WiLink™ 8 WLAN Software - 802.11s Mesh

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ABSTRACT

This application report contains information on the WiLink 8 software mesh solution.

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1 Introduction

The different use cases for using mesh network, recommended configuration and provisioning methods are discussed. To make sure your software version supports this feature, see the product page.

2 General Information

A wireless mesh network is a network topology in which each peer transmits its own data as well as serves as a relay for other peers in the network. Unlike the standard star topology, where all peers are connected to the AP and all the data between the peers is transmitted via a single point, in mesh topology the data between source and destination has a dynamic route. Each peer periodically finds the best route to each destination in the network. That way, there is no bottleneck in the network and if a certain peer has dropped, the network has the ability for self-healing. The mesh network also has the capability to inter-operate with other networks as described in Figure 1.
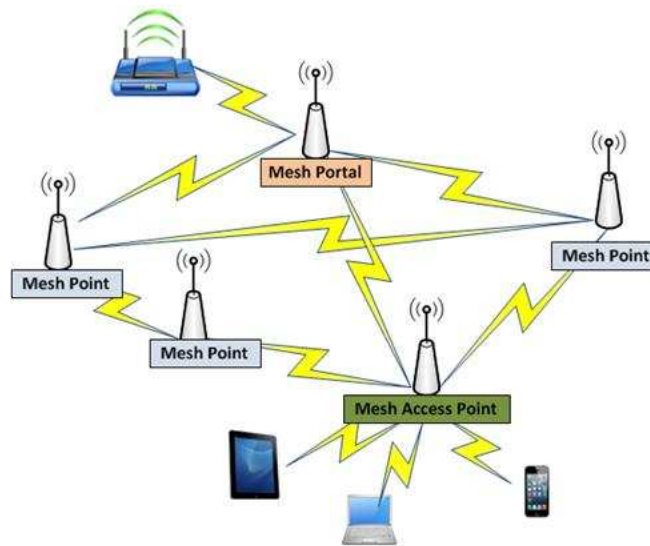

Figure 1. Mesh Network Topology

3 Supported Modes

3.1 Mesh Station/Mesh Point

A Mesh Station (mesh STA), sometime referred to as Mesh Point (MP), uses beacons with special mesh attributes to advertise itself, to discover neighboring nodes and to keep track of them. Note that neighbor discovery is only limited to nodes that are in range of an MP. The Peer Link Management protocol is used to connect to adjacent MPs.

For communicating with nodes that are farther than one hop (not in range of the MP), an MP also supports Hybrid Wireless Mesh Protocol (HWMP). It is hybrid because it supports two kinds of path selection protocols: on-demand and proactive.

WiLink 8 software has made multiple optimizations to the basic HWMP that is implemented in the Linux™ kernel, in order to maximize the throughput and reduce the latency that is required in many use cases and especially for wireless audio applications.

3.2 Mesh Portal/Gate

A mesh network could be used for a variety of purposes. One of the purposes of a mesh network is providing internet access. In this case, at least one node and potentially some of the nodes are connected to the internet. Users connected to the mesh network can access the internet via these gateway nodes called Mesh Portals (MPP), which are connected to both the mesh network and the internet.

The Internet connection can be set up by one of two options:

- Bridging Ethernet and the mesh interfaces (see Section 5.2)
- Running Mesh and Station interfaces on the device and using IP forwarding between these interfaces. The station IF will connect to an external AP for internet connection (see Section 5.3)

3.3 Mesh Access Point

A Mesh Access Point (MAP) is a combination of a traditional AP with mesh functionality. By starting AP and Mesh interfaces on the device it is possible to serve as an AP and also be a part of a mesh network at the same time. In such case, the two interfaces should use the same channel.

3.4 Capabilities

Table 1. Mesh Network Capabilities

| Attribute	Value
RF Bands	2.4 GHz and 5 GHz
Data rates	All HT rates
Radio modes	20 Mhz SISO @2.4
	20 Mhz MIMO @2.4
	20 Mhz SISO @5
	40 Mhz SISO @5
Maximum number of connected peers per single peer in the network	10
Maximum number of nodes in the entire network	32
Maximum number of hops in network	6
Path selection	Optimized HWMP
Self-healing Time to establish an alternate path once a peer have dropped	500 ms-1500 ms with active traffic
Security	AuthSAE via wpa_supplicant
Multicast/Broadcast distribution over the network	Supported
DHCP	Supported
IP Routing	Supported
Mesh power save (Light sleep/Deep sleep)	Not Supported
Mesh operating on DFS channel	Not Supported
Mesh zone time synchronization (requires hardware modification)	< 20 µsec

4 General Hardware/Software Requirements

4.1 Hardware Requirements

WiLink8 mesh solution is compatible with any WiLink8 supported platforms. To get the latest updated list of supported host platforms, see product page.

To add Mesh zone time synchronization support, see Section 6.

4.2 Software Requirements

WiLink8 mesh solution is based on the open80211s implementation of the Linux kernel MAC80211 and the hostap user space package. Migration to any Linux-based operating system can be done using standard tools and compilation methods such as backports. For more information, see the Linux Getting Started Guide. Note that the current solution provided in the mainline Linux has a limited performance due to its generic nature. WiLink8 implementation have added several new features and adaptions to achieve a robust and high performance solution.
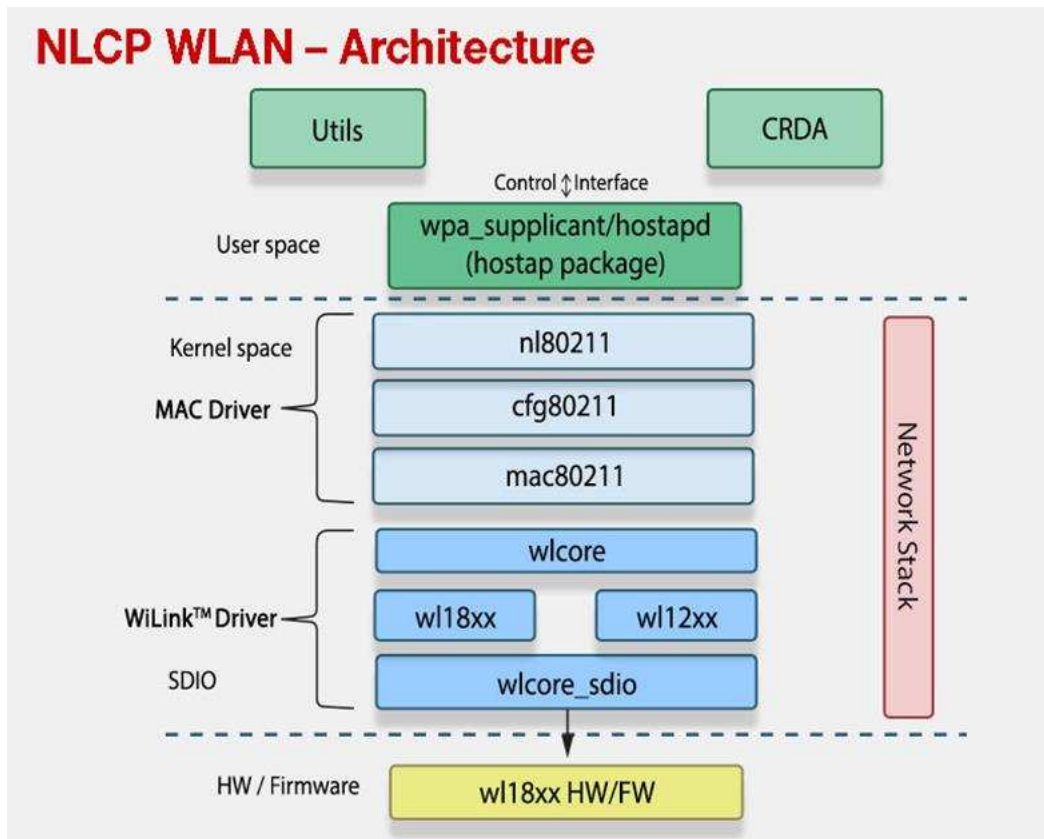
Figure 2. NLCP WLAN - Architecture

The hostap user space package is responsible for the mesh interface connection, management packets and secured connection.

The Linux kernel MAC80211 is responsible for the mesh path selection algorithm and for updating the mesh beacons according to the indications from the hostap user space application. In order to configure and manage the mesh interface, one should connect/send commands to the wpa_supplicant via its control interface.

5   Use Cases

5.1   Mesh Standalone

5.1.1   General Overview

This use case is to serve a case where there is no central AP within the network. All mesh points are connected to each other and can pass information from one to any other. This type of network configuration can be used to setup a M2M infrastructure or a set of speakers playing the same music simultaneously.

5.1.2 Usage

5.1.2.1 Configurations

The following parameters in the wpa_supplicant configuration file should be updated, in order to work with mesh:

- **max_peer_links** - Should be set to maximum of 10.
- **mesh_max_inactivity** - Timeout in seconds to detect mesh peer inactivity. May be set, default is 300 seconds.
- **p2p_disabled** - Must be set to 1 in order to disable p2p interface.
- A profile may be added in order to define the mesh network. For details, see Section 5.1.2.3.

5.1.2.2 Channel selection

Mesh can run on all 2.4GHz channels and on all 5GHz channels, except DFS channels.

5.1.2.3 Commands

1. Bring-up mesh interface by using the scripts provided in the WiLink8 SW package.
   ```
   sh /usr/share/wl18xx/mesh_start.sh
   ```
   The script will:

   (a) Add interface of type mesh point:
   ```
   iw phy phy0 interface add mesh0 type mp
   ```

   (b) Start wpa_supplicant attached to the new mesh interface, with the mesh_supplicant.conf configuration file

   (c) Enable RTS for any packet length:
   ```
   iw phy phy0 set rts 0
   ```

2. Connect to the mesh network by using one of the following methods:

   (a) Define a profile in the wpa_supplicant's configuration file, as follows:
   ```
   network={
       ssid="MESH_NETWORK_SSID"
       mode=5
       frequency=MESH_NETWORK_FREQ
       key_mgmt=NONE or SAE
       psk="12345678" //Needed only if SAE is the key_mgmt type
    }
   ```

   (b) Use the mesh_join.sh script (provided in the WiLink8 SW package):
   ```
   sh /usr/share/wl18xx/mesh_join.sh
   ```
   This script will:

   (i) Add a network via the wpa_cli, and set the following parameters: ssid, mode (5), frequency, key_mgmt (NONE or SAE) and psk (only if key_mgmt=SAE)

   (ii) Run: `wpa_cli enable_network NETID`

   For example: `sh mesh_join.sh MESH_NETWORK_SSID MESH_NETWORK_FREQ PSK`

5.2 Mesh + Ethernet Bridge

5.2.1 General Overview

Setting the mesh and the Ethernet interfaces under the same bridge, enables the mesh network to be connected to the backbone network. It also enables AP range extension, in case the device is connected to the AP via the Ethernet interface.

5.2.2 Usage

5.2.2.1 Configurations

For mesh, same as Mesh Standalone.

5.2.2.2 Channel Selection

For mesh, same as Mesh Standalone.

5.2.2.3 Commands

1. Start mesh the same way as Mesh Standalone.
2. Bring up the Ethernet interface (for example, eth0).
3. Setup a bridge, using mesh_bridge.sh: `sh /usr/share/wl18xx/mesh_bridge.sh`

    The script will:

    (a) Create a bridge: `brctl addbr br0`

    (b) Set the two interface to be under the bridge:

    (i) `brctl addif br0 mesh0`

    (ii) `brctl addif br0 eth0`

5.3 Mesh + Station

5.3.1 General Overview

Running mesh and station interfaces on the same device enables range extension of the AP and offloading from the AP to the mesh network.

5.3.2 Usage

5.3.2.1 Configurations

For the station interface, use the wpa_supplicant configuration file. For mesh, same as Mesh Standalone.

> **NOTE:** Once Mesh and STA are both up, P2P device cannot be started.

5.3.2.2 Channel Selection

The Station interface can run on all 2.4 and 5 GHz channels, including DFS channels, according to configuration. The Mesh interface can run on all 2.4GHz and 5 GHz channels, except DFS channels. It is recommended that both interfaces work on the same channel, which improves the latency. It is the responsibility of the network administrator to make sure both interfaces are on the same channel. Multi channel is also supported. The impact of working in multi channel is increased latency.

5.3.2.3 Commands

Bring-up the STA and mesh interfaces by using the scripts provided in the WiLink8 software package:

`sh /usr/share/wl18xx/sta_start.sh`

- The script will add the Station interface and start the wpa_supplicant with the station configuration file.

`sh /usr/share/wl18xx/mesh_start.sh`

- The script will add the Mesh interface and start another wpa_supplicant with the mesh configuration file.

Note that there will be two wpa_supplicants running in the system.

Connections on both interfaces:

- Station: Same as before.
- Mesh: Same as Mesh Standalone.
- When using wpa_cli commands, one must indicate the interface the commands should be performed on: `wpa_cli -i IF_NAME`

5.4 Mesh + AP

5.4.1 General Overview

Running mesh and AP interfaces on the same device, allows connecting legacy devices to the mesh network. Meaning, legacy devices, that supports station interface only, can connect to our AP interface, and through it be connected to the mesh network.

5.4.2 Usage

5.4.2.1 Configurations

For the AP interface, use the hostapd configuration file. For mesh, same as Mesh Standalone.

5.4.2.2 Channel Selection

The AP interface can run on all 2.4 and 5 GHz channels, including DFS channels, according to configuration. The Mesh interface can run on all 2.4GHz and 5 GHz channels, except DFS channels. Both interfaces must run on the same channel. TI solution is responsible to make sure both IFs run on the same channel, and will fail the bring-up of the IFs if this is not the case.

5.4.2.3 Commands

- AP: Same as before.
- Mesh: Same as Mesh Standalone.

6 Mesh Zone Time Sync

The mesh zone time synchronization, unlike traditional infrastructure network time synchronization, is not well defined. In mesh network it is required to determine in advance which mesh peer is the one that all other mesh peers in its zone need to be synchronized to. The mesh time synchronization is mainly used for Audio use cases.

The mesh network is divided into zones where each zone has its own time synchronized. For each zone, a mesh peer will be selected in advance as the master peer for synchronization and its identification (MAC Address) will be configured to each one of the mesh peers in that zone.
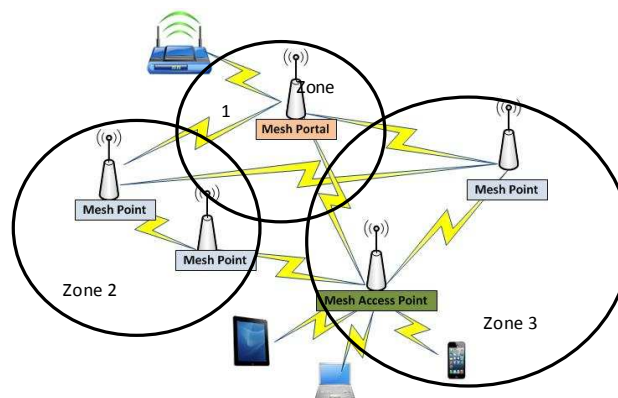
Figure 3. Mesh Network Zone Time Synchronization

6.1 Hardware Requirements

The Mesh Zone Time Synchronization (as the traditional time synchronization) implementation was done using Sitara™ AM335 host processor. A general-purpose input/output (GPIO) line should be connected between the AM335 device and the WL8 device:

- On WL8 side: COEX_MWS_FRAME_SYNC (GPIO11 on TI module)
- On AM335 side: GPIO 2_2 (TIMER4) This GPIO line is responsible for the synchronizing between two different hardware devices.

6.2 Software Requirements

The Mesh Time Synchronization feature is fully supported starting from WL8 R8.7 software release.

6.3 Assumptions/Limitations

- Supported starting version R8.7 and up
- Zone time sync is applicable for TI only mesh network
- The synchronizer mesh peer is assumed to be connected directly (one hop) to each one of the mesh peers in its zone.
- The synchronizer mesh peer MAC address is needed to be configured to itself and to each one of the mesh peers in its zone.
- No automatic recovery for time synchronization is implemented if the synchronizer mesh peer was dropped. A new one should be assign manually. On the fly configuration of the new MAC address is supported.
- Once a mesh peer (not the synchronizer) gets disconnected it is not considered as synchronized anymore.

6.4 How to select the Zone Synchronizer Mesh Peer

The synchronizer mesh peer is selected and its MAC address is configured to each mesh peer in its zone. The configuration is done via host command to FW with the MAC address of the synchronizer mesh peer. Once a valid and existent MAC address is configured, the synchronizer mesh is automatically marked (by MAC address comparison). Meaning, if the configured MAC address matchs one of the addresses of a mesh peer, it is selected as synchronizer. It is possible to configure the address via new ACX command (ACX_TIME_SYNC_CFG) with the MAC address value. This also allows changing/reconfiguring the synchronization mode (STA/AP/Mesh) which initially was taken from the wlconf file.

It is also possible to configure the address via debugfs command as follows: (example for DO:39:72:50:7C:85)

Configure Address:

echo D03972507C85 > /sys/kernel/debug/ieee80211/phy0/wlcore/wl18xx/time_sync_zone_addr

Read Address:

cat /sys/kernel/debug/ieee80211/phy0/wlcore/wl18xx/time_sync_zone_addr

6.5 Notes

- No Broadcast Mac address is allowed.
- Configuring non-existent MAC address will get the mesh peer out of synchronization but will not have impact on its functionality.

6.6 How to Synchronize to Zone Synchronizer Mesh Peer

The synchronization mechanism is based on existing time synchronization made previously for STA and AP roles. Configure the synchronization for mesh role via the "wlconf-toggle-set.sh" script.

```
root@am335-evm:/usr/share/wl18xx#
root@am335-evm:/usr/share/wl18xx# ./wlconf-toggle-set.sh
Usage: wlconf-toggle-set.sh <bin path> <feature> <mode>
Please note that all of the above require HW modifications.
      Feature Options:
                  'dual'              - Dual Antenna
                  'zigbee'            - Zigbee Coex
                  'sync'              - Time Sync (1-STA, 2-SP, 3-MESH)
```

6.7 Capabilities

The synchronization mechanism is based on existing time synchronization made previously for STA and AP.

7 Mesh On Demand

Mesh on demand helps the network adjust and change its topology upon need. It saves power by acting as a station and using its mesh capabilities only when needed.

The mesh on demand feature provides wireless access in situations where the device is mobile and needs to maintain its connection in a dynamically changing environment, while trying to provide the best possible connectivity solution available under these circumstances.
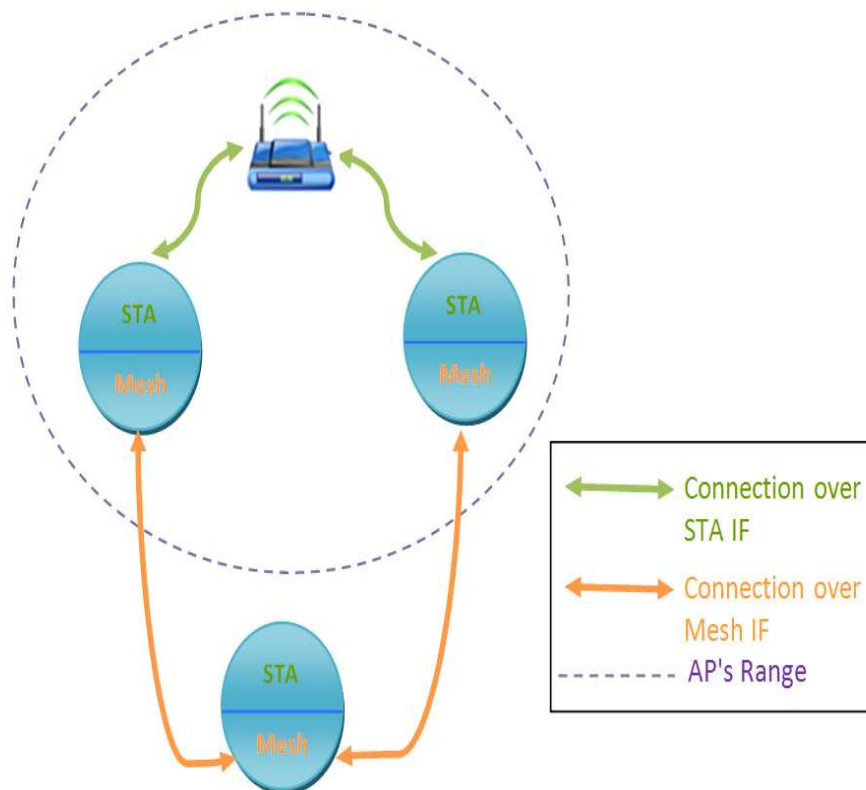
The topology is dual interfaces of station + mesh with a predefined behavior how to pass between the two interfaces in order to maintain the best possible connectivity solution.

The system always prefers connecting directly to an AP (on the Station IF) unless there isn't one or the connection is not stable, in which case it will look for a mesh substitute in order to maintain connectivity.

Mesh on demand benefits summary:

- Supplicant add-on
- Assures L2 range extension and connectivity
- Easy to setup
- Useful in dynamic and semi-dynamic deployments
- Automatic mesh establishment
- Device operates in STA with "dormant" mesh
- While in AP range – devices remain in STA mode
- When outside of AP range – devices peer with other WiLink 8 devices to form mesh
- New devices can join either mesh or STA

7.1 Hardware Requirements

The Mesh On Demand implementation is compatible with any WiLink8 supported platforms.

7.2 Software requirements

The Mesh On Demand feature is fully supported starting from WL8 R8.7 software release.

7.3 Limitations

- Supported starting version R8.7 and up.
- Mesh On Demand is applicable only for WiLink 8 mesh devices.
- Network management layer is not supplied by TI and is required for end products

7.4 How to Enable Mesh On Demand Feature

7.4.1 Configurations

Two configuration files should be defined:

- wpa_supplicant.conf for the Station IF:
  - It is recommended (but not mandatory) to pre-define the AP's profile in the configuration file.
- mesh_supplicant.conf for the Mesh IF:
  - Add the following parameter to the configuration file in order to enable MOD: mesh_on_demand=1
  - It is recommended (but not mandatory) to pre-define a mesh profile in the configuration file.

7.4.2 Commands

1. Bring-up the STA and Mesh Interfaces, using the scripts provided in the WiLink8 SW package: `sh /usr/share/wl18xx/mod_start.sh`.

   The script will:

   (a) Add Station and Mesh interfaces

   (b) Start the wpa_supplicant attached to the two interfaces:

   ```
   wpa_supplicant -e/usr/share/wl18xx/entropy.bin \
       -iwlan0 -Dnl80211 -c/usr/share/wl18xx/wpa_supplicant.conf -N\
       -imesh0 -Dnl80211 -c/usr/share/wl18xx/mesh_supplicant.conf &
   ```

If profiles were defined in the configuration files, the connection (on either the Station or the Mesh IFs) will be dynamic, according to the environment. If profiles were not defined, you should add networks dynamically on both interfaces, in order to connect.

7.4.3   Networking Configuration

1. Station will receive an IP address from the AP (assuming the AP has DHCP server)
2. Enable IP forwarding to support routing between interfaces:

   ```
   echo 1> /proc/sys/net/ipv4/ip_forward
   ```
3. Example of networking option for the mesh:

   (a) a. The station will get the ip address via the AP's DHCP server.

   For example: 10.20.30.44 (We should make sure this address never changes – lease time will be forever).

   (b) b. The mesh role will get the same ip address on a predefined subnet.

   For example: The predefined subnet 15.25.35.XXX

   Mesh IP: 15.25.35.44

   Code example for IP copy:

   ```
   udhcpc -i wlan0 &
   sleep 2
   var=$(ip addr | grep 'wlan0' | grep 'inet' | awk '{print $2}' | cut -f1  -d'/')
   mask=${var:7:3}
   newsubnet_part1='ifconfig mesh0 15.25.35.'
   newsubnet_part3=' netmask 255.255.255.0'
   $newsubnet_part1$mask$newsubnet_part3
   ```

   > **NOTE:**   It is required to establish a connection over the Station IF, in order to have a valid IP address for the Mesh IF.
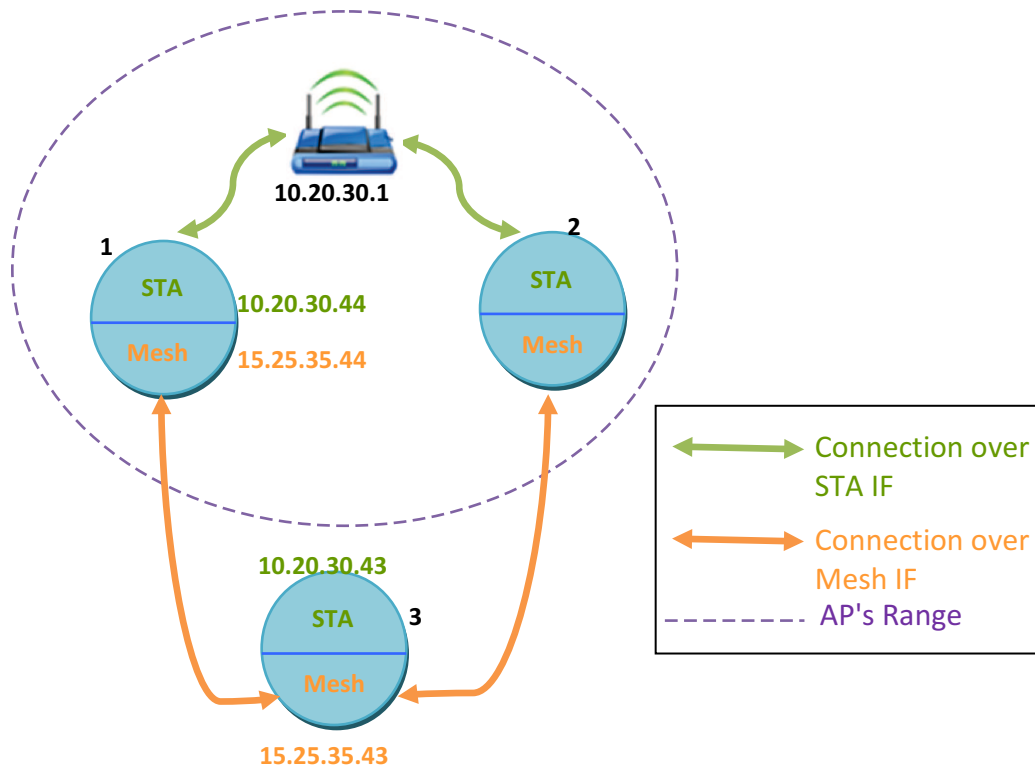
   (c) Routing

   When we have connection over the Mesh IF (and are not connected via the STA IF), In order to reach the AP, we need to add a route to the AP network via the Mesh IF.

   When we have connection over the Mesh IF (and are not connected via the STA IF), In order to reach the AP, we need to add a route to the AP network via the Mesh IF.

   Device #3 Mesh IP address is: 15.25.35.43 And we are connected to device #1, its Mesh IP address: 15.25.35.44 AP's subnet: 10.20.30.xx

   Upon connection over the Mesh IF, we need to configure route on device #3 as follows: route add –net 10.20.30.0 netmask 255.255.255.0 gw 15.25.35.44

   Upon re-connection to the AP via the STA IF (which will lead to disconnection on the Mesh IF), we need to delete the routing:

   ```
   route del –net 10.20.30.0 netmask 255.255.255.0
   ```

Due to the dynamic nature of such deployment there is a need for a network management application to control the above definitions. Adoptions to the routing configuration are required on both the static and moving devices to support a full L3 packet transmission. There are multiple ways to handle this setup – NAT, Broadcast forwarding, ARP proxies and more. They will not be detailed in this document as it is highly dependent on the exact use case and requirements.

8 Provisioning

There are multiple deployment options for a mesh network, each might require a different provisioning `philosophy` to fit with the specific use-case, customer requirements, desired effort and more. Mesh devices can be provisioned to each other and/or to an external network. In the following section we will detail a few ideas and possible flows to provision a mesh device.

8.1 *Provision a Mesh Only Network Using a Pre-Defined Configuration*

In this example, a simple connection of multiple mesh devices is demonstrated to one another with minimal user intervention.

- **Flow:**
  - All devices will be configured with the same configuration file, setting the same mesh ID, channel and security if desired.
  - User will trigger provisioning mode by clicking a button, or it will start automatically on the loading sequence.
  - As all devices are pre-configured with the same information, they will self-create the connection between the nodes.
- **Pros:** Easy to setup, fast network establishment for the user.
- **Cons:** Unsecure (password is fixed and pre-defined), any device in range will be connected – no control on mesh network scale.

8.2 Provision a Mesh Only Network Using Key Exchange (WPS like)

- **Flow:**
  - All devices will be configured with the same configuration file, setting the same mesh ID, channel and security if desired.
  - User will trigger provisioning mode by clicking a button, or by other means
    Phase 1:
  - As all devices are pre-configured with the same information, they will self-create the connection between the nodes.
    Phase 2:
  - Master device will be selected to generate a new mesh ID, channel and security key. Device can be selected as the one having the lowest MAC address, or by frame exchange.
  - Master device will send the new information to the slave devices.
  - Slave devices reconfigure their mesh network and will join the new one.
- **Pros:** More secured, relatively simple and transparent to the user.
- **Cons:** Harder to add a new device after the group has been established. Establishing a network takes longer.

8.3 Provision a Mesh Only Network Using Bluetooth Phone Connection

- **Flow:**
  - Phone is paired with the mesh devices over Bluetooth.
  - User will configure the devices using a phone application, setting the mesh ID, frequency and passkey (all or some can be automatically set).
  - Mesh devices will receive network information and start mesh according to the received configuration
  - User will repeat the steps on other devices.
  - Feedback to the user can be provided upon success/failure.
- **Pros:** More controlled by the user, fully aware of the provisioning state.
- **Cons:** Requires a dedicated application and HW to support iPhone (MFI).

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