Lecture #8
Cloud IoT

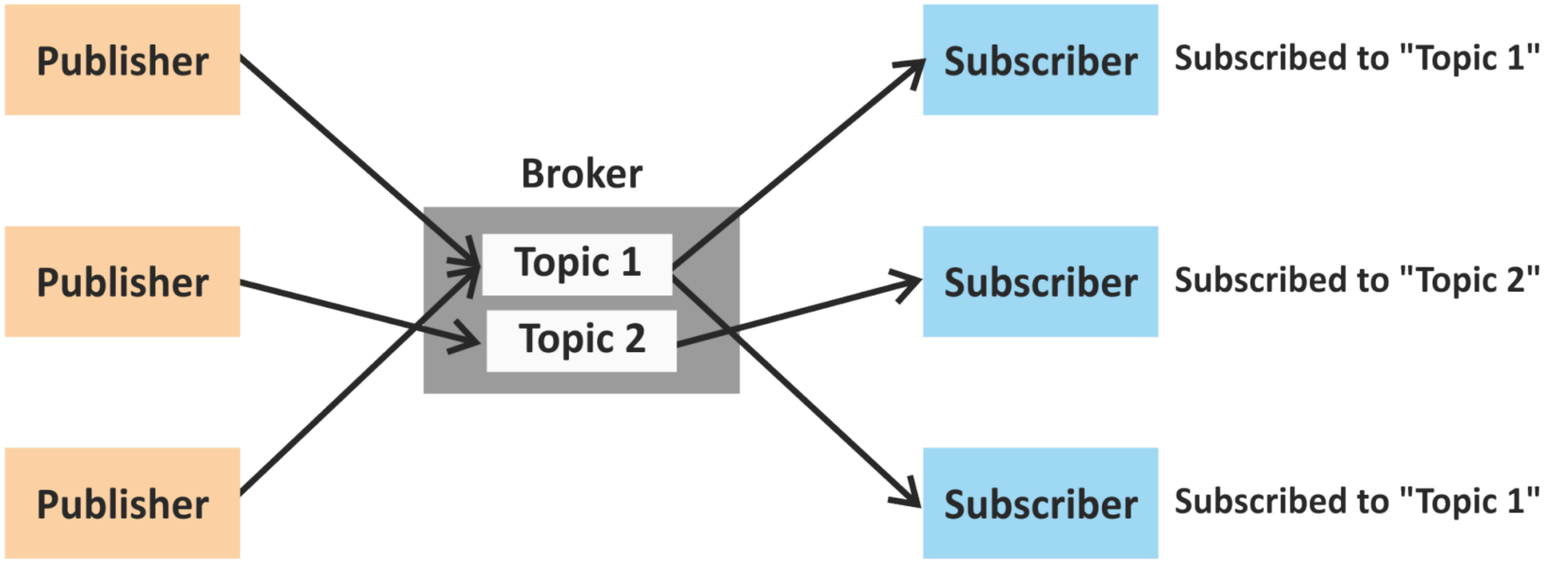
Spring 2024

MQTT

Message Queue Telemetry Transport

- Publish-subscribe.
- A message **broker** is required.
- Standard: ISO/IEC PRF 20922.
- Developed in 1999 (and released royalty free in 2010).
- Small code footprint.
- Limited network bandwidth / constrained environments.
- Data agnostic.

Model

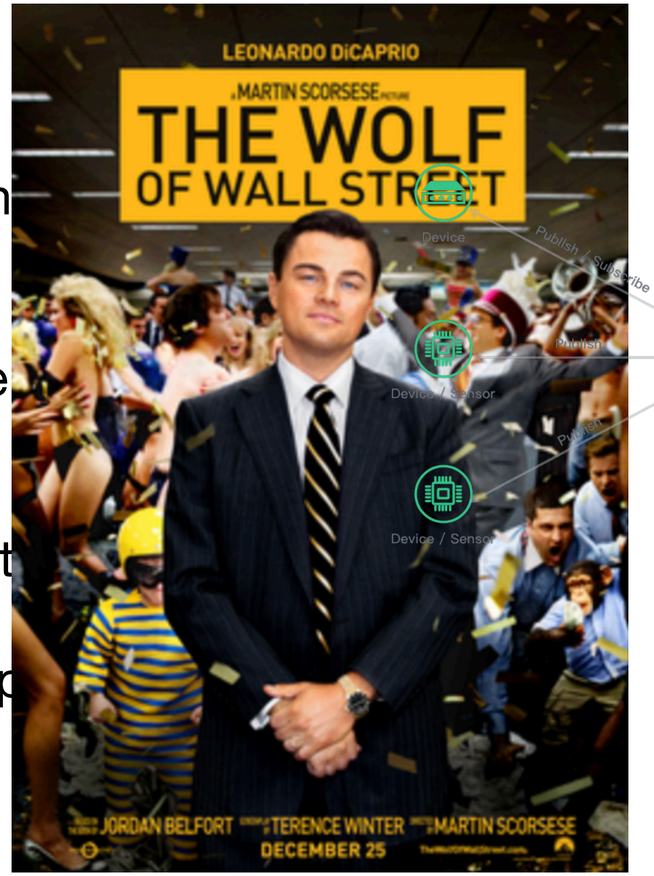

Publisher
Publisher
Publisher
Broker
Topic 1
Topic 2
Subscriber
Subscribed to "Topic 1"
Subscriber
Subscribed to "Topic 2"
Subscriber
Subscribed to "Topic 1"

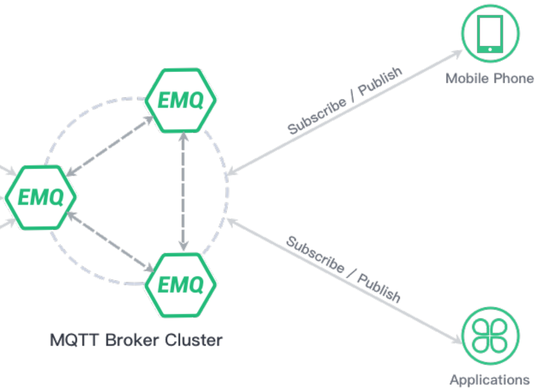
Broker Benefits

- Eliminates insecure connections.
- Easily scales.
- Manages client connect states.
- Reduce network strain.

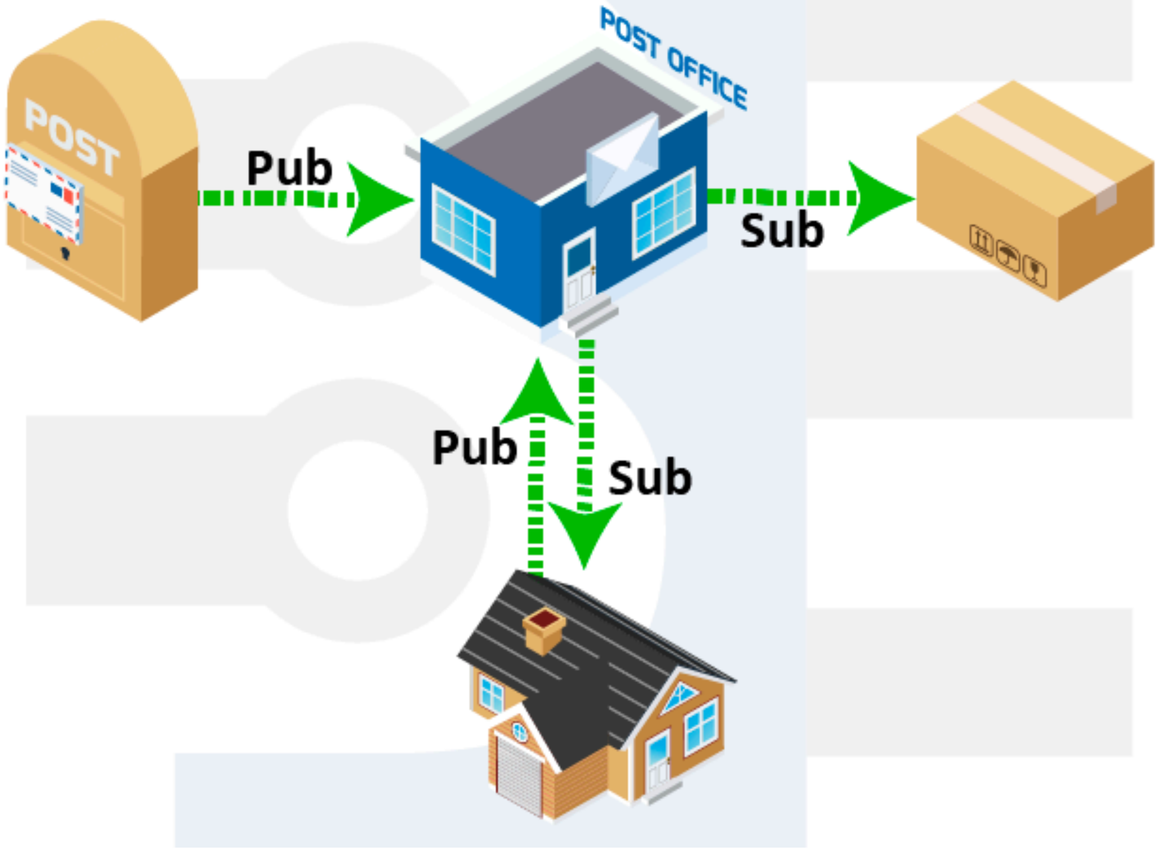
What is a broker

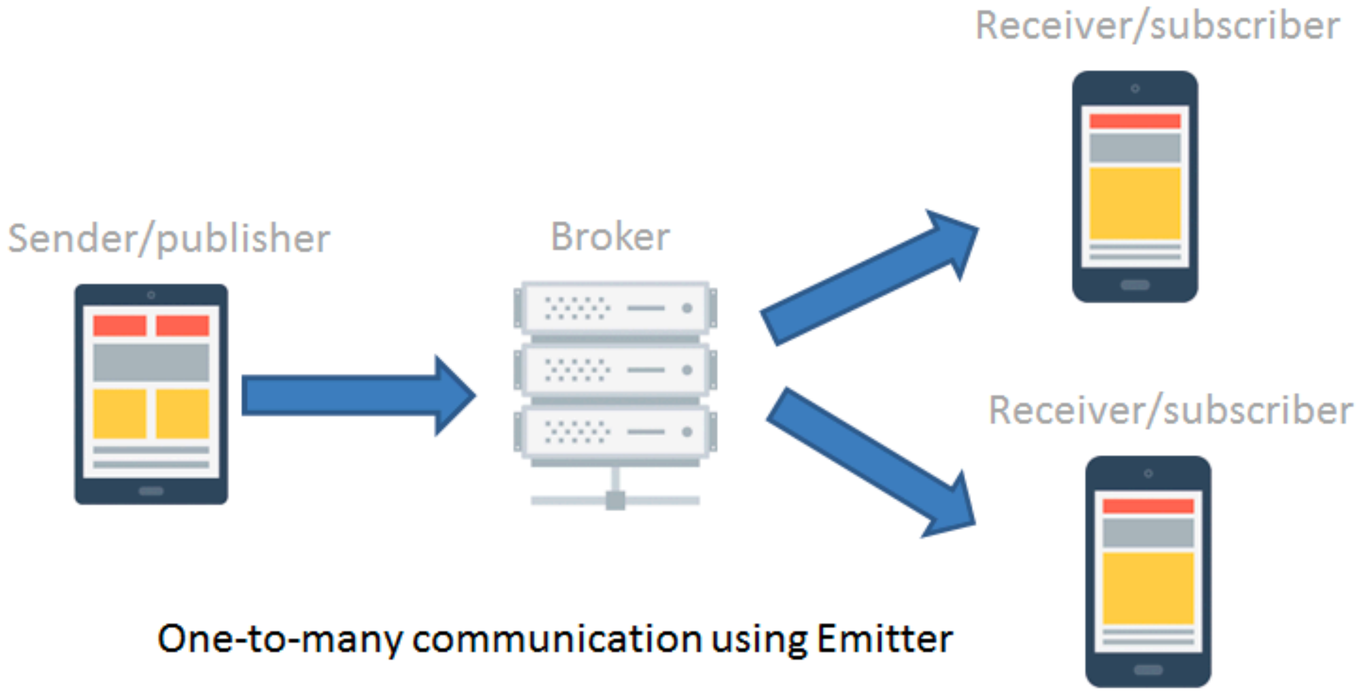
- Software running on computer.
- Running on premise cloud.
- Self-Built or 3rd part
- Open source or prop



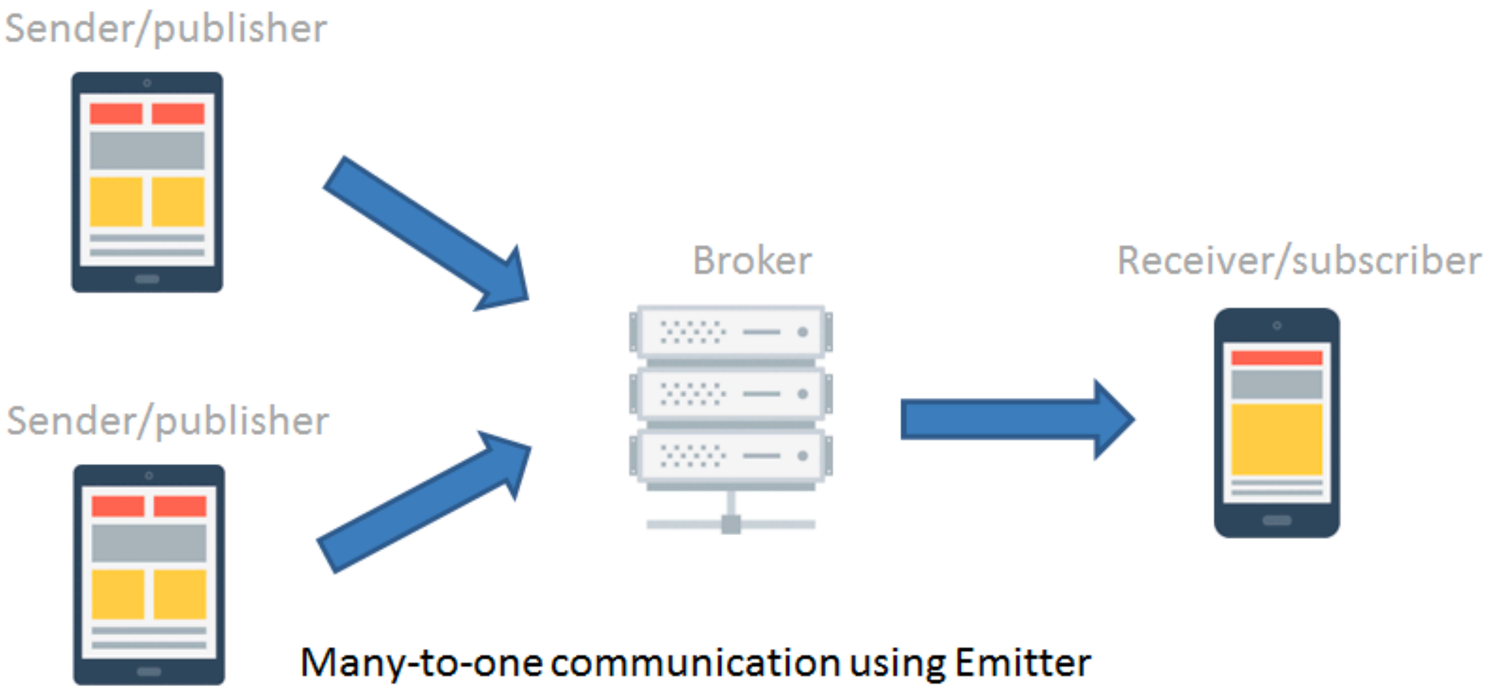


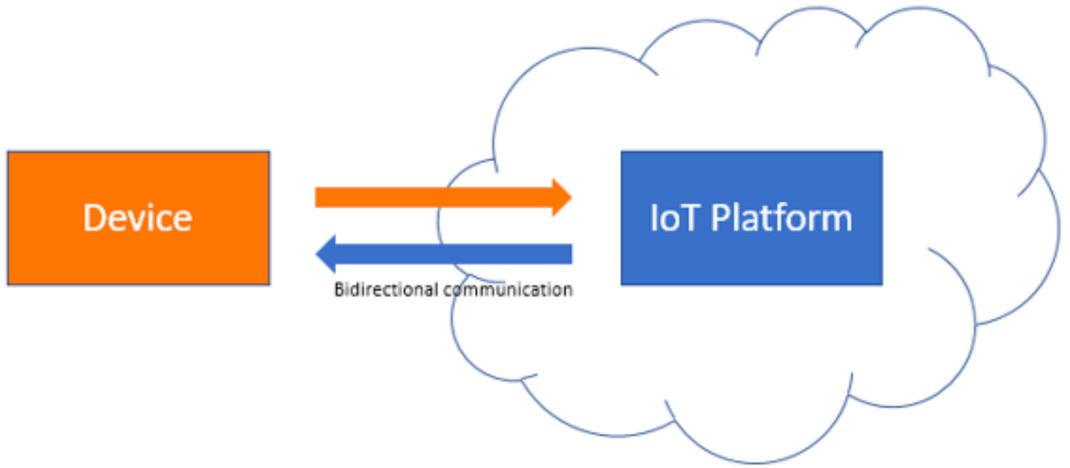
mqtt://broker/topic/message





One-to-many communication using Emitter

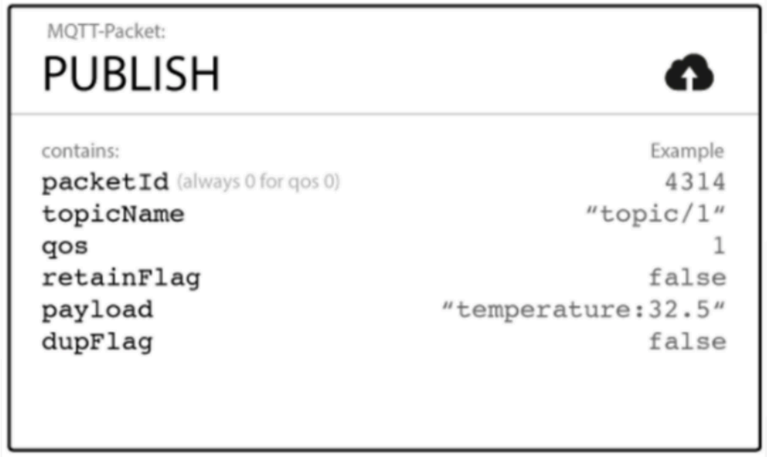

Sender/publisher
Sender/publisher
Broker
Receiver/subscriber
Many-to-one communication using Emitter


Device
IoT Platform
Bidirectional communication

Connecting to the broker

Value	Return Code Response	Description
0	0x00 Connection Accepted	Connection accepted
1	0x01 Connection Refused, unacceptable protocol version	The Server does not support the level of the MQTT protocol requested by the Client
2	0x02 Connection Refused, identifier rejected	The Client identifier is correct UTF-8 but not allowed by the Server
3	0x03 Connection Refused, Server unavailable	The Network Connection has been made but the MQTT service is unavailable
4	0x04 Connection Refused, bad user name or password	The data in the user name or password is malformed
5	0x05 Connection Refused, not authorized	The Client is not authorized to connect
6-255		Reserved for future use

Publishing to a topic



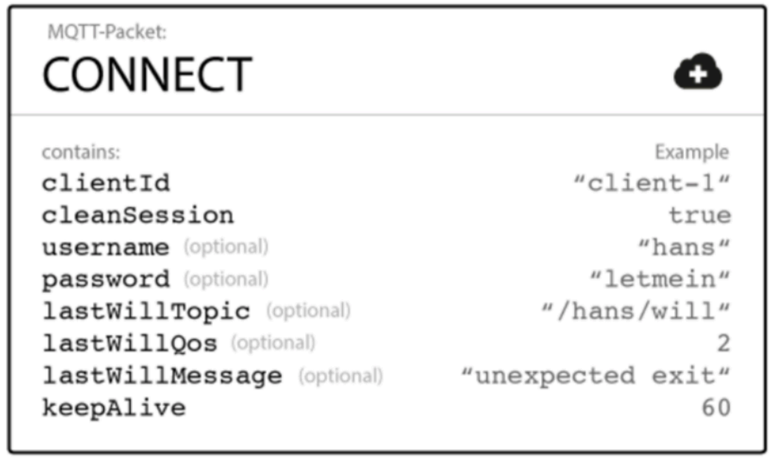
Subscribing to a topic

- Example:
  - Topic #1: home/groundfloor/kitchen/temperature
  - Topic #2: office/conferenceroom/luminance
- Wild cards
  - Single-level:
    - home/groundfloor/**+**/temperature (to subscribe to **all the temperature readings** in all the rooms of the ground floor)
  - Multi-level:
    - home/groundfloor/**#** (to subscribe to **all the readings** in all the rooms of the ground floor, **not only the temperature**)

Quality of Service

- **0**: The broker/client will deliver the message once, with no confirmation.
- **1**: The broker/client will deliver the message at least once, with confirmation required.
- **2**: The broker/client will deliver the message exactly once by using a four step handshake.

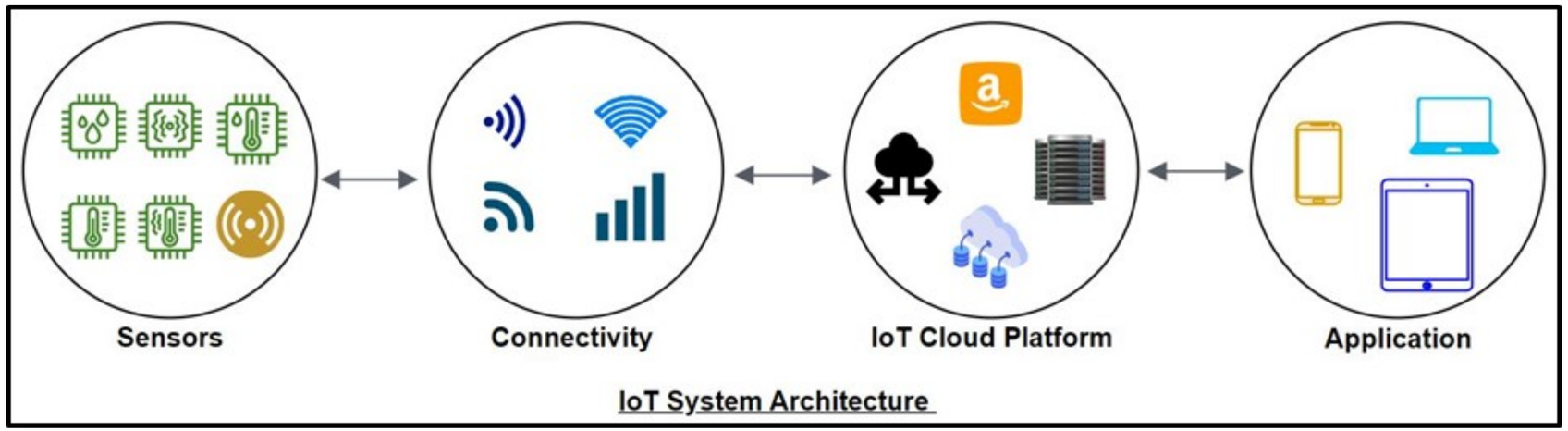
Last will and testament



Learn More

- Learn more: mqtt.org
- Software: mqtt.org/software
- Recommended broker (C): Mosquitto (mosquitto.org)
- Lots of good tutorials out the on Android Things, Python, Java and Mobile.

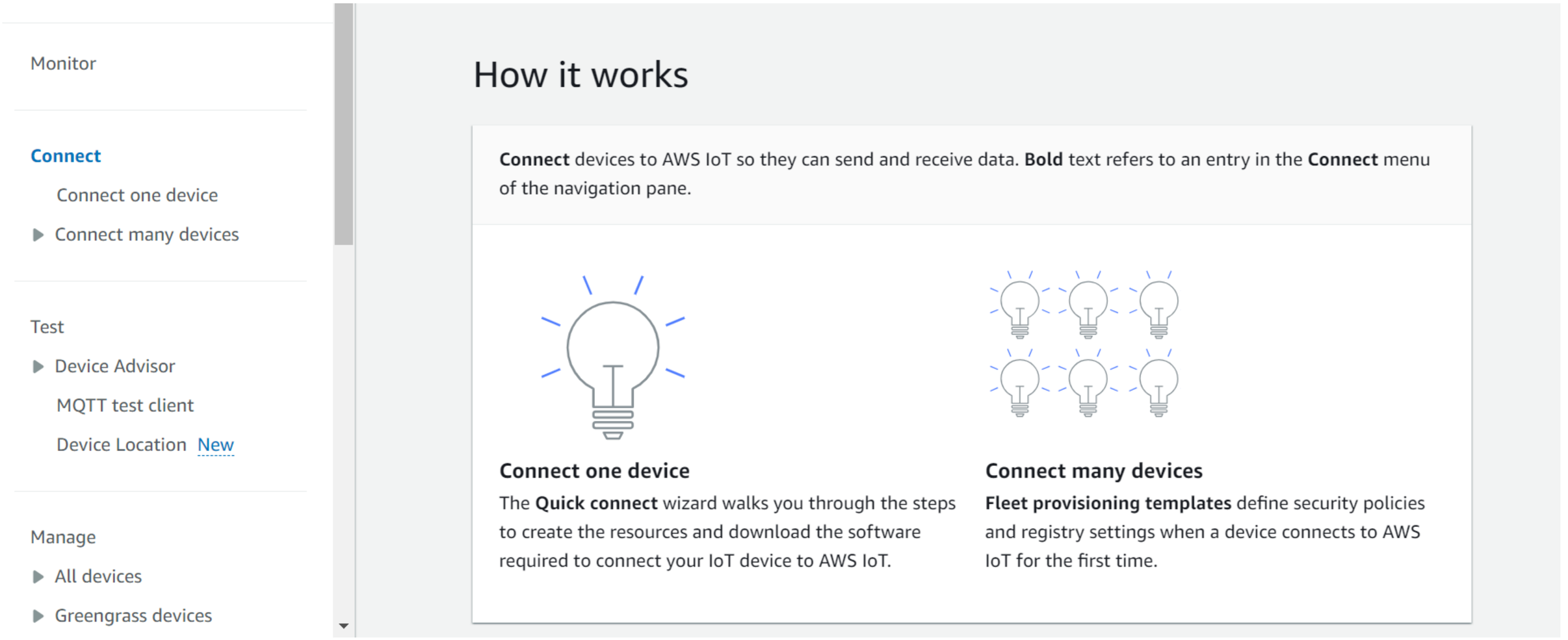
Architecture of an IoT System



Top 7 IoT Cloud Platforms

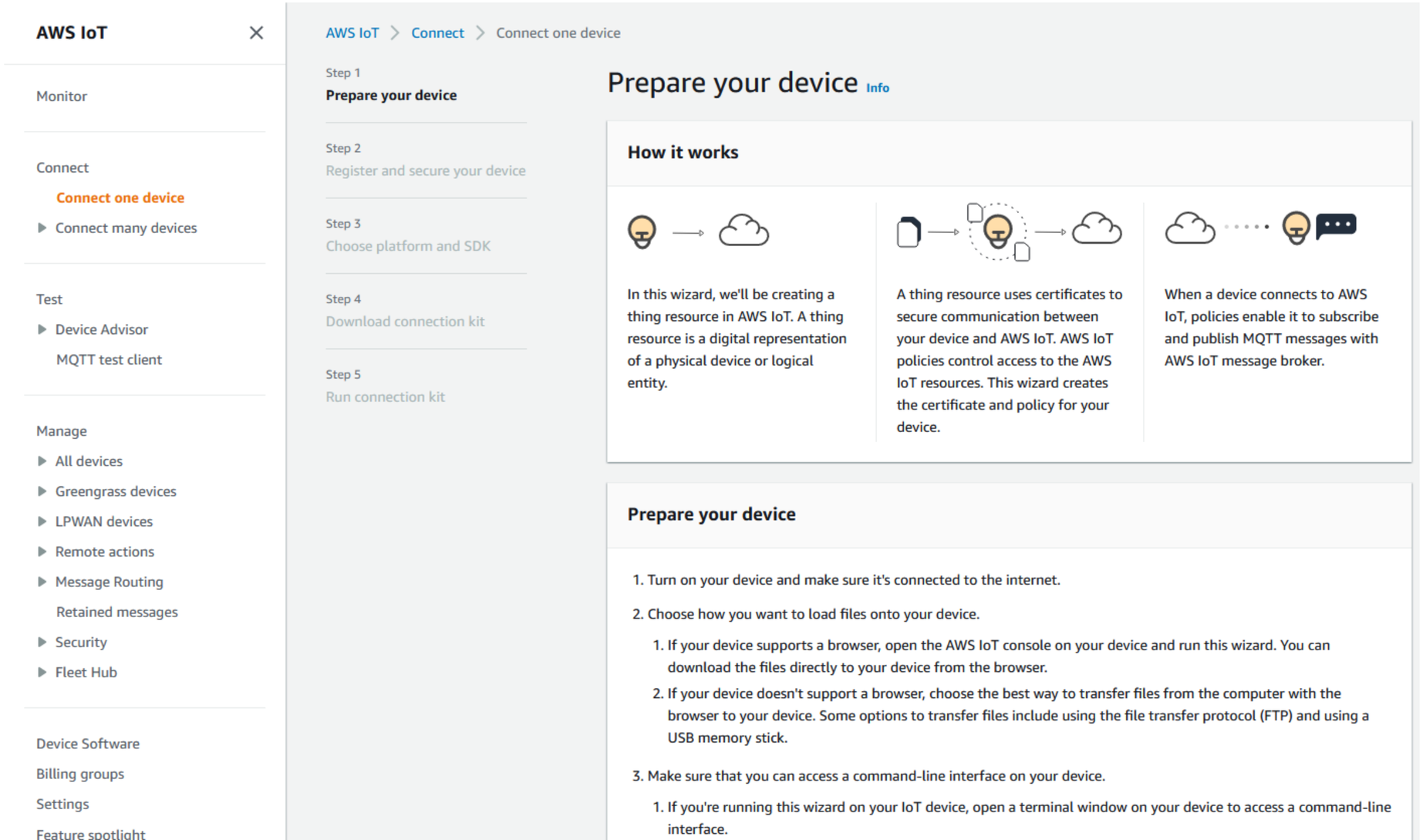
- Amazon Web Services (AWS) IoT Platform
- Microsoft Azure IoT
- Google IoT
- IBM Watson IoT
- Cisco IoT Cloud Connect
- ThingsBoard Open-Source IoT Platform
- Oracle IoT Intelligent Applications

AWS IoT

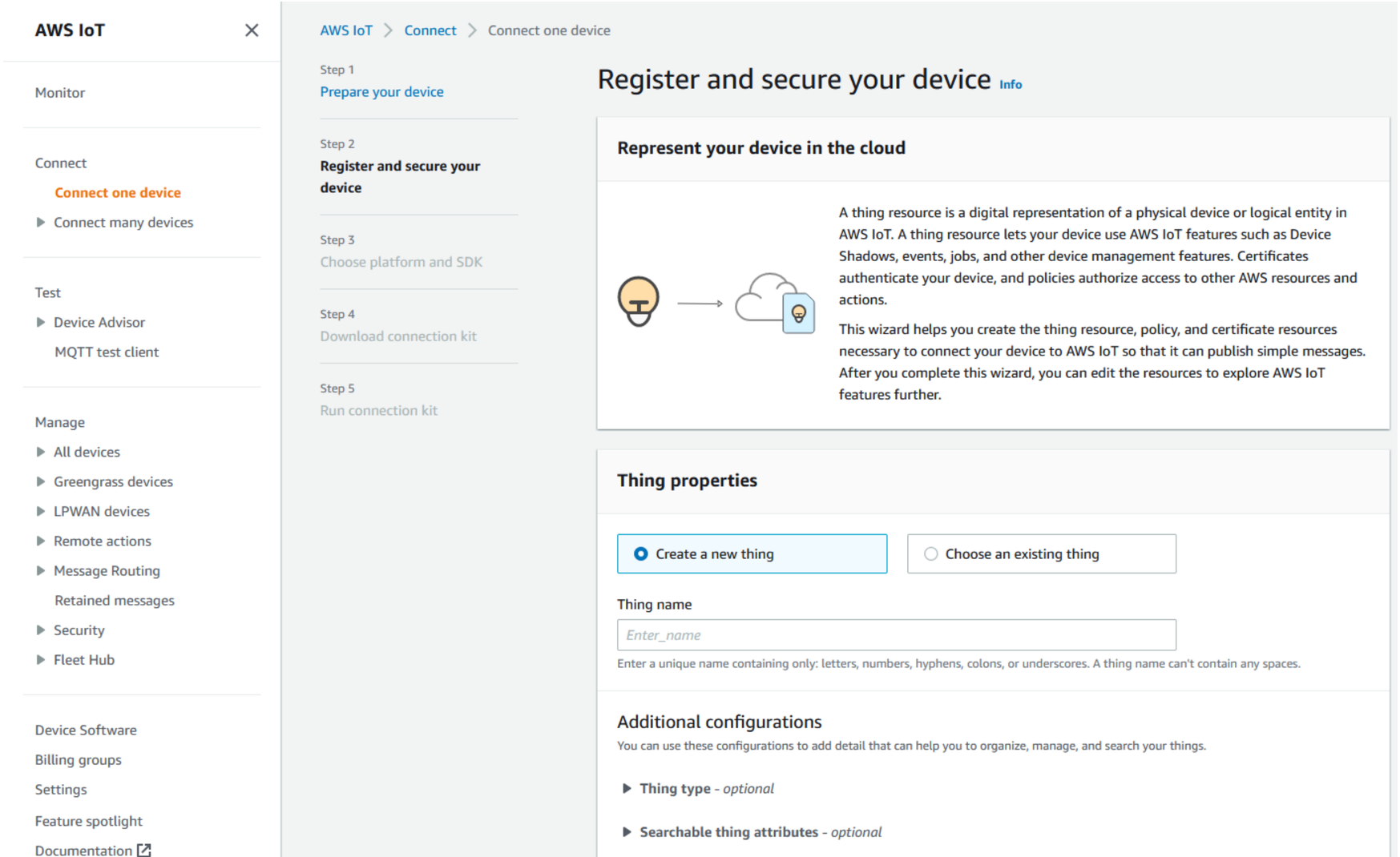


https://console.aws.amazon.com/iot/home

Create a thing object



Register and secure your device



Choose platform and SDK

AWS IoT > Connect > Connect one device

Step 1
Prepare your device

Step 2
Register and secure your device

Step 3
Choose platform and SDK

Step 4
Download connection kit

Step 5
Run connection kit

Choose platform and SDK Info

Choose the software for your device

This wizard helps you download a software development kit (SDK) to your device. AWS IoT supports Device SDKs that run on your device and include a sample program that publishes and subscribes to MQTT messages. AWS IoT supports Device SDKs in the languages shown below.

Platform and SDK

Choose the platform OS and AWS IoT Device SDK that you want to use for your device.

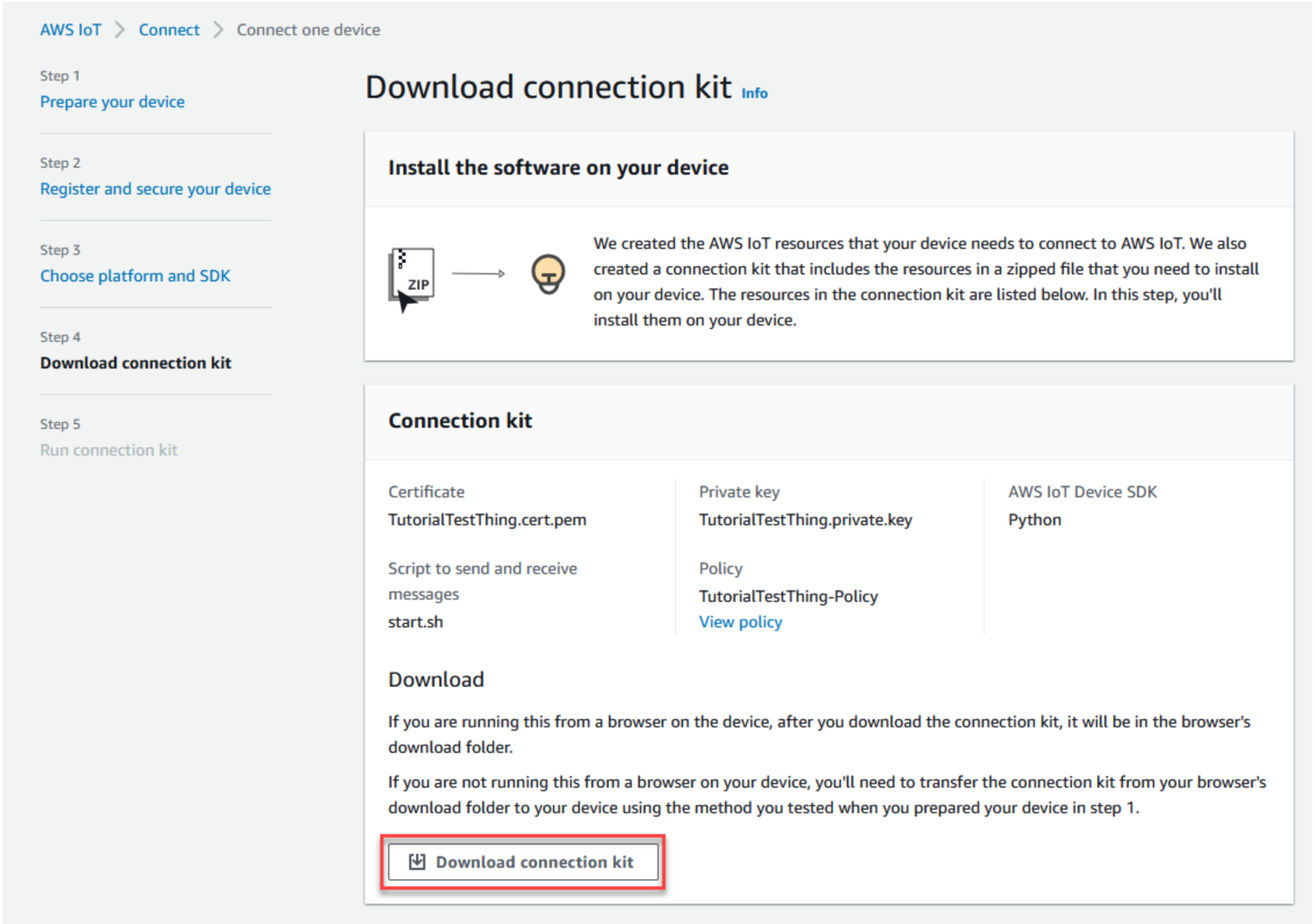
Device platform operating system
This is the operating system installed on the device that will connect to AWS.

- (●) Linux / macOS
  Linux version: any
  macOS version: 10.13+
- ( ) Windows
  Version 10

AWS IoT Device SDK
Choose a Device SDK that's in a language your device supports.

- ( ) Node.js
  Version 10+
  Requires Node.js and npm to be installed
- (●) Python
  Version 3.6+
  Requires Python and Git to be installed
- ( ) Java
  Version 8
  Requires Java JDK, Maven, and Git to be installed

Download files to your device



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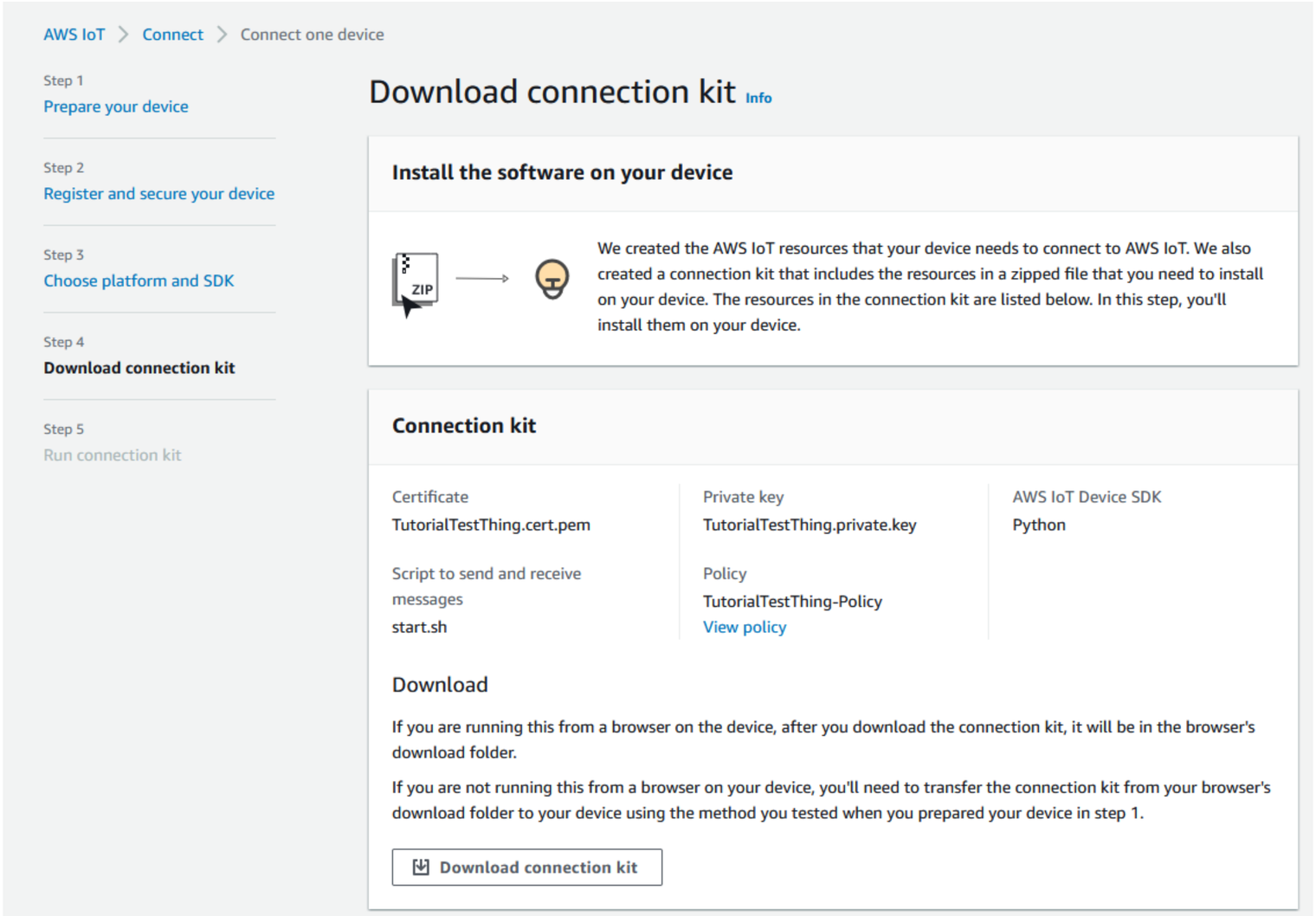

Run the sample

AWS IoT > Connect > Connect one device

Step 1
Prepare your device

Step 2
Register and secure your device

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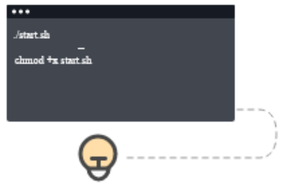
Run connection kit Info

How to display messages from your device

Step 1: Add execution permissions
On the device, launch a terminal window to copy and paste the command to add execution permissions.

chmod +x start.sh Copy



Step 2: Run the start script
On the device, copy and paste the command to the terminal window and run the start script.

./start.sh Copy

Step 3: Return to this screen to view your device's messages
After running the start script, return to this screen to see the messages between your device and AWS IoT. The messages from your device appear in the following list.

Subscriptions	sdk/test/Python	Pause	Clear
sdk/test/Python	Waiting for messages		

Output

```
Running pub/sub sample application...
Connecting to a13hikvzkye6lx-ats.iot.us-east-1.amazonaws.com with client ID 'basicPubSub'...
Connected!
Subscribing to topic 'sdk/test/Python'...
Subscribed with QoS.AT_LEAST_ONCE
Sending messages until program killed
Publishing message to topic 'sdk/test/Python': Hello World! [1]
Received message from topic 'sdk/test/Python': b'"Hello World! [1]"'
Publishing message to topic 'sdk/test/Python': Hello World! [2]
Received message from topic 'sdk/test/Python': b'"Hello World! [2]"'
Publishing message to topic 'sdk/test/Python': Hello World! [3]
Received message from topic 'sdk/test/Python': b'"Hello World! [3]"'
```

Output

AWS IoT > Connect > Connect one device

Step 1
Prepare your device

Step 2
Register and secure your device

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Run connection kit Info

How to display messages from your device

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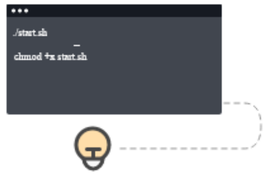

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Subscriptions

sdk/test/Python

sdk/test/Python Resume Clear

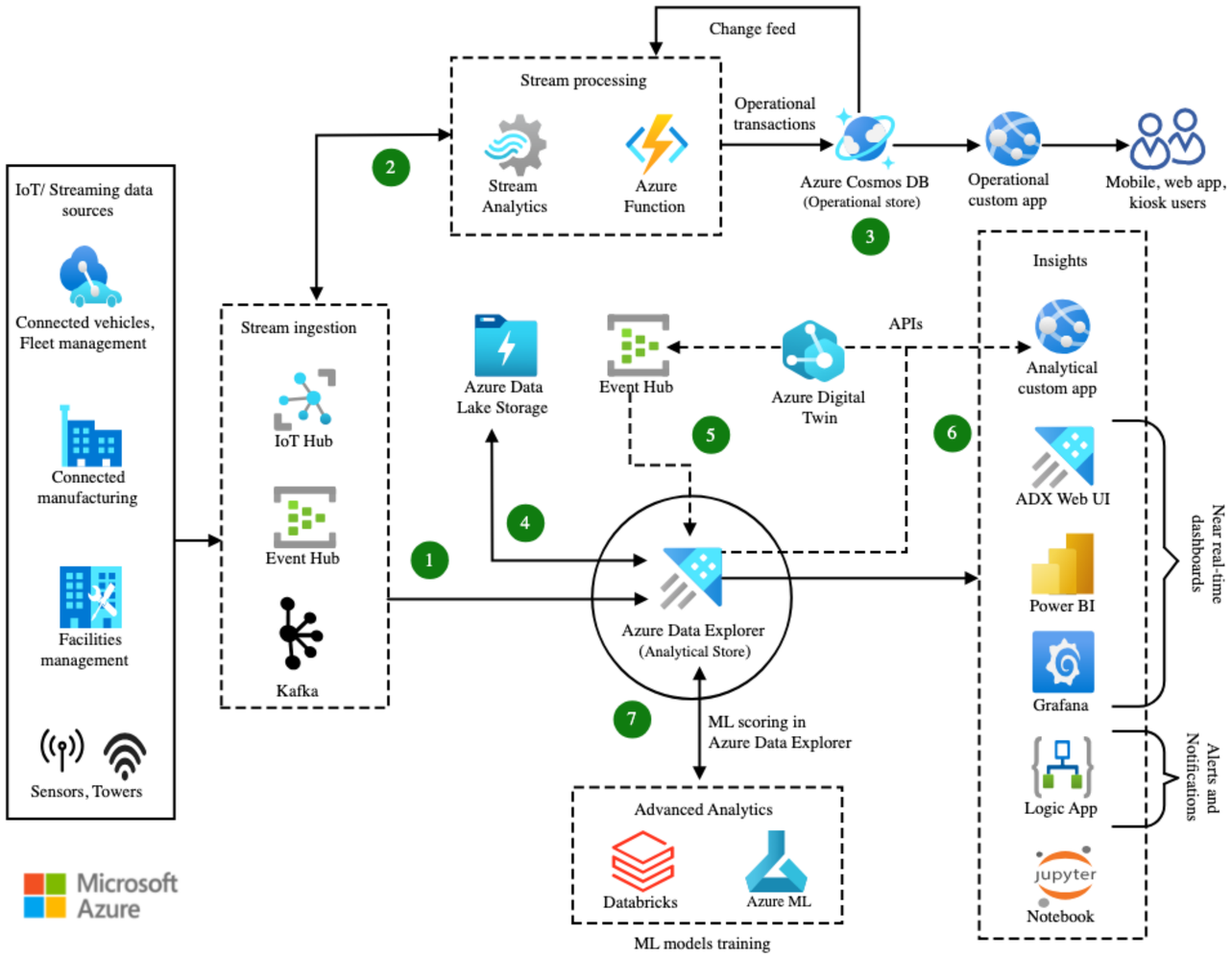
▼ sdk/test/Python September 14, 2022, 10:47:44 (UTC-0700)

```
"Hello World! [3]"
```

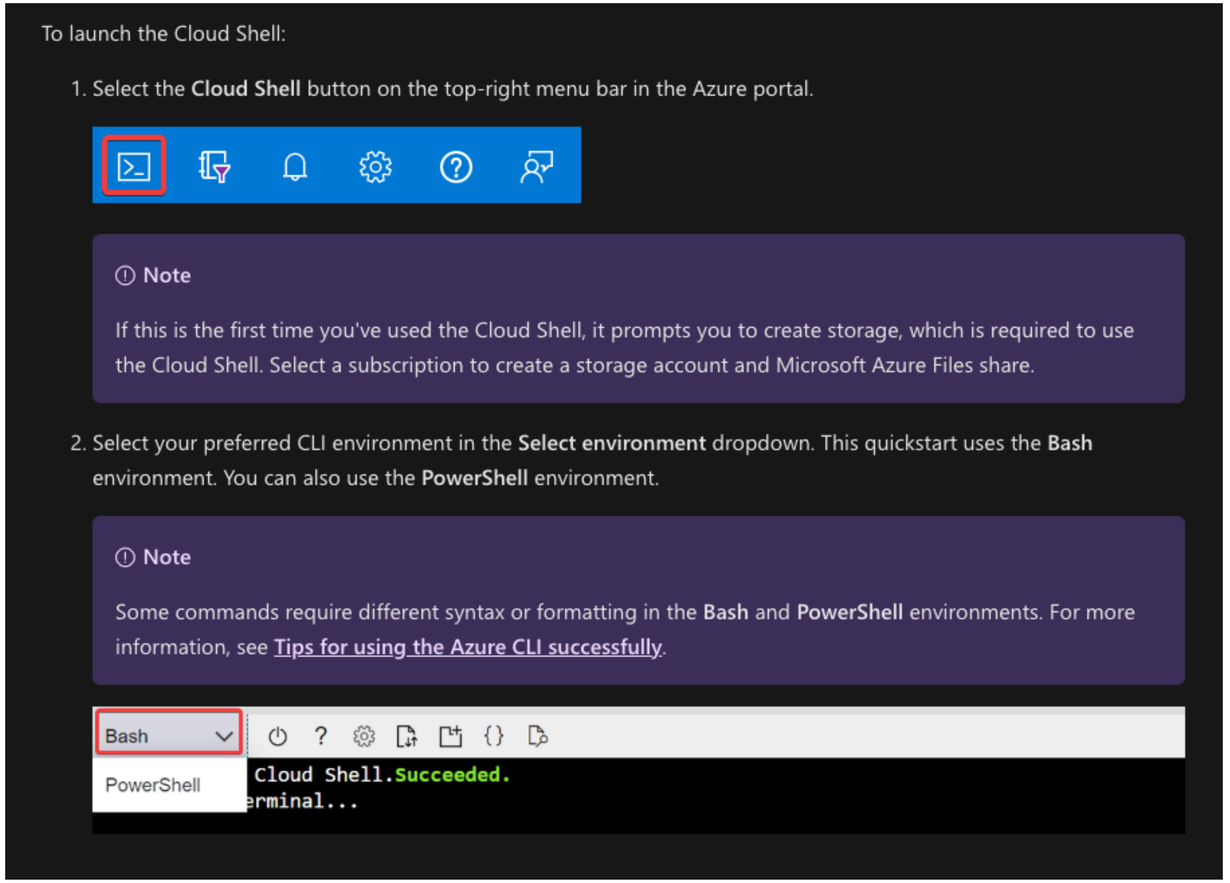
▼ sdk/test/Python September 14, 2022, 10:47:43 (UTC-0700)

```
"Hello World! [2]"
```

Azure IoT


Change feed
Stream processing
Stream Analytics
Azure Function
Operational transactions
Azure Cosmos DB (Operational store)
Operational custom app
Mobile, web app, kiosk users
IoT/ Streaming data sources
Connected vehicles, Fleet management
Connected manufacturing
Facilities management
Sensors, Towers
Stream ingestion
IoT Hub
Event Hub
Kafka
Azure Data Lake Storage
Event Hub
Azure Digital Twin
APIs
Insights
Analytical custom app
ADX Web UI
Power BI
Grafana
Logic App
Notebook
Near real-time dashboards
Alerts and Notifications
Azure Data Explorer (Analytical Store)
ML scoring in Azure Data Explorer
Advanced Analytics
Databricks
Azure ML
ML models training
1
2
3
4
5
6
7
Microsoft Azure

Launch the Cloud Shell



https://portal.azure.com/

Prepare CLI sessions

- In the first CLI session, run the az extension add command. The command adds the Microsoft Azure IoT Extension for Azure CLI to your CLI shell. The IOT Extension adds IoT Hub, IoT Edge, and IoT Device Provisioning Service (DPS) specific commands to Azure CLI.

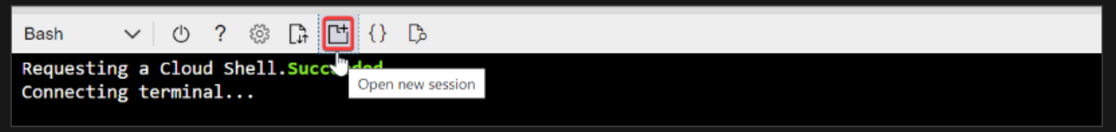
  Azure CLI — Copy

  ```
  az extension add --name azure-iot
  ```

  After you install the Azure IOT extension, you don't need to install it again in any Cloud Shell session.

  > **Note**
  >
  > This article uses the newest version of the Azure IoT extension, called `azure-iot`. The legacy version is called `azure-cli-iot-ext`.You should only have one version installed at a time. You can use the command `az extension list` to validate the currently installed extensions.
  >
  > Use `az extension remove --name azure-cli-iot-ext` to remove the legacy version of the extension.
  >
  > Use `az extension add --name azure-iot` to add the new version of the extension.
  >
  > To see what extensions you have installed, use `az extension list`.

- Open the second CLI session. If you're using the Cloud Shell in a browser, use the **Open new session** button. If using the CLI locally, open a second CLI instance.



Create an IoT hub

1. In the first CLI session, run the az group create command to create a resource group. The following command creates a resource group named *MyResourceGroup* in the *eastus* location.

```
Azure CLI                                                    Copy

az group create --name MyResourceGroup --location eastus
```

2. In the first CLI session, run the Az PowerShell module iot hub create command to create an IoT hub. It takes a few minutes to create an IoT hub.

   YourIotHubName. Replace this placeholder and the surrounding braces in the following command, using the name you chose for your IoT hub. An IoT hub name must be globally unique in Azure. Use your IoT hub name in the rest of this quickstart wherever you see the placeholder.

```
Azure CLI                                                    Copy

az iot hub create --resource-group MyResourceGroup --name {YourIoTHubName}
```

Create and monitor a device

1. In the first CLI session, run the az iot hub device-identity create command. This command creates the simulated device identity.

   YourIotHubName. Replace this placeholder below with the name you chose for your IoT hub.

   simDevice. You can use this name directly for the simulated device in the rest of this quickstart. Optionally, use a different name.

   Azure CLI Copy

   ```
   az iot hub device-identity create -d simDevice -n {YourIoTHubName}
   ```

2. In the first CLI session, run the az iot device simulate command. This command starts the simulated device. The device sends telemetry to your IoT hub and receives messages from it.

   YourIotHubName. Replace this placeholder below with the name you chose for your IoT hub.

   Azure CLI Copy

   ```
   az iot device simulate -d simDevice -n {YourIoTHubName}
   ```

To monitor a device

1. In the second CLI session, run the az iot hub monitor-events command. This command continuously monitors the simulated device. The output shows telemetry such as events and property state changes that the simulated device sends to the IoT hub.

   YourIotHubName. Replace this placeholder below with the name you chose for your IoT hub.

   Azure CLI Copy

```
az iot hub monitor-events --output table -p all -n {YourIoTHubName}
```

Bash

```
Starting event monitor, use ctrl-c to stop...
event:
  annotations:
    iothub-connection-auth-generation-id:
    iothub-connection-auth-method: '{"scope":"device","type":"sas","issuer":"iothub","acceptingIpFilterRule":null}'
    iothub-connection-device-id: simDevice
    iothub-enqueuedtime: 1653493361818
    iothub-message-source: Telemetry
    x-opt-enqueued-time: 1653493361826
    x-opt-offset: '59904'
    x-opt-sequence-number: 117
  component: ''
  interface: ''
  module: ''
  origin: simDevice
  payload:
    data: 'Ping from Az CLI IoT Extension #14'
    id:
    timestamp: '2022-05-25 15:42:41.809391'
  properties:
    application: {}
    system:
      content_encoding: utf-8
      content_type: application/json
```

2. After you monitor the simulated device in the second CLI session, press Ctrl+C to stop monitoring. Keep the second CLI session open to use in later steps.

Use the CLI to send a message

1. In the first CLI session, confirm that the simulated device is still running. If the device stopped, run the following command to restart it:

   YourIotHubName. Replace this placeholder below with the name you chose for your IoT hub.

   Azure CLI Copy

   ```
   az iot device simulate -d simDevice -n {YourIoTHubName}
   ```

2. In the second CLI session, run the az iot device c2d-message send command. This command sends a cloud-to-device message from your IoT hub to the simulated device. The message includes a string and two key-value pairs.

   YourIotHubName. Replace this placeholder below with the name you chose for your IoT hub.

   Azure CLI Copy

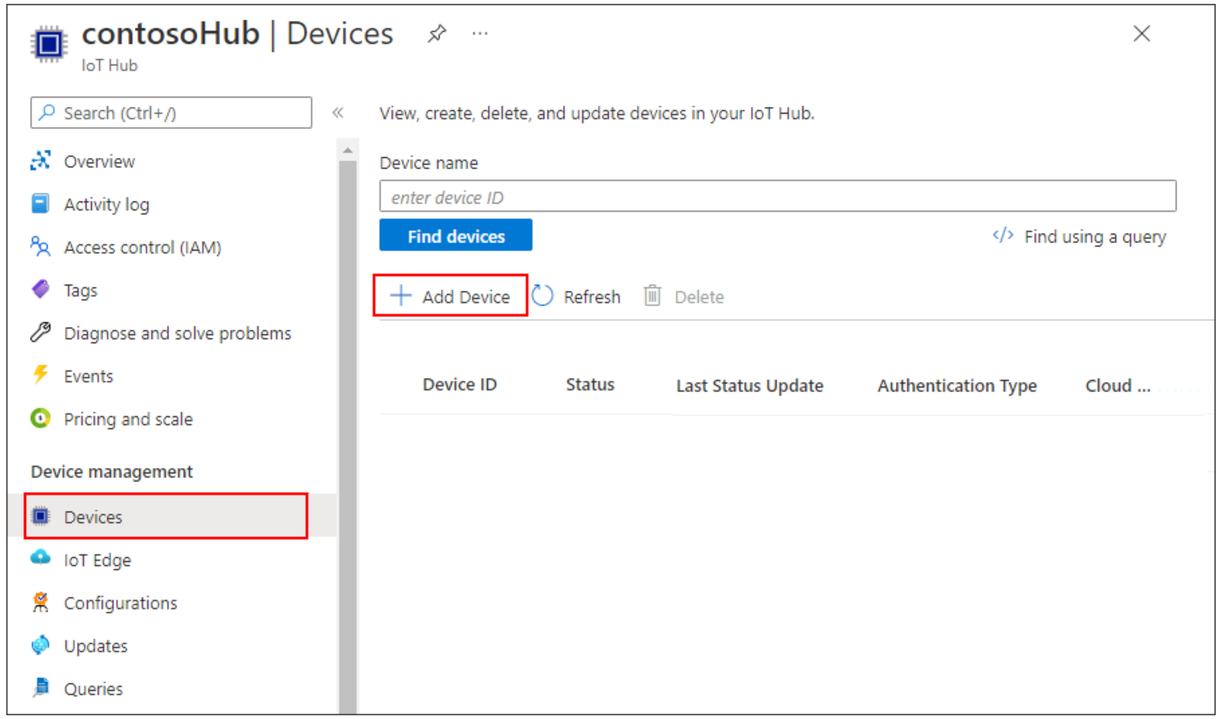
   ```
   az iot device c2d-message send -d simDevice --data "Hello World" --props "key0=value0;key1=val
   ```

   Optionally, you can send cloud-to-device messages by using the Azure portal. To do this, browse to the overview page for your IoT Hub, select **IoT Devices**, select the simulated device, and select **Message to Device**.

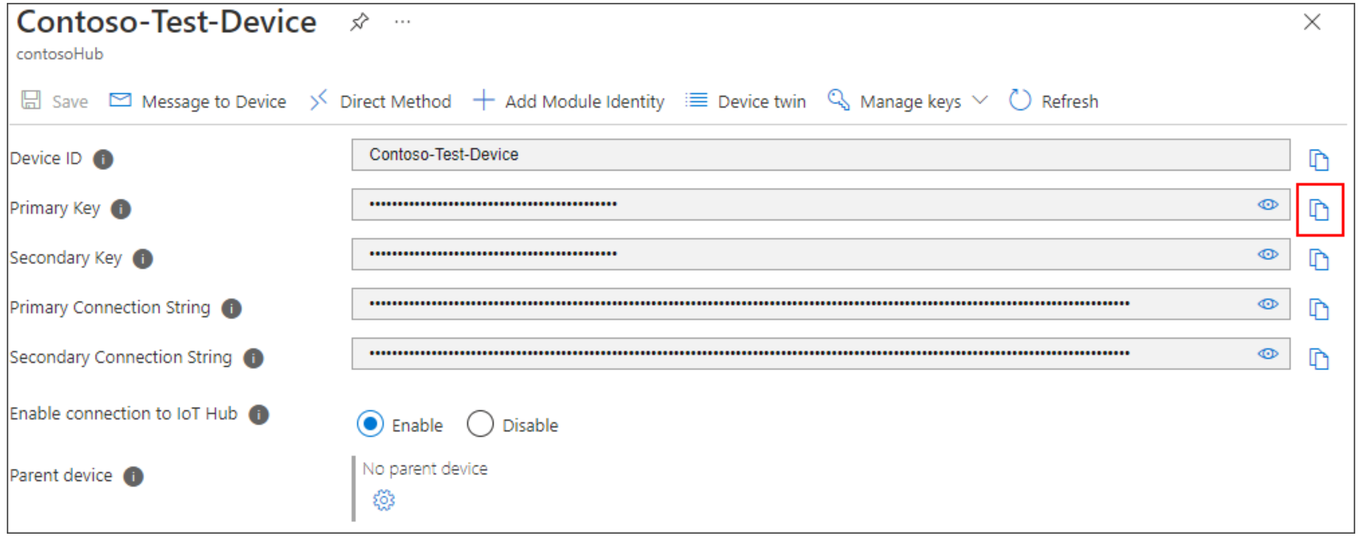
3. In the first CLI session, confirm that the simulated device received the message.

   ```
   C2D Message Handler [Received C2D message]:
   { 'Message Properties': { 'content_encoding': 'utf-8',
                             'key0': 'value0',
                             'key1': 'value1',
                             'message_id':
     'Payload': 'Hello World',
     'Topic': '/devices/simDevice/messages/devicebound'}
   Device simulation in progress:  19%|########################################
   ```

Register a device and send messages to IoT Hub

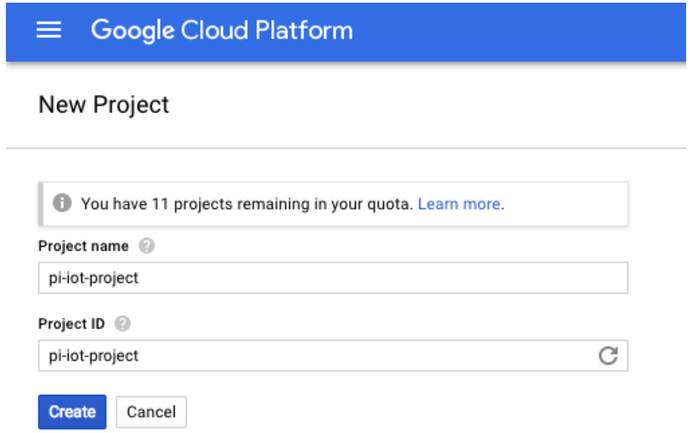


Credentials

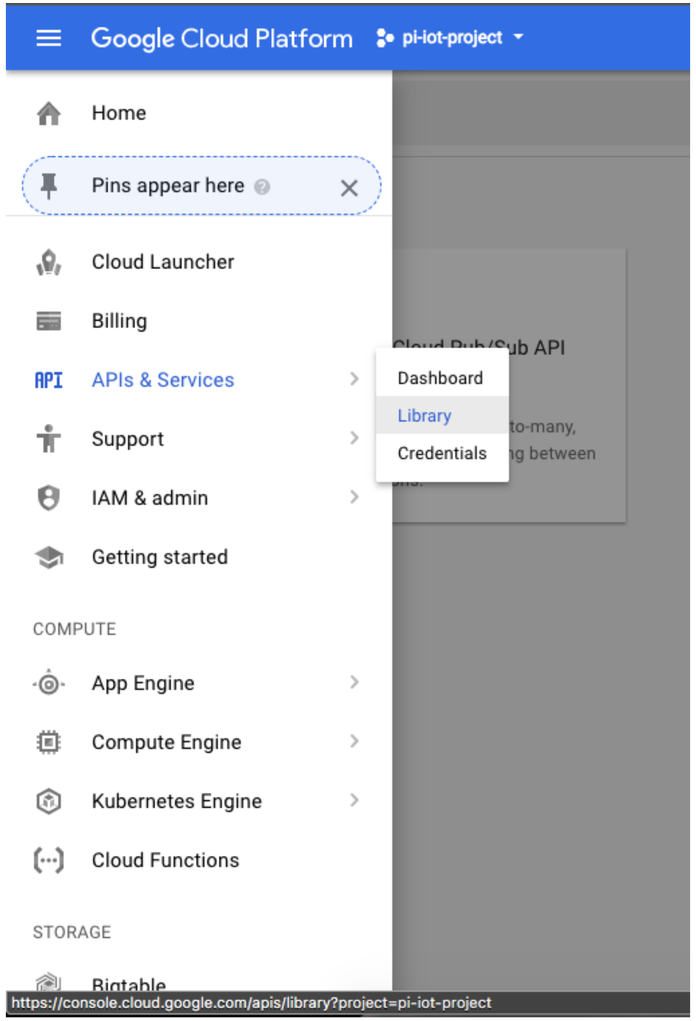


https://github.com/Azure/azure-iot-sdk-csharp

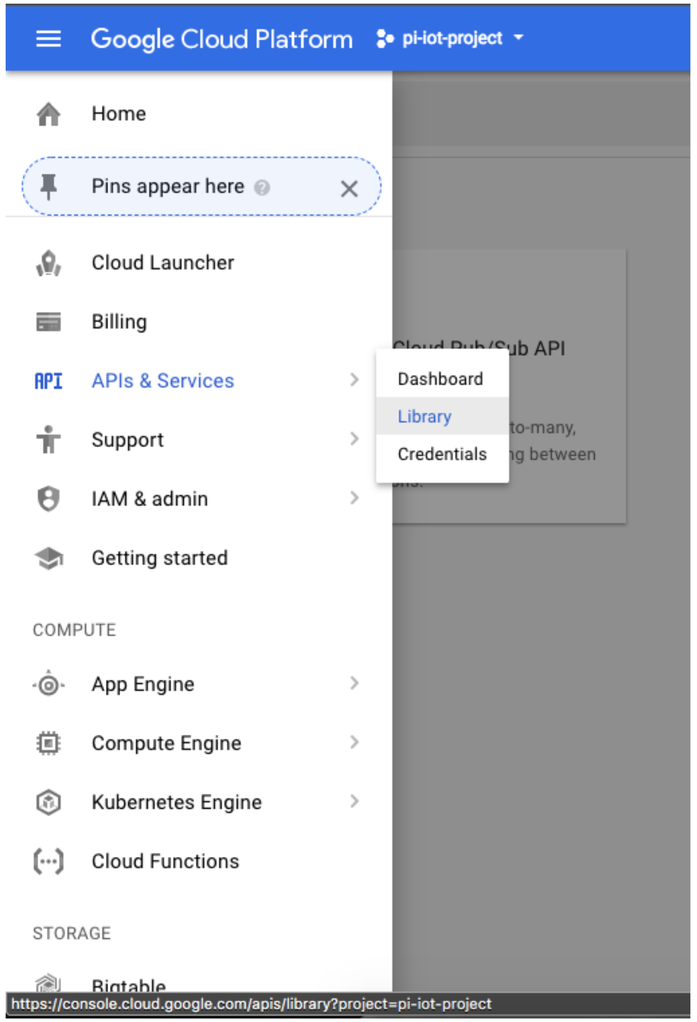
Google IoT

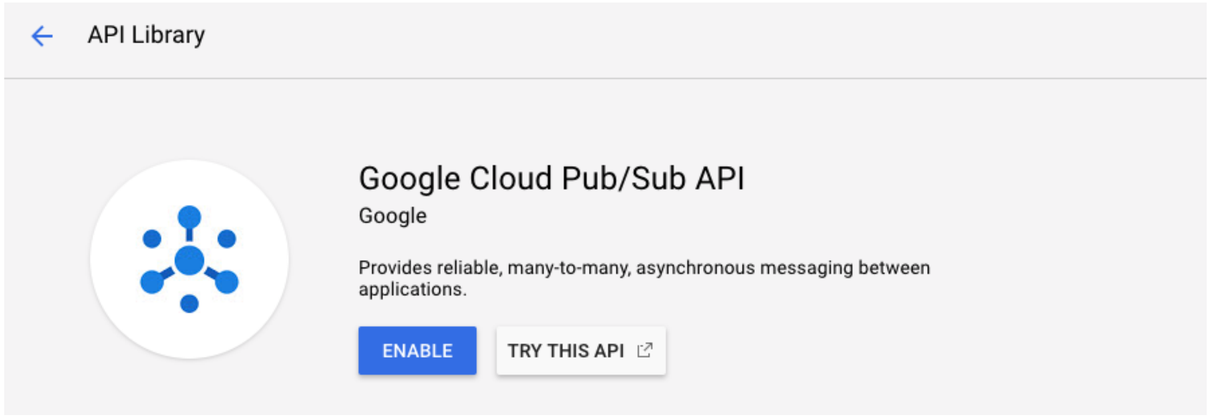

Google Cloud Platform
New Project
You have 11 projects remaining in your quota. Learn more.
Project name
pi-iot-project
Project ID
pi-iot-project
Create
Cancel

Enabling APIs

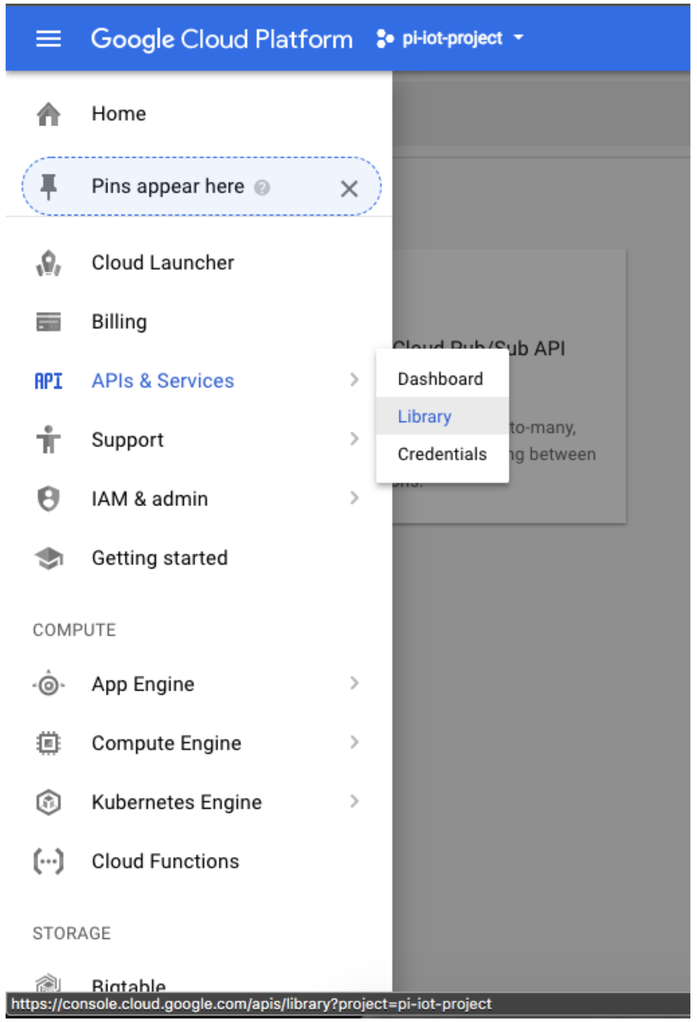


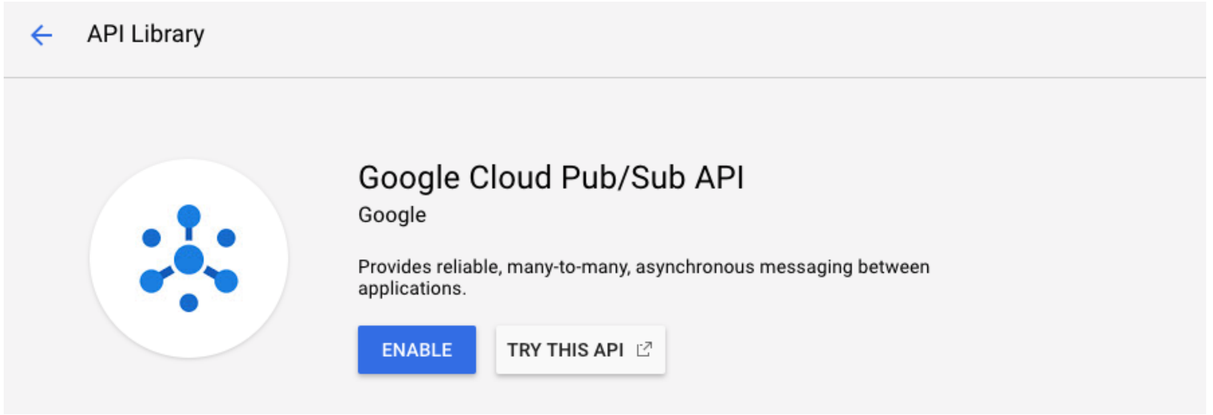
Enabling APIs

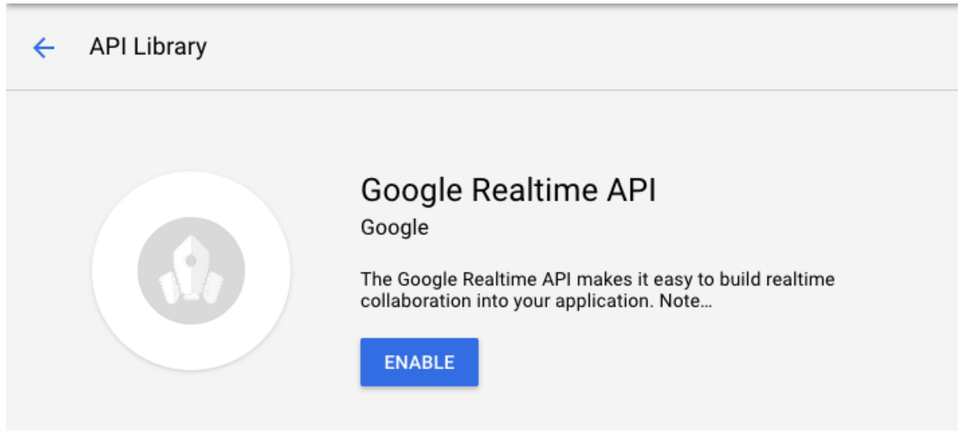




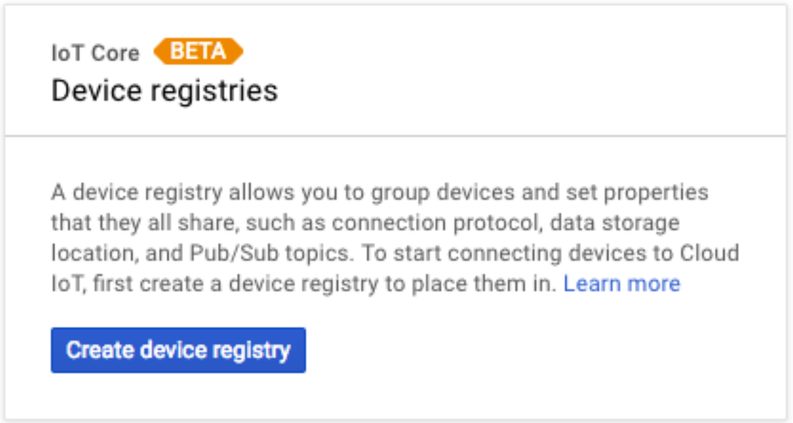
Enabling APIs





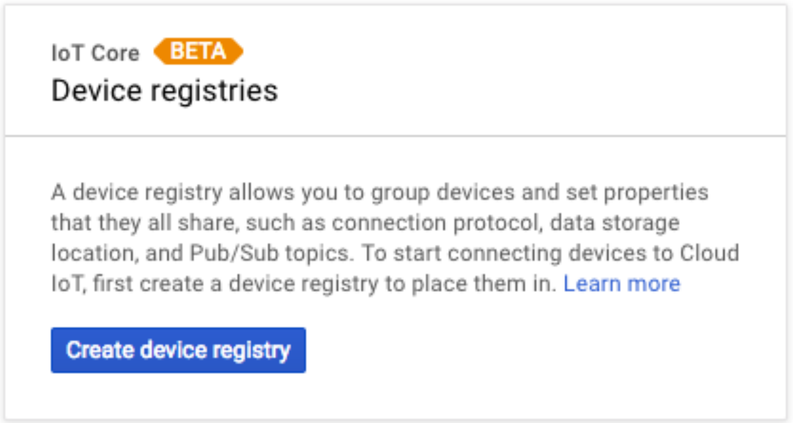


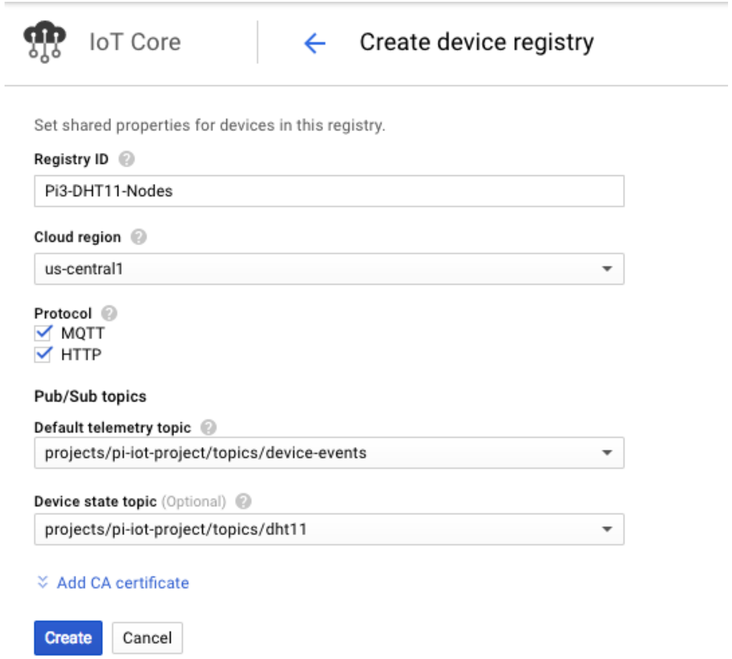
Enabling device registry and devices



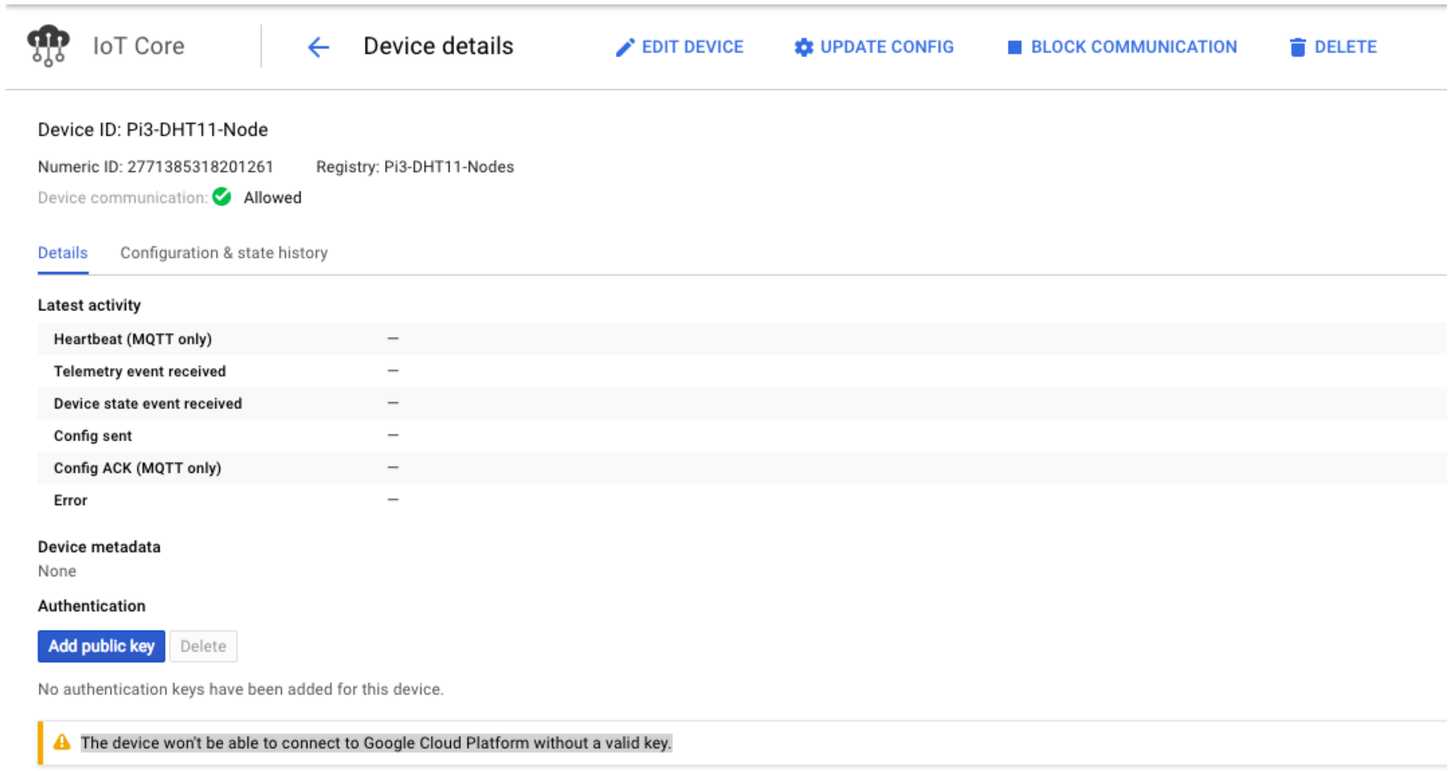
Field	Value
Registry ID	`Pi3-DHT11-Nodes`
Cloud region	us-central1
Protocol	MQTT HTTP
Default telemetry topic	device-events
Default state topic	dht11

Enabling device registry and devices



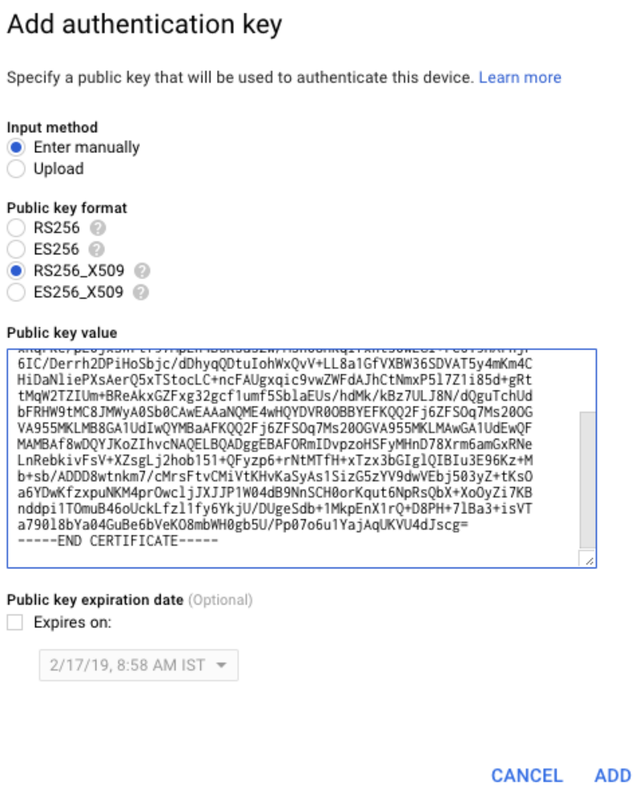


Public key



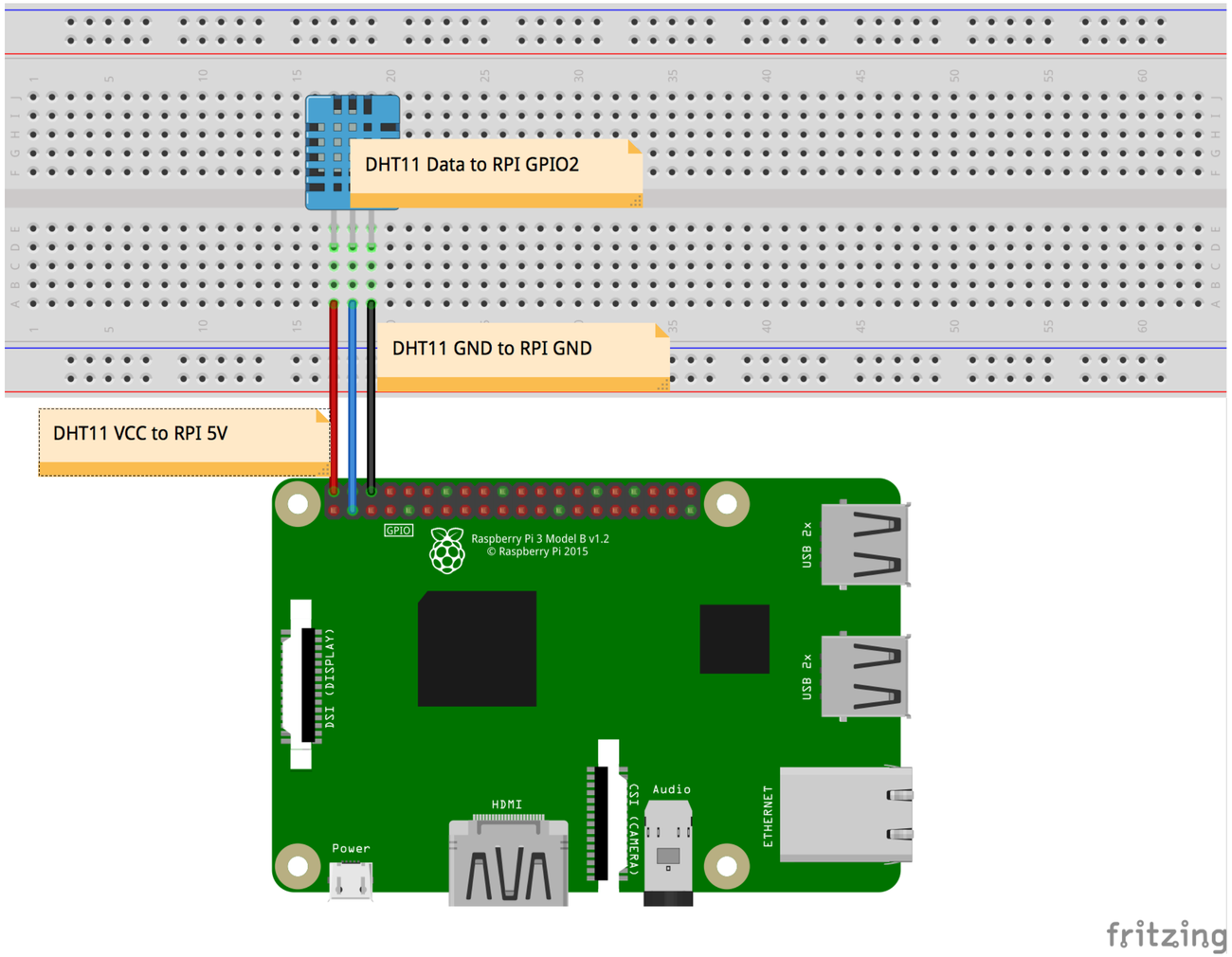

```
openssl req -x509 -newkey rsa:2048 -keyout rsa_private.pem -nodes -out rsa_cert.pem -subj "/CN=unused"
```

Public key




```
openssl req -x509 -newkey rsa:2048 -keyout rsa_private.pem -nodes -out rsa_cert.pem -subj "/CN=unused"
```

Setting up Raspberry Pi 3 with DHT11 node



Setting up Node.js

1. Open a new Terminal and run the following commands:

```
$ sudo apt update
$ sudo apt full-upgrade
```

2. This will upgrade all the packages that need upgrades. Next, we will install the latest version of Node.js. We will be using the Node 7.x version:

```
$ curl -sL https://deb.nodesource.com/setup_7.x | sudo -E bash -
$ sudo apt install nodejs
```

3. This will take a moment to install, and once your installation is done, you should be able to run the following commands to see the version of Node.js and npm:

```
$ node -v
$ npm -v
```

Developing the Node.js device app

1. From the Terminal, once you are inside the `Google-IoT-Device` folder, run the following command:

```
$ npm init -y
```

2. Next, we will install `jsonwebtoken` (https://www.npmjs.com/package/jsonwebtoken) and `mqtt` (https://www.npmjs.com/package/mqtt) from npm. Execute the following command:

```
$ npm install jsonwebtoken mqtt--save
```

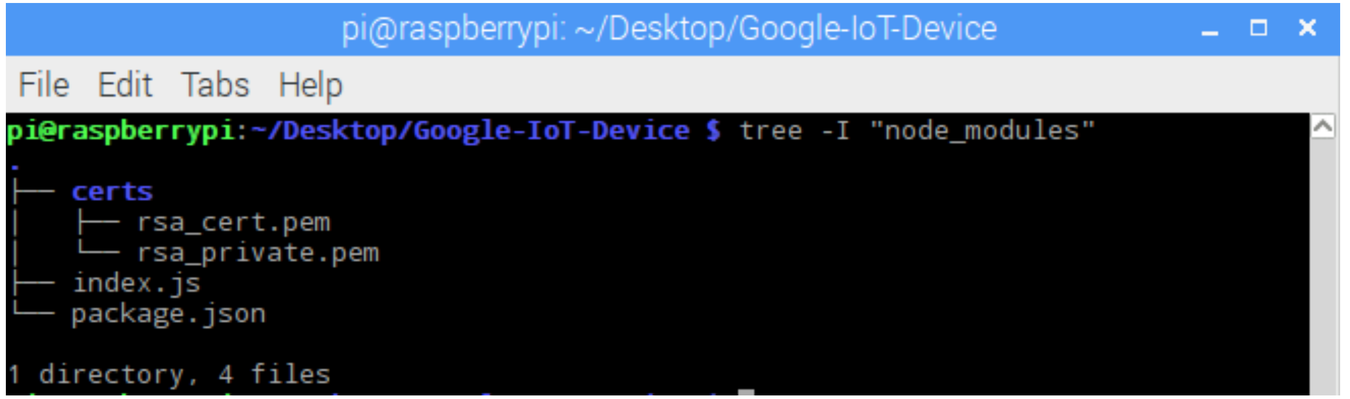
3. Next, we will install `rpi-dht-sensor` (https://www.npmjs.com/package/rpi-dht-sensor) from npm. This module will help in reading the DHT11 temperature and humidity values:

```
$ npm install rpi-dht-sensor --save
```

package.json

```
{
 "name": "Google-IoT-Device",
 "version": "1.0.0",
 "description": "",
 "main": "index.js",
 "scripts": {
  "test": "echo "Error: no test specified" && exit 1"
 },
 "keywords": [],
 "author": "",
 "license": "ISC",
 "dependencies": {
  "jsonwebtoken": "^8.1.1",
  "mqtt": "^2.15.3",
  "rpi-dht-sensor": "^0.1.1"
 }
}
```

Project Structure



```
var fs = require('fs');
var jwt = require('jsonwebtoken');
var mqtt = require('mqtt');
var rpiDhtSensor = require('rpi-dht-sensor');

var dht = new rpiDhtSensor.DHT11(2); // `2` => GPIO2

var projectId = 'pi-iot-project';
var cloudRegion = 'us-central1';
var registryId = 'Pi3-DHT11-Nodes';
var deviceId = 'Pi3-DHT11-Node';

var mqttHost = 'mqtt.googleapis.com';
var mqttPort = 8883;
var privateKeyFile = '../certs/rsa_private.pem';
var algorithm = 'RS256';
var messageType = 'state'; // or event

var mqttClientId = 'projects/' + projectId + '/locations/' + cloudRegion + '/registries/' + registryId + '/devices/' + deviceId;
var mqttTopic = '/devices/' + deviceId + '/' + messageType;

var connectionArgs = {
  host: mqttHost,
  port: mqttPort,
  clientId: mqttClientId,
  username: 'unused',
  password: createJwt(projectId, privateKeyFile, algorithm),
```

```
var connectionArgs = {
  host: mqttHost,
  port: mqttPort,
  clientId: mqttClientId,
  username: 'unused',
  password: createJwt(projectId, privateKeyFile, algorithm),
  protocol: 'mqtts',
  secureProtocol: 'TLSv1_2_method'
};

console.log('connecting...');
var client = mqtt.connect(connectionArgs);

// Subscribe to the /devices/{device-id}/config topic to receive config updates.
client.subscribe('/devices/' + deviceId + '/config');

client.on('connect', function(success) {
  if (success) {
    console.log('Client connected...');
    sendData();
  } else {
    console.log('Client not connected...');
  }
});

client.on('close', function() {
  console.log('close');
});
```

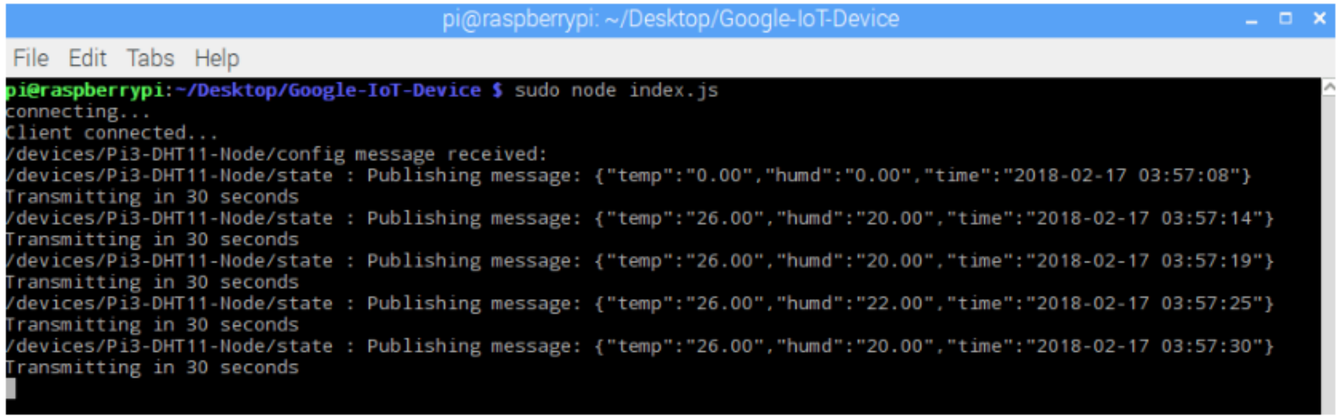
```
client.on('error', function(err) {
  console.log('error', err);
});

client.on('message', function(topic, message, packet) {
  console.log(topic, 'message received: ', Buffer.from(message, 'base64').toString('ascii'));
});

function createJwt(projectId, privateKeyFile, algorithm) {
  var token = {
    'iat': parseInt(Date.now() / 1000),
    'exp': parseInt(Date.now() / 1000) + 86400 * 60, // 1 day
    'aud': projectId
  };
  var privateKey = fs.readFileSync(privateKeyFile);
  return jwt.sign(token, privateKey, {
    algorithm: algorithm
  });
}

function fetchData() {
  var readout = dht.read();
  var temp = readout.temperature.toFixed(2);
  var humd = readout.humidity.toFixed(2);

  return {
    'temp': temp,
    'humd': humd,
```

```
    algorithm: algorithm
  });
}

function fetchData() {
  var readout = dht.read();
  var temp = readout.temperature.toFixed(2);
  var humd = readout.humidity.toFixed(2);

  return {
    'temp': temp,
    'humd': humd,
    'time': new Date().toISOString().slice(0, 19).replace('T', ' ')
  };
}

function sendData() {
  var payload = fetchData();

  payload = JSON.stringify(payload);
  console.log(mqttTopic, ': Publishing message:', payload);
  client.publish(mqttTopic, payload, { qos: 1 });

  console.log('Transmitting in 30 seconds');
  setTimeout(sendData, 30000);
}
```

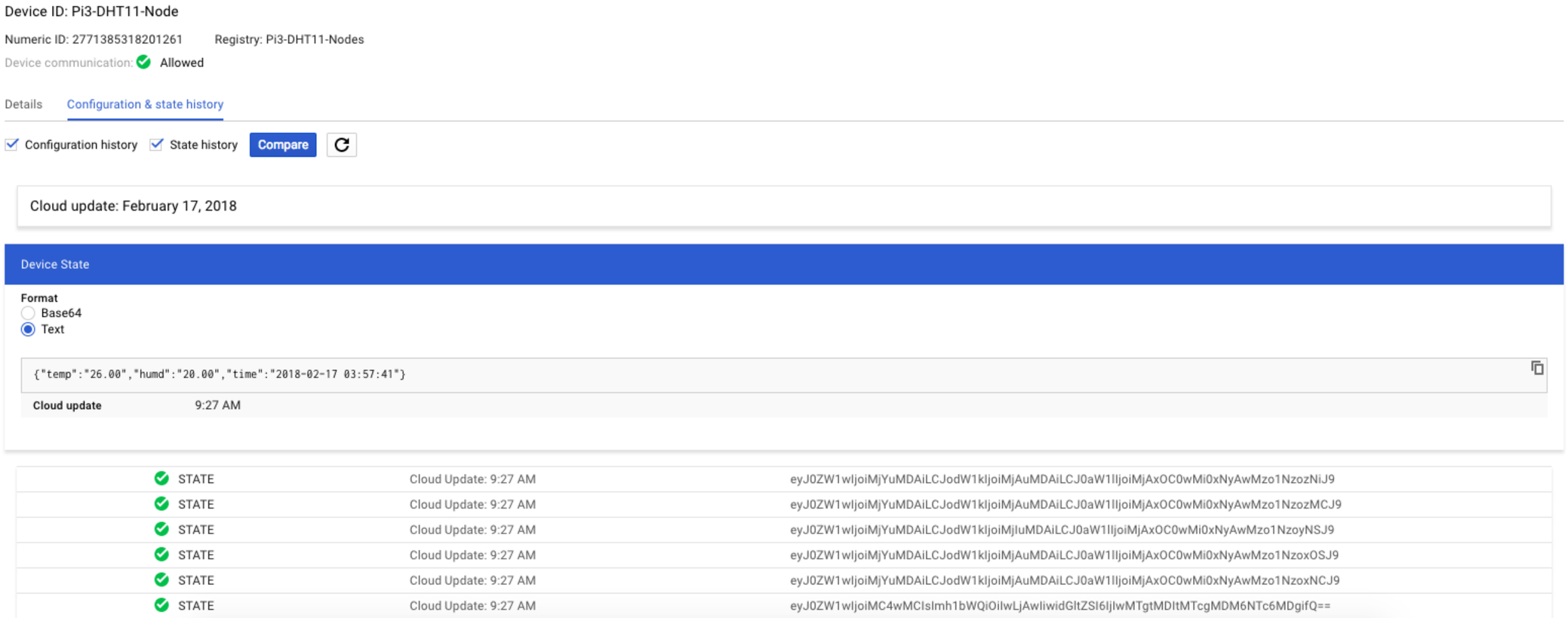
Running

```
$ sudo node index.js
```

And we should see something like this:



Console


Device ID: Pi3-DHT11-Node
Numeric ID: 2771385318201261
Registry: Pi3-DHT11-Nodes
Device communication: Allowed
Details
Configuration & state history
Configuration history
State history
Compare
Cloud update: February 17, 2018
Device State
Format
Base64
Text
{"temp":"26.00","humd":"20.00","time":"2018-02-17 03:57:41"}
Cloud update
9:27 AM
STATE
Cloud Update: 9:27 AM
eyJ0ZW1wIjoiMjYuMDAiLCJodW1kIjoiMjAuMDAiLCJ0aW1lIjoiMjAxOC0wMi0xNyAwMzo1NzozNiJ9
STATE
Cloud Update: 9:27 AM
eyJ0ZW1wIjoiMjYuMDAiLCJodW1kIjoiMjAuMDAiLCJ0aW1lIjoiMjAxOC0wMi0xNyAwMzo1NzozMCJ9
STATE
Cloud Update: 9:27 AM
eyJ0ZW1wIjoiMjYuMDAiLCJodW1kIjoiMjIuMDAiLCJ0aW1lIjoiMjAxOC0wMi0xNyAwMzo1NzoyNSJ9
STATE
Cloud Update: 9:27 AM
eyJ0ZW1wIjoiMjYuMDAiLCJodW1kIjoiMjAuMDAiLCJ0aW1lIjoiMjAxOC0wMi0xNyAwMzo1NzoxOSJ9
STATE
Cloud Update: 9:27 AM
eyJ0ZW1wIjoiMjYuMDAiLCJodW1kIjoiMjAuMDAiLCJ0aW1lIjoiMjAxOC0wMi0xNyAwMzo1NzoxNCJ9
STATE
Cloud Update: 9:27 AM
eyJ0ZW1wIjoiMC4wMCIsImh1bWQiOiIwLjAwIiwidGltZSI6IjIwMTgtMDItMTcgMDM6NTc6MDgifQ==

Lecture outcomes

- MQTT Protocol
- Cloud
  - AWS
  - Azure
  - Google