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| VIETNAMESE-GERMAN UNIVERSITY  KARLSRUHE UNIVERSITY OF APPLIED SCIENCES  **MASTER THESIS**  **DEVELOPING MQTT DASHBOARD**  **WITH SCALA AND AKKA**  *Author: Tan Dung, Tran*  *VGU Student ID: 18859*  *HKA Matriculation Number: 81182*  *Referee: Prof. Dr.- Ing. Thorsten Leize*  *Co-referee: Prof. Dr.- Ing.*  *Supervisor:*  *Supervisor:*    A thesis submitted in partial fulfillment of the requirements for the degree of  **MASTER OF SCIENCE**  in Faculty of  **Mechatronics and Sensor Systems Technology**  **2022** |

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# 1. Overview:

## 1.1. Abstract:

Time has been changed, the expansion of information makes a big change in industry or heath care, service or transportation. As a result, the concept of IoT was introduced and becomes more popular, it appears and is often an integral part of all aspects of life and technology. For example, many years ago, to measure heart rate parameters, patients had to make an appointment and visit a doctor, which is troublesome when compared to today, when IoT was applied, patients only need to wear an end-device, which has the necessary sensors and connection (WiFi, 4G). Then, the doctor can update his heath continuously, real-time without the two even having to see each other, that's really is a revolution.

To do that, the connections between devices have to be established for data sharing. In the previous example, it is the connection and communication between patient’s end-device and doctor’s laptop/smartphone. This is also correct with a bigger system, which includes many smaller systems, when each small system – likes a device in the big system, need to “talk” to each other to deligate tasks or receive the input for its tasks.

Hence, data contribution is the most important. Additionally, the way to contribute information, must be reliable, stable, and lightweight as well. As a result, MQTT protocol came to solve all that problems, which was invented in 1999 by Andy Stanford-Clark (IBM) and Arlen Nipper (Arcom, now Cirrus Link). Nowaday, it is the most commonly used messaging protocol for the Internet of Things (IoT).

## 1.2. Literature review:

### 1.2.1. Conceptions:

#### MQTT Protocol

“MQTT is a Client Server publish/subscribe messaging transport protocol. It is light weight, open, simple, and designed so as to be easy to implement. These characteristics make it ideal for use in many situations, including constrained environments such as for communication in Machine to Machine (M2M) and Internet of Things (IoT) contexts where a small code footprint is required and/or network bandwidth is at a premium.“

Citation from the official MQTT 3.1.1 specification. [1]

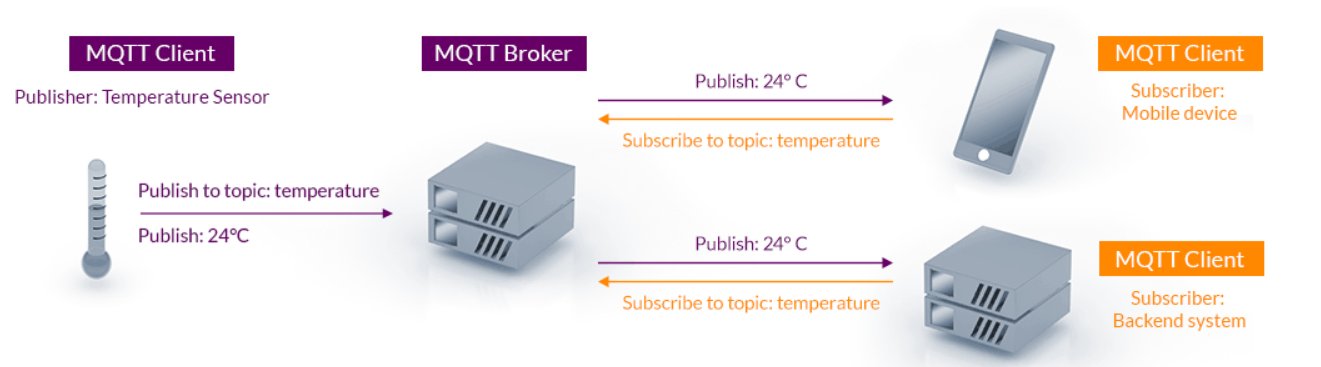


Figure 1. MQTT Architecture (Pub/Sub Model) [2]

MQTT protocol follows publish/subscribe model, which is also a client-server architecture base on TCP/IP. In MQTT, it defines MQTT Client (client) and MQTT Broker (server). When a Client want to send its information to another Client, the data is not transmitted directly between two devices. Instead, the Client will connect and send the information to Broker – that action is called Publishing and the Client is called Publisher. After that, Broker will pass that data to the Client - which asks for that information – the action is called Subscribing and the Client is called Subscriber.

That means in MQTT protocol, every Clients do not need to know each other, they just need to deal with Broker and Broker will try to manage any communications between Clients.

The essential properties of MQTT that meet the needs of IoT applications are conceptual, but for a deeper understanding, we will compare it to a highly popular protocol, HTTP. Both are based on TCP/IP, which has lately become the most widely used data transmission technology. They also share a Client-Server architecture, as seen in the table below: [3]

|  |  |  |
| --- | --- | --- |
|  | MQTT | HTTP |
| Architecture | Publish subscribe | Request response |
| Command targets | Topics | URLs |
| Underlying Protocol | TCP/IP | TCP/IP |
| Secure connections | TLS + username/password (SASL support possible) | TLS + username/password (SASL support possible) |
| Client observability | Known connection status (holding connection) | Unknown connection status |
| Messaging Mode | Asynchronous, event-based | Synchronous |
| Message queuing | The broker can queue messages for disconnected subscribers | Application needs to implement |
| Message overhead | 2 bytes minimum. Header data can be binary | 8 bytes minimum (header data is text - compression possible) |
| Message Size | 256MB maximum | No limit but 256MB is beyond normal use cases anyway. |
| Content type | Any (binary is normal) | Text (Base64 encoding for binary) |
| Message distribution | One to many | One to one |
| Reliability | Three qualities of service (QoS) | Has to be implemented in the application |

Table 1. Comparation about features between MQTT and HTTP Protocol [4]

Besides, by trying to connect to Google IOT Core, we can measure performance of 02 protocols:

|  |  |  |
| --- | --- | --- |
|  | MQTT Bytes | HTTP Bytes |
| Establish connection | 5572 | 2261 |
| Disconnect | 376 (Optional) | 0 |
| For each message published | 388 | 3285 |
| Sum for 1 message | 6336 | 5546 |
| Sum for 10 messages | 9829 | 55460 |
| Sum for 100 messages | 44748 | 554600 |

Table 2. TCP message overhead [4]

The MQTT Procol definetly consumes less bytes then HTTP, that means the application can save a lot of bandwidth and enery.

Finally, we measure the response time:

|  |  |  |
| --- | --- | --- |
| No. messages in a connection cycle for MQTT | MQTT avg. response time per message (ms) (QoS 1) | HTTP avg. response time per message (ms) |
| 1 | 113 | 289 |
| 100 | 47 | 289 |
| 1000 | 43 | 289 |

Table 3. Response time per message [4]

Arcording the measurement above, we can confirm that the features of MQTT Protocol, are mostly more suitable with IoT applications than HTTP.

#### MQTT Broker:

The author will implement the most important, the heart of a MQTT network - MQTT Broker - in this project. In a nutshell, MQTT Broker is the location where all network packets must be stopped. Furthermore, it must handle many messages and tasks concurrently: receiving all messages from clients, checking the packet, routing the message to the destinations... In other words, MQTT Broker is a hub where all of the main tasks of the MQTT network are carried out. To summarize, whether or not a MQTT network can function properly is largely determined by its Broker.

Concisely, MQTT Broker need to handle these basic tasks:

* Receiving all messages,
* Filtering the messages,
* Determining who is subscribed to each message,
* Sending the message to these subscribed clients

Otherwise, there are some other tasks of a MQTT Broker:

* Holds the session data of all clients
* Authentication and authorization of clients

Therefore, it is important that your broker is highly scalable, integratable into backend systems, easy to monitor, and (of course) failure-resistant. (\*)

### 1.2.2. Topic review:

There are many documents, including articles, open sources, blogs, etc., that explain the MQTT Protocol, therefore it can be difficult for researchers to get started. Fortunately, a [website](https://mqtt.org/) [5] has been created to compile and summarize the vast majority of the information you need to know about the MQTT Protocol, including its specifications, standards, applications, and usage. However, it frequently focuses on practical rather than intellectual features. It is appropriate for this thesis and will be referred.

[The website](https://mqtt.org/software/) [5] is a fairly complete and reliable aggregator of MQTT concepts and applications, softwares, and libraries in progress (both open sources and comercial products). Obviously, individual projects with limited resources and applications are not included, which are not widely publicized, so this will be an important reference and will be cited throughout this thesis.

Generally, MQTT Brokers can be classified into two types: Managed Brokers và Self-Hosted Brokers.

**Managed Brokers** do not require any server configuration to enable MQTT communication. You can use Managed Broker services to use their hosted brokers for your system. A good example of a managed MQTT Broker is [AWS IoT Core](https://aws.amazon.com/iot-core/) [6].

To compare, **Self-hosted MQTT Brokers** necessitate the installation of the broker on your own VPS or server with a static IP address. The installation process is simple, but managing, securing, and scaling the brokers necessitates extensive knowledge of the system. There are several open-source MQTT brokers available, including [mosquitto](https://mosquitto.org/) [7] and [hivemq](https://www.hivemq.com/) [3].

**A Managed Broker** service makes sense if you need to quickly construct a prototype or proof-of-concept (POC) and do not want to spend time managing the infrastructure and protecting the connections. You can access a Broker that is ready to use in just a few clicks. Though, managed brokers can have some disadvantages. For instance, you will be charged based on the quantity of data packets sent (the pricing model varies from service provider to service provider). The majority of the Broker's settings are out of your hands; you may only make changes that the vendor permits. Data transfer and packets/second or packets/minute are frequently capped by managed broker providers, which might impede communication.

**A Self-hosted Broker** can be the best option if you try a Managed Broker but the cost or control restrictions caused an issue, that also means you are required programming and networking skills. On contrast, with a Self-hosted Broker, you can quickly implement your rules, scale the system as you see fit, and configure it anyway you choose.

Here is an overview of some of the most popular options.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type | Type | WebSocket Support | SSL Support | Scalability |
| [AWS IoT Core MQTT](https://docs.aws.amazon.com/iot/latest/developerguide/mqtt.html) | Managed | Dynamically assigned | Yes, port=443 | Yes, port=8883 |
| [Mosquitto](https://mosquitto.org/) | Self-hosted and Managed | test.mosquitto.org | Yes, port=8081,8080 | Yes, port=8883,8884 |
| [Mosca/Aedes](https://github.com/moscajs/aedes) | Self-hosted and Managed | test.mosca.io | Yes, port=3000 | Yes, port=8883 |
| [HiveMQ](https://www.hivemq.com/) | Self-hosted and Managed | broker.hivemq.com | Yes, port=8000,443 | Yes, port=8883 |
| [VerneMQ](https://vernemq.com/) | Self-hosted and Managed | self-assigned | Yes, port=9001,9002 | Yes, port=8883 |
| [Azure IoT Hub](https://docs.microsoft.com/en-us/azure/iot-hub/iot-hub-mqtt-support) | Managed | Dynamically assigned | Yes, port=443 | Yes, port=8883 |
| [EMQ X](https://www.emqx.com/en/mqtt/public-mqtt5-broker) | Self-hosted | Self-assigned | Yes, port=8083, 8084 | Yes, port=8883 |
| [ejabberd](https://www.process-one.net/en/ejabberd/#getejabberd) | Self-hosted and managed | Self-assigned and dynamically allocated | Yes | Yes |

Table 4. List of Popular MQTT Brokers

Generally speaking, the analysis above highlights both the pros and cons of the published MQTT Brokers projects. There is a comment stating that the aforementioned programs are either paid or opened source - but challenging to understand and modify to the demands. All the brokers have been found as good performance, but they are not easy to customize in mostly cases.

In order to create a MQTT Dashboard that can further configure for other applications, the author will create a new program using a different paradigm based on the Actor Model (to be discussed later). Self-hosted Broker would be the preferred approach because it is simpler to understand and control, lighter, more convenient, and does not impose fees.

# 2. Introduction of thesis:

## 2.1. The approach of this thesis:

Based on the idea of ​​developing such a MQTT Dashboard, the author will implement a MQTT Broker written in Scala - a powerful language supported by the AKKA toolkit, with a set of tools powerful processing engine, and very good at scalability and self-healing. As stated in the introduction to MQTT Broker, this will be useful in the role of a broker, who must always connect to many devices, handle many processes, and must always be stable, but easily extendable.

The development of user functions, on the other hand, will be based on the Play Framework - a framework built on top of the AKKA model that allows it to inherit the power of AKKA and is also the framework used for the Scala language.

Thanks to the developer Butaji, who has released an open source (MIT license) from [the webpage](https://github.com/kumquatt/mqttd). [8]

This project was developed 7 years ago and is almost impossible to run at the present time, when the libraries are no longer supported and downloaded from the internet. Howerver, it also provides logical directions for this project, especially the core MQTT Broker.

## 2.2. Thesis aims and objectives:

#### Aim:

To develop a MQTT Broker Core using Scala and AKKA toolkit.

To develop a Dashboard using Scala and Play Framework.

To acquire and implement AKKA model in MQTT Protocol.

To achieve the reliability of the program in real IoT applications.

#### Objectives:

* Developing a MQTT Broker Program.
* Developing a Website with User Functions and User Interface interacts with MQTT Broker Core to monitor the devices in network.
* *Measure performance of the website. (considering)*
* Programing language: Scala.
* Model/Framework: AKKA & Play.

#### Diagram:

(TBD)

#### 

Figure 2. Illustrating images of dashboard

To compare with previous projects, this is a new approach, base on Scala language and AKKA model could be a good perspective for other projects using Scala or AKKA.

# 3. Tools and Methods:

The combo Scala, Akka toolkit and Play Framework will come together to implement the ideas in this project.

3.1. Introduction of Scala:

Scala is a powerful statically typed general-purpose programming language that can be used for both object-oriented and functional programming. Designed to be concise,[9] many of Scala's design decisions are intended to address Java's criticisms.[7]

Scala source code can be compiled into Java bytecode and then executed on a Java virtual machine (JVM). Scala and Java share language interoperability, allowing libraries written in either language to be referenced directly in Scala or Java code.[10] Scala, like Java, is object-oriented and employs a syntax known as curly-brace, which is similar to the language C. Since Scala 3, there is also the option of using the off-side rule (indenting) to structure blocks, which is recommended. According to Martin Odersky, this was the most fruitful change introduced in Scala 3.[11]

Advantages:

* Easy to Pick Up
* Pretty Good IDE Support
* Scalability
* Highly Functional
* Code cleaner

3.2. Introduction of AKKA:

AKKA is a toolkit that includes a collection of modules and libraries for building distributed applications with the Actor Model as the programming model. AKKA supports the Scala and Java programming languages and has an API for each of them. This toolkit is used by companies such as Verizon, Intel, PayPal, Norwegian Cruise Lines, and Samsung.

Advantages:

* Event-driven: With Actors, requests can be done asynchronously and non-blocking operations exclusively
* Scalable: By message passing and location transparency, adding nodes without having to modify the code is possible.
* Resilient: Akka fault tolerance is to encounter errors a self-healing system.
* Responsive: Akka’s non-blocking, message-based strategy helps to give quick feedback to request.

AKKA documentation is thorough and provides a comprehensive understanding of the many ideas and tools available. The majority of toolkit implementations are based on field research and industry expertise. Lightbend - the firm driving AKKA's development, is a commercial company that provides corporate software solutions for distributed systems and the cloud environment. This business is also responsible for the creation of other frameworks and platforms, like the Play framework and the Lagom framework5, which employ AKKA as an underlying technology.

### 3.2.1. AKKA Actor:

#### Actor programming model

The Actor Model consists of a set of actors, which are isolated, concurrent, and solely interacted through a network with a transparent message-passing technique. [9] The Actor Model was introduced by Carl Hewitt in 1973. [10] The model was designed to provide a general paradigm for concurrent computing in a highly concurrent and parallelizable distributed environment. At a higher level, the model is straightforward and allows for a high degree of parallelism. An Actor is the primary unit of the computing model. An Actor is a type of entity that may connect with other actors via network communications. [11] An actor can also generate additional actors in the network based on the needs. In this situation, the creator actor will be the "parent actor," and the created actors will be the "child actors." The following are the key benefits of the Actor Model.

* An Actor Model extends the benefits of object-oriented programming by decoupling business logic and control flow.
* An Actor Model enables the decomposition of a system into independent, autonomous, and interacting components that can function in parallel.

The race situation is avoided because one actor cannot corrupt the state of the other actors in the network. Each actor uses the spawn procedure to add a new actor to the network. This method is frequently used to spread workloads using a divide and conquer strategy. An actor separates incoming tasks into a set of sub-tasks and distributes them simultaneously among freshly formed actors using the spawn operation to speed up processing and improve response time of IoT applications. During the processing or analysis of an IoT application, each actor watches the other actors in the network to discover and propagate faults in the distributed environment. Bi-directional connections can express stronger coupling between network actors for improved message conveyance and prevent incorrect states during run-time. An actor embodies the three qualities listed below.

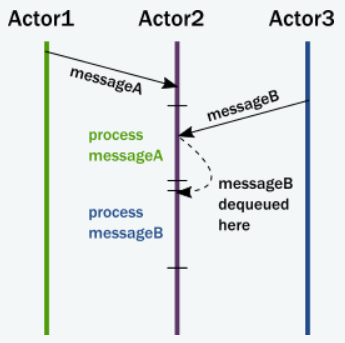


Figure 3. The message passing and processing flow of multiple actors [12]

* **Information processing**: Partial/complete processing of applications for their behavior.
* **Storage**: Save an actor's current state.
* **Data Communication**: Using the message passing approach, send the message to the remaining network actors.

Scala is a programming language that includes the actors for the standard distribution with the AKKA framework.

#### Actor model of computation

In the OOP Paradigm, an actor, like an object, has state and behavior. However, there are several constraints in the Actor Model that provide assurances while performing out calculations. [11] The state is totally owned by the actor and cannot be shared or accessed by other players in the system. This means that locks or other sorts of synchronization methods are unnecessary in a multi-threaded system. An actor can alter its state in response to a message or execute some calculation based on the message. The computation capabilities of the actor define its behavior.

One of the core ideas of the Actor Model is message passing. Fig. 3 depicts the message passing processing flow of various actors. An actor can respond to perceived signals sequentially and analyze each message separately, i.e. one at a time. While each actor processes the incoming messages sequentially, the other actors can operate concurrently with each other, allowing the network to handle numerous messages at the same time. It is the sole permitted method of communication between network participants. The following are the stages an actor takes when processing a message.

* + The actor adds the current incoming message to the queue's end.
  + If the actor is unavailable and the message was not scheduled for processing, the actor marks the message as ready to process.
  + A secret scheduler pulls the most recent ready message from the queue and begins processing it.
  + The actor updates current state information and sends it to another actor.
  + Finally, the actor takes the message out of the queue.

In order to carry out the above operation, an actor must have the following properties:

* + **A** **mailbox** queues incoming messages on a first-come-first-served basis.
  + **A** **behavior** includes internal variables, an actor's state, and so on.
  + **Incoming messages** contain data for expressing single or more methods and their parameters.
  + **A processing environment** takes the actors who have certain messages to react to and calls their message handling codes.
  + **An address** indicates an actor who will allocate incoming messages.

Because each actor may only process one message at a time, the invariant of an actor can be maintained without synchronization. This occurs automatically without the use of locks. One of the model's primary successes is the decoupling of the actor from the message-sending mechanism, which may be done asynchronously. An actor in a network can only communicate with other linked actors. Direct physical attachment, memory/disk access, network address, or E-mail address can all be used to connect the actors.

The addresses of the actors will vary depending on the sort of connections. In the event of a physical link, it may be a MAC address or just a memory address. Messages are provided using all reasonable attempts. It is the receiver's job to handle a message once it has been sent by an actor. This is the crucial component that allows a message to be decoupled from the sender actor. This method of communication is also known as "fire and forget."

The Actor Model is therefore an abstract construct based on some axioms that describe the model's behavior and structure. Several qualities and mechanisms are at work behind the scenes. Implementations of the model should follow those principles and may utilize other ideas on top of them to reveal the model's behavior in a practical fashion.

### 3.2.2. AKKA Stream:

#### Reative Stream

In an asynchronous system, dealing with data streams—particularly "live" data whose volume cannot be predicted—requires special care. The most obvious difficulty is that resource consumption must be managed so that a rapid data source does not overwhelm the stream destination. Asynchrony is required to allow for the concurrent usage of computer resources, whether on collaborating network hosts or numerous CPU cores inside a single system. [13]

The primary purpose of Reactive Streams is to manage the exchange of stream data over an asynchronous boundary (imagine transferring components on to another thread or thread-pool) while preventing the receiving side from being compelled to buffer arbitrary quantities of data. In other words, back pressure is an essential component of this paradigm in order to keep the queues that mediate between threads constrained. Because the benefits of asynchronous processing would be negated if back pressure communication was synchronous, care must be taken to require entirely non-blocking and asynchronous behavior of all components of a Reactive Streams implementation. [13]

The goal of this specification is to enable the design of multiple conforming implementations that, by adhering to the rules, will be able to interoperate easily, keeping the aforementioned advantages and features over the whole processing graph of a stream application. [13]

#### AKKA Stream

Actors in AKKA may also be thought of as dealing with streams: they send and receive a sequence of messages in order to convey knowledge (or data) from one location to another. In that process, it time-consuming and error-prone to implement all of the necessary measures in order to achieve stable streaming between actors, because in addition to sending and receiving, we must also avoid overflowing any buffers or mailboxes in the process. Another drawback is that Actor messages might be lost and must be resent in such cases. If this is not done, holes will form on the receiving side.

That is the reason for AKKA Stream API. The goal is to provide an easy and secure approach to create stream processing configurations that can then be executed fast and with little resource usage—no more OutOfMemoryErrors. In oder to achieve it, these streams must be able to control the amount of buffering they utilize, as well as slow down producers if consumers cannot keep up. This feature is known as back-pressure, and it is at the heart of the Reactive Streams effort, of which AKKA is a founding member. This implies that the difficult challenge of propagating and responding to back-pressure has already been included into the architecture of Akka Streams, giving users one less thing to worry about. [14]

The Akka Streams API is entirely independent of the Reactive Streams interfaces. While Akka Streams is concerned with the formulation of transformations on data streams, the goal of Reactive Streams is to create a standard method for moving data across an asynchronous boundary without loss, buffering, or resource depletion.

## 3.3. Introduction of Play framework:

Play is a very simple and straightforward Web Framework. It was designed to help you make changes more quickly and easily, with less stress on you.

Thanks of its smooth and user-friendly interface, not to mention several options for maximizing your computer's resources - CPU, RAM - it's simple to grow the software you're building. It is intended for developers that want to create contemporary web and mobile apps.

Play is developed on top of the AKKA toolkit, a popular open source toolkit that runs on top of the JVM. It has the same fundamental tools and functionality as the AKKA toolkit, but operates in a more user-friendly manner that allows you to simply create, design, and test the apps you're building. Many developers have remained loyal to it, citing how it has increased their productivity due to its simplicity and ease of use.

Advantages:

* Huge productivity improvement
* Workflow is easy
* Flexible Tool
* Everything works from the moment you start
* Effective resource management unit
* Easy to scale software

# 4. Developing of MQTT Broker:

## 4.1. Software design of programs:

The previous section discussed AKKA Toolkit and why AKKA was chosen to develop MQTT Broker for this project. In this section, we will clarify the ideas for implementing the MQTT Broker program.

### Actors Model of Program:

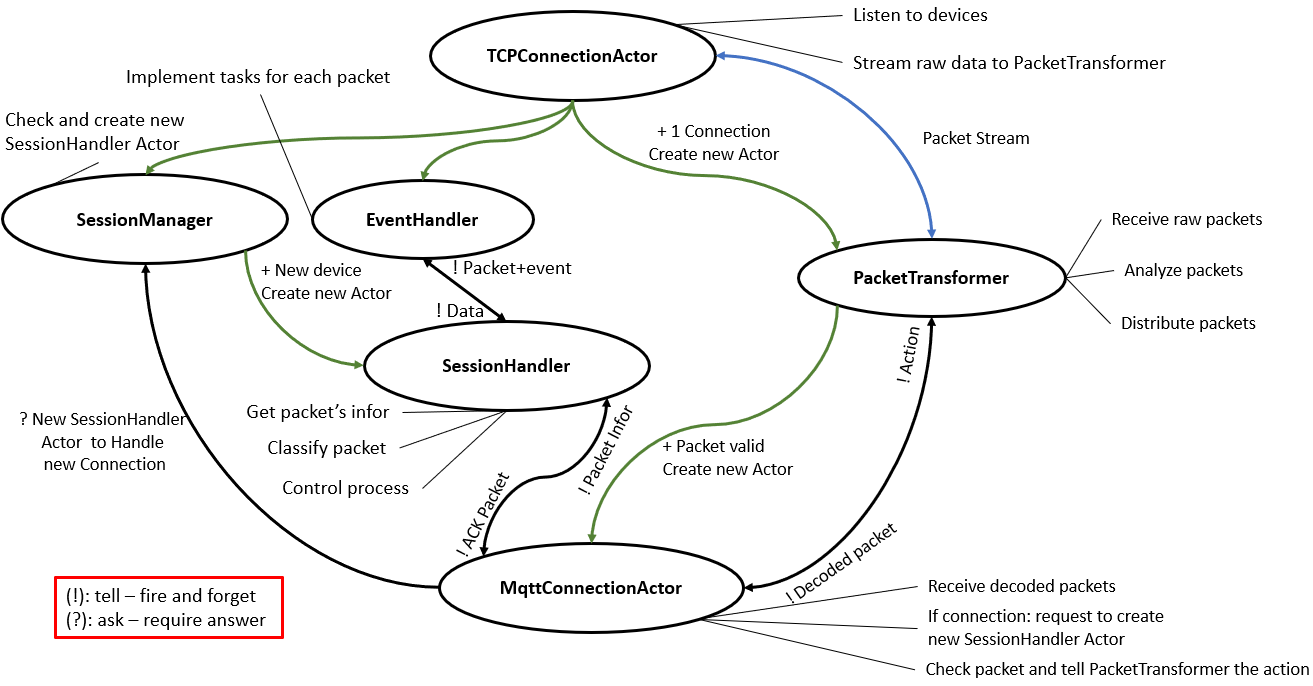


Figure 4. Actor Model for Core MQTT Broker

The figure above is the project's official model, displaying the functions as well as communication between actors via the Actor model - Hierarchy.

There is a root actor, which serves as the root for all actors in the system. Because of the centralized management but independent handling of connections – which representatives for a Client or Device, groups of Actors will be born to handle each connection. Actors will be managed using the Hierachical model, which aids in the accurate management of executions and errors, resulting in high system stability. For more detail, these are explanations:

* **TCPConnectionHandler**: It handles all connection requests and communicates with peripheral devices by opening a socket and listening; for each valid connection, it spawns ***PacketTransformer*** actor for that connection. AKKA Stream is created and used to transmit data in streams and queues between them rather than sending messages directly; this allows for more accurate and reliable packet delivery and management.
* **PacketTransformer**: Every time a connection is established, this actor is born to be in charge of delivering packets from the connection to other actors so that they can handle tasks or return ACK packets to peripheral devices. Its major function is to decode and transport packets in the system in the manner of a distributed station.
* **MqttConnectionActor**: This actor will be spawned at the same time as the actor ***PacketTransformer***; it will receive packets from the ***PacketTransformer*** and analyze them; if it is a valid Connection Packet, it will request (ask -?) to create an actor handles this connection; otherwise, it will forward the packet to actor ***SessionHandler*** for further processing. Cases that are invalid will be rejected.
* **SessionManager**: The ***MqttConnectionActor*** will then check to see if an actor SessionHandler is already handling this connection; if not, the ***SessionManager*** will create a new Actor ***SessionHandler*** to handle this connection.
* **SessionHandler**: This actor is in charge of analyzing and classifying packets sent over the connection, including checking the Header and Control Flags ,etc. After classifying the packet and gathering the required information, the actor will send (tell - !) the data to actor ***EventHandler***, which will handle the tasks required by each packet, to get feedback. Besides, it also generate ACK packet to send back to connection (or client) via ***MqttConnectionActor***.
* **EventHandler**: once the packets have been classified, they will be sent (tell - !) to this actor who will execute the packet's request and return the result to the ***SessionHandler***.

The table below summarizes the actor descriptions as well as their interactions with other actors.

|  |  |  |  |
| --- | --- | --- | --- |
| No. | Actor | Description | Related Actor |
| 1 | TCPConnectionHandler | This actor handles TCP connection and listen to device. Receive and transmit raw packet from devices. | → SessionManager → EventHandler ↔ PacketTranformer |
| 2 | PacketTransfomer | This actor handles packets which are sent via TCP and filter/decode/transfer them between other actors (inbound) or client (outbound) | ↔TCPConnectionHandler ↔MqttConnectionActor |
| 3 | SessionManager | Check and create new SessionHandler to control a new connection | ← MqttConnectionActor |
| 4 | MqttConnectionActor | This actor handles packets inbound:  + Receive decoded packet → analyze  + Decide action for each packet → PacketTransformer  + Separate & send packet infor → SessionHandler to process  + Receive feedback from SessionHandler → send to PacketTransfromer | ↔PacketTransformer  ↔ SessionHandler |
| 5 | SessionHandler | Control operation process of each connection:  + Get packet’s infor → classify packet  + After classifying → Tell EventHandler to implement the task  + Get the data after Event handled  + Send feedback MqttConnectionActor | ↔ EventHandler ↔ MqttConnectionActor |
| 6 | EventHandler | Implement the packet’s requirement (task) | ↔ SessionHandler |

Table 5. Description of Actors in MQTT Broker Program

## 4.2. Implemeting by Coding:

In the preceding section, we used the Actor Model to model the program for MQTT Broker. Following that, we will apply this model to a specific program.

However, quoting and explaining thousands of lines of code is time-consuming and unnecessary. As a result, to ensure the report's conciseness, the author will only point out and analyze relatively complex programming techniques. In addition, the program's explanations is commented in the source code comments.

*To view full source code, please access the link* [*github*](https://github.com/nicolas-le-petit/MQTT_Broker_AkkaModel/tree/Developing) *repository of project* [15]*.*

#### Finite State Machine (FMS):

FMS is the programming method used throughout (Finite State Machine). This is a tried-and-true method with high reliability.

A FSM can be described as a set of relations of the form [16]

State(S) × Event(E) → Actions (A), State(S’)

These relations are interpreted as meaning [16]

If we are in state S and the event E occurs, we should perform the actions A and make a transition to the state S’.

Thanks to AKKA Toolkit, implemeting FSM is more concise and reliable.

The FSM is applied to control the process in each actor. By forecasting and planning states, programming becomes more accurate and trustworthy.

The table below shows the FMS for **MQTTConnectionActor**:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| No. | State | Event | Action | Next State |
| 1 | Wait (Idle) | Receive:  Connect Packet | Ask for SessionManager | Active (Connected) |
| 2 | Wait (Idle) | Receive:  Unvalid packet | Send Closing (connection) | Wait (Idle) |
| 3 | Active (Connected) | Receive:  Outbound packet | Send back to Connection | Active (Connected) |
| 4 | Active (Connected) | Receive:  Inbound packet | Send to Session | Active (Connected) |
| 5 | Active (Connected) | Timeout | Send Closing (connection) | Active (Connected) |
| 6 | Active (Connected) | Bad packet | Send Closing (connection) | Active (Connected) |

Table 6. FMS for MQTT Connection Actor

The FMS for **SessionHandler** is revealed:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| No. | State | Event | Action | Next State |
| 1 | WaitingForNewSession | Receive:  Connect Packet | Take the infor Send CONNACK to PacketTransformer | SessionConnected |
| 2 | WaitingForNewSession | Receive:  bad packet | Send error → Closing | WaitingForNewSession |
| 3 | WaitingForNewSession | Receive: PublishPayload | Check qos > 0 → EventHandler | SessionConnected |
| 4 | SessionConnected | Timeout | Close Connection | SessionConnected |
| 5 | SessionConnected | Receive: Sub | Packet → EventHandler SubAck → MqttConnectionActor | SessionConnected |
| 6 | SessionConnected | Receive: Publish | qos = 1 →  EventHandler + PubAck qos = 2 →  Pubrec + EventHandler | SessionConnected |
| 7 | SessionConnected | Receive: PubAck | stay | SessionConnected |
| 8 | SessionConnected | Receive: PubRec | → send PubRel | SessionConnected |
| 9 | SessionConnected | Receive: PubRel | → send PubComp | SessionConnected |
| 10 | SessionConnected | Receive: PubComp | stay | SessionConnected |
| 11 | SessionConnected | Receive: Sub | Packet → EventHandler | SessionConnected |
| 12 | SessionConnected | Receive: Unsub | Packet → EventHandler | SessionConnected |
| 13 | SessionConnected | Receive: Ping | Stay | SessionConnected |

Table 7. FMS for Session Handler Actor

## 4.3. Testing and Result:

The intriguing aspect of AKKA Toolkit is that it provides both testing functionality for our applications, allowing us to test functions independently while also testing a group of functions or even the entire system with various scenarios.

The AKKA test tookit is used to check every single test case in order to guarantee that every single function works flawlessly. As a result, each test case passing indicates that the function works properly.

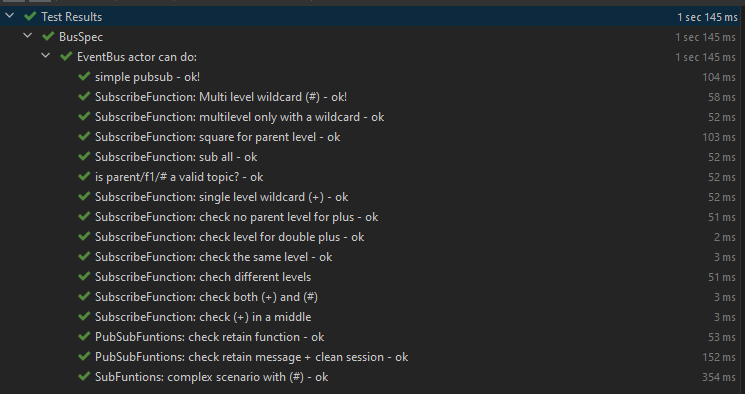
First of all, the test cases should be predicted and defined. Then, the code blocks to run thoes scenarios have to be writen to illustrate the situations. For example:

class BusSpec extends TestKit(ActorSystem("BusSpec")) with ImplicitSender  
 with AnyWordSpecLike  
 with Matchers  
 with BeforeAndAfterAll {  
  
 "EventBus actor can do:" should {  
  
 "simple pubsub - ok!" in {  
  
 val bus = system.actorOf(Props[EventBusActor])  
  
 bus ! BusSubscribe("greetings", self)  
 bus ! BusPublish("time", "123")  
 bus ! BusPublish("greetings", "hello")  
  
 expectMsg(PublishPayload("hello", false))  
  
 expectNoMessage(UserTimer.wait\_time)  
 }

In here, the test simulates a simple task for EventHandler actor. As mentioned, this actor need to classify the topic and do the task as requests. In this case, the requests are to subscribe a topic name “greeting” then publish two topics name “time” and “greeting” with the value “123” and “hello” respectively. If the task has been done correctly, the expectMsg()will receive the payload “hello” and the comment “simple pubsub – ok!” will be marked by green tick.

The test also can combine burst of code blocks, which represent for many test cases. If all the test passed, that means the actor works well.

The test results are showed below for **EventHandler** actor:



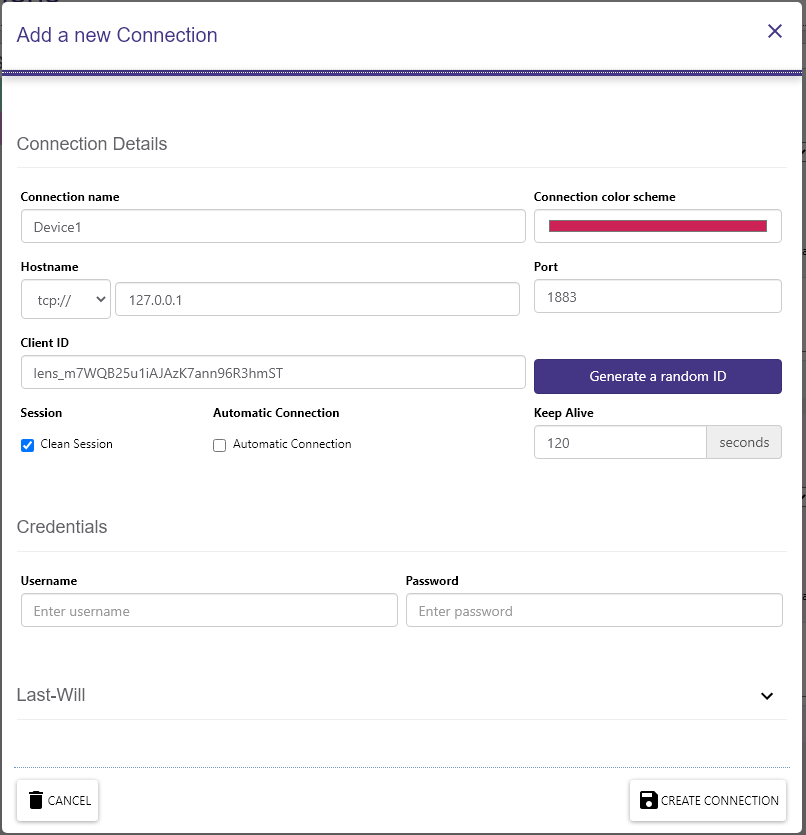
This way to save the effort for debuging, by testing single case and intergated case, it can easily dectect the problems, where and how to fix them.

However, we need to analyze the overall performance of the system, which should behave like a genuine MQTT Broker, thus an external tool will be utilized in this situation. This tool emulates MQTT clients that attempt to connect to and publish/subscribe to our Broker. MQTTlens, which is available in the [Chrome Store](https://chrome.google.com/webstore/detail/mqttlens/hemojaaeigabkbcookmlgmdigohjobjm), is utilized.

We will go through and envaluate all the functions. So here we go.

#### Connection Function

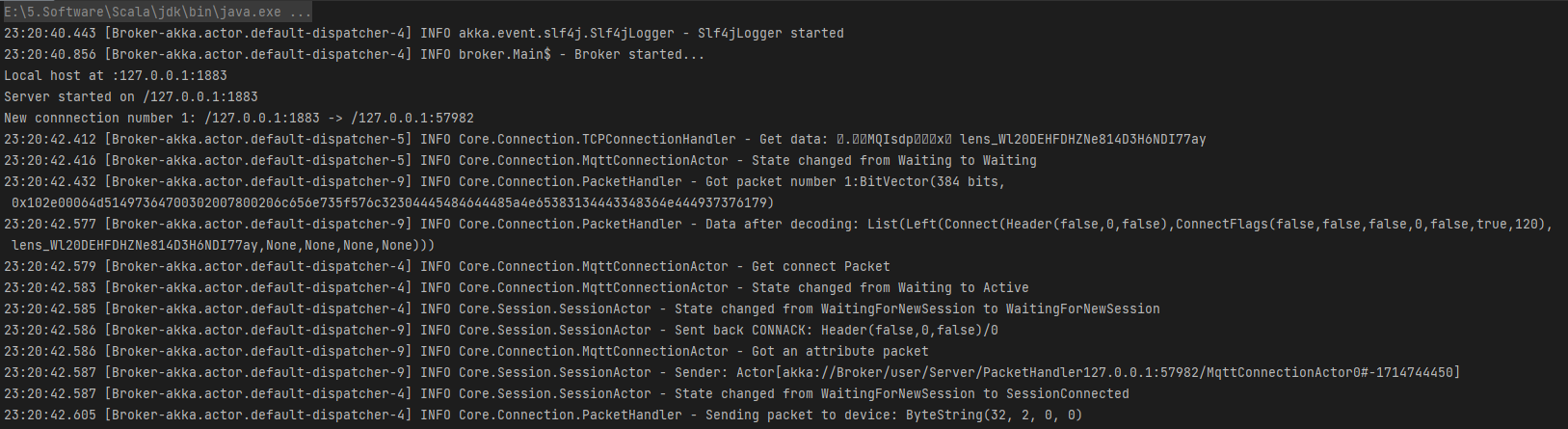
First of all, we need to create a new MQTT client (or a new device/connection) named “Device1”. The image below shows how the information has to be set, including: ***Hostname***, ***Port***, ***Keep Alive*** (Timeout of connection), and ***Clean Session*** with MQTTlens.



After that, we create and connect Device1 to our Broker by pressing CREATE CONNECTION. On the other hand, from Broker side, the Connection Request has been received and proceeded. Finally, in the end of the logger, we see the line:

23:20:42.605 [Broker-akka.actor.default-dispatcher-4] INFO Core.Connection.PacketHandler - Sending packet to device: ByteString(32, 2, 0, 0)

The packet **(32, 2, 0, 0)** is definitely the CONNACK packet, that means the MQTT connection in between them has been established.



Now, by repeating those previous steps, we will create 03 MQTT connections named: Device1, Device2 and Device3.

#### Publish/Subscribe Function and Retain Flag

Theory review: If a client subscribes to a topic, it will be updated from the Broker whenever that topic has been published with new packets. Furthermore, the retain flag is quite crucial. If this flag is set to 1 when publishing the packet, the Broker is required to preserve the packet in case a new client subscribes to the same topic, that client will get the latest packet with retain flag = 1. If the retain flag is set to 1 and the QoS is set to 0, it will remove all previously broadcast packets.

In this evaluation, Device1 serves as a Publisher, while Devices 2 and 3 serve as Subscribers. Then, as a scenario, these devices publish and subscribe in order to test the Broker's Functions. The following table details the actions of various devices:

|  |  |  |  |
| --- | --- | --- | --- |
| Time | Device1 (Publisher) | Device2 (Subscriber) | Device3 (Subscriber) |
| 11:39:01 | Topic: topic1  Message send: “message1”  Retain: False |  |  |
| 11:39:10 |  | Topic: topic1  Message receive: None |  |
| 11:39:17 | Topic: topic1  Message send: “message1”  Retain: False | Topic: topic1  Message receive: “message1” |  |
| 11:39:32 | Topic: topic1  Message send: “message2”  Retain: True | Topic: topic1  Message receive: “message2” |  |
| 11:39:45 | Topic: topic1  Message send: “message3”  Retain: False | Topic: topic1  Message receive: “message3” |  |
| 11:39:51 |  |  | Topic: topic1  Message receive: “message2” |

Now we analyze the timeline:

11:39:01: Device1 published topic “topic1” with message “message1”, retain flag = false.

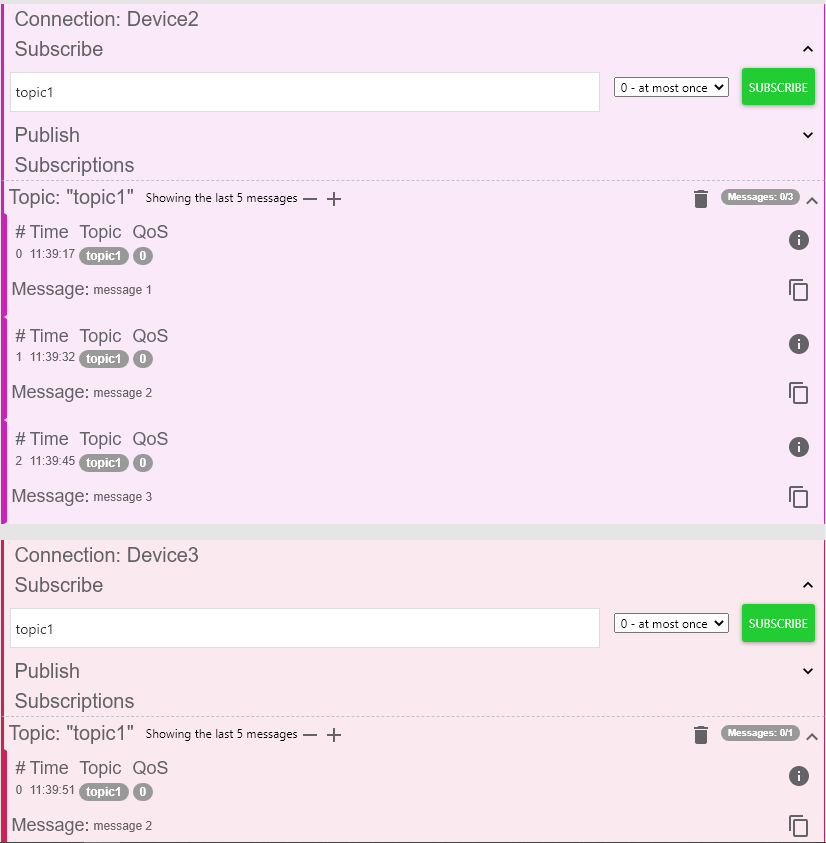
11:39:10: Device2 subscribed topic “topic1”, but received nothing, because the action subscribing happened after the action publishing from Device 1 and retain flag = false.

11:39:17: Device1 published topic “topic1” with message “message1”, retain flag = false. Meanwhile, Device2 received message “message1”, because Device2 already subscribed to that topic, ***that means the Publish and Subscribe functions work well in basic concept***.

11:39:32: Device1 published topic “topic1” with message “message2”, retain flag = true. At the same time, Device2 received message “message2”, again, ***the Publish and Subscribe functions work well in basic concept***. Note that retain flag now is true.

11:39:45: Device1 published topic “topic1” with message “message3”, retain flag = false. Since, Device2 received message “message3”, because Device2 already subscribed to that topic.

11:39:51: This time, Device3 joined, also subscribed “topic1” and it received message “message2”. Back to 11:39:10, Device2 subscribed “topic1” after Device1’s publishing but could not receive any message, but now Device3 could. The point here is, the retain flag was set to true at 11:39:32, so then Broker had to save that value (“message2”) and give it to any devices subscribe “topic2” since then. ***In short***, ***that means the Publish and Subscribe functions work well with retain flag***.



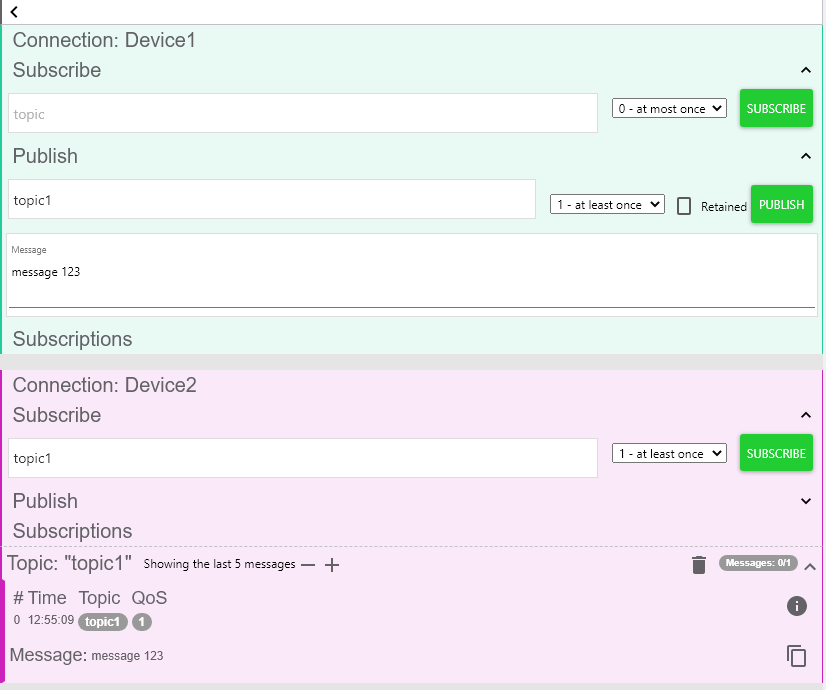
#### Qualities of service (QoS)

The Quality of Service (QoS) level is an agreement between a message's sender and recipient that establishes the assurance of delivery for a given message. MQTT has 03 degrees of QoS:

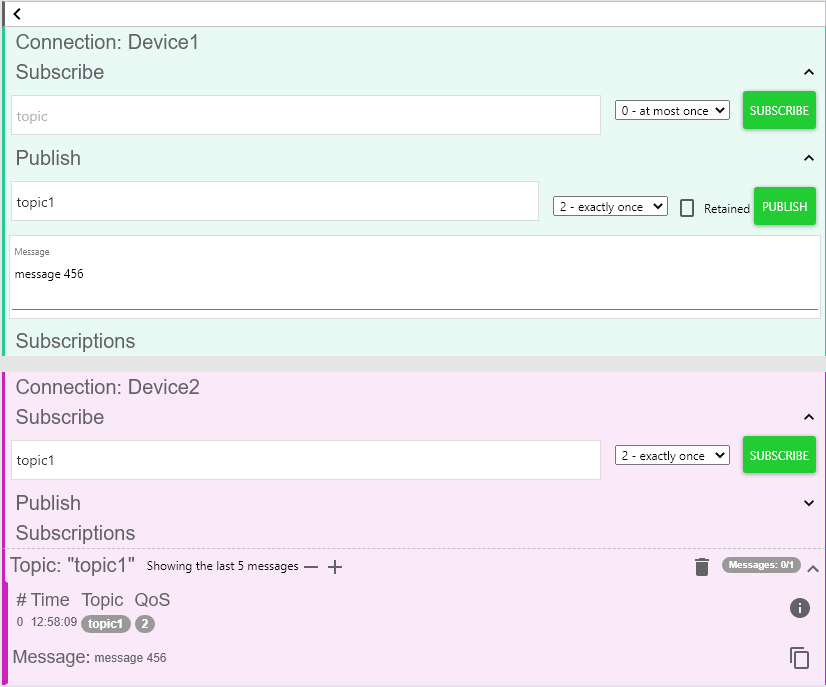
* At most once (0): QoS level 0 is sometimes known as "fire and forget" since it offers the same guarantees as the underlying TCP protocol.
* At least once (1): QoS level 1 ensures that a message is delivered to the receiver at least once. The message is stored by the sender until it receives a PUBACK packet from the receiver acknowledging receipt of the message. A communication has the potential to be transmitted or delivered several times.
* Exactly once (2): QoS 2 is the most secure and sluggish quality of service level. At least two request/response flows (a four-part handshake) between the sender and the recipient offer the assurance.

In this step, QoS complicant is verified by doing the simple test. Thanks to MQTTlens tool, the connection is supported to change the QoS.

QoS = 1:



QoS = 2:



As we can see, all the functions have been done correctly, that means the MQTT Broker Program work well in every single cases.

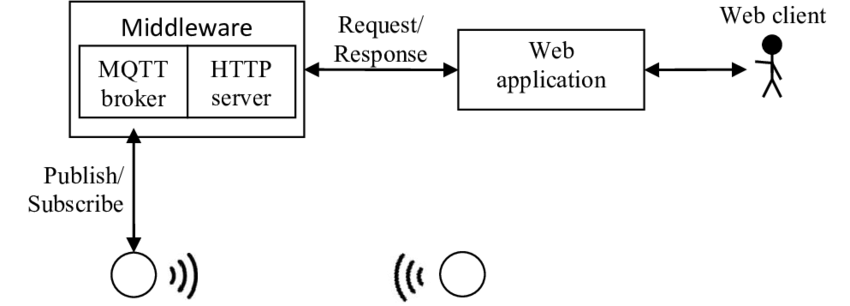
In another word, the task to implement MQTT Broker by using Scala and AKKA Model is done.

# 5. Developing of User Functions:

## 5.1. The approach:

We basically solved nearly half of our finance demands after building the MQTT Broker application described above. Now, we have a MQTT Broker with full capability and power for the IoT system after deploying the MQTT Broker program on a server. However, it is only the inner core; what must be constructed in this thesis is a Dashboard, which is essentially a website that can directly interact and display with the program fragment.

To do this, we will try to build a web application like the architecture below:



**Device n**

**Device 1**

Figure 5. Illustrating of Project Achitecture

The figure above depicts a view of the model of the user interface that will be built, which contains two main clients sides: one side includes devices and one side has user and web application. In the center is MQTT Broker.

The fundamental MQTT concept, the side from devices to Broker, is relatively recognizable. Devices in the IoT system will transmit MQTT packets (connect/publish/subscribe...) to the MQTT Broker's host address and receive corresponding response. On the other side, users want to monitor or send information (setup, control) to these devices through a *web client* application.

This web client points directly to the address of the server running the MQTT Broker program and will communicate with this Server using the HTTP protocol. The problem is, a web client can only communicate using HTTP request/response, while MQTT is a completely different protocol (although both are built on top of TCP/IP). So then, on the MQTT Broker side, there is a program to decode the HTTP request into the MQTT packet format, then the converted packet will be sent to the MQTT Broker for execution. The results returned in the form of MQTT packets will be converted back to HTTP and become the HTTP response of the web client's request.

By using the above model, users have in hand a Dashboard interface to directly interact with MQTT Broker, through which can create new clients, send information to clients and view desired information from them.

## 5.2. Software design of programs:

Regarding previous part, the main idea for approaching the challenge of constructing the Dashboard interface is to build a web client that interacts with users, then convert those interactions into HTTP requests to send to the Server. The server's answer (HTTP response) will be processed and shown to the user.

In this part, we use Scala and Play framework to develop the website.

### 5.2.1. Conceptions:

#### Play Framework:

Play is a high-productivity Java and Scala web application framework that unifies components and APIs for contemporary online application development. Play was created by web developers for the creation of online applications. [17]

Play is a full-stack framework, base on Model-View-Controller (MVC) architecture, it provides everything you need to develop Web Applications and REST services, including an integrated HTTP server, form handling, CSRF protection, a robust routing system, support, and more.

Under the hood, Play's lightweight, stateless, web-friendly design employs Akka and Akka Streams to guarantee predictable and low resource use (CPU, memory, threads). Applications scale organically, both horizontally and vertically, thanks to its reactive approach. [17]

#### MVC Achitecture:

Model-view-controller (MVC) is a software architecture paradigm often used for building user interfaces that divides the underlying program logic into three interrelated pieces. This is done to separate internal representations of information from how it is presented to and accepted by the user. [18]

* **Model:** The central component of the pattern. It is the application's dynamic data structure, independent of the user interface. [18] It directly manages the data, logic and rules of the application.
* **View:** Any information representation, such as a chart, diagram, or table. Multiple perspectives of the same information, such as a bar chart for management and a tabular view for accountants, are feasible.
* **Controller:** Accepts input and converts it to commands for the model or view. [19]

### 5.2.2. Achitecture of a general Play project:

Base on MVC achitecture, a Play project structure looks like this:

app → Application sources

└ assets → Compiled asset sources

└ stylesheets → Typically LESS CSS sources

└ javascripts → Typically CoffeeScript sources

└ controllers → Application controllers

└ models → Application business layer

└ views → Templates

build.sbt → Application build script

conf → Configurations files and other non-compiled resources (on classpath)

└ application.conf → Main configuration file

└ routes → Routes definition

dist → Arbitrary files to be included in your projects distribution

public → Public assets

└ stylesheets → CSS files

└ javascripts → Javascript files

└ images → Image files

project → sbt configuration files

└ build.properties → Marker for sbt project

└ plugins.sbt → sbt plugins including the declaration for Play itself

lib → Unmanaged libraries dependencies

logs → Logs folder

└ application.log → Default log file

target → Generated stuff

└ resolution-cache → Info about dependencies

└ scala-2.11

└ api → Generated API docs

└ classes → Compiled class files

└ routes → Sources generated from routes

└ twirl → Sources generated from templates

└ universal → Application packaging

└ web → Compiled web assets

test → source folder for unit or functional tests

#### The app/directory

The app directory includes all executable artifacts, including Java and Scala source code, templates, and the sources of built assets.

In the *app* directory, three packages which represent for each component of the MVC architectural pattern:

* *app/controllers*
* *app/models*
* *app/views*

Users can add-in their own packages, for instance, an *app/utils* package.

#### The public/directory

The static assets saved in the *public* directory are provided directly by the Web server.

There are three sub-directories for images, CSS stylesheets and JavaScript files in this directory. To keep all Play applications consistent, developers should organize static assets as default like this.

#### The conf/directory

The configuration files for the program are stored in the *conf* directory. The major configuration files are::

* *application.conf*, the main configuration file for the application, which contains configuration parameters
* *routes*, the routes definition file.

It's a good idea to add extra options to the *application.conf* file if you need to add configuration settings particular to your application.

Additionally, if a library needs a specific configuration file, puy it under the *conf* directory.

#### The lib/directory

The *lib* directory is optional, and it contains unmanaged library dependencies, such as all JAR files that you want to handle manually outside of the build system. Simply place any JAR files here and they will be added to the classpath of your application.

#### The build.sbt file

The main build declarations of the project are generally found in *build.sbt*, which places at the root of the project.

#### The project/ directory

The *project* directory contains the sbt build definitions:

* *plugins.sbt* defines sbt plugins used by this project.
* *build.properties* contains the sbt version to use to build the app.

#### The target/directory

The *target* directory contains everything generated by the build system. The list below show which are generated:

* *classes/* includes all compiled classes (from sources code).
* *classes\_managed/* contains only the classes that are managed by the framework (such as the classes generated by the router or the template system). It can be useful to add this class folder as an external class folder in your IDE project.
* *resource\_managed/* contains generated resources, typically compiled assets such as LESS CSS and CoffeeScript compilation results.
* *src\_managed/* contains generated sources, such as the Scala sources generated by the template system.
* *web/* contains assets processed by sbt-web such as those from the *app/assets* and *public* folders.

#### Typical .gitignore file

Generated folders should be ignored by your version control system.

## 5.3. Implementation by Coding:

### 5.3.1. MQTT Broker Add-in:

First of all, we must include a MQTT-to-HTTP converter in the MQTT Broker program. This is accomplished by include an actor HttpHandler in the MQTT Broker program; this actor will accept HTTP requests, validate them, and convert them back to MQTT packets, which will then be processed as other MQTT packets. After processing is finished, the packet will be converted back to the form of the HTTP response provided to the web client.

Then, we can update the actor model in MQTT Broker program as below:

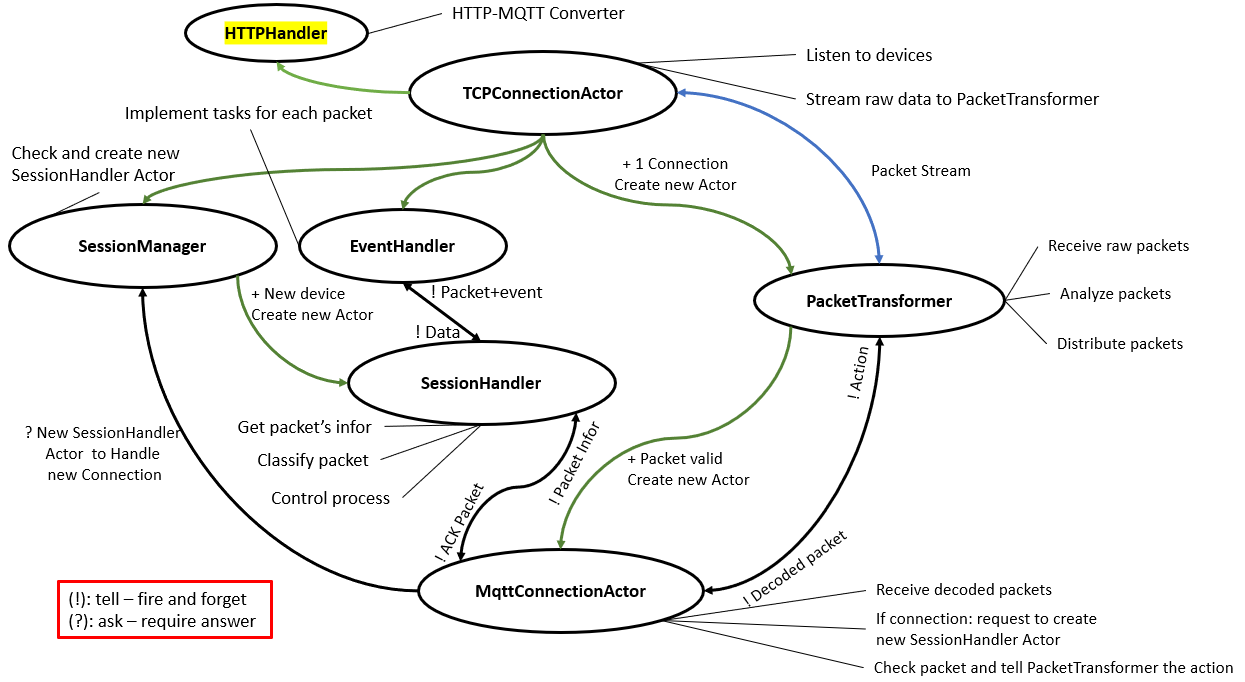


Figure 6. MQTT Broker AKKA Model updated

Hence, we achive the MiddleWare in the Fig in part 5.1.

### 5.3.2. MQTT Dashboard (Web Client):

#### Objects

This step, a web client will be developed to:

* Send/receive MQTT packets (wrap on HTTP request/response) with MQTT Broker
* Visualize data on dashboard

The user interface will be explained clearer in the next part, this part we just try to implement the logic inside of the web application, or in another word, the backend of the website.

In part 5.2, structure of a Play project was showed and explained, now we use that template to develop our website. That means the three main packages and other directories already have been created and we just base on that to add some user functions to help implement the objects above.

Firstly, to implement MQTT protocol for the web application, we use a library – which is provided by Paho.

## 5.4. Testing and Result:

# 6. Developing of User Interface:

### 5.2.3. Extra libraries:

AdminLTE 3 will be selected to develop the front end (the views) in the project.

Vài thứ về AdminLTE 3

## 6.1. Block diagram:

## 6.2. Software design of programs:

## 6.3. Explanation of Coding:

## 6.4. Testing and Result:

# 7. Intergration of MQTT Dashboard:

## 7.1. Testing and Result:

## 7.2. Conclusion:

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|  |  |
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