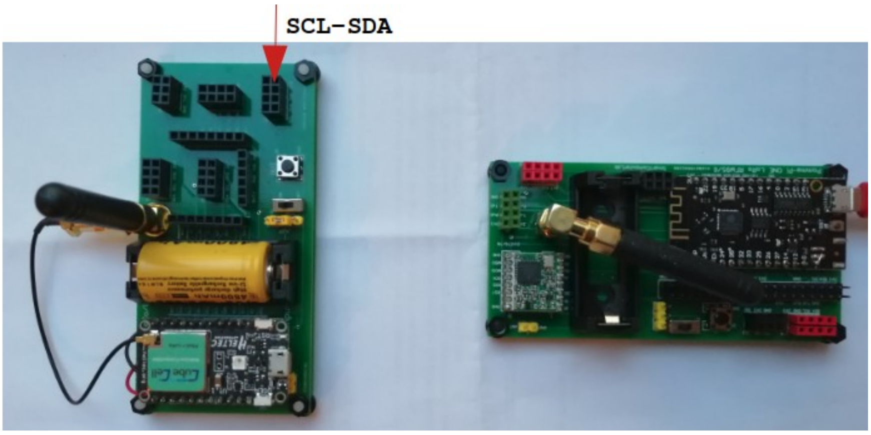
Exercise 1

Sending and receiving LoRa packets

In this exercise we are going to use two different IoT DevKits

- Pomme-Pi ONE LoRa DevKit and
- CubleCell: LoRa/LoRaWAN Devkit

as shown on the following figure:



Both boards are programmed with **Arduino IDE** or **PlatformIO**.

Attention:
This exercise is the **starting point** for our 4 hours lab including the development of complete IoT architecture with low power terminal nodes and IoT gateway with Lora to WiFi relay. The gateway sends the data to MQTT and TS IoT servers.

Content

Attention:

You should install the libraries (tools) for ESP32 and CubeCell boards. Use preferences and board manager to do it.

Remember that you are using **ESP32** – **Lolin D32** board and **CubeCell** board – **HTCC-AB01** board.

The **MCUs of these boards are completely different**:

ESP32 uses **Extensa-LX06** micro-processor while CubeCell integrates an **ARM-CORTEX-M0** microprocessor.

1.1 Receiver side on Lolin D32

The following is the code for receiver on Pomme-Pi ONE LoRa board. Note the use of **`union`** construct to send/receive LoRa packets in a simple but formatted way.

```
union pack
{
 uint8_t frame[16]; // trames avec octets
  float  data[4];   // 4 valeurs en virgule flottante
} rdp ;  // paquet d'émission
```

The same **`union`** should be used at the sender side.

```
#include <SPI.h>
#include <LoRa.h>
#define SCK     18   // GPIO18 -- SX127x's SCK
#define MISO    19   // GPIO19 -- SX127x's MISO
#define MOSI    23   // GPIO23 -- SX127x's MOSI
#define SS       5   // GPIO05 -- SX127x's CS
#define RST     15   // GPIO15 -- SX127x's RESET
#define DI0     25   // GPIO25 (integrated modem)  -- SX127x's IRQ(Interrupt Request)
#define freq    8685E5
#define sf 9
#define sb 125E3

union pack
{
 uint8_t frame[16]; // trames avec octets
  float  data[4];   // 4 valeurs en virgule flottante
} rdp ;  // paquet d'émission

void setup() {
  Serial.begin(9600);
  delay(1000);
  SPI.begin(SCK,MISO,MOSI,SS);
  LoRa.setPins(SS,RST,DI0);
  Serial.println();delay(100);Serial.println();
  if (!LoRa.begin(freq)) {
    Serial.println("Starting LoRa failed!");
    while (1);
  }

Serial.println("Starting LoRa OK!");
delay(1000);
LoRa.setSpreadingFactor(sf);
LoRa.setSignalBandwidth(sb);
LoRa.setCodingRate4(5);
}

int rssi;

void loop()
{
int packetLen;
packetLen=LoRa.parsePacket();
if(packetLen==16)
  {
  int i=0;
  while (LoRa.available()) {
    rdp.frame[i]=LoRa.read();i++;
    }
  rssi=LoRa.packetRssi();  // force du signal en réception en dB
  Serial.printf("V:%2.2f,T:%2.2f,H:%2.2f\n",rdp.data[0],rdp.data[1],rdp.data[2]);
  Serial.printf("RSSI=%d\n",rssi);
  }
}
```

1.2 Sender side on CubeCell board

```
#include "LoRaWan_APP.h"
#include "Arduino.h"
#ifndef LoraWan_RGB
#define LoraWan_RGB 0
#endif
#define RF_FREQUENCY                                868500000 // Hz
#define TX_OUTPUT_POWER                             14        // dBm
#define LORA_BANDWIDTH                              0         // [0: 125 kHz,
                                                              //  1: 250 kHz,
                                                              //  2: 500 kHz,
                                                              //  3: Reserved]
#define LORA_SPREADING_FACTOR                       9         // [SF7..SF12]
#define LORA_CODINGRATE                             1         // [1: 4/5,
                                                              //  2: 4/6,
                                                              //  3: 4/7,
                                                              //  4: 4/8]
#define LORA_PREAMBLE_LENGTH                        8         // Same for Tx and Rx
#define LORA_SYMBOL_TIMEOUT                         0         // Symbols
#define LORA_FIX_LENGTH_PAYLOAD_ON                  false
#define LORA_IQ_INVERSION_ON                        false
#define RX_TIMEOUT_VALUE                            1000
#define BUFFER_SIZE                                 128 // Define the payload size here

char txPacket[BUFFER_SIZE];
static RadioEvents_t RadioEvents;
void OnTxDone( void );
void OnTxTimeout( void );

typedef enum
{
    LOWPOWER,  ReadVoltage,  TX   // 3 states (1,2,3)
} States_t;

States_t state;
bool sleepMode = false;
int16_t rssi,rxSize;
uint16_t voltage;

union pack
{
 uint8_t frame[16]; // trames avec octets
  float  data[4];   // 4 valeurs en virgule flottante
} sdp ;  // paquet d'émission

void setup()
{
    Serial.begin(9600);
    voltage = 0;
    rssi=0;
    RadioEvents.TxDone = OnTxDone;
    RadioEvents.TxTimeout = OnTxTimeout;
    Radio.Init( &RadioEvents );
    Radio.SetChannel( RF_FREQUENCY );
    Radio.SetTxConfig( MODEM_LORA, TX_OUTPUT_POWER, 0, LORA_BANDWIDTH,
                                   LORA_SPREADING_FACTOR, LORA_CODINGRATE,
                                   LORA_PREAMBLE_LENGTH, LORA_FIX_LENGTH_PAYLOAD_ON,
                                   true, 0, 0, LORA_IQ_INVERSION_ON, 3000 );
    state=ReadVoltage;
}

void loop()
{
  switch(state)
  {
    case TX:
    {
      memset(txPacket,0x00,BUFFER_SIZE);
      sprintf(txPacket,"%s","ADC_battery (mV): ");
      int plen= strlen(txPacket);
      sprintf(txPacket+plen,"%d",voltage);
      sdp.data[0] = (float)voltage;
      if(voltage<(uint16_t)3680)turnOnRGB(COLOR_SEND,0);
      else turnOnRGB(COLOR_RECEIVED,200);
      Serial.printf("\r\nsending packet \"%s\"\r\n",txPacket);
```

```
       // Radio.Send( (uint8_t *)txPacket, strlen(txPacket) );
        Radio.Send(sdp.frame,16);
        Serial.println(strlen(txPacket));delay(100);
        state=LOWPOWER;
        break;
      }
      case LOWPOWER:
      {
        lowPowerHandler();delay(100);
        turnOffRGB();
        delay(2000);  //LowPower time
        state = ReadVoltage;
        break;
      }
      case ReadVoltage:
      {
        pinMode(VBAT_ADC_CTL,OUTPUT);
        digitalWrite(VBAT_ADC_CTL,LOW);
        voltage=analogRead(ADC)+550; //*2;
        pinMode(VBAT_ADC_CTL, INPUT);
        state = TX;
        break;
      }
       default:
            break;
  }
  Radio.IrqProcess();
}

void OnTxDone( void )
{
  Serial.print("TX done!");
  turnOnRGB(0,0);
}

void OnTxTimeout( void )
{
    Radio.Sleep( );
    Serial.print("TX Timeout......");
    state=ReadVoltage;
    Serial.print(state);
}
```

To do:

Analyze both codes:

- LoRa modem initialization
- LoRa radio parameters
- Lora packets structure and content

Modify the Lora radio parameters

Add a sensor to send second value (the first is battery voltage)

Then you can start the main lab – Building complete IoT architecture with LoRa and WiFi links

Documents to be used:

IoT.Labs.1.and2.Low.Power.IoT.Architectures.2023

and

IoT.Labs.ESP32.D32.arduino.2023

1.3 Sender side on CubeCell board with SHT21 & BH1750 sensors

```
#include "LoRaWan_APP.h"
#include "Arduino.h"
#include <BH1750.h>
BH1750 lightMeter;
#include <SHT21.h>  // include SHT21 library
SHT21 sht;
#ifndef LoraWan_RGB
#define LoraWan_RGB 0
#endif
#define RF_FREQUENCY                                868500000 // Hz
#define TX_OUTPUT_POWER                             14        // dBm
#define LORA_BANDWIDTH                              0         // [0: 125 kHz,
                                                              //  1: 250 kHz,
                                                              //  2: 500 kHz,
                                                              //  3: Reserved]
#define LORA_SPREADING_FACTOR                       9         // [SF7..SF12]
#define LORA_CODINGRATE                             1         // [1: 4/5,
                                                              //  2: 4/6,
                                                              //  3: 4/7,
                                                              //  4: 4/8]
#define LORA_PREAMBLE_LENGTH                        8         // Same for Tx and Rx
#define LORA_SYMBOL_TIMEOUT                         0         // Symbols
#define LORA_FIX_LENGTH_PAYLOAD_ON                  false
#define LORA_IQ_INVERSION_ON                        false
#define RX_TIMEOUT_VALUE                            1000
#define BUFFER_SIZE                                 128 // Define the payload size here

char txPacket[BUFFER_SIZE];
static RadioEvents_t RadioEvents;
void OnTxDone( void );
void OnTxTimeout( void );

typedef enum
{
  LOWPOWER,  ReadVTHL,  TX   // 3 states (1,2,3)
} States_t;

States_t state;
bool sleepMode = false;
int16_t rssi,rxSize;
uint16_t voltage;
float temperature, humidity, luminosity;

union pack
{
 uint8_t frame[16]; // trames avec octets
  float  data[4];   // 4 valeurs en virgule flottante
} sdp ;  // paquet d'émission

void setup()
{
    Serial.begin(9600); delay(200);
    pinMode(Vext, OUTPUT);
    digitalWrite(Vext, LOW); delay(100);
    Wire.begin();
    voltage = 0;
    rssi=0;
    RadioEvents.TxDone = OnTxDone;
    RadioEvents.TxTimeout = OnTxTimeout;
    Radio.Init( &RadioEvents );
    Radio.SetChannel( RF_FREQUENCY );
    Radio.SetTxConfig( MODEM_LORA, TX_OUTPUT_POWER, 0, LORA_BANDWIDTH,
                               LORA_SPREADING_FACTOR, LORA_CODINGRATE,
                               LORA_PREAMBLE_LENGTH, LORA_FIX_LENGTH_PAYLOAD_ON,
                               true, 0, 0, LORA_IQ_INVERSION_ON, 3000 );
    state=ReadVTHL;   // read voltage , temperature and humidity
}

void loop()
{
  switch(state)
  {
    case TX:
    {
      sdp.data[0] = (float)voltage;
      sdp.data[1] = temperature;
      sdp.data[2] = humidity;
      sdp.data[3] = luminosity;
      if(voltage<(uint16_t)3680)turnOnRGB(COLOR_SEND,0);
      else turnOnRGB(COLOR_RECEIVED,200);
      Serial.printf("\r\nsending packet- mV:%d, T:%d, H:%d, L:%d\n",voltage,(int)temperature,
(int)humidity,(int)luminosity);
      Radio.Send(sdp.frame,16);
      Serial.println(strlen(txPacket));delay(100);
      state=LOWPOWER;
      break;
    }
    case LOWPOWER:
    {
      lowPowerHandler();delay(100);
      turnOffRGB();
      delay(2000);  //LowPower time
      state = ReadVTHL;
      break;
    }
    case ReadVTHL:
    {
      pinMode(VBAT_ADC_CTL,OUTPUT);
      digitalWrite(VBAT_ADC_CTL,LOW);
      voltage=analogRead(ADC)+550; //*2;
      pinMode(VBAT_ADC_CTL, INPUT);
      pinMode(Vext, OUTPUT);delay(40);
      digitalWrite(Vext, LOW); delay(40);
      Wire.begin();delay(40);
      temperature = sht.getTemperature();  // get temp from SHT
      humidity = sht.getHumidity(); // get temp from SHT
      Serial.print("Temp: ");     // print readings
      Serial.print(temperature);
      Serial.print("\t Humidity: ");
      Serial.println(humidity);delay(40);
      digitalWrite(Vext,LOW); // start power before activating Wire
      Wire.begin();delay(100);
      lightMeter.begin(); delay(200);   // 200
      luminosity = lightMeter.readLightLevel();
      Serial.print("Light: ");
      Serial.print(luminosity);
      Serial.println(" lux");
      delay(40);
      Wire.end();delay(40);
      digitalWrite(Vext, HIGH); delay(40);
      state = TX;
      break;
    }
     default:
          break;
  }
  Radio.IrqProcess();
}

void OnTxDone( void )
{
  Serial.print("TX done!");
  turnOnRGB(0,0);
}

void OnTxTimeout( void )
{
    Radio.Sleep( );
    Serial.print("TX Timeout......");
    state=ReadVTHL;
    Serial.print(state);
}
```

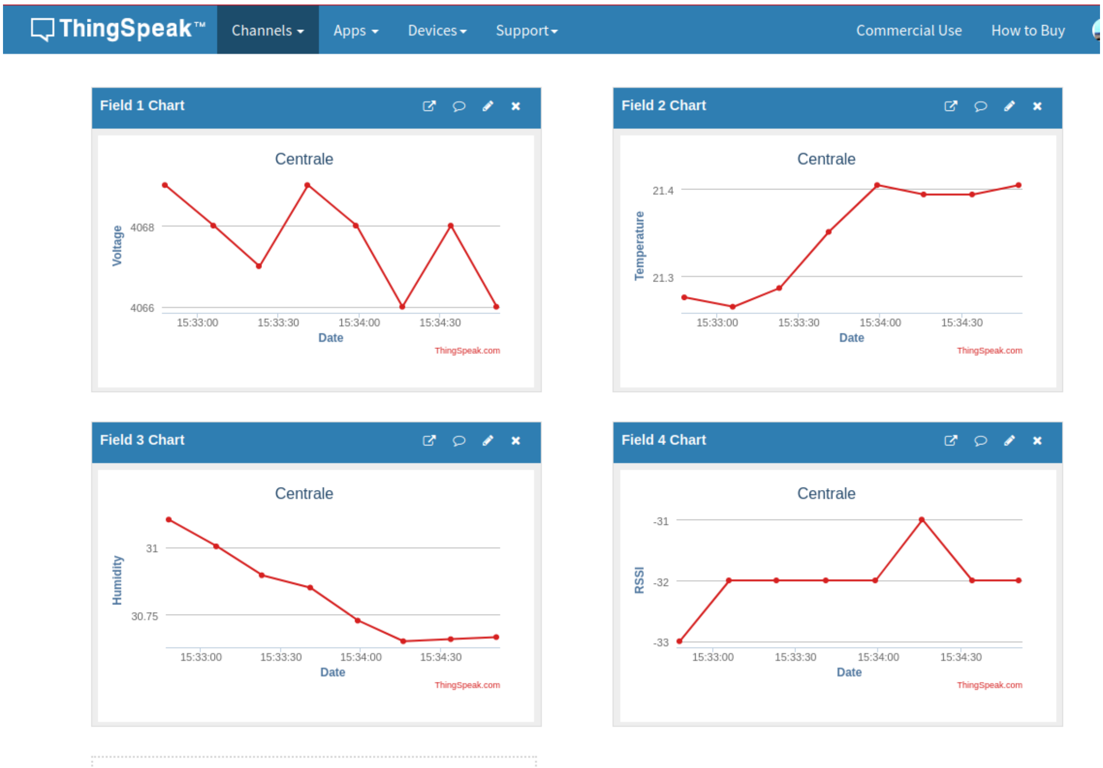
To do:

In order to shorten the high power period experiment with shorter delay() periods in **`ReadVTHL`** state.

1.4 Receiver/gateway side on Lolin D32 board

```
#include <WiFi.h>
#include "ThingSpeak.h"
#include <SoftwareSerial.h>

const char* ssid     = "Livebox-08B0";
const char* password = "G79ji6dtEptVTPWmZP";

#include <SPI.h>
#include <LoRa.h>
#define SCK     18   // GPIO18 -- SX127x's SCK
#define MISO    19   // GPIO19 -- SX127x's MISO
#define MOSI    23   // GPIO23 -- SX127x's MOSI
#define SS       5   // GPIO05 -- SX127x's CS
#define RST     15   // GPIO15 -- SX127x's RESET
#define DI0     25   // GPIO25 (integrated modem) -- SX127x's IRQ(Interrupt Request)
#define freq    8685E5
#define sf 9
#define sb 125E3

union pack
{
 uint8_t frame[16]; // trames avec octets
  float  data[4];   // 4 valeurs en virgule flottante
} rdp ;  // paquet d'émission

WiFiClient  client;
unsigned long myChannelNumber = 1697980;
const char * myWriteAPIKey = "4K897XNNHTW7I4NO";

void setup() {
  Serial.begin(9600);
  Serial.print("[WiFi] Connecting to ");
  Serial.println(ssid);
  WiFi.begin(ssid, password);
  while(WiFi.status() != WL_CONNECTED)
    {
      Serial.print(".");
      delay(500);
    }
  Serial.println("");
  Serial.println("WiFi connected");
  Serial.println("IP address: ");
  Serial.println(WiFi.localIP());
  delay(500);
  ThingSpeak.begin(client);  // Initialize ThingSpeak
  delay(1000);
  SPI.begin(SCK,MISO,MOSI,SS);
  LoRa.setPins(SS,RST,DI0);
  Serial.println();delay(100);Serial.println();
  if (!LoRa.begin(freq)) {
    Serial.println("Starting LoRa failed!"); while (1);
  }
Serial.println("Starting LoRa OK!");delay(1000);
LoRa.setSpreadingFactor(sf);
LoRa.setSignalBandwidth(sb);
LoRa.setCodingRate4(5);
}

int rssi;

void loop()
{
int packetLen;
packetLen=LoRa.parsePacket();
if(packetLen==16)
  {
  int i=0;
  while (LoRa.available()) {
    rdp.frame[i]=LoRa.read();i++;
    }
  rssi=LoRa.packetRssi();  // force du signal en réception en dB
  Serial.printf("V:%2.2f,T:%2.2f,H:%2.2f\n",rdp.data[0],rdp.data[1],rdp.data[2]);
  Serial.printf("RSSI=%d\n",rssi);
  ThingSpeak.setField(1, rdp.data[0]);
  ThingSpeak.setField(2, rdp.data[1]);
  ThingSpeak.setField(3, rdp.data[2]);
  ThingSpeak.setField(4, rssi);
  int x = ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);
  if(x == 200){
    Serial.println("Channel update successful.");
  }
  else{
    Serial.println("Problem updating channel. HTTP error code " + String(x));
  }
  delay(15000);
  }
}
```

```
WiFi connected
IP address:
192.168.1.50

Starting LoRa OK!
V:4069.00,T:21.35,H:30.84
RSSI=-32
Channel update successful.
V:4068.00,T:21.32,H:30.81
RSSI=-33
Channel update successful.
V:4068.00,T:21.34,H:30.71
RSSI=-32
Channel update successful.
V:4069.00,T:21.27,H:30.77
RSSI=-32
Channel update successful.
V:4069.00,T:21.30,H:30.77
RSSI=-33
Channel update successful.
V:4068.00,T
```



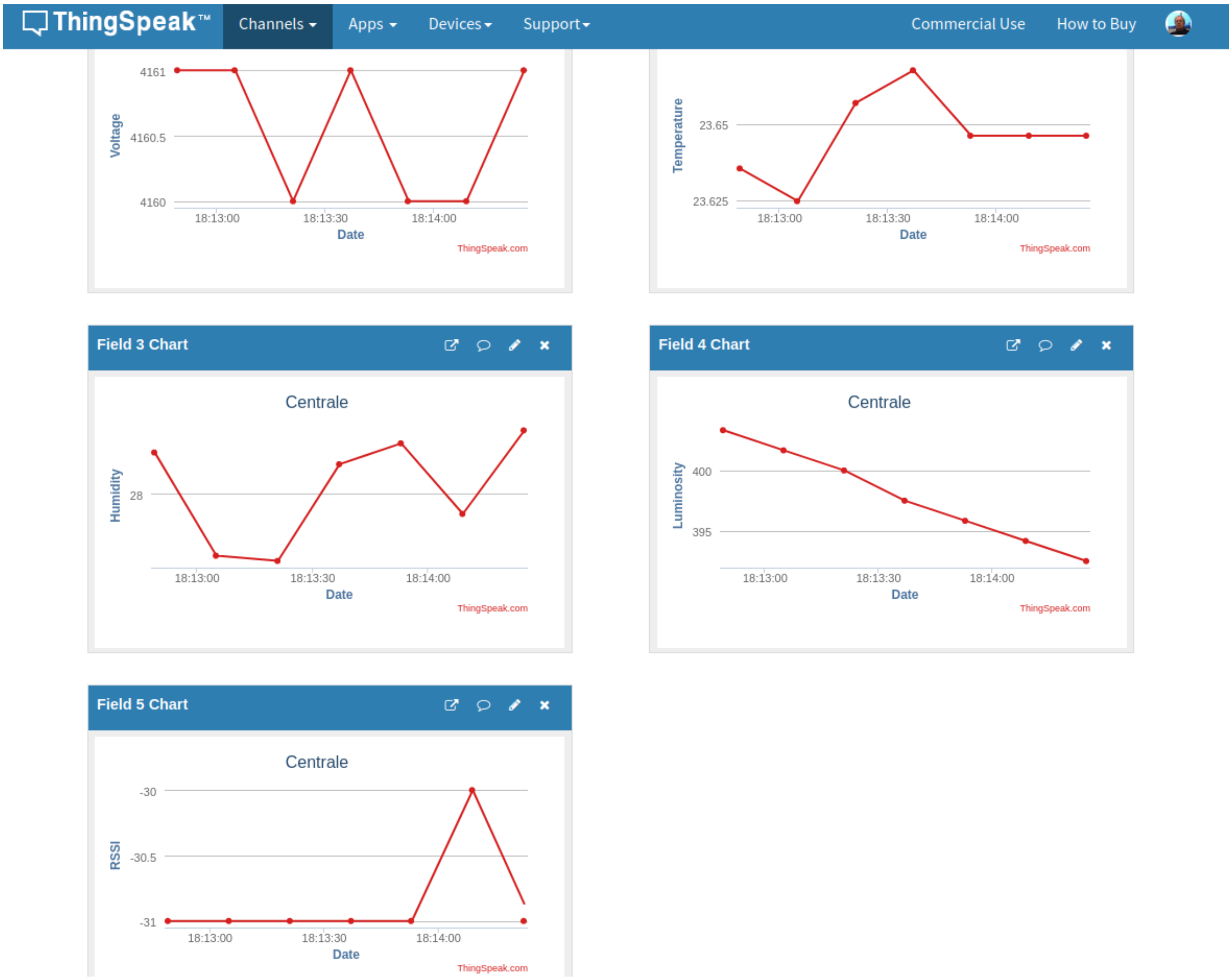
To do:

1. Instead of simple WiFi connection use WiFiManager to provide your credentials via local access point and simple web server at : 192.168.1.4
2. Use callback function onReceive to capture the arriving LoRa packets

1.5 Receiver/gateway on Lolin D32 board (with callback) & OLED

```
#include <WiFi.h>
#include "ThingSpeak.h"
#include <SoftwareSerial.h>
#include <Wire.h>
#include "SSD1306Wire.h"
SSD1306Wire display(0x3c, 12, 14);

const char* ssid     = "Livebox-08B0";
const char* password = "G79ji6dtEptVTPWmZP";

#include <SPI.h>
#include <LoRa.h>
#define SCK     18   // GPIO18 -- SX127x's SCK
#define MISO    19   // GPIO19 -- SX127x's MISO
#define MOSI    23   // GPIO23 -- SX127x's MOSI
#define SS       5   // GPIO05 -- SX127x's CS
#define RST     15   // GPIO15 -- SX127x's RESET
#define DI0     25   // GPIO26 -- SX127x's IRQ(Interrupt Request)
#define freq    8685E5
#define sf 9
#define sb 125E3

typedef union
{
 uint8_t frame[16]; // frames with bytes
  float  data[4];   // 4 floating point values
} pack_t ;  // packet type

WiFiClient  client;

unsigned long myChannelNumber = 1697980;
const char * myWriteAPIKey = "4K897XNNHTW7I4NO";

int rssi=0;
QueueHandle_t dqueue;  // queues for data packets

void disp(char *d1,char *d2,char *d3, char *d4, char *d5)
{
  display.init();
  //display.flipScreenVertically();
  display.setTextAlignment(TEXT_ALIGN_LEFT);
  display.setFont(ArialMT_Plain_10);  // ArialMT_Plain_10
  display.drawString(0, 0, d1);
  display.drawString(0, 9, d2);
  display.drawString(0, 18, d3);
  display.drawString(0, 27, d4);
  display.drawString(0, 36, d5);
  display.drawString(20, 52, "SmartComputerLab");
  display.display();
}

void onReceive(int packetSize)
{
pack_t rdp;
Serial.println("received packet");
  if(packetSize==16)
  {
    int i=0;
    while (LoRa.available())  {  rdp.frame[i]=LoRa.read();i++; }
    rssi=LoRa.packetRssi();
    xQueueReset(dqueue); // to keep only the last element
    xQueueSend(dqueue, &rdp, portMAX_DELAY);
  }
}

void setup() {
  Serial.begin(9600);
  Serial.print("[WiFi] Connecting to ");
  Serial.println(ssid);
  WiFi.begin(ssid, password);
  while(WiFi.status() != WL_CONNECTED)
    {
      Serial.print(".");
      delay(500);   }
  Serial.println("");
  Serial.println("WiFi connected");
  Serial.println("IP address: ");
  Serial.println(WiFi.localIP());
  delay(500);
  ThingSpeak.begin(client);  // Initialize ThingSpeak
  delay(1000);
  SPI.begin(SCK,MISO,MOSI,SS);
  LoRa.setPins(SS,RST,DI0);
  Serial.println();delay(100);Serial.println();
  if (!LoRa.begin(freq)) {
    Serial.println("Starting LoRa failed!");
    while (1);
  }
  Serial.println("Starting LoRa OK!");
  delay(1000);
  LoRa.setSpreadingFactor(sf);
  LoRa.setSignalBandwidth(sb);
  LoRa.setCodingRate4(5);
  dqueue = xQueueCreate(4,16); // queue for 4 data packets
  LoRa.onReceive(onReceive);  // register the receive callback
  LoRa.receive();  // put the radio into receive mode
}

void loop()
{
  pack_t rdp;
  char d1[32],d2[32],d3[32],d4[32], d5[32];
  xQueueReceive(dqueue,rdp.frame,portMAX_DELAY); // default:portMAX_DELAY
  Serial.printf("Volt(mV):%2.2f,T:%2.2f,H:%2.2f,L:%2.2f\
n",rdp.data[0],rdp.data[1],rdp.data[2],rdp.data[3]);
  Serial.printf("RSSI=%d\n",rssi);
  ThingSpeak.setField(1, rdp.data[0]);
  ThingSpeak.setField(2, rdp.data[1]);
  ThingSpeak.setField(3, rdp.data[2]);
  ThingSpeak.setField(4, rdp.data[3]);
  ThingSpeak.setField(5, rssi);
  int x = ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);
  if(x == 200){
    Serial.println("Channel update successful.");
  }
  else{
    Serial.println("Problem updating channel. HTTP error code " + String(x));
  }
  sprintf(d1,"Battery (mV): %2.2f",rdp.data[0]);sprintf(d2,"Temperature : %2.2f",rdp.data[1]);
  sprintf(d3,"Humidity : %2.2f",rdp.data[2]);sprintf(d4,"Luminosity : %2.2f",rdp.data[3]);
  sprintf(d5,"RSSI: %d",rssi);
  disp(d1,d2,d3,d4,d5);
  delay(15000);
}
```

```
Starting LoRa OK!
received packet
V:4169.00,T:23.69,H:27.55,L:400.83
RSSI=-30
Channel update successful.
received packet
received packet
received packet
received packet
V:4162.00,T:23.69,H:27.66,L:400.83
RSSI=-30
received packet
Channel update successful.
received packet
received packet
received packet
received packet
V:4161.00,T:23.68,H:29.42,L:400.83
RSSI=-31
received packet
Channel update successful.
received packet
received packet
received packet
received packet
V:4160.00,T:23.68,H:28.34,L:408.33
RSSI=-31
Channel update successful.
received packet
received packet
received packet
received packet
received packet
V:4162.00,T:23.65,H:27.72,L:408.33
RSSI=-31
Channel update successful.
received packet
received packet
received packet
received packet
```



Assignment (for students not having a comprehensive specific project)

After testing the presented IoT Architecture example let us extend it with new features.

1.The gateway receives LoRa packet and confirms it with a short **ACK packet**. It means that the sender (CubeCell board) needs to wait a few seconds for this packet – **wait state**, before going to deep sleep – low power stage.

2. The IoT Architecture provides a means to operate with many terminals such as CubeCell boards. In this case the terminals must be identified by a number (address). We have to add it to the packet as a header. Note that different terminals may use **separate** ThingSpeak channels, how to do it ?

3. The LoRa packets are not protected; so we have to add encryption to hide the payload. We can do it with **AES encryption** available in software for CubeCell, and integrated in hardware with ESP32.

4. The terminals should not communicate with other terminals. In order to separate the communication between the terminals and the gateway we may use down-chirp/up-chirp modes. For example the terminal nodes send the "**up-chirp**" packets to the gateway and receive the "**down-chirp**" packets ACK from the gateway.