NEW RADIO COMMUNICATION FOR NEW ERA

NRC7292 Application Note

(11s mesh)

Ultra-low power & Long-range Wi-Fi

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NEWRACOM, Inc.

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Ultra-low power & Long-range Wi-Fi

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1 Overview

This document describes the IEEE 802.11s mesh networking to create a Wi-Fi mesh network, which may be used for relatively fixed (not mobile) topologies and wireless ad hoc networks.

1.1 Terminology

As shown in Figure 1.1, the 11s mesh network has four device classes.

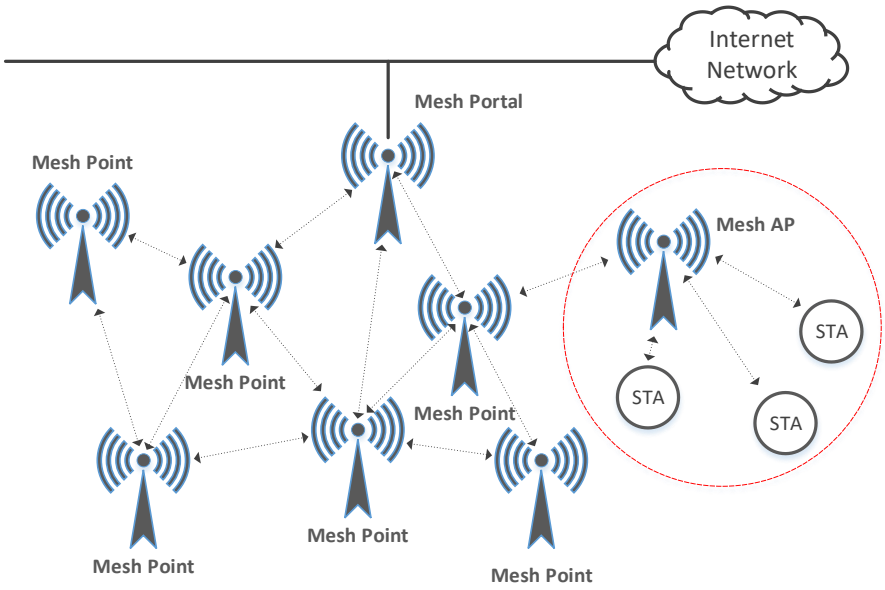

Figure 1.1 11s mesh network

Following is the brief description of each device class.

- Mesh Point (MP): establishes peer links with MP neighbors, full participant in WLAN Mesh services
- Mesh AP (MAP): functionality of a MP, collocated with AP which provides BSS services to support communication with STAs
- Mesh Portal (MPP): point at which MSDUs exit and enter a WLAN Mesh (relies on higher layer bridging functions)
- Station (STA): outside of the WLAN Mesh, connected via Mesh AP
- MBSS: Mesh Basic Service Set
- Peering: relationship between two mesh STA for direct communication

- Path Metric: performance, quality, and eligibility of a mesh path
- Hybrid Wireless Mesh Protocol (HWMP): mesh path selection protocol
- B.A.T.M.A.N: Better Approach To Mobile Ad-hoc Network (routing protocol)

1.2 Addressing

As shown in Figure 1.2 and Figure 1.3, the 11s mesh frame has additional address fields which are used in proxy transmission from/to DS.

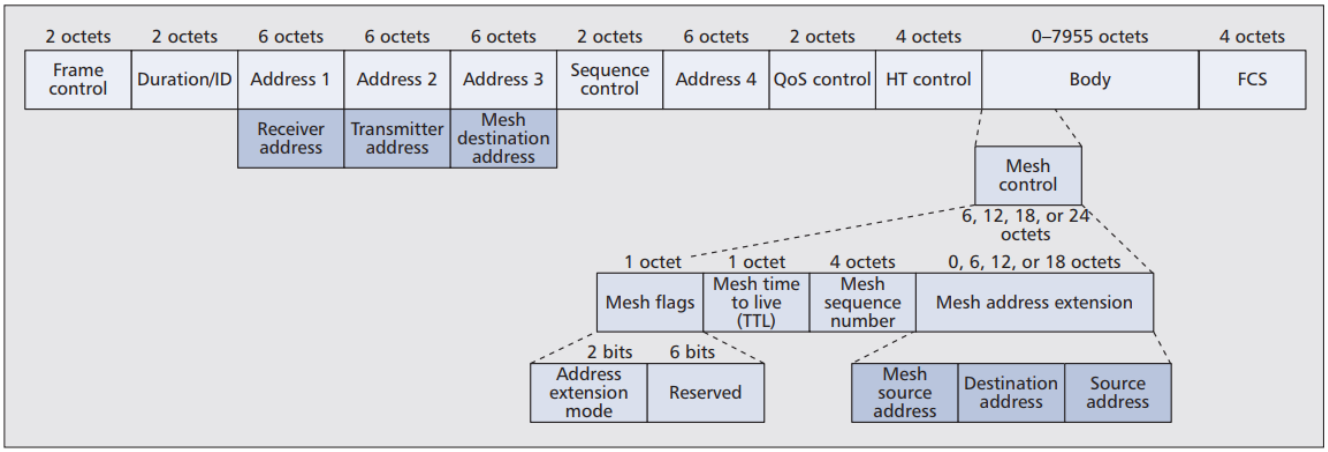

Figure 1.2 Mesh address fields

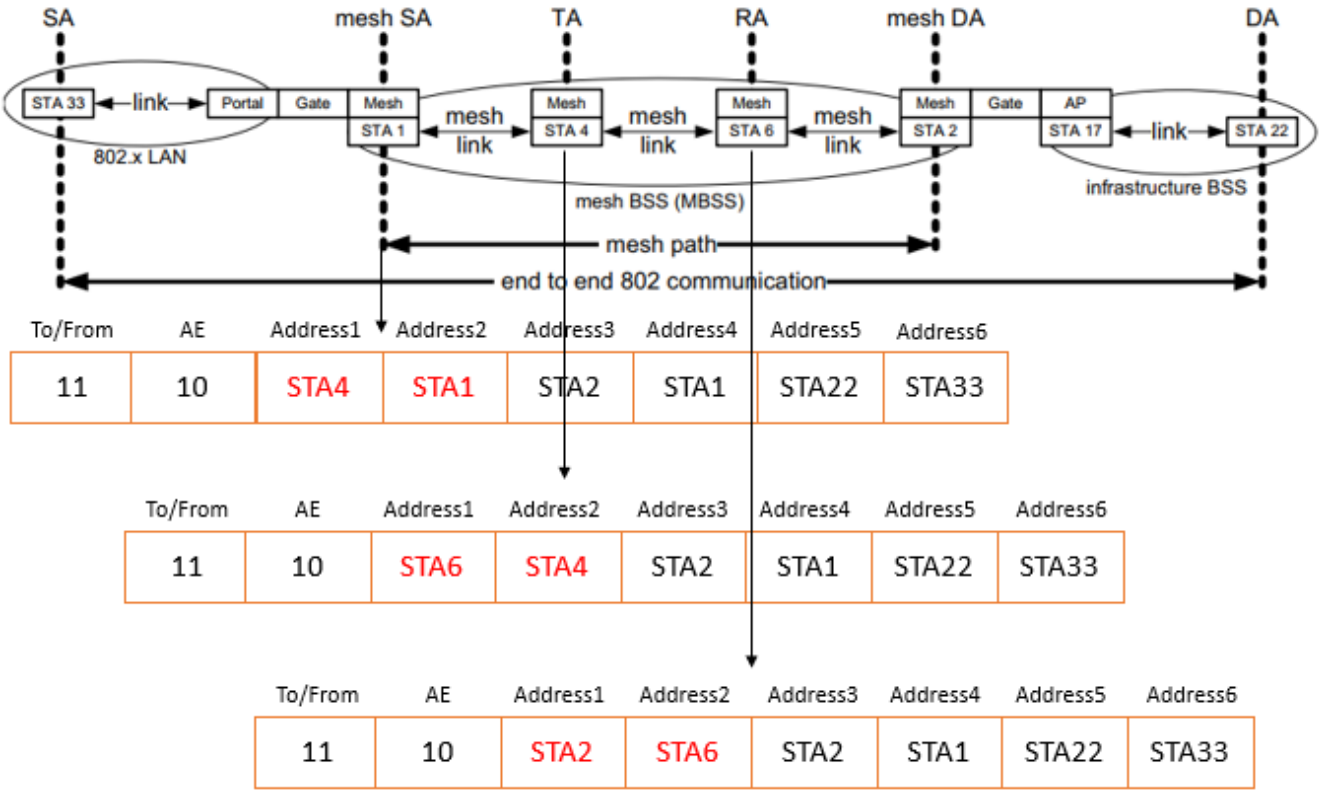

Figure 1.3 Mesh addressing example

Figure 1.3 shows a mesh addressing example which is a frame from STA33 to STA22. Address5 and Address6 include DS addresses.

1.3 Mesh Discovery

As shown in Figure 1.4, mesh STAs broadcast beacon with own mesh profile including mesh configuration element. Each mesh STA registers neighbor mesh STAs as candidates for peering if the received mesh profile is matched with own mesh profile.

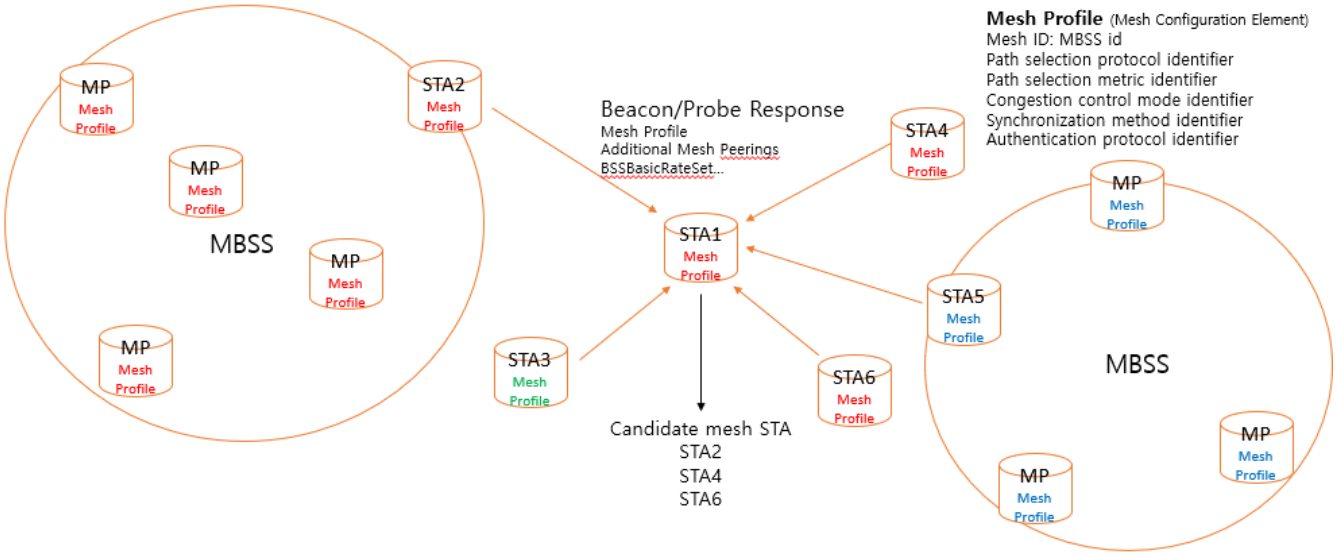

Figure 1.4 Mesh Discovery

1.4 Mesh Peering

To connect mesh network, the mesh STA should succeed in peering handshake. Peering shall be completed only if a 'Mesh Peering Open' frame is sent/received and a 'Mesh Peering Confirm' is received. If the AMPE protocol is used for peering, the SAE authentication is performed before. Figure 1.5 shows this process shortly.

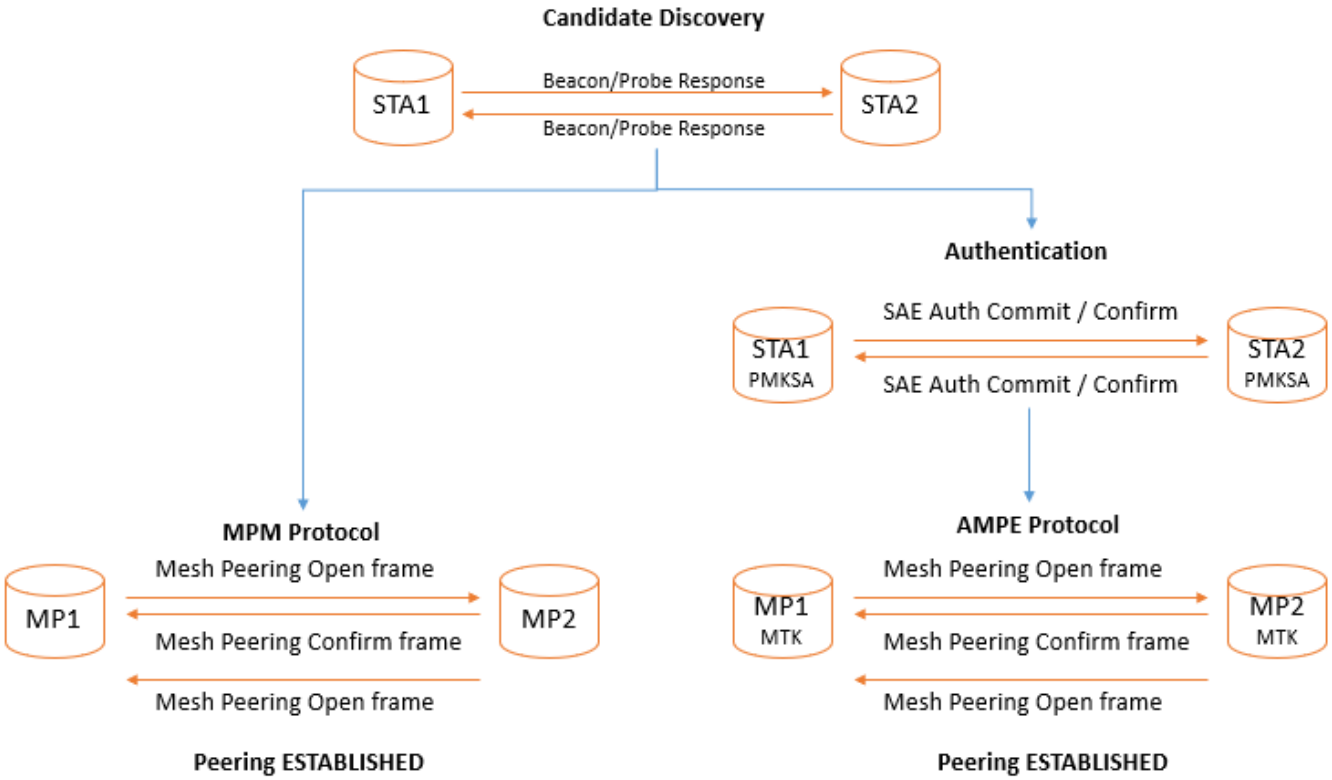

Figure 1.5 Mesh Peering

1.5 Hybrid Wireless Mesh Protocol (HWMP)

HWMP is a default mesh path selection protocol.

- Path originator: The mesh STA that triggers the path discovery.
- Path Target: The entity to which the path originator attempts to establish a path.
- HWMP Sequence Number: Each mesh HWMP path selection element contains an HWMP seuquence number.
- Forwarding information: allows the mesh STA to perform its path selection and forwarding functions.
    - Destination Address
    - Next-hop Address
    - Path Metric
    - Lifetime, HWMP SN, Hop Count

- Element TTL: an integer number that is used to limit the number of hops an HWMP element may be processed and propagated.
- Airtime link metric: default metric formula.
  - $C_a = \left[O + \frac{B_t}{r}\right]\frac{1}{1-e_f}$
  - O : PHY Header Overhead Time
  - r : Transmission Time
  - B_t : Number of bits in test frame
  - $\frac{1}{1-e_f}$: Error Adjustment
- PREQ element: discovering/maintenance/confirming a path to one or more target mesh STAs
- PREP element: establish a forward path to a target and confirm that a target is reachable
- PRRR element: announcing an unreachable destination

Figure 1.6 shows a simple HWMP process. The originator A broadcasts PREQ to neighbors propagating it consecutively. If PREQ is reached the target H, it updates its forwarding information for the originator A and reply the PREP to the originator A through the updated path. If the originator A receives a PREP, it updates its forwarding information for the target H. Now the originator A has the best path to the target H.

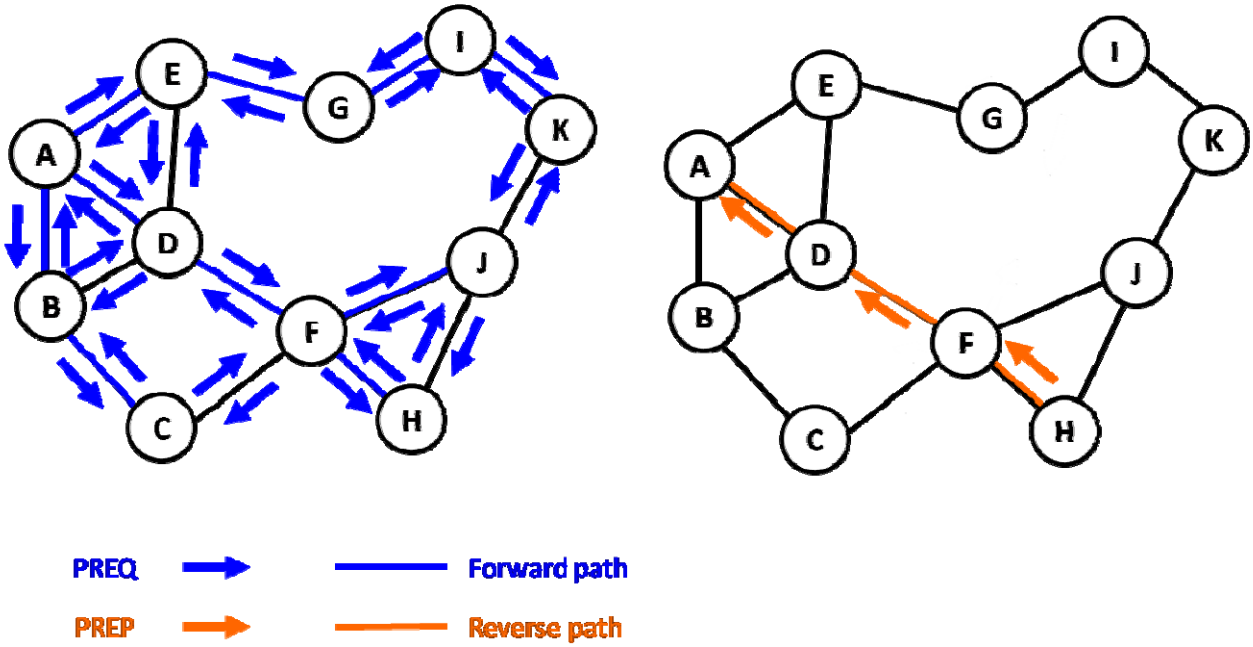

Figure 1.6 HWMP

Metric is a cumulated airtime value from the metric owner to the target. As shown examples in Figure 1.7 and Figure 1.8, the forwarding information will be updated if the new metric is better than before.

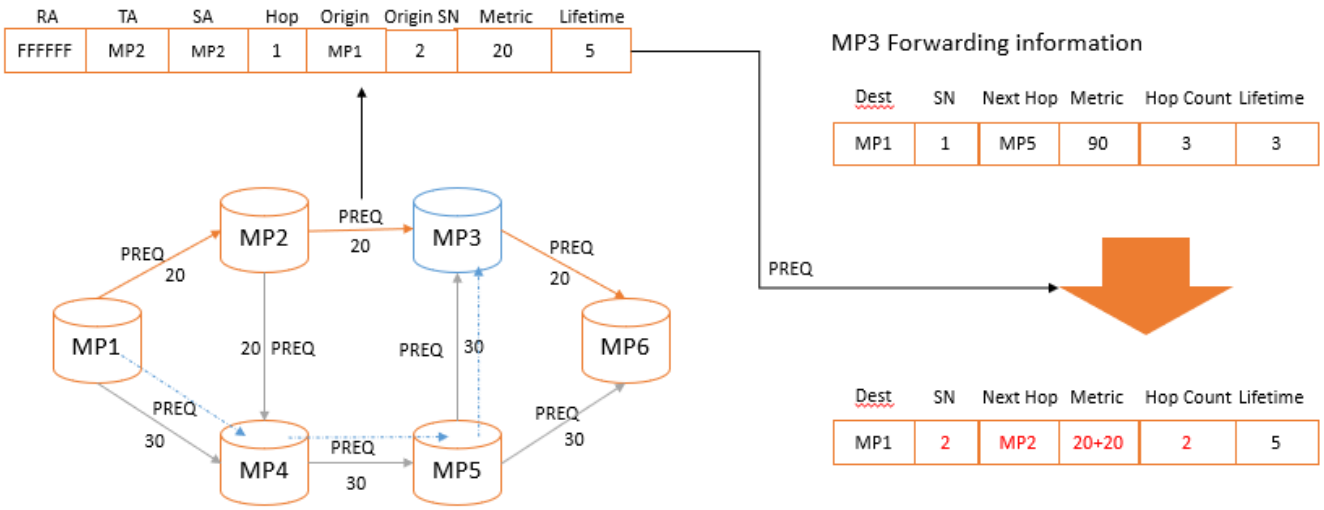

Figure 1.7 Update forwarding information in PREQ

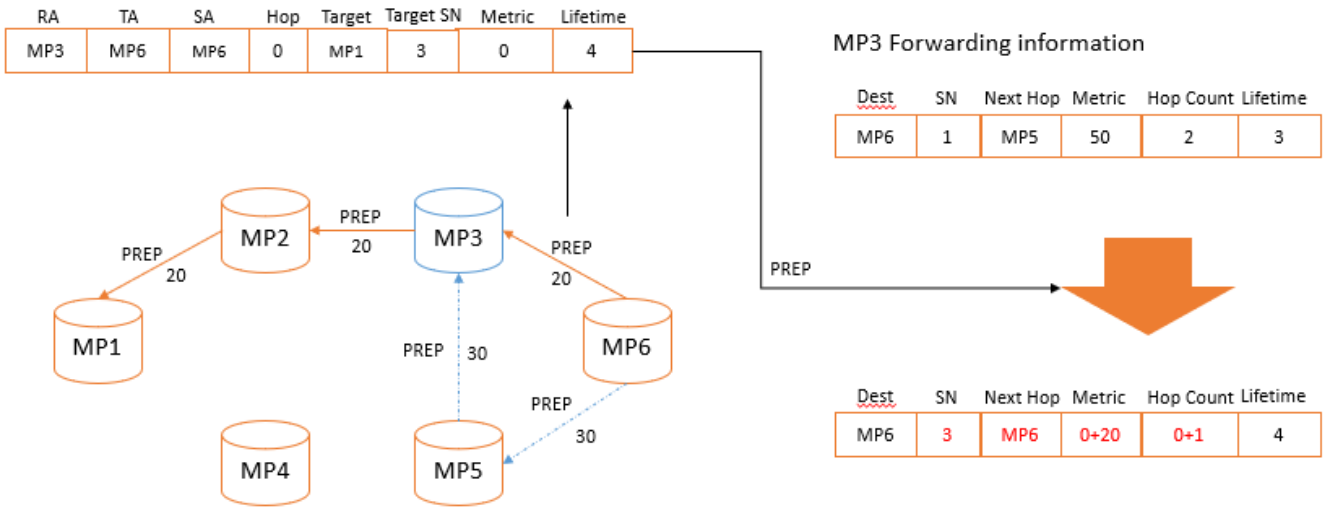

Figure 1.8 Update forwarding information in PREP

1.6 Mesh Procedure Example

Here is a general mesh procedure example.

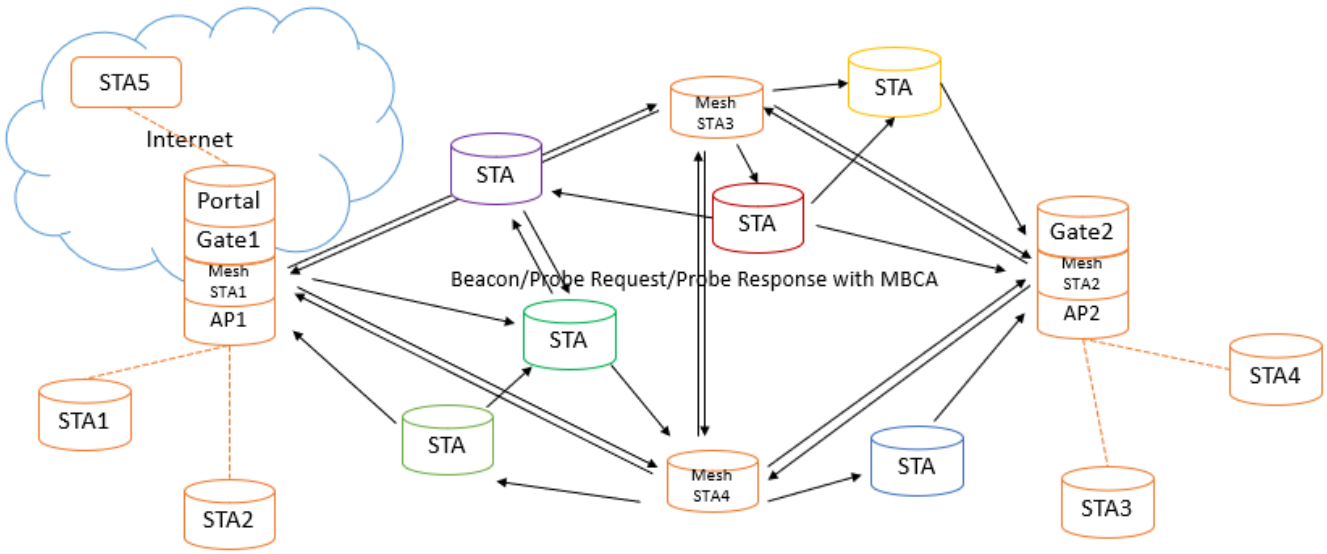

Figure 1.9 Scanning to find candidates for peering

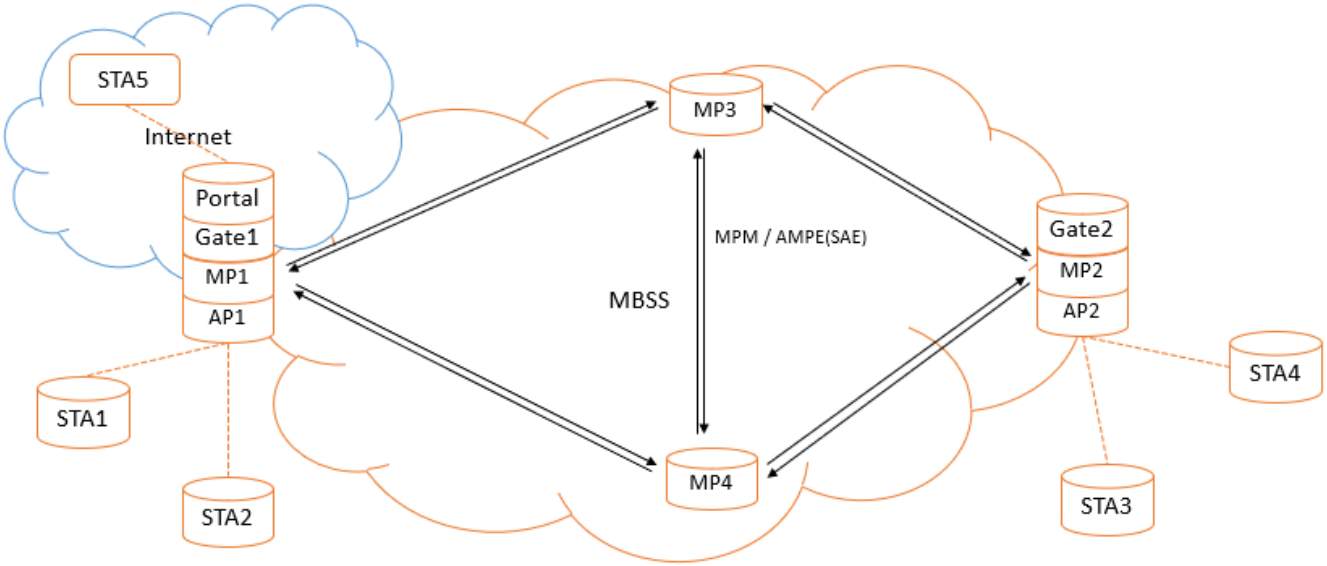

Figure 1.10 Peering with candidates

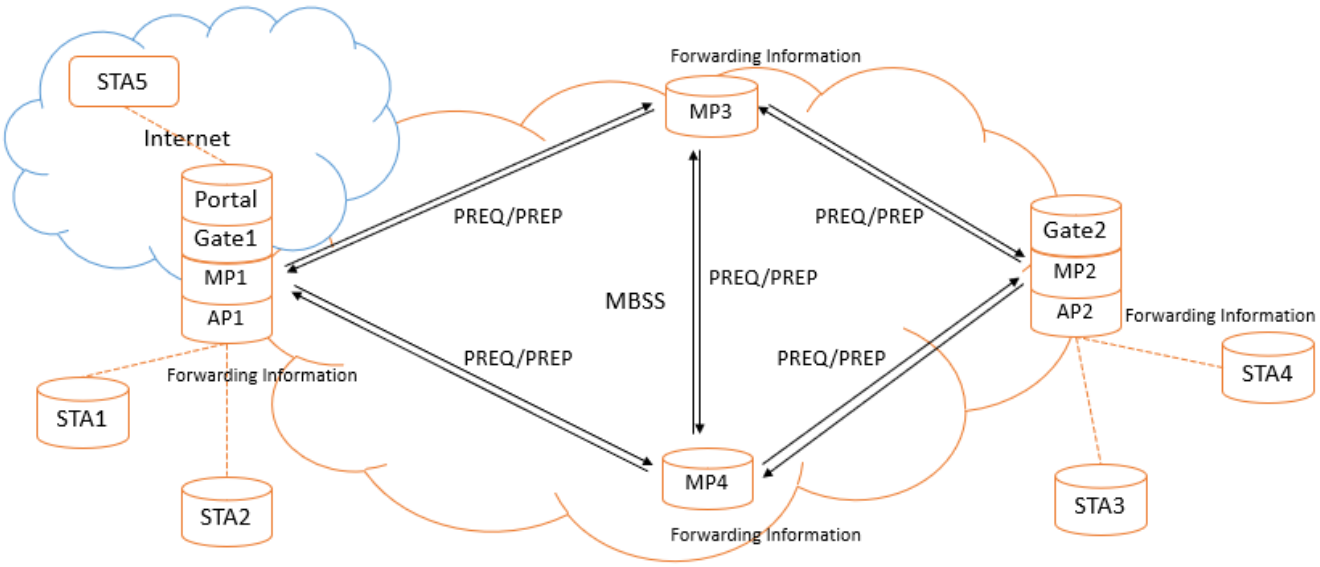

Figure 1.11 Update forwarding information via HWMP

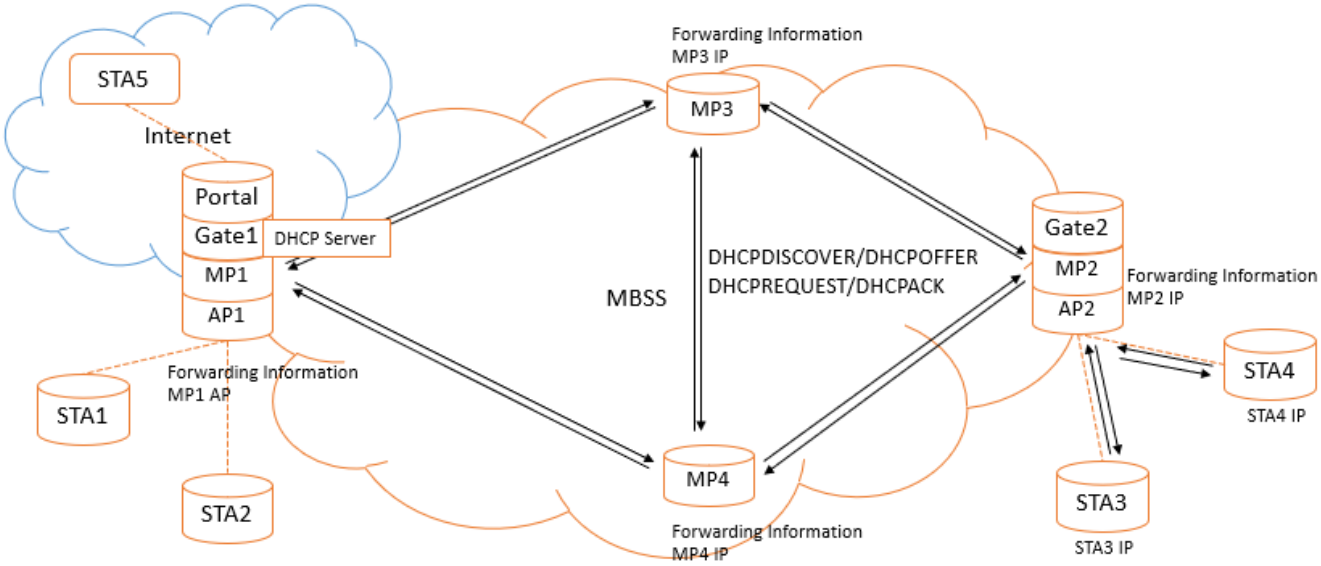

Figure 1.12 IP address allocation from DHCP server in Mesh Portal

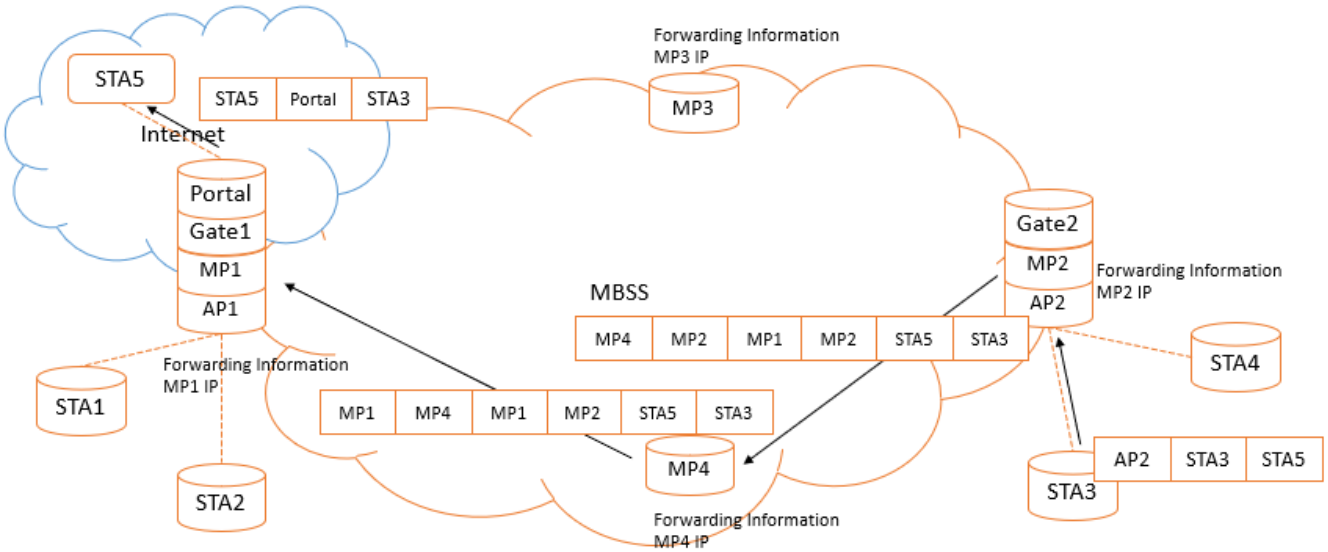

Figure 1.13 Data transmission as the forwarding information

1.7 B.A.T.M.A.N.

B.A.T.M.A.N. is a routing protocol for multi-hop ad-hoc mesh networks. However, we don't need to use B.A.T.M.A.N. instead of HWMP because it's no difference of performance between them and B.A.T.M.A.N. use additional routing frames (OGM).

- batman-adv
  - batman-adv operates on ISO/OSI layer 2 only uses and routes ethernet frames.
  - batman-adv encapsulates all traffic from entry to exit and thereby acts as a virtual switch between all nodes in the network
  - batman-adv was implemented as a linux kernel module to reduce the overhead to a minimum.
- batctl
  - batctl offers a convenient way to configure the batman-adv kernel module as well as displaying debug information such as originator tables and translation tables.
- OGM (Originator Messages)
  - Primary packet of the B.A.T.M.A.N. Adv. protocol
  - It is used to discover nodes and routes in the network
  - Each node in the network creates and broadcasts an OGM at a fixed interval (default 1sec).
  - Neighbor nodes updates their routing table and rebroadcasts batman packets, so that distant nodes also learn about the orignating node.
  - Originator address : identifying the node who created the batman packet
  - Sequence Number : detection of duplicates
  - Transmit Quality(TQ) : describes the link quality of the total route to the originator.
  - Address of the previous sender : used to discard OGMs already broadcasted by the receiving node.
  - Time To Live(TTL) : limts the number of nodes an OGM can traverse.
  - Translation Table : client(bat0) address hash

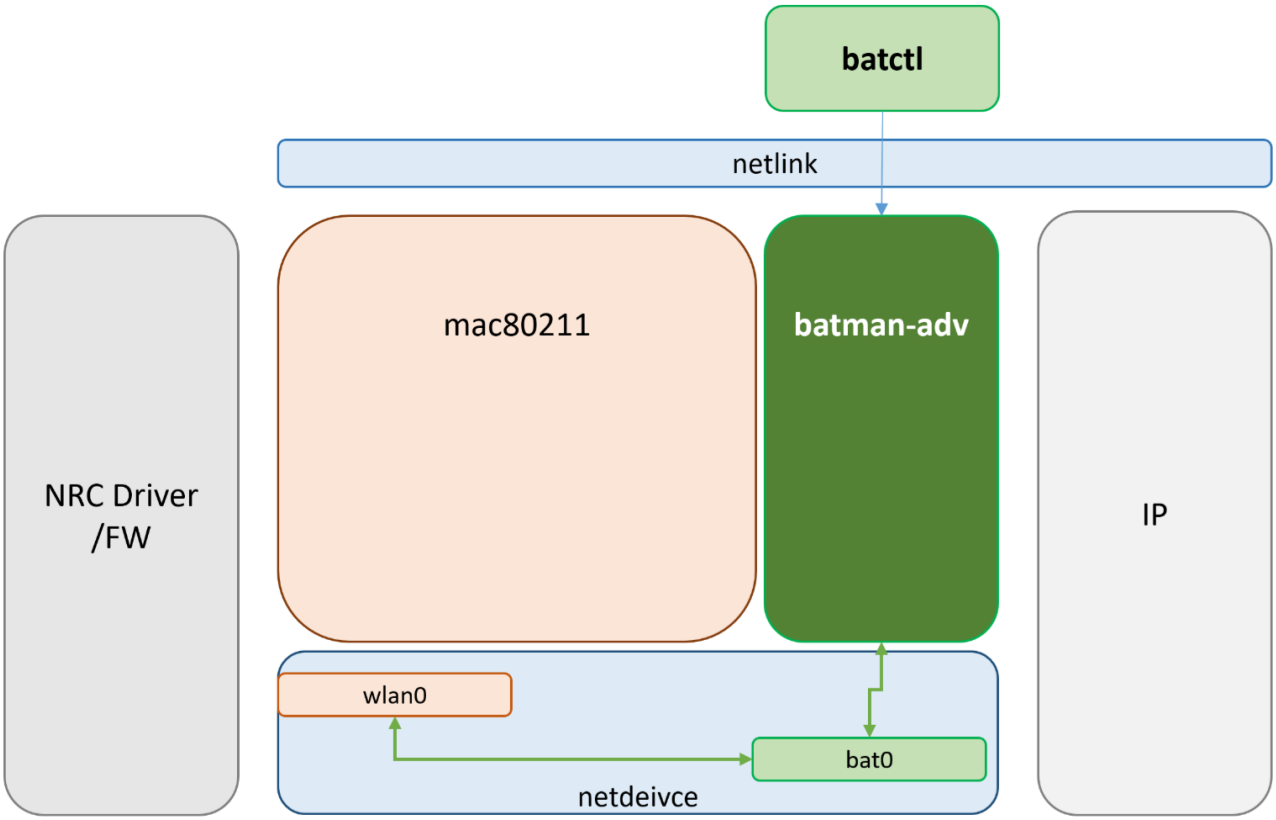

Figure 1.14 B.A.T.M.A.N. SW Layer

Please refer to open-mesh website for more detail.
https://www.open-mesh.org/projects/batman-adv/wiki/Doc-overview

2 11s Mesh Operation

By using different class of 11s mesh device, the user can configure the wireless ad-hoc network or relatively fixed network.

These contents in this clause contains commands to run the 11s mesh devices with NRC7394 EVKs including steps to build wpa_supplicant and establish links among MPs.

2.1 Prerequisite

2.1.1 wpa_supplicant

There's no dependency on the wpa_supplicant version, but it's recommended to use version 2.9 to enable WFA3-Personal(SAE) and CONFIG_MESH.

```
$ wget https://w1.fi/releases/wpa_supplicant-2.10.tar.gz
$ tar zxf wpa_supplicant-2.10.tar.gz
$ sudo apt-get update
$ sudo apt-get install libnl-3-dev libnl-genl-3-dev libssl-dev
$ sudo apt-get install libdbus-1-dev libdbus-glib-1-dev
$ cd wpa_supplicant-2.10/wpa_supplicant
$ cp defconfig .config

Edit .config to include below:
CONFIG_IEEE80211N=y
CONFIG_OWE=y
CONFIG_SAE=y
CONFIG_MESH=y
CONFIG_IEEE80211W=y

$ make -j4
$ sudo make install
```

2.1.2 batman-adv

```
$ make M=$KERNEL_SRC/net/batman-adv KBUILD_EXTRA_SYMBOLS=$KERNEL_SRC/net/wireless/Module.symvers
modules
$ sudo ln -s $KERNEL_SRC/net/batman-adv/batman-adv.ko /lib/modules/'uname -r'
$ sudo depmod -a
$ sudo modprobe batman-adv
```

2.1.3 bridge

Bridge tools should be installed as below.

```
$ sudo apt-get install bridge-utils
```

2.1.4 batctl

Download batctl here: https://downloads.open-mesh.org/batman/releases/

```
$ make
$ sudo make install
```

2.2 Run script: start.py

The start.py can be found in nrc_pkg and following is the usage of start.py script.

- nrc_pkg/script/start.py
- start.py [sta_type] [security_mode] [country] [mesh_mode]
- sta_type : 4 (Mesh)
- security mode : 0 (Open), 3(WPA3-SAE)
- country : US, JP, KR(K0/K1/K2), CN, EU, TW
- mesh_mode : 0 (MPP), 1(MP), 2(MAP)

2.3 MP (Mesh Point)

MP runs on wpa_supplicant with mesh mode (5).

dhcpcd allocates IP address from DHCP server (MPP).

You can modify wpa_supplicant configuration file to change the SSID & channel.

- nrc_pkg/script/conf/[country]/mp_halow_[security_mode].conf

```
$ ./start.py 4 0|3 US|JP|K0|K1|K2|CN|EU|TW|NZ|AU 1
```

```
      ctrl_interface=/var/run/wpa_supplicant

      country=US
      update_config=1
      network={
         ssid="nrc_mesh"
         mode=5
         scan_ssid=1
         proto=RSN
         key_mgmt=SAE
         pairwise=CCMP
         group=CCMP
         psk="12345678"
         ieee80211w=2
         beacon_int=100
         frequency=5795
         freq_list=5795
         scan_freq=5795
         dot11MeshRetryTimeout=1000
```

```
        dot11MeshHoldingTimeout=400
        dot11MeshMaxRetries=4
        mesh_rssi_threshold=0
        mesh_basic_rates= 60 120 240
        #no_auto_peer=1
    }
    p2p_disabled=1
    ignore_old_scan_res=1
```

2.4 MPP (Mesh Portal)

MPP has DHCP server using dnsmasq.

NAT, IP forwarding is needed to connect with Internet.

You can modify wpa_supplicant configuration file to change the SSID & channel.

- nrc_pkg/script/conf/[country]/mp_halow_[security_mode].conf

```
$ ./start.py 4 0|3 US|JP|K0|K1|K2|CN|EU|TW|NZ|AU 0
```

```
Use same configuration files with MP's (mp_halow_sae.conf, mp_halow_open.conf)
```

2.5 MAP (Mesh AP: MP + AP)

MAP is composed of a MP interface and an AP interface.

The key management of AP interface can be changed to SAE, WPA2 or OWE.

- 0 (Open), 1 (WPA2-PSK), 2 (WPA3-OWE), 3 (WPA3-SAE)

You can modify wpa_supplicant configuration file to change the SSID & channel.

- nrc_pkg/script/conf/[country]/mp_halow_[security_mode].conf
- nrc_pkg/script/conf/[country]/map_halow_[security_mode].conf

```
$ ./start.py 4 0|1|2|3 US|JP|K0|K1|K2|CN|EU|TW|NZ|AU 2
```

```
MP interface use same files with MP's (mp_halow_sae.conf, mp_halow_open.conf)
AP interface use map_halow_sae.conf, map_halow_open.conf, map_halow_owe.conf, map_halow_wpa2.conf

    ctrl_interface=/var/run/hostapd
    country_code=US
    interface=wlan0
    ssid=nrc_mesh
    hw_mode=a
    bridge=br0
    basic_rates=60 120 240
    channel=159
    ieee80211h=1
    ieee80211d=1
    ieee80211n=1
    ieee80211w=2
```

```
#wmm_enabled=1
macaddr_acl=0
driver=nl80211
beacon_int=100
#disable_sgi=0
#ap_max_inactivity=3
ap_max_inactivity=16779
# USF=0, UI=2 : 3
# USF=1, UI=2 : 16780
# USF=0, UI=10: 11
# USF=1, UI=10: 16788
#listen_interval=2

#WPA3-SAE
#auth_alg=1 #1=wpa, 2=wep, 3=open
wpa=2     # wpa2 only
wpa_key_mgmt=SAE
wpa_pairwise=CCMP
rsn_pairwise=CCMP
wpa_passphrase=12345678
```

2.6 STA

Use same SSID & channel with mesh network.

- nrc_pkg/script/conf/[country]/sta_halow_[security_mode].conf

```
$ ./start.py 0 0|1|2|3 US|JP|K0|K1|K2|CN|EU|TW|NZ|AU
```

2.7 Static IP

Static IP setting is possible like below.

- start.py [sta_type] [security_mode] [country] [mesh_mode] [mesh_ip]

```
$ ./start.py 4 3 US 0 192.168.222.1       # SAE mode Mesh Portal with Static IP
$ ./start.py 4 0 US 2 192.168.222.2       # Open mode Mesh AP with Static IP
```

2.8 Manual Peering

Mesh node do peering automatically by default but you can disable it and connect manually.

- start.py [sta_type] [security_mode] [country] [mesh_mode] [peer mac address]

```
$ ./start.py 4 3 US 1 8c:0f:fa:00:29:46   # SAE mode Mesh Point trying to peer only 8c:0f:fa:00:29:46
$ ./start.py 4 0 US 2 192.168.222.2       # Open mode Mesh AP trying to peer only 8c:0f:fa:00:29:46
```

Both Static IP & Manual Peering are possible in one command like below.

- start.py [sta_type] [security_mode] [country] [mesh_mode] [peer mac address] [mesh_ip]

```
# SAE mode Mesh Point trying to peer only 8c:0f:fa:00:29:46 and set static IP 192.168.222.2
$ ./start.py 4 3 US 1 8c:0f:fa:00:29:46 192.168.222.2
```

2.9 Mesh Portal without DHCP Server

Mesh Portal (MPP) basically have DHCP server but some users may want to use own DHCP server. They can start Mesh Portal without DHCP server like this.

```
$ ./start.py 4 0|3 US|JP|K0|K1|K2|CN|EU|TW|NZ|AU 0 nodhcp
```

2.10 B.A.T.M.A.N.

Modify the ‘batman’ variable in ‘start.py’ like this.

```
# Mesh Options (Mesh Only)
#  Manual Peering & Static IP
peer              = 0     # 0 (disable) or Peer MAC Address
static_ip          = 0     # 0 (disable) or Static IP Address
batman            = ‘bat0’ # 0 (disable) or 'bat0' (B.A.T.M.A.N routing protocol)
```

batman=’bat0’ makes the B.A.T.M.A.N. node as adding below commands.

```
$ insmod nrc.ko
$ wpa_supplicant -iwlan0 -c wpa_supplicant.conf
$ sudo batctl if add wlan0
$ sudo ifconfig bat0 up
$ sudo ifconfig wlan0 mtu 1532
DHCP Configuration of ’bat0’
```

’start.py’ includes all of this so you can run B.A.T.M.A.N. node as the same way of running a general mesh node.

3 11s Mesh Test Procedure

The content in this clause contains steps to compose 11s mesh network with NRC7394 EVKs.

3.1 Setup Mesh Network

3.1.1 Connecting MP and STA

Establish the mesh network connecting one or more MP to MPP and MAP.

Finally connect one or more STA to MAP then a test topology is completely set up.

Please utilize the manual peering commands if you want to set up in close distance.

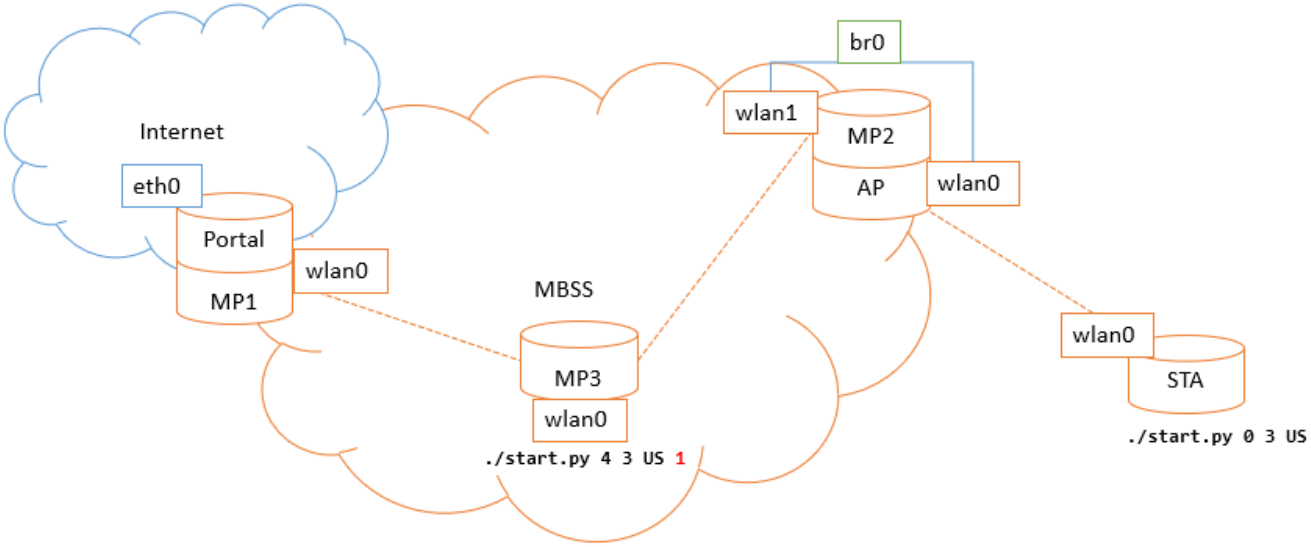

Figure 3.1 Mesh test topology

3.2 IP Allocation with DHCP

MPP is a DHCP server for the mesh network and default gateway is 192.168.200.1.

You can change this in the CONFIG_IP file.

```
# Config for HaLow Mesh's IP and DHCPS configuration
HALOW_MESH_IP=192.168.222.1
HALOW_MESH_NETMASK=24
HALOW_MESH_DHCPS_CONFIG=192.168.200.10,192.168.200.250,255.255.255.0,infinite
```

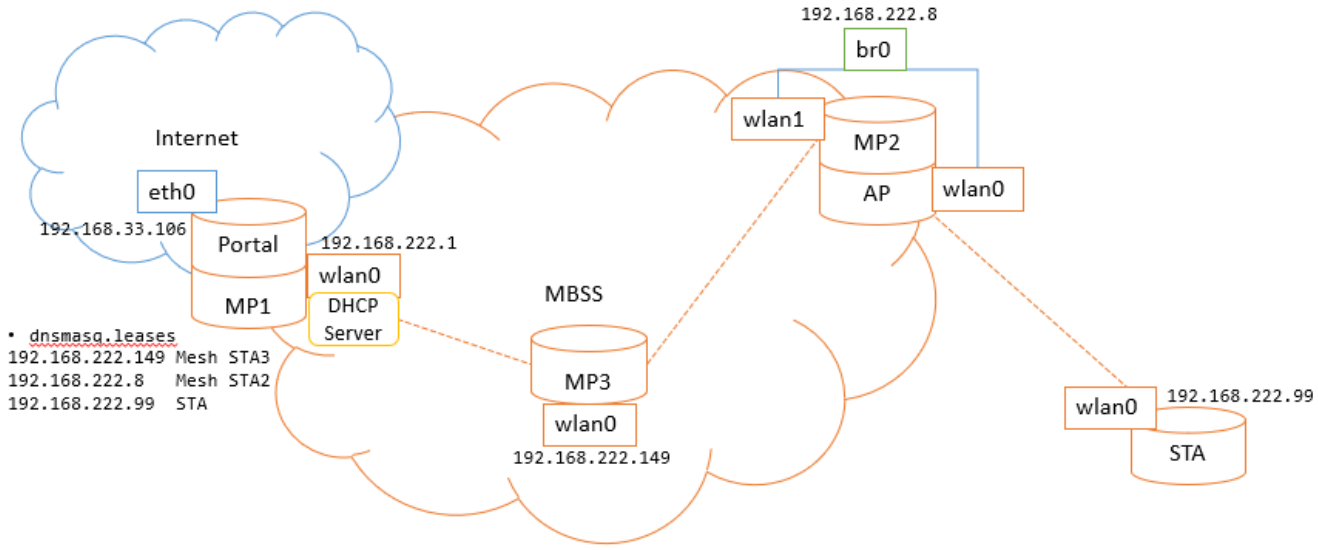

Figure 3.2 IP allocation of mesh network

3.3 Test commands

3.3.1 Ping

STA can communicate with internet server.

```
$ ping google.com
```

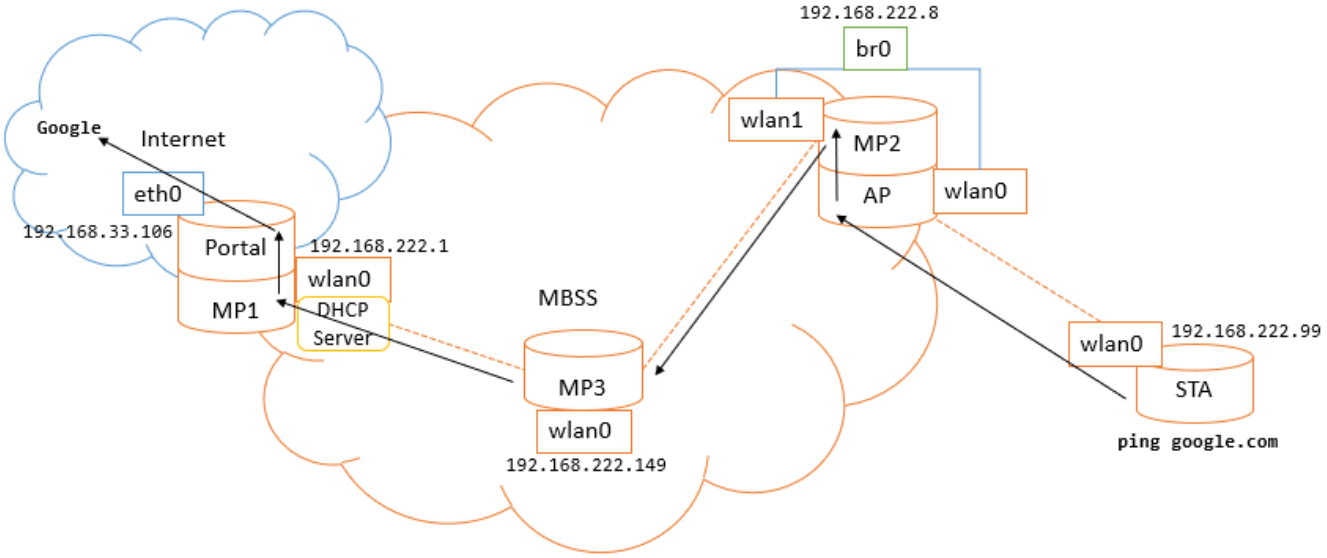

Figure 3.3 ping google.com from STA

MPP can communicate with STA.

```
$ ping 192.168.222.99
```

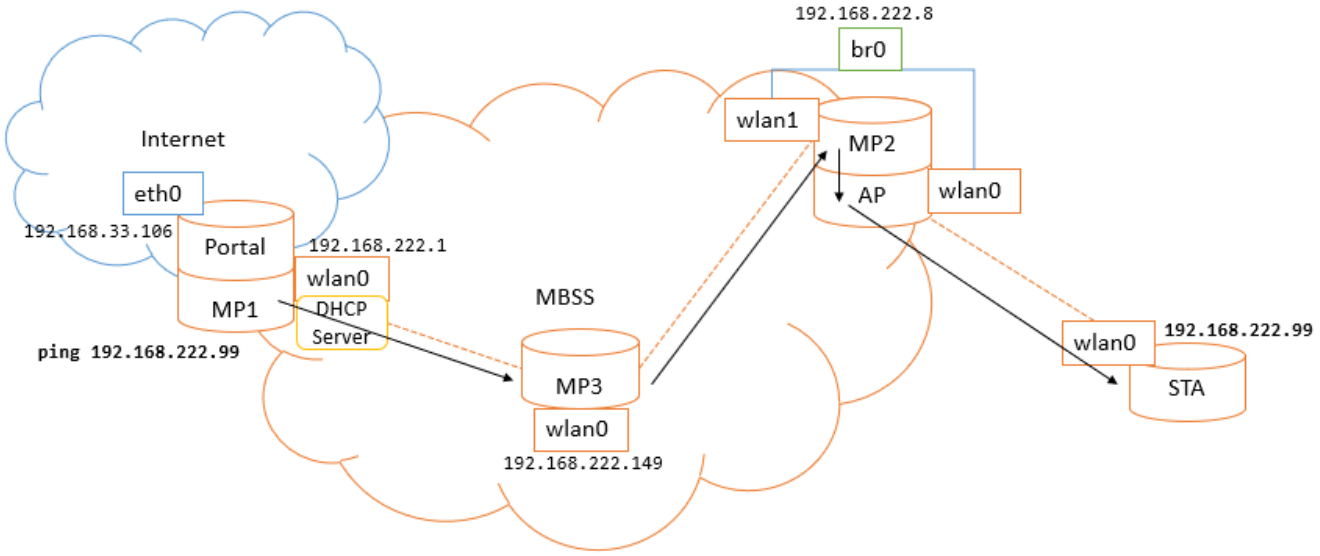

Figure 3.4 ping [STA IP] from MPP

3.3.2 Mesh status check

Following two commands can be used to check the 11s mesh connection status.

- To see a list of mesh paths: sudo iw dev wlan0 mpath dump
- To get current WPA status: sudo wpa_cli status

```
$ sudo iw dev wlan0 mpath dump
DEST ADDR         NEXT HOP          IFACE     SN    METRIC  QLEN    EXPTIME    DTIM   DRET    FLAGS
02:00:eb:cf:0e:d4 02:00:eb:cf:0e:d4 wlan0     15    1377    0       3590       0      0       0x15
02:00:eb:98:eb:25 02:00:eb:98:eb:25 wlan0     1     1377    0       3600       0      0       0x15
$ sudo wpa_cli status
Selected interface 'wlan0'
bssid=00:00:00:00:00:00
freq=5795
ssid=halow_mesh
id=0
mode=mesh
pairwise_cipher=UNKNOWN
group_cipher=UNKNOWN
key_mgmt=UNKNOWN
wpa_state=COMPLETED
ip_address=192.168.201.2
address=00:01:02:03:04:14
uuid=1aa91a70-1281-53aa-9a1d-ce76cc1f0d70
```

4 Revision history

Revision No	Date	Comments
Ver 1.0	11/6/2019	Initial version
Ver 1.1	3/31/2021	Update overview and test procedure
Ver 1.2	8/18/2021	Mesh AP Concurrent mode
Ver 1.3	9/16/2021	Change start script (start.py)
Ver 1.4	6/12/2023	Update for v1.4 SW package