Building a simple Proxy Fuzzer for the MQTT protocol using the Polymorph framework

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https://github.com/shramos/polymorph

This article shows how easy you can build a fuzzer for the MQTT protocol by using the Polymorph framework.

I will start by assuming that the reader knows the MQTT protocol. For those who do not know it, you can find more information here. The first thing we will do is prepare the environment where we will perform the fuzzing, in this case, it will be very simple, a Kali Linux machine in which we will install the following dependencies:

Polymorph framework

apt-get install build-essential python-dev libnetfilter-queue-dev tshark tcpdump python3-pip wireshark

pip3 install --process-dependency-links polymorph

Mosquitto

apt-get install mosquitto mosquitto-clients

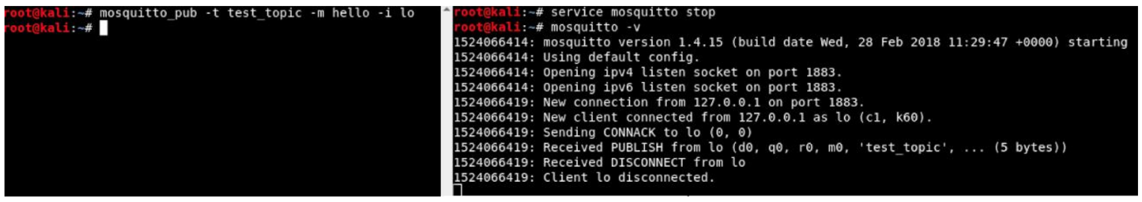
Radamsa

sudo apt-get install gcc make git wget

git clone https://github.com/aoh/radamsa.git && cd radamsa && make && sudo make install

With all this installed, we are ready to start!

Before starting the construction of the fuzzer, we are going to test our ***mosquitto*** installation in localhost. To do this, we are going to open two terminals and execute a client that is going to subscribe to a certain topic and another one that publishes to that same topic. In the following image you can see the commands and the result.



```
root@kali:~# mosquitto_pub -t test_topic -m hello -i lo
root@kali:~#
```

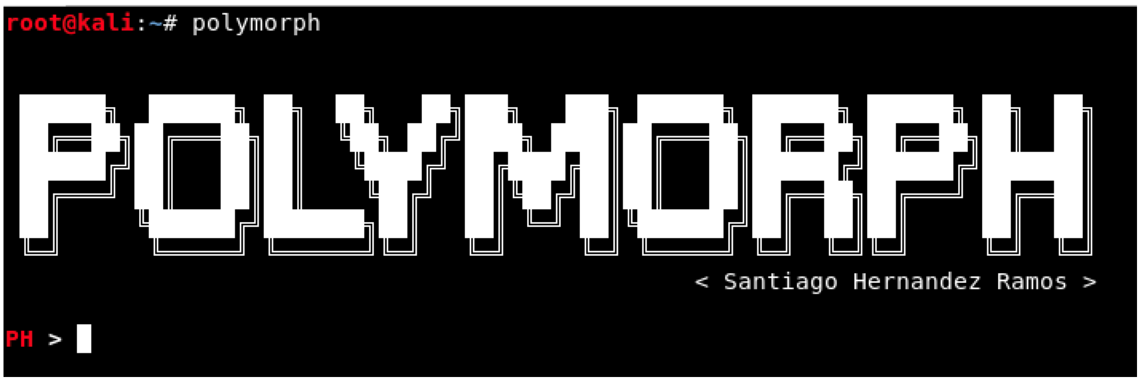
```
root@kali:~# service mosquitto stop
root@kali:~# mosquitto -v
1524066414: mosquitto version 1.4.15 (build date Wed, 28 Feb 2018 11:29:47 +0000) starting
1524066414: Using default config.
1524066414: Opening ipv4 listen socket on port 1883.
1524066414: Opening ipv6 listen socket on port 1883.
1524066419: New connection from 127.0.0.1 on port 1883.
1524066419: New client connected from 127.0.0.1 as lo (c1, k60).
1524066419: Sending CONNACK to lo (0, 0)
1524066419: Received PUBLISH from lo (d0, q0, r0, m0, 'test_topic', ... (5 bytes))
1524066419: Received DISCONNECT from lo
1524066419: Client lo disconnected.
```

Well, now that we have tested the communication between both clients, we are going to open **Polymorph** and begin with the capture and modification of MQTT packets in real time.

In our particular case, we are going to fuzz the ***msg*** field of the ***MQTTPublish*** packets, notice that the modification of any other field would be done in exactly the same way. Also, for simplicity, we are going to modify MQTT packets that implement the ***IPv4*** protocol. Sometimes you will see that Polymorph captures the MQTT protocol over ***IPv6***, to temporarily disable ***IPv6*** you can use the following command over the ***loopback*** interface:

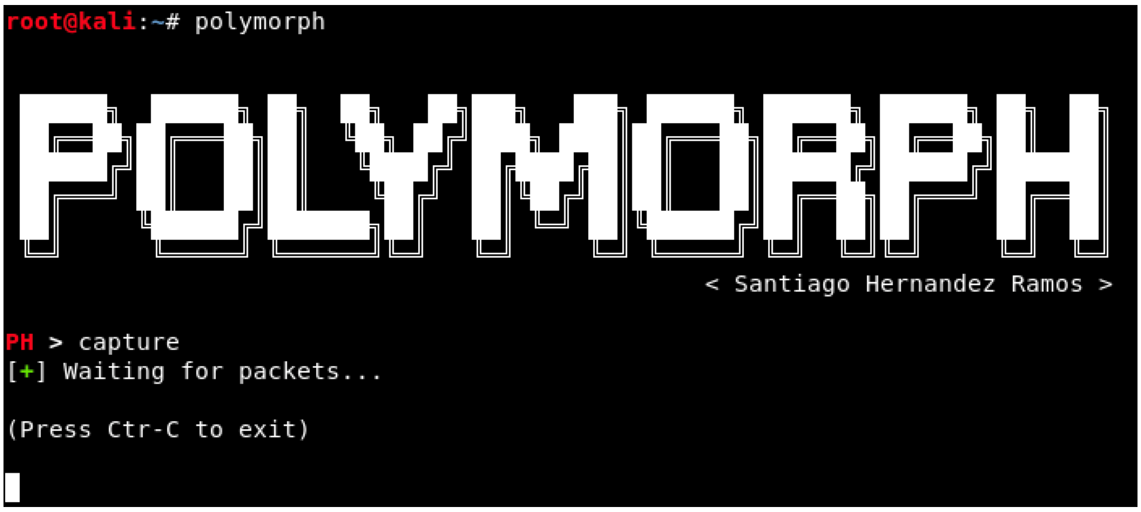
sudo sh -c 'echo 1 > /proc/sys/net/ipv6/conf/loopback/disable_ipv6'

Having said that, we are going to access the Polymorph main interface, to do that, we only have to introduce the ***polymorph*** command from a Linux terminal.



```
root@kali:~# polymorph

POLYMORPH

                                        < Santiago Hernandez Ramos >

PH >
```

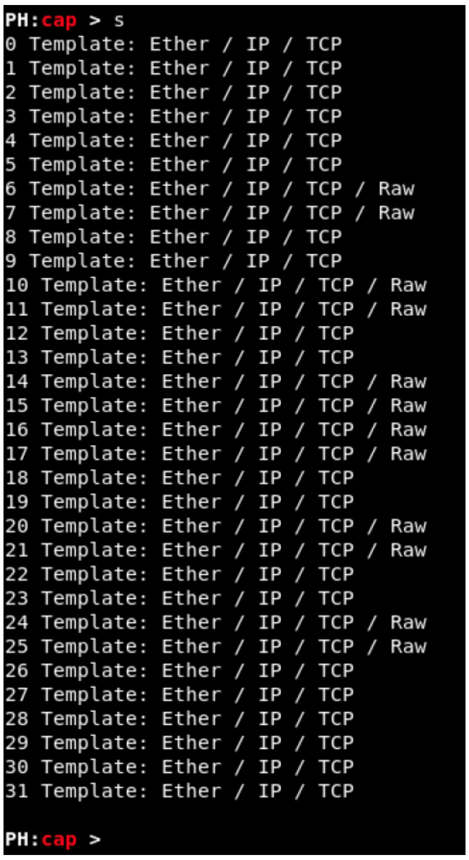
Once here, let´s start with the construction of the ***fuzzer***. As in this case we will not need to intercept the communication between two machines because the clients will be in ***localhost***, we do not need to use any spoofing technique. We can simply use the ***capture*** command to start the packet sniffing process.



```
root@kali:~# polymorph

POLYMORPH

                                        < Santiago Hernandez Ramos >

PH > capture
[+] Waiting for packets...

(Press Ctr-C to exit)
```

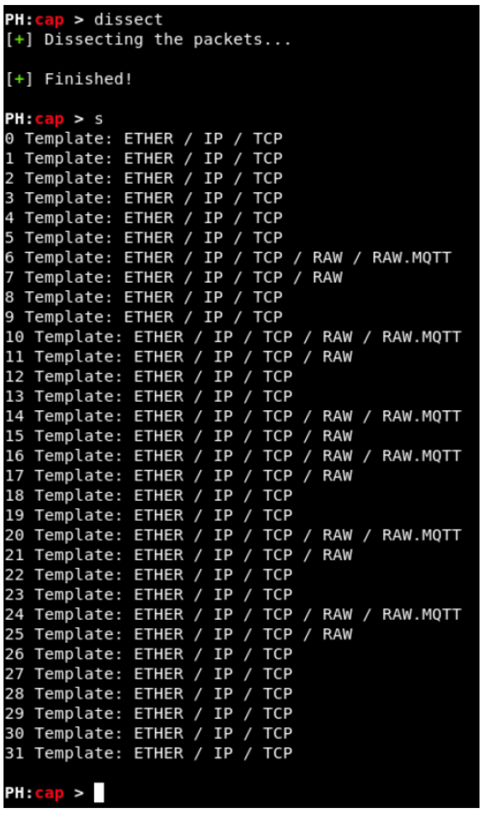
Our goal at this point is to capture one of the packets that we want to modify, so that the framework converts it into a ***template*** and we can work on it. Therefore, while the tool is sniffing packets, we place ourselves in our MQTT client and send an ***MQTTPublish*** message to the client that is listening.

Once this is done, we use ***Ctr-C*** to finish the sniffing process in Polymorph and use the ***show*** command to show the captured packets on the screen.



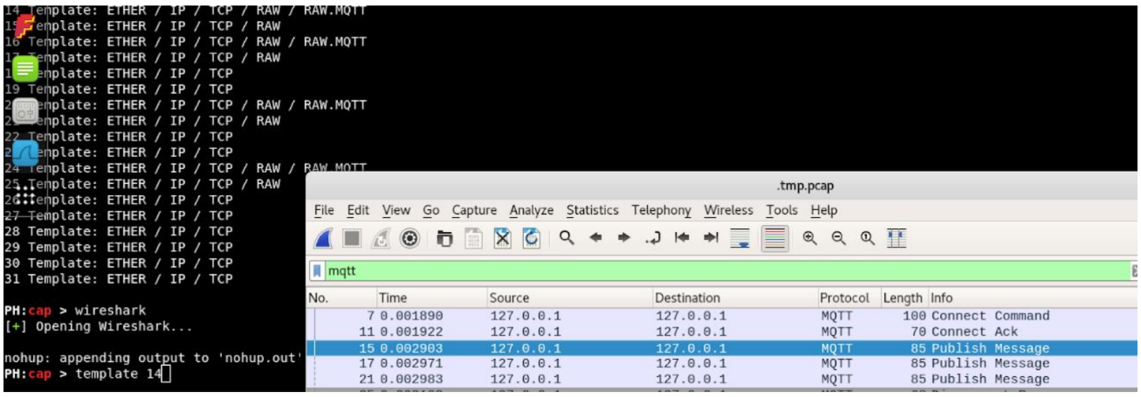
```
PH:cap > s
0 Template: Ether / IP / TCP
1 Template: Ether / IP / TCP
2 Template: Ether / IP / TCP
3 Template: Ether / IP / TCP
4 Template: Ether / IP / TCP
5 Template: Ether / IP / TCP
6 Template: Ether / IP / TCP / Raw
7 Template: Ether / IP / TCP / Raw
8 Template: Ether / IP / TCP
9 Template: Ether / IP / TCP
10 Template: Ether / IP / TCP / Raw
11 Template: Ether / IP / TCP / Raw
12 Template: Ether / IP / TCP
13 Template: Ether / IP / TCP
14 Template: Ether / IP / TCP / Raw
15 Template: Ether / IP / TCP / Raw
16 Template: Ether / IP / TCP / Raw
17 Template: Ether / IP / TCP / Raw
18 Template: Ether / IP / TCP
19 Template: Ether / IP / TCP
20 Template: Ether / IP / TCP / Raw
21 Template: Ether / IP / TCP / Raw
22 Template: Ether / IP / TCP
23 Template: Ether / IP / TCP
24 Template: Ether / IP / TCP / Raw
25 Template: Ether / IP / TCP / Raw
26 Template: Ether / IP / TCP
27 Template: Ether / IP / TCP
28 Template: Ether / IP / TCP
29 Template: Ether / IP / TCP
30 Template: Ether / IP / TCP
31 Template: Ether / IP / TCP

PH:cap >
```

As you can see, most of the packets include a last ***Raw*** layer, which means that, at first glance, they have not been ***interpreted/dissected*** correctly by the primary dissectors. With the ***dissect*** command, we use more advanced dissectors that give us a representation of the part of the packets that have not been represented.



```
PH:cap > dissect
[+] Dissecting the packets...

[+] Finished!

PH:cap > s
0 Template: ETHER / IP / TCP
1 Template: ETHER / IP / TCP
2 Template: ETHER / IP / TCP
3 Template: ETHER / IP / TCP
4 Template: ETHER / IP / TCP
5 Template: ETHER / IP / TCP
6 Template: ETHER / IP / TCP / RAW / RAW.MQTT
7 Template: ETHER / IP / TCP / RAW
8 Template: ETHER / IP / TCP
9 Template: ETHER / IP / TCP
10 Template: ETHER / IP / TCP / RAW / RAW.MQTT
11 Template: ETHER / IP / TCP / RAW
12 Template: ETHER / IP / TCP
13 Template: ETHER / IP / TCP
14 Template: ETHER / IP / TCP / RAW / RAW.MQTT
15 Template: ETHER / IP / TCP / RAW
16 Template: ETHER / IP / TCP / RAW / RAW.MQTT
17 Template: ETHER / IP / TCP / RAW
18 Template: ETHER / IP / TCP
19 Template: ETHER / IP / TCP
20 Template: ETHER / IP / TCP / RAW / RAW.MQTT
21 Template: ETHER / IP / TCP / RAW
22 Template: ETHER / IP / TCP
23 Template: ETHER / IP / TCP
24 Template: ETHER / IP / TCP / RAW / RAW.MQTT
25 Template: ETHER / IP / TCP / RAW
26 Template: ETHER / IP / TCP
27 Template: ETHER / IP / TCP
28 Template: ETHER / IP / TCP
29 Template: ETHER / IP / TCP
30 Template: ETHER / IP / TCP
31 Template: ETHER / IP / TCP

PH:cap >
```

Now that we have a more concrete representation of all the bytes of the packets that we have captured, what we must do is choose the ***template*** that corresponds to the packet that we want to modify. We can use the ***wireshark*** command to open this application and perform a more detailed filtering. Once the ***template*** is selected, we access it using the ***template*** command.



```
14 Template: ETHER / IP / TCP / RAW / RAW.MQTT
15 Template: ETHER / IP / TCP / RAW
16 Template: ETHER / IP / TCP / RAW / RAW.MQTT
17 Template: ETHER / IP / TCP / RAW
18 Template: ETHER / IP / TCP
19 Template: ETHER / IP / TCP
20 Template: ETHER / IP / TCP / RAW / RAW.MQTT
21 Template: ETHER / IP / TCP / RAW
22 Template: ETHER / IP / TCP
23 Template: ETHER / IP / TCP
24 Template: ETHER / IP / TCP / RAW / RAW.MQTT
25 Template: ETHER / IP / TCP / RAW
26 Template: ETHER / IP / TCP
27 Template: ETHER / IP / TCP
28 Template: ETHER / IP / TCP
29 Template: ETHER / IP / TCP
30 Template: ETHER / IP / TCP
31 Template: ETHER / IP / TCP

PH:cap > wireshark
[+] Opening Wireshark...

nohup: appending output to 'nohup.out'
PH:cap > template 14
```

.tmp.pcap
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
mqtt

```
No.   Time        Source      Destination  Protocol  Length Info
    7 0.001890    127.0.0.1   127.0.0.1    MQTT         100 Connect Command
   11 0.001922    127.0.0.1   127.0.0.1    MQTT          70 Connect Ack
   15 0.002903    127.0.0.1   127.0.0.1    MQTT          85 Publish Message
   17 0.002971    127.0.0.1   127.0.0.1    MQTT          85 Publish Message
   21 0.002983    127.0.0.1   127.0.0.1    MQTT          85 Publish Message
```

Right now, we are in the context of the selected ***template***. With the ***show*** command we can see the different layers and fields that it has, as well as the type of them. The ***template*** concept is the most important abstraction of the framework, and it is what allows the user to access the captured packets in real time using simple syntax in the code he writes to perform complex processing on them. Furthermore, it is the container in which all the conditional functions and structures of the framework are stored when we save a session.

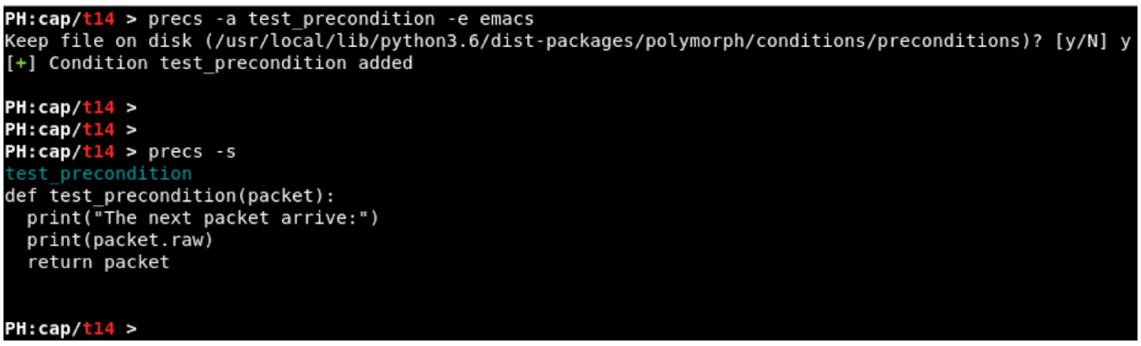
Once this is done, the ***conditional functions*** come into play (***preconditions, postconditions and executions***). When the user enters the ***intercept*** command in the ***template*** interface, the machine that hosts Polymorph will stop forwarding the packets at the kernel level and start sending those packages to the tool to be processed before being forwarded. The conditional functions defined by the user will be executed in each of the intercepted packets.

Let's see a simple example of how these functions work, we are going to add the following ***precondition*** to our current ***template*** using the command ***precs -a test_condition***.

*if you are using the default editor, pico, remember not to mix tabs and spaces, better use only spaces to indent the code. (You can specify another editor that is in your **PATH** using the option **-e**):*

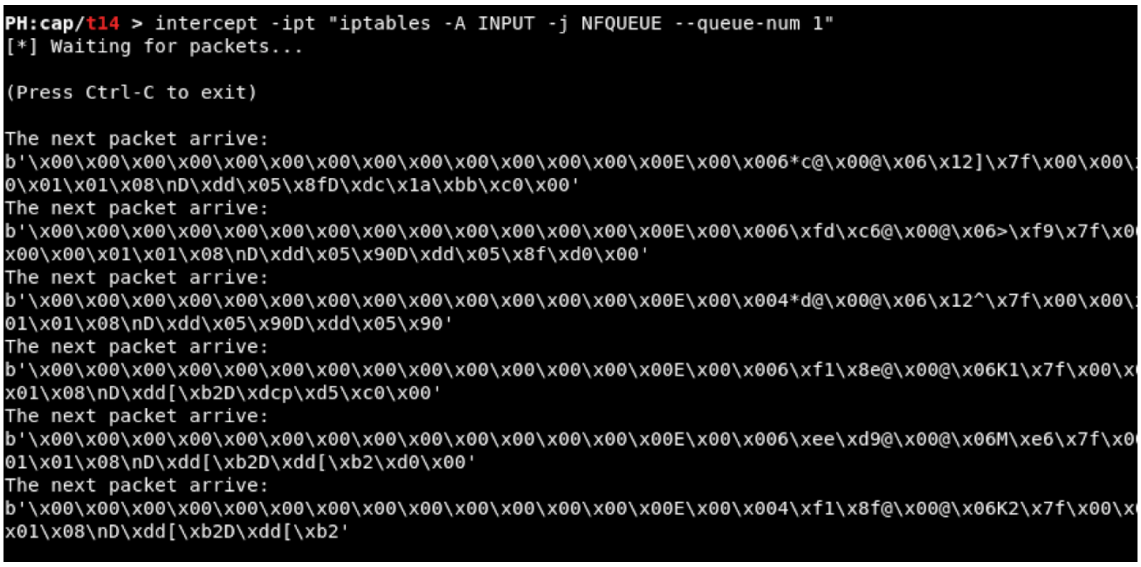
```python
def test_precondition(packet):
    print("The next packet arrive:")
    print(packet.raw)
    return packet
```

Enter "***y***" to keep the code on disk and enter ***precs -s*** to visualize the added ***precondition***.



```
PH:cap/t14 > precs -a test_precondition -e emacs
Keep file on disk (/usr/local/lib/python3.6/dist-packages/polymorph/conditions/preconditions)? [y/N] y
[+] Condition test_precondition added

PH:cap/t14 >
PH:cap/t14 >
PH:cap/t14 > precs -s
test_precondition
def test_precondition(packet):
  print("The next packet arrive:")
  print(packet.raw)
  return packet


PH:cap/t14 >
```

Now, introduce the ***intercept*** command:



```
PH:cap/t14 > intercept -ipt "iptables -A INPUT -j NFQUEUE --queue-num 1"
[*] Waiting for packets...

(Press Ctrl-C to exit)

The next packet arrive:
b'\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00E\x00\x006*c@\x00@\x06\x12]\x7f\x00\x00\
0\x01\x01\x08\nD\xdd\x05\x8fD\xdc\x1a\xbb\xc0\x00'
The next packet arrive:
b'\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00E\x00\x006\xfd\xc6@\x00@\x06>\xf9\x7f\x0
x00\x00\x01\x01\x08\nD\xdd\x05\x90D\xdd\x05\x8f\xd0\x00'
The next packet arrive:
b'\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00E\x00\x004*d@\x00@\x06\x12^\x7f\x00\x00\
01\x01\x08\nD\xdd\x05\x90D\xdd\x05\x90'
The next packet arrive:
b'\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00E\x00\x006\xf1\x8e@\x00@\x06K1\x7f\x00\x
x01\x08\nD\xdd[\xb2D\xdcp\xd5\xc0\x00'
The next packet arrive:
b'\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00E\x00\x006\xee\xd9@\x00@\x06M\xe6\x7f\x0
01\x01\x08\nD\xdd[\xb2D\xdd[\xb2\xd0\x00'
The next packet arrive:
b'\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00E\x00\x004\xf1\x8f@\x00@\x06K2\x7f\x00\x
x01\x08\nD\xdd[\xb2D\xdd[\xb2'
```

Look how all the packets that flow through the machine are processed by the tool in real time and the precondition we have added is executed on each of them. We can test it just by sending a ***MQTTPublish*** message from one MQTT client to the broker.

The conditional functions are another important abstraction of the framework and work as follows. When a packet is intercepted in real time, the conditional functions defined by the user are executed on it following a certain order, first the ***preconditions*** are executed in the order in which the user has added them to the ***template***, then the ***executions*** and finally the ***postconditions***. If at any point of the execution of any of the three types of conditional functions the value ***None*** is returned by one of them, the execution chain is broken and the packet is forwarded as it is at that moment. On the other hand, if the packet that is received as an argument is returned, the chain of execution of conditions continues. Remember that the packet that is received as argument is the packet that has been intercepted in real time at that moment.

Once this is understood, we are going to exit the ***intercept*** mode in Polymorph by entering ***Ctr-C*** (in this way, the machine that hosts Polymorph only forwards the packets without passing them through the tool). After that, we are going to add the following ***preconditions***, ***executions*** and ***postconditions***, which, I insist, when we start intercepting will be executed on each of the packets that are intercepted. To eliminate the test precondition that we added before, use ***precs -d test_condition***.

Preconditions

Two preconditions have been added using the commands:

precs -a global_vars -e editor
precs -a filter_mqttpublish -e editor

The first precondition, ***global_vars***, is creating a global variable that will remain constant for all intercepted packets. It will be used to store all the test cases that we will use to fuzz the ***MQTTPublish*** packets.

```
def global_vars(packet):
    try:
        packet.fuzz_cases
    except:
        setattr(packet, 'fuzz_cases', [])
    return packet
```

On the other hand, the second precondition, ***filter_mqttpublish***, will filter the incoming packets so that they only continue executing the rest of the conditional functions those whose ***msgtype*** field is equals to ***48***. Notice that thanks to the ***template*** abstraction, Polymorph knows the position that the ***msgtype*** field occupies within the bytes of the intercepted packet, and therefore, the user can access it much more easily.

```
def filter_mqttpublish(packet):
    try:
        if packet['RAW.MQTT']['msgtype'] == 48:
        return packet
    except:
        return None
```

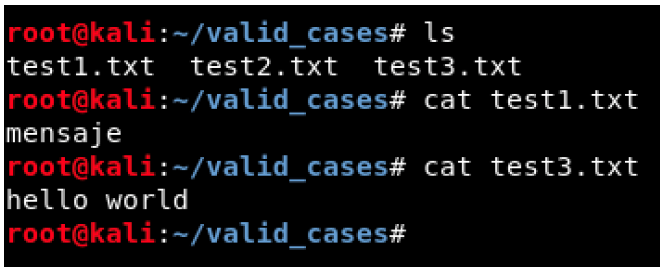
Executions

The execution is a bit longer than the preconditions, but it remains simple. The piece of code shown below performs the following tasks:

1. Transforms the intercepted packet into a ***Scapy*** representation. We do this to be able to interact more easily with the fields of the MQTT layer, especially with the lengths, which are encoded. I wrote the MQTT specification for ***Scapy*** a while ago, you can find it here.
2. We check if fuzzing values remain in our list of test cases. The list is stored in the global variable created above. If the list is empty, we invoke ***Radamsa*** to generate more test cases and we stored them in the global variable.
3. Finally, we use ***Scapy*** to insert the fuzzing value in the ***msg*** field of the packet and we eliminate that value from our list, so that it is not inserted twice. In addition, we recalculate the control fields, such as **lengths** and ***chksums***.

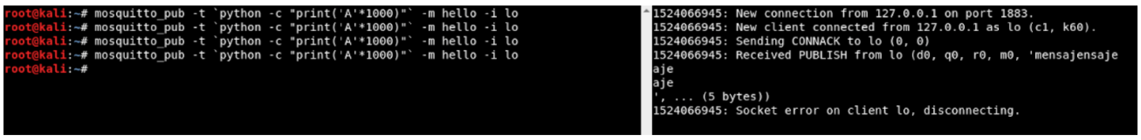
```
def insert_value(packet):
    import subprocess
    from os import listdir
    from os.path import join
    from scapy.all import IP
    from scapy.contrib.mqtt import MQTT
    # Building a Scapy packet
    pkt = IP(packet.raw[14: ])
    # Retrieving the fuzzing case
    if not packet.fuzz_cases:
        valid_cases = "valid_cases"
        dpath = "fuzz_cases"
        subprocess.check_call(["radamsa",
                               "-o",
                              join(dpath, "fuzz-%n.%s"),
                              "-n",
                              "58",
                              "-r",
                               valid_cases])
        packet.fuzz_cases = [open(join(dpath, f), 'rb').read()
                            for f in listdir(dpath)]
    # Inserting the value and recalculating some fields
    del pkt['IP'].len
    del pkt['IP'].chksum
    del pkt['TCP'].chksum
    del pkt['MQTT'].len
    del pkt['MQTTPublish'].length
    pkt['MQTTPublish'].topic = packet.fuzz_cases.pop()
    pkt.show2()
    packet.raw = bytes(pkt)
    return packet
```

That's all we need to build a **Proxy Fuzzer** for the MQTT protocol using Polymorph!
To put it into operation, we will create two directories in the ***PATH*** from which we have run Polymorph, one called ***valid_cases*** and another called ***fuzz_cases***. These directories will be used by Radamsa to read valid test cases and mutate them in cases that may unravel in a possible vulnerability. We can add some valid cases like the following ones.



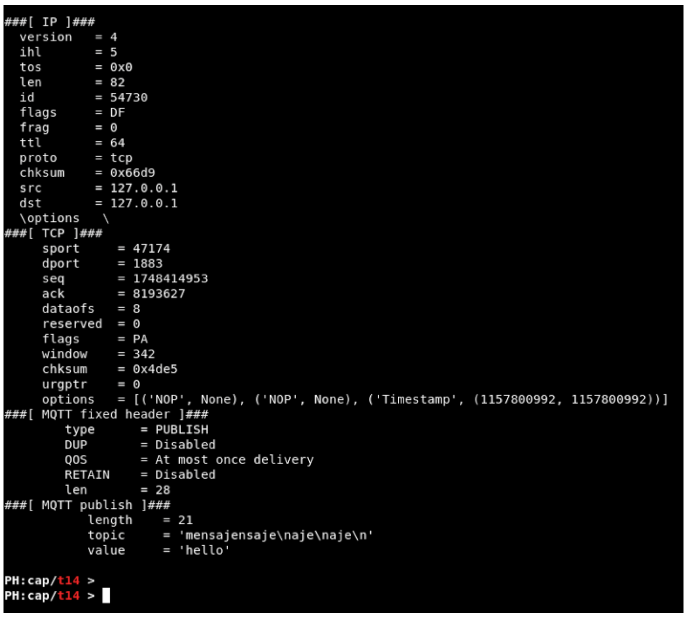
```
root@kali:~/valid_cases# ls
test1.txt  test2.txt  test3.txt
root@kali:~/valid_cases# cat test1.txt
mensaje
root@kali:~/valid_cases# cat test3.txt
hello world
root@kali:~/valid_cases#
```

Once this is done we simply go to the ***template*** interface in Polymorph and enter the ***intercept*** command. After that, we go to our MQTT client and publish a message, **preferably with a long value** so that there are no problems with the sequence numbers of the ***TCP/IP*** session.



```
root@kali:~# mosquitto_pub -t `python -c "print('A'*1000)"` -m hello -i lo
root@kali:~# mosquitto_pub -t `python -c "print('A'*1000)"` -m hello -i lo
root@kali:~# mosquitto_pub -t `python -c "print('A'*1000)"` -m hello -i lo
root@kali:~# mosquitto_pub -t `python -c "print('A'*1000)"` -m hello -i lo
root@kali:~#
```

```
1524066945: New connection from 127.0.0.1 on port 1883.
1524066945: New client connected from 127.0.0.1 as lo (c1, k60).
1524066945: Sending CONNACK to lo (0, 0)
1524066945: Received PUBLISH from lo (d0, q0, r0, m0, 'mensajensaje
aje
aje
', ... (5 bytes))
1524066945: Socket error on client lo, disconnecting.
```



```
###[ IP ]###
  version   = 4
  ihl       = 5
  tos       = 0x0
  len       = 82
  id        = 54730
  flags     = DF
  frag      = 0
  ttl       = 64
  proto     = tcp
  chksum    = 0x66d9
  src       = 127.0.0.1
  dst       = 127.0.0.1
  \options   \
###[ TCP ]###
     sport     = 47174
     dport     = 1883
     seq       = 1748414953
     ack       = 8193627
     dataofs   = 8
     reserved  = 0
     flags     = PA
     window    = 342
     chksum    = 0x4de5
     urgptr    = 0
     options   = [('NOP', None), ('NOP', None), ('Timestamp', (1157800992, 1157800992))]
###[ MQTT fixed header ]###
        type      = PUBLISH
        DUP       = Disabled
        QOS       = At most once delivery
        RETAIN    = Disabled
        len       = 28
###[ MQTT publish ]###
           length    = 21
           topic     = 'mensajensaje\naje\naje\n'
           value     = 'hello'

PH:cap/t14 >
PH:cap/t14 > 
```

We can observe how the packet is modified in real time and the value produced by ***Radamsa*** is introduced. What we could do now is making a simple loop in ***Bash*** and let it test a significant number of test values. Also, the most common thing would be that we run the application that we are testing under a debugger, so we can capture the exceptions that occur and analyze them.

```
#!/bin/bash

while true; do
  mosquitto_pub -t `python3 -c "print('A'*10000)"` -m 'hello'
done
```

Finally, we can use the ***save*** command from the ***template*** interface to export the ***template*** and import it into Polymorph with the command ***polymorph -t template.json*** in another machine, so you can share it with your colleagues! I leave mine here!

https://gist.github.com/shramos/2b98867d2c344b36bfee6a7c799fbb8f