

CS536 Lab 3

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we don't make mistakes, we have happy accidents

Bob Ross

Problem 1.

1.1 System Set-Up, Traffic Generation, and Capture

To begin, the Ethernet interface `veth0` on one of the amber machines in the HAAS G050 lab was used. Promiscuous mode was required for sniffing Ethernet frames, which necessitated superuser privileges.

```
sudo /usr/local/etc/tcpdumpwrap-veth0 -c 32 -w - > etherlogfile
```

This command captures 32 Ethernet frames and stores them into `etherlogfile`. The captured file was placed under the directory `lab3/v1/` as required.

Traffic generation: Traffic was generated using the UDP ping application from Lab 2. The ping server was bound to IP address `192.168.1.1`, and the client was executed from the same machine with:

```
veth 'udppingc 192.168.1.1 8080 123456 8081 100'
```

Here, the `veth` wrapper executed the client on the virtual interface with IP `192.168.1.2`. This allowed packet exchange between `192.168.1.1` and `192.168.1.2` over a virtual Ethernet link. The configuration of `veth0` at the remote end was verified using:

```
veth 'ifconfig veth0'
```

1.2 Traffic Analysis

After generating sufficient traffic, the file `etherlogfile` was analyzed using Wireshark.

Step 1 - Opening in Wireshark: The file was opened in Wireshark with:

```
/usr/bin/wireshark etherlogfile
```

Wireshark automatically decoded the Ethernet, IP, and UDP headers, displaying packet structure. Results is shown in Figure 1 and 2.

[h]

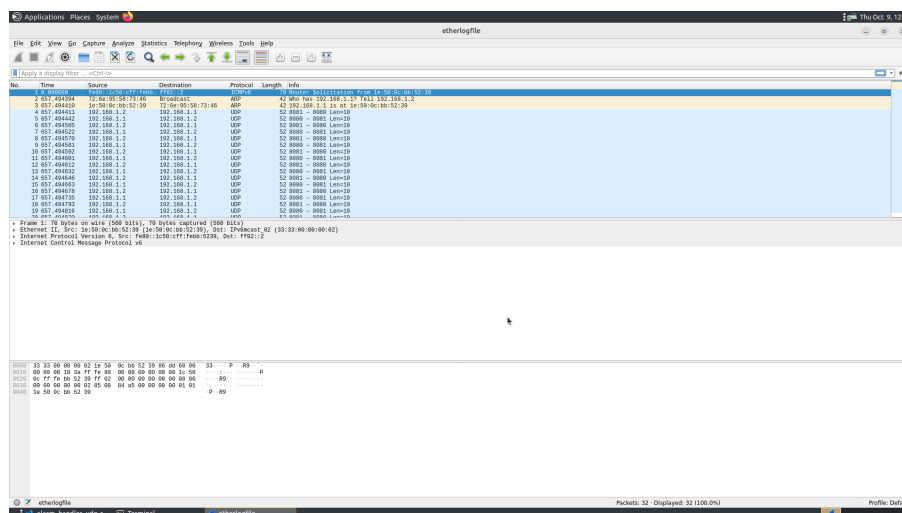


Figure 1: Wireshark environment

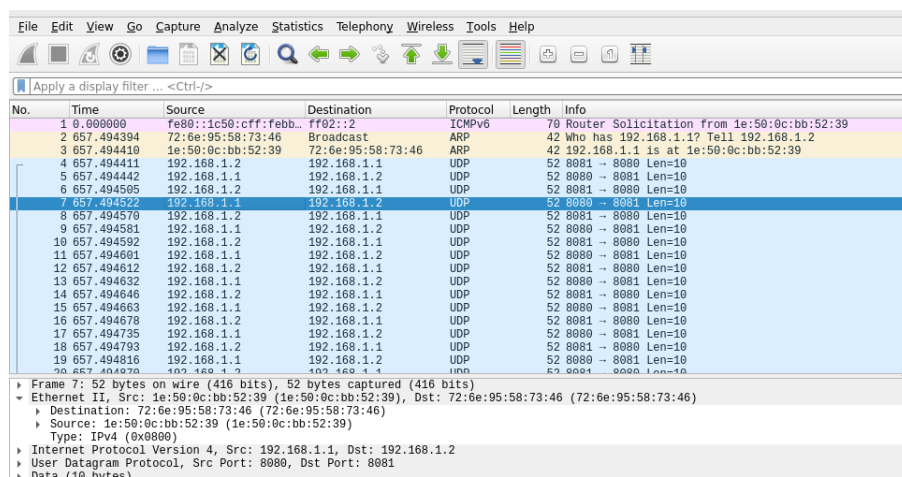


Figure 2: Wireshark closer look

Step 2 - Identifying MAC addresses: The MAC addresses corresponding to 192.168.1.1 and 192.168.1.2 were obtained using:

```
ifconfig -a
veth 'ifconfig -a'
```

These were then matched with the source and destination addresses in the Ethernet frames. Results is shown in Figure 3 and 4.

Note that 0xc0a80101 is hex for 192.168.1.1. Similarly 0xc0a80102 is hex for 192.168.1.2.

Step 3 - Checking Frame Type: The Ethernet Type field was inspected and confirmed to correspond to IPv4 (0x0800), meaning the frames used the DIX (Ethernet II) format. Results is shown in Figure 5.

Step 4 - Inspecting IP and UDP headers: The source and destination IP addresses, as well as port numbers, were confirmed to match the ones used in the `udppingc` application. Results is shown in Figure 6.

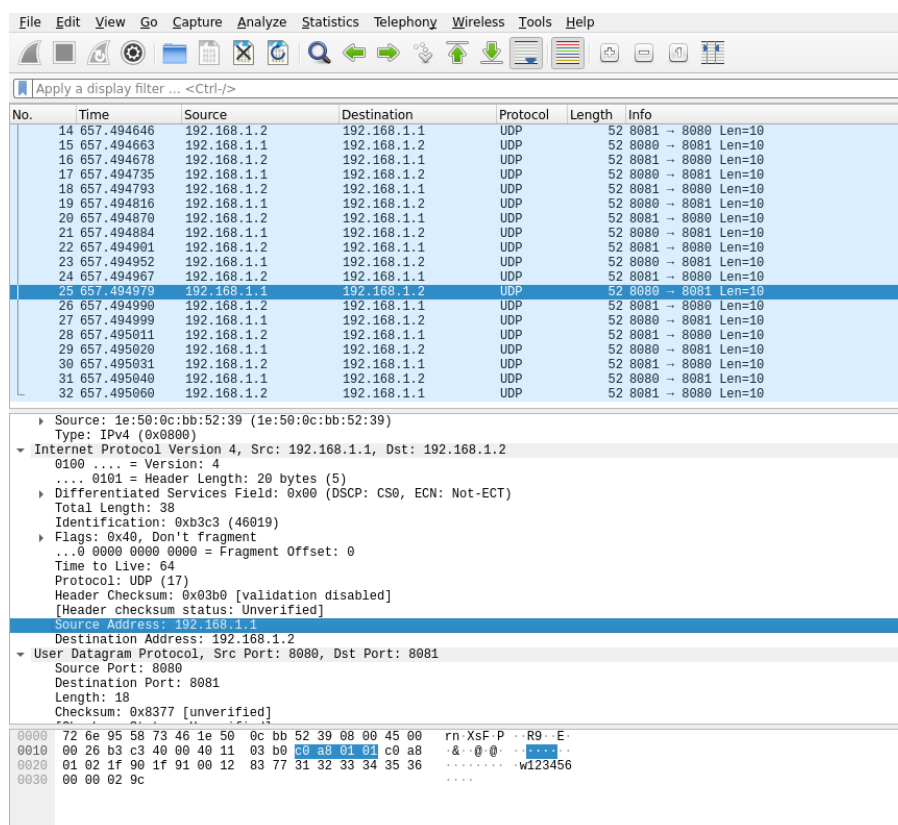


Figure 3: Source Mac Address

Step 5 - Inspecting application layer payload: The remaining bytes beyond the UDP header correspond to the application-layer payload sent via `sendto()`. By switching to “View → Packet Bytes” in Wireshark, the payload was viewed in raw hexadecimal format to verify transmitted data. Results is shown in Figure 7.

We can verify that this payload is consistent among packets. Results is shown in Figure 8.

Verification with tcpdump: To double-check, the following command was used:

```
tcpdump -r - < etherlogfile
```

This confirmed consistent IP addresses, port numbers, and packet structure as seen in Wireshark. Results is shown in Figure 9.

Summary

- The Ethernet frames were confirmed to use Ethernet II (DIX) format with Type field value 0x0800.
- IP headers contained source and destination IPs of 192.168.1.1 and 192.168.1.2.
- UDP headers contained the correct source (8080) and destination (8081) port numbers used by the client and server.
- The application payload matched the data generated by the `udppingc` ping client.
- Both Wireshark and tcpdump produced consistent interpretations of the captured data.

No.	Time	Source	Destination	Protocol	Length	Info
14	657.494646	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
15	657.494663	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
16	657.494678	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
17	657.494735	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
18	657.494793	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
19	657.494816	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
20	657.494870	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
21	657.494884	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
22	657.494901	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
23	657.494952	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
24	657.494967	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
25	657.494990	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
26	657.494999	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
27	657.494999	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
28	657.495011	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
29	657.495020	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
30	657.495031	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
31	657.495040	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
32	657.495060	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10

▶ Source: 1e:50:0c:bb:52:39 (1e:50:0c:bb:52:39)
 Type: IPv4 (0x0800)
 ▶ Internet Protocol Version 4, Src: 192.168.1.1, Dst: 192.168.1.2
 0100 = Version: 4
 0101 = Header Length: 20 bytes (5)
 ▶ Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
 Total Length: 38
 Identification: 0xb3c3 (46019)
 Flags: 0x40, Don't fragment
 ...0 0000 0000 0000 = Fragment Offset: 0
 Time to Live: 64
 Protocol: UDP (17)
 Header Checksum: 0x03b0 [validation disabled]
 [Header checksum status: Unverified]
 Source Address: 192.168.1.1
 Destination Address: 192.168.1.2
 ▶ User Datagram Protocol, Src Port: 8080, Dst Port: 8081
 Source Port: 8080
 Destination Port: 8081
 Length: 18
 Checksum: 0x8377 [unverified]

0000 72 6e 95 58 73 46 1e 50 0c bb 52 39 08 00 45 00 rn:XsF:P..R9..E-
 0010 00 26 b3 c3 40 00 40 11 03 b0 c0 a8 01 01 00 00 &..@.@.....
 0020 01 02 1f 90 1f 91 00 12 83 77 31 32 33 34 35 36w123456
 0030 00 00 02 9c

Figure 4: Destination Mac Address

No.	Time	Source	Destination	Protocol	Length	Info
14	657.494646	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
15	657.494663	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
16	657.494678	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
17	657.494735	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
18	657.494793	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
19	657.494816	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
20	657.494870	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
21	657.494884	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
22	657.494901	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
23	657.494952	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
24	657.494967	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
25	657.494990	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
26	657.494999	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
27	657.494999	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
28	657.495011	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
29	657.495020	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
30	657.495031	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
31	657.495040	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
32	657.495060	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10

▶ Source: 1e:50:0c:bb:52:39 (1e:50:0c:bb:52:39)
 Address: 1e:50:0c:bb:52:39 (1e:50:0c:bb:52:39)
 11 = L6 bit: Locally administered address (this is NOT the factory default)
 0 = IG bit: Individual address (unicast)
 Type: IPv4 (0x0800)
 ▶ Internet Protocol Version 4, Src: 192.168.1.1, Dst: 192.168.1.2
 0100 = Version: 4
 0101 = Header Length: 20 bytes (5)
 ▶ Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
 Total Length: 38
 Identification: 0xb3c3 (46019)
 Flags: 0x40, Don't fragment
 ...0 0000 0000 0000 = Fragment Offset: 0
 Time to Live: 64
 Protocol: UDP (17)
 Header Checksum: 0x03b0 [validation disabled]
 [Header checksum status: Unverified]
 Source Address: 192.168.1.1
 Destination Address: 192.168.1.2
 ▶ User Datagram Protocol, Src Port: 8080, Dst Port: 8081
 Source Port: 8080

0000 72 6e 95 58 73 46 1e 50 0c bb 52 39 08 00 45 00 rn:XsF:P..R9..E-
 0010 00 26 b3 c3 40 00 40 11 03 b0 c0 a8 01 01 c0 a8 &..@.@.....
 0020 01 02 1f 90 1f 91 00 12 83 77 31 32 33 34 35 36w123456
 0030 00 00 02 9c

Figure 5: Ethernet Type

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter ... <Ctrl-/>

No.	Time	Source	Destination	Protocol	Length	Info
14	657.494646	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
15	657.494663	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
16	657.494678	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
17	657.494735	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
18	657.494793	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
19	657.494816	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
20	657.494870	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
21	657.494884	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
22	657.494901	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
23	657.494952	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
24	657.494967	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
25	657.494979	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
26	657.494990	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
27	657.494999	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
28	657.495011	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
29	657.495020	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
30	657.495031	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
31	657.495040	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
32	657.495060	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10

Frame 25: 52 bytes on wire (416 bits), 52 bytes captured (416 bits) on interface 0

Ethernet II, Src: 1e:50:0c:bb:52:39 (1e:50:0c:bb:52:39), Dst: 72:6e:95:58:73:46 (72:6e:95:58:73:46)

Internet Protocol Version 4, Src: 192.168.1.1, Dst: 192.168.1.2

User Datagram Protocol, Src Port: 8080, Dst Port: 8081

Source Port: 8080
Destination Port: 8081
Length: 18
Checksum: 0x8377 [unverified]
[Checksum Status: Unverified]
[Stream index: 0]
[Timestamps]
UDP payload (10 bytes)
Data (10 bytes)
Data: 3132333435360000029c
[Length: 10]

0000 72 6e 95 58 73 46 1e 50 0c bb 52 39 08 00 45 00 rn XsF P . R9 . E .
0010 00 26 b3 c3 40 00 40 11 03 b0 c0 a8 01 01 c0 a8 . & . 0 . 0
0020 01 02 1f 90 1f 91 00 12 83 77 31 32 33 34 35 36 w123456
0030 00 00 02 9c

Figure 6: UDP Headers

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter ... <Ctrl-/>

No.	Time	Source	Destination	Protocol	Length	Info
14	657.494646	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
15	657.494663	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
16	657.494678	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
17	657.494735	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
18	657.494793	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
19	657.494816	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
20	657.494870	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
21	657.494884	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
22	657.494901	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
23	657.494952	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
24	657.494967	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
25	657.494979	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
26	657.494990	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
27	657.494999	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
28	657.495011	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
29	657.495020	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
30	657.495031	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
31	657.495040	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
32	657.495060	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10

Frame 25: 52 bytes on wire (416 bits), 52 bytes captured (416 bits) on interface 0

Ethernet II, Src: 1e:50:0c:bb:52:39 (1e:50:0c:bb:52:39), Dst: 72:6e:95:58:73:46 (72:6e:95:58:73:46)

Internet Protocol Version 4, Src: 192.168.1.1, Dst: 192.168.1.2

User Datagram Protocol, Src Port: 8080, Dst Port: 8081

Source Port: 8080
Destination Port: 8081
Length: 18
Checksum: 0x8377 [unverified]
[Checksum Status: Unverified]
[Stream index: 0]
[Timestamps]
UDP payload (10 bytes)
Data (10 bytes)
Data: 3132333435360000029c
[Length: 10]

0000 72 6e 95 58 73 46 1e 50 0c bb 52 39 08 00 45 00 rn XsF P . R9 . E .
0010 00 26 b3 c3 40 00 40 11 03 b0 c0 a8 01 01 c0 a8 . & . 0 . 0
0020 01 02 1f 90 1f 91 00 12 83 77 31 32 33 34 35 36 w123456
0030 00 00 02 9c

Figure 7: Payload View

The image shows a Wireshark packet capture interface. The top menu bar includes File, Edit, View, Go, Capture, Analyze, Statistics, Telephony, Wireless, Tools, and Help. Below the menu is a toolbar with various icons. A display filter is set to "Apply a display filter ... <Ctrl-/>".

No.	Time	Source	Destination	Protocol	Length	Info
14	657.494646	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
15	657.494663	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
16	657.494678	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
17	657.494735	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
18	657.494793	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
19	657.494816	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
20	657.494870	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
21	657.494884	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
22	657.494901	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
23	657.494952	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
24	657.494967	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
25	657.494979	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
26	657.494990	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
27	657.494999	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
28	657.495011	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
29	657.495020	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
30	657.495031	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10
31	657.495040	192.168.1.1	192.168.1.2	UDP	52	8080 → 8081 Len=10
32	657.495060	192.168.1.2	192.168.1.1	UDP	52	8081 → 8080 Len=10

Packet 28 details:

- Frame 28: 52 bytes on wire (416 bits), 52 bytes captured (416 bits)
- Ethernet II, Src: 72:6e:95:58:73:46 (72:6e:95:58:73:46), Dst: 1e:50:0c:bb:52:39 (1e:50:0c:bb:52:39)
- Internet Protocol Version 4, Src: 192.168.1.2, Dst: 192.168.1.1
- User Datagram Protocol, Src Port: 8081, Dst Port: 8080
 - Source Port: 8081
 - Destination Port: 8080
 - Length: 18
 - Checksum: 0x8377 [unverified]
 - [Checksum Status: Unverified]
 - [Stream index: 0]
 - [Timestamps]
 - UDP payload (10 bytes)
- Data (10 bytes)
 - Data: 3132333435360000029e
 - [Length: 10]

Packet bytes (hex and ASCII):

```

0000  1e 50 0c bb 52 39 72 6e 95 58 73 46 08 00 45 00  .P..R9rn..XsF..E.
0010  00 26 71 60 40 00 40 11 46 13 c0 a8 01 02 c0 a8  .&q@.@.F.....
0020  01 01 1f 91 1f 90 00 12 83 77 31 32 33 34 35 36  .....w123456
0030  90 00 02 9e                                     ....

```

Figure 8: Checking payload consistency

```

data 57 $ tcpdump -r - < etherlogfile
reading from file -, link-type EN10MB (Ethernet), snapshot length 262144
12:00:13.240318 IP6 fe80::1c50:cff:febb:5239 > ip6-allrouters: ICMP6, router solicitation, length 16
12:11:10.734712 ARP, Request who-has 192.168.1.1 tell 192.168.1.2, length 28
12:11:10.734728 ARP, Reply 192.168.1.1 is-at 1e:50:0c:bb:52:39 (oui Unknown), length 28
12:11:10.734729 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.734760 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.734823 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.734840 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.734888 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.734899 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.734910 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.734919 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.734930 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.734950 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.734964 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.734981 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.734996 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735053 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735111 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735134 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735188 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735202 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735219 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735270 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735285 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735297 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735308 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735317 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735329 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735338 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735349 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
12:11:10.735358 IP 192.168.1.1.8080 > 192.168.1.2.8081: UDP, length 10
12:11:10.735378 IP 192.168.1.2.8081 > 192.168.1.1.8080: UDP, length 10
data 58 $ 

```

Figure 9: TCP dump output

Problem 2.

Asynchronous Concurrency Management

The sender implementation introduces asynchrony through the `SIGIO` signal handler, which processes incoming ACK packets while the main synchronous loop transmits data packets. This creates potential race conditions when both the signal handler and main loop access shared data structures, specifically the `ack_received[]` array that tracks which packets have been successfully acknowledged.

Our implementation uses a reader-writer separation strategy that avoids the need for complex synchronization primitives such as mutexes or signal masking. If you look at the code:

- Synchronous code (main loop): Only reads from the `ack_received[]` array
- Asynchronous code (`SIGIO` handler): Only writes to the `ack_received[]` array

By doing so, we avoid race conditions because:

1. Neither component performs atomic read-modify-write sequences on shared data
2. The signal handler only transitions flags from 0 to 1, never reverses them
3. If the main loop reads a stale value (0 instead of 1), it simply retransmits the packet unnecessarily, which is safe because the receiver handles duplicates correctly
4. On modern architectures, byte-sized writes are atomic which means we won't have any incomplete reads of individual array elements

Thus by enforcing strict read-only and write-only roles for the synchronous and asynchronous components respectively, our implementation achieves correct concurrent operation without the overhead and complexity of explicit synchronization primitives.

Duplicate File Transfer Initiation Packet Handling

After the receiver sends an acknowledgment to a file transfer initiation packet, it sets a 250ms timer to wait for the first data packet. During this waiting period, duplicate initiation packets may arrive from the sender: either due to network delays causing the sender to timeout and retransmit, or due to genuine packet duplication in the network. The receiver must handle these duplicates correctly without disrupting the established session.

In our approach, the receiver maintains a `transfer_active` flag that tracks whether a file transfer session is currently in progress. This flag transitions through three states:

1. Idle (`transfer_active = 0`): Waiting for a new initiation packet
2. Handshake (`transfer_active = 1, next_expected = 0`): Init ACK sent, waiting for first data packet
3. Active transfer (`transfer_active = 1, next_expected > 0`): Receiving data packets

If a duplicate initiation packet (16 bytes) arrives before the first data packet, the receiver responds with an idempotent acknowledgment and resends the 6-byte filename ACK without modifying any state (memory buffers, tracking arrays, session parameters remain unchanged). This is safe because multiple identical ACKs don't corrupt protocol state. Moreover, if the original ACK was lost, the duplicate provides recovery. We will then restart the 250ms timer automatically and wait for the data. Once the first data packet arrives, initiation packets from different senders are ignored to prevent session hijacking. Note that once the connection is established, getting 16 byte packets (whole packet or remainder of a packet) will not cause any issues since we will be in the third stage.

Performance Optimization

Experimental Setup and Result

We conducted performance experiments using a 102.0 kB test file to evaluate the impact of protocol parameters on transfer completion time. The two primary tunable parameters are:

- Micropace: Delay in microseconds between consecutive packet transmissions
- Payload size: Number of data bytes per UDP packet (excluding 4-byte sequence number header)

All tests were performed in the local lab environment (low latency, high bandwidth, minimal background loss). Below is our result:

Micropace (μ s)	Payload (bytes)	Transfer Time (ms)
500	200	100
500	500	35
500	1000	22
500	2000	14
500	3000	10
300	1000	26
100	1000	15

Table 1: Transfer completion time for 102.0 kB file

Analysis

Impact of Payload Size Holding micropace constant at 500 μ s while varying payload size reveals a clear inverse relationship between payload size and transfer time. Key observations:

- Larger payloads reduce the number of packets required: 102 kB with 200-byte payload requires 510 packets, while 3000-byte payload requires only 34 packets
- Fewer packets mean less per-packet overhead (UDP/IP headers, system calls, protocol bookkeeping)
- Transfer time improves dramatically: from 100ms (200B payload) to 10ms (3000B payload)

However, payload size is constrained by the maximum UDP payload that avoids IP fragmentation. We limited our experiments to payloads ≤ 3000 bytes to stay safely below the typical MTU of 1500 bytes.

Impact of Micropace Holding payload constant at 1000 bytes while varying micropace shows diminishing returns:

- Reducing micropace from 500 μ s to 100 μ s improves time from 22ms to 15ms (32% improvement)
- However, reducing micropace from 500 μ s to 300 μ s *increases* time from 22ms to 26ms

The non-monotonic behavior at 300 μ s suggests measurement variability or system scheduling effects at small time scales. The general trend shows that lower micropace (faster transmission rate) reduces completion time by minimizing idle time between packet transmissions.

Through iterative experimentation, we identified that a configuration of approximately:

- **Micropace:** 300 μ s
- **Payload:** 8000 bytes

yields transfer times around **3ms** for the 102 kB file in our lab environment. This is a 33 \times speedup compared to the baseline configuration (500 μ s, 200B payload).

Final Notes

While decreasing micropace improves performance in ideal conditions, excessively low values introduce reliability concerns:

- Bursts of packets may exceed the receiver's socket buffer capacity, causing kernel-level packet drops
- In shared network environments, aggressive sending can overwhelm switch buffers or compete unfairly with other traffic
- Higher packet loss rates trigger more retransmissions, potentially negating performance gains

We observed that micropace values below 100 μ s occasionally resulted in failed transfers due to excessive packet loss, even in the controlled lab environment.

While larger payloads improve efficiency, they have drawbacks:

- Larger payloads mean more wasted bandwidth when a packet is lost and must be retransmitted
- For small files, large payloads may not improve performance and can increase latency variance

Performance optimization in reliable UDP protocols involves balancing throughput (achieved through large payloads and low micropace) against reliability (which degrades under aggressive parameters). For small file transfers in low-loss, low-latency environments like our lab, the protocol can achieve sub-5ms completion times with careful parameter tuning. However, these optimal parameters are environment-specific and may require adjustment for production deployments with higher loss rates, variable latency, or shared network resources.

Bonus

File: m2.ch1.2024-02-19.pcap

Selected interval: 13:00:05.07 – 13:00:05.60 (first 0.5 s, 806 frames)

- **Network type:** 802.11b/g/n (2.4 GHz band, Channel 1).
- **Frame types observed:** Predominantly *Beacon* frames, with occasional *Probe Request*, *Acknowledgment*, *Clear-to-Send (CTS)*, and *Null Function* frames.
- **Data rates:** Initially 1 Mbps for the first few frames, later increasing up to 12 Mbps.
- **SSID(s):** PAL3.0, PAL-Recreational, attwifi, eduroam
- **Signal strength** ≈ -65 dBm
- **Signal strength ratio** $\approx [-5, 90]$ dBm
- **Notes:** The presence of multiple beacon frames suggests nearby access points broadcasting their presence. The mixture of management and control frames indicates active association and channel scanning activity.

Below is a summary of our result:

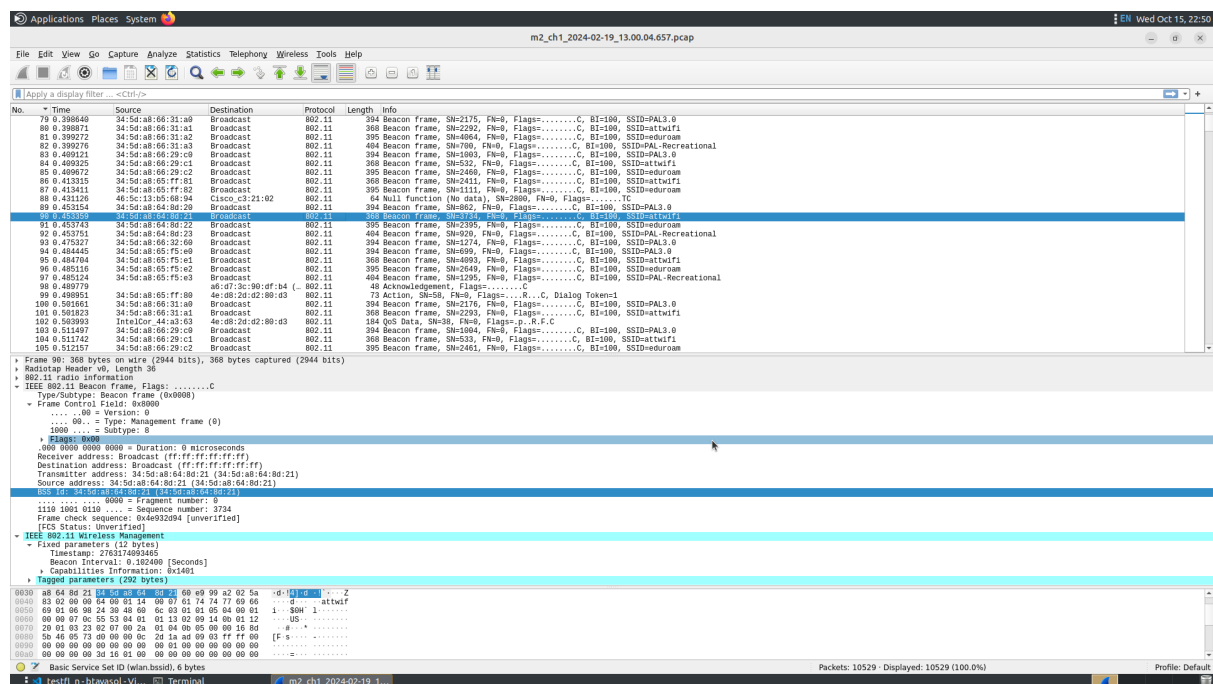


Figure 10: Bssid and ssid

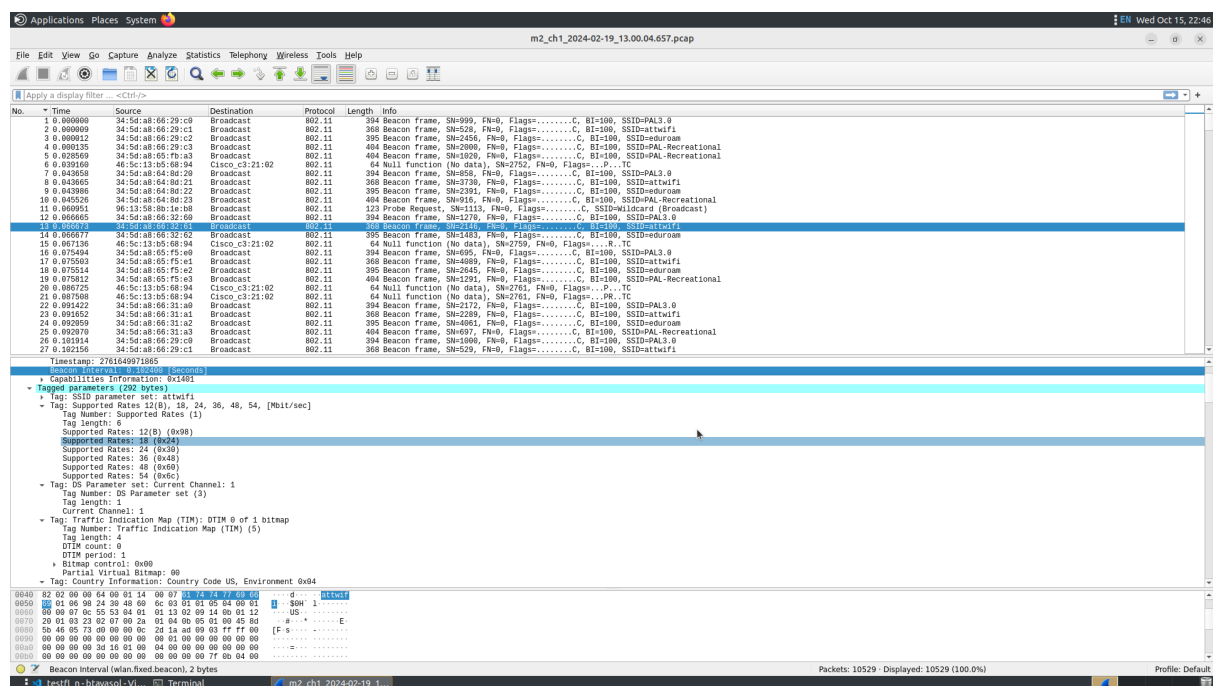


Figure 11: Channel info

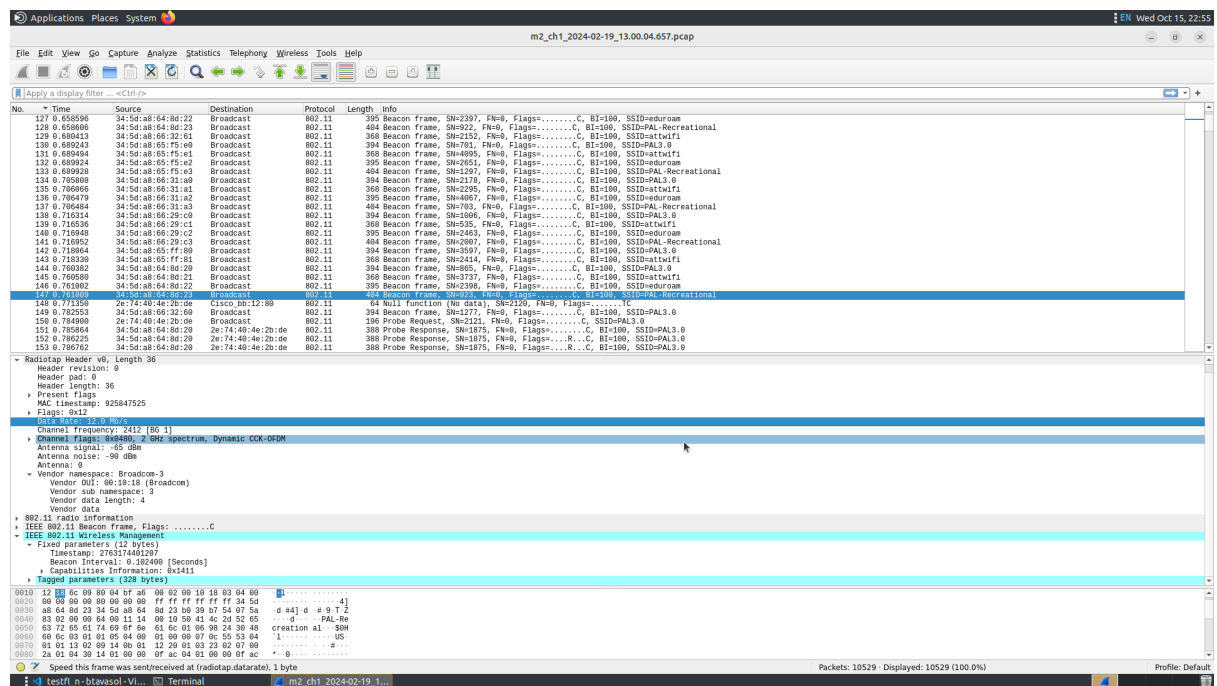


Figure 12: Data rate info

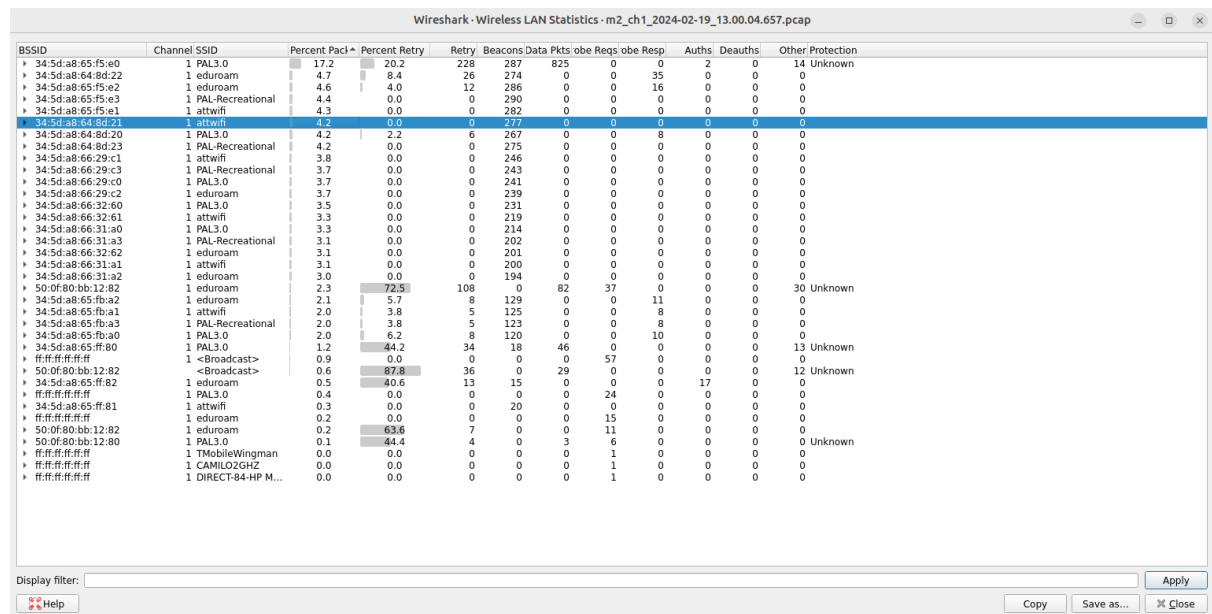


Figure 13: Frame type summary

137 0.796484	34:5d:a8:66:31:a3	Broadcast	802.11	404 Beacon frame, SN=703, FN=0, Flags=.....C, BI=100, SSID=PAL-Recreational
138 0.716314	34:5d:a8:66:29:c9	Broadcast	802.11	394 Beacon frame, SN=1006, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
139 0.716536	34:5d:a8:66:29:c1	Broadcast	802.11	368 Beacon frame, SN=535, FN=0, Flags=.....C, BI=100, SSID=attwifi
140 0.716948	34:5d:a8:66:29:c2	Broadcast	802.11	395 Beacon frame, SN=2463, FN=0, Flags=.....C, BI=100, SSID=eduroam
141 0.716952	34:5d:a8:66:29:c3	Broadcast	802.11	404 Beacon frame, SN=2007, FN=0, Flags=.....C, BI=100, SSID=PAL-Recreational
142 0.718064	34:5d:a8:65:ff:80	Broadcast	802.11	394 Beacon frame, SN=3597, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
143 0.718330	34:5d:a8:65:ff:81	Broadcast	802.11	368 Beacon frame, SN=2414, FN=0, Flags=.....C, BI=100, SSID=attwifi
144 0.760382	34:5d:a8:64:8d:20	Broadcast	802.11	394 Beacon frame, SN=805, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
145 0.760580	34:5d:a8:64:8d:21	Broadcast	802.11	368 Beacon frame, SN=3737, FN=0, Flags=.....C, BI=100, SSID=attwifi
146 0.761802	34:5d:a8:64:8d:22	Broadcast	802.11	395 Beacon frame, SN=2398, FN=0, Flags=.....C, BI=100, SSID=eduroam
147 0.771350	2e:74:40:4e:2b:de	Cisco bb:12:80	802.11	64 Null function (No data), SN=2120, FN=0, Flags=.....TC
149 0.782553	34:5d:a8:66:32:60	Broadcast	802.11	394 Beacon frame, SN=1277, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
150 0.784999	2e:74:40:4e:2b:de	Broadcast	802.11	196 Probe Request, SN=2121, FN=0, Flags=.....C, SSID=PAL3.0
151 0.785064	34:5d:a8:64:8d:20	2e:74:40:4e:2b:de	802.11	388 Probe Response, SN=1875, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
152 0.786225	34:5d:a8:64:8d:20	2e:74:40:4e:2b:de	802.11	388 Probe Response, SN=1875, FN=0, Flags=.....R...C, BI=100, SSID=PAL3.0
153 0.786762	34:5d:a8:64:8d:20	2e:74:40:4e:2b:de	802.11	388 Probe Response, SN=1875, FN=0, Flags=.....R...C, BI=100, SSID=PAL3.0
MAC timestamp: 925847525				
Flags: 0x12				
Data Rate: 12.0 Mb/s				
Channel frequency: 2412 [B6 1]				
Channel flags: 0x0480, 2 GHz spectrum, Dynamic CCK-OFDM				
Antenna signal: -65 dBm				
Antenna noise: -90 dBm				
Antenna: 0				
Vendor namespace: Broadcom-3				
Vendor OUI: 00:10:18 (Broadcom)				
Vendor sub namespace: 3				
Vendor data length: 4				
Vendor data				
802.11 radio information				
PHY type: 802.11g (ERP) (6)				
Proprietary mode: None (0)				
Data rate: 12.0 Mb/s				
Channel: 1				
Frequency: 2412MHz				
Signal strength (dBm): -65 dBm				
Noise level (dBm): -90 dBm				
Signal/noise ratio (dB): 25 dB				
TSF timestamp: 925847525				
Duration: 268µs				
IEEE 802.11 Beacon Frame, Flags:C				
IEEE 802.11 Wireless Management				
0020	00 00 00 00 00 00 00 00 ff ff ff ff ff 34 5d4]		
0030	a8 64 8d 23 34 5d a8 64 8d 23 00 39 b7 54 07 5a	..d #4] d # 9 T Z		
0040	63 02 00 00 64 00 11 14 00 10 50 41 4c 2d 52 65	...d ..PAL-Re		
0050	63 72 65 61 74 69 6f 6e 61 6c 01 06 98 24 30 48	creation al...\$0H		
0060	60 6c 03 01 01 05 04 00 01 00 00 07 0c 55 53 04	..l.....US..		
0070	01 01 13 02 09 14 0b 01 12 20 01 03 23 02 07 00B.....		
0080	2a 01 04 30 14 01 00 00 0f ac 04 01 00 00 0f ac	..#..0.....		
0090	04 01 00 00 0f ac 01 28 00 06 03 c9 b7 00 0b 05{ ..6.....		

Figure 14: Signal strength

ApplicationsPlacesSystem

m2_ch1_2024-02-19_13.00.04.657.pcap

FileEditViewGoCaptureAnalyzeStatisticsTelephonyWirelessToolsHelp

[wlan.bssid==34:5d:a8:64:8d:20 | wlan.ssid==PAL3.0]

No.	Time	Source	Destination	Protocol	Length	Info
18.	0.164489	34:5d:a8:65:ff:80	Broadcast	802.11	394	Beacon frame, SN=774, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
18.	0.181053	34:5d:a8:66:31:a3	Broadcast	802.11	394	Beacon frame, SN=2251, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
18.	0.191503	34:5d:a8:66:29:c3	Broadcast	802.11	394	Beacon frame, SN=1079, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
18.	0.235518	34:5d:a8:64:8d:20	Broadcast	802.11	394	Beacon frame, SN=938, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.263476	34:5d:a8:66:31:a3	Broadcast	802.11	394	Beacon frame, SN=2252, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.293904	34:5d:a8:66:29:c3	Broadcast	802.11	394	Beacon frame, SN=1080, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.322116	34:5d:a8:65:ff:80	Broadcast	802.11	394	Beacon frame, SN=802, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.338750	34:5d:a8:64:8d:20	Broadcast	802.11	394	Beacon frame, SN=939, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.369165	34:5d:a8:66:31:a3	Broadcast	802.11	394	Beacon frame, SN=1351, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.369280	34:5d:a8:65:ff:80	Broadcast	802.11	394	Beacon frame, SN=776, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.396279	34:5d:a8:66:29:c3	Broadcast	802.11	394	Beacon frame, SN=1081, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.422100	34:5d:a8:65:ff:80	Broadcast	802.11	394	Beacon frame, SN=774, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.440319	34:5d:a8:64:8d:20	Broadcast	802.11	394	Beacon frame, SN=940, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.462597	34:5d:a8:66:31:a3	Broadcast	802.11	394	Beacon frame, SN=1352, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.471675	34:5d:a8:65:ff:80	Broadcast	802.11	394	Beacon frame, SN=777, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.488287	34:5d:a8:66:31:a3	Broadcast	802.11	394	Beacon frame, SN=2254, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.498701	34:5d:a8:66:29:c3	Broadcast	802.11	394	Beacon frame, SN=1082, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.500509	34:5d:a8:65:ff:80	Broadcast	802.11	394	Beacon frame, SN=3674, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
19.	0.564957	34:5d:a8:66:31:a3	Broadcast	802.11	394	Beacon frame, SN=1353, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
20.	0.574065	34:5d:a8:65:ff:80	Broadcast	802.11	394	Beacon frame, SN=778, FN=0, Flags=.....C, BI=100, SSID=PAL3.0
20.	0.590714	34:5d:a8:66:31:a3	Broadcast	802.11	394	Beacon frame, SN=2255, FN=0, Flags=.....C, BI=100, SSID=PAL3.0

Data Rate: 12.0 Mb/s

Channel frequency: 2412 [B6 1]

Channel flags: 0x0480, 2 GHz spectrum, Dynamic CCK-OFDM

Antenna signal: -89 dBm

Antenna noise: -91 dBm

Antenna: 0

Vendor namespace: Broadcom-3

Vendor OUI: 00:10:18 (Broadcom)

Vendor sub namespace: 3

Vendor data length: 4

Vendor data

802.11 radio information

PHY type: 802.11g (ERP) (6)

Proprietary mode: None (0)

Data rate: 12.0 Mb/s

Channel: 1

Frequency: 2412MHz

Signal strength (dBm): -89 dBm

Noise level (dBm): -91 dBm

Signal/noise ratio (dB): 2 dB

0020 02 00 00 00 00 00 00 ff ff ff ff ff 34 5d
0030 a8 65 ff a0 34 5d a8 65 ff a0 30 32 00 11 9b bb
0040 82 02 00 00 64 00 11 14 00 00 50 41 4c 33 2e 30
0050 01 06 98 24 30 48 60 6c 03 01 01 05 04 00 01 00
0060 00 07 0c 55 53 04 01 01 13 02 09 14 0b 01 12 20
0070 01 03 23 02 07 00 2a 01 04 30 14 01 00 00 0f ac

Signal strength (dBm) | wlan.radio.signal.dbm |

Testet n-Biosvol-Vi... Terminal

m2_ch1_2024-02-19_13.00.04.657.pcap

WireShark-Wireless

WireShark-Wireless

Packets: 10529 · Displayed: 1430 (13.6%) · Marked: 1 (0.0%)

Profile: Default

Figure 15: SNR of hightraffic basic service sets and their MAC addresses

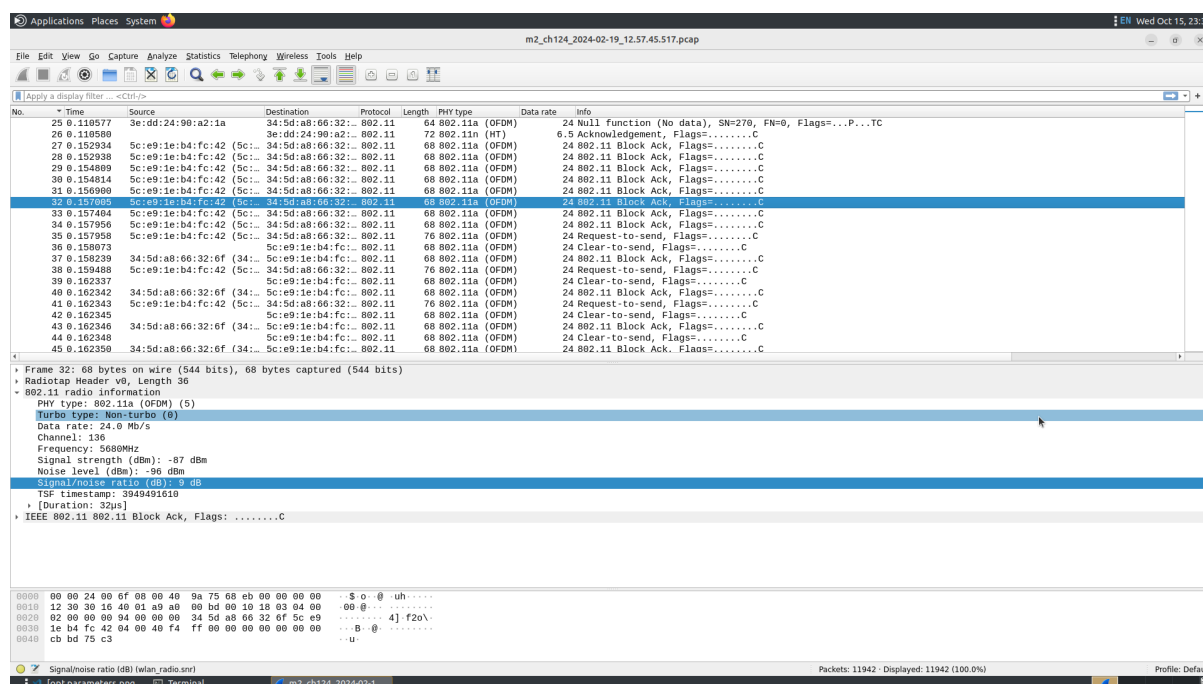


Figure 16: SNR, network type, and signal strength

File: m2_ch124_2024-02-19.pcap

Selected interval: [Specify e.g., 12:57:45.88 – 12:57:46.39] (about 256 packets)

- **Network type:** 802.11a (5 GHz band, Channel 136).
- **Frame types observed:** Mostly Block Ack, RTS and CTS, some beacon
- **Data rates:** 24 to 12 Mb/s (we also have 6, 6.5, and 48)
- **SSID(s):** Same as before
- **Signal strength:** ≈ -80 dBm
- **Signal strength ratio:** $\approx [9, 15]$ dBm
- **Notes:** Signal seems to be stronger than before. Also we have a wider band.

Below is a summary of our results:

File: m2_ch153_2024-02-19.pcap

Selected interval: The complete interval.

- **Network type:** Likely 802.11a same as before (5 GHz band, Channel 153).
- **Frame types observed:** Block Ack, RTS, CTS, VHT/HE NDP Announcement, Probe Request
- **Data rates:** 6, 6.5 and 24
- **SSID(s):** Wildcard, PAL3.0, Hilton Honors, Rajkiran, FreeORDWiFi, SSN, Hotel bobo

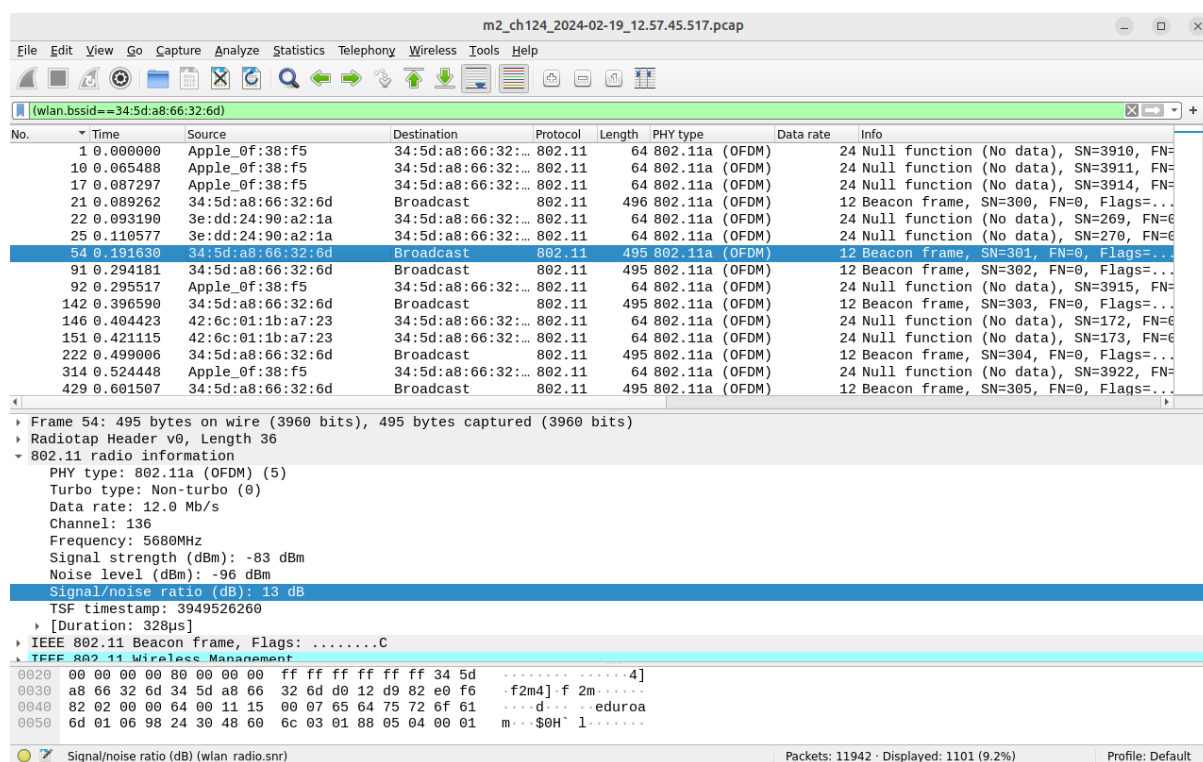


Figure 17: SNR of hightraffic basic service sets and their MAC addresses

- **Signal strength: -86 dBm**
- **Signal strength ratio: 45 dBm**
- **Notes:** Same band as before. Better signal ratio. Less different data rates. Different SSIDs.

Below is a summary of our findings:

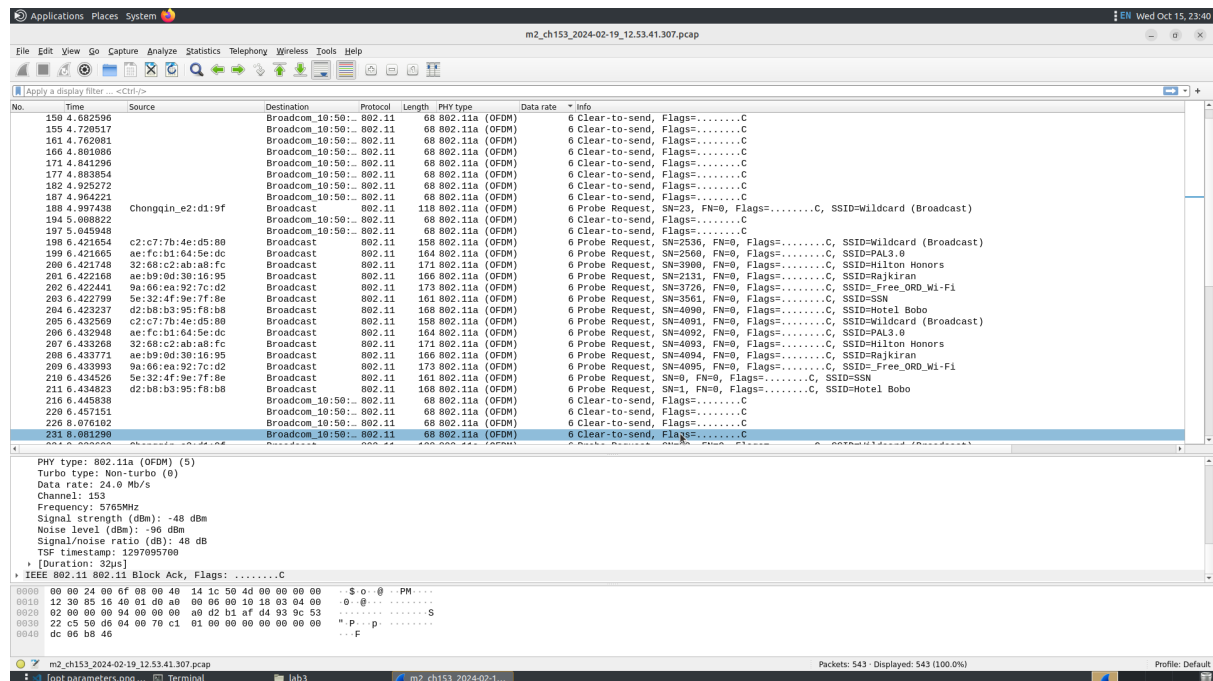


Figure 18: SSID and datarates

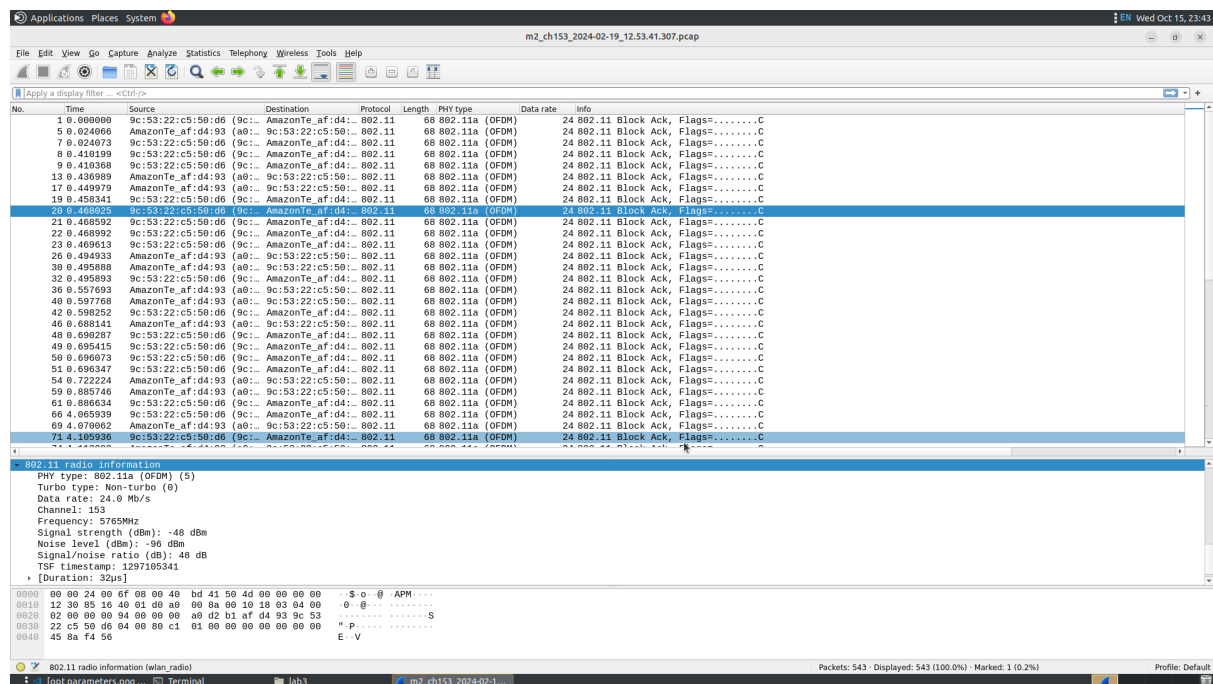


Figure 19: SNR and strength

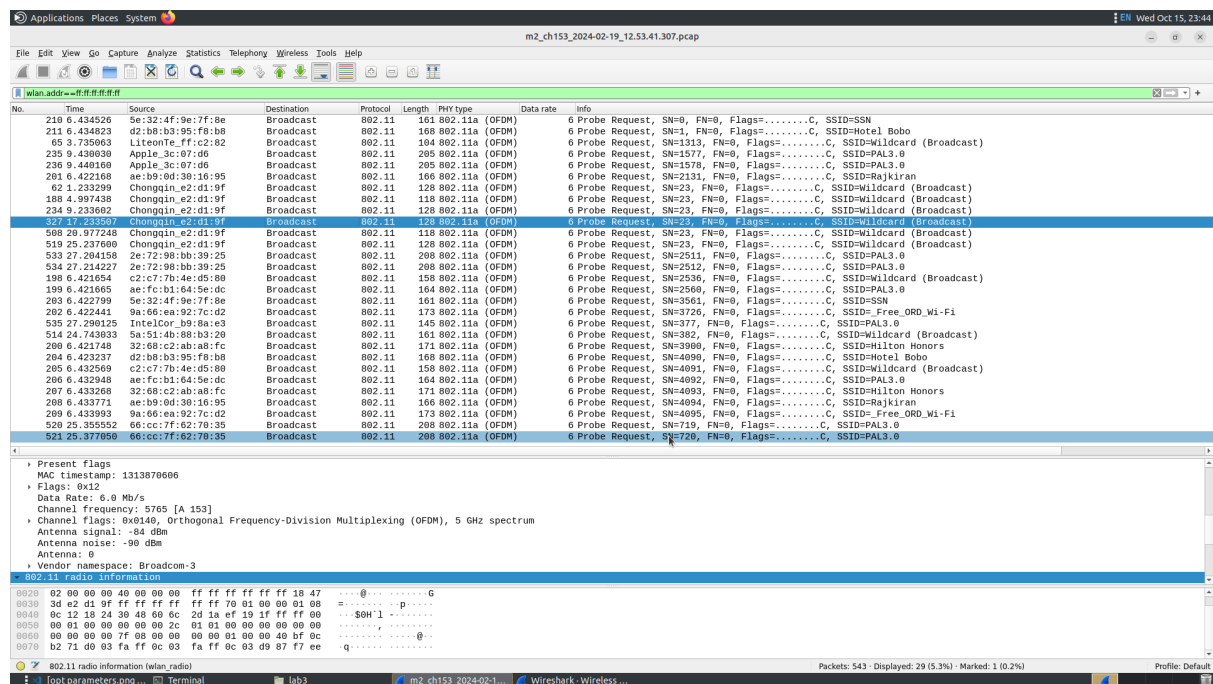


Figure 20: SNR of hightraffic basic service sets and their MAC addresses