

# AN14212

## 802.11kvr Roaming

Rev. 2.0 — 13 January 2025

Application note

### Document information

Information	Content
Keywords	802.11kvr, roaming, bgscan, wpa_supplicant, fast transition, resource management, basic service set transition management, neighbor report, beacon report, wireless network management
Abstract	Explains how to enable fast transition, configure wpa_supplicant, load the driver parameters. And describes different types of fast transition.



## 1 Introduction

NXP Wi-Fi radios support 802.11kvr roaming standards:

- **802.11k (Radio Resource Measurement):** provides information about the available APs and respective RSSI to help the client choose the best AP.
- **802.11v (Wireless Network Management):** provides information to the client about available APs for roaming, without a full scan.
- **802.11r (Fast Basic Service Set Transition):** eliminates the need for fresh authentication when a client roams to another network.

This document explains how to use 802.11kvr for roaming.

**Note:** 802.11kvr is supported only in STA mode. Mobile AP mode does not support 802.11k, 802.11v, and 802.11r standards.

### 1.1 Supported devices

Refer to the feature list in the release note to check if 802.11kvr is supported in the software release package. The wireless SoCs that support 802.11kvr are:

- 88W8987 [\[5\]](#)
- 88W8997 [\[6\]](#)
- 88Q9098 [\[7\]](#)
- 88W9098 [\[8\]](#)
- IW416 [\[13\]](#)
- IW611 [\[14\]](#)
- IW612 [\[15\]](#)
- IW620 [\[16\]](#)
- AW611 [\[9\]](#)
- AW690 [\[10\]](#)
- AW692 [\[11\]](#)
- AW693 [\[12\]](#)

### 1.2 Prerequisites

- Open source wpa\_supplicant v2.10 or higher [\[17\]](#)
- Open source kernel v4.6 or higher

## 2 802.11kvr

Figure 1 shows the interaction between 802.11k, 802.11v, and 802.11r for roaming.

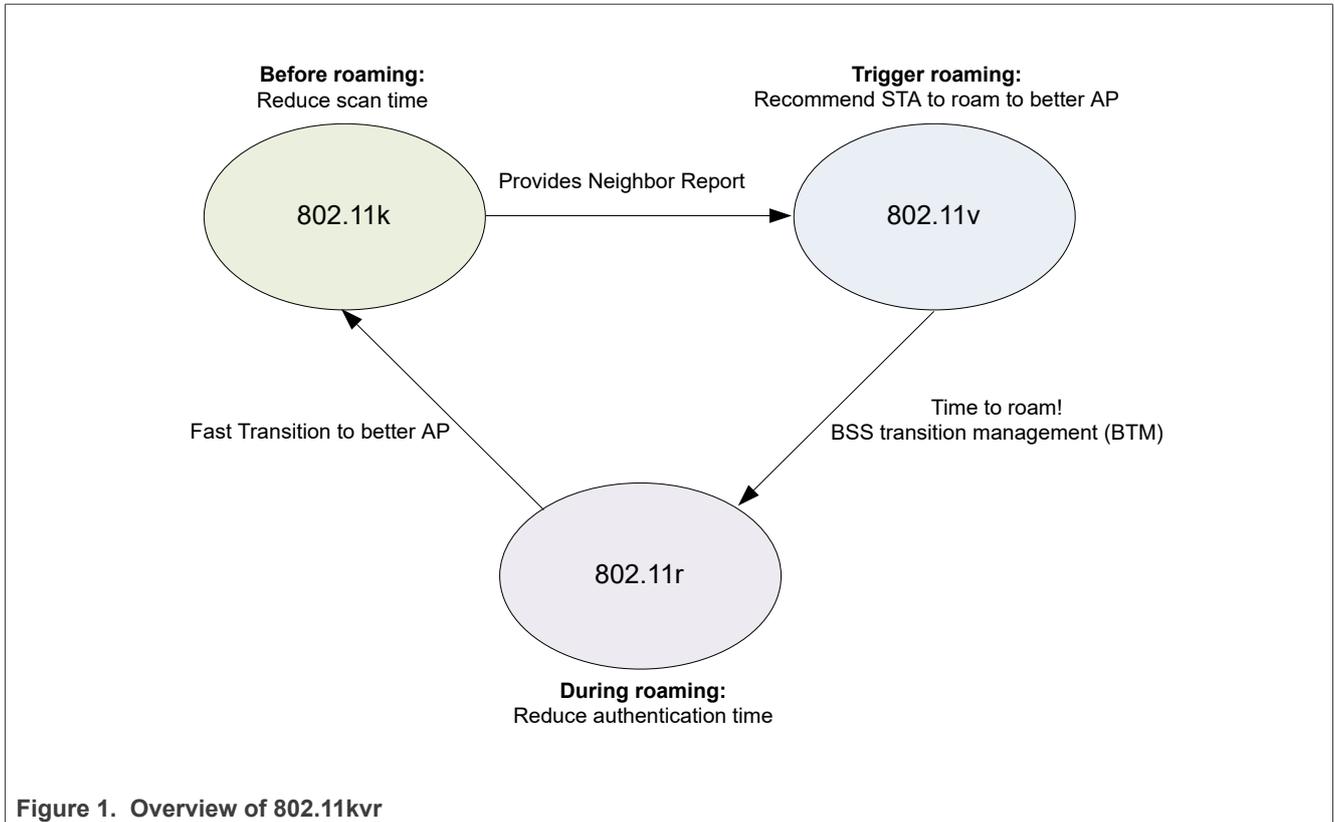


Figure 1. Overview of 802.11kvr

**802.11k** is a Radio Resource Management (RRM) that provides mechanisms for APs and clients to dynamically measure the available radio resources. APs and clients can send neighbor reports, beacon reports, and link measurement reports to each other.

- Neighbor reports: information about known neighbor APs to help STA better understand its surroundings
- Beacon reports: information about channel configuration, location, coverage/frequency planning, and AP detection
- Link measurement reports: information about a requested link

**802.11v** is BSS transition management (BTM) with Wireless Network Management (WNM) that allows client devices to exchange information about the network topology. The information includes RF environment, making each client network aware of its surroundings. STA can send a BTM query to the AP and get a list of preferred candidates.

- BTM query: A connected AP suggests the STA to roam to another APs with a better connection with a preferred candidate list.

**802.11r** is Fast Basic Service Set Transition (FT), which is faster than normal roaming because it avoids a 4-way handshake when transitioning from one AP to another. The two types of FT are over-the-air and over-the-distribution-system (over-the-DS).

## 3 Configuration

This section explains how to configure 802.11kvr.

### 3.1 Driver load parameters

To enable 802.11kvr, load the driver with the parameters:

```
host_mlme=1
cfg80211_wext = 0xf (STA mask of CFG80211 and WEXT control)
```

**Note:** For more details about the driver load parameters, refer to README in the SW release package.

Example of driver loading:

```
insmod wlan.ko
insmod moal.ko fw_name=nxp/<fw_name>.bin cfg80211_wext=0xf auto_ds=2 ps_mode=2
txpwrlimit_cfg=nxp/<power_table>.bin cal_data_cfg=nxp/WlanCalData.conf host_mlme=1
drvdbg=0x20037
```

**Note:** Setting `drvdbg = 0x20037` is optional and used to log roaming messages on `dmesg`.

### 3.2 wpa\_supplicant

wpa\_supplicant is the MAC Sublayer Management Entity (MLME) to send/receive RRM action frames, FT action frames, and BTM frames. Refer to `/wpa_supplicant/README` for more information.

**Note:** Open source wpa\_supplicant version v.2.10 or above must be used. wpa\_supplicant must be built with the flag, `CONFIG_80211R` enabled.

**Step 1** – Download wpa\_supplicant open source code (`wpa_supplicant-2.10.tar.gz`) (see [17]).

**Step 2** – Decompress the file.

```
tar -xvf wpa_supplicant-2.10.tar.gz
```

**Step 3** – Move to the `wpa_supplicant` directory. See Figure 2.

```
cd wpa_supplicant
```

Name	Date modified	Type	Size
binder	1/16/2022 12:51 PM	File folder	
dbus	1/16/2022 12:51 PM	File folder	
doc	1/16/2022 12:51 PM	File folder	
examples	1/16/2022 12:51 PM	File folder	
systemd	1/16/2022 12:51 PM	File folder	
utils	1/16/2022 12:51 PM	File folder	
vs2005	1/16/2022 12:51 PM	File folder	
wpa_gui-qt4	1/16/2022 12:51 PM	File folder	
.gitignore	1/16/2022 12:51 PM	Text Document	1 KB
android.config	1/16/2022 12:51 PM	XML Configuration...	20 KB
Android.mk	1/16/2022 12:51 PM	Makefile	38 KB
ap.c	1/16/2022 12:51 PM	C Source	51 KB
ap.h	1/16/2022 12:51 PM	C/C++ Header	5 KB
autoscan.c	1/16/2022 12:51 PM	C Source	4 KB
autoscan.h	1/16/2022 12:51 PM	C/C++ Header	2 KB
autoscan_exponential.c	1/16/2022 12:51 PM	C Source	3 KB
autoscan_periodic.c	1/16/2022 12:51 PM	C Source	2 KB
bgscan.c	1/16/2022 12:51 PM	C Source	3 KB
bgscan.h	1/16/2022 12:51 PM	C/C++ Header	2 KB

Figure 2. wpa\_supplicant directory content

**Step 4** – Enable the IEEE80211R flag in the `.config` file.

```
CONFIG_IEEE80211R=y
```

**Step 5** – Build `wpa_supplicant`.

```
make
```

Example of output:

```
CC ../src/drivers/driver_nl80211.c
CC ../src/drivers/driver_nl80211_capa.c
CC ../src/drivers/driver_nl80211_event.c
CC ../src/drivers/driver_nl80211_monitor.c
...
```

**Step 6** – Create the configuration file `wpa_supplicant.conf`.

Example of `wpa_supplicant.conf` content:

```
ctrl_interface=/var/run/wpa_supplicant
ctrl_interface_group=0
update_config=1
ap_scan=1
network={
  ssid="TEST_NETWORK"
  key_mgmt=FT-PSK                # Fast Transition Key Management
  proto=RSN
  pairwise=CCMP
  group=CCMP
  psk="1234567890"
  bgscan="simple:30:-75:120"     # Background scan settings
}
```

- Set the key management to FT-PSK or FT-EAP.

```
key_mgmt=FT-PSK
key_mgmt=FT-EAP
```

- Set the background scanning parameters.

```
bgscan="simple:<short scan interval> : <signal strength threshold> : <long scan interval>"
```

Where:

**Table 1. Command parameters**

Parameter	Description
short scan interval	Perform a scan every X seconds when the signal strength is weaker than the threshold
signal strength threshold	Signal strength from AP (dBm)
long scan interval	Perform a scan every X seconds when the signal strength is higher than the threshold

Example of command:

```
bgscan="simple:30:-75:120"
```

In the example, a scan is performed every 30 seconds when the signal strength from the current AP is below -75dBm. If the signal strength is above -75dBm, the interval is every 120 seconds.

**Step 7** – Run wpa\_supplicant.

```
wpa_supplicant -B -Dnl80211 -<interface> -c/etc/wpa_supplicant.conf
```

## 4 wpa\_cli

---

Once 802.11kvr is enabled, wpa\_supplicant automatically handles roaming. The command line interface wpa\_cli is used to interact with wpa\_supplicant and trigger the following actions:

- Neighbor report
- BTM query
- Over-the-Air Fast Transition
- Over-the-DS Fast Transition

## 5 Setup

The setup to demonstrate 802.11kvr consists of:

- Enterprise Wireless LAN controller
- at least two APs
- at least one STA

**Note:** Refer to the user manual of your Enterprise controller and APs to enable 802.11kvr.

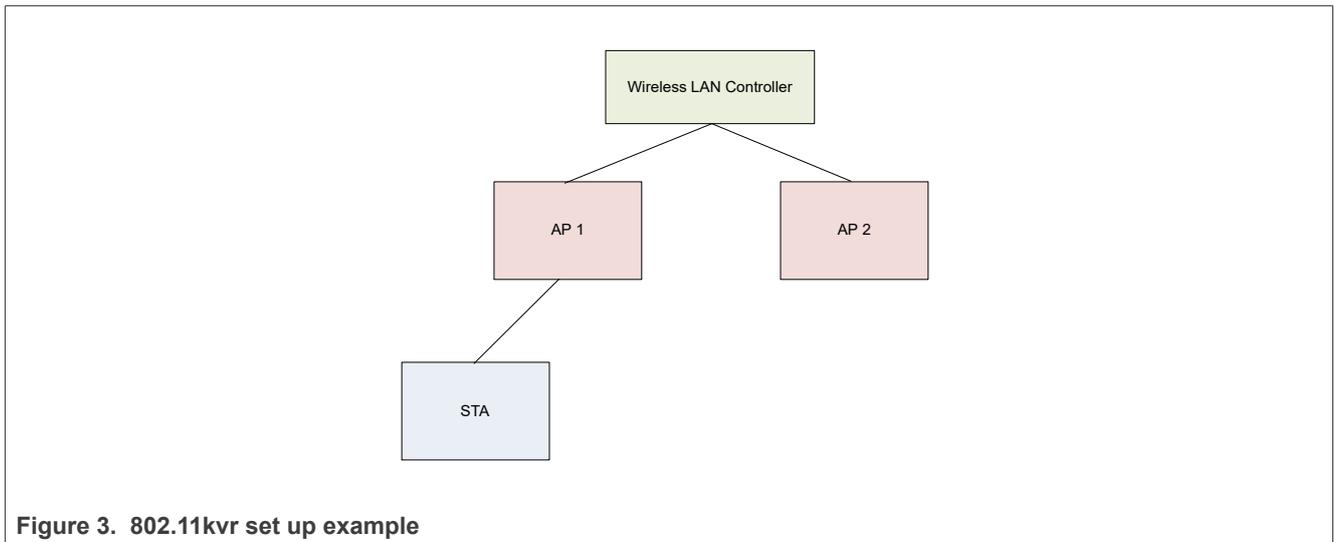


Figure 3. 802.11kvr set up example

**Step 1** – Connect the APs to the Wireless LAN controller.

Figure 4 shows the AP enabled with 802.11kvr.

- AP MAC= d0:4d:c6:b2:07:32
- 802.11kvr (Link measurement and Neighbor report) is enabled in the AP.

No.	Time	Delta Time	Source address	Destination	PHY type	Sequence	MCS inde	Protocol	TID	Length	Info
127741	2023-09-24 09:54:48.988984	0.000796s	d0:4d:c6:b2:07:31	Broadcast	802.11a (OFDM)	1712		802.11		443	Beacon frame, SN=1712, FN=0, Flags=.....C, BI=100,
127742	2023-09-24 09:54:48.989577	0.000593s	d0:4d:c6:b2:07:32	Broadcast	802.11a (OFDM)	1713		802.11		426	Beacon frame, SN=1713, FN=0, Flags=.....C, BI=100,
127743	2023-09-24 09:54:48.990116	0.000539s	d0:4d:c6:b2:07:33	Broadcast	802.11a (OFDM)	1714		802.11		395	Beacon frame, SN=1714, FN=0, Flags=.....C, BI=100,
127744	2023-09-24 09:54:48.990696	0.000580s	d0:4d:c6:b2:07:34	Broadcast	802.11a (OFDM)	1715		802.11		441	Beacon frame, SN=1715, FN=0, Flags=.....C, BI=100,

```
<
> IEEE 802.11 Beacon frame, Flags: .....C
v IEEE 802.11 Wireless Management
  > Fixed parameters (12 bytes)
  v Tagged parameters (361 bytes)
    > Tag: SSID parameter set: WPA2-ECSA-655
    > Tag: Supported Rates 6(B), 9, 12(B), 18, 24(B), 36, 48, 54, [Mbit/sec]
    > Tag: DS Parameter set: Current Channel: 40
    > Tag: Traffic Indication Map (TIM): DTIM 0 of 0 bitmap
    > Tag: Country Information: Country Code CA, Environment Any
    > Tag: Power Constraint: 0
    > Tag: TPC Report Transmit Power: 12, Link Margin: 0
    > Tag: RSN Information
    > Tag: QSSS Load Element 802.11e CCA Version
    > Tag: AP Channel Report: Operating Class 1, Channel List : 36, 40, 44, 48,
    > Tag: AP Channel Report: Operating Class 2, Channel List : 52, 56, 60, 64,
    > Tag: AP Channel Report: Operating Class 3, Channel List : 100, 104, 108, 112, 116, 132, 136, 140, 144,
    > Tag: AP Channel Report: Operating Class 17, Channel List : 149, 153, 157, 161, 165,
    > Tag: BSS Available Admission Capacity
    v Tag: RM Enabled Capabilities (5 octets)
      Tag Number: RM Enabled Capabilities (70)
      Tag length: 5
      v RM Capabilities: 0x73 (octet 1)
        .... .1 = Link Measurement: Enabled
        .... .1 = Neighbor Report: Enabled
        .... 0. = Parallel Measurements: Disabled
        .... 0... = Repeated Measurements: Disabled
        ...1 .... = Beacon Passive Measurement: Enabled
        ..1 .... = Beacon Active Measurement: Enabled
        .1. .... = Beacon Table Measurement: Supported
        0... .... = Beacon Measurement Reporting Conditions: Disabled
      > RM Capabilities: 0x00 (octet 2)
      > RM Capabilities: 0x01 (octet 3)
      > RM Capabilities: 0x00 (octet 4)
      > RM Capabilities: 0x0d (octet 5)
```

Figure 4. Example of AP enabled with 802.11kvr

**Step 2** – Bring up the DUT in STA mode and define the configuration ([Section 3](#)).

**Step 3** – Connect the STA to the AP.

[Figure 5](#) shows the STA enabled with 802.11kvr.

- AP MAC= d0:4d:c6:b2:07:32
- STA MAC= 00:04:9f:06:7a:f6
- STA and AP exchange association request and responses.
- 802.11kvr (Link measurement and Neighbor report) is enabled in the Wi-Fi environment.

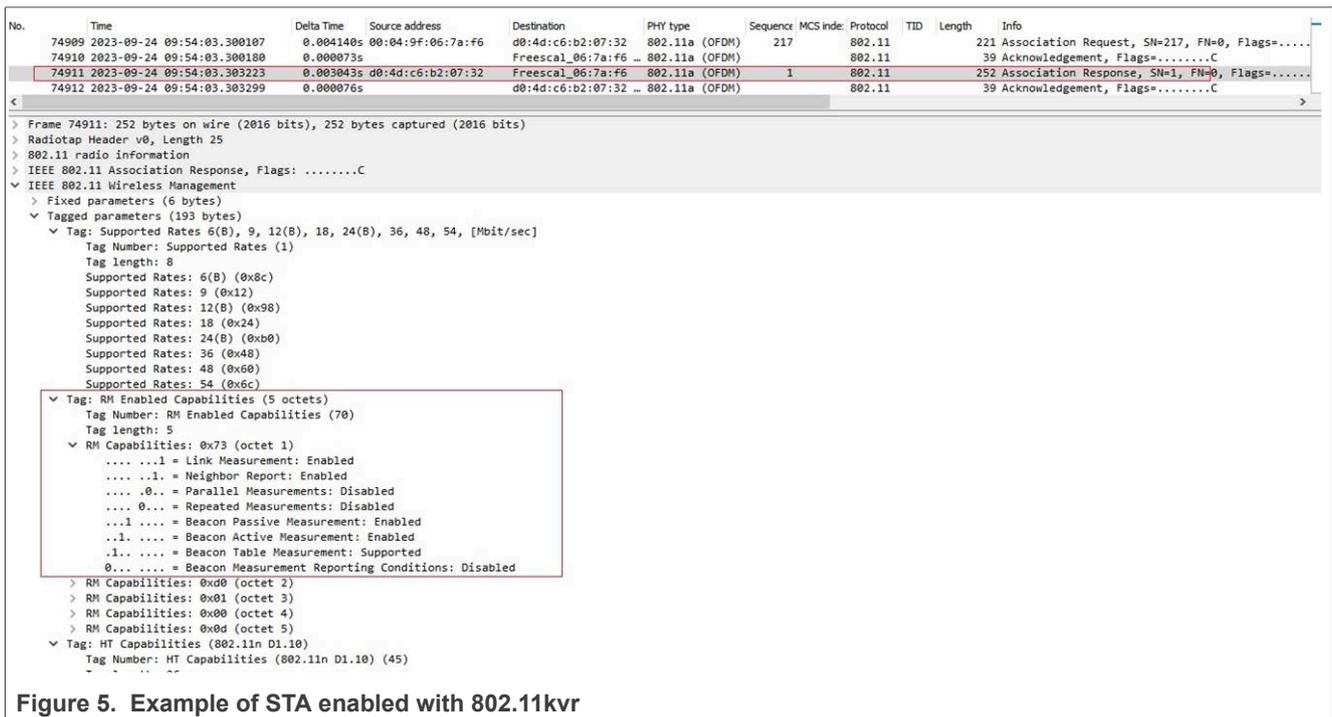


Figure 5. Example of STA enabled with 802.11kvr

## 6 802.11k examples

This section provides examples for Neighbor Report, Link measurement, and Beacon report.

### 6.1 Neighbor report

The example demonstrates a Neighbor report request from the STA. AP 1 responds with a list of neighboring APs on the same Wi-Fi network, including AP 2. If there are no other APs in the environment, the neighbor report is empty.

wpa\_supplicant handles the Neighbor reports. A `wpa_cli` command (in step 2) can be used to manually request a neighbor report.

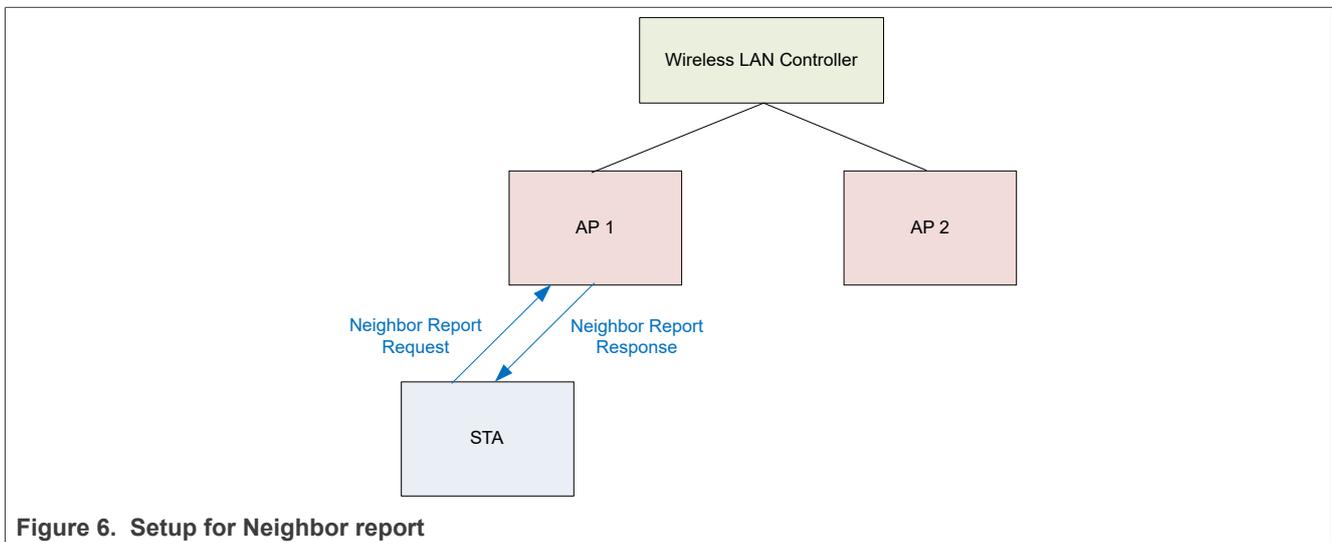


Figure 6. Setup for Neighbor report

**Step 1** – Set up the environment ([Section 5](#)).

**Step 2** – Run the `wpa_cli` command to trigger a Neighbor report request.

```
./wpa_cli neighbor_rep_request
```

Command output example:

The log shows STA sending “RRM: Neighbor report request” to the AP.

```
RRM: Neighbor report request (for ), token=4
nl80211: Send Action frame (ifindex=3, freq=2422 MHz wait=0 ms no_cck=0 offchanok=1)
nl80211: Drv Event 60 (NL80211_CMD_FRAME_TX_STATUS) received for mlan0
nl80211: Frame TX status event_A1=00:11:32:ed:9e:b0 stype=13 cookie=0xf6573dff ack=1
nl80211: Frame TX status: cookie=0xf6573dff (match) (ack=1)
mlan0: Event TX_STATUS (16) received
mlan0: EVENT_TX_STATUS dst=00:11:32:ed:9e:b0 type=0 stype=13
Off-channel: Ignore Action TX status - no pending operation
nl80211: BSS Event 59 (NL80211_CMD_FRAME) received for mlan0
nl80211: RX frame da=c0:95:da:00:e5:38 sa=00:11:32:ed:9e:b0 bssid=00:11:32:ed:9e:b0
freq=2422 ssi_signal=0 fc=0xd0 seq_ctrl=0x60 stype=13 (WLAN_FC_STYPE_ACTION) len=27
mlan0: Event RX_MGMT (18) received
mlan0: Received Action frame: SA=00:11:32:ed:9e:b0 Category=5 DataLen=2 freq=2422 MHz
```

Figure 7 shows a sniffer capture example of the Neighbor Report Request from the STA to the AP.

- STA MAC= 00:04:9f:06:7a:f6
- AP MAC= d0:4d:c6:b2:07:32

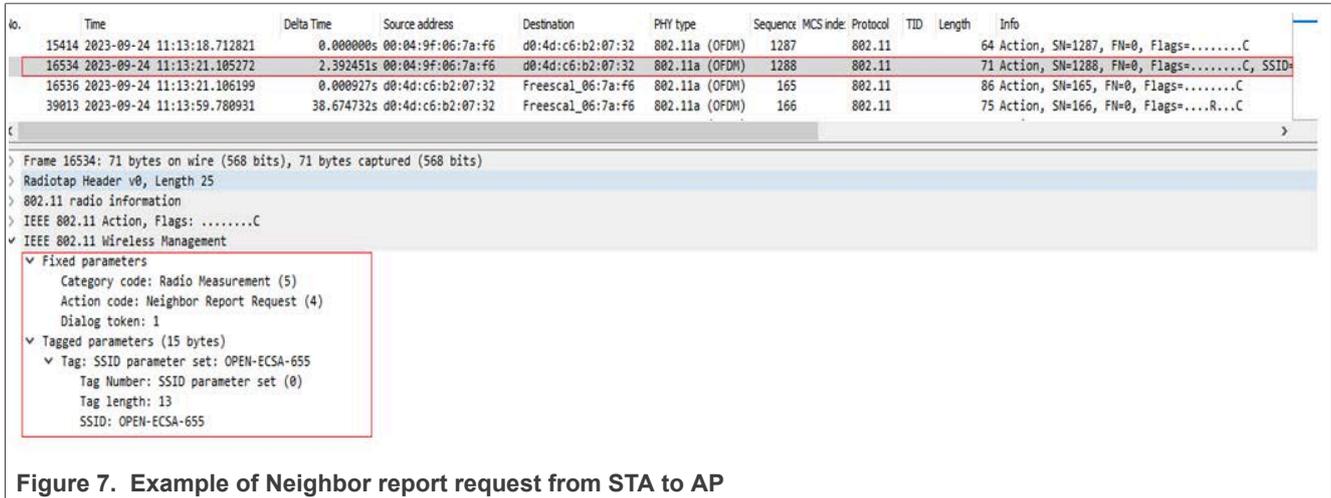


Figure 7. Example of Neighbor report request from STA to AP

Step 3 – Look for AP response (Neighbor report displayed on the console of the STA).

Command output example:

The log shows “RRM: New Neighbor Report”.

```
<3>CTRL-EVENT-SCAN-RESULTS
<3>RRM-NEIGHBOR-REP-RECEIVED bssid=dc:ce:c1:23:9a:4b info=0x2f7 op_class=115 chan=40
phy_type=7
<3>RRM-NEIGHBOR-REP-RECEIVED bssid=dc:ce:c1:23:9a:44 info=0x2e7 op_class=81 chan=1
phy_type=7
<3>CTRL-EVENT-SCAN-STARTED
<3>CTRL-EVENT-SCAN-RESULTS
...
RRM: New Neighbor Report - hexdump(len=31): 02 34 0d d0 4d c6 b2 07 32 f7 02 00 00 7d a1
07 34 d0 4d c6 b2 07 12 e7 02 00 00 51 0b 07
mlan0: RRM: Notifying neighbor report (token = 2)
mlan0: RRM-NEIGHBOR-REP-RECEIVED bssid= d0:4d:c6:b2:07:32 info=0x2f7 op_class=125
chan=161 phy_type=7
mlan0: RRM-NEIGHBOR-REP-RECEIVED bssid= d0:4d:c6:b2:07:12 info=0x2e7 op_class=81 chan=11
phy_type=7
```

Figure 8 shows a sniffer capture example of Neighbor report response from the AP.

- AP MAC= d0:4d:c6:b2:07:32
- STA MAC= 00:04:9f:06:7a:f6

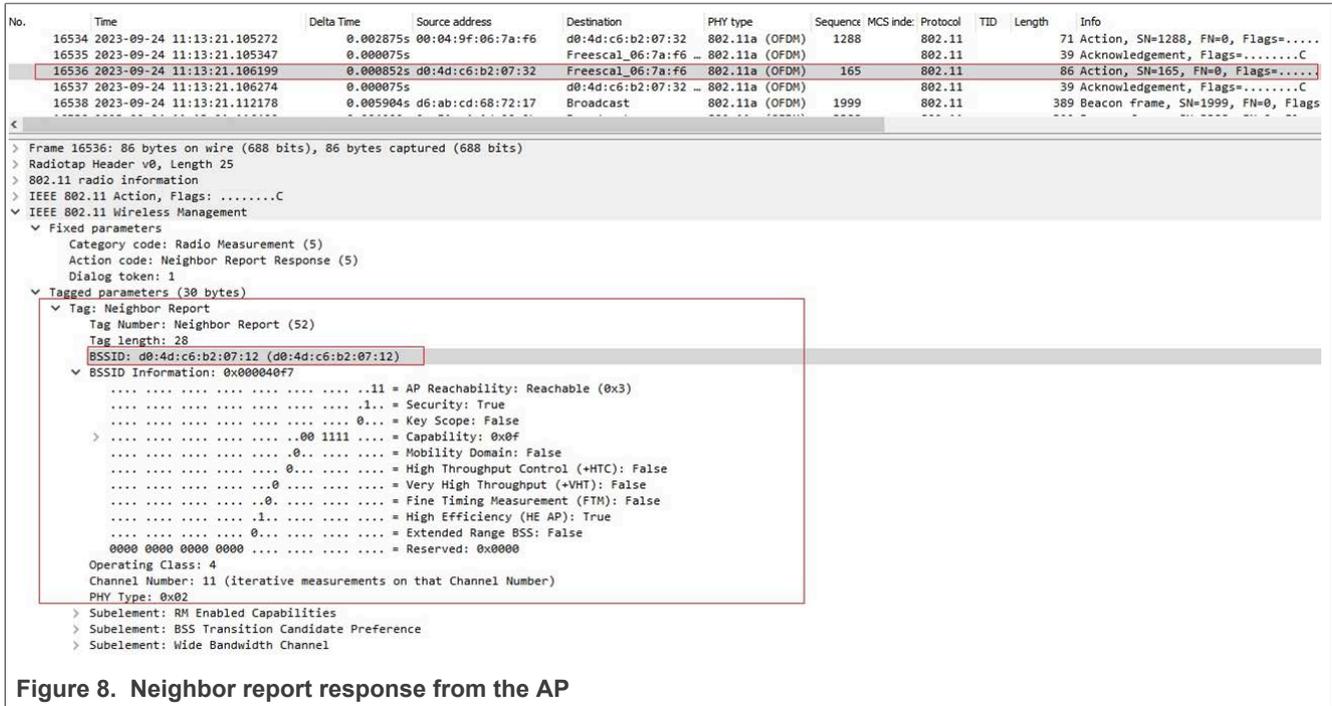


Figure 8. Neighbor report response from the AP

## 6.2 Link measurement

wpa\_supplicant initiates link measurement requests and responses to and from the AP and STA. In this example, the STA sends a link measurement report to the AP.

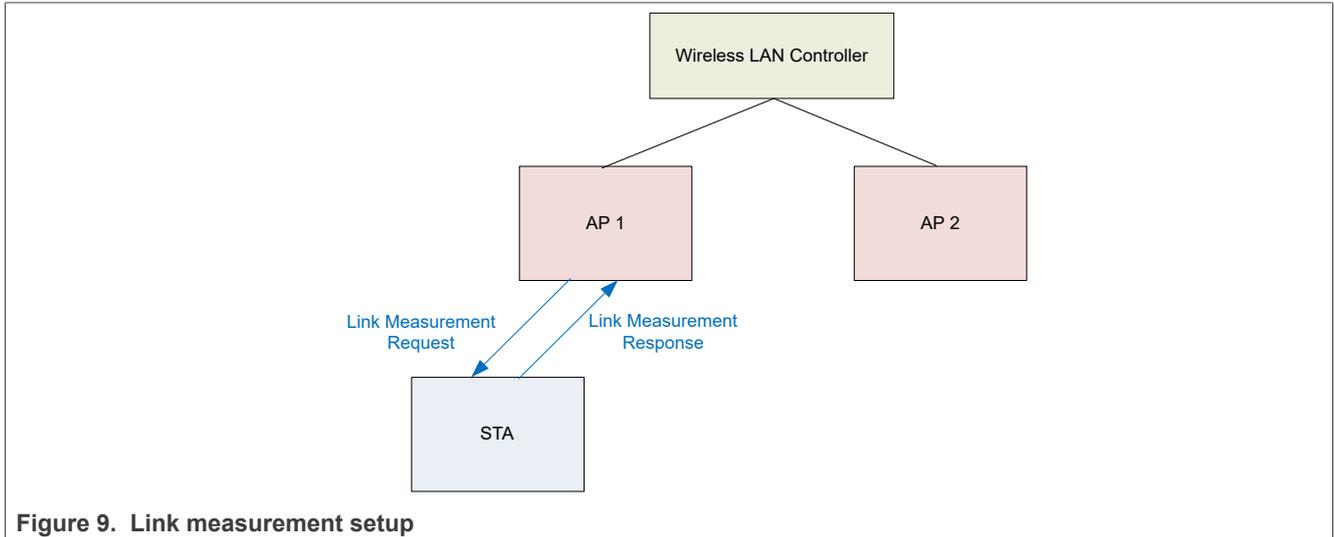


Figure 9. Link measurement setup

**Step 1** – Set up the environment ([Section 5](#)).

**Step 2** – The AP sends a link measurement request to the STA. The request shows on the console of the STA.

Example of output:

```
mlan0: Received Action frame: SA=cc:88:c7:10:d7:11 Category=5 DataLen=31 freq=5805 MHz
Measurement request type 5 token 151
SSID subelement with zero length - wildcard SSID
```

Figure 10 shows an example of the STA receiving a link measurement request from the AP.

- AP MAC= d0:4d:c6:b2:07:32
- STA MAC= 00:04:9f:06:7a:f6

No.	Time	Delta Time	Source address	Destination	PHY type	Sequence	MCS inde	Protocol	TID	Length	Info
103285	2023-09-24 09:54:27.753834	0.000796s	d0:4d:c6:b2:07:32	Freescal_06:7a:f6	802.11a (OFDM)	4		802.11		62	Action, SN=4, FN=0, Flags=.....C
137790	2023-09-24 09:55:03.878644	36.116810s	d0:4d:c6:b2:07:32	Freescal_06:7a:f6	802.11a (OFDM)	6		802.11		73	Action, SN=6, FN=0, Flags=.....C, SSID=OPE
137792	2023-09-24 09:55:03.878824	0.000180s	00:04:9f:06:7a:f6	d0:4d:c6:b2:07:32	802.11a (OFDM)	263		802.11		64	Action, SN=263, FN=0, Flags=.....C
137795	2023-09-24 09:55:03.878469	0.007645s	00:04:9f:06:7a:f6	d0:4d:c6:b2:07:32	802.11a (OFDM)	265		802.11		1036	Action, SN=265, FN=0, Flags=.....C, BI=0,

```
> Frame 137790: 73 bytes on wire (584 bits), 73 bytes captured (584 bits)
> Radiotap Header v0, Length 25
> 802.11 radio information
> IEEE 802.11 Action, Flags: .....C
> IEEE 802.11 Wireless Management
  > Fixed parameters
    > Category code: Radio Measurement (5)
    > Action code: Link Measurement Request (2)
    > Dialog token: 1
    > Transmit Power Used: 12dBm
    > Max Transmit Power: 23dBm
  > Tagged parameters (15 bytes)
    > Tag: SSID parameter set: OPEN-ECSA-655
      > Tag Number: SSID parameter set (0)
      > Tag length: 13
      > SSID: OPEN-ECSA-655
```

Figure 10. Example of STA receiving link measurement request from the AP

**Step 3** – STA responds with a link measurement response on the console.

Command output example:

```
RRM: Radio Measurement report - hexdump(len=35): 27 21 97 00 05 80 a1 00 00 00 00 00 00 00 00 00 00 09 3e ff cc 88 c7 10 d7 11 00 00 00 00 00 02 02 01 00
nl80211: Send Action frame (ifindex=3, freq=5805 MHz wait=0 ms no_cck=0 offchanok=1)
```

Figure 11 shows an example of link measurement response from STA to AP.

- AP MAC= d0:4d:c6:b2:07:32
- STA MAC= 00:04:9f:06:7a:f6

The image shows a Wireshark packet capture interface. At the top, a table lists three packets. The second packet, at time 09:55:03.878469, is highlighted. Below the table, the packet details pane is expanded to show the structure of the IEEE 802.11 Action frame. A red box highlights the 'Fixed parameters' section, which includes: Category code: Radio Measurement (5), Action code: Radio Measurement Report (1), and Dialog token: 1. Below this, the 'Tagged parameters' section shows three 'Tag: Measurement Report' entries, each with a Tag Number of 39 and a Tag length of 33. The first tag's details are expanded to show: Measurement Token: 0x01, Measurement Report Mode: 0x00, Measurement Report Type: Beacon Report (0x05), and Reported Frame Information: 0x09.

Figure 11. Example of link measurement response from the STA to the AP

### 6.3 Beacon report

wpa\_supplicant initiates the STA and AP to send beacon reports to each other. In this example, the STA sends a beacon report to the AP.

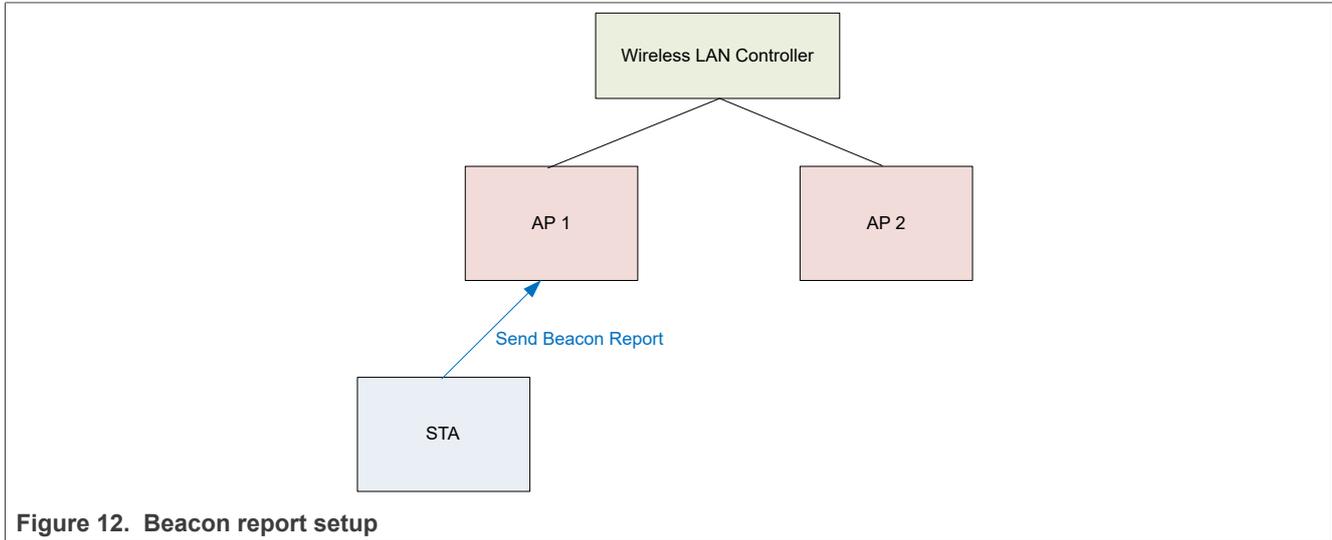


Figure 12. Beacon report setup

**Step 1** – Set up the environment (Section 5).

**Step 2** – STA sends a beacon report to the AP.

Figure 13 shows a sniffer capture example of the STA sending a Beacon Report to the AP.

- AP MAC= d0:4d:c6:b2:07:32
- STA MAC= 00:04:9f:06:7a:f6

No.	Time	Delta Time	Source address	Destination	PHY type	Sequence	MCS	Index	Protocol	TID	Length	Info
137792	2023-09-24 09:55:03.870824	0.000180s	00:04:9f:06:7a:f6	d0:4d:c6:b2:07:32	802.11a (OFDM)	263			802.11		64	Action, SN=263, FN=0, Flags=.....C
137795	2023-09-24 09:55:03.878469	0.007645s	00:04:9f:06:7a:f6	d0:4d:c6:b2:07:32	802.11a (OFDM)	265			802.11		1036	Action, SN=265, FN=0, Flags=.....C BI=0,
137797	2023-09-24 09:55:03.878611	0.000142s	00:04:9f:06:7a:f6	d0:4d:c6:b2:07:32	802.11a (OFDM)	266			802.11		64	Action, SN=266, FN=0, Flags=.....C

```

    .... ..0. = Incapable: No
    .... ..0. = Refused: No
    0000 0... = Reserved: 0x00

    ✓ Measurement Report Type: Beacon Report (0x05)
      Operating Class: 81
      Measurement Channel Number: 11 (iterative measurements on that Channel Number)
      Measurement Start Time: 0x0000000000000000
      Measurement Duration: 0x0000
      Received Channel Power Indicator (RCPI): 0x32
      Received Signal to Noise Indicator (RSNI): 0xff
      BSSID Being Reported: HewlettP_b6:d3:ae (30:8d:59:b6:d3:ae)
      Antenna ID: 0x00
      Parent Timing Synchronization Function (TSF): 0x00000000
      SubElement ID: Unknown (2)
      Length: 2
      SubElement ID: Reported Frame Body (1)
      Length: 0
    > Reported Frame Body
    > Reported Frame Information: 0x06
    ✓ Tag: Measurement Report
      Tag Number: Measurement Report (39)
      Tag Length: 39
      Measurement Token: 0x01
    > Measurement Report Mode: 6x00
    ✓ Measurement Report Type: Beacon Report (0x05)
      Operating Class: 128
      Measurement Channel Number: 157 (iterative measurements on that Channel Number)
      Measurement Start Time: 0x0000000000000000
      Measurement Duration: 0x0000
      Received Channel Power Indicator (RCPI): 0x22
      Received Signal to Noise Indicator (RSNI): 0xff
      BSSID Being Reported: ae:4c:a5:b2:d8:08 (ae:4c:a5:b2:d8:08)
      Antenna ID: 0x00
      Parent Timing Synchronization Function (TSF): 0x00000000
      SubElement ID: Unknown (2)
      Length: 2
      SubElement ID: Reported Frame Body (1)
  
```

Figure 13. Example of the STA sending a beacon report to the AP

## 7 802.11v example

The example shows a BSS transition management query (BTM) from the STA. The AP responds with a request for the STA to roam based on a preferred candidate list. The request is in a BSS management frame.

If the AP is configured with disassociation imminent function enabled, the STA is forced to roam to a better AP. If disassociation imminent function is disabled, the STA can reject or accept the request. Refer to the user manual of the AP manual for this configuration.

wpa\_supplicant handles BTM queries. Issue a wpa\_cli command (in step 2) to manually send a BTM query.

Figure 14 shows the BTM query sequence, where:

1. BTM query
2. BTM request
3. BTM response

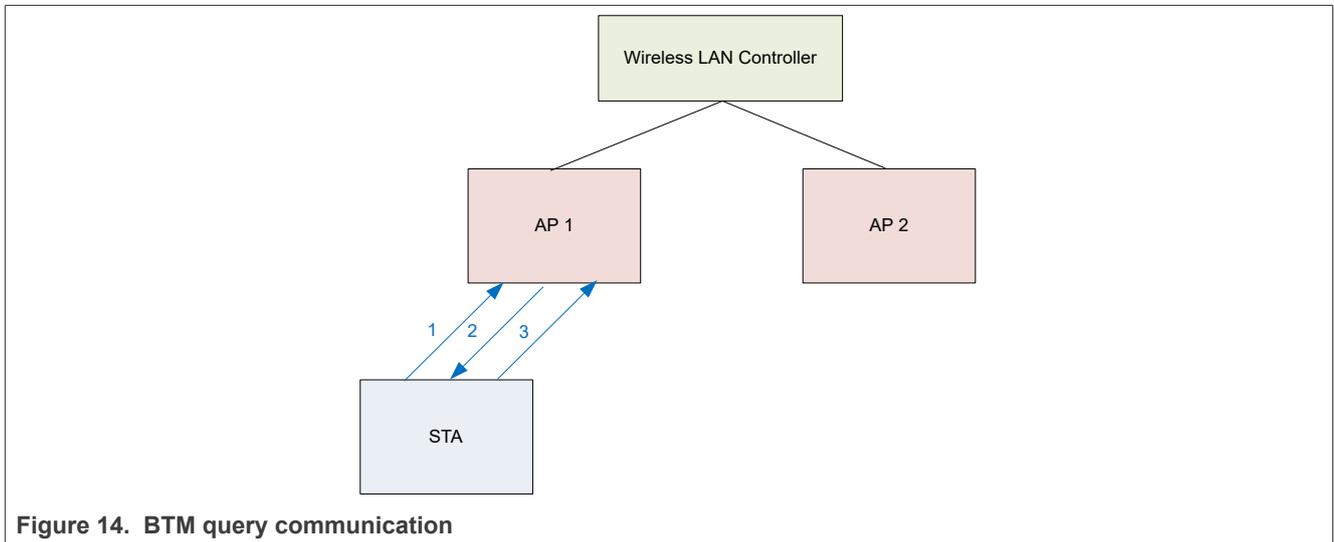


Figure 14. BTM query communication

**Step 1** – Set up the environment ([Section 5](#)).

**Step 2** – Issue a wpa\_cli command to trigger a BTM query.

```
./wpa_cli wnm_bss_query 1
```

Command output example:

```
WNM: Send BSS Transition Management Query to 00:11:32:ed:9e:b0 query_reason=1
nl80211: Send[ 3172.437052] wlan: mlan0 START SCAN
Action frame (ifindex=3, freq=2422 MHz wait=0 ms no_cck=0 offchanok=1)
OK
nl80211: Drv Event 60 (NL80211_CMD_FRAME_TX_STATUS) received for mlan0
nl80211: Frame TX status event A1=00:11:32:ed:9e:b0 stype=13 cookie=0x75319743 ack=1
nl80211: Frame TX status: cookie=0x75319743 (match) (ack=1)
mlan0: Event TX_STATUS (16) received
mlan0: EVENT_TX_STATUS dst=00:11:32:ed:9e:b0 type=0 stype=13
Off-channel: Ignore Action TX status - no pending operation
nl80211: BSS Event 59 (NL80211_CMD_FRAME) received for mlan0
nl80211: RX frame da=c0:95:da:00:e5:38 sa=00:11:32:ed:9e:b0 bssid=00:11:32:ed:9e:b0
freq=2422 ssi_signal=0 fc=0xd0 seq_ctrl=0x90 stype=13 (WLAN_FC_STYPE_ACTION) len=54
mlan0: Event RX_MGMT (18) received
mlan0: Received Action frame: SA=00:11:32:ed:9e:b0 Category=10 DataLen=29 freq=2422 MHz
WNM: RX action 7 from 00:11:32:ed:9e:b0
```

Figure 15 shows the example where the STA sends a BTM query to the AP 1.

- STA MAC= c0:95:da:00:e5:38
- AP MAC= dc:ce:c1:23:9a:4b

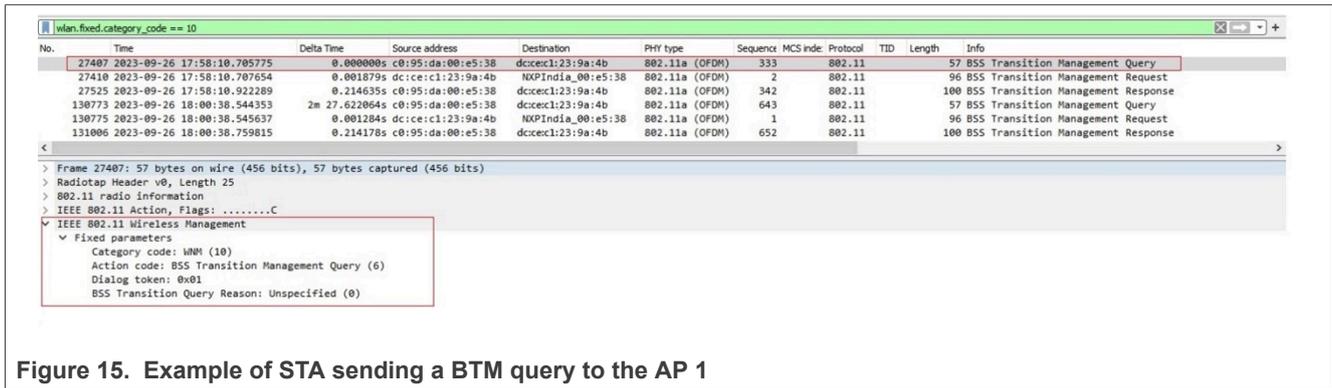


Figure 15. Example of STA sending a BTM query to the AP 1

**Step 3** – AP 1 sends STA a BTM request with a preferred candidate list. The request is displayed on the console of the STA. The STA decides whether to roam or not based on this information.

dmesg output example:

```
WNM: BSS Transition Management Request: dialog_token=1 request_mode=0x1 disassoc_timer=0
  validity_interval=100
mLAN0: WNM: Preferred List Available
WNM: Neighbor report tag 52
WNM: Subelement id=6 len[ 3172.532203] wlan: SCAN COMPLETED: scanned AP count=1
n=3
WNM: Subelement id=3 len=1
...
WNM: BSS Transition Candidate List
0: 00:11:32:ed:9e:b0 info=0x17 op_class=12 chan=3 phy=0 pref=1 freq=2422
WNM: Candidate list valid for 10240 ms
mLAN0: WNM: Fetch current scan results from the driver for checking transition candidates
nl80211: Received scan results (1 BSSes)
nl80211: Scan results indicate BSS status with 00:11:32:ed:9e:b0 as associated
mLAN0: WNM: No transition candidate matches existing scan results
WNM: Scan 1 frequencies based on transition candidate list
WNM: Scan only for a specific BSSID since there is only a single candidate
  00:11:32:ed:9e:b0
mLAN0: Setting scan request: 0.000000 sec
mLAN0: Starting AP scan for wildcard SSID
WPS: Building WPS IE for Probe Request
WPS: * Version (hardcoded 0x10)
WPS: * Request Type
WPS: * Config Methods (3108)
WPS: * UUID-E
WPS: * Primary Device Type
WPS: * RF Bands (3)
WPS: * Association State
WPS: * Configuration Error (0)
WPS: * Device Password ID (0)
WPS: * Manufacturer
WPS: * Model Name
WPS: * Model Number
WPS: * Device Name
WPS: * Version2 (0x20)
P2P: * P2P IE header
P2P: * Capability dev=25 group=00
P2P: * Listen Channel: Regulatory Class 81 Channel 6
mLAN0: Optimize scan based on previously generated frequency list
mLAN0: Scan a previously specified BSSID 00:11:32:ed:9e:b0 and SSID synology_wifi_2.4G
mLAN0: Add radio work 'scan'@0xaaable40e190
mLAN0: First radio work item in the queue - schedule start immediately
mLAN0: Starting radio work 'scan'@0xaaable40e190 after 0.000030 second wait
mLAN0: nl80211: scan request
nl80211: Scan for a specific BSSID: 00:11:32:ed:9e:b0
Scan requested (ret=0) - scan timeout 30 seconds
nl80211: Drv Event 33 (NL80211_CMD_TRIGGER_SCAN) received for mLAN0
mLAN0: nl80211: Scan trigger
```

Figure 16 shows an example of BTM query request from the AP to the STA.

- STA MAC= c0:95:da:00:e5:38
- AP MAC= dc:ce:c1:23:9a:4b
- Preferred candidate list with the AP BSSID = 00:a6:ca:42:8b (AP 2).
- Dissociation Imminent enabled. STA is forced to roam.

No.	Time	Delta Time	Source address	Destination	PHY type	Sequence	MCS inde	Protocol	TID	Length	Info
27407	2023-09-26 17:56:10.785775	0.000000s	c0:95:da:00:e5:38	dc:ce:c1:23:9a:4b	802.11a (OFDM)	333		802.11		57	BSS Transition Management Query
27410	2023-09-26 17:58:10.787654	0.001879s	dc:ce:c1:23:9a:4b	NXPIndia_00:e5:38	802.11a (OFDM)	2		802.11		96	BSS Transition Management Request
27525	2023-09-26 17:58:10.922289	0.214635s	c0:95:da:00:e5:38	dc:ce:c1:23:9a:4b	802.11a (OFDM)	342		802.11		100	BSS Transition Management Response
138773	2023-09-26 18:00:38.544353	2m 27.622064s	c0:95:da:00:e5:38	dc:ce:c1:23:9a:4b	802.11a (OFDM)	643		802.11		57	BSS Transition Management Query
138775	2023-09-26 18:00:38.545637	0.001284s	dc:ce:c1:23:9a:4b	NXPIndia_00:e5:38	802.11a (OFDM)	1		802.11		96	BSS Transition Management Request
131006	2023-09-26 18:00:38.759815	0.214178s	c0:95:da:00:e5:38	dc:ce:c1:23:9a:4b	802.11a (OFDM)	652		802.11		100	BSS Transition Management Response

```
> Frame 27410: 96 bytes on wire (768 bits), 96 bytes captured (768 bits) on interface 0
> Radiotap Header v0, Length 25
> 802.11 radio information
> IEEE 802.11 Action, Flags: .....C
IEEE 802.11 Wireless Management
  Fixed parameters
    Category code: NMN (10)
    Action code: BSS Transition Management Request (7)
    Dialog token: 0x01
    ... .1 = Preferred Candidate List Included: 1
    ... .0 = Abridged: 0
    ... .1 = Disassociation Imminent: 1
    ... .0 = BSS Termination Included: 0
    ... .0 = ESS Disassociation Imminent: 0
    Disassociation Timer: 0
    Validity Interval: 200
    BSS Transition Candidate List Entries: 3410dccec1239a4bf702000073280703015f341000a6ca0...
  Tag: Neighbor Report
  Tag: Neighbor Report
    Tag Number: Neighbor Report (52)
    Tag length: 16
    BSSID: 00:a6:ca:42:8b (00:a6:ca:0a:42:8b)
  BSSID Information: 0x00002f7
    ... .11 = AP Reachability: Reachable (0x3)
    ... .1 = Security: True
    ... .0 = Key Scope: False
    ... .10 1111 = Capability: 0x2f
    ... .0 = Mobility Domain: False
    ... .0 = High Throughput Control (+HTC): False
    ... .0 = Very High Throughput (+VHT): False
    ... .0 = Fine Timing Measurement (FTM): False
    ... .0 = High Efficiency (HE AP): False
    ... .0 = Extended Range BSS: False
    0000 0000 0000 0000 = Reserved: 0x0000
    Operating Class: 125
    Channel Number: 161 (iterative measurements on that Channel Number)
    PHY Type: 0x08
  Subelement: BSS Transition Candidate Preference
    ID: 3
    Length: 1
    Preference: 255
```

Figure 16. Example of BTM query request from the AP to the STA

**Step 4** – STA responds to the request of AP1 to roam to a different AP.

**Note:** STA roams using 802.11r. Refer to Section 9.

Figure 17 shows an example of the STA response to AP 1 with the decision to roam to AP 2.

- STA MAC= c0:95:da:00:e5:38
- AP MAC= dc:ce:c1:23:9a:4b
- BSS Transition Target BSS = 00:a6:ca:42:8b (decides to roam to AP 2)

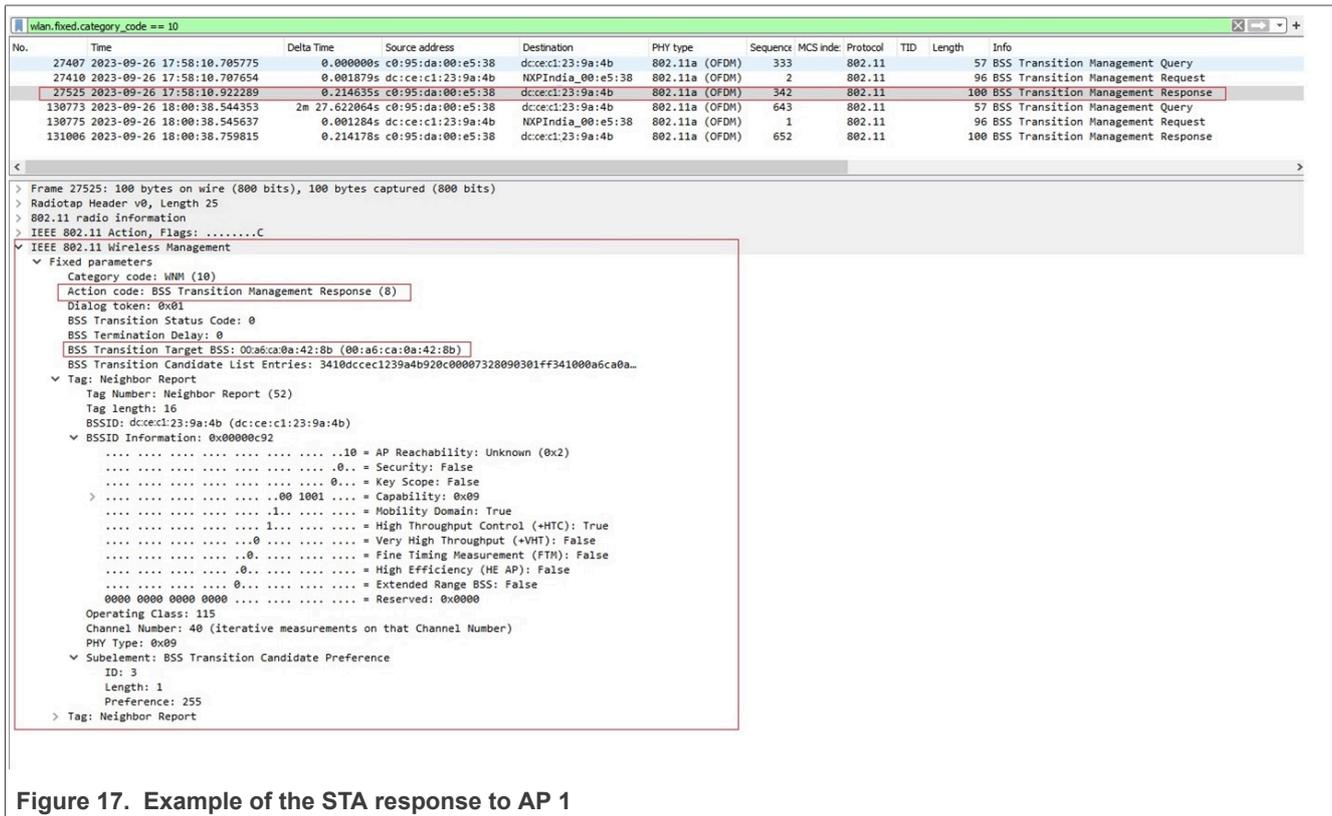


Figure 17. Example of the STA response to AP 1

## 8 802.11r examples

This section provides an example for over-the-air and over-the-distribution-system (over-the-DS) Fast Transition. A EAPoL key 4-way handshake is not required for FT.

### 8.1 Over-the-air fast transition (FT)

In Over-the-Air FT, the STA directly communicates with the target AP using IEEE 802.11 FT-Auth and FT-(Re)Association during the FT association flow. The capability for FT is advertised in the Beacon Mobility Domain Information Element of the AP.

In this example, the wireless LAN controller is configured for over-the-air FT. The STA is connected to AP1 at location A. As the STA moves closer to AP2 at location B, the received signal strength from AP1 drops below the set signal threshold. The STA automatically switches to AP2.

wpa\_supplicant handles Over-the-Air FT. The following wpa\_cli command can also be used to manually trigger Over-the-Air FT.

```
./wpa_cli -i wlan0 ROAM <MACaddress of Target AP >
```

Figure 18 shows Over-the-Air FT communication. The arrows represent the Over-the-Air FT sequence:

1. Authentication
2. Authentication
3. Reassociation Request
4. Reassociation Response

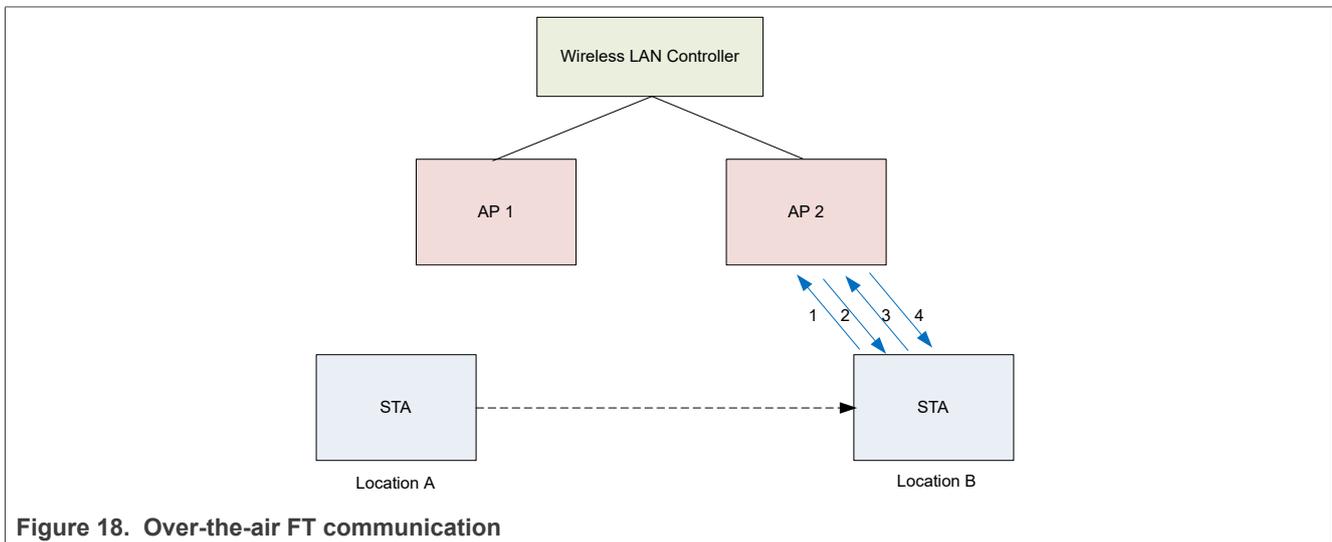


Figure 18. Over-the-air FT communication

**Step 1** – Set up the environment ([Section 5](#)).

**Step 2** – Move STA closer to AP 2 until the signal strength from AP1 is less than the threshold.

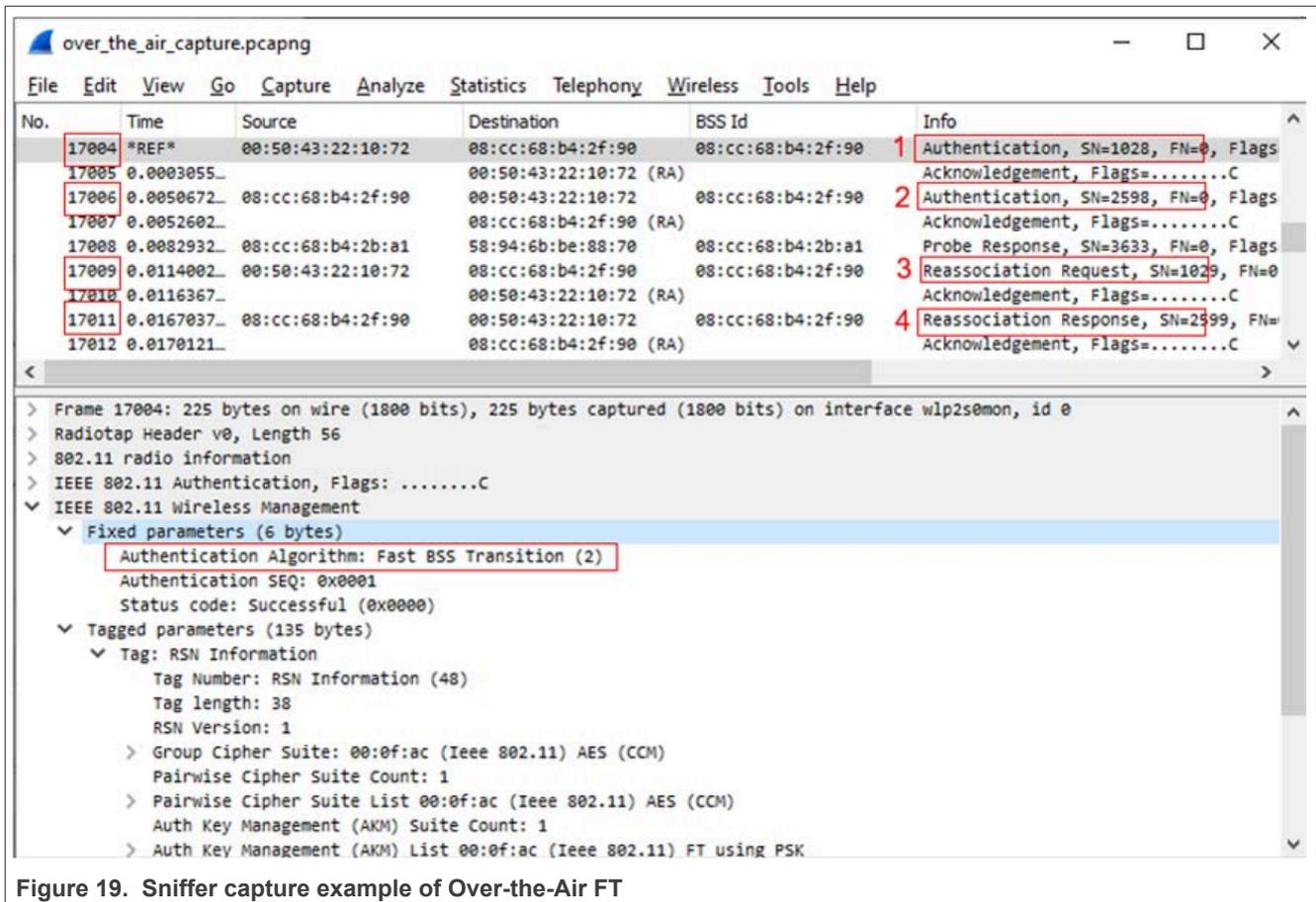
**Step 3** – STA roams from AP 1 to AP 2, which is also shown on the console.

Command output example:

```
wlan: send out FT auth,wait for auth response
wlan : FT response target AP 08:XX:XX:XX:2f:90
wlan: FT auth received
Fast BSS Transition use ft-over-air
wlan: Fast Bss transition to bssid 08:XX:XX:XX:2f:90 successfully
```

Figure 19 shows a sniffer capture example of Over-the-Air FT.

- AP 1 MAC= 08:cc:68:b4:2b:a0
- STA MAC= 00:50:43:22:10:72
- AP 2 MAC= 08:cc:68:b4:2f:90
- Over-the-Air Transition sequence of Authentication, Authentication, Reassociation Request, and Reassociation Response.

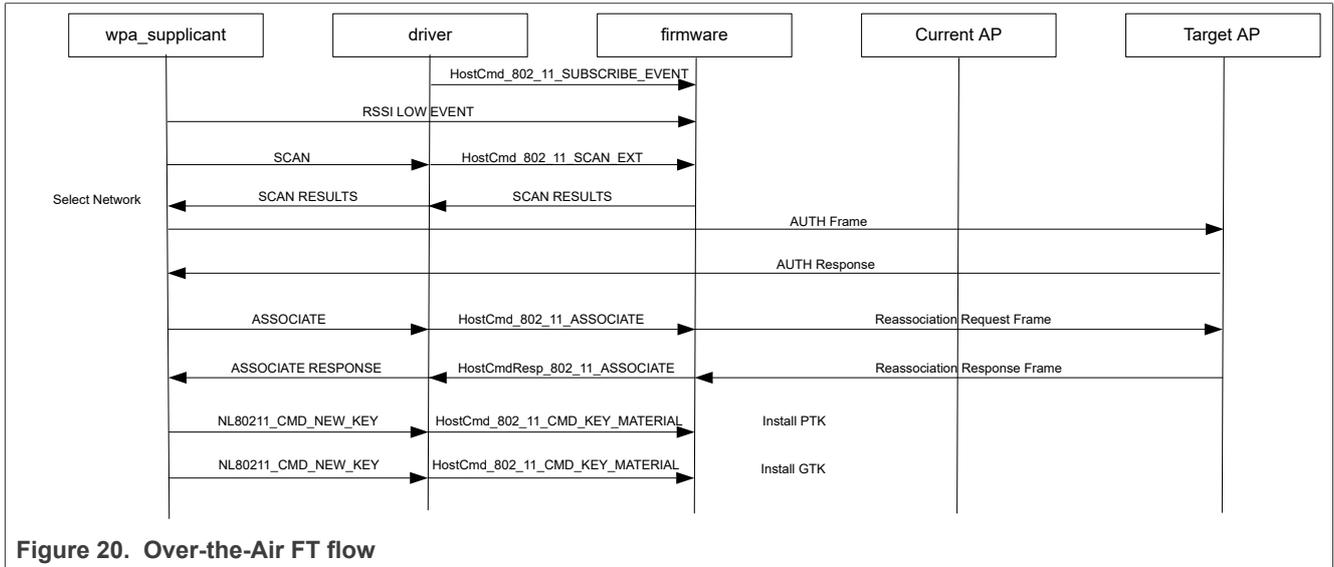


### 8.1.1 Over-the-Air FT flow

The [Figure 20](#) shows the interaction between the wpa\_supplicant, Wi-Fi driver, and firmware.

The wpa\_supplicant commands (in uppercase) are defined in *hostap/src/drivers/nl80211\_copy.h*.

For more details about the driver to firmware APIs, refer to [\[1\]](#), [\[2\]](#), [\[3\]](#), and [\[4\]](#).



## 8.2 Over-the-DS fast transition (FT)

In over-the-DS FT, the STA communicates with the target AP through the current AP. STA sends IEEE 802.11 FT action frames to the current AP, which forwards the frames to the target. The capability for FT is advertised in the Beacon Mobility Domain Information Element of the AP.

In this example, the wireless LAN controller is configured for Over-the-DS FT. The STA is connected to AP1 at location A. When the STA moves closer to AP2 at location B, the received signal strength from AP1 drops below the set signal threshold. The STA is triggered to roam to AP 2 when the `wpa_supplicant` command is issued.

**Note:** *Open source wpa\_supplicant does not support automatic roaming Over-the-DS.*

The command to manually trigger Over-the-DS FT is:

```
./wpa_cli -i wlan0 FT_DS <MACaddress of Target AP >
```

Figure 21 shows Over-the-DS FT communication. The arrows represent the FT Over-the-DS sequence:

1. Action Frame (Fast Transfer Request)
2. Action Frame (Fast Transfer Response)
3. Reassociation Request
4. Reassociation Response

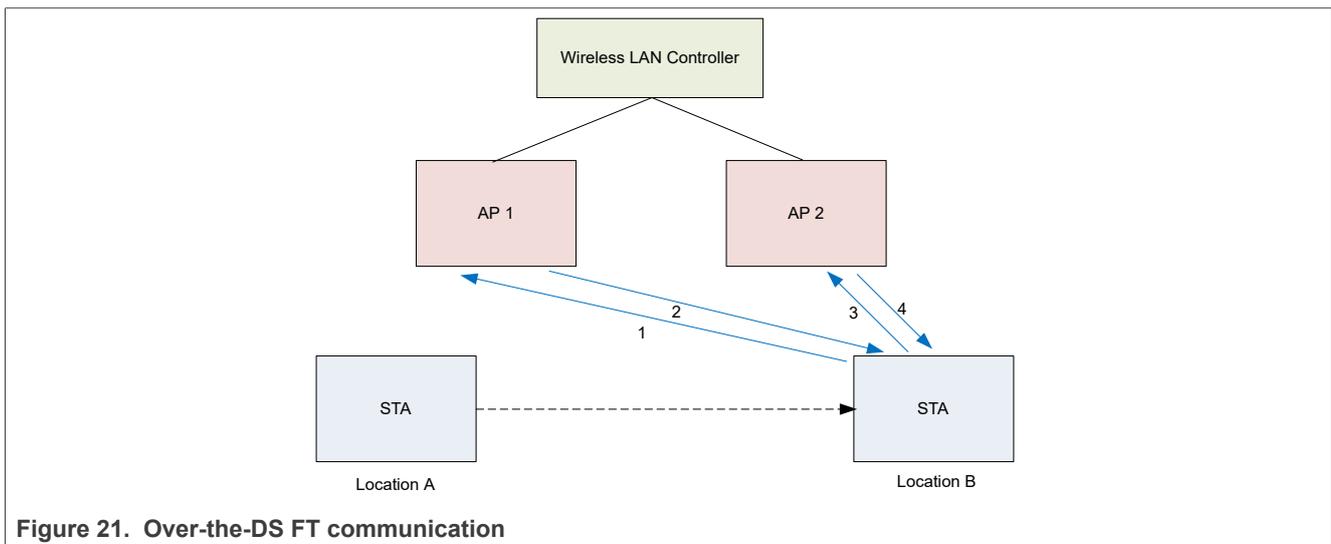


Figure 21. Over-the-DS FT communication

**Step 1** – Set up the environment ([Section 5](#)).

**Step 2** – Move STA closer to AP 2, where the signal strength from AP 1 will be less than the threshold.

**Step 3** – Run the `wpa_cli` command to trigger Over-the-DS FT.

```
./wpa_cli -i wlan0 FT_DS <MACaddress of Target AP >
```

**Step 4** – The STA roams from AP 2 to AP 1 (also shown on the console).

Output example:

```
wlan: send out FT request,wait for FT response
wlan : FT response target AP 08:XX:XX:XX:2f:90
wlan: received FT response
Fast BSS transition to bssid 08:XX:XX:XX:2f:90 successfully
```

Figure 22 shows a sniffer capture example of Over-the-DS FT.

- AP 1 MAC= 08:cc:68:b4:2b:a0
- STA MAC= 00:50:43:22:10:72
- AP 2 MAC= 08:cc:68:b4:2f:90
- Over-the-DS FT sequence of Action, Action, Reassociation Request, and Reassociation Response.

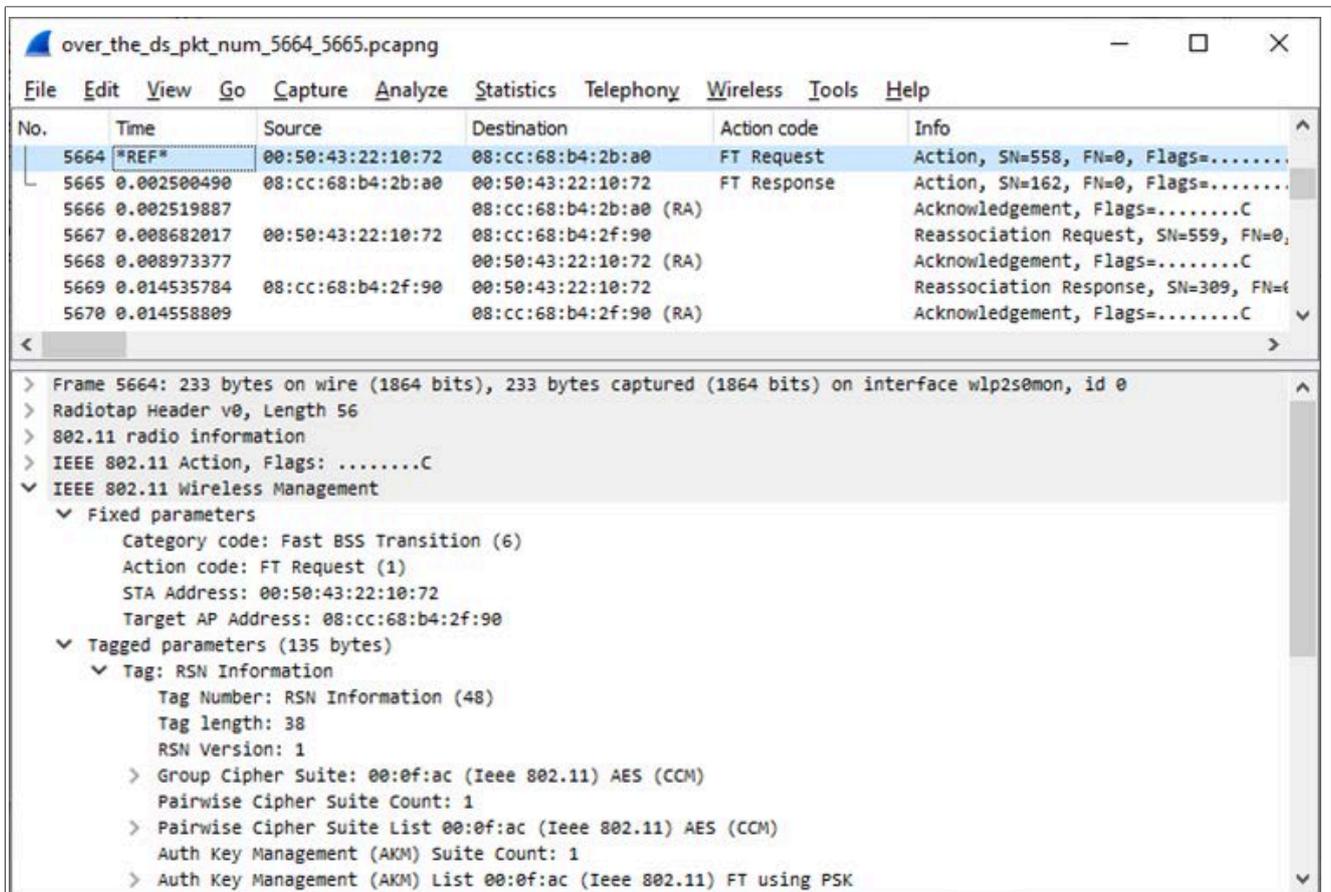


Figure 22. Sniffer capture example of Over-the-DS FT



## 9 Abbreviations

Table 2. Abbreviations

Abbreviation	Description
AP	Access point
bgscan	Background scan
BSS	Basic service set
BTM	BSS transition management
DS	Distribution system
DUT	Device under test
ESS	Extended service set
FT	Fast transition
MLME	MAC sublayer management entity
RRM	Radio resource management
RSSI	Receive signal strength indication
STA	Station
WNM	Wireless network management
wpa_cli	Command line interface for wpa_supplicant

## 10 References

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- [1] Application note – AN13296: Embedded Wi-Fi Subsystem API Specification V16 ([link](#))
- [2] Application note – AN13297: Embedded Wi-Fi Subsystem API Specification V17 ([link](#))
- [3] Application note – AN13538: Embedded Wi-Fi Subsystem API Specification V18 ([link](#))
- [4] Application note – AN14314: Embedded Wi-Fi Subsystem API Specification for AW692/AW693 ([link](#))
- [5] Webpage – 88W8987: 2.4/5 GHz Dual-Band 1x1 Wi-Fi® 5 (802.11ac) + Bluetooth® Solution ([link](#))
- [6] Webpage – 88W8997: 2.4/5 GHz Dual-Band 2x2 Wi-Fi® 5 (802.11ac) + Bluetooth® Solution ([link](#))
- [7] Webpage – 88Q9098: 2.4/5 GHz Dual-Band 2x2 Wi-Fi® 6 (802.11ax) + Bluetooth® Automotive Solution ([link](#))
- [8] Webpage – 88W9098: 2.4/5 GHz Dual-Band 2x2 Wi-Fi® 6 (802.11ax) + Bluetooth® ([link](#))
- [9] Webpage – AW611: 2.4/5 GHz Dual-band 1x1 Wi-Fi® 6 (802.11ax) + Bluetooth® Automotive Solution ([link](#))
- [10] Webpage – AW690: Wi-Fi® 6 1x1 Concurrent Dual Wi-Fi (CDW) and Bluetooth® Combo SoC ([link](#))
- [11] Webpage – AW692: 2x2 Single-band (5 GHz) Concurrent Dual Wi-Fi® 6, 1x1 (2.4 GHz) Wi-Fi 6, and Bluetooth® Combo Solution ([link](#))
- [12] Webpage – AW693: 2x2 Dual-band (5-7 GHz), 1x1 (2.4 GHz) Concurrent Dual Wi-Fi 6/6E and Bluetooth Combo Solution ([link](#))
- [13] Webpage – IW416: 2.4/5 GHz Dual-Band 1x1 Wi-Fi® 4 (802.11n) + Bluetooth® Solution ([link](#))
- [14] Webpage – IW611: 2.4/5 GHz Dual-band 1x1 Wi-Fi® 6 (802.11ax) + Bluetooth® Solution ([link](#))
- [15] Webpage – IW612: 2.4/5 GHz Dual-Band 1x1 Wi-Fi® 6 (802.11ax) + Bluetooth® + 802.15.4 Tri-radio Solution ([link](#))
- [16] Webpage – IW620: 2.4/5 GHz Dual-Band 2x2 Wi-Fi® 6 (802.11ax) + Bluetooth® Solution ([link](#))
- [17] Webpage – Linux WPA/WPA2/WPA3/IEEE 802.1X Supplicant ([link](#))

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## 12 Revision history

Table 3. Revision history

Document ID	Release date	Description
AN14212 v.2.0	13 January 2025	<ul style="list-style-type: none"><li>• Changed the access of the document to public.</li><li>• Supersedes AN13888 – 802.11r and fast transition (FT).</li></ul>
AN14212 v.1.0	22 August 2024	<ul style="list-style-type: none"><li>• Initial version</li></ul>

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Please be aware that important notices concerning this document and the product(s) described herein, have been included in section 'Legal information'.

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