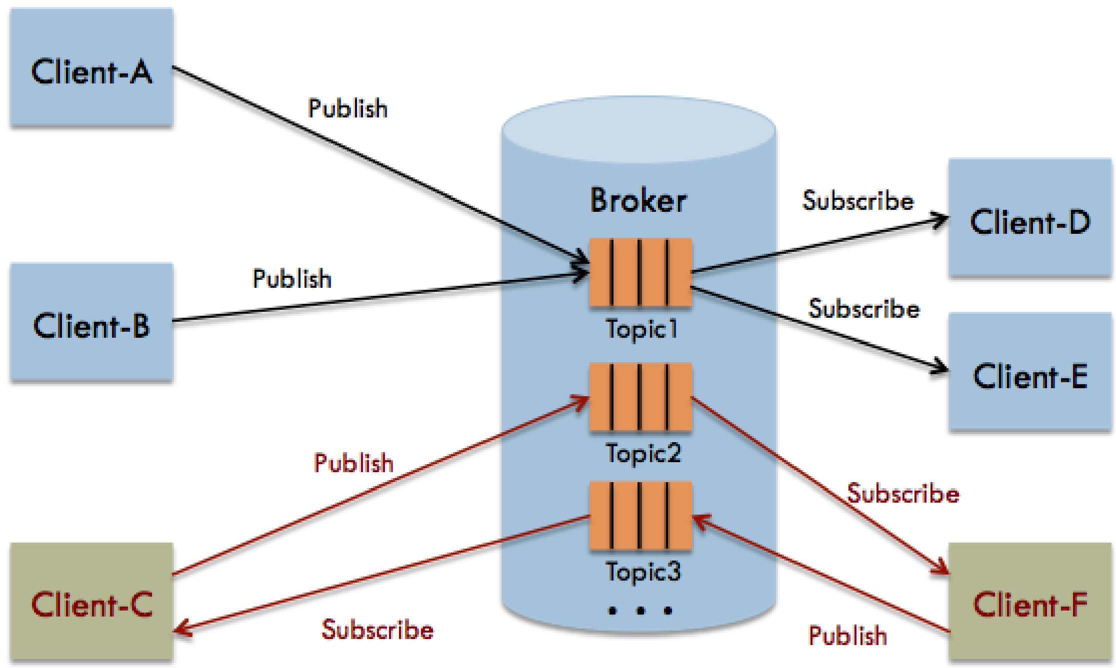
6. Messaging with MQTT

MQTT (MQ Telemetry Transport) is a lightweight publish/subscribe messaging protocol frequently used in IoT applications. It is a very thin layer over TCP/IP, and has many implementations. MQTT is even an OASIS standard [1]. The Micropython software for ESP8266 includes a client implementation in the `umqtt` module [2].

MQTT Basics

An MQTT-based application will include two or more *clients*, which are applications exchanging messages, and a *broker*, which is a server that accepts incoming messages and routes them to the appropriate destination client. As with most *publish-subscribe* systems, message sends involve *publishing* on a specified *topic*. The broker then forwards the message to all *subscribers* of that topic. These primitives can be used to build different interaction patterns. The picture below shows an example:



Here, we see a broker with three topics: *topic1*, *topic2*, and *topic3*, which interact with clients using two different interaction patterns. *Client-A* and *Client-B* are publishing their messages to *topic1*. When a message is received at the broker, it is passed on to any current subscribers to the topic. In this case, both *Client-D* and *Client-E* will receive each message. We will call this a *push* pattern, as it is one directional, and the interaction is initiated by the output_thing. In an IoT context, the output_thing is usually a sensor node and the subscriber(s) are servers that process and store the sensor data.

Client-C and *Client-F* are interacting in a request-response or *pull* pattern. *Client-C* sends request messages to *topic2*. These are received by *Client-F*, which sends responses on *topic3*. In an IoT context, this pattern may be useful when the server wishes to poll the sensor nodes for data or for situations where the sensor nodes need to query a server for configuration data.

In our application, we will be using the simpler push pattern.

Quality of Service

Networked systems are never 100% reliable – systems may crash, connections can be lost, or parts of an application taken down for maintenance. This is even more true for IoT systems, where sensors may be in harsh physical environments. Middleware like MQTT can improve reliability by storing messages and implementing handshake protocols. However, this has a cost in terms of resources and system complexity. MQTT gives you flexibility by specifying a *Quality of Service* (QoS) with each message.

`qos` is a parameter available on each publish call. It is one of three levels:

- `0` – at most once. This means that the system will make a best effort to deliver the message, but will not store it and will drop the message in the event of an error. This is typically the behavior you would use in a sensor application: if a message is lost, the next sensor sample will be coming soon, anyway.
- `1` – at least once. This means that the system will use storage and handshaking to ensure that the message is delivered. However, in doing so it may send the same message multiple times, resulting in duplicates.
- `2` – exactly one. This means that each message will be delivered, and the handshaking protocol will ensure that duplicates are not passed to clients. This is the behavior you want if you are implementing a banking system (but not so much in the IoT world).

For our application, we will use QoS level `0`.

Security

MQTT provides security, but it is not enabled by default. For our experiments, we will rely on the encrypted WiFi connection to provide a basic level of security. MQTT has the option for Transport Layer Security (TLS) encryption, just as used with HTTPS. We recommend using that for any system you put into production.

MQTT also provides username/password authentication. Note that the password is transmitted in clear text. Thus, be sure to use TLS encryption if you are using authentication.

Host-side Setup

Now, let us install an MQTT broker on our host system. We will use Mosquitto, an open source broker from the Eclipse Foundation. It is implemented in C, and can run well on fairly constrained systems (e.g. a Raspberry Pi). The documentation and other other resources may be found at http://mosquitto.org. The downloads are hosted at the main Eclipse Foundation Website, and may be found at https://www.eclipse.org/mosquitto/download/. That page has instructions for installing on most platforms.

You will want to install both the broker and the client utilities (in particular, `mosquitto_sub`). On Debian-based Linux distributions (Debian, Ubuntu, Raspbian, etc.) these are in two packages, so you will install them as follows:

```
sudo apt-get install mosquitto mosquitto-clients
```

Once installed, make sure that your Mosquitto broker is running and listening to port 1883 (the default). A simple test can be done with the `mosquitto_pub` and `mosquitto_sub` clients. Open two terminal windows. In one, type:

```
mosquitto_sub -t sensor-data
```

It should hang and not print anything immediately. The process is subscribing to the topic `sensor-data` and will print to standard output any messages that it receives. In the second window, run the following:

```
mosquitto_pub -t sensor-data -m "hi, there"
```

You should now see the message printed in the first (subscriber) window. This means that the broker is working. You can now kill the subscriber with a Control-C.

Finally, if your system has a firewall, make sure that port 1883 is open. Otherwise, connections from the ESP8266 system will be blocked.

ESP8266 Setup

MicroPython already has an MQTT client in its standard library, so we do not need to do much on the ESP8266-side. We will just copy over some convenience modules provided by ThingFlow.

On your host machine, go to the `micropython` subdirectory of your ThingFlow repository. Run `mpfshell` and copy the scripts for WiFi configuration and MQTT as follows (substituting your tty device name for `TTYDEVICE`):

```
open TTYDEVICE
put wifi.py
put mqtt_writer.py
```

Interactive Testing

Now, go to the MicroPython REPL (via either the `repl` command of `mpfshell` or through `screen`). We will first run our import statements:

```
>>> from thingflow import *
>>> from tsl2591 import Tsl2591
>>> from wifi import wifi_connect
>>> from mqtt_writer import MQTTWriter
```

Next, we configure the WiFi connection and then connect to the MQTT broker. Here is the code in the REPL (replace `my_wifi_sid`, `my_wifi_password`, and `mqtt_broker_ip` with values for your environment):

```
>>> SID='my_wifi_sid'
>>> PASSWORD='my_wifi_password'
>>> MQTT_HOST='mqtt_broker_ip'
>>> wifi_connect(SID, PASSWORD)
network config: ( ... )
>>> m = MQTTWriter('esp8266', MQTT_HOST, 1883, 'sensor-data')
Connecting to xxx.xxx.xxx.xxx:1883
Connection successful
```

We can now create a sensor and connect two downstream components: `Output`, which prints events to the standard output, and `m`, our MQTTWriter instance. Here is the REPL session:

```
>>> sensor = SensorAsOutputThing(Tsl2591('lux-1'))
>>> sensor.connect(Output())
<closure>
>>> sensor.connect(m)
<closure>
```

Finally, we instantiate an ThingFlow scheduler and schedule our sensor to be sampled once every two seconds:

```
>>> sched = Scheduler()
>>> sched.schedule_periodic(sensor, 2.0)
<closure>
>>> sched.run_forever()
('lux-1', 611, 284.1312)
('lux-1', 613, 284.1312)
('lux-1', 615, 284.1312)
...
```

To verify that these messages are being sent to our broker, we can use the utility `mosquito_sub` on the host machine. It takes one command line argument, the topic name (in our case `sensor-data`). We should see something like the following when we run it:

```
$ mosquitto_sub -t sensor-data
["lux-1", 624, 284.1312]
["lux-1", 626, 288.2113]
["lux-1", 627, 77.0304]
["lux-1", 629, 35.90401]
...
```

Great, now you have gotten live sensor data off your ESP8266 board!

Putting it all Together

Now, we will set up the ESP8266 to run our sample/send loop upon startup. We will also run a script on the host to subscribe to our topic and write the events to a CSV (spreadsheet) file. The source code for this section may be found on GitHub in the repository for this tutorial. Specifically, look in the `example_code` folder (https://github.com/jfischer/micropython-iot-hackathon/tree/master/example_code). The program `client.py` will run on the ESP8266 and the program `server.py` will run on our host.

client.py

First, open an editor and create a file `config.py` that contains configuration variables needed for your network and system. It should look something like this:

```
SENSOR_ID='lux-1'
WIFI_ESSID='my_wifi_sid'
WIFI_PASSWORD='my_wifi_password'
MQTT_HOST='mqtt_broker_ip'
MQTT_TOPIC='sensor-data'
SLEEP_TIME=5.0
```

You will definitely need to change the values for `WIFI_ESSID`, `WIFI_PASSWORD`, and `MQTT_HOST`. The others can be left as-is.

Now, use `mpfshell` to copy `config.py` and `client.py` to your ESP8266 (substituting for TTYDEVICE or use Control-] to exit the repl if `mpfshell` is already running):

```
open TTYDEVICE
put config.py
put client.py
```

Next, open a MicroPython REPL session. To start our main loop, we just need to import the `client` module. Here is what the REPL session looks like:

```
>>> import client
Disabled access point, network status is -1
network config: (...)
Connecting to xxx.xxx.xxx.xxx:1883
Connection successful
Running main loop with sample every 5.0 seconds...
```

The REPL should hang at this point because the ESP8266 is in its main loop. Messages should be sent to the MQTT broker once every 5 seconds.

Now that we have verified the `client.py` script, we will configure it to start upon boot. While still in your REPL session, enter Control-C to break out of the loop. You should see a `KeyboardInterrupt` exception. We will now rename `client.py` to `main.py` using `os.rename()`. Upon completion of its boot procedure, MicroPython will always run the script `main.py` if it is present. Here is the REPL:

```
>>> import os
>>> os.rename('client.py', 'main.py')
>>> os.listdir()
['boot.py', 'tsl2591.py', 'thingflow.py', 'wifi.py', 'mqtt_writer2.py', 'mqtt_writer.py
>>>
```

Finally, press the reset button of your ESP8266 board. It will reboot. You should see some garbage data followed by the same sequence of messages that you saw when you imported `client` from the REPL.

Now, let us turn our attention to the host side of things.

Verifying messages at the server

First, we will verify that we are getting the messages on the host. From your command line run:

```
mosquitto_sub -t sensor-data
```

You should see the sensor events printed once every five seconds.

server.py

We will next use the `server.py` script to read these events and write to a CSV file. It is an ThingFlow script that subscribes to messages on a specified topic, parses the messages, overwrites the timestamps with the server timestamp [3], and writes the events to a CSV file. Here is a graphical view of the dataflow:

Here is what the core part of the script looks like:

```
mqtt.select(lambda m:(m.payload).decode('utf-8'))\
    .from_json(constructor=SensorEvent)\
    .select(lambda evt: SensorEvent(sensor_id=evt.sensor_id,
                                    ts=time.time(),
                                    val=evt.val))\
    .csv_writer(filename)
```

Since it is running on a PC or server, this script uses the full CPython version of ThingFlow. You will need to have an installation of Python 3. You will also need the `paho-mqtt` package (installable via pip) and the `thingflow` package in your Python environment. Installing ThingFlow can be done in one of three ways:

1. Install ThingFlow via pip: `pip install thingflow`
2. Install from your local repository by going to the `thingflow-python` directory and running `python setup.py install`.
3. Just set your PYTHONPATH environment variable to the full absolute path of the repository directory `thingflow-python`.

Once this is done, you should be able to run the following:

```
$ python3
>> import thingflow.base
```

If this succeeds, you have ThingFlow properly set up. We are now ready to run the `server.py` script. It takes two command line arguments: the topic to which it will subscribe and the name of the out CSV file. We'll run it as follows:

```
python3 server.py sensor-data test.csv
```

It should print a message about connecting successfully and then, once every five seconds, print the latest sensor event like this:

```
SensorEvent(sensor_id='lux-1', ts=1484535480.613611, val=371.6063)
SensorEvent(sensor_id='lux-1', ts=1484535485.6078472, val=371.6063)
SensorEvent(sensor_id='lux-1', ts=1484535490.4335377, val=371.6063)
SensorEvent(sensor_id='lux-1', ts=1484535495.4575906, val=371.6063)
...
```

If you look at the file test.csv, you should see four data values for each row:

1. The timestamp in Unix format (seconds since 1970)
2. The timestamp in human readable format
3. The sensor id.
4. The sensor value.

Congratulations! You have gotten the entire system working!

If you are interested, you can look at some more projects to do with your board.

[1] http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/mqtt-v3.1.1.html

[2] The `umqtt` module is not in the official Micropython documentation, but module is definitely present in the firmware image. The API is simple enough that you can understand it by a quick read of the source code: https://github.com/micropython/micropython-lib/tree/master/umqtt.simple and https://github.com/micropython/micropython-lib/tree/master/umqtt.robust.

[3] The ESP8266 does not have a realtime clock and the timestamps we get from it are only seconds since startup time. To work around this, we overwrite the timestamps on the server. This introduces some inaccuracy, but it should not be significant at our sample rates.

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