IoT Platform Setup

- Date: 29-05-2024
- Instruction Resource for Beginners
- Server code last update: 30-05-2024. (Pull new server code)

1. Material to Grasp the Available IoT System

- The university thesis illustrating the system:
  - ThesisVersioning0_1_0/Thesis-Template0_1_0/main.pdf at main · ngminhthanh12a3/ThesisVersioning0_1_0 (github.com)
  - ThesisVersioning0_1_0/Presentation/ThesisPresentation/slides.pdf at main · ngminhthanh12a3/ThesisVersioning0_1_0 (github.com)
- Source code of the system:
  - Server side: ngminhthanh12a3/desiot-server at 1.x.x (github.com)
  - ESP32 Gateway: ngminhthanh12a3/DESIoT_ESP32_Gateway at 1.x.x (github.com)

2. The Available IoT Architecture

3. The Available IoT Model

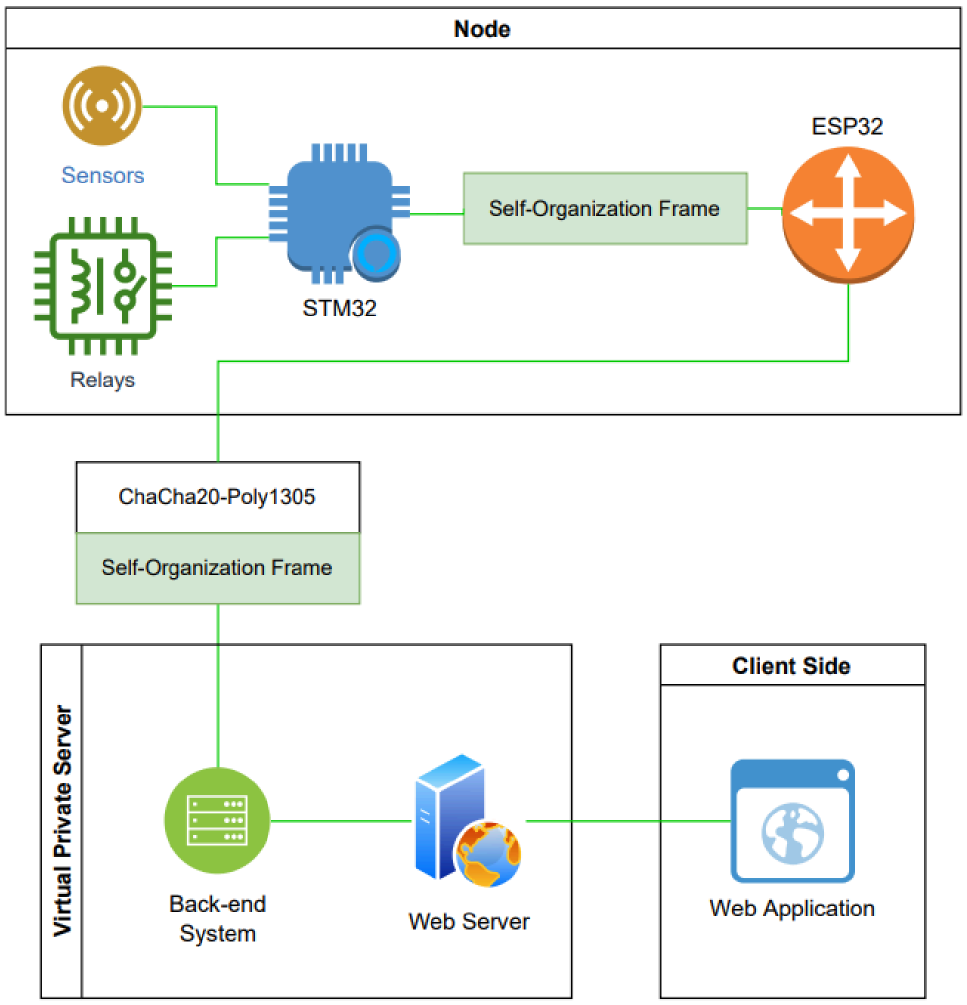
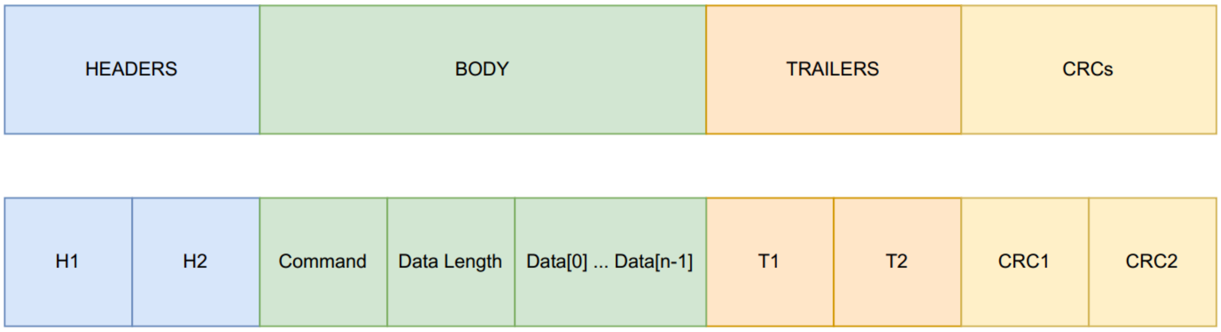


Fig. 5: Implementation of ChaCha20-Poly1305 and Data Framing on the IoT System

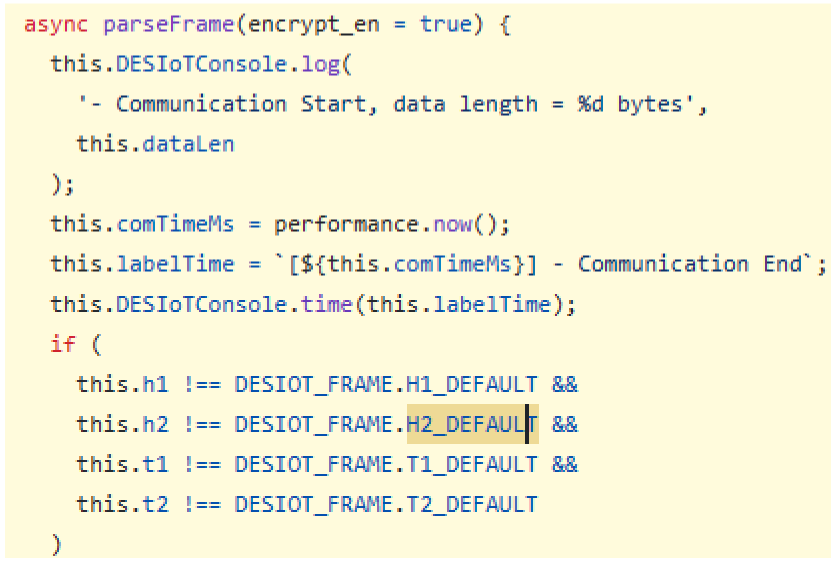
4. Frame Protocol: Structure and Parsing



Hình 2.2: Cấu trúc frame của hệ thống.

4.1. Frame Parsing in the server-side

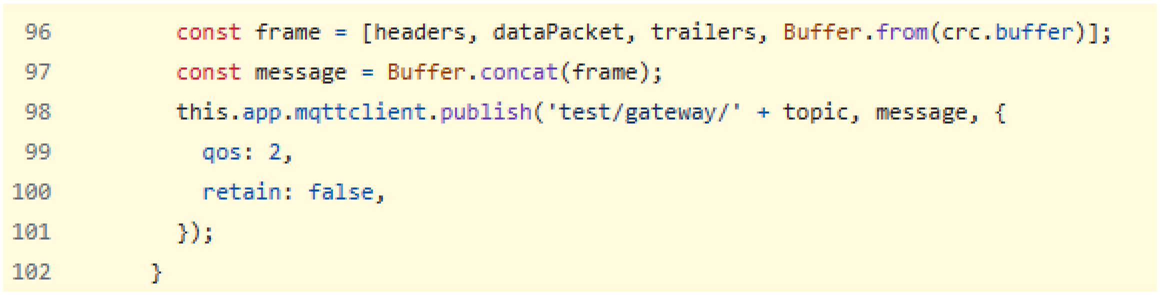
- [desiot-server/lib/src/frameHandler/index.js at 1.x.x · ngminhthanh12a3/desiot-server (github.com)]



```
async parseFrame(encrypt_en = true) {
  this.DESIoTConsole.log(
    '- Communication Start, data length = %d bytes',
    this.dataLen
  );
  this.comTimeMs = performance.now();
  this.labelTime = `[${this.comTimeMs}] - Communication End`;
  this.DESIoTConsole.time(this.labelTime);
  if (
    this.h1 !== DESIOT_FRAME.H1_DEFAULT &&
    this.h2 !== DESIOT_FRAME.H2_DEFAULT &&
    this.t1 !== DESIOT_FRAME.T1_DEFAULT &&
    this.t2 !== DESIOT_FRAME.T2_DEFAULT
  )
```

4.2. Frame Composing from the Server

- Before sending a frame to the ESP32 Gateway, the server constructs the frame components following the frame structure.



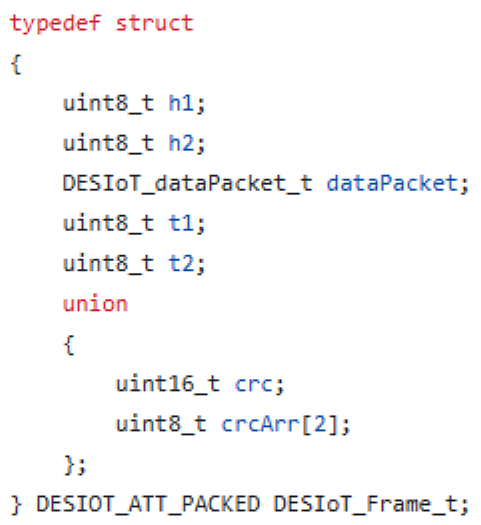
```
      const frame = [headers, dataPacket, trailers, Buffer.from(crc.buffer)];
      const message = Buffer.concat(frame);
      this.app.mqttclient.publish('test/gateway/' + topic, message, {
        qos: 2,
        retain: false,
      });
    }
```

4.3.

- [desiot-server/lib/utils/DevSyncFrame.js at 1.x.x · ngminhthanh12a3/desiot-server (github.com)]

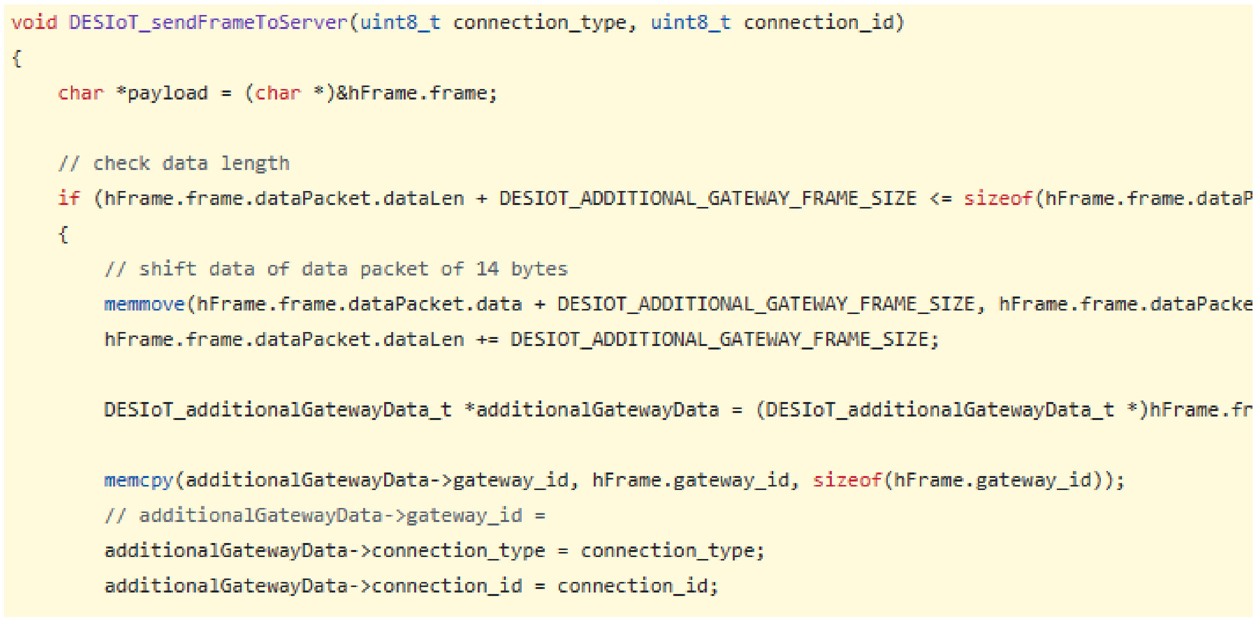
4.4. Frame Composing from the ESP32 Gateway

- The frame structure definition of the hardware:
  - [DESIoT_ESP32_Gateway/include/DESIoT_Gateway.h at 1.x.x · ngminhthanh12a3/DESIoT_ESP32_Gateway (github.com)]



```
typedef struct
{
    uint8_t h1;
    uint8_t h2;
    DESIoT_dataPacket_t dataPacket;
    uint8_t t1;
    uint8_t t2;
    union
    {
        uint16_t crc;
        uint8_t crcArr[2];
    };
} DESIOT_ATT_PACKED DESIoT_Frame_t;
```

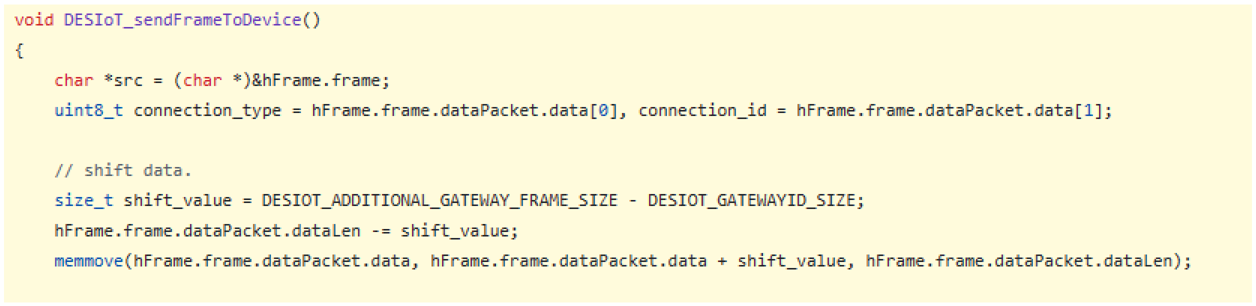
- The composing function manually constructs a frame before sending it to the server:



```
void DESIoT_sendFrameToServer(uint8_t connection_type, uint8_t connection_id)
{
    char *payload = (char *)&hFrame.frame;

    // check data length
    if (hFrame.frame.dataPacket.dataLen + DESIOT_ADDITIONAL_GATEWAY_FRAME_SIZE <= sizeof(hFrame.frame.dataP
    {
        // shift data of data packet of 14 bytes
        memmove(hFrame.frame.dataPacket.data + DESIOT_ADDITIONAL_GATEWAY_FRAME_SIZE, hFrame.frame.dataPacke
        hFrame.frame.dataPacket.dataLen += DESIOT_ADDITIONAL_GATEWAY_FRAME_SIZE;

        DESIoT_additionalGatewayData_t *additionalGatewayData = (DESIoT_additionalGatewayData_t *)hFrame.fr

        memcpy(additionalGatewayData->gateway_id, hFrame.gateway_id, sizeof(hFrame.gateway_id));
        // additionalGatewayData->gateway_id =
        additionalGatewayData->connection_type = connection_type;
        additionalGatewayData->connection_id = connection_id;
```

- [DESIoT_ESP32_Gateway/src/DESIoT_Gateway.cpp at 1.x.x · ngminhthanh12a3/DESIoT_ESP32_Gateway (github.com)]

- The composing function manually constructs a frame before sending it to the hardware:



```
void DESIoT_sendFrameToDevice()
{
    char *src = (char *)&hFrame.frame;
    uint8_t connection_type = hFrame.frame.dataPacket.data[0], connection_id = hFrame.frame.dataPacket.data[1];

    // shift data.
    size_t shift_value = DESIOT_ADDITIONAL_GATEWAY_FRAME_SIZE - DESIOT_GATEWAYID_SIZE;
    hFrame.frame.dataPacket.dataLen -= shift_value;
    memmove(hFrame.frame.dataPacket.data, hFrame.frame.dataPacket.data + shift_value, hFrame.frame.dataPacket.dataLen);
```

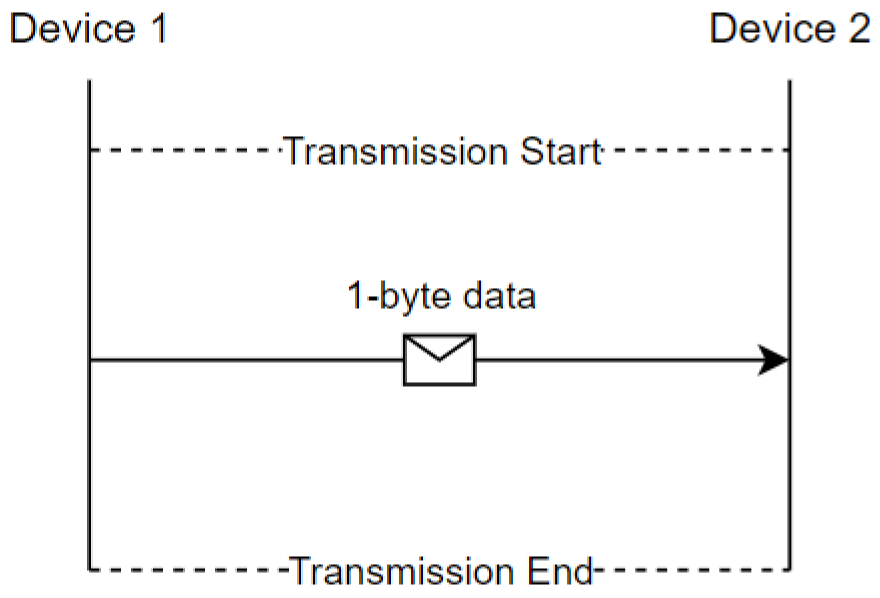
- [DESIoT_ESP32_Gateway/src/DESIoT_Gateway.cpp at 1.x.x · ngminhthanh12a3/DESIoT_ESP32_Gateway (github.com)]

5. Frame Protocol: Use Cases and Profound Issue

5.1. UART's Typical Cases

5.1.1. Simple Transmission: only-1-byte transmission

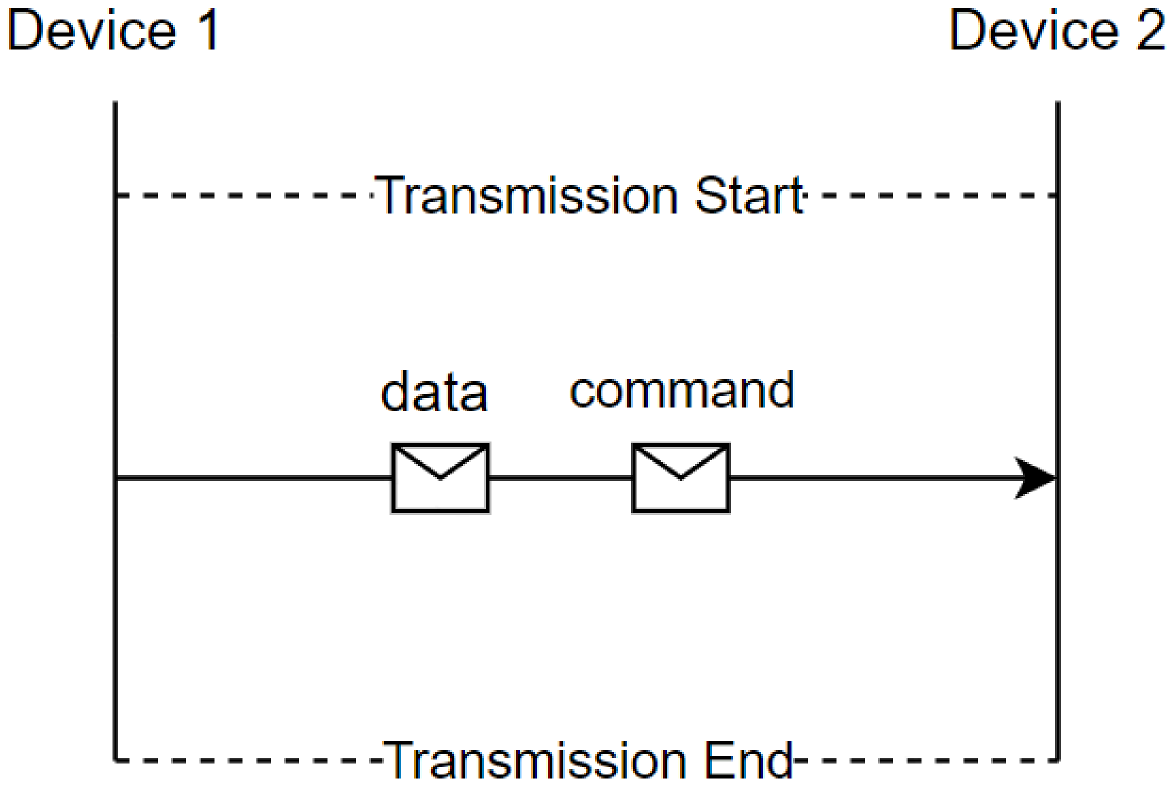
- This is a typical case for beginners' approach.



- This case can be used to test the UART operation between 2 MCU.
- Communication operations between 2 MCU take place only based on 1-byte transmission data.
- For example, when a device receives the 1-byte transmission data, the device assigns the LED state to the 1-byte data value.

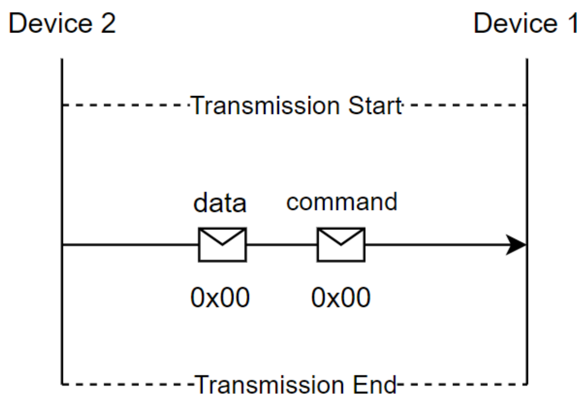
1.1.1. Simple Transmission: 2-byte transmission

- Another simple case of using UART is 2-byte communication.
- The operation is similar to the 1-byte communication.
- But the 1-byte transmission data is indexed by a 1-byte command.

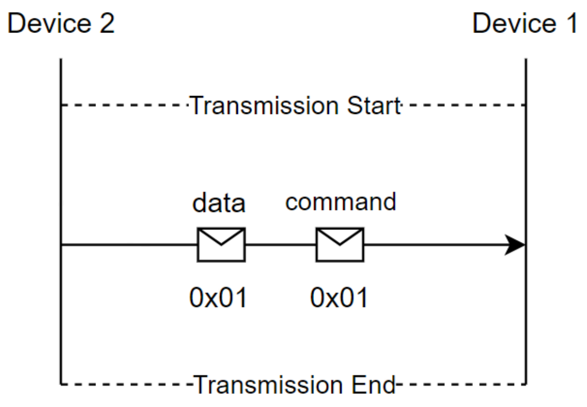


- The command is used to consider what exact operation is the transmission data used for.
- For example, an operation of transmission when the “Device 1” gets the LED or Switch state of the “Device 2”

Command	**Operation**
0x00	Device 1 gets the current LED state of Device 2
0x01	Device 1 gets the current Switch state of Device 2



The LED of Device 2 is off

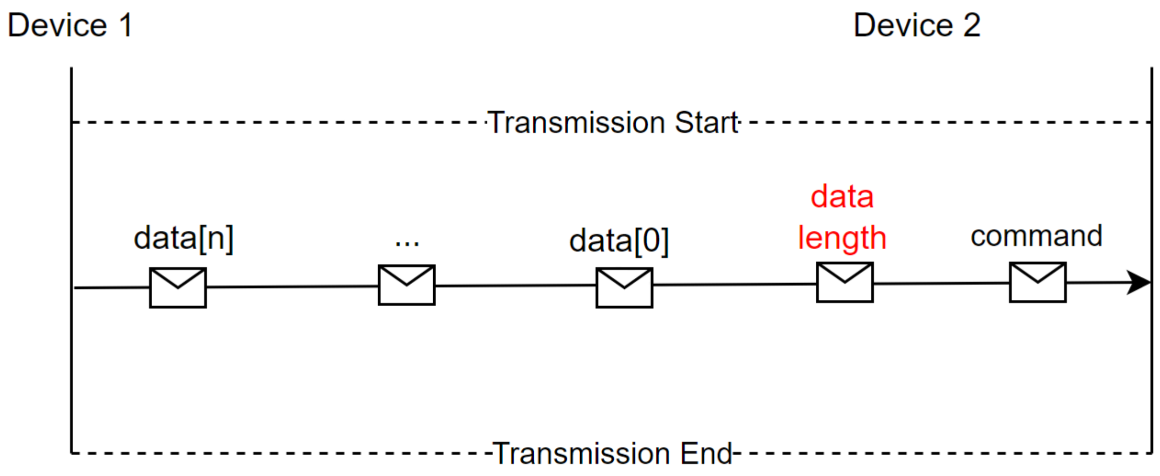


The Switch of Device 2 is on

- So, this is an example of using the "indexing" technique in a serial protocol.

5.1.2. Other Cases of Using Indexing Technique

- The usage of the indexing technique can be applied to complicated transactions requiring multiple-byte data for transmission.
- The number of data bytes is managed by the "data length" byte.

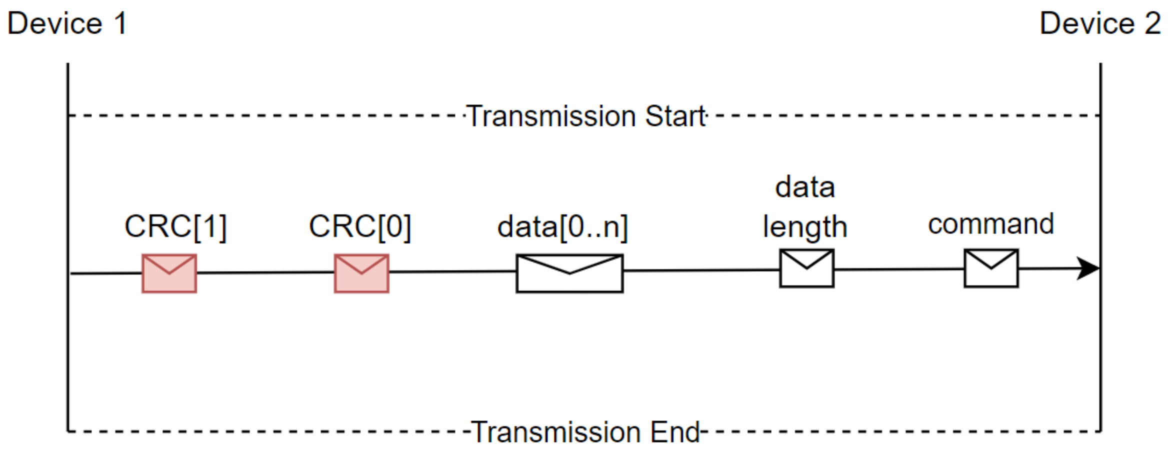


- So, this is a simple example of using the data management technique in transmission.

5.1.3. Case of Error Detection Technique

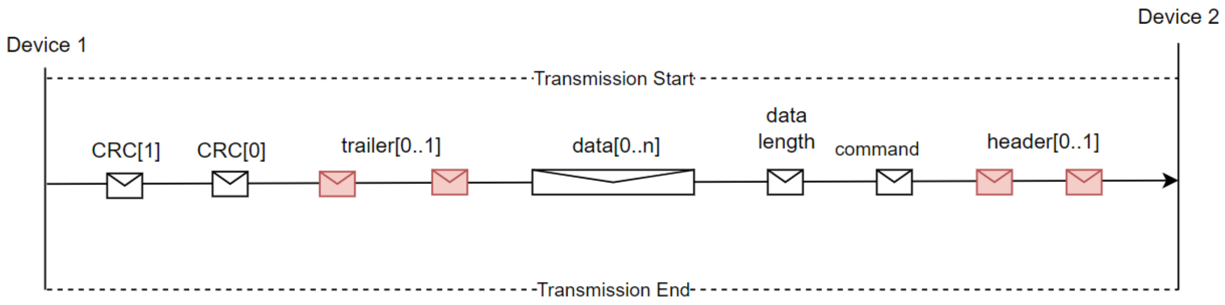
- The UART may perform correctly in short-term monitoring or operations.
- However, in long-term monitoring and operations, UART transmission is not always reliable and correct.

- So, how to deal with wrong-data value?
- The origin UART itself doesn't have any actual mechanism to detect errors.
- The Cyclic redundancy check (CRC) is a common method to detect errors in serial protocols such as UART.
- An example of using CRC is inserting 2 additional bytes to transmission to perform 16-bit CRC.



5.1.4. Case of Data Framing Technique

- In data transmission, there are several profound problems:
  1. Identification: how to determine whether a device is connecting with another reliable device in the same system or an external alias device?
  2. Configuration and synchronization: how to determine whether a device is contacting with another device having the same settings such as CRC type (8-, 16-, or 32-bit), command design,…?
  3. Security: how to determine that the transmission of the system is private and isolated on compared to other systems?
     Reference: UART: A Hardware Communication Protocol Understanding Universal Asynchronous Receiver/Transmitter | Analog Devices
- Data framing is the typical technique to provide identification, synchronization, and security to a transmission protocol.
- The normal usage of data framing is inserting additional headers and trailers to the transmission data.
- For example, we can insert a 2-byte header and trailer respectively to the start and end of a data package.



6. Hardware Implementation of the ESP32 Gateway

7. Lightweight Cryptography Implementation

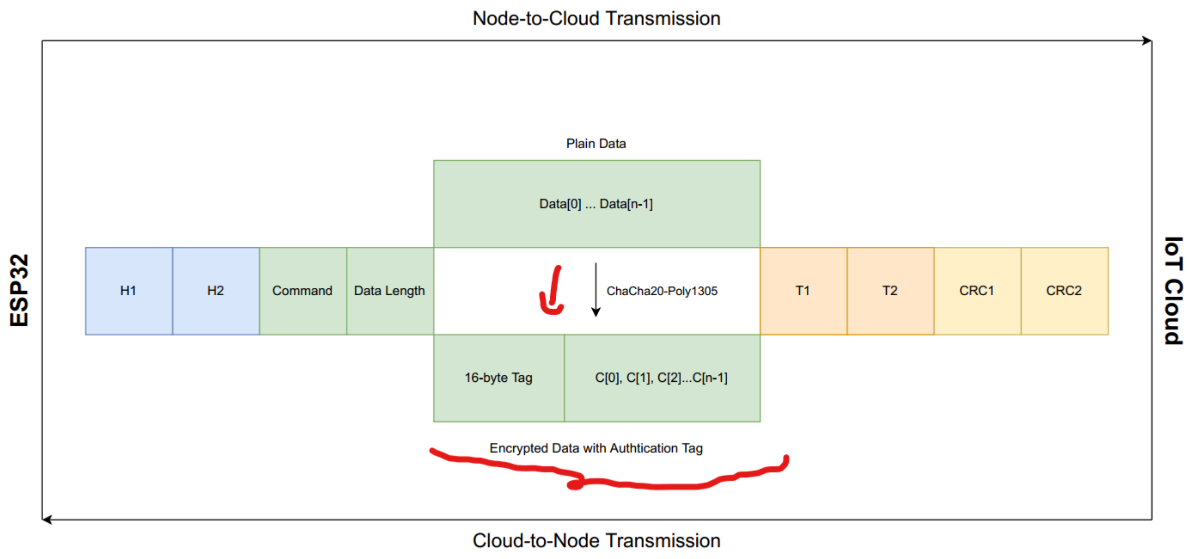

Node-to-Cloud Transmission
ESP32
IoT Cloud
Plain Data
Data[0] ... Data[n-1]
H1
H2
Command
Data Length
ChaCha20-Poly1305
T1
T2
CRC1
CRC2
16-byte Tag
C[0], C[1], C[2]...C[n-1]
Encrypted Data with Authtication Tag
Cloud-to-Node Transmission

Fig. 2: The ChaCha20-Poly1305 Implementation on the Proposed Frame Protocol

8. Setup Server

- Test the system in your local VM server.

8.1. Download the source code

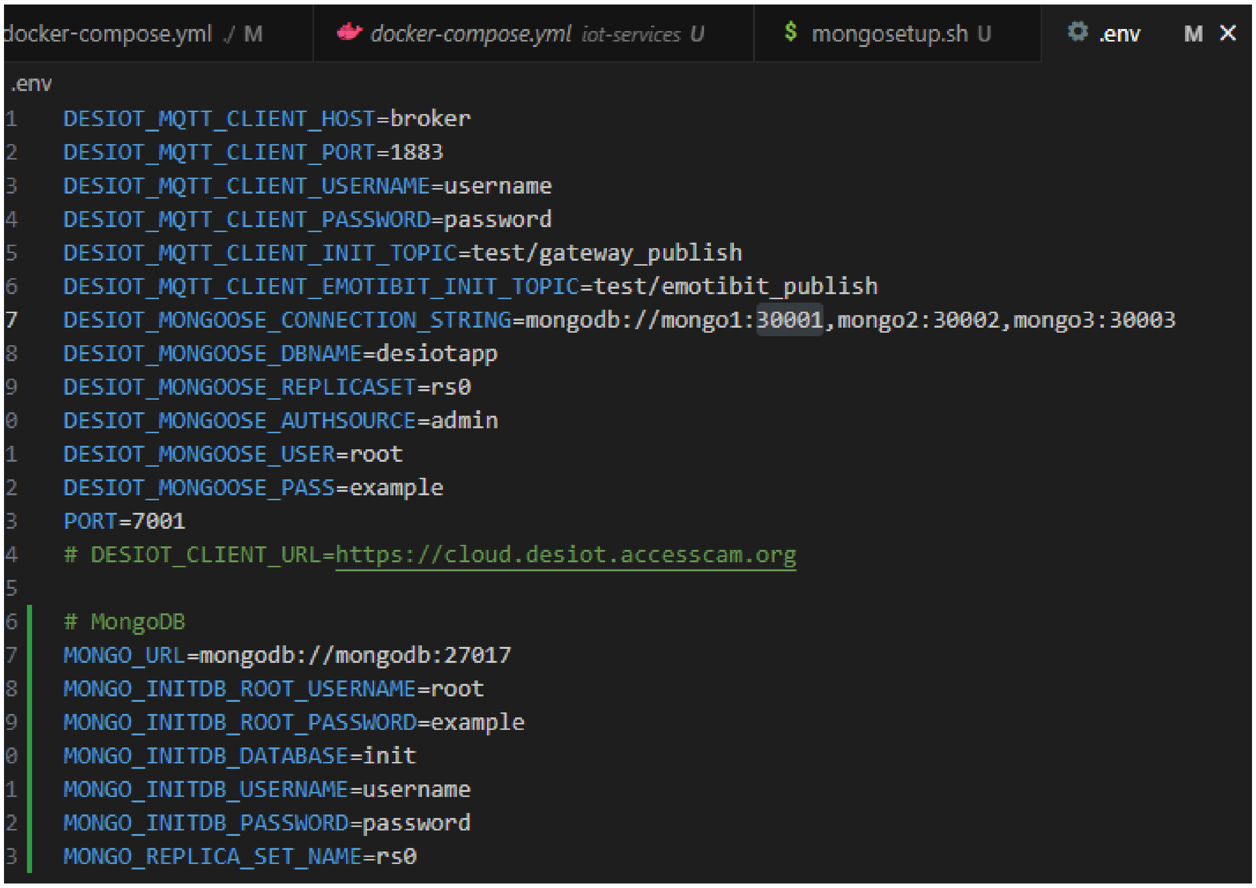
- desiot@desiot:~/desiot-server/testdir/desiot-server$ **git clone --branch QT-Demo https://github.com/ngminhthanh12a3/desiot-server.git**

8.2. Setup Database Private Key

- [install make in ubuntu - Tìm trên Google]

    - "sudo apt-get -y install make"
- Run the following command to initialize the database key:
    - desiot@desiot:~/desiot-server$ **make mongo-key-init**
- Start the system
    - desiot@desiot:~/desiot-server$ **make dev-up**

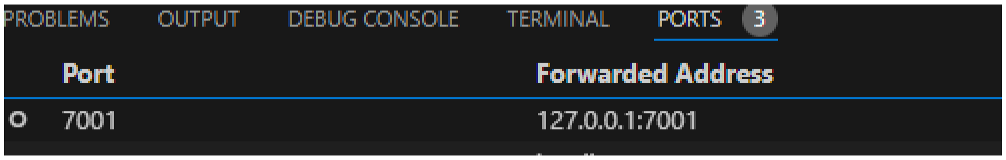
8.3. Server configuration environment



```
DESIOT_MQTT_CLIENT_HOST=broker
DESIOT_MQTT_CLIENT_PORT=1883
DESIOT_MQTT_CLIENT_USERNAME=username
DESIOT_MQTT_CLIENT_PASSWORD=password
DESIOT_MQTT_CLIENT_INIT_TOPIC=test/gateway_publish
DESIOT_MQTT_CLIENT_EMOTIBIT_INIT_TOPIC=test/emotibit_publish
DESIOT_MONGOOSE_CONNECTION_STRING=mongodb://mongo1:30001,mongo2:30002,mongo3:30003
DESIOT_MONGOOSE_DBNAME=desiotapp
DESIOT_MONGOOSE_REPLICASET=rs0
DESIOT_MONGOOSE_AUTHSOURCE=admin
DESIOT_MONGOOSE_USER=root
DESIOT_MONGOOSE_PASS=example
PORT=7001
# DESIOT_CLIENT_URL=https://cloud.desiot.accesscam.org

# MongoDB
MONGO_URL=mongodb://mongodb:27017
MONGO_INITDB_ROOT_USERNAME=root
MONGO_INITDB_ROOT_PASSWORD=example
MONGO_INITDB_DATABASE=init
MONGO_INITDB_USERNAME=username
MONGO_INITDB_PASSWORD=password
MONGO_REPLICA_SET_NAME=rs0
```

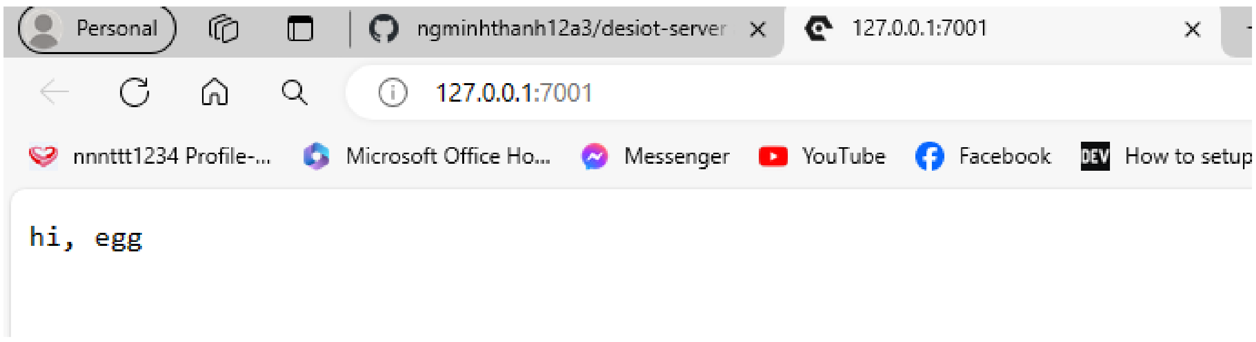
- Change the configuration environment in the ".env" file if you want to change the **port** of the broker or server.

8.4. Test the Server

- 

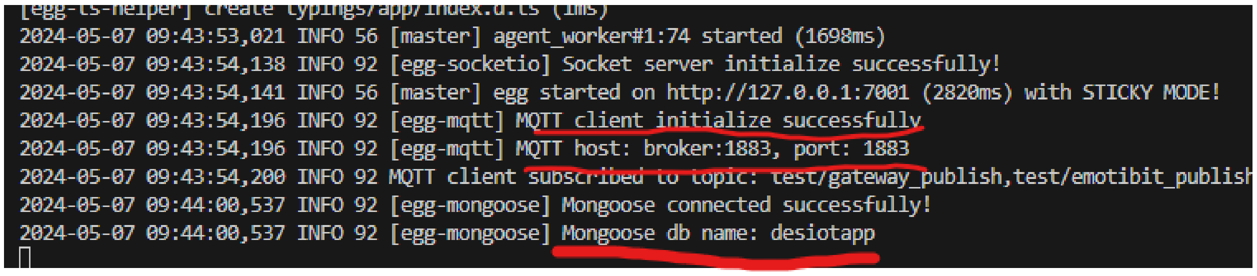
```
Port        Forwarded Address
7001        127.0.0.1:7001
```

    - Setup the port forwarding.



```
hi, egg
```

- View server logs for checking the successful configurations of MQTT Broker and MongoDB connections
  - desiot@desiot:~/desiot-server$ **docker logs -f desiot-server-desiot-server-1**

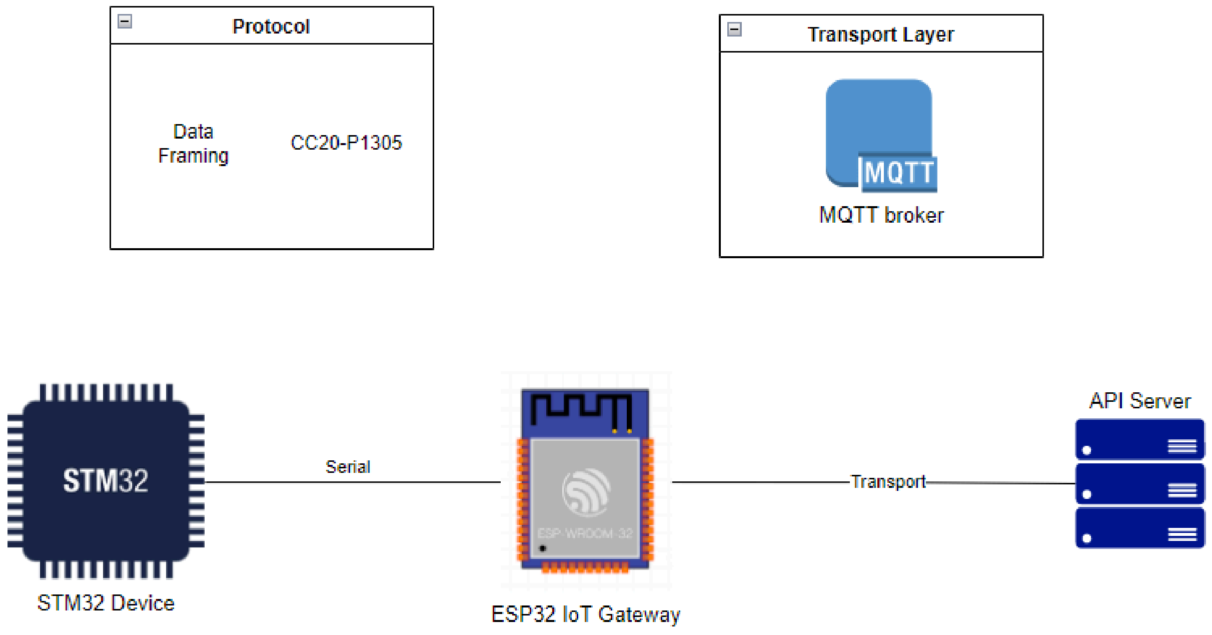


```
[egg-ts-helper] create typings/app/index.d.ts (1ms)
2024-05-07 09:43:53,021 INFO 56 [master] agent_worker#1:74 started (1698ms)
2024-05-07 09:43:54,138 INFO 92 [egg-socketio] Socket server initialize successfully!
2024-05-07 09:43:54,141 INFO 56 [master] egg started on http://127.0.0.1:7001 (2820ms) with STICKY MODE!
2024-05-07 09:43:54,196 INFO 92 [egg-mqtt] MQTT client initialize successfully
2024-05-07 09:43:54,196 INFO 92 [egg-mqtt] MQTT host: broker:1883, port: 1883
2024-05-07 09:43:54,200 INFO 92 MQTT client subscribed to topic: test/gateway_publish,test/emotibit_publish
2024-05-07 09:44:00,537 INFO 92 [egg-mongoose] Mongoose connected successfully!
2024-05-07 09:44:00,537 INFO 92 [egg-mongoose] Mongoose db name: desiotapp
```

- Re-run the system if any error occur:
  - desiot@desiot:~/desiot-server$ **make dev-reup**

9. Physical Node Setup

Based on the system structure, a node is composed of an STM32 device and an ESP32 gateway. The data exchanging is undertaken by the MQTT Broker at the transport layer.



9.1. Command Design Pattern of the system

- Inspired from: Command :: IoT Atlas
- The command pattern is to construct interactions between node and server in the system. The command set just simply contains command codes assign data to database from node and synchronize updated data from database to the node.

Device	Command Code	Command Description
STM32	0x00	Request to assign data of the node device to a virtual storage of the database.
	0x01	Get updated data of virtual storage from the database.
	0x02	Request to read data of a virtual storage of the database.
IoT Server	0x00	Assign data of the node device to a virtual storage of the database.
	0x01	Synchronize updated data of virtual storage from the database with a node device
	0x02	Read requested data of virtual storage of the database and send it to the node device.

- List command in the source of the STM32: DESIoT_STM_Device/Core/Inc/DESIoT_device.h at QT_IoT · ngminhthanh12a3/DESIoT_STM_Device (github.com)
- List command in the source of the IoT server: desiot-server/lib/src/configs/frameHandler.js at QT-Demo · ngminhthanh12a3/desiot-server (github.com)

9.2. Connection Pinout for this Quick Start

Any STM32F4 family and an ESP32 can be used to form a node for this quick start.

Device	STM32F407VGT6	ESP32 Dev Module
UART Hardware	UART6	UART2
TX Pin	PC6	GPIO17
RX Pin	PC7	GPIO16

9.3. ESP32 Environment

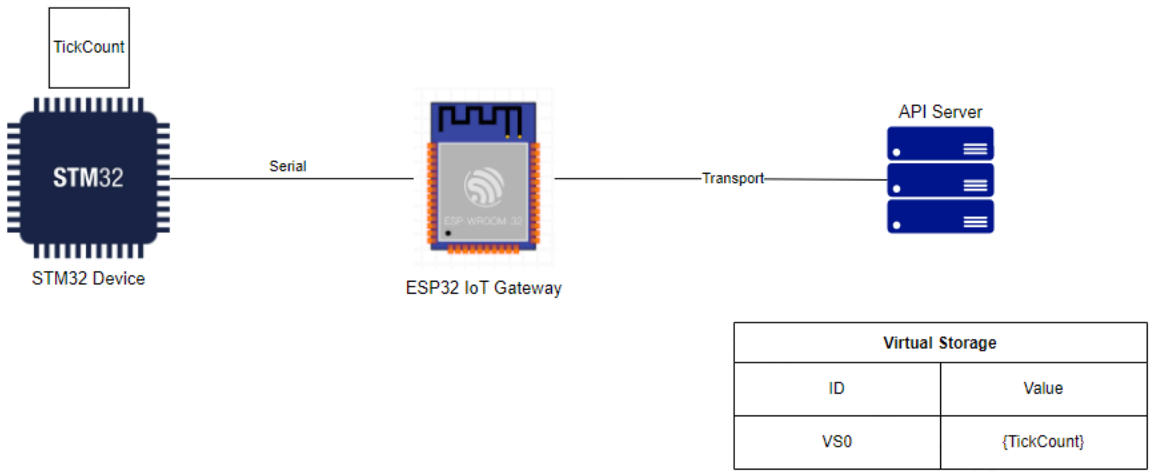
- Source code: ngminhthanh12a3/DESIoT_ESP32_Gateway at QT_IoT (github.com)
- IDE: PlatformIO IDE - Visual Studio Marketplace

9.4. STM32 Environment

- Source: ngminhthanh12a3/DESIoT_STM_Device at QT_IoT (github.com)
- IDE: STM32CubeIDE - Integrated Development Environment for STM32 - STMicroelectronics

9.5. Demo Operation

In this demo, STM32 simply sends the current tick count of the SysTick to the API server. The server then assigns this data to a "Virtual storage", in this case: the Virtual Storage 0, in the database.



Virtual Storage	
ID	Value
VS0	{TickCount}

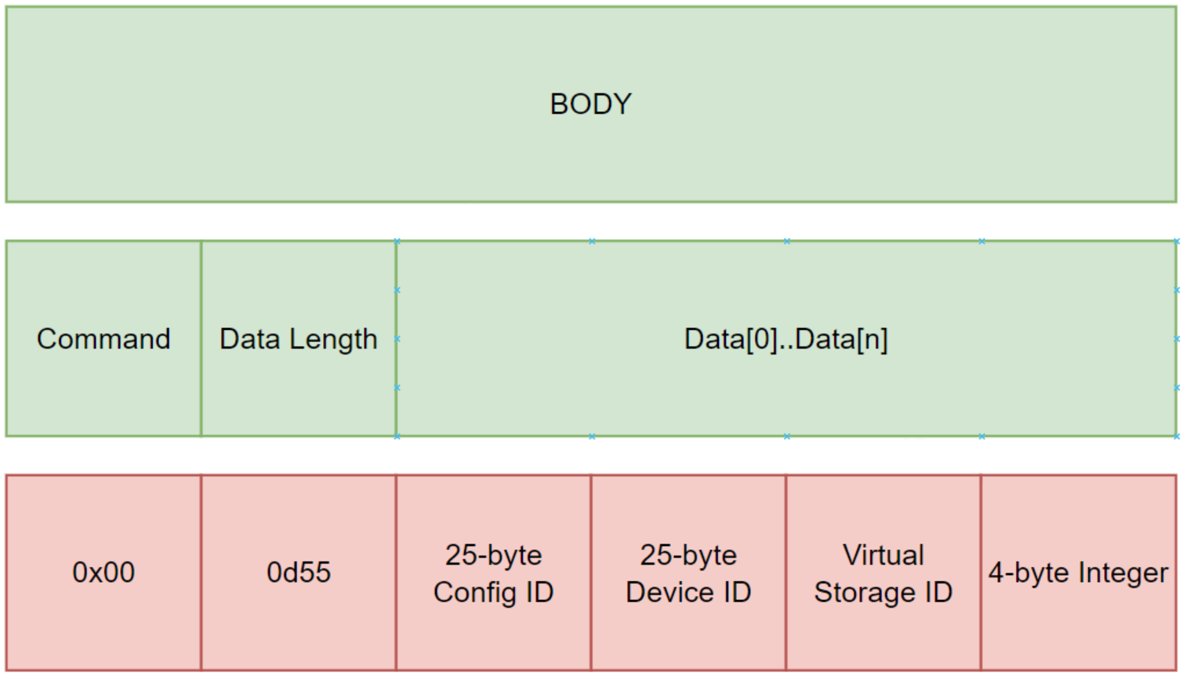
Based on this demo flow, let determine how the data is packaged and how is it encrypted at each device: STM32, ESP32, and API server.

9.5.1. Data Framing of the STM32 to ESP32

On assigning new data to virtual storage, the STM32 packages the data frame containing the following fields:

- 25-byte Config ID: to indicate what configuration is used for this device.
- 25-byte Device ID: to identify what device.

- 1-byte Virtual storage ID: to indicate what storage of the database needs to be assigned new data. At each device, there are 32 virtual storage to assign data. Inspired from: Virtual Pins | Blynk Documentation.
- 4-byte integer data: to store integer data of the tick count.

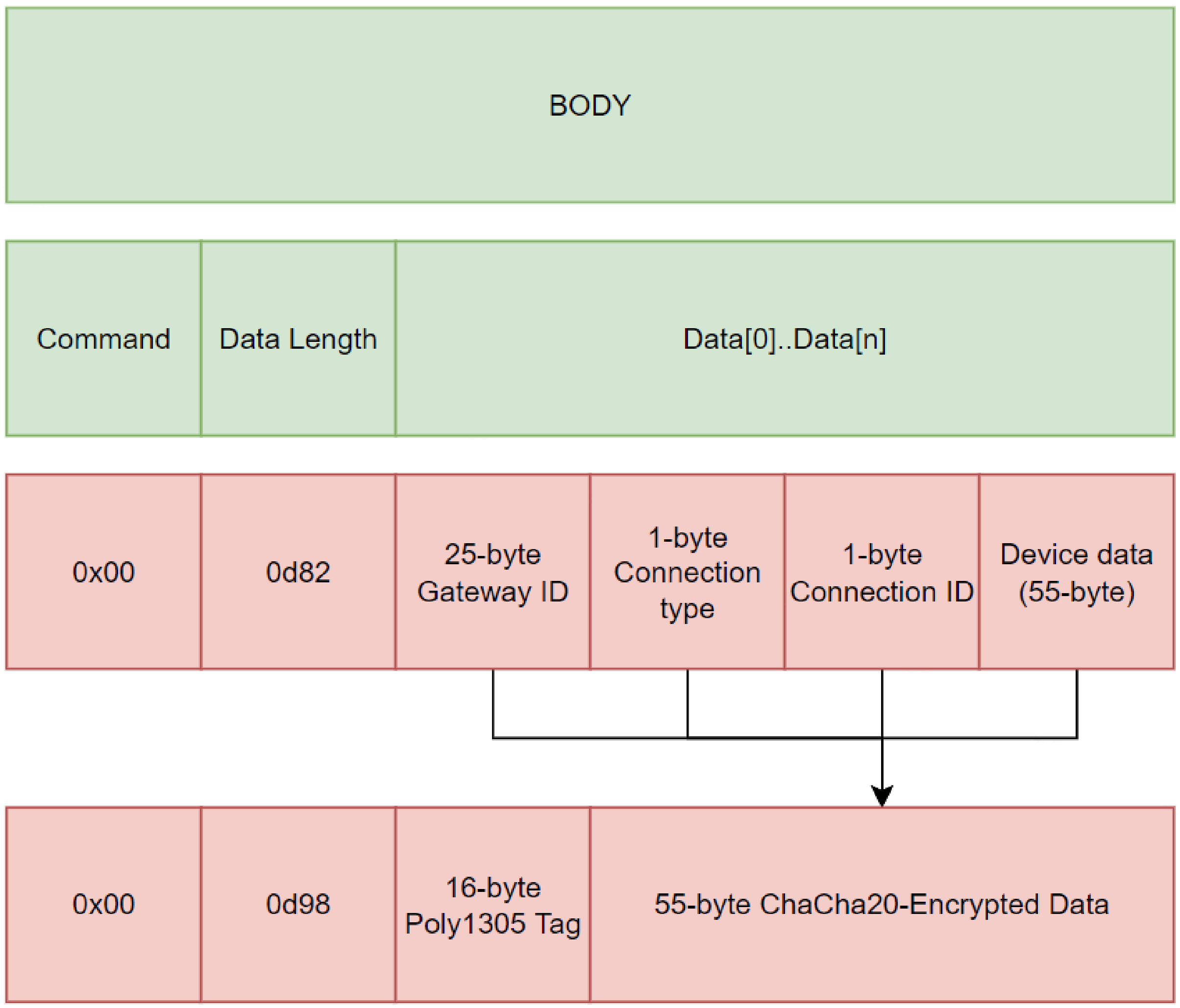


9.5.2. Data Framing from the ESP32 to IoT Server

When the frame comes to the ESP32, additional data is appended to the frame in order to identify the ESP32 and the connection between the ESP32 and STM32. These additional data include:

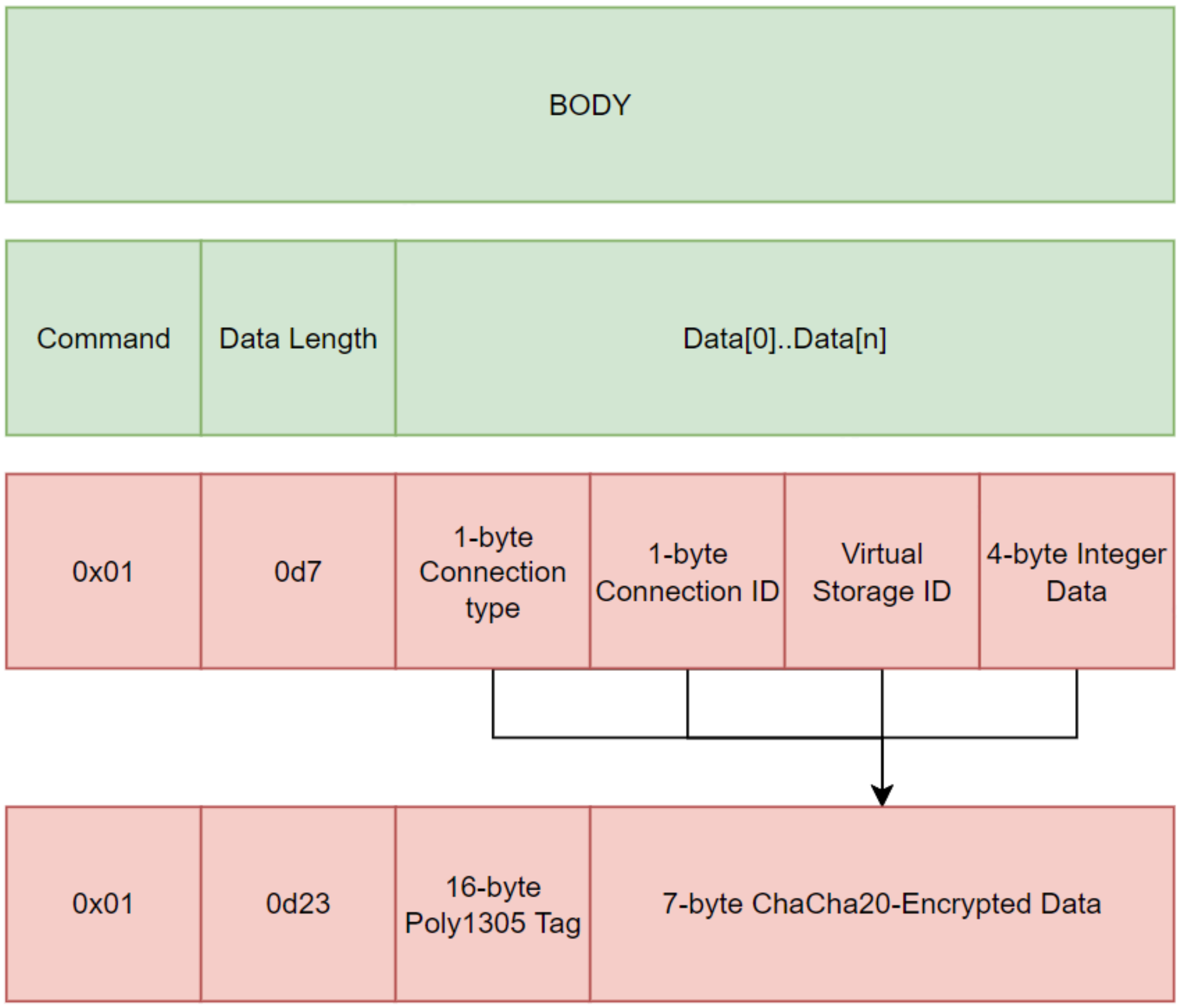
- 25-byte Gateway ID: to identify the gateway.
- 1-byte connection type: 0 or 1. 0: serial connection. 1: wireless connection
- 1-byte connection ID: to indicate the ID of hardware for connection. 0: UART. 1, 2, 3,.. is now optional, maybe I2C, SPI, CAN, Bluetooth…

The whole data package is then encrypted before sending to the server.



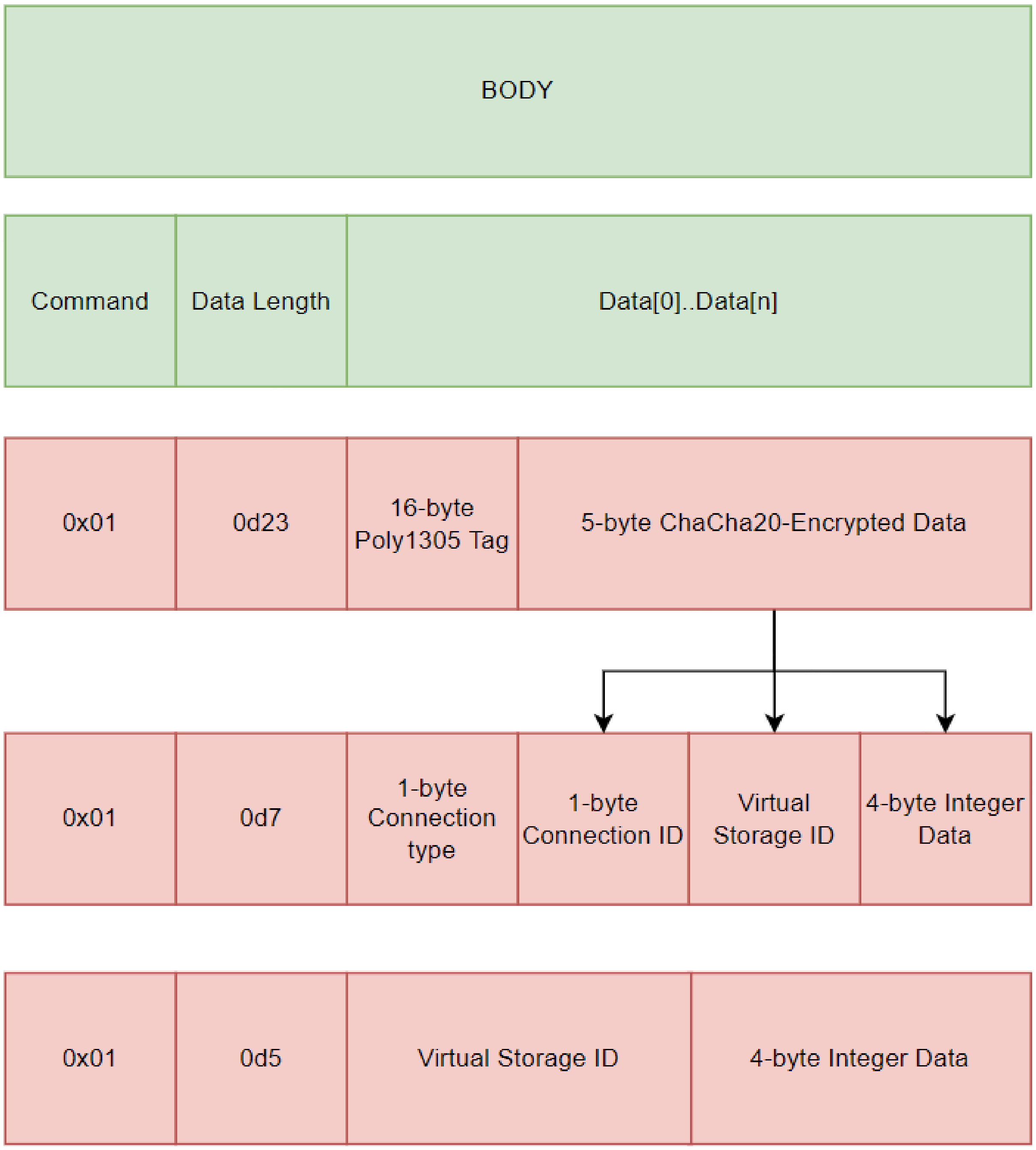
9.5.3. Data Framing from the IoT Server to ESP32 for synchronization of updated data.

On having updated the data to the virtual storage, the server then sends back a package containing the updated data of the virtual storage to the device. The data is encrypted before sending to the ESP32. The data before encrypted, include: connection type, connection ID, virtual storage ID, and 4-byte updated integer data. The gateway ID is not necessary, because the server has acknowledged it when receiving the data-assignment package.



9.5.4. Data Synchronization from the ESP32 to STM32

On receiving the updated data, the ESP32 decrypts the data. The ESP32 uses connection fields to acknowledge what device to forward data. Therefore, after acknowledging, the ESP32 only sends the virtual storage and the appropriate data to the STM32 device without connection firlds/



9.6. Virtual Storage Configuration of Demo Device Profile

The demo device and its configuration are created automatically when the server runs. The 24-character device and configuration ID for the demo are: “64c35b08b8f8d3dd7653f5d3” and “64c35b01b8f8d3dd7653f5cf”. They have already been located in the demo source of the STM32 DESIoT_STM_Device/Core/Src/main.c at QT_IoT · ngminhthanh12a3/DESIoT_STM_Device (github.com).

Virtual Storage ID	Data type
0x00	Integer (Int32)
0x01	Float (Float32)
0x02	String

- Firmware API of the STM32 to assign value to or read a virtual storage: DESIoT_STM_Device/Core/Inc/DESIoT_device.h at QT_IoT · ngminhthanh12a3/DESIoT_STM_Device (github.com)