Li+ Pin and 3V3 pin. When providing power via VUSB pin minimum output voltage must be 5 VDC and maximum current is 500mA. The input voltage on Li+ pin must be 3.6 to 4.2 VDC. 3V3 pin can be used power Argon when other pins are not working. While giving power through this pin the enable pin needs to be connected to the ground so that the regulator is disabled. Figure 6 below shows power supply to Argon via LiPo. [4]

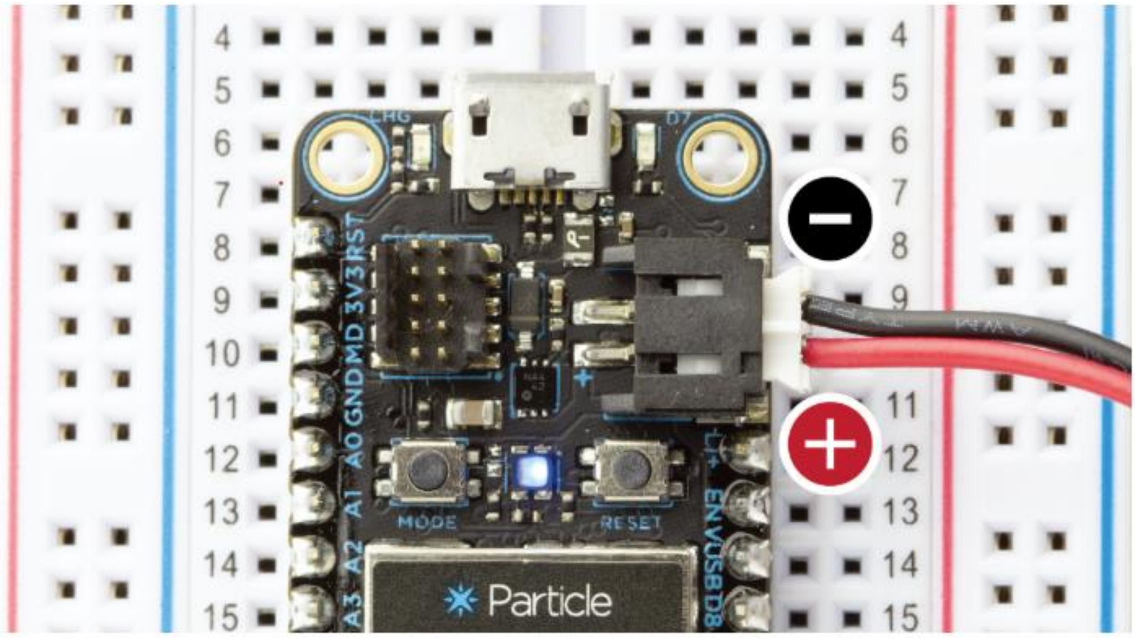
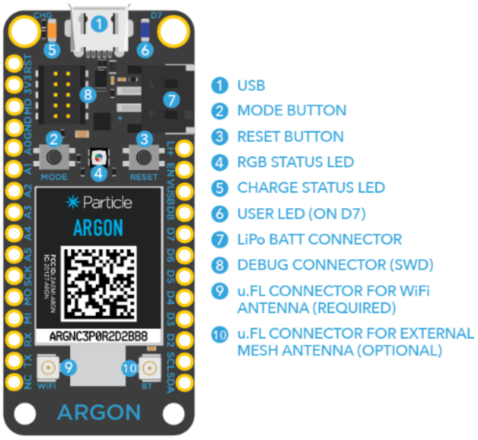


Figure 6. Power supply to Argon[4]

3.1.1 Antenna

The Argon consists of two kinds of radio antenna: a BLE radio antenna (nRF52840) and a Wi-Fi radio antenna (ESP32). To use Wi-Fi in the Wi-Fi radio, a u.FL connector needs to be plugged in the Wi-Fi antenna. BLE antenna comes with PCB antenna which is default in the device OS, whereas u.FL connector is used if it is needed to connect an external antenna. It is important to issue an appropriate command in the firmware if external antenna is used. It is also possible to use most antennas designed for Wi-Fi (2.4 GHz) as a BLE antenna and in some situations, a u.FL to RP-SMA adapter will be needed. Figure 7 shows pin markings of Argon top view and bottom view respectively.



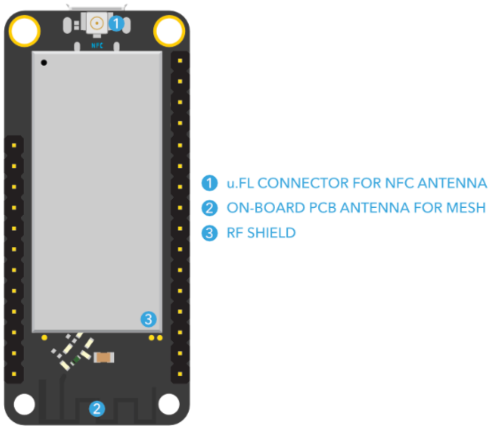


Figure 7. Pin markings top view and buttom view [4]

3.1.2 Connectors

There are four connectors on the Argon that might get damaged with wrong handling. The JST connector on the circuit board, which is connected in the LiPo battery, is durable but the connector on the battery itself is not.

The micro B USB connector on the Argon is soldered on the PCB with longer surface pads along with couple of through hole anchor points. Even with this reinforcement, it is very easy to break out the connector if too much pressure is put on in the vertical direction. The U.FL antenna connector is not meant to be constantly plugged and unplugged. The antenna pin is static sensitive and can be destroyed with improper handling. A tiny dab of glue (epoxy, rubber cement, liquid tape or hot glue) on the connector can be added to securely hold the plug in its place.
The 10 pin SWD connector gives an easy in-system debugging access to the equipment. The pins on the connector can easily be broken if the mating connector cable is connected in a wrong way.

3.1.3 Default Settings

The Argon is pre-programmed with a bootloader and a user application called Tinker. This application performs with an iOS and Android app also named Tinker that allows very easily toggle digital pins, take analog and digital readings, and drive variable PWM outputs.
The bootloader provides update to the user application via several different methods, USB, OTA, Serial Y-Modem, and internally through the Factory Reset procedure. [4]

3.2 Particle Xenon

3.2.1 Overview

The Xenon is a cost-effective mesh-enabled development board that can perform as either an endpoint or repeater within a Particle Mesh network.
The Xenon is mesh only and created to work as the endpoint of IoT network. It is built on the Nordic nRF52840 and has built-in battery charging circuitry so it’s simple to connect a Li-Po and deploy to the local network quickly.
The Xenon is excellent when connecting sensors, motors, pumps, valves, and points of data-interest. Top and bottom view of Argon pins marking is shown in Figure 8.

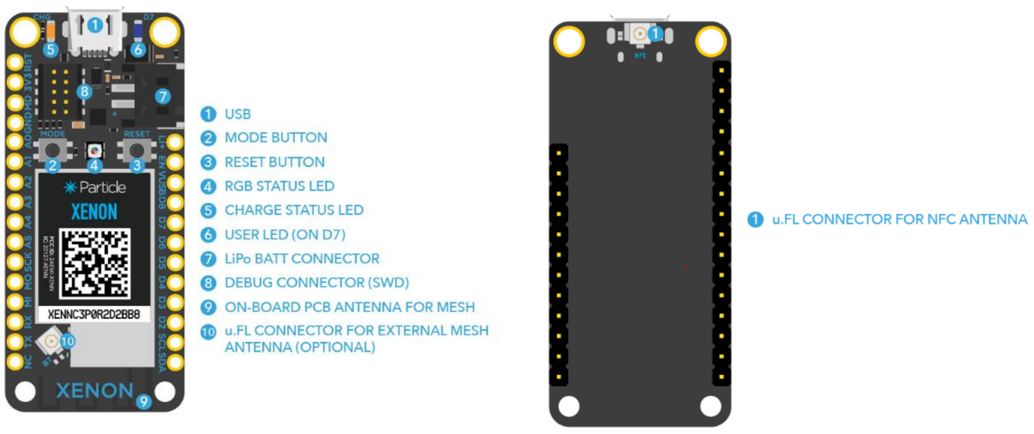


Figure 8. Xenon Pins marking top view and bottom view [5]

3.2.2 Power

Powering up the Xenon is similar as of Argon. It can be powered with USB port, VUSB pin, LiPo, Li+ Pin and 3V3 pin. There are two choices for the Mesh antenna on the Xenon. It comes with an on-board PCB antenna which is chosen by default in the device OS and a u.FL connector if needed to connect an external antenna. If the external antenna is used, it is necessary to issue an appropriate command in the firmware. It is also available to use most antennas designed for Wi-Fi (2.4 GHz) as a mesh antenna. For example, duck or even Yagi antennas for longer range can be implemented. In some cases, a u.FL to RP-SMA adapter will be needed.[5]

4 Software

Under this Chapter various software and platform used in the project are described. This project works primarily on particle Integrated Development Environment (IDE). IDE provides a platform to create an application, where the code can be written, edited and viewed at this stage. The particle provides three various platform for developing an application, which are Web Integrated development Environment, Desktop Integrated Development Environment and Command Line Interface. Screenshot of particle web IDE is shown in Figure 9.

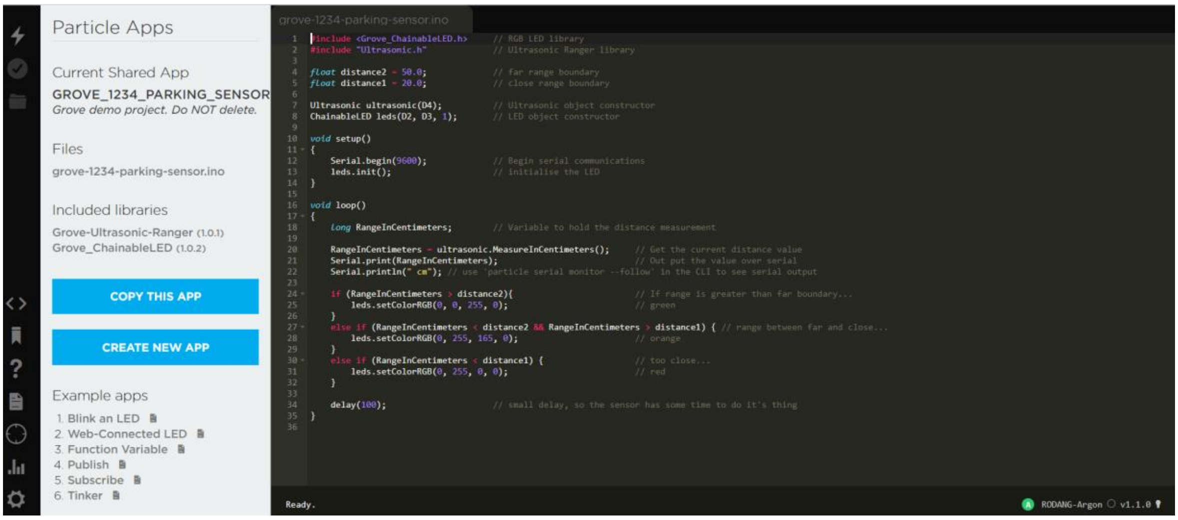


Figure 9. Screenshot of the particle web IDE

Particle web IDE can be accessed globally. To say this means the application can be compiled, developed, flashed and debugged from anywhere in the world with internet access. On the other hand, Particle's desktop IDE consists of modern functions for organizing complicated projects easily. However, the platform needs internet access to compile the files because the development tool is completely online. The desktop IDE is quite easy to get on most devices like Windows, Linux and MacOS. A powerful software for the interaction with cloud and device is used by CLI which is called Node.js. It enables uploading the program via cloud to the particle's devices within created Wi-Fi module. In addition, the program can also be uploaded through USB cable. The uploading process details can be seen in the device screen.

Particle IDE is similar to Arduino IDE i.e. both of these IDE are based on wiring (software abstraction).The coding language is based on C++ so virtually all Arduino code are compatible to particle IDE with some little changes. The program developed in this platform is called Application which has file extension name .ino which is same as in Arduino. This application normally has two main functions: Setup and Loop. The setup function is used for the initialization of input/output pins and variables which runs only once while the loop function runs repeatedly until the program is finished. This software is outfitted with large number of public guided libraries and illustration codes.

Particle mobile application

A mobile application available in windows, android, and IOS is provided by particle. This application is handy and easy to use. This application controls the particle devices and monitor the device event streaming without writing any codes. Screenshot of particle mobile app is shown in Figure 10.

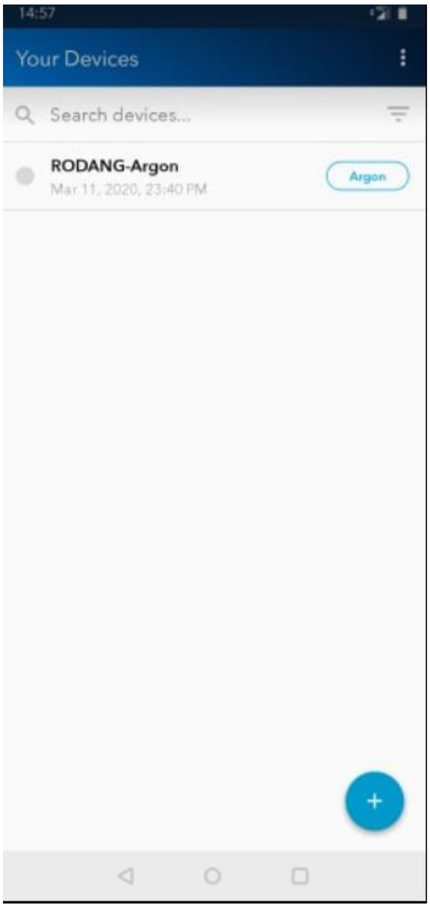


Figure 10. Particle mobile app

5 Instructions On Building Up A Sensor Network With Particle Mesh

Before starting to build any mesh network with the help of particle mesh, first the devices need to be set up. Below is described how to set up Argon and Xenon devices. Setting up of Argon and Xenon devices are very similar.

5.1 Setting Up The Argon and Xenon

First step is to activate and configure Argon and Xenon devices, we need to have Wi-Fi antenna, cable, Argon device itself and particle IoT application in your gadget, either on a phone or computer. Argon should be connected to power via USB cable or any other way of powering. Wi-Fi antenna is also needed to connect with Argon. Once all the set up are ready, open the IoT application in your gadget it then scans the QR code and gives instruction. In the beginning as per instruction Argon was supposed to blink blue but mine was blinking green so I pressed continuously the mode button (left to the led) and it started to blink blue. Here one thing to keep in mind the device will not connect in the gadget unless it turns out blue. When its blinking blue, that means it is in listening mode and is ready to be configured.

Now the mobile device should have Bluetooth on before logging in to the particle application. Add the new device by following the instruction provided by the application. Next step will be to connect the Argon to local available Wi-Fi network, for this click next and the application will search the local Wi-Fi networks available, click on your Wi-Fi and put the password to connect to Wi-Fi. Once the password is provided the application will connect the Argon device to the cloud server. Once done it will ask to give a name to the device and is ready to be used. Once devices are set up it is possible to program the devices and send over the air (OTA) updates to them.

5.2 Hardware Assembly

Led, Photo transistor and two 220 ohm resistors were connected to form a circuit as shown in the schematic on the below Figure 11.

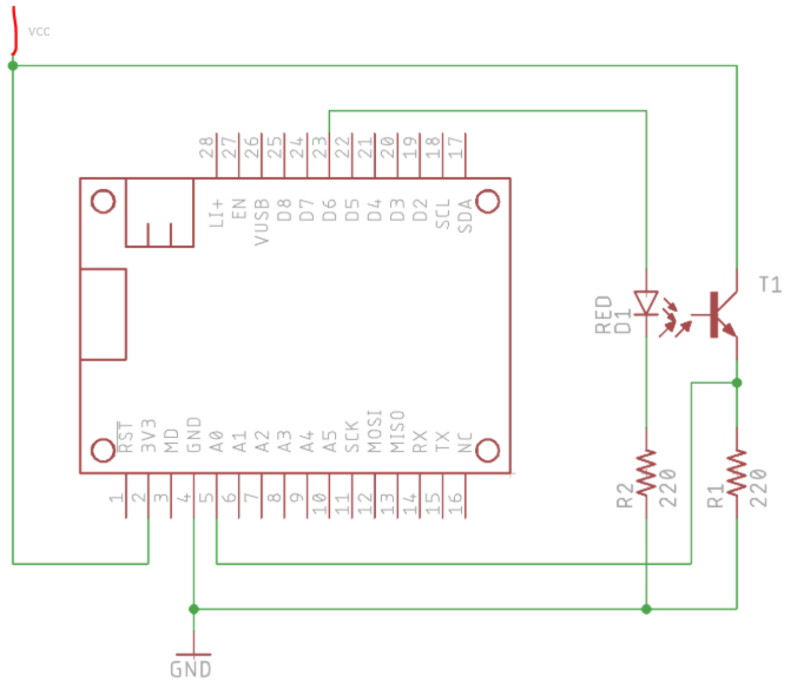


Figure 11. Schematic for blinking LED using Argon

5.3 Programming The Devices

Once the desired schematic circuit is ready an application needs to be created in the particle web IDE. Particle devices can be coded easily from everywhere at web IDE. A desired application needs to be crated at particle web IDE. The particle web IDE provides large number of example codes and community driven libraries. Programming for Argon and Xenon using particle web IDE is very simple and convenient. Below is the example code for Xenon and Argon.

```
int boardLed = D7; // This is the LED that is already on your device.
```

```
void setup() {
  // This part is mostly the same:
  pinMode(boardLed,OUTPUT); // Our on-board LED is output as well
}
// Now for the loop.

void loop() {
        Mesh.publish ("beam", "broken");
        digitalWrite(boardLed,HIGH);
        delay(500);
        digitalWrite(boardLed,LOW);
        Mesh.publish ("beam", "fixed");
        delay (5000);
}
```

Listing 1. Xenon code

```
int led1 = D7; // Instead of writing D0 over and over again, we'll
write led1

void beamAction(const char *event, const char *data) {

   if (strcmp (data, "broken")==0) { digitalWrite (led1, HIGH);}
   if (strcmp (data, "fixed")==0) { digitalWrite (led1, LOW);}

    Serial.println (data); //Use e.g. Arduino serial monitor to show
data on PC
}

void setup() {

  pinMode(led1, OUTPUT);
  Serial.begin(9600); //Serial port at 9600bps
  Mesh.subscribe ("beam", beamAction);
```

```
}


void loop() {

  // Wait 1 second...
  delay(1000);

}
```

Listing 2. Argon Code

All the device activities can be monitored remotely from mobile application. Screenshot of Argon activities shown in mobile application is shown is Figure 13. Here a circuit was created which changes the LED state based on the amount of light detected by the photo transistor.

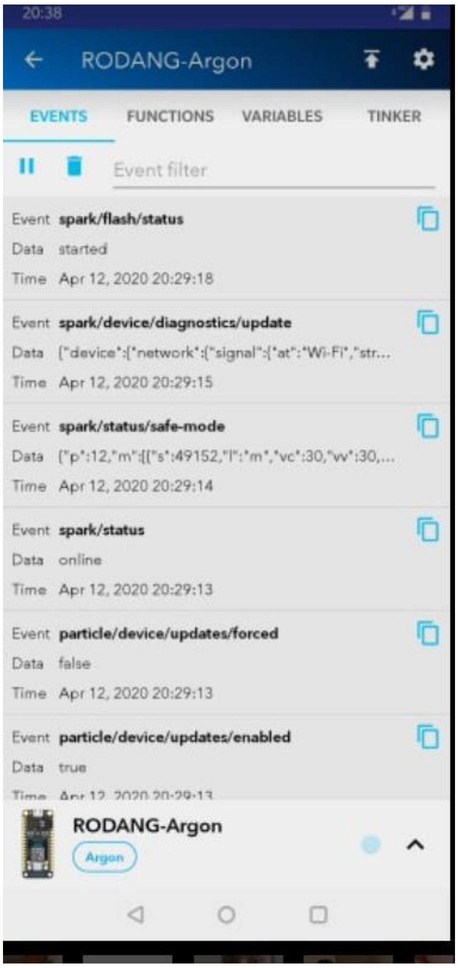


Figure 12. Screenshot of the Argon activities

6 Conclusion

The main aim of this thesis was to create and implement a sensor network using particle mesh technology. The IoT components used in this project are particle Argon and Xenon.

The particle hardware, Argon and Xenon come with the IoT device Cloud and IoT apps. These devices are of great use to take environmental measures and can be modified for various purposes. The particle Xenon is a mesh and Bluetooth development kit while particle Argon is a development kit with Wi-Fi and Bluetooth radios for building connected projects and products.

The brief instructions of creating a sensor network using Xenon and Argon is explained in this report. Moreover, protocols of other mesh networks like ZigBee and BLE was studied and compared with Thread protocols.

Even though Argon and Xenon devices were successfully coded, connected and a simple circuit was created, a fully functional sensor device could not be developed because of the current pandemic as the laboratories are closed.

Overall, it was a great experience doing this thesis work as I got more information about mesh technology, sensor network and particle IoT. Also, my writing skills and knowledge are improved from this thesis. Although this thesis work is completed, I am still working on this project to develop a proper functional sensor device.

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