Basic Principles in Networking
Assignment 1 - Wi-Fi measurement
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Note to professors: Our laptop is using Windows OS and we use windows command lines in cmd/PowerShell for this assignment instead of linux command in linux OS

I) Wifi AP Scanning

1: Check the configuration of the Wi-Fi network interface on your own computer

This is information on configuration of the Wi-Fi network interface, which has over 7 features listed in the requirements: SSID, BSSID, used channel, band, network protocol (802.11n), supported data rates and signal strength

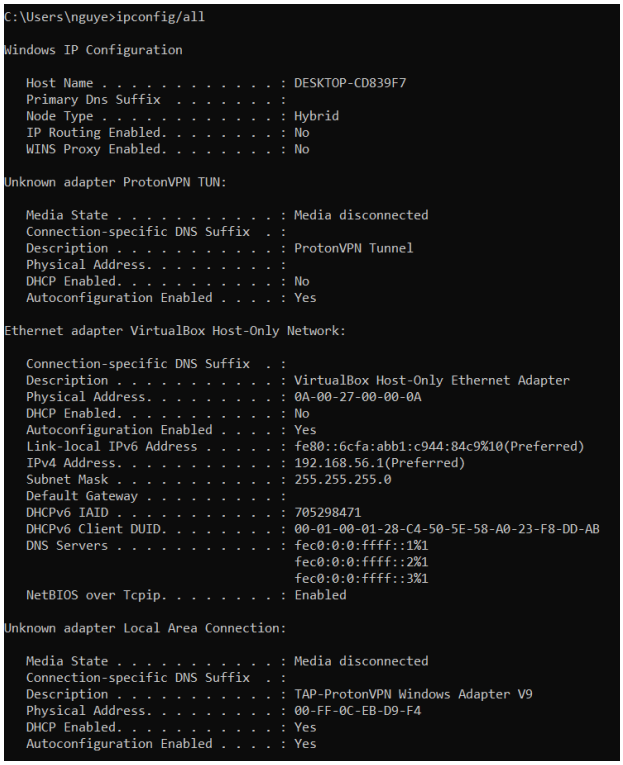
Command line: netsh wlan show interfaces

```
Microsoft Windows [Version 10.0.19043.1466]
(c) Microsoft Corporation. All rights reserved.

C:\Windows\system32>netsh wlan show interfaces

There is 1 interface on the system:

    Name                   : Wi-Fi
    Description            : Intel(R) Wireless-AC 9260 160MHz
    GUID                   : 7c5ab65a-7c26-44a4-97db-60643ee2db04
    Physical address       : 58:a0:23:f8:dd:ab
    State                  : connected
    SSID                   : ProtoManX
    BSSID                  : 1c:b7:2c:7c:c4:20
    Network type           : Infrastructure
    Radio type             : 802.11n
    Authentication         : WPA2-Personal
    Cipher                 : CCMP
    Connection mode        : Auto Connect
    Channel                : 6
    Receive rate (Mbps)    : 130
    Transmit rate (Mbps)   : 144.4
    Signal                 : 98%
    Profile                : ProtoManX

    Hosted network status  : Not available
```

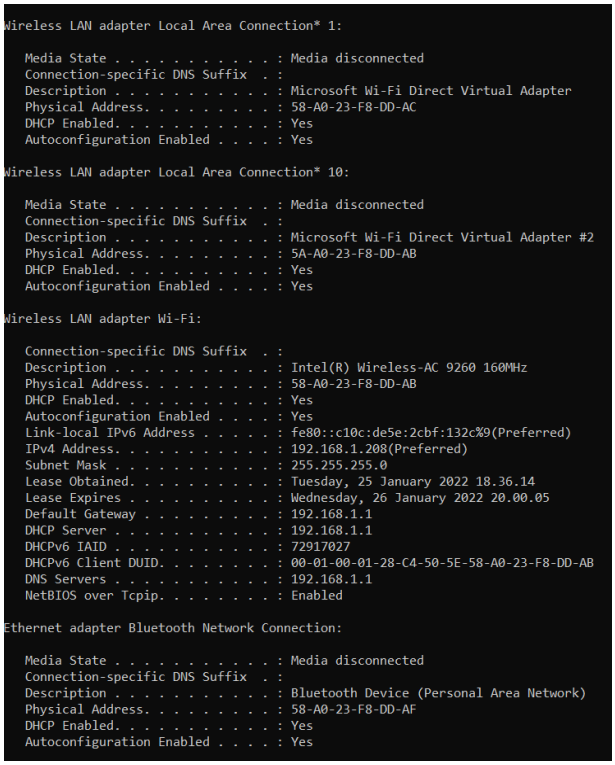
2: Use command line to scan the Wi-Fi access points and record information of all the APs you observe from one location

Command line: ipconfig/all

Information of all APs observed and their related information



```
C:\Users\nguye>ipconfig/all

Windows IP Configuration

   Host Name . . . . . . . . . . . . : DESKTOP-CD839F7
   Primary Dns Suffix  . . . . . . . :
   Node Type . . . . . . . . . . . . : Hybrid
   IP Routing Enabled. . . . . . . . : No
   WINS Proxy Enabled. . . . . . . . : No

Unknown adapter ProtonVPN TUN:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : ProtonVPN Tunnel
   Physical Address. . . . . . . . . :
   DHCP Enabled. . . . . . . . . . . : No
   Autoconfiguration Enabled . . . . : Yes

Ethernet adapter VirtualBox Host-Only Network:

   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : VirtualBox Host-Only Ethernet Adapter
   Physical Address. . . . . . . . . : 0A-00-27-00-00-0A
   DHCP Enabled. . . . . . . . . . . : No
   Autoconfiguration Enabled . . . . : Yes
   Link-local IPv6 Address . . . . . : fe80::6cfa:abb1:c944:84c9%10(Preferred)
   IPv4 Address. . . . . . . . . . . : 192.168.56.1(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . :
   DHCPv6 IAID . . . . . . . . . . . : 705298471
   DHCPv6 Client DUID. . . . . . . . : 00-01-00-01-28-C4-50-5E-58-A0-23-F8-DD-AB
   DNS Servers . . . . . . . . . . . : fec0:0:0:ffff::1%1
                                       fec0:0:0:ffff::2%1
                                       fec0:0:0:ffff::3%1
   NetBIOS over Tcpip. . . . . . . . : Enabled

Unknown adapter Local Area Connection:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : TAP-ProtonVPN Windows Adapter V9
   Physical Address. . . . . . . . . : 00-FF-0C-EB-D9-F4
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
```



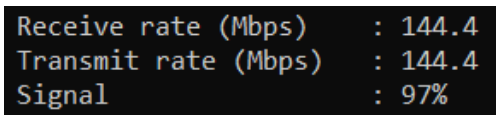
```
Wireless LAN adapter Local Area Connection* 1:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Microsoft Wi-Fi Direct Virtual Adapter
   Physical Address. . . . . . . . . : 58-A0-23-F8-DD-AC
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes

Wireless LAN adapter Local Area Connection* 10:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Microsoft Wi-Fi Direct Virtual Adapter #2
   Physical Address. . . . . . . . . : 5A-A0-23-F8-DD-AB
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes

Wireless LAN adapter Wi-Fi:

   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Intel(R) Wireless-AC 9260 160MHz
   Physical Address. . . . . . . . . : 58-A0-23-F8-DD-AB
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
   Link-local IPv6 Address . . . . . : fe80::c10c:de5e:2cbf:132c%9(Preferred)
   IPv4 Address. . . . . . . . . . . : 192.168.1.208(Preferred)
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Lease Obtained. . . . . . . . . . : Tuesday, 25 January 2022 18.36.14
   Lease Expires . . . . . . . . . . : Wednesday, 26 January 2022 20.00.05
   Default Gateway . . . . . . . . . : 192.168.1.1
   DHCP Server . . . . . . . . . . . : 192.168.1.1
   DHCPv6 IAID . . . . . . . . . . . : 72917027
   DHCPv6 Client DUID. . . . . . . . : 00-01-00-01-28-C4-50-5E-58-A0-23-F8-DD-AB
   DNS Servers . . . . . . . . . . . : 192.168.1.1
   NetBIOS over Tcpip. . . . . . . . : Enabled

Ethernet adapter Bluetooth Network Connection:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Bluetooth Device (Personal Area Network)
   Physical Address. . . . . . . . . : 58-A0-23-F8-DD-AF
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
```

II) Impact of distance and obstacles on signal strength

3: Observe the changes in signal strength when moving around, and analyze the impact of distance and obstacles on wireless signal strength.

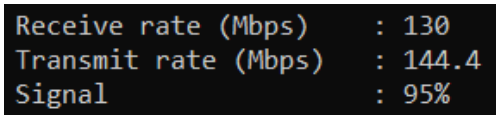
Command line: netsh wlan show interfaces

Right at the router, no obstacle: 97%



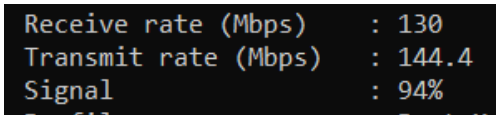
```
Receive rate (Mbps)    : 144.4
Transmit rate (Mbps)   : 144.4
Signal                 : 97%
```

2 meters away, no obstacle: 95%



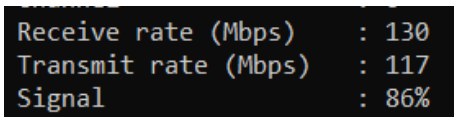
```
Receive rate (Mbps)    : 130
Transmit rate (Mbps)   : 144.4
Signal                 : 95%
```

5 meters away, no obstacle: 94%



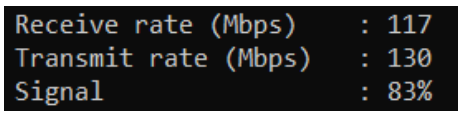
```
Receive rate (Mbps)    : 130
Transmit rate (Mbps)   : 144.4
Signal                 : 94%
```

7 meters away, 1 door obstacle: 86%



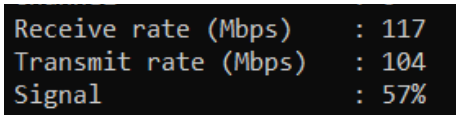
```
Receive rate (Mbps)    : 130
Transmit rate (Mbps)   : 117
Signal                 : 86%
```

12 meters away, 1 door obstacle: 83%



```
Receive rate (Mbps)    : 117
Transmit rate (Mbps)   : 130
Signal                 : 83%
```

15 meters away, 2 door obstacles: 57%



```
Receive rate (Mbps)    : 117
Transmit rate (Mbps)   : 104
Signal                 : 57%
```

Analysis of impact of distance on wireless signal strength: The further away the laptop from the router, the weaker the signal.

Analysis of impact of obstacles on wireless signal strength: The more obstacles between the laptop and the router, the weaker the signal. Signal may become weaker if the obstacle is denser => Findings: obstacles seems to weakens the wireless signal strength significantly more than distance does

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III) Wi-Fi AP Association

4: Associate your phone or laptop with one Wi-Fi AP, and parse the beacon frames. Compare the description of AP with the result of (1)

To do this, the client must be successfully connected to one of the access point (AP). The BSSID field below will indicate the MAC address used by the access point, with the last three octets to identify the AP.

```
GUID                   : 7c5ab65a-7c26-44a4-97db-60643ee2db04
Physical address       : 58:a0:23:f8:dd:ab
State                  : connected
SSID                   : ProtoManX
BSSID                  : 1c:b7:2c:7c:c4:20
Network type           : Infrastructure
Radio type             : 802.11n
```

Next step: to parse the beacon frames, we used Acrylic Wifi application to analyse WiFi networks. A beacon frame is found for the current AP

Number	Time	RSSI	Chan	Type	SubType	Source Mac	BSSID	Destination Mac	Size	Description
0	30.3271	-83	36	Management	Beacon	Zyxel:79:47:A2	Zyxel:79:47:A2	[Broadcast]	328	SSID: Zyxel_47A1_5G
1	30.3760	-85	10	Management	Beacon	TP-LINK:F5:FB:58	TP-LINK:F5:FB:58	[Broadcast]	389	SSID: TP-LINK_FB58
2	30.3950	-69	8	Management	Beacon	TP-LINK:C2:83:6C	TP-LINK:C2:83:6C	[Broadcast]	422	SSID: TP-LINK_C2836C
3	30.4139	-82	6	Management	Beacon	TP-LINK:A2:00:E4	TP-LINK:A2:00:E4	[Broadcast]	290	SSID: PoliceVan
4	30.4338	-48	44	Management	Beacon	ASUSTek:67:81:85	ASUSTek:67:81:85	[Broadcast]	219	SSID: asus225G
5	30.4559	-40	3	Management	Beacon	ASUSTek:67:81:84	ASUSTek:67:81:84	[Broadcast]	384	SSID: asus22
6	30.4817	-53	11	Management	Beacon	Belkin:1A:DA:08	Belkin:1A:DA:08	[Broadcast]	379	SSID: BoomBox808
7	30.5067	-40	1	Management	Beacon	TP-LINK:BD:45:62	TP-LINK:BD:45:62	[Broadcast]	282	SSID: Lin's
8	30.5325	-56	6	Management	Beacon	ASUSTek:B6:CD:0D	ASUSTek:B6:CD:0D	[Broadcast]	245	SSID: elamaOnFysiikkafunktio
9	30.5516	-41	6	Management	Beacon	ASUSTek:B6:CD:0C	ASUSTek:B6:CD:0C	[Broadcast]	402	SSID: vvv
10	30.5625	-48	6	Management	Beacon	ASUSTek:7C:C4:20	ASUSTek:7C:C4:20	[Broadcast]	408	SSID: ProtoManX
11	32.9170	-83	36	Management	Beacon	Zyxel:79:47:A2	Zyxel:79:47:A2	[Broadcast]	328	SSID: Zyxel_47A1_5G
12	32.9374	-82	10	Management	Beacon	TP-LINK:F5:FB:58	TP-LINK:F5:FB:58	[Broadcast]	291	SSID: TP-LINK_FB58
13	32.9600	-77	8	Management	Beacon	TP-LINK:C2:83:6C	TP-LINK:C2:83:6C	[Broadcast]	422	SSID: TP-LINK_C2836C
14	32.9799	-82	6	Management	Beacon	TP-LINK:A2:00:E4	TP-LINK:A2:00:E4	[Broadcast]	290	SSID: PoliceVan
15	32.9810	-54	44	Management	Beacon	ASUSTek:67:81:85	ASUSTek:67:81:85	[Broadcast]	219	SSID: asus225G
16	32.9819	-40	3	Management	Beacon	ASUSTek:67:81:84	ASUSTek:67:81:84	[Broadcast]	384	SSID: asus22

Packet Tree and Hexadecimal view

- Beacon
  - Fixed
  - Information Elements
    - Ssid: ProtoManX
    - Supported Rates: 0x0801
    - DS Parameter Set: Channel 6
    - Erp
    - Rsn
    - Extendedsupportedrates
    - Htcapabilities
    - Htoperation
    - Overlappingbssscan
    - Extendedcapabilities
    - Vendorspecific
- Frame Check Sequence

	00 01 02 03 04 05 06 07	08 09 0A 0B 0C 0D 0E 0F
0000	00 00 1A 00 6F 18 00 00	9C 58 D2 01 00 00 00 00
0010	01 02 85 09 80 00 D0 76	00 7F 80 00 00 00 FF FF
0020	FF FF FF FF 1C B7 2C 7C	C4 20 1C B7 2C 7C C4 20
0030	00 00 BD EB B8 69 74 04	00 00 00 00 11 04 00 09
0040	50 72 6F 74 6F 4D 61 6E	58 01 08 82 84 8B 96 24
0050	30 48 6C 03 01 06 2A 01	04 2F 01 04 30 14 01 00
0060	00 0F AC 04 01 00 00 0F	AC 04 01 00 00 0F AC 02
0070	0C 00 32 04 0C 12 18 60	2D 1A FC 19 1B FF FF 00
0080	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
0090	00 00 00 00 3D 16 06 08	04 00 00 00 00 00 00 00
00A0	00 00 00 00 00 00 00 00	00 00 00 00 4A 0E 14 00
00B0	0A 00 2C 01 C8 00 14 00	05 00 19 00 7F 01 01 DD
00C0	AE 00 50 F2 04 10 4A 00	01 10 10 44 00 01 02 10

AP's name parameter set

```
Ssid: ProtoManX
    Element Id: 0
    Length: 9
    Ssid: ProtoManX
```

AP's MAC address

```
Source Address: 1C:B7:2C:7C:C4:20 - ASUSTek COMPUTER INC.
BSSID: 1C:B7:2C:7C:C4:20 - ASUSTek COMPUTER INC.
```

Compared with AP results in (1):

```
Name                   : Wi-Fi
Description            : Intel(R) Wireless-AC 9260 160MHz
GUID                   : 7c5ab65a-7c26-44a4-97db-60643ee2db04
Physical address       : 58:a0:23:f8:dd:ab
State                  : connected
SSID                   : ProtoManX
BSSID                  : 1c:b7:2c:7c:c4:20
```

Frame control field of the beacon frame

```
Frame Control: 0x80
    .... ..00 = Version: 0
    .... 00.. = Type: 0
    1000 .... = Subtype: 8
```

Interval of transmitting the beacon frame

```
Beacon
    Fixed
        Time Stamp: 0x0000047469B8EBBD
        Beacon Interval: 0 TUs
```

IV) Impact of signal strength on data rate

5: Send data from one station to another one connected to the same AP (check BSSID), and measure data rate. You can use iperf (https://iperf.fr/) for example to implement data transmission.

Command line: "ipconfig" to find out the IP address

```
PS C:\Users\nguye\Desktop\iperf-3.1.3-win64> ipconfig

Windows IP Configuration
```

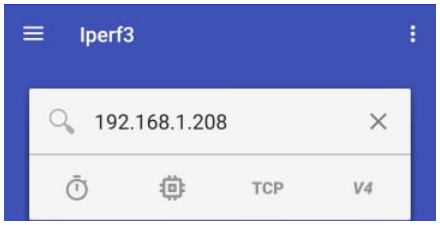
```
Wireless LAN adapter Wi-Fi:

   Connection-specific DNS Suffix  . :
   Link-local IPv6 Address . . . . . : fe80::c10c:de5e:2cbf:132c%9
   IPv4 Address. . . . . . . . . . . : 192.168.1.208
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . : 192.168.1.1
```

Command line: "./iperf3.exe -s" to start the server. The laptop will start the server

```
PS C:\Users\nguye\Desktop\iperf-3.1.3-win64> ./iperf3.exe -s
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

As we can see, the IPv4 address of wireless LAN adapter Wi-Fi is 192.168.1.208. So this IP address will be hosting the server.

Command line: "./iperf3.exe -c 192.168.1.208" where tag -c denotes client device. Due to some error connections, we use a phone which uses the iperf Android application he.net - Network Tools. In Iperf3, we search for the IPv4 address of the AP



After accepting the client, the data rate of the server laptop is recorded as follows:

```
Accepted connection from 192.168.1.182, port 41528
[  5] local 192.168.1.208 port 5201 connected to 192.168.1.182 port 41530
[ ID] Interval           Transfer     Bandwidth
[  5]   0.00-0.03   sec  12.8 KBytes  3.14 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth
[  5]   0.00-0.03   sec  0.00 Bytes  0.00 bits/sec                  sender
[  5]   0.00-0.03   sec  12.8 KBytes  3.14 Mbits/sec                receiver
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

6: Analyze the impact on data rate from signal strength. You can measure the data rate with three different levels of signal strength

We analyze the impact of signal strength on data rate by changing signal strength based on distance and obstacles. The results are:

Right at the router, no obstacle:

192.168.1.208:5201 (TCP)

Interval	Transfer	Bandwidth
0.00-0.00 sec	344 KBytes	4.24 Gbits/sec

2 meters away, no obstacle

192.168.1.208:5201 (TCP)

Interval	Transfer	Bandwidth
0.00-0.00 sec	344 KBytes	4.18 Gbits/sec

5 meters away, no obstacle:

192.168.1.208:5201 (TCP)

Interval	Transfer	Bandwidth
0.00-0.00 sec	344 KBytes	4.14 Gbits/sec

7 meters away, behind 1 door:

192.168.1.208:5201 (TCP)

Interval	Transfer	Bandwidth
0.00-0.00 sec	344 KBytes	3.82 Gbits/sec

12 meters away, behind 1 door:

192.168.1.208:5201 (TCP)

Interval	Transfer	Bandwidth
0.00-0.00 sec	342 KBytes	2.63 Gbits/sec

15 meters away, behind 2 wooden doors

192.168.1.208:5201 (TCP)

Interval	Transfer	Bandwidth
0.00-0.00 sec	342 KBytes	2.13 Gbits/sec

This experiment is conducted exactly like part (2), so we can reference the signal strength from (2) and compare them to the data rate obtained here in part (6)

=> Conclusion: Within a certain range (0-7 meters), the data rate is at its maximum value with little variance. This could be the optimal distance range for stable data rate. Outside of this optimal range, the data rate decreases linearly with respect to signal strength. The further and more obstacles there are, the weaker the signal strength and hence the weaker the data rate.

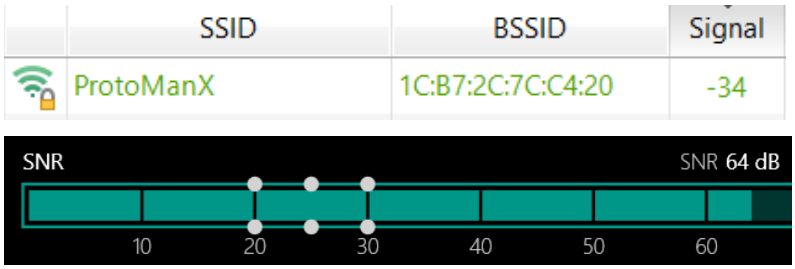
V) Impact of interference on throughput

7: Generate interference and monitor noise level and signal-to-noise ratio. Analyze the impact of interference on throughput. Repeat the experiment to compare the impact from different levels of interference.

In this exercise, we use two softwares called WinFi and NetSpot. WinFi is used for measuring Signal to Noise Ratio (SNR) in db and NetSpot is used for measuring signal strength or throughput in db.

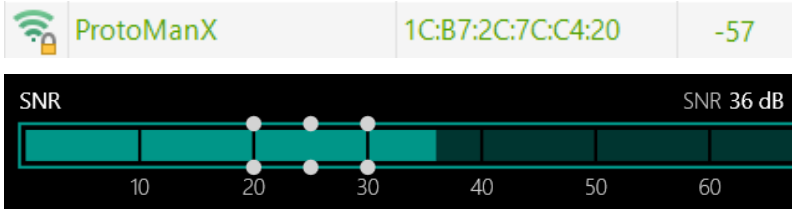
Formula of SNR: $SNR = P_{signal}/P_{noise} = P_{signal,db} - P_{noise,db}$. From this formula, if we know SNR and signal strength, we can calculate noise level: $P_{noise,db} = P_{signal,db} - SNR$.

- When there is no signal interference (the noise power is very low)



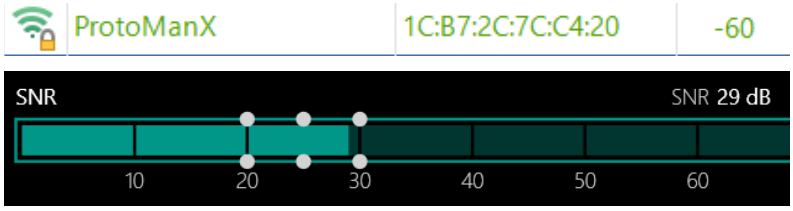
=> $P_{noise,db} = P_{signal,db} - SNR = -34 - 64 = -98$ db

- When the laptop is 2 meters away from a running microwave



=> $P_{noise,db} = P_{signal,db} - SNR = -57 - 36 = -93$ db

- When the laptop is right next to the running microwave



=> $P_{noise,db} = P_{signal,db} - SNR = -60 - 29 = -89$ db

Analysis of the impact of interference on throughput: Signal strength is strong when there are few noise interference in the network. An acceptable level of noise power would range from -100 to -90 db, which results in a reliable network => The stronger the interference, the weaker and unreliable the throughput becomes.