Assignment 3

COMP6331 – COMPUTER NETWORKS

SYED ALI HUSSAIN

U6028474

Question 1

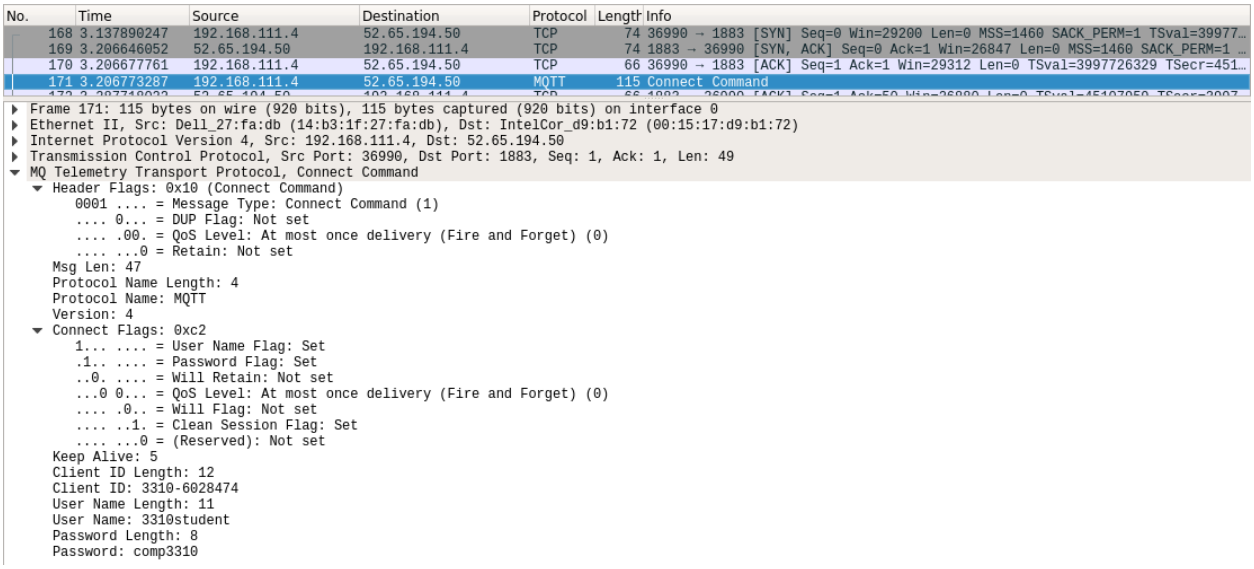
The three channels were subscribed using matching QoS and the data capture with Wireshark for each of them are shown below. Filter was applied to show the traffic between 3310exp.hopto.org (broker) and the client.

Slow Counter q0

The command used to subscribe to the first counter, Q0, is:

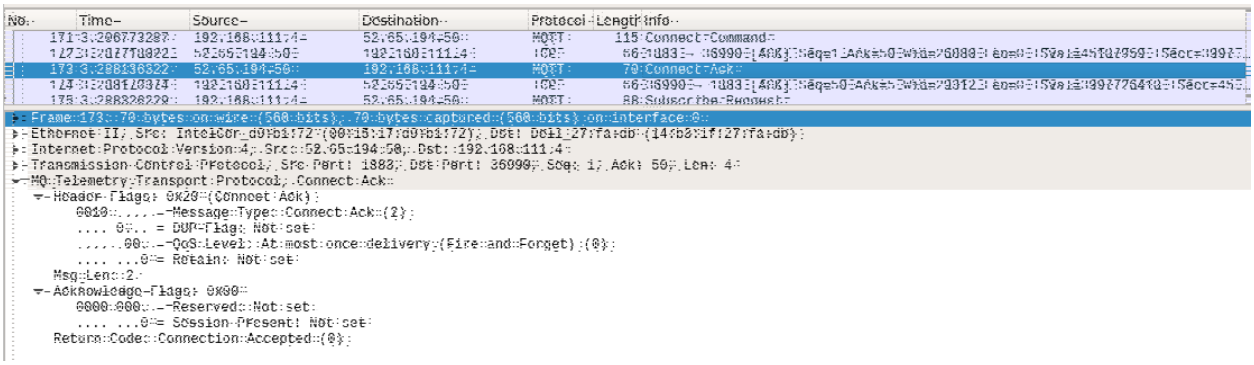
```
$ ./mosquito_sub -i 3310-6028474 -L
mqtt://3310student:comp3310@3310exp.hopto.org/counter/slow/q0 -d -k 5
-C 10 -q 0
```

Acknowledge:



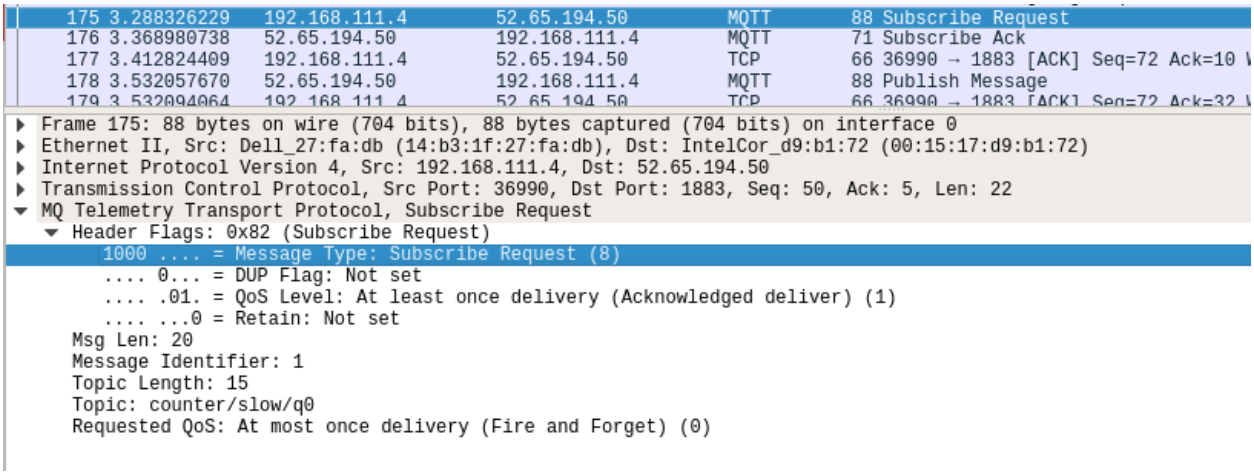
We can see that the MQTT is using the TCP to communicate with the broker. First of the MQTT commands is a Connect command which is sent from the client to the broker. The first four bits of the header flag, 0001, show this in the figure above. The next four bits, 0000, show that the Duplicate (DUP) is not set, Quality of Service (QoS) is set at 00 which is Fire and Forget, and the Retain flag is not set also.

Connect Acknowledge:



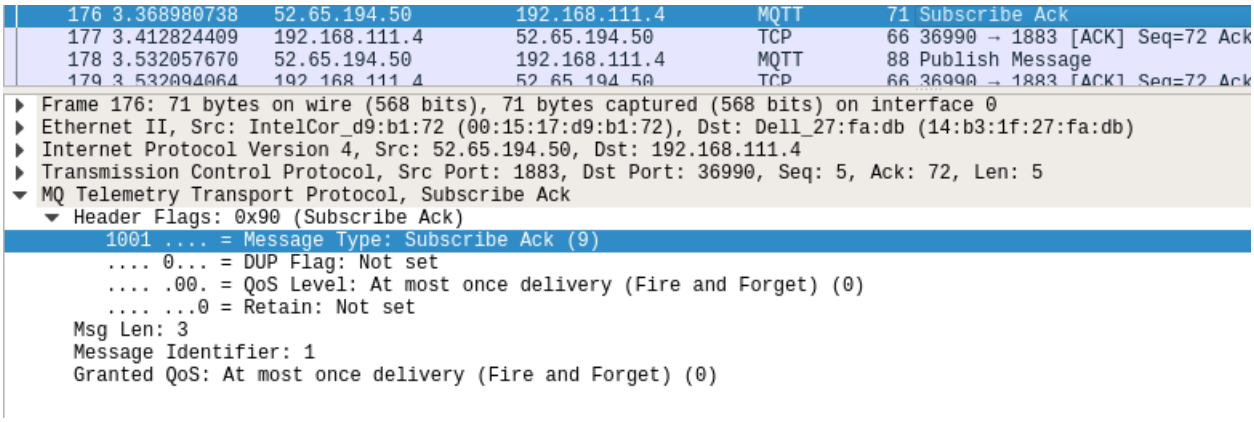
The second of the command is sent from the broker to the client and is a Connect Acknowledge. The return code is 0 which means the broker has authorized and the username and password provided in the Connect command before were valid.

Subscribe Request:



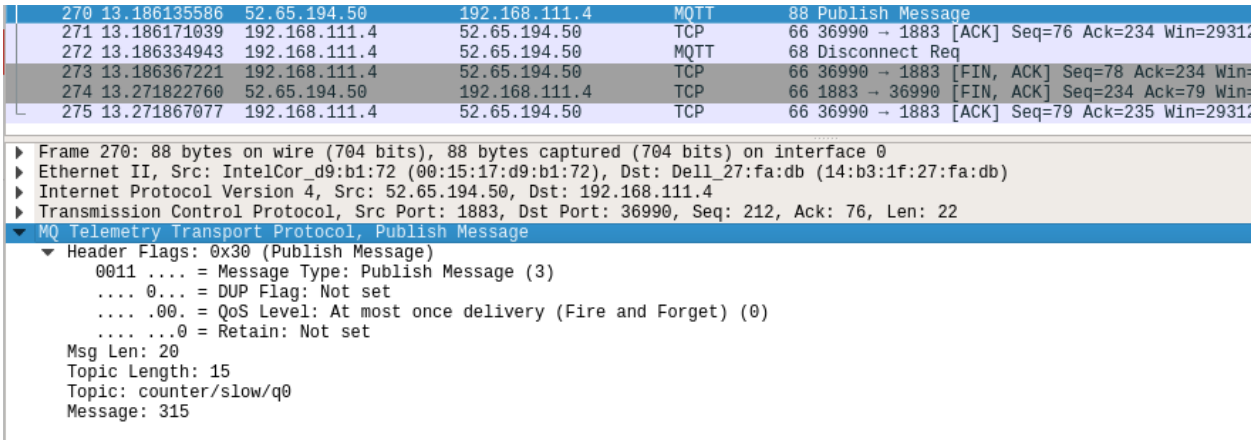
When the client receives the Connect Acknowledge command it sends a Subscribe Request as the third command. The QoS level is set at 01 to make sure the request is delivered at least once to the broker. The topic requested can also be seen as ‘counter/slow/q0’.

Subscribe Ack:



The server replies with the Subscriber Acknowledge request that has a length of 71.

Publish:



After the client has subscribed to the topic ‘counter/slow/q0’, each time the key-value pair at the broker is updated, a publish message is sent to all the subscribing client. The figure above shows one of such messages.

Disconnect:

In the end, when the client wants to disconnect with the broker, it sends a disconnect message. After this, the connection is terminated. The figure below shows the disconnect message.

```
    272 13.186334943  192.168.111.4    52.65.194.50     MQTT      68 Disconnect Req
    273 13.186367221  192.168.111.4    52.65.194.50     TCP       66 36990 → 1883 [FIN, ACK] S
    274 13.271822760  52.65.194.50     192.168.111.4    TCP       66 1883 → 36990 [FIN, ACK] S
    275 13.271867077  192.168.111.4    52.65.194.50     TCP       66 36990 → 1883 [ACK] Seq=79
```

```
▸ Frame 272: 68 bytes on wire (544 bits), 68 bytes captured (544 bits) on interface 0
▸ Ethernet II, Src: Dell_27:fa:db (14:b3:1f:27:fa:db), Dst: IntelCor_d9:b1:72 (00:15:17:d9:b1:72)
▸ Internet Protocol Version 4, Src: 192.168.111.4, Dst: 52.65.194.50
▸ Transmission Control Protocol, Src Port: 36990, Dst Port: 1883, Seq: 76, Ack: 234, Len: 2
▾ MQ Telemetry Transport Protocol, Disconnect Req
  ▾ Header Flags: 0xe0 (Disconnect Req)
      1110 .... = Message Type: Disconnect Req (14)
      .... 0... = DUP Flag: Not set
      .... .00. = QoS Level: At most once delivery (Fire and Forget) (0)
      .... ...0 = Retain: Not set
    Msg Len: 0
```

Slow Counter q1

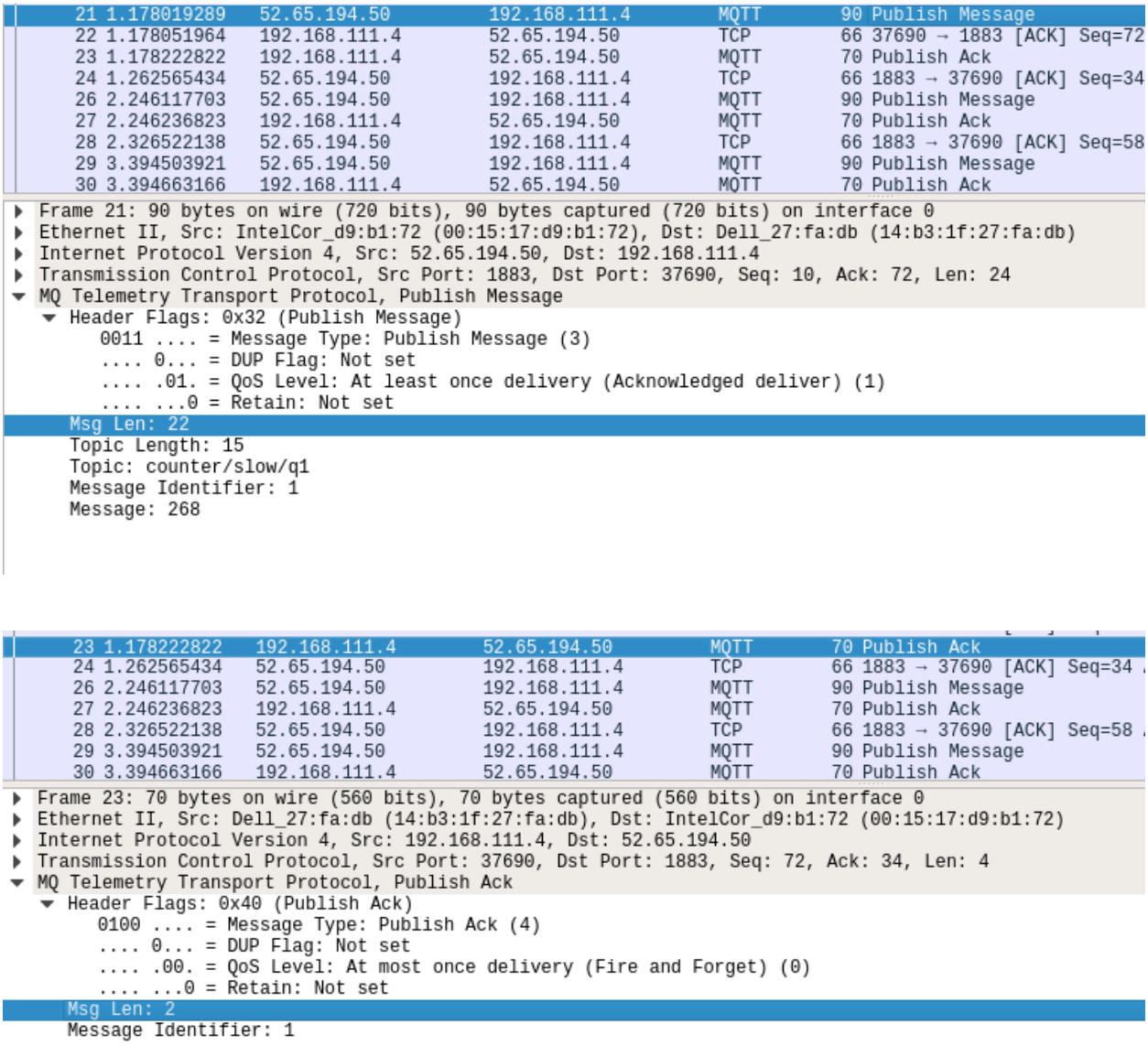
The slow counter uses QoS 1 and we will subscribe to it using this QoS. We will only however compare the differences in the MQTT messages send and received to save space as much of the handshake messages sent and received are similar to counter q0. The figure below shows all the MQTT and TCP messages sent and received between the client and the broker.

```
ip.addr == 52.65.194.50                                                    Expression...  +
No.  Time          Source          Destination     Protocol  Length Info
   8 0.426831445   192.168.111.4   52.65.194.50    TCP         74 37690 → 1883 [SYN] Seq=0 Win=29200 Len=0 MSS=1460 SACK_PERM=1 TSval=4011549462 …
   9 0.442574629   52.65.194.50    192.168.111.4   TCP         74 1883 → 37690 [SYN, ACK] Seq=0 Ack=1 Win=26847 Len=0 MSS=1460 SACK_PERM=1 TSval=…
  10 0.442630728   192.168.111.4   52.65.194.50    TCP         66 37690 → 1883 [ACK] Seq=1 Ack=1 Win=29312 Len=0 TSval=4011549478 TSecr=48563762
  11 0.442770640   192.168.111.4   52.65.194.50    MQTT       115 Connect Command
  12 0.523510061   52.65.194.50    192.168.111.4   TCP         66 1883 → 37690 [ACK] Seq=1 Ack=50 Win=26880 Len=0 TSval=48563783 TSecr=4011549478
  13 0.523944647   52.65.194.50    192.168.111.4   MQTT        70 Connect Ack
  14 0.523977765   192.168.111.4   52.65.194.50    TCP         66 37690 → 1883 [ACK] Seq=50 Ack=5 Win=29312 Len=0 TSval=4011549559 TSecr=48563783
  15 0.524132878   192.168.111.4   52.65.194.50    MQTT        88 Subscribe Request
  16 0.685811372   52.65.194.50    192.168.111.4   TCP         66 1883 → 37690 [ACK] Seq=5 Ack=72 Win=26880 Len=0 TSval=48563823 TSecr=4011549560
  17 0.771415275   52.65.194.50    192.168.111.4   MQTT        71 Subscribe Ack
  18 0.811935169   192.168.111.4   52.65.194.50    TCP         66 37690 → 1883 [ACK] Seq=72 Ack=10 Win=29312 Len=0 TSval=4011549807 TSecr=48563845
  21 1.178019289   52.65.194.50    192.168.111.4   MQTT        90 Publish Message
  22 1.178051964   192.168.111.4   52.65.194.50    TCP         66 37690 → 1883 [ACK] Seq=72 Ack=34 Win=29312 Len=0 TSval=4011550213 TSecr=48563946
  23 1.178222822   192.168.111.4   52.65.194.50    MQTT        70 Publish Ack
  24 1.262565434   52.65.194.50    192.168.111.4   TCP         66 1883 → 37690 [ACK] Seq=34 Ack=76 Win=26880 Len=0 TSval=48563967 TSecr=4011550214
  26 2.246117703   52.65.194.50    192.168.111.4   MQTT        90 Publish Message
  27 2.246236823   192.168.111.4   52.65.194.50    MQTT        70 Publish Ack
  28 2.326522138   52.65.194.50    192.168.111.4   TCP         66 1883 → 37690 [ACK] Seq=58 Ack=80 Win=26880 Len=0 TSval=48564233 TSecr=4011551282
  29 3.394503921   52.65.194.50    192.168.111.4   MQTT        90 Publish Message
  30 3.394663166   192.168.111.4   52.65.194.50    MQTT        70 Publish Ack
  31 3.474878049   52.65.194.50    192.168.111.4   TCP         66 1883 → 37690 [ACK] Seq=82 Ack=84 Win=26880 Len=0 TSval=48564520 TSecr=4011552430
  45 4.377897639   52.65.194.50    192.168.111.4   MQTT        90 Publish Message
  46 4.378052435   192.168.111.4   52.65.194.50    MQTT        70 Publish Ack
  47 4.378137348   192.168.111.4   52.65.194.50    MQTT        68 Disconnect Req
  48 4.457927220   52.65.194.50    192.168.111.4   TCP         66 1883 → 37690 [ACK] Seq=106 Ack=88 Win=26880 Len=0 TSval=48564766 TSecr=40115534…
  49 4.457960251   52.65.194.50    192.168.111.4   TCP         66 1883 → 37690 [FIN, ACK] Seq=106 Ack=91 Win=26880 Len=0 TSval=48564766 TSecr=401…
  50 4.457981550   192.168.111.4   52.65.194.50    TCP         66 37690 → 1883 [ACK] Seq=91 Ack=107 Win=29312 Len=0 TSval=4011553493 TSecr=485647…
```

```
▸ Frame 15: 88 bytes on wire (704 bits), 88 bytes captured (704 bits) on interface 0
▸ Ethernet II, Src: Dell_27:fa:db (14:b3:1f:27:fa:db), Dst: IntelCor_d9:b1:72 (00:15:17:d9:b1:72)
▸ Internet Protocol Version 4, Src: 192.168.111.4, Dst: 52.65.194.50
▸ Transmission Control Protocol, Src Port: 37690, Dst Port: 1883, Seq: 50, Ack: 5, Len: 22
▾ MQ Telemetry Transport Protocol, Subscribe Request
  ▾ Header Flags: 0x82 (Subscribe Request)
      1000 .... = Message Type: Subscribe Request (8)
      .... 0... = DUP Flag: Not set
      .... .01. = QoS Level: At least once delivery (Acknowledged deliver) (1)
      .... ...0 = Retain: Not set
    Msg Len: 20
    Message Identifier: 1
    Topic Length: 15
    Topic: counter/slow/q1
    Requested QoS: At least once delivery (Acknowledged deliver) (1)
```

The client sends a Connect command to the broker and is replied a Connect Ack command. After that a Subscribe Request is sent with the QoS flag set to 01 as shown in the figure above which is at least once delivery.

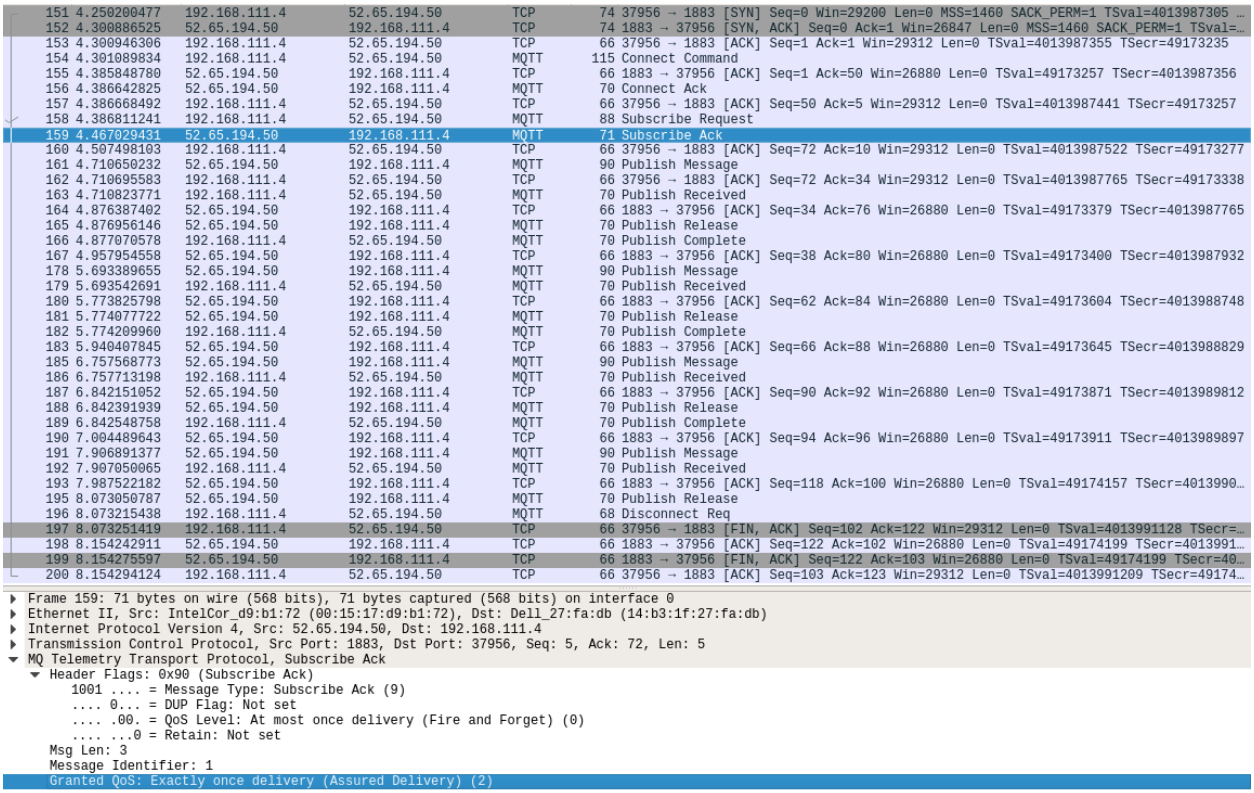
Publish and Publish Acknowledge:



After the subscription is successful, a Publish message is sent by the broker to the client. We can see from the figure above that the QoS flag is set to 01 which ensures that the client receives the message at least once. For this reason, every Publish message from the broker to the client is followed by a Publish Acknowledge message. Also, each Publish message has a message identifier which is replied in the Publish Ack to tell broker that the message has been received. In the end the client and broker disconnect as q0.

Slow Counter q2

The slow counter q2 uses QoS 2 which is ‘Exactly Once’. The figure below shows the MQTT messages sent and received between the client and the broker. Again, we will discuss the differences in MQTT messages with respect to QoS.



The Connect command follows with the usual Connect Acknowledge command. It can be seen that QoS 2 is granted to the client in the Subscriber Ack.

Publish:

Each of the Publish Message sent from the broker is replied with Publish Received message by the client. The broker then sends a Publish Release command and the client replies with the Publish Complete command ensuring that the message is received exactly once. Each of the messages have the Message Identifier.

Summary:

For QoS 0, the message duplication bit carries no significance. The broker pushes out the message as soon as it receives. The message from the broker received do not necessarily have to be in order therefore. It will be used where the data will not severely effect if it is lost. For example, if a temperature sensor is sending the data at a very fast rate, a few packets lost will not make a significant difference.

For QoS 1, The broker ensures that the client receives the message at least once and if the client does not receive, the message is sent again with the duplicate bit set. The message is deleted after the receiver processes it and sends an acknowledgement to the sender who then deletes it.

In QoS 2, the message is delivered exactly once, and this is the safest mode of transfer. Two pairs of transmission between the sender and receiver are used for this. In the first, sender sends the message to the receiver telling it that it has stored the message. Once the receiver replies with an acknowledgement a PUBREL is sent by the sender that tells the receiver that it can complete processing the message. When the client sends the acknowledgement of the PUBREL, sender deletes the message.

Question 2(a)

The following statistics for different QoS was collected from one run of the code:

QoS: 0

1. Rate of messages received: 3485
2. Rate of messages lost: 0
3. Rate of duplicated messages: 0
4. Rate of out-of-order messages: 0

QoS: 1

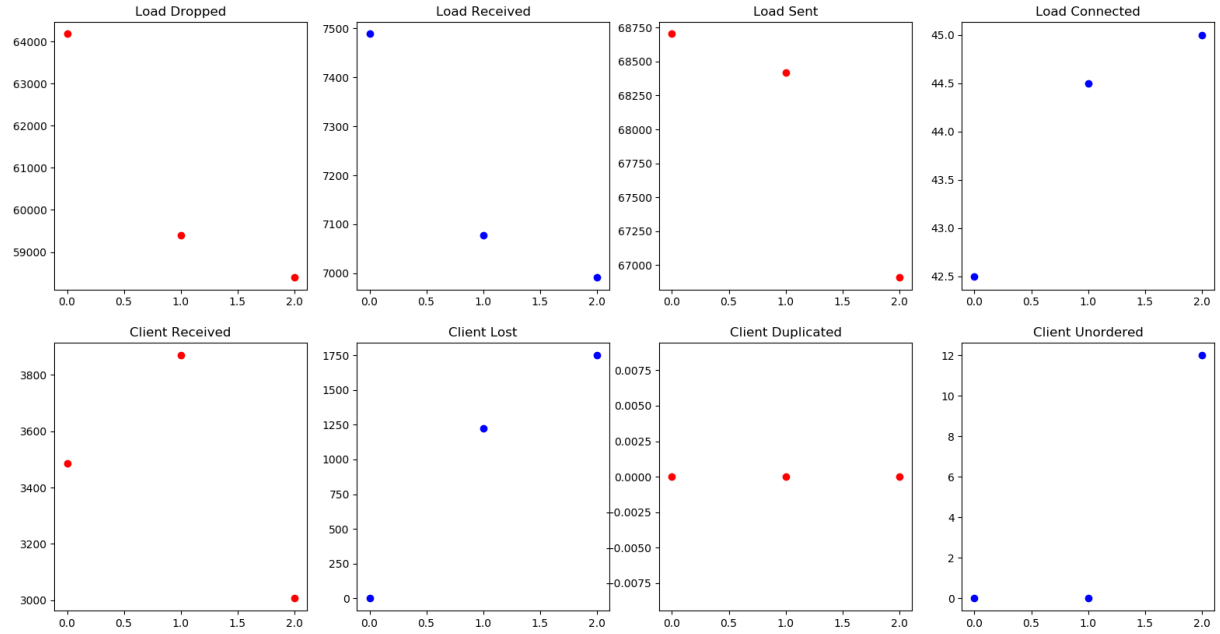
1. Rate of messages received: 3870
2. Rate of messages lost: 1226
3. Rate of duplicated messages: 0
4. Rate of out-of-order messages: 0

QoS: 2

1. Rate of messages received: 3007
2. Rate of messages lost: 1751
3. Rate of duplicated messages: 0
4. Rate of out-of-order messages: 12

Question 2(b)

The following figure shows how broker and client perform for different QoS for one session the client is connected to the broker. The first row shows the messages dropped, received, sent and number of active client on the broker in one minute from left to right. The second row shows messages received, lost, duplicated and unordered in one minute that the client experiences.



We can see that the dropped messages and the received messages on the broker are correlated. This is expected as the broker will lose more messages if the publishers want to send more data. If they send less data, the broker is less likely to lose messages. Another correlation we can expect is between number of clients connected to the broker and the rate of message loss by the client. As the number of active clients subscribed increase, we would expect the client to lose more messages. This is proven in the figure above as the number of clients increase from QoS 0 to 2, more messages are lost by the client.

Question 4

Results were compared across loss/dupe/out-of-order for the timestamp 152696xxxx for similar time comparison. The table below summarizes the values for each of the messages

Sr. No	Loss QoS (1)	Dupe	Out-of-order
1	88	24	4.15
2	47	20	1.39
3	0	12	1.77
4	59	2.38	6
5	14	24.82	1.6
6	68	15.4	8.38
7	40	2.66	1
8	35	0	10

9	39	13.64	11.59
10	36	13	1.9

There is similarity between the different rates although some extreme values can be seen as well.

No correlation in performance is seen from the different use of language.

Question 5

a. In the broader end-to-end environment, there is a limit to which the network's performance could be extended. A CPU is one element in an MQTT network and performs processing tasks such as updating the key-value pairs when a message is received from the publishers and retrieving when subscribers need it. If processing is slow then there will be delays in subscribers receiving information and publishers would have to wait. Memory especially heap memory is another element which allows for quick update of key-value pairs of MQTT. Heap memory is dynamic and provides for quick access to key-value pairs. Amount of memory is directly proportional to different number of topics that need updating. If new topics are added, heap memory will be consumed faster. This is especially important if the messages sent to the broker have the 'retain' flag set. Lastly, type of network defines how quickly messages are transferred between the broker and subscribers and clients. A fast connection over a fiber optic would update and deliver the messages fast. If the network is slow, then it may be the case that the values received by subscribers may not be most recent. Also, fewer messages will be dropped with a more reliable mode of transfer.
b. Different QoS can have different effects on the performance of the broader MQTT network. The 0 QoS which is 'fire and forget' will increase performance in a certain way. With this QoS, the broker does not have to ensure that the client receives the message or not and thus other clients' message will be sent more frequently. Fewer memory will be consumed as well as the broker does not have to keep an account of who has received what message as it does not send puback messages. Over a less reliable network though, clients may have a high chance that they are not receiving message and they have no way of telling the broker. QoS 1 which is 'At least once' would use more of the computing resources but it means that clients will receive message at least once. More memory would be required thus as the broker needs to keep track if the message has been received by the client. QoS 2 which is 'Exactly once' is the safest but will reduce the performance of the network the most. It involves a four-way handshake, thus using even more computing resources. Messages sent and received by the broker need to be tracked more so needs more memory resources as well. However, like other QoS it does not improve or deteriorate the effect of network type on the performance.
c. We can see from the diagram that the number of messages received decrease as QoS level increase. This Is because, lost messages are sent again until the broker is sure that we have received it. Also, as QoS levels increase, more acknowledge messages are exchanged between the client and the broker.