Low Power IoT Architectures

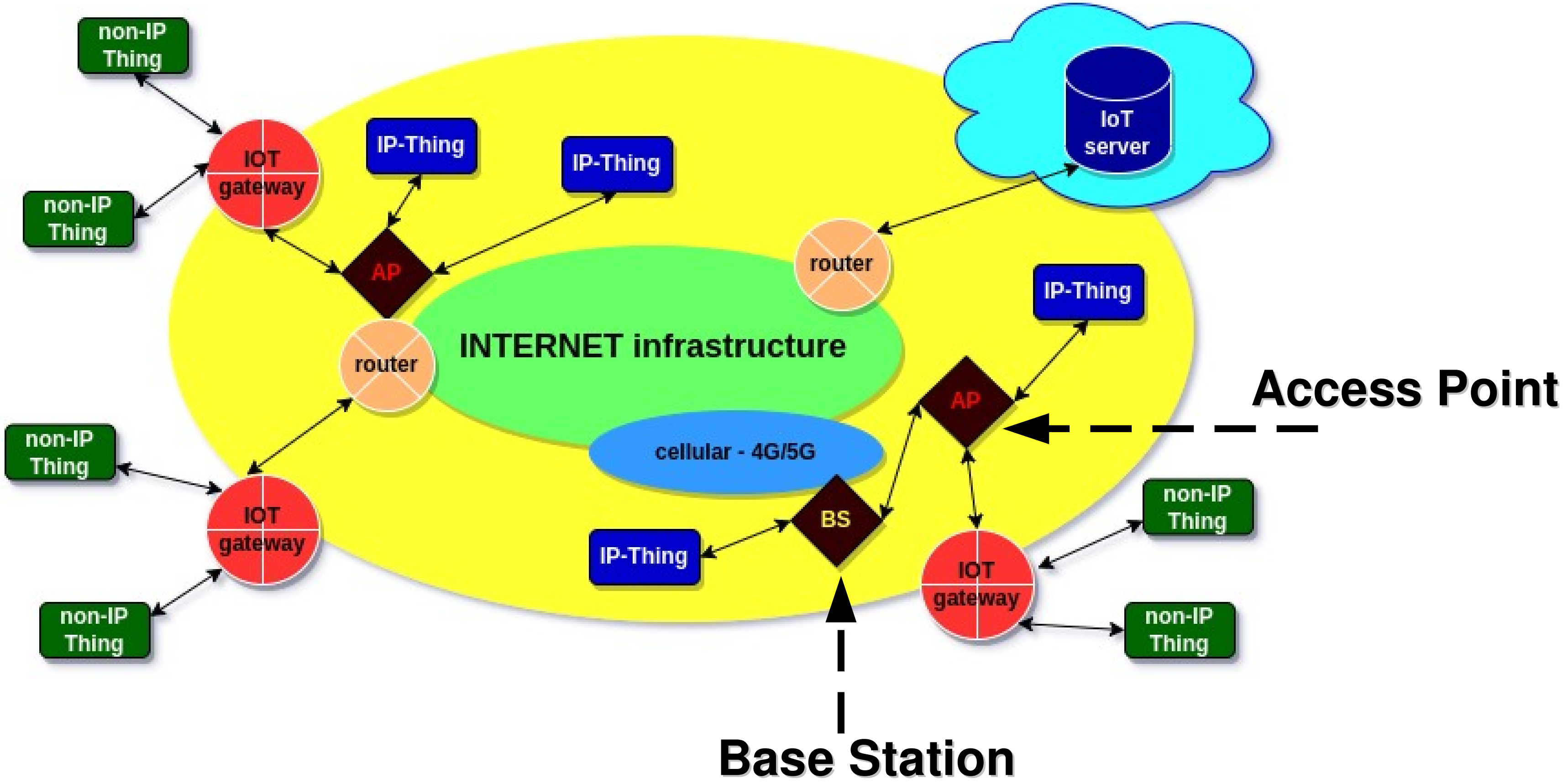
SmartComputerLab

Low Power IoT Architectures

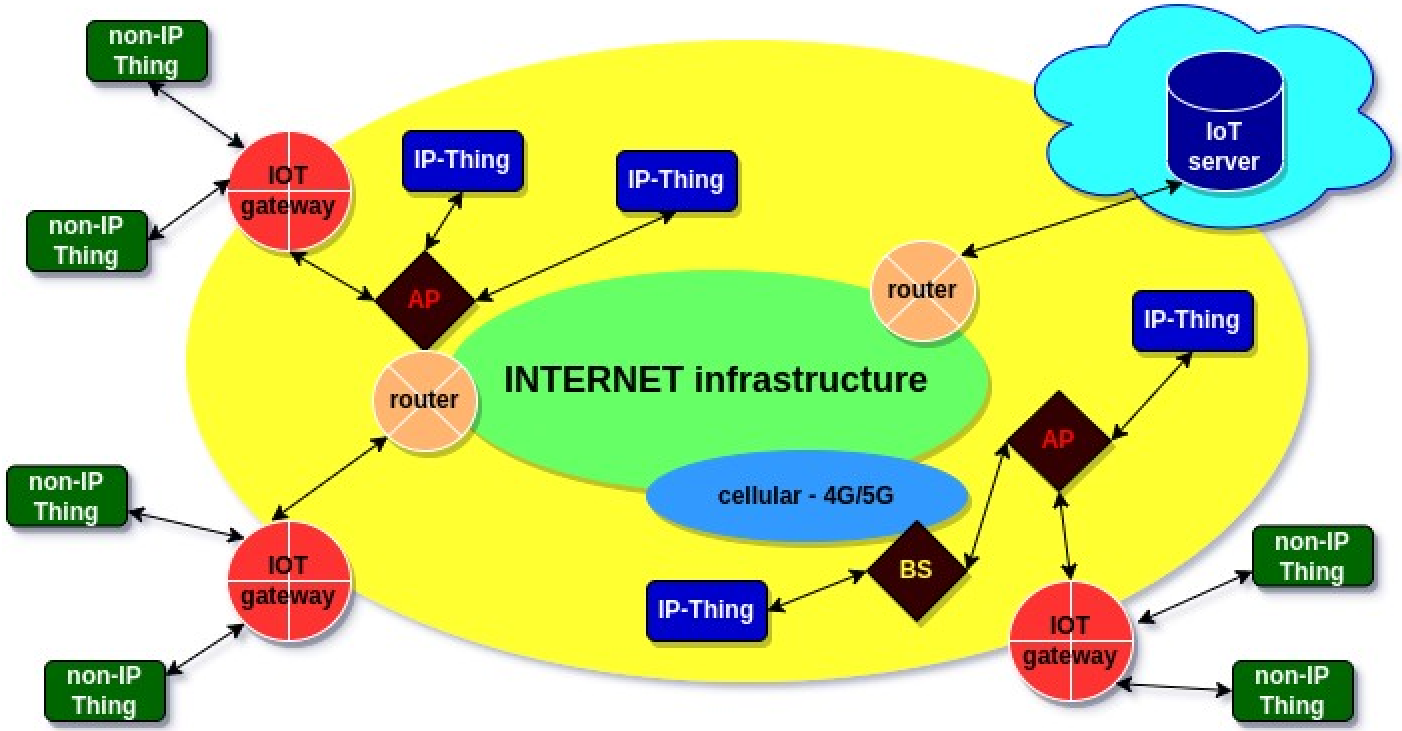
Low power IoT architectures are crucial for ensuring that IoT devices can operate efficiently with minimal energy consumption, especially in applications where devices are expected to function for extended periods on battery power or energy harvesting.

By focusing on energy-efficient components , communication protocols, and design practices, it is possible to develop IoT systems that meet the demands of modern applications while minimizing their environmental impact.

IoT Architectures



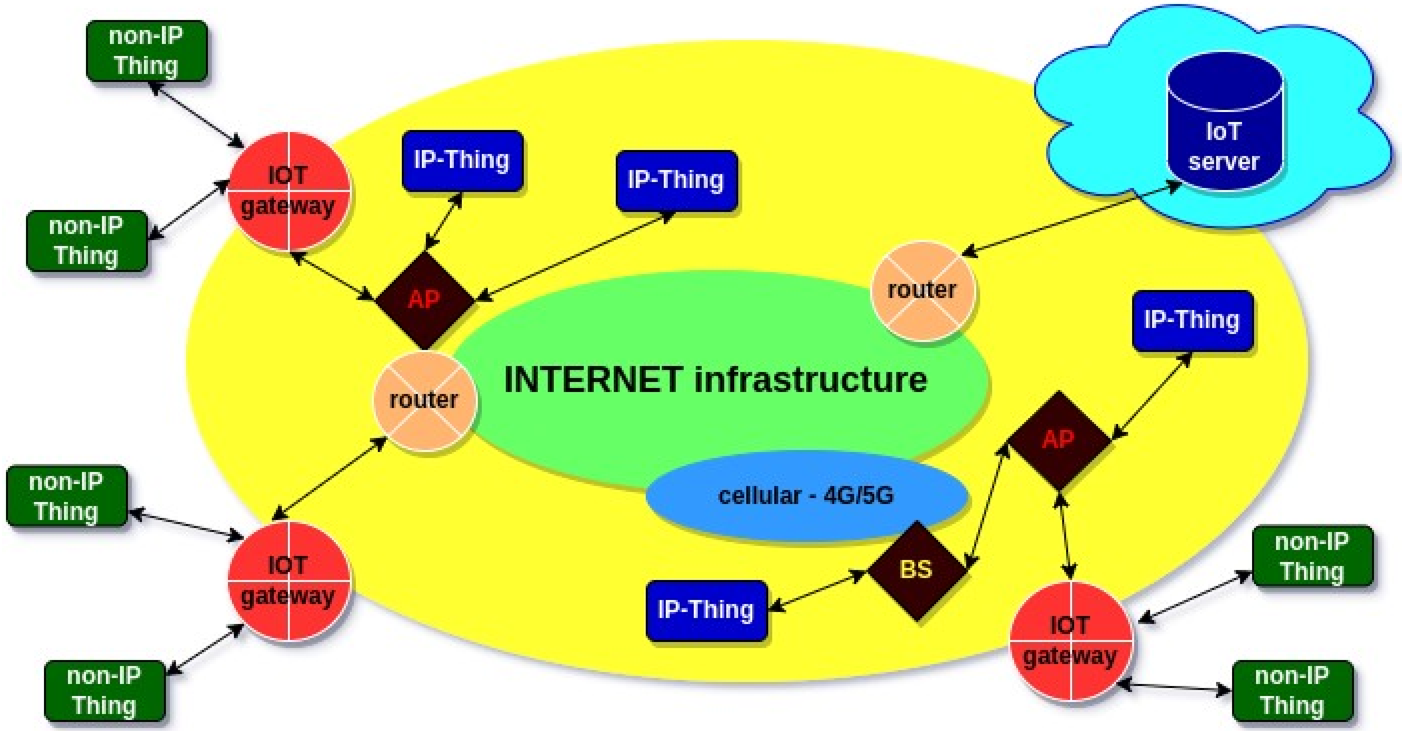
IoT Architectures



IP-Thing : **Direct Terminal** connected to Inet via WiFi/Ethernet link

non-IP-Thing : **Remote Terminal** connected to Inet via LoRa link

IoT Architectures



IoT-Gateway : ex. **LoRa – WiFi** gateway

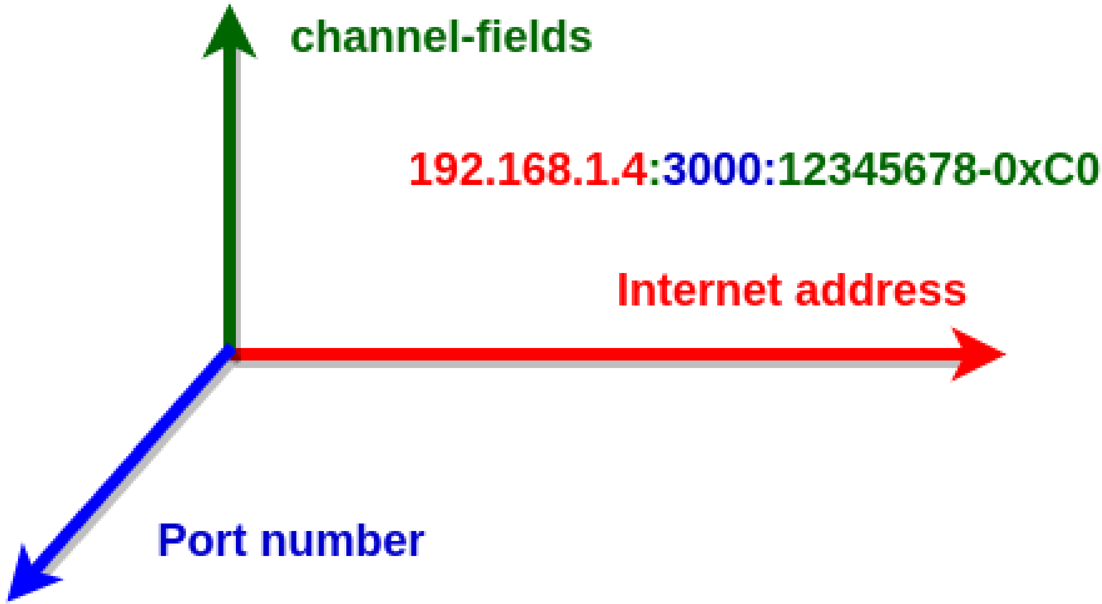
IoT-Server : ex. **ThingSpeak**

Low Power IoT Architectures

- IP Terminals (DT) and Non-IP Terminals (RT)
- low_power and high_power stages and phases
- Power consumption analysis of IP Terminals (DT)
- Power consumption analysis of Non-IP Terminals (RT)
- Complete IoT – Architectures :

  with IoT Terminals – Gateways - Servers

Global IoT space and IoT Sockets



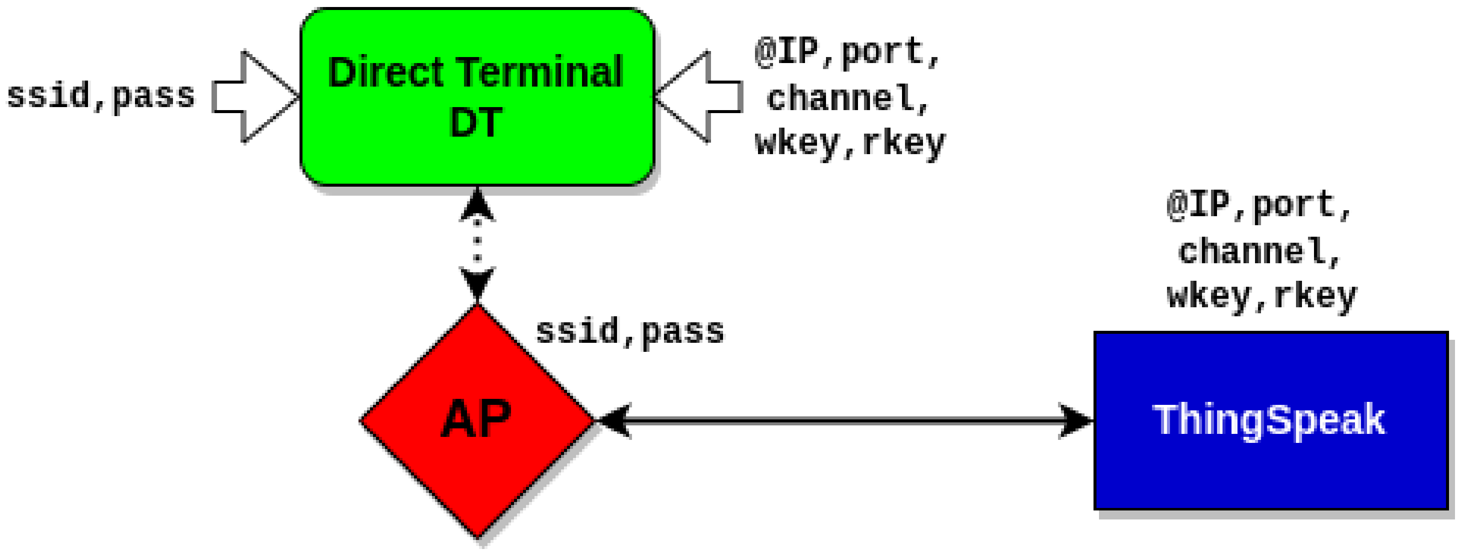
IoT socket => IP address: Service port:Channel number-fields

Direct Terminals know IP address:Service port:Channel number

Gateways know IP address:Service port

Remote Terminals know only Channel number (identifier)

Direct Terminals and IoT Sockets

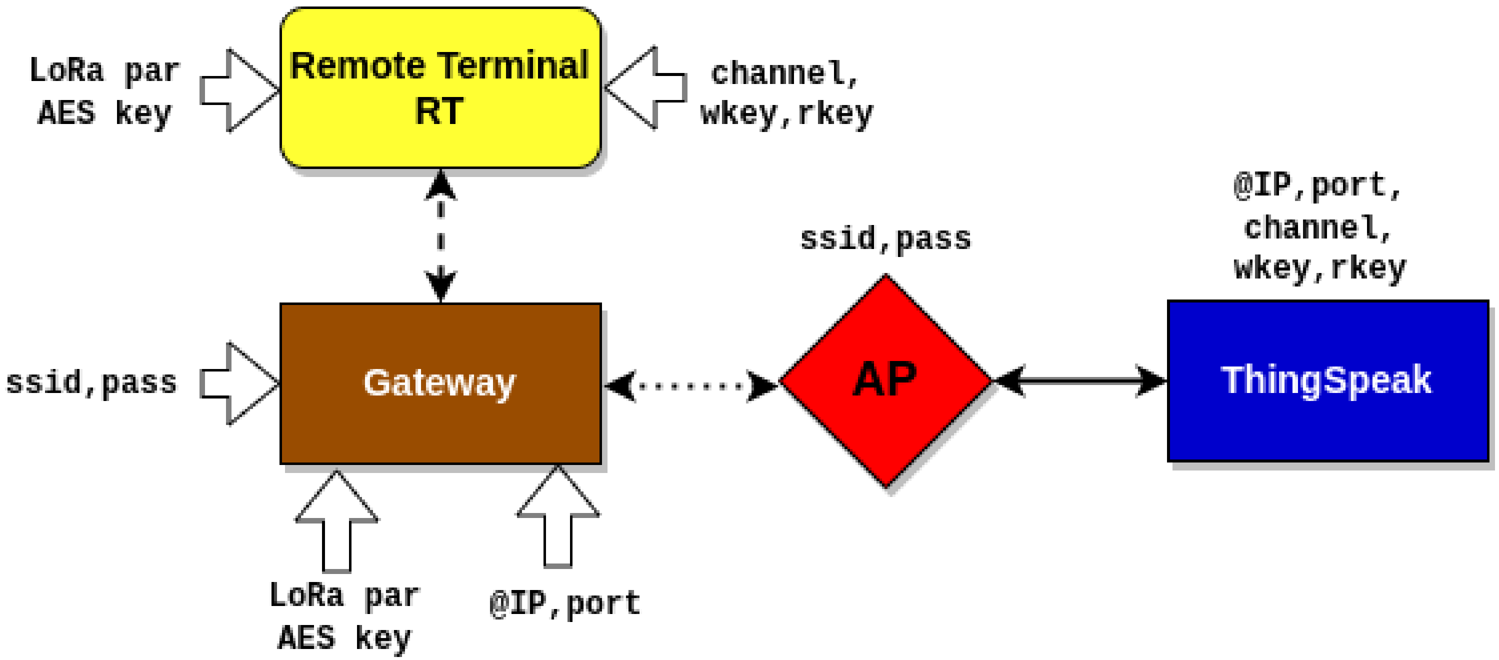


Direct Terminals know IP address:Service port:Channel number

plus: write and optionally read key

A channel contains fields (max.8) that may be interpreted as IoT data streams.

Global IoT space and IoT Sockets

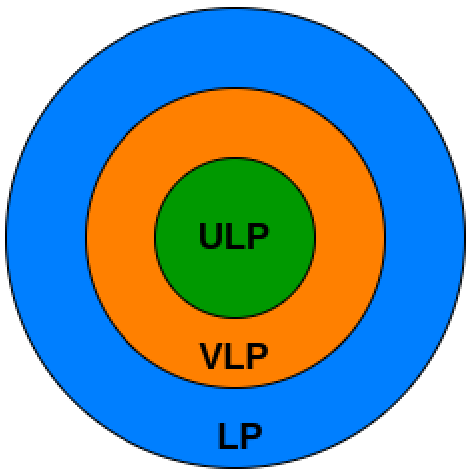


Gateways know IP address:Service port

Remote Terminals know only Channel number (identifier)

plus: write and optionally read key

Low and Very Low Power consumption IoT Architectures



ULP < 10 µA

VLP < 100 µA

LP < 1000 µA

Example of average current (power) consumption:
deepsleep mode for `low_power` stage = 10µA and 100s
normal mode for `high_power` stage = 40mA and 0.5s

`low_power` charge + `high_power` charge= 10µA*100s + 40 000µA*0.5s = 1000µC+20000µC= 21mC

average_current = charge/time = 21mC/100.5s = 0.21mA = 210µA

To do:
Calculate the same for `low_power` stage duration of 600s.

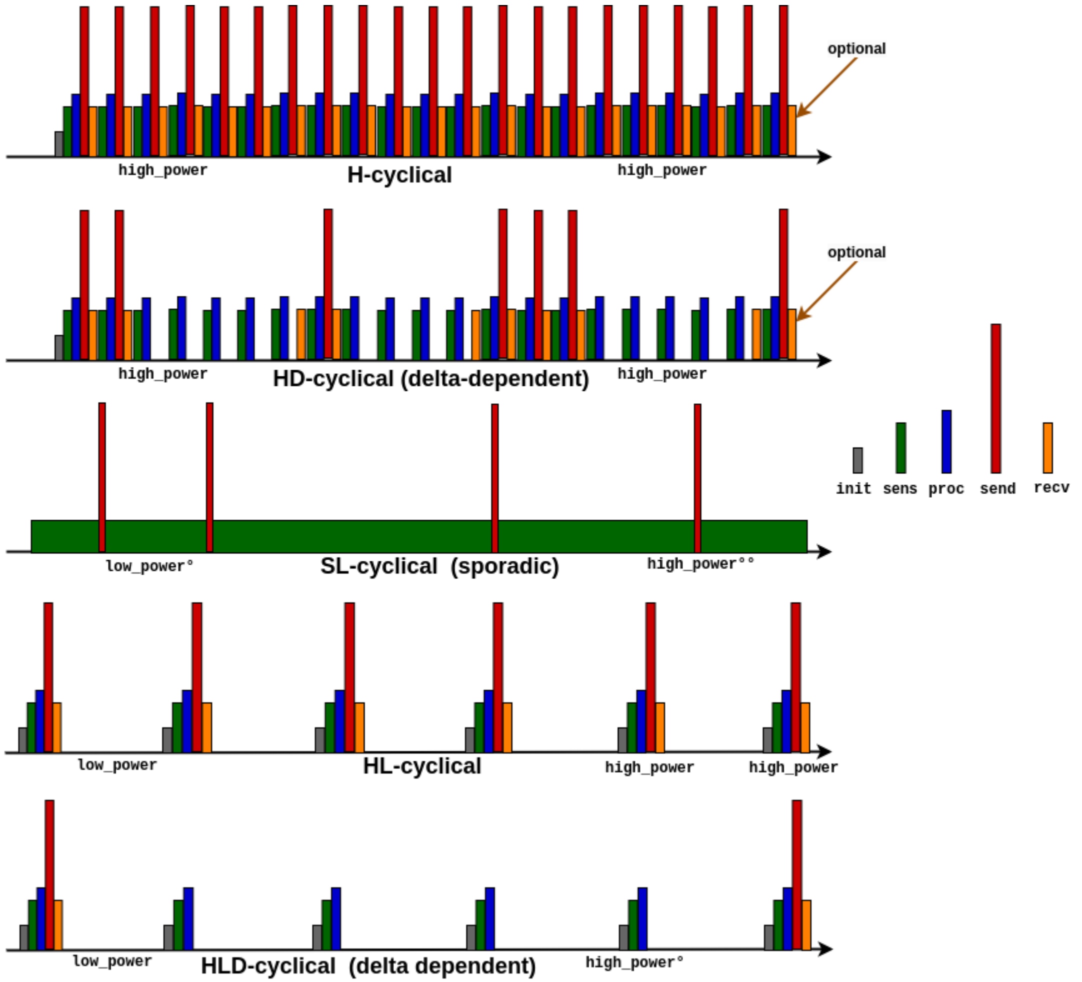
Terminals: Operational modes

high average current

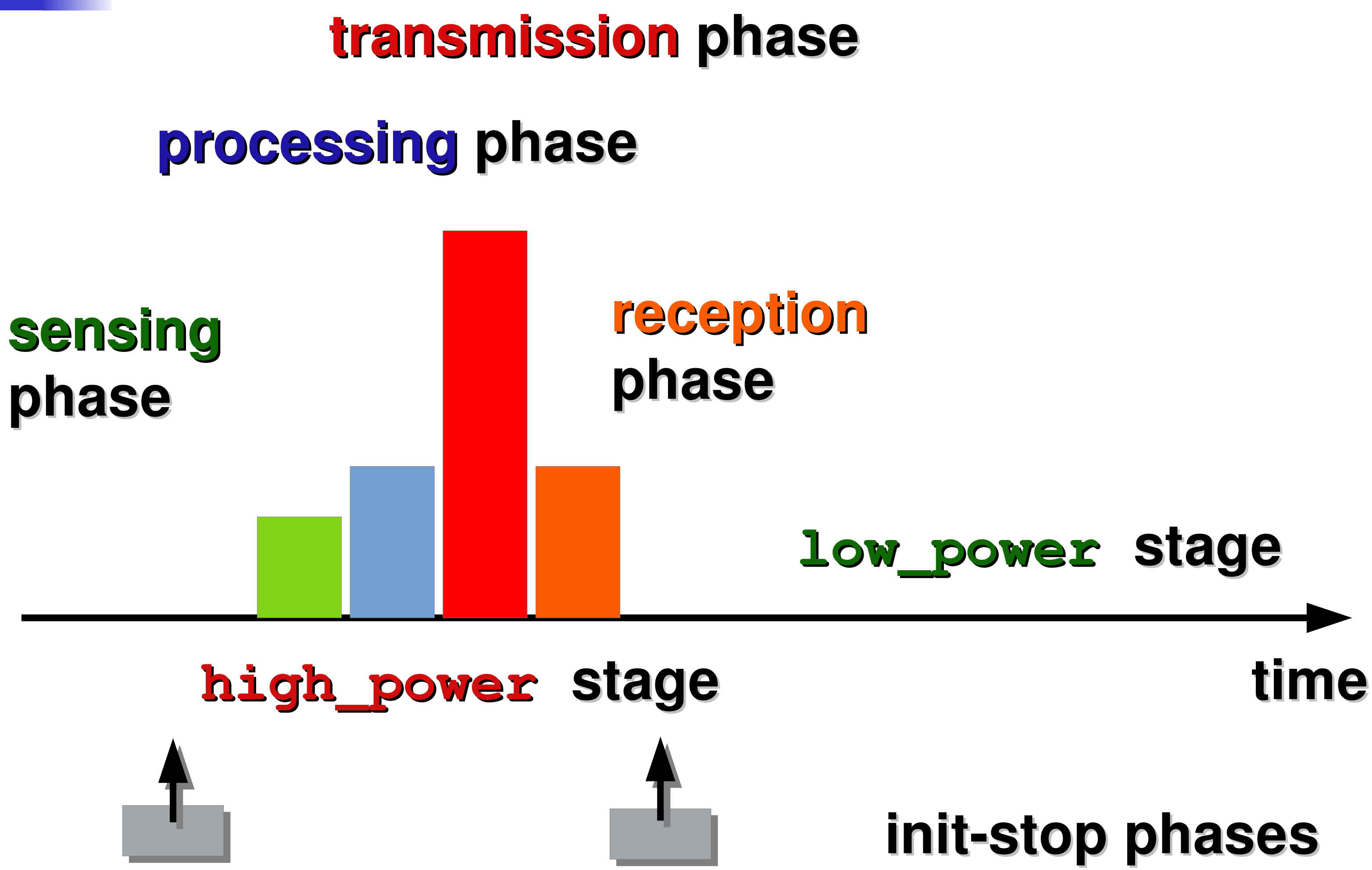
`delta` (δ) parameter defines required precision-difference

"sporadic cycle" – activated by an interruption (level change) signal

low average current



high_power stage - phases

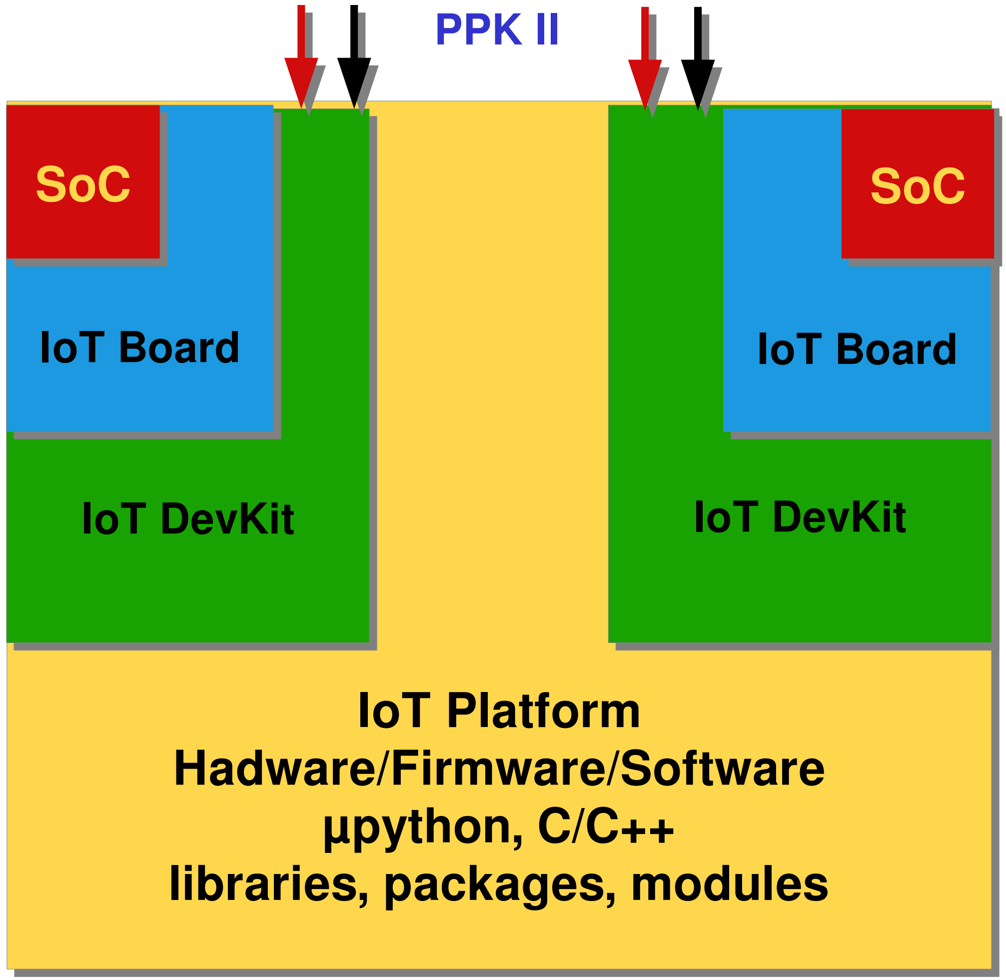


From IoT SoC to IoT Platform

ARM-M0
SX1262
Bus I/O,..

EEPROM
USB, solar
Converters,
Bus I/O, ..

UART,I2C,SPI
sensors/actuators
solar panel, battery
Supercapa, ..



ESP32C3
ESP32C6
WiFi/BLE
Bus I/O,..

EEPROM
USB,
Converters,
Bus I/O, ..

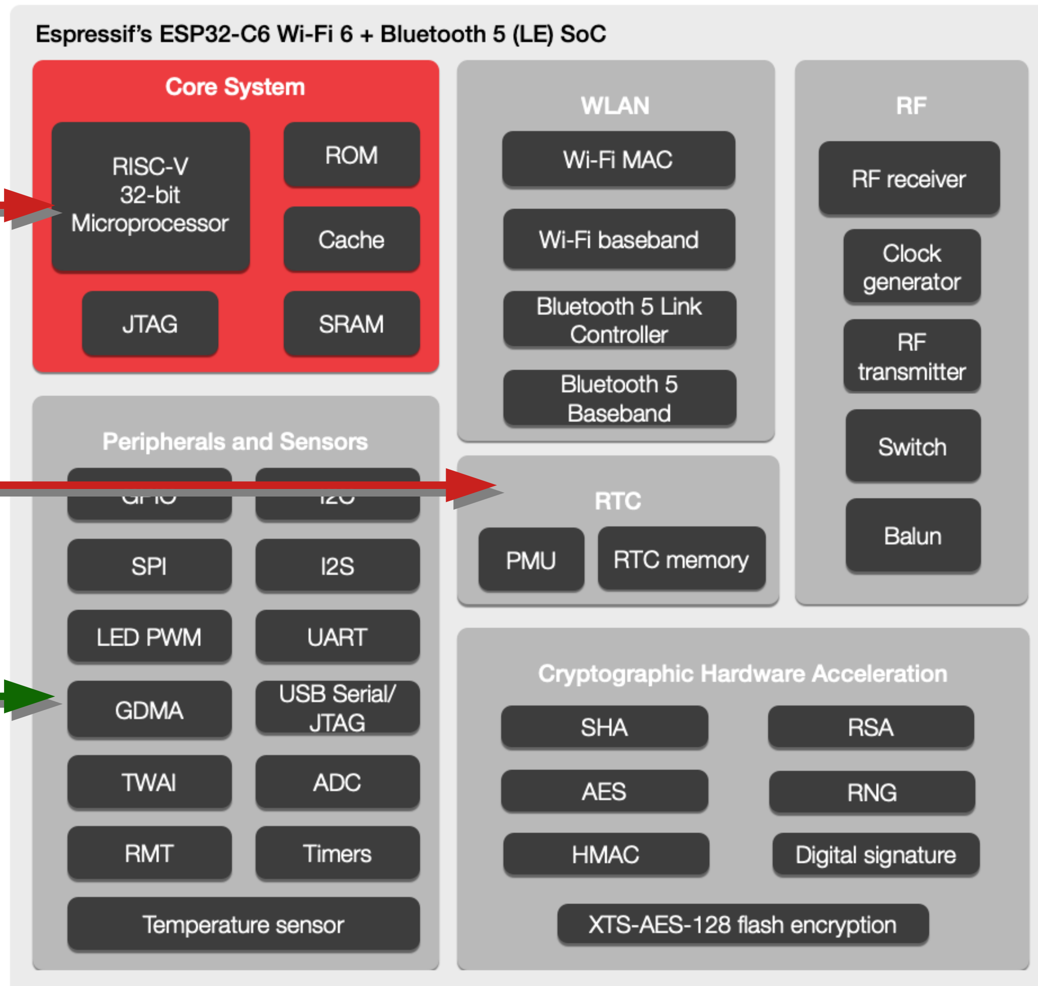
UART,I2C,SPI
sensors/actuators
solar panel, battery
Supercapa, ..

IoT SoC ESP32C6: low power features

RISC-V: RV32
5 stages pipeline

Low Power (2mA)
RISC-V: RV32
2 stages pipeline

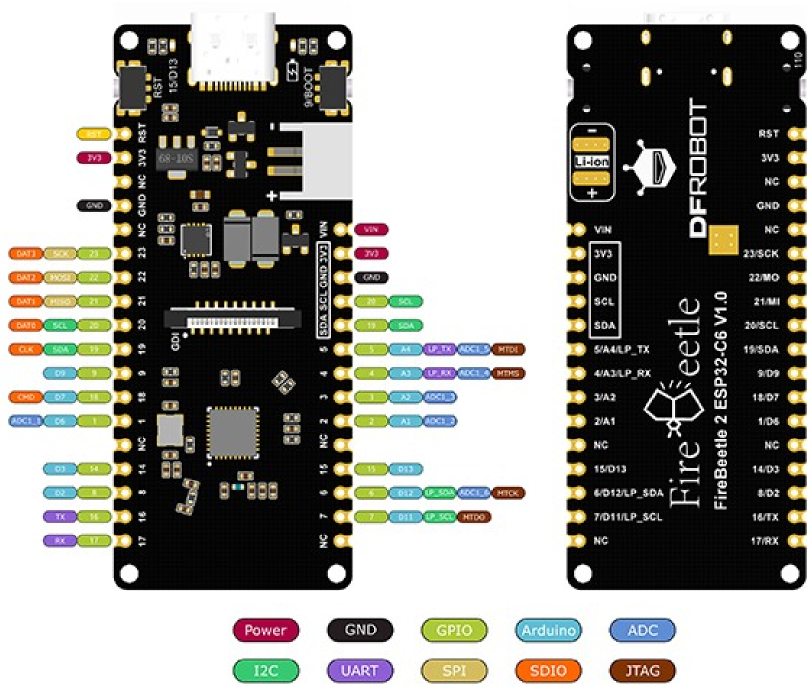
Buses including Low Power (I2C,UART)



WiFi6 with TWT - Target Wake Time

Crypto and Security

IoT Board (Direct Terminal)

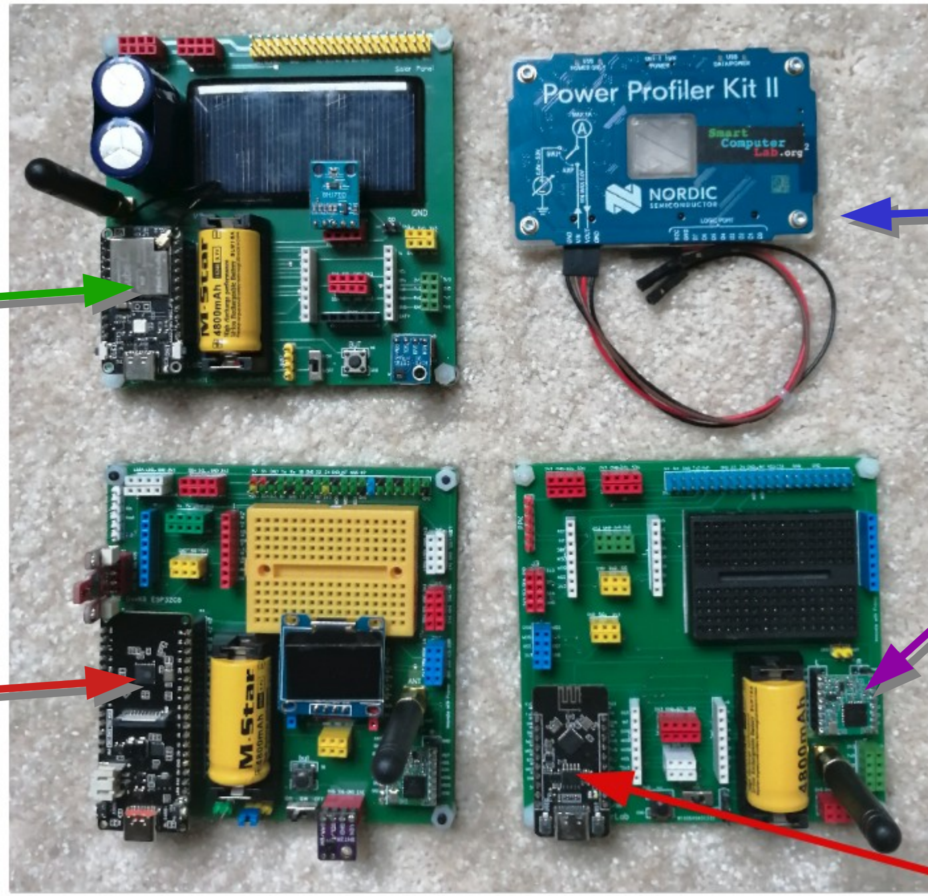


IoT Board: DFRobot FireBeetle2 (ESP32C3) : EEPROM, battery, solar converters, USB bus, I2C, UART,SPI, .. (low/high power)

SmartComputerLab IoT DevKits

Nordic PPK II (power profiler kit)

Heltec CubeCell (ASR6501)

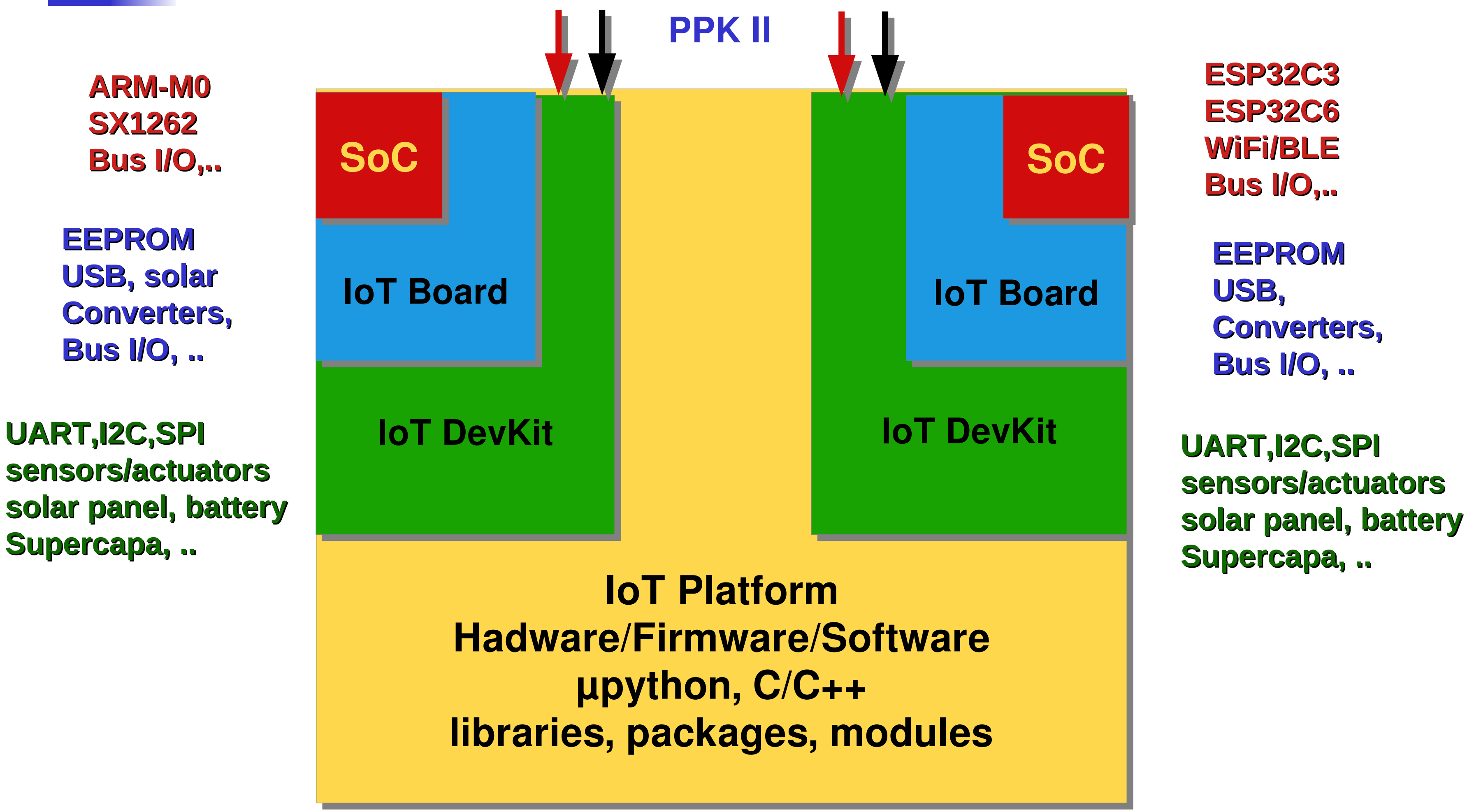


SX1276 (LoRa modem)

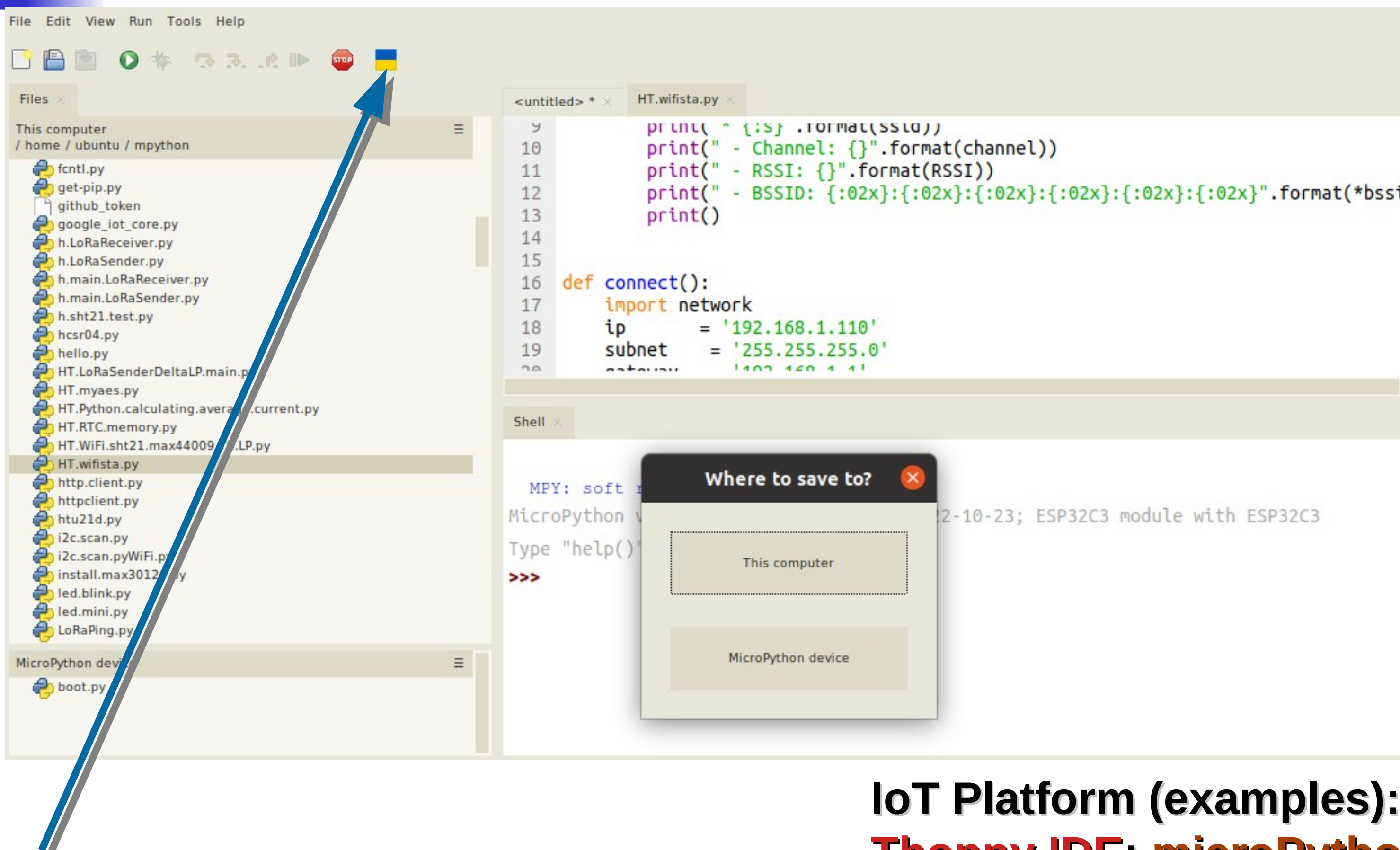
RFRobot FireBeetle 2 (ESP32C6)

Heltec (ESP32-C3)

From IoT SoC to IoT Platform



Thonny : IoT Platform -µPython



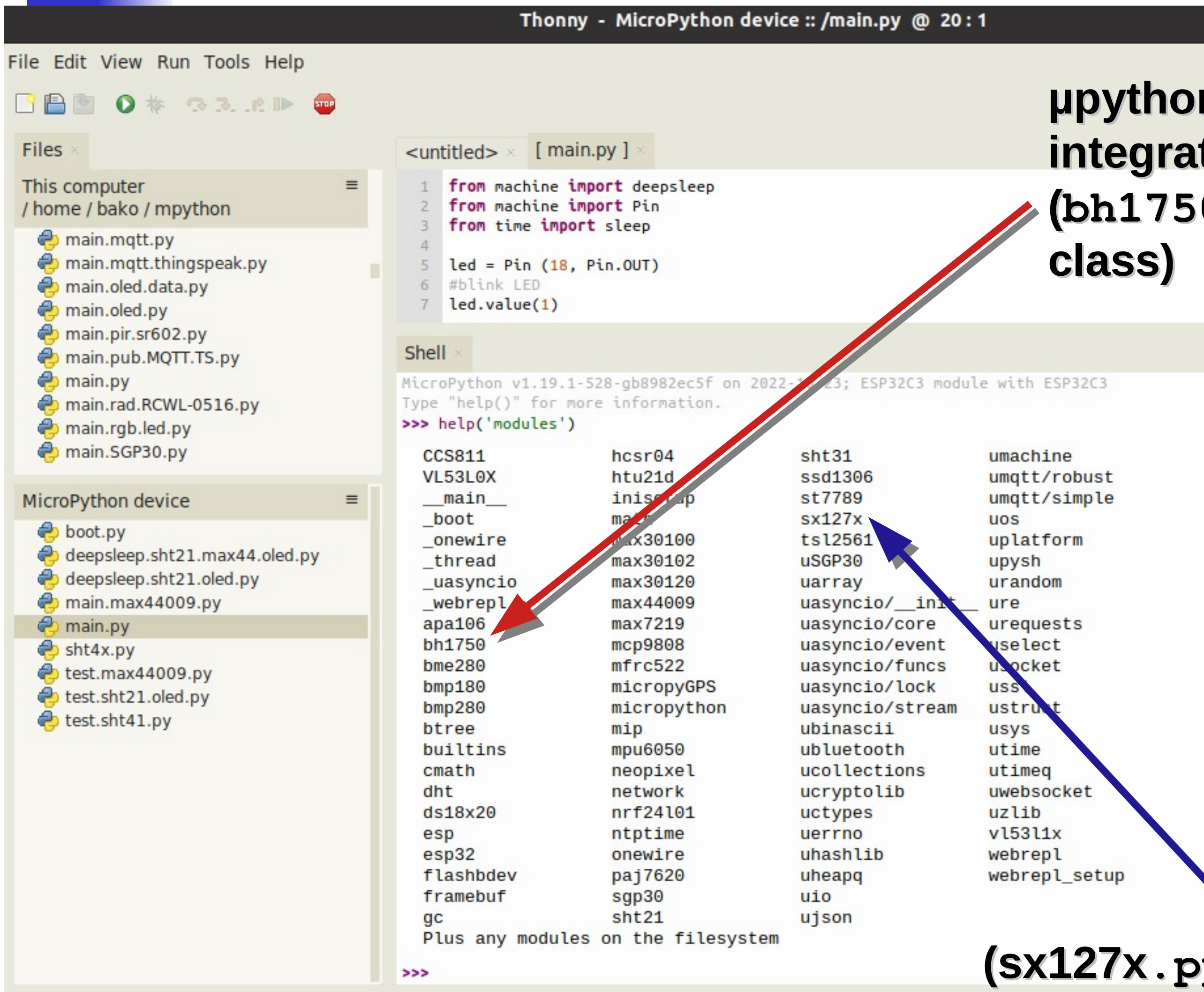
IoT Platform (examples):

Thonny IDE: microPython

Jupiter: microPython

..

Thonny : IoT Platform -µPython



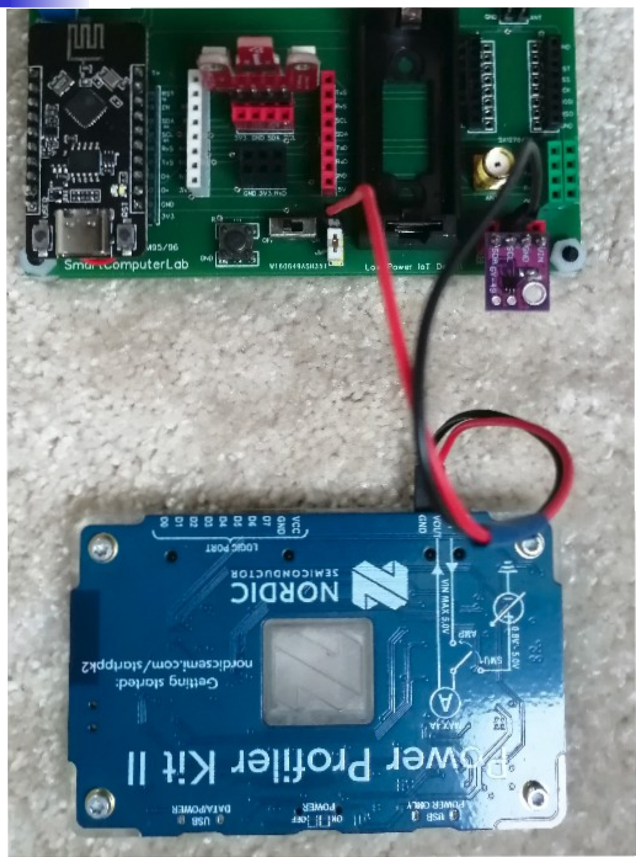
µpython interpreter and integrated (cold) modules: (`bh1750.py` with BH1750 class)

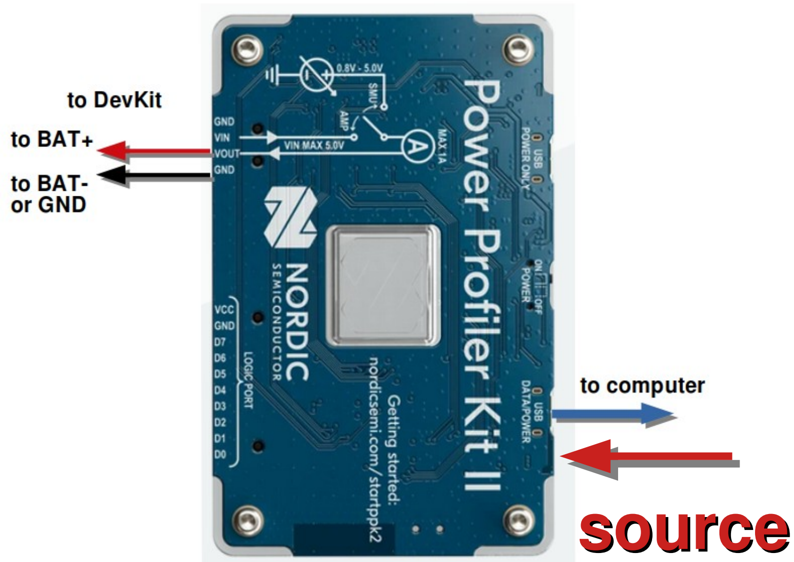
sensor driver

modem driver

(`sx127x.py` with SX127x class)

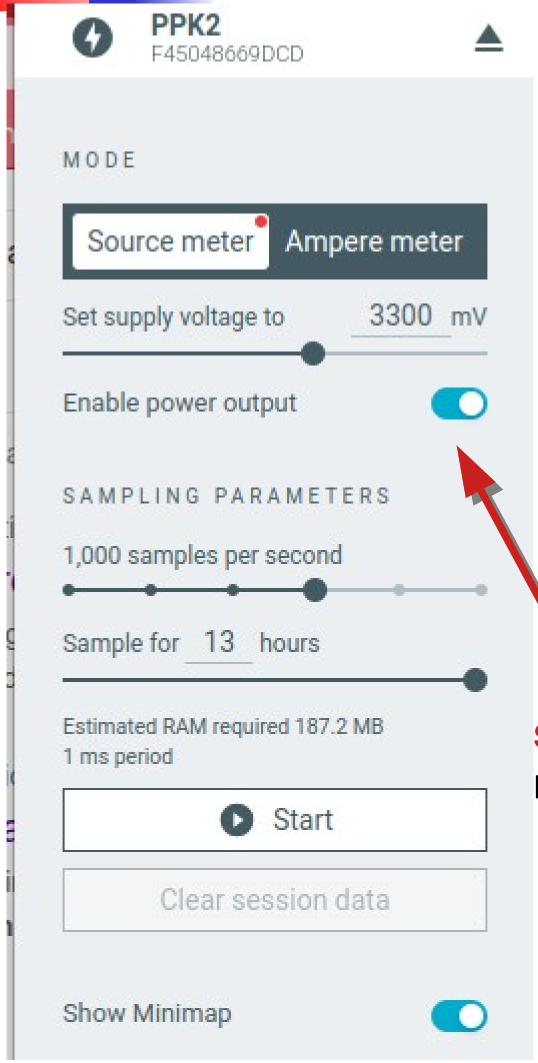
Power Profiler Kit II : connection





Power Profiler with source mode

Power Profiler Kit II - IDE



main window

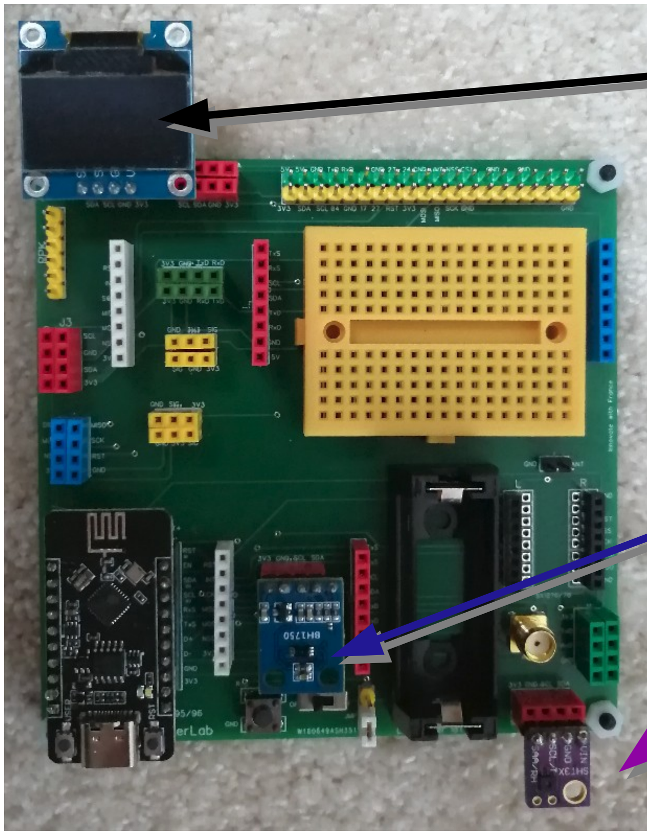
source mode

low_power stage

high_power stage

Average current consumption in low_power stage (10.39µA)

Example: HL cycle operation with sensors and OLED display



OLED display – `sdd1306`,
two sensors to capture
the **`temperature`**,
the **`humidity`**, and
the **`luminosity`** or **brightness**
values:

BH1750 (L) - luminosity

SHT31 (T/H) – temperature/humidity

Attention:
All these components communicate over the same (shared) I2C bus !

Example: HL cycle operation with sensors and OLED display

```
from machine import deepsleep
from machine import Pin, SoftI2C
from time import sleep

import ssd1306
import bh1750
import sht31
```

Preparing buses, drivers and sleep operators

Example: HL cycle operation with sensors and OLED display

```
def disp(p1,p2,p3):
    oled = ssd1306.SSD1306_I2C(128, 64, i2c, 0x3c)
    oled.fill(0)
    oled.text("SmartComputerLab",0,0)    # column 0 and line 0
    oled.text(p1,0,16)
    oled.text(p2,0,32)
    oled.text(p3,0,48)
    oled.show()
    sleep(5)
    oled.poweroff()    # disconnects the OLED power lines
```

Defining display function to show the data during 5 seconds and disconnect

Example: HL cycle operation with sensors and OLED display

PPK diagram for the above example with two sensors and OLED screen operating with HL mode (high_power stage+low_power stage).

Note the current consumption in low_power stage – 20.42µA with three sensors/actuators attached.

What is ThingSpeak (.com)?

ThingSpeak is an **open-source software** written in **Ruby** which allows users to communicate with **internet enabled devices**.

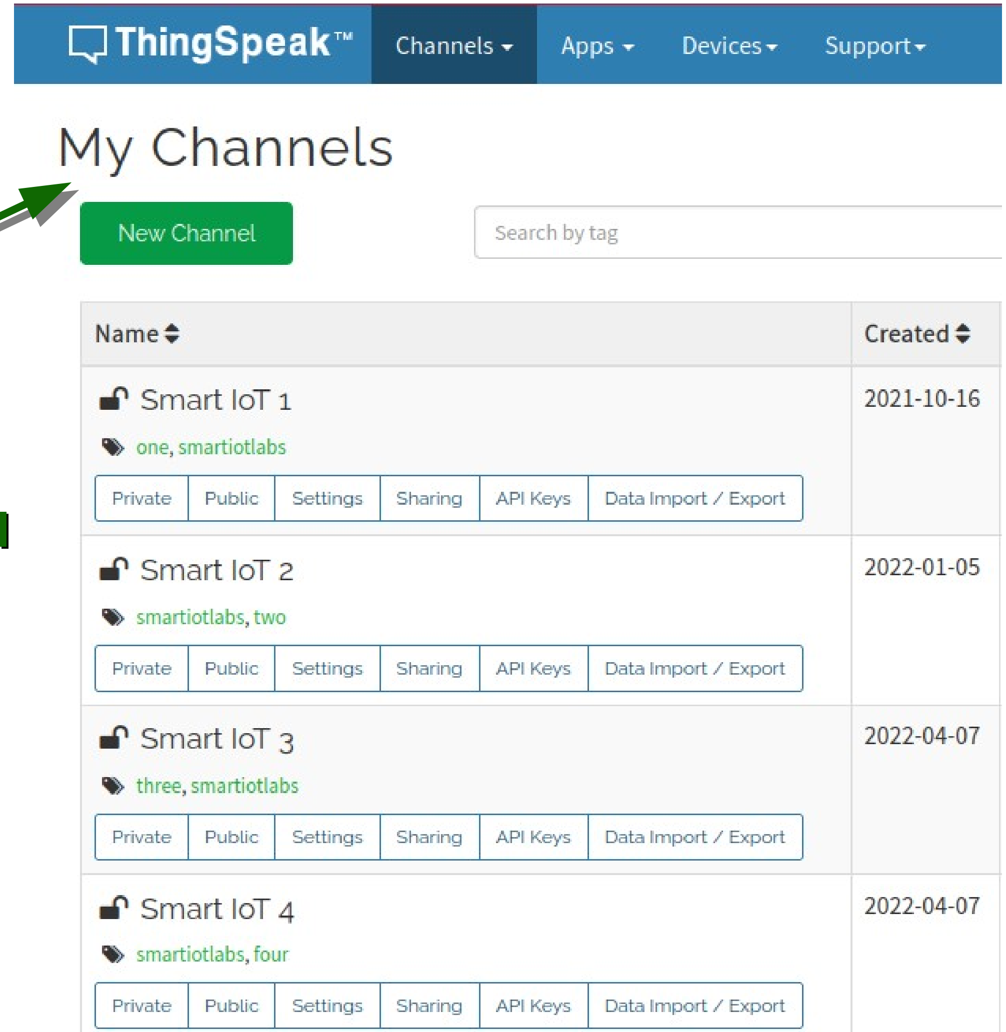
It facilitates data access, retrieval and **logging of data** by providing an API to both the devices and social network websites.

ThingSpeak was originally launched by **ioBridge** in 2010 as a service in support of IoT applications.

ThingSpeak has integrated support from the numerical computing software **MATLAB** from **MathWorks**, allowing `ThingSpeak.com` users to **store**, **analyze** and **visualize** uploaded data using MATLAB **without requiring the purchase of a MATLAB license from MathWorks**.

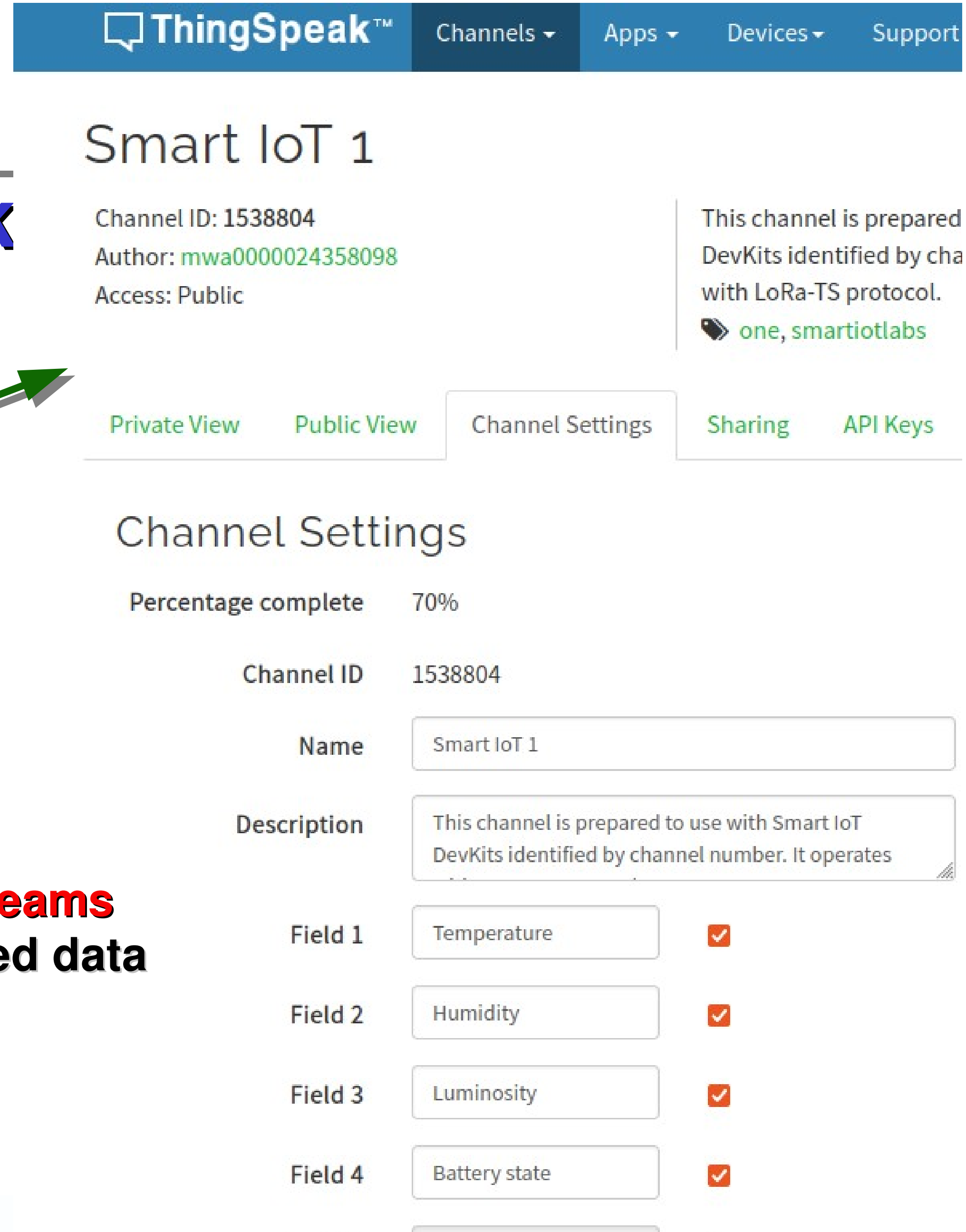
Attention: Free account on `ThingSpeak.com` is limited to last **256 records** (storage) and **usage frequency** of **max. 50 mHz** (communication).

Sending data to ThingSpeak



ThingSpeak.com – free account
- max. 10 channels
- max. 256 last records per channel
- max frequency ~50mHz

Sending data to ThingSpeak



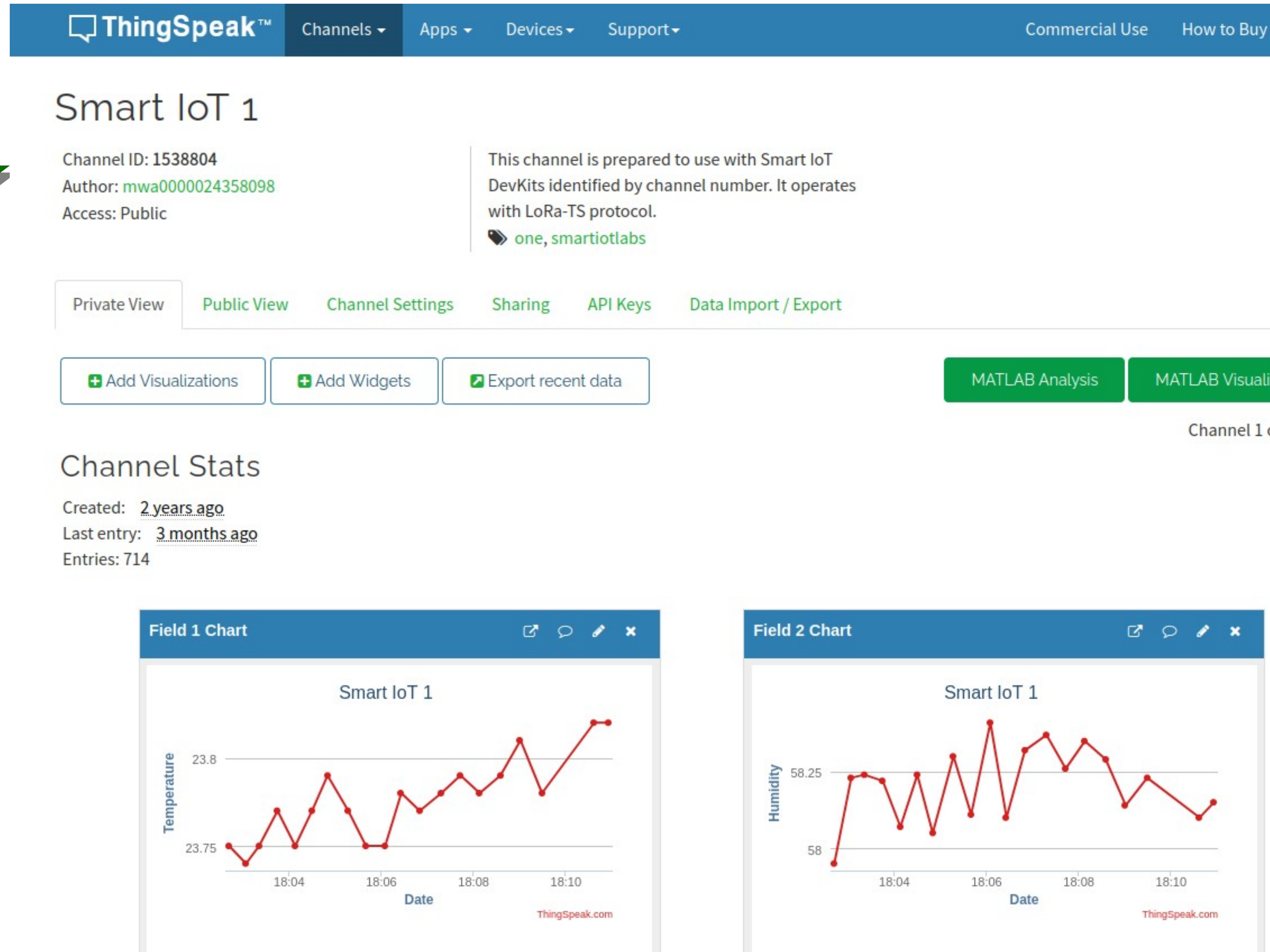
TS Channel ID

it will be your device identifier

TS Channel Fields –> IoT data streams

are the places to store the received data
max 8 fields per channel
one field (stream) per sensor

Sending data to ThingSpeak



Channel ID

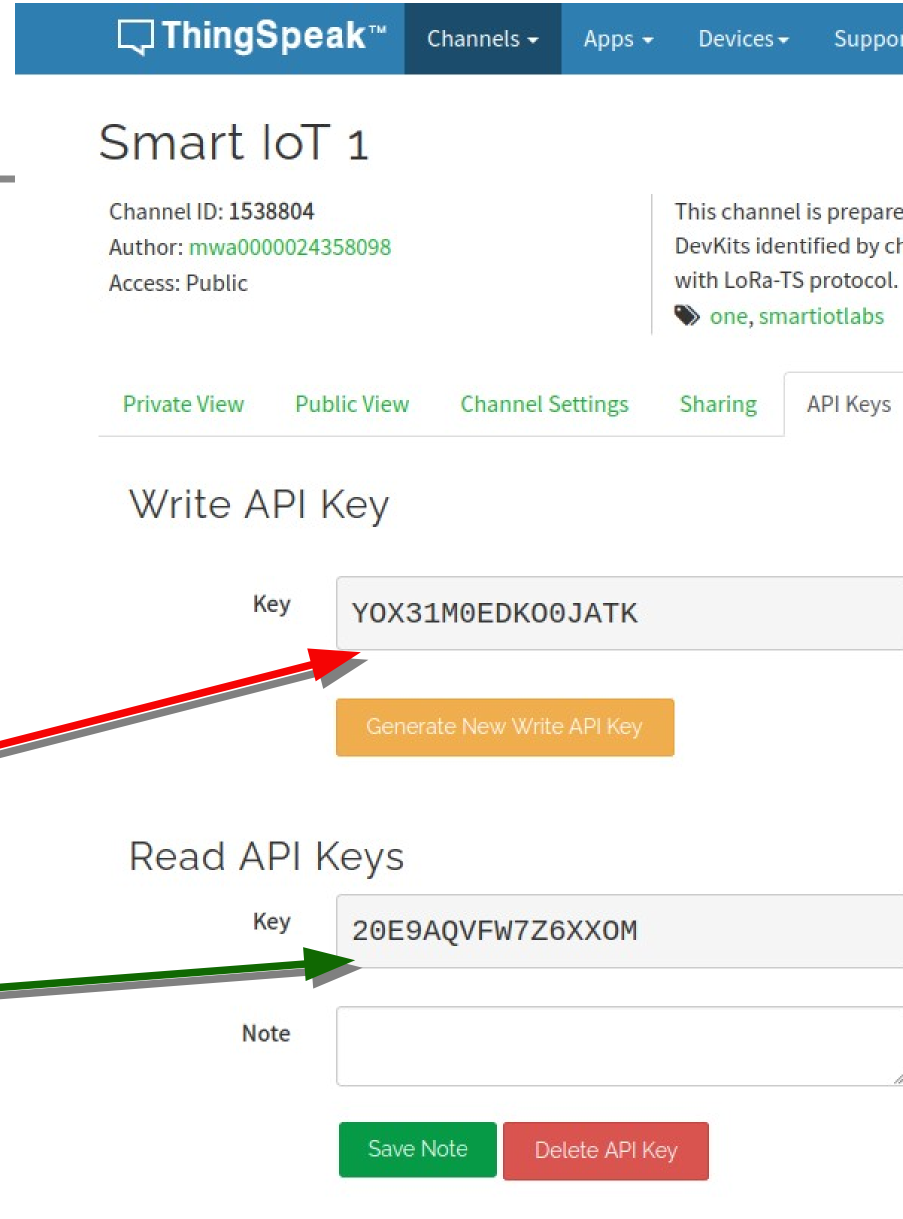
it will be your device identifier

One field (stream) per sensor:

- **Temperature**
- **Humidity**
- **Luminosity**

...

Sending data to ThingSpeak



Channel ID

it will be your device identifier

Write Key

Read Key

Example: sending sensor data to ThingSpeak via WiFi

```
def connect():
    import network
    ssid      = "PhoneAP"
    password  = "smartcomputerlab"
    station = network.WLAN(network.STA_IF)
    if station.isconnected() == True:
        print("Already connected")
        return station

    station.active(True)
    station.connect(ssid,password)
    station.config(txpower=8.5)
    while station.isconnected() == False:
        pass
    print("Connection successful")
    print(station.ifconfig())
    return station

def disconnect():
    import network
    station = network.WLAN(network.STA_IF)
    station.disconnect()
    station.active(False)

#disconnect()          # to be uncommented for test
#connect()             # to be uncommented for test
```

Preparing module `wifista.py` for communication via WiFi – with personal AP

Example: sending sensor data to ThingSpeak via WiFi

```
import machine
from machine import deepsleep,Pin,SoftI2C
import max44009
import sht21
import wifista
import thingspeak
from thingspeak import ThingSpeakAPI, Channel, ProtoHTTP

i2c = SoftI2C(scl=Pin(9), sda=Pin(8), freq=100000)
sensor = max44009.MAX44009(i2c)
luminosity=sensor.lux
temperature = sht21.SHT21_TEMPERATURE(i2c)
humidity = sht21.SHT21_HUMIDITE(i2c)
print("current temperature: " +str(temperature))
```

Reading data from sensors : sensing phase

Example: sending sensor data to ThingSpeak via WiFi

```
print("current temperature: " +str(temperature))
rtc = machine.RTC()
stfloat=0.0
r=rtc.memory()
print('woken with value',r)   # testing the last temp value
if(r!=b''):                   # skiping first empty value
    stfloat=float(r)
    print(stfloat)

if (temperature>(stfloat+0.2) or temperature<(stfloat-0.2)):
# delta in °C ex. 0.2 °C
```

processing data from sensors : processing phase with delta parameter. Comparing with previously sent data.

Attention: requires the use of RTC memory

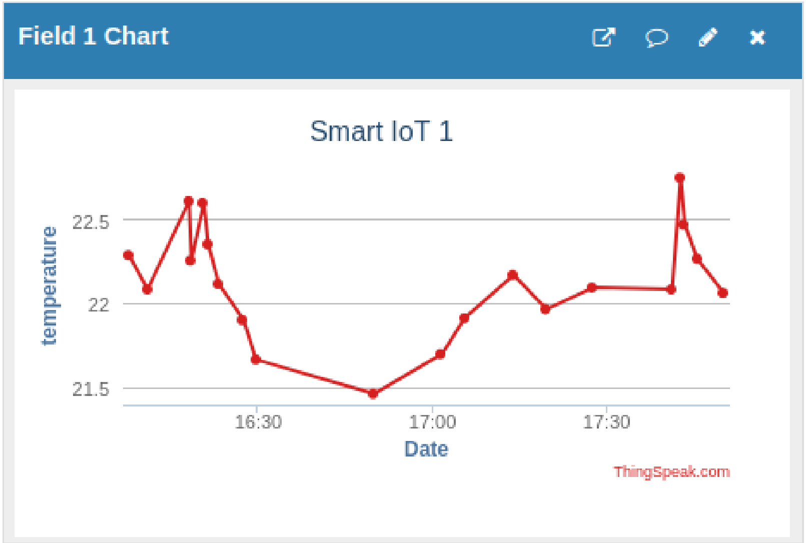
Example: sending sensor data to ThingSpeak via WiFi

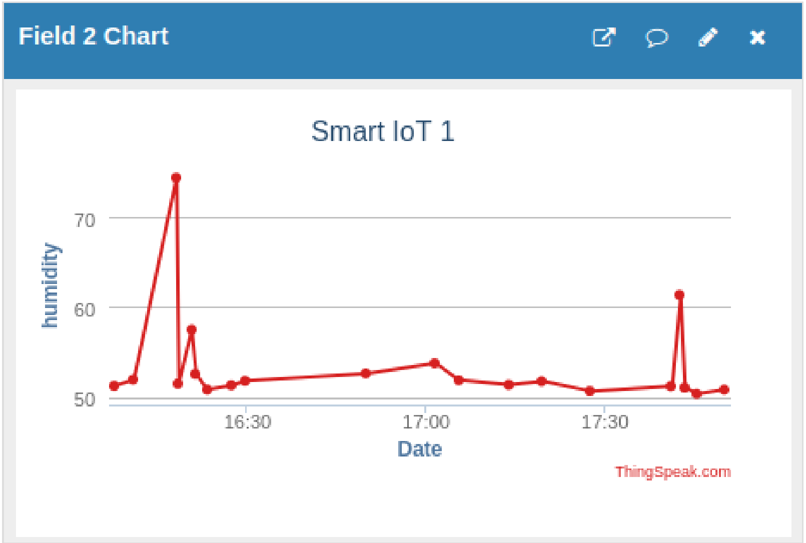
```
if (temperature>(stfloat+0.2) or temperature<(stfloat-0.2)):
    rtc.memory(str(temperature))
    channel_living_room = "1538804"
    field_temperature = "Temperature"
    field_humidity = "Humidity"
    field_luminosity = "Luminosity"
    active_channel = channel_living_room
    thing_speak = ThingSpeakAPI([
    Channel(channel_living_room , 'YOX31M0EDKO0JATK',[field_temperature,
      field_humidity, field_luminosity])],protocol_class=ProtoHTTP,log=True)
    wifista.connect()
    thing_speak.send(active_channel, { field_temperature: temperature,
      field_humidity: humidity, field_luminosity: luminosity })
    print('send to TS')
    wifista.disconnect()

deepsleep(20000)  # or thing_speak.free_api_delay
```

Sending data to ThingSpeak via WiFi connection: transmission phase

Example: sending sensor data to ThingSpeak via WiFi

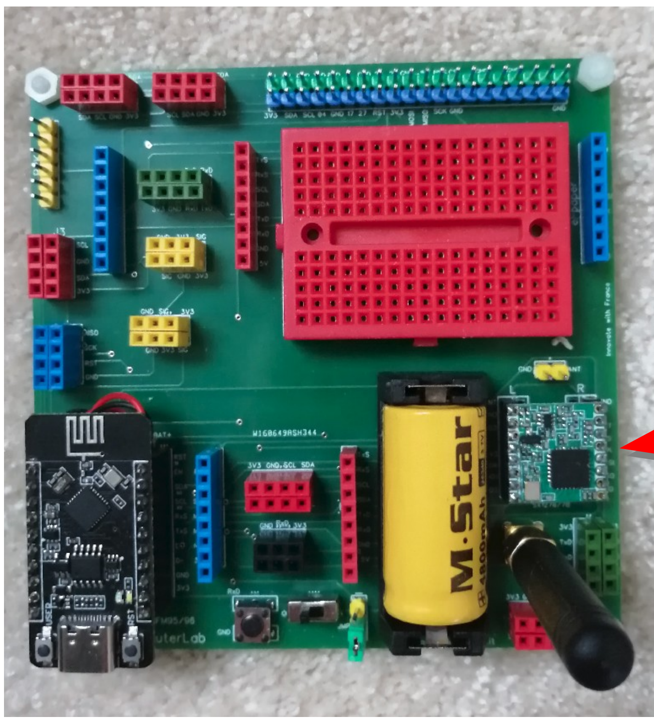
```
Connection successful
('192.168.43.36', '255.255.255.0', '192.168.43.1', '192.168.43.1')
current temperature: 22.73444
woken with value b'22.82024'
22.82024
new value to rtc memory b'22.73444'
Already connected
ThingSpeak at 52.201.163.117:80
1538804 {'Luminosity': 348.48, 'Temperature': 22.73444, 'Humidity':
49.95398} #31, took 1.16s, next in 14.84s
```



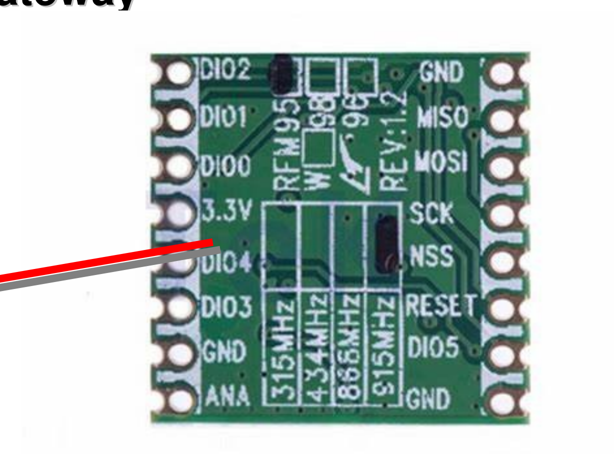


Part II: Long Range (LoRa) & Remote Terminals

Remote Terminals communicate with the IoT servers via the dedicated Gateways that relay the LoRa packets to the WiFi packets to be sent to IoT server.
To build a simple IoT architecture with Remote Terminals (at least one) we need to enlarge/enhance our initial Direct Terminal to a LoRa-WiFi Gateway.

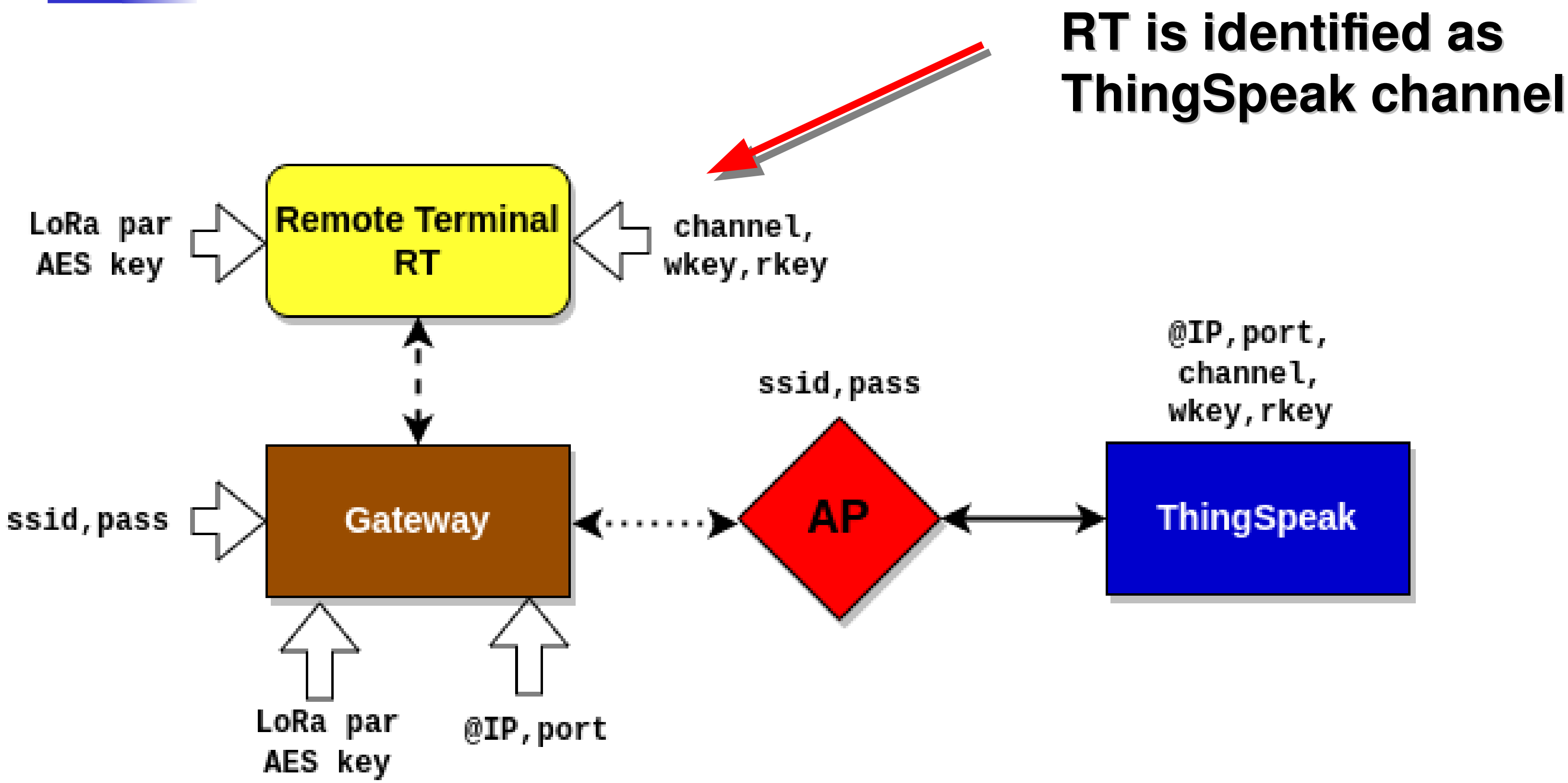


Remote Terminals or
Lora-WiFi Gateway



RFM95 – SX1278 LoRa modem with SPI bus

Remote Terminal & Gateway (LoRa)



Complete IoT architecture with RT, GW and SV (ThingSpeak)

RT – LoRa SPI and radio parameters

main.py

```
lora_default { frequency,signal_bandwidth,
spreading_factor, coding_rate .. }
```

```
lora_pins { dio, ss, reset,sck, miso, mosi }
```

```
lora_spi = SPI(
baudrate=10000000, polarity=0, phase=0,
bits=8, firstbit=SPI.MSB,
sck=Pin(lora_pins['sck'], Pin.OUT, Pin.PULL_DOWN),
mosi=Pin(lora_pins['mosi'], Pin.OUT, Pin.PULL_UP),
miso=Pin(lora_pins['miso'], Pin.IN, Pin.PULL_UP), )
```

```
lora = SX127x(lora_spi, pins=lora_pins,
              parameters=lora_default)
type = 'sender' # let us select sender method
if __name__ == '__main__':
   if type == 'sender':
       LoRaSenderDeltaLP.send(lora)
       lora.sleep()
       deepsleep(5000)
```

lora

LoRaSenderDeltaLP.py

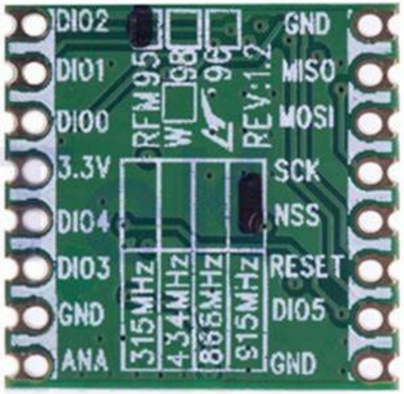
```
disp(t,h,l)
send(lora)
```

RT sender

low_power stage

RT – main and sender modules

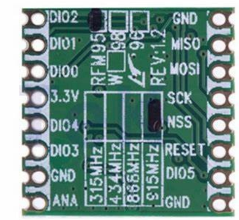
```
from machine import Pin,SPI
from sx127x import SX127x
from time import sleep
import LoRaSenderDelatLP
```




```
lora_pins = {
    'dio_0':2,       # interrupt signal - useful for callback
    'ss':4,          # 16 on SPI-LoRa ext. card
    'reset':10,      # necessary to start
    'sck':6,         # SPI bus clock signal
    'miso':5,        # SPI bus - master-in-slave-out
    'mosi':7,        # SPI bus - master-out-slave-in
}
```

Defining SPI connection lines to RFM95/SX1278 LoRa modem

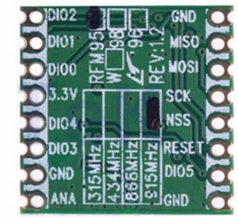
RT – main and sender modules




```
lora_default = {
    'frequency': 869e6,              # base frequency: 8695e5,435e6, ..
    'frequency_offset':0,
    'tx_power_level': 14,            # max 100mW
    'signal_bandwidth': 125e3,       # modulation frequency band: 250e3,500e3
    'spreading_factor': 9,           # spreading factor: 7,..,11
    'coding_rate': 5,                # coding rate: 5,..,8 (5/4,..,8/4)
    'preamble_length': 8,
    'implicitHeader': False,
    'sync_word': 0x12,               # examples: 0x12 private, 0x34 public, ..
    'enable_CRC': False,
    'invert_IQ': False,              # normal: up-chirp, inverted: down-chirp
    'debug': False,
}
```

LoRa radio – default parameters

RT – main and sender modules



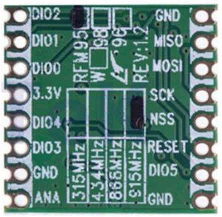

```
lora = SX127x(lora_spi, pins=lora_pins, parameters=lora_default)

type = 'sender'     # let us select sender method

if __name__ == '__main__':
    if type == 'sender':
        LoRaSenderDeltaLP.send(lora)
        lora.sleep()
        deepsleep(5000)
```

Selecting `LoRaSenderDeltaLP.py` module with `lora` parameters

`lora.sleep` suspends LoRa modem activity

`deepsleep` MCU enters `low_power` stage

RT – main and sender modules




```
rtc = machine.RTC()
stfloat=0.0
r=rtc.memory()
print('woken with value',r)          # testing the last temp value
if(r!=b''):                          # skiping first empty value
    stfloat=float(r)
    print(stfloat)


chan =12345
wkey="abcdefghijklmnop"
lumsensor = max44009.MAX44009(i2c)
luminosity=lumsensor.lux
temperature = sht21.SHT21_TEMPERATURE(i2c)
humidity = sht21.SHT21_HUMIDITE(i2c)
```

high_power stage – sensing phase

Building packet structure and sending packet

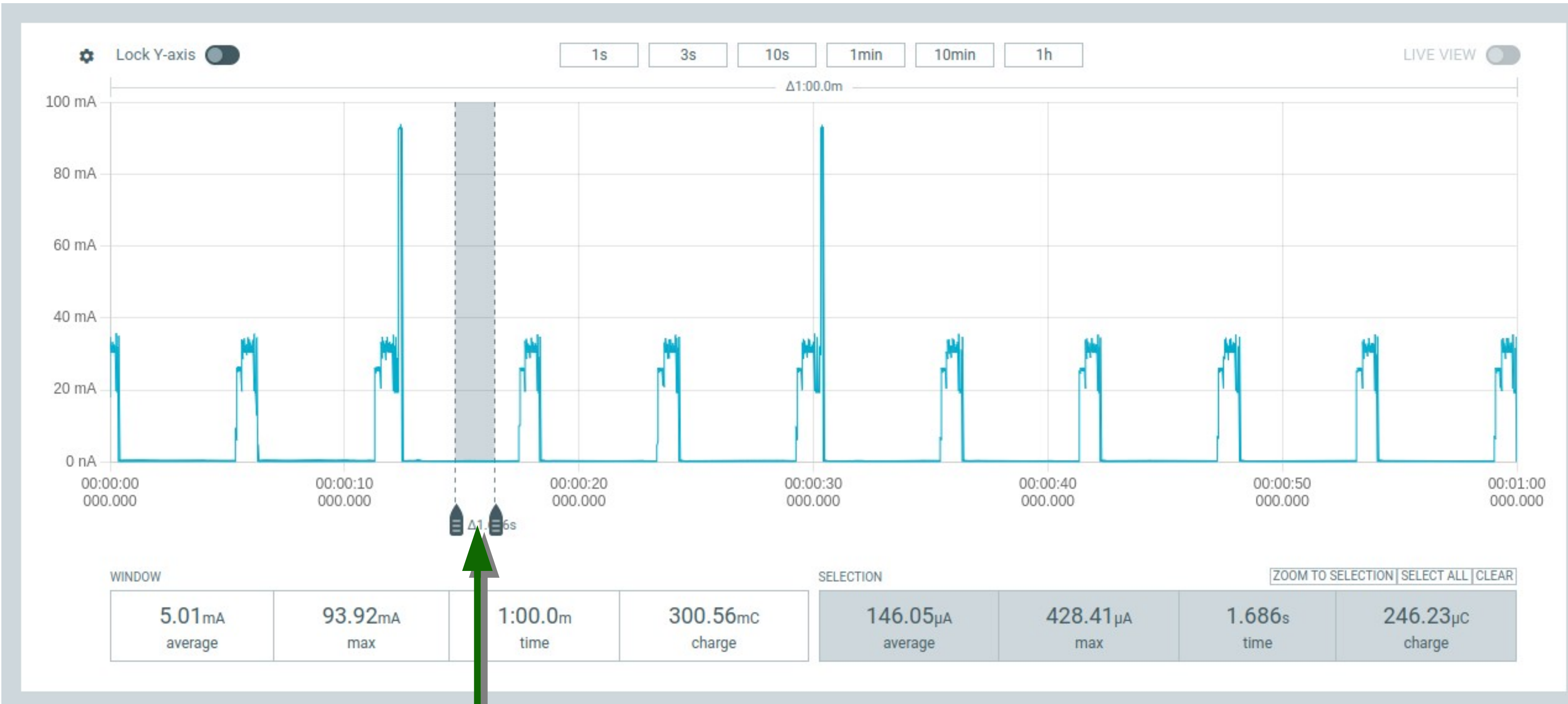
```
if (temperature>(stfloat+0.01) or temperature<(stfloat-0.01)):
    led = Pin (18, Pin.OUT)
    led.value(1)
    rtc.memory(str(temperature))
    print('new value to rtc memory',rtc.memory())  # test of the stored value
    print("LoRa Sender")
    counter=0.0
    data=ustruct.pack('i16s4f',chan,wkey,
                                    temperature,humidity,luminosity,counter)
    print("datalen: " + str(len(data)))
    lora.beginPacket()
    lora.write(data)
    lora.endPacket()
    sleep(1)
    led.value(0)
    disp(temperature,humidity,luminosity)
```

chan	wkey	temp	humi	lumi	count

i | 16s | 4f

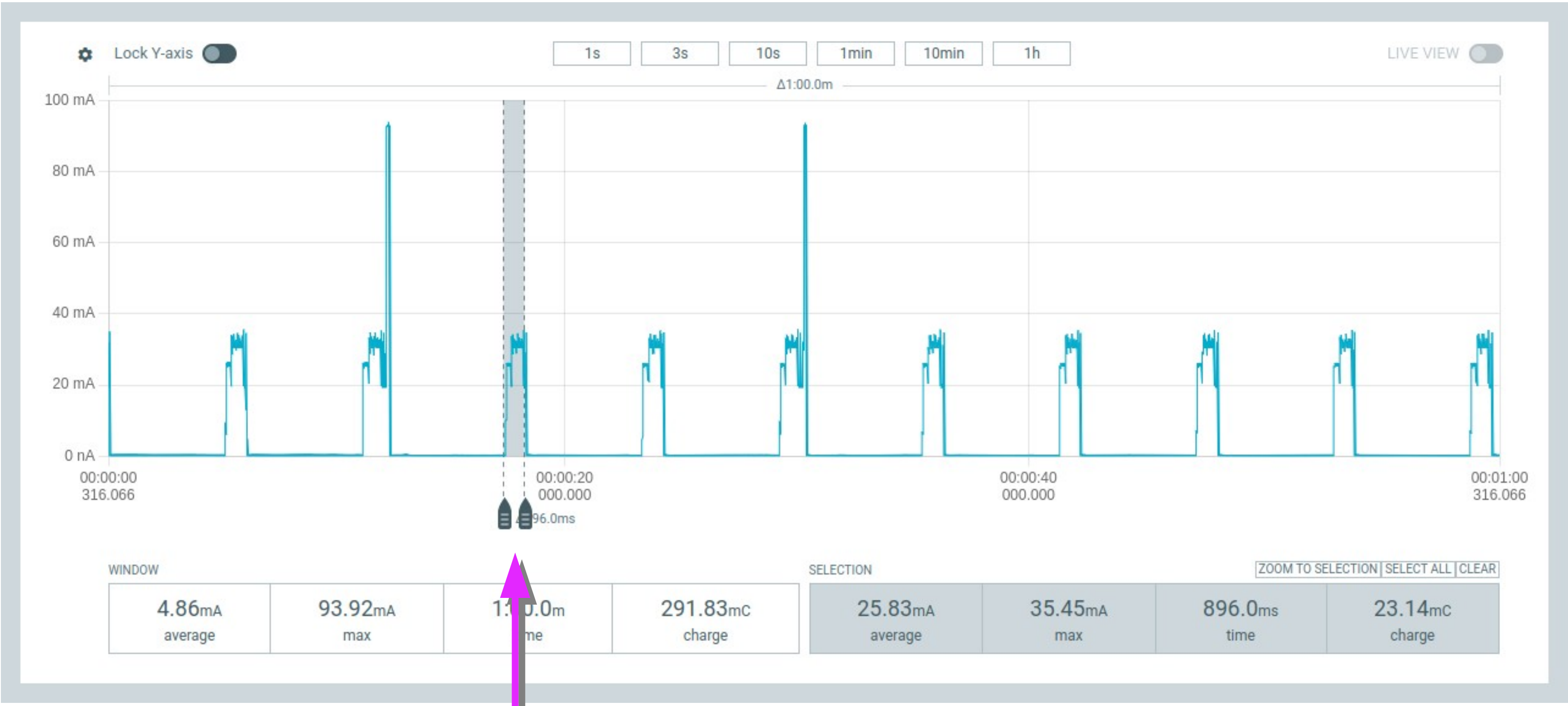
int chan | char wkey[16] | float temp,humi,lumi,count

RT - Power consumption with LoRa link



`low_power` stage – 146.05µA

RT - Power consumption with LoRa link

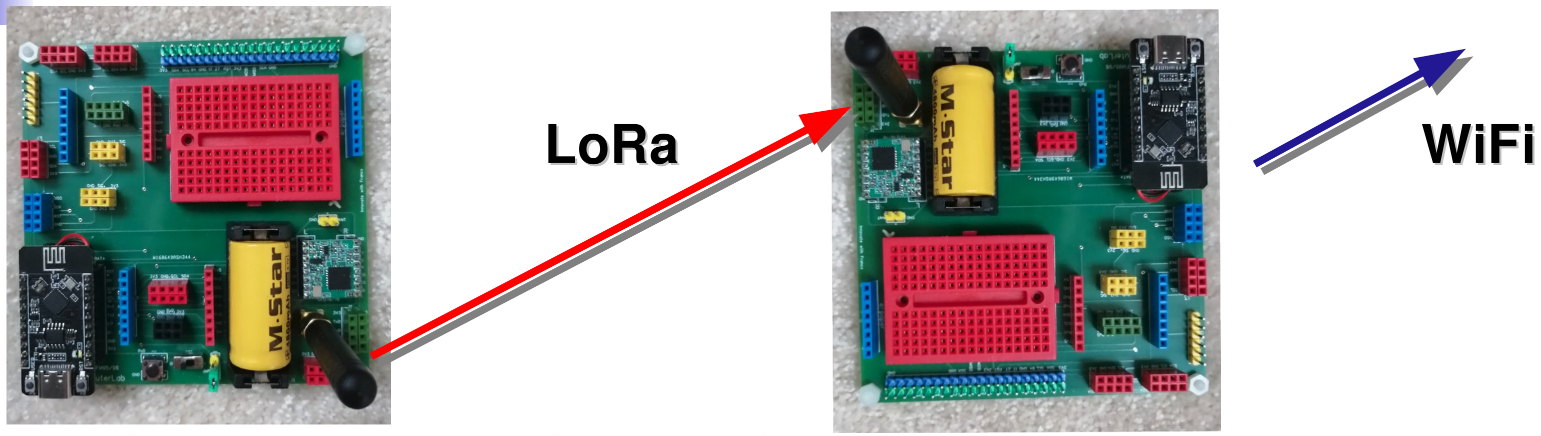


high_power stage sensing/processing phases only – 23.14mC

RT - Power consumption with LoRa link

high_power stage sensing, processing,transmission phases – 39.67mC

LoRa-WiFi Gateway



chan	wkey	temp	humi	lumi	count
i	16s	4f			
int chan	char wkey[16]	float temp,humi,lumi,count			

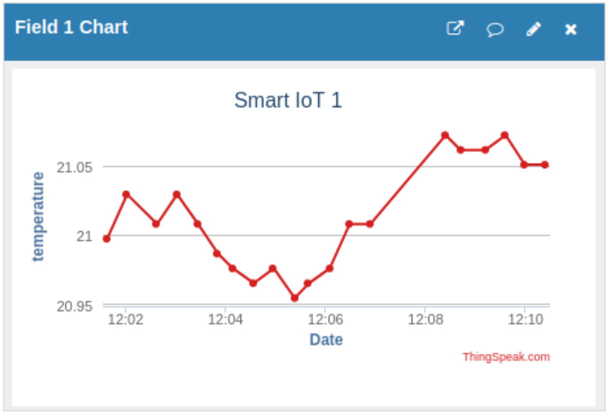
```
lora = SX127x(lora_spi, pins=lora_pins, parameters=lora_default)
type = 'receiver_gateway'     # let us select sender method

if __name__ == '__main__':
    if type == 'sender':
        LoRaSenderDeltaTS.send(lora)
    if type == 'receiver':
        LoRaReceiver.receive(lora)
    if type == 'receiver_gateway':
        LoRaReceiverWiFiTS.receive(lora)
```

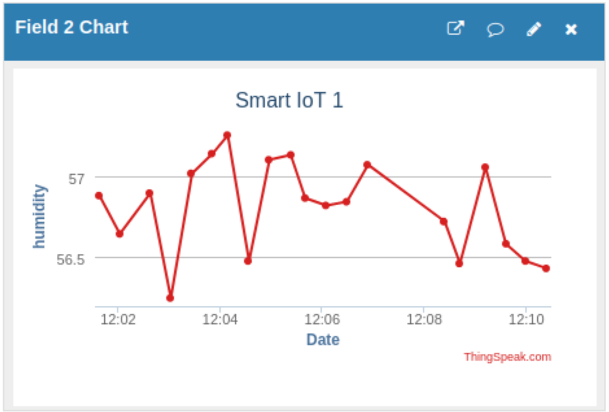
LoRa receive and WiFi-TS send

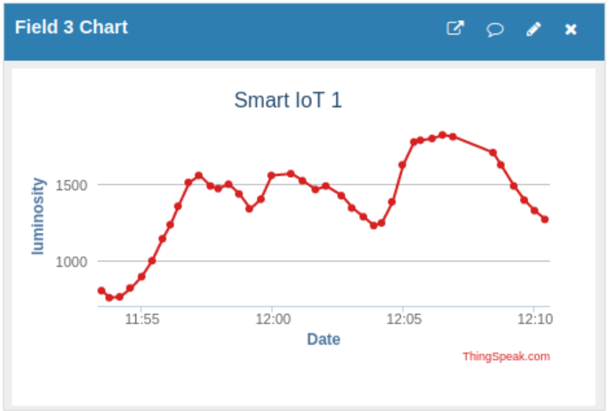
chan	wkey	temp	humi	lumi	count
i	16s	4f			
int chan	char wkey[16]	float temp,humi,lumi,count			

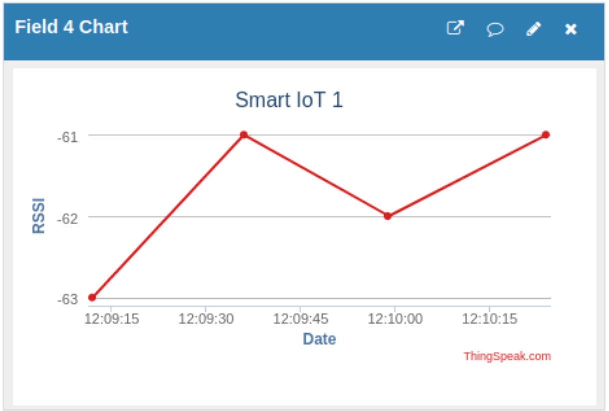
```
def receive(lora):
    print("LoRa Receiver and WiFi Gateway")
    wifista.connect()
    while True:
        if lora.receivedPacket():
            try:
                data = lora.readPayload()
                rssi = float(lora.packetRssi())
                chan,wkey,temp,humi,lumi,count=ustruct.unpack('i16s4f',data)
                disp(temp,humi,lumi,rssi)
                channel_living_room = chan
                active_channel = channel_living_room
                field_temp = "Temperature"
                field_humi = "Humidity"
                field_lumi = "Luminosity"
                field_rssi = "RSSI"
                thing_speak = ThingSpeakAPI([
                Channel(channel_living_room ,wkey,[field_temp,field_humi,field_lumi,
                                                   field_rssi])],
                protocol_class=ProtoHTTP,log=True)
                thing_speak.send(active_channel,{field_temp: temp,
                        field_humi: humi,field_lumi: lumi,field_rssi: rssi
                        })
                print('send to TS')
                time.sleep(thing_speak.free_api_delay)
            except Exception as e:
                print(e)
```

LoRa-WiFi Gateway







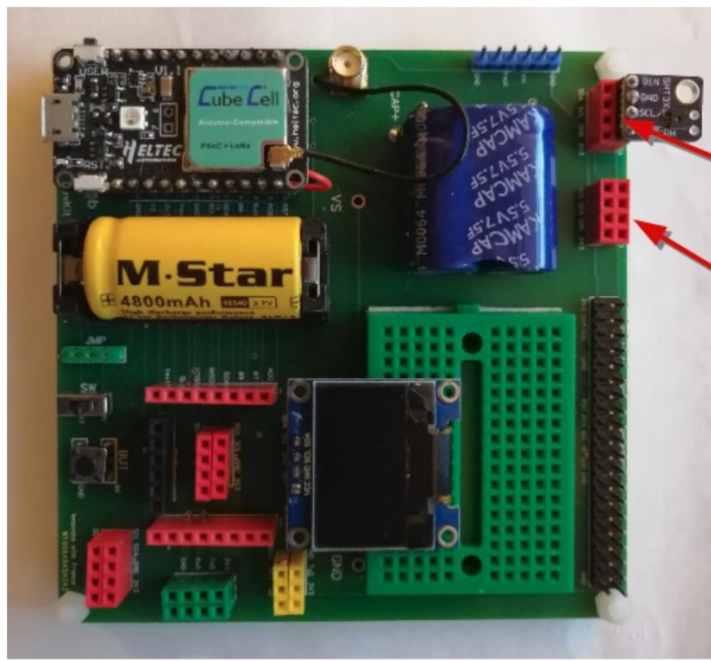


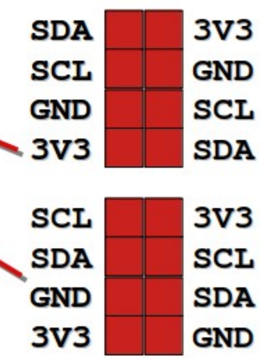
Part III : Long Range (LoRa) with CubeCell

The Remote Terminal on our HT board (RISC-V,WiFi,+LoRa modem) can operate in `low_power` mode that consumes about 150µA. This value may be acceptable for Low Power solutions, however is too high for Very Low Power consumption. We need here different board specifically designed for LoRa communication such as CubeCell.

CubeCell is based on ARM-M0+SX1262 LoRa modem

CubeCell cannot be programmed with µPython – no space and no sufficient processing power





Attention !
The bus lines may be in different order !

CubeCell : Arduino IDE

Legacy IDE (1.8.X)

Arduino IDE 1.8.19

The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. This software can be used with any Arduino board.

Refer to the **Arduino IDE 1.x documentation** for installation instructions.

SOURCE CODE

Active development of the Arduino software is **hosted by GitHub**. See the instructions for **building the code**. Latest release source code archives are available **here**. The archives are PGP-signed so they can be verified using **this** gpg key.

DOWNLOAD OPTIONS

Windows Win 7 and newer
Windows ZIP file
Windows app Win 8.1 or 10 Get
Linux 32 bits
Linux 64 bits
Linux ARM 32 bits
Linux ARM 64 bits
Mac OS X 10.10 or newer
Release Notes
Checksums (sha512)

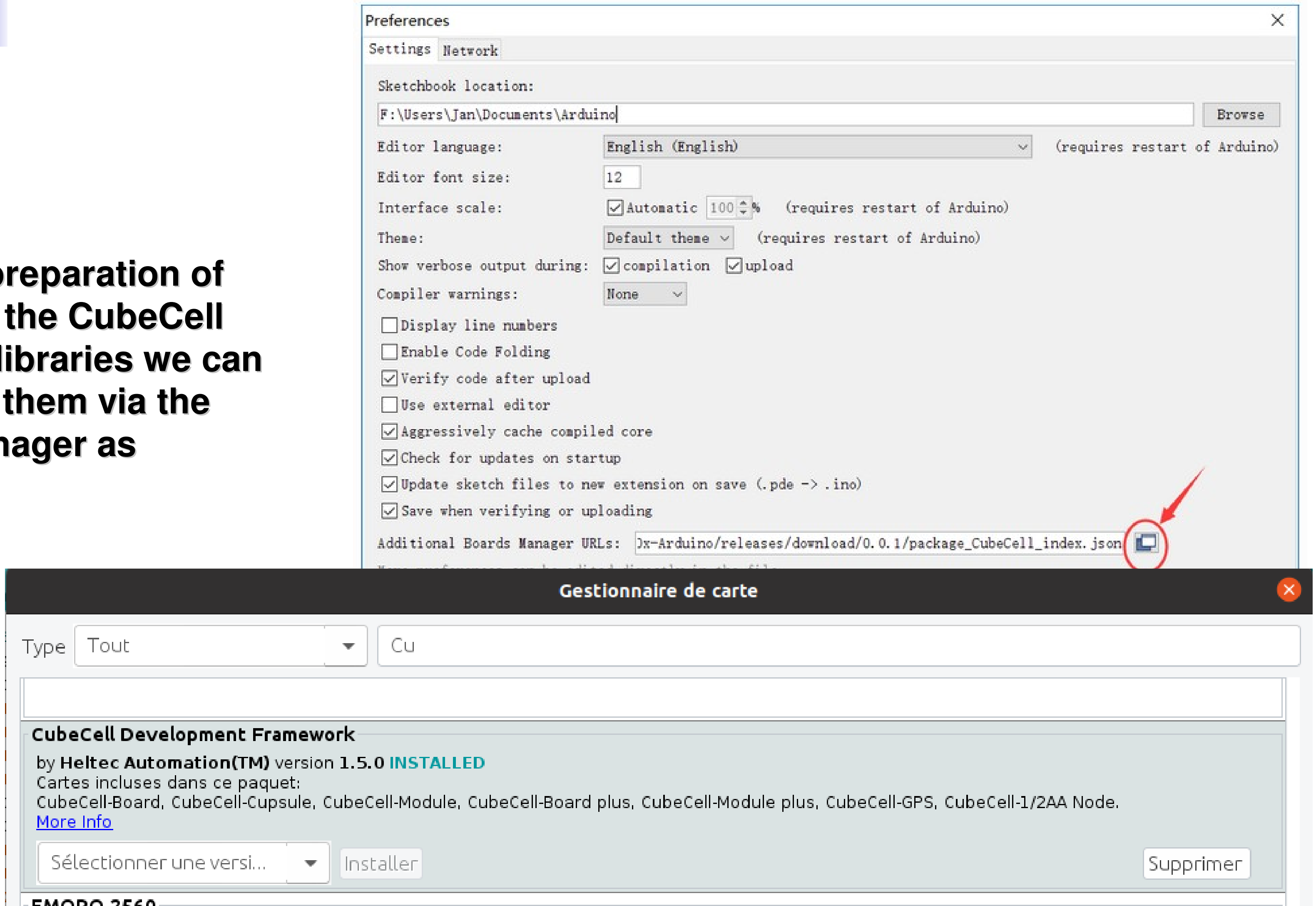
After the installation of the Arduino IDE we have to add the architectural platform to work with CubeCell boards.

This needs the addition of JSON link in the preferences of IDE:

https://github.com/HelTecAutomation/CubeCell-Arduino/releases/download/V1.5.0/package_CubeCell_index.json

CubeCell tools : (crossscompiler,loader)

After the preparation of the link to the CubeCell tools and libraries we can download them via the Board Manager as follows.



CubeCell : headers & events

The Arduino C/C++ code is compiled (cross-compiled) and loaded into flash memory of the board.
The initial section includes a number of libraries required to run the code for the SoM and the associated sensors.

```
#include "LoRaWan_APP.h"
#include "Arduino.h"
#include <Wire.h>
#include "Adafruit_SHT4x.h"
Adafruit_SHT4x sht4 = Adafruit_SHT4x();
#include "Max44009.h"
Max44009 myLux(0x4A);

#define RX_TIMEOUT_VALUE 1000
static RadioEvents_t RadioEvents;
float txNumber;
bool lora_idle=true;
```

`LoRaWan_APP.h` is a complete library with the functions to operate with the basic LoRa transmissions as well as the LoRaWAN protocol.
As we use two sensors: `SHT41` and `Max44009` we need the corresponding libraries.
The operational timing of the LoRa modem (SX1262) is controlled via `RadioEvents` with timeout value.

CubeCell: `low_power` stage

The terminal is identified by the channel number associated to the ThingSpeak server. To write/read the data into/from this channel we need to provide read/write keys of 16-byte length.
Next code section defines the timer operations to put into sleep and to wakeup the processor.

```
unsigned long myChannelNumber =1626377;  // put here your channel number
const char *myWriteAPIKey="3IN09682SQX3PT4Z" ;
const char *myReadAPIKey="9JVTP8ZHVTB9G4TT" ;
TimerEvent_t sleepTimer;
bool sleepTimerExpired;  //Records whether our sleep/low power timer expired

static void wakeUp()
{
  sleepTimerExpired=true;
}

static void lowPowerSleep(uint32_t sleeptime)   // corresponds to low_power stage
{
  sleepTimerExpired=false;
  TimerInit( &sleepTimer, &wakeUp );
  TimerSetValue( &sleepTimer, sleeptime );
  TimerStart( &sleepTimer );
  while (!sleepTimerExpired) lowPowerHandler();
  TimerStop( &sleepTimer );
  }
```

CubeCell: LoRa parameters

LoRa modem radio parameters are registered in the structure **`par`**; . We have here the essential LoRa modulation parameters such as:

base frequency – **`freq`**,
spreading factor – **`sf`**,
signal modulation bandwidth – **`bw`**,
and code rate - **`cr`**.

```
typedef union
{
  uint8_t buff[28];
  struct
  {
    uint32_t  freq;          // GW - link frequency
    uint8_t   power;         // GW - emission power
    uint8_t   sf;            // GW - link spreading factor
    uint32_t  bw;            // GW - link signal bandwidth: [125E3, 250E3,500E3]
    uint8_t   cr;            // GW - link coding rate: [5,6,7,8] in function
    uint8_t   aeskey[16];    // GW - AES key
    uint8_t   pad;
  } par;
} rt_lora_t;              // type definition
rt_lora_t rtlora;         // declaration
```

CubeCell: LoRa packet

LoRa packet sent to the receiver/gateway is structured as follows. Its format corresponds to the **µPython** structure declared as:

```
chan,wkey,temp,humi,lumi,count=ustruct.unpack('i16s4f',data)
```

where: `i → uint32_t, 16s → char[16], 4f → float[4]`

```
typedef union
{
 uint8_t frame[36];
 struct
  {
   uint32_t    channel;        // channel number
   char        wkey[16];       // TS write key
   float       sens[4];        // temp,humi,lumi,count
  } pay;
} pack_t;
pack_t sdp; // packet to send
```

CubeCell: reading sensors – sensing phase

The following declarations allows us to keep some values alive during the deep-sleep stage. They are declared as **`static`**.

```
static uint16_t counter=0;
static float stemp=0.0,shumi=0.0,slumi=0.0;

float temp=0.0,humi=0.0,lumi=0.0;
```

There are two functions to read separately the values of temperature-humidity and luminosity sensors.

```
void readSHT41(float *tem, float *hum){ .. }
```

and

```
void readMAX44009(float *lux) { .. }
```

Note that both functions take the pointers to the variables used to return the sensor values.

CubeCell: `setup()` function

`setup()` section contains all necessary initialization to run the sender code. First we prepare the LoRa radio parameters via **`setLoRaPar()`** function. Then we prepare the events to capture the end of data transmission without (**`OnTxDone`**) or with an error (**`OnTxTimeout`**). The prepared LoRa radio parameters are activated via **`SetChannel()`** and **`SetTxConfig()`** methods.

```
void setup(){
  Serial.begin(9600);delay(300);
  setLoRaPar();                          // read lora parameters and TS
parameters
..
  txNumber=0;
  RadioEvents.TxDone = OnTxDone;
  RadioEvents.TxTimeout = OnTxTimeout;
  Radio.Init( &RadioEvents );
  Radio.SetChannel(rtlora.par.freq);
  Radio.SetTxConfig( MODEM_LORA, rtlora.par.power, 0, rtlora.par.bw,
        rtlora.par.sf, rtlora.par.cr, 8, false,
        true, 0, 0, false, 3000 );
}
```

CubeCell: `loop()` function

`loop()` section runs in **two stages** : the entry into `low_power` **stage** is activated by: `lowPowerSleep(ttsleep);`

```
void loop()
{
  turnOffRGB();counter++; digitalWrite(Vext,HIGH); delay(100);
  lowPowerSleep(ttsleep); // lora_idle = true;
  float ntemp,nhumi,nlumi,lux;
  readSHT41(&ntemp,&nhumi); readMAX44009(&nlumi);
  if(sent_valid(stemp,ntemp,0.05))
    {
    if(lora_idle == true)  // is true when TX is done !
      {
      stemp=ntemp;shumi=nhumi;slumi=nlumi;
      sdp.pay.channel=myChannelNumber;
      strncpy(sdp.pay.wkey,myWriteAPIKey,16);
      sdp.pay.sens[0]=ntemp; sdp.pay.sens[1]=nhumi;sdp.pay.sens[2]=nlumi;
      Radio.Send( (uint8_t *)sdp.frame,36 ); //send the package out
      lora_idle = false; delay(100);
      turnOnRGB(COLOR_SEND,0);counter++;delay(100);digitalWrite(Vext, HIGH);
      }
  }
}
```

Power consumption : `low_power` stage

`low_power` stage – 10.27µA

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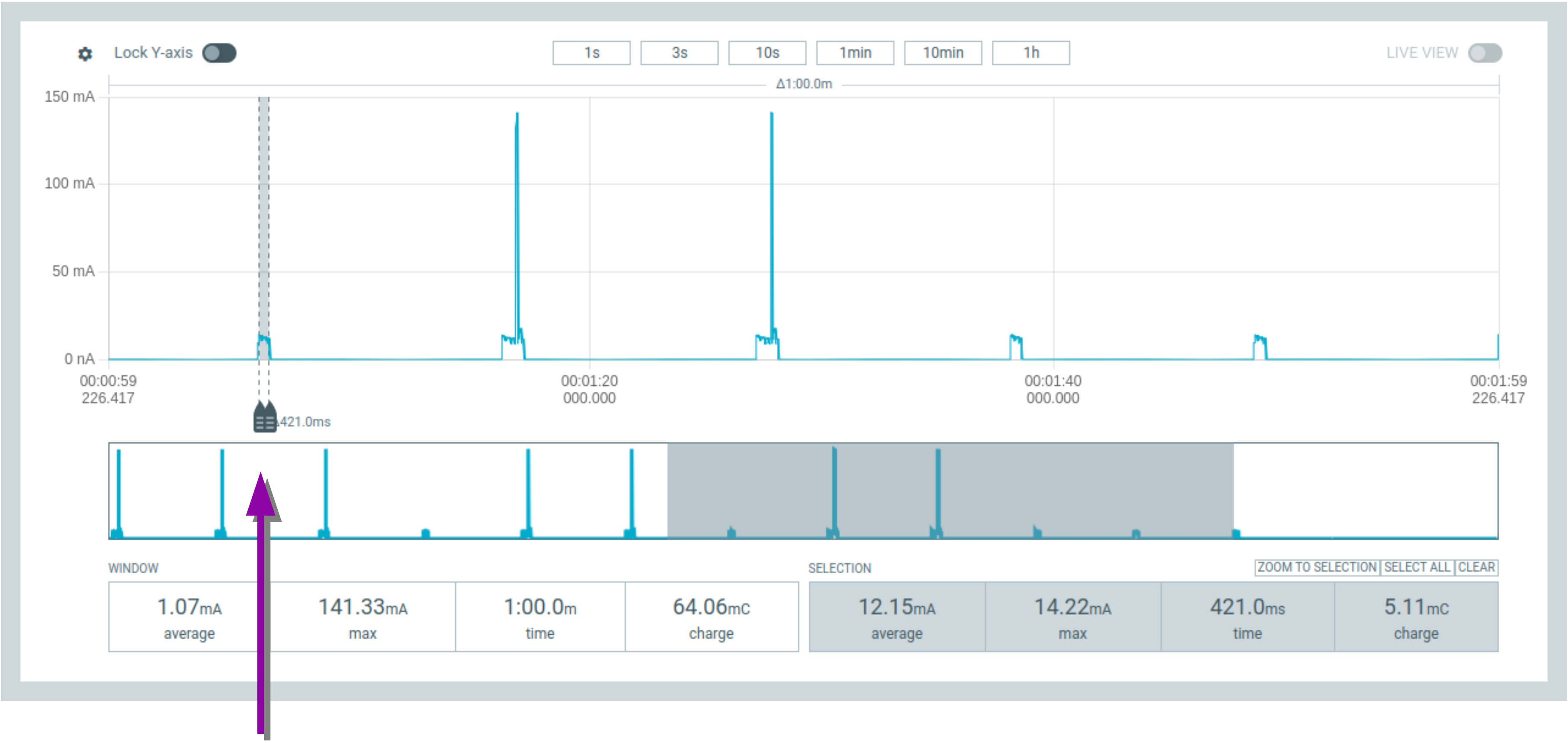
Power consumption : full high_power stage

full high_power stage – 20.19mC

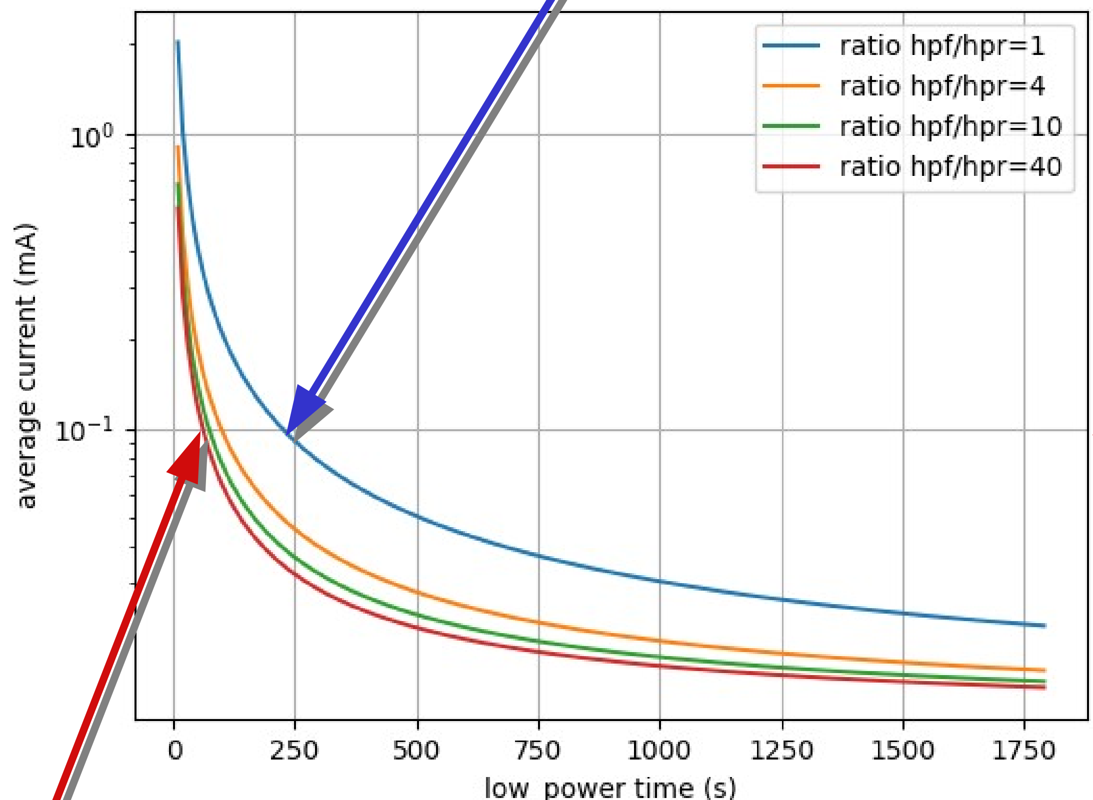
Power consumption : reduced high_power stage



reduced high_power stage – 5.11mC

Average current function of low_power stage time

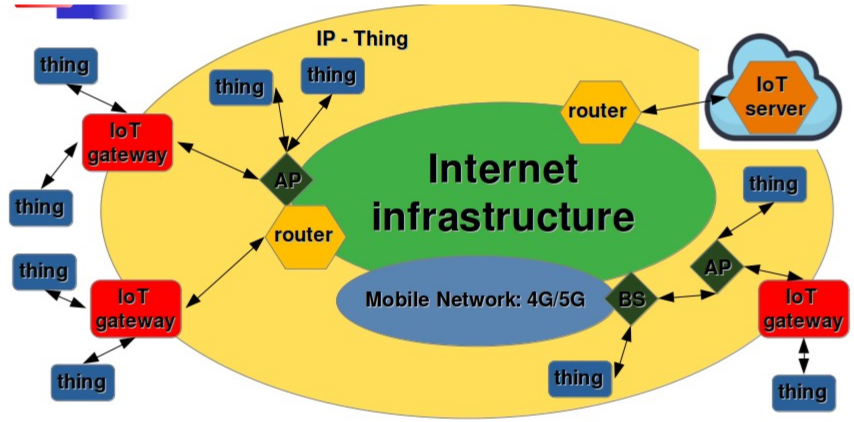
high_power reduced/high_power full = 1 => 240s



100µA

high_power reduced/high_power full = 100 => 60s

Summary



IoT infrastructure & **Devices**

IoT devices **identification**:

@IP: port_n: channel_id

Low Power modes: **stages & phases**

Direct Terminals - **WiFi** (HT: RISC-V)

Power consumption on Direct Terminals

Remote Terminals – Lora (HT: RISC-V) , (CC: ARM-M0)

Power consumption on Remote Terminals

LoRa-WiFi **Gateways** & **Complete IoT Architectures**