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<th>Content</th>
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<tr>
<td>Keywords</td>
<td>Host wake-up over Bluetooth/Low Energy (LE) connectivity, GPIO interrupt by firmware</td>
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<tr>
<td>Abstract</td>
<td>Describes the procedure for host wake-up using Bluetooth or Bluetooth Low Energy (LE) on NXP wireless solutions (wireless SoCs).</td>
</tr>
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1 Revision history

<table>
<thead>
<tr>
<th>Rev</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>v.1</td>
<td>14 August 2023</td>
<td>Initial version</td>
</tr>
</tbody>
</table>
2 Overview

This document describes the steps for host wake-up using Bluetooth/Bluetooth Low Energy (LE) on NXP Wi-Fi and Bluetooth combo solutions (wireless SoCs).

The implementation described in this document assumes the following:

- The host CPU is powered down, and the host stack is not running.
- The Wi-Fi/Bluetooth module is powered on, and the firmware is running.
- The host has a general-purpose input/output (GPIO) handler, which monitors the GPIO interrupt by firmware.
- Upon a GPIO interrupt, the host is brought to a running state and the host stack is initialized.

Note: The implementation of the GPIO handler is not covered in this application note.

For example, in a typical TV-remote control pair setup, both the TV and the remote control have Bluetooth integrated. If the TV is in Standby mode, and the power button on the remote control is pressed:

- The remote control initiates a Bluetooth connection.
- Upon receiving connection request from the remote control, the firmware generates the GPIO interrupt to wake up the host.

The general idea is to configure the firmware so it generates a GPIO interrupt when certain criterion is met, that is: when receiving the basic rate (BR)/enhanced data rate (EDR), and/or the Bluetooth LE connection request, and/or the advertising packet.

The following sections describe the different triggering points for the GPIO interrupt by firmware.

2.1 GPIO interrupt

This section describes the different trigger points for the GPIO interrupt by firmware.

Host wake-up over Bluetooth connectivity

Bluetooth asynchronous connectionless link (ACL) connection wake-up

The host wake-up is triggered when the ACL connection request from the remote device is received.

Host wake-up with Bluetooth LE connection

Upon receiving the Bluetooth LE connection request from the peer devices (included in the allowlist), the firmware generates the interrupt on the configured GPIO pin to wake up the host.

Host wake-up with Bluetooth LE scanning

Upon receiving the advertising packet from the peer devices (included in the allowlist) or through the defined scan filters, the firmware generates the interrupt on the configured GPIO pin to wake up the host.

Host wake-up with RX data

The Bluetooth LE connection is active with the peer device and the host is in Sleep mode. After receiving the data packet from the peer devices, the firmware generates the interrupt on the configured GPIO pin to wake up the host.
GPIO pin polarity
The GPIO pin remains active high in Standby mode. When the firmware receives a trigger packet, the GPIO pin is pulled active low for the GPIO_GAP (~250us) time duration. See Figure 1.

Note: The GPIO_GAP time duration cannot be changed when using UART interface for Bluetooth.

In Figure 1, GPIO is the GPIO pin number used to wake up the host. It can be any valid GPIO pin number. Section 5 for the GPIO pin number of the supported products.

![Figure 1. GPIO signal status](image)

2.2 GPIO pin configuration
The GPIO pin configuration is specific to the wireless SoC and host interface. The GPIO pin can also be changed based on availability.

<table>
<thead>
<tr>
<th>Wireless SoC</th>
<th>Controller to host GPIO configuration pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>88W8987</td>
<td>GPIO[1] to GPIO[20]</td>
</tr>
<tr>
<td>88W9098</td>
<td>GPIO[1] to GPIO[24]</td>
</tr>
<tr>
<td>IW612</td>
<td>GPIO[19]</td>
</tr>
</tbody>
</table>
3 Host wake-up over Bluetooth

3.1 Host wake-up via Bluetooth ACL connection request

In this implementation, the host wake-up is triggered when there is an ACL connection request from any Bluetooth remote device.

**Step 1 - Enable page scan.**

Enable page scan on the Device Under Test (DUT) to accept the incoming ACL connection request.

```
hciconfig hci0 pscan  // Set the device in connectable mode
```

**Step 2 - Configure the GPIO pin for the interrupt.**

Refer to Section 5 for the commands to configure the GPIO pin of the supported products. The firmware will generate an interrupt on the configured GPIO pin.

**Step 3 - Enable host sleep.**

Refer to Section 6 for the commands to enable host sleep for the supported products.

**Step 4 - Initiate the ACL connection from the remote device to the DUT.**

```
hcitool -i hci0 cmd cc <BD_Address_DUT>
```

The host monitors the configured GPIO pin for interrupts. After receiving the ACL connection request, the firmware generates the interrupt on the configured GPIO pin. Once the interrupt is detected, the host mode changes to active.
4 Host wake-up over Bluetooth LE

4.1 Host wake-up over Bluetooth LE connection

In this case, the Bluetooth controller is advertising, and the host is asleep.

**Step 1** - Add the peer device to the DUT allowlist:

```
hcitool -i hci0 cmd 0x08 0x0011 <Address_Type> <BD_Address>
```

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address_Type</td>
<td>The device address type 0x00 = public device address</td>
</tr>
<tr>
<td></td>
<td>0x01 = random device address</td>
</tr>
<tr>
<td>BD_Address</td>
<td>The public or random Bluetooth device address to be added to the allowlist</td>
</tr>
</tbody>
</table>

**Step 2** - Configure the GPIO pin.

Refer to Section 5 for the commands to configure the GPIO pin of the supported products. The firmware will generate an interrupt on the configured GPIO pin.

**Step 3** - Start advertising on the DUT.

- Set the advertising parameter

```
hcitool -i hci0 cmd 08 06 00 02 02 00 00 00 00 00 00 00 00 07 03
```

Where 00 is the advertising type set to connectable and scannable undirected advertisement, 07 is the advertising policy set to scan, and 03 is for connection requests allowed only from devices in the allowlist.

- Set the advertising data

```
hcitool -i hci0 cmd 08 08 1F 00 99 88 77 66 55 44 33 22 11 00 99 88 77 66 55 44 33 22 11 00
```

- Enable advertising

```
hcitool -i hci0 cmd 08 0A 01
```

**Step 4** - Enable host sleep

Refer to Section 6 for the commands to enable host sleep for the supported products.

**Step 5** - Enable Bluetooth LE connection from the remote device with Initiator_Filter_Policy set to the allowlist.

**Expected results**

After receiving the Bluetooth LE connection request from the peer device (included in the allowlist), the firmware generates the interrupt on the configured GPIO pin.
4.2 Host wake-up over Bluetooth LE scanning

In this case, the Bluetooth controller is scanning, and the host is asleep.

**Step 1** - Add the peer device to the DUT allowlist

hcitool -i hci0 cmd 0x08 0x0011 <Address_Type> <Address>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address_Type</td>
<td>The device address type 0x00 = public device address</td>
</tr>
<tr>
<td></td>
<td>0x01 = random device address</td>
</tr>
<tr>
<td>Address</td>
<td>The public or random device address to be added to the allowlist</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Use one of the following values:</td>
</tr>
<tr>
<td></td>
<td>LE_Scan_Type, LE_Scan_Interval, LE_Scan_Window, Own_Address_Type,</td>
</tr>
<tr>
<td></td>
<td>Scanning_Filter_Policy (0x01 = set to allowlist)</td>
</tr>
<tr>
<td></td>
<td>Other parameters can be referred through Bluetooth specification 4.1.</td>
</tr>
</tbody>
</table>

**Step 2** - Set the scan parameters on the DUT

hcitool -i hci0 cmd 0x08 0x000B <Parameters>

**Step 3** - Configure the GPIO pin.

Refer to Section 5 for the commands to configure the GPIO pin of the supported products. The firmware will generate an interrupt on the configured GPIO pin.

**Step 4** - Enable Bluetooth LE scan on the DUT.

hcitool -i hci0 cmd 0x08 0x000C 0x01 0x01

**Step 5** - Enable host sleep.

Refer to Section 6 for the commands to enable host sleep for the supported products.

**Step 6** - Start advertising on the peer device.

- Set the advertising parameter.
  
  hcitool -i hci0 cmd 08 06 00 02 00 02 00 00 00 00 00 00 00 00 07 03

  Where 00 is the advertising type set to connectable and scannable undirected advertisement, 07 is the advertising policy set to scan, and 03 is for connection requests allowed only from devices in the allowlist.

- Set the advertising data.

  hcitool -i hci0 cmd 08 08 1F 00 99 88 77 66 55 44 33 22 11 00 99 88 77 66 55 44 33 22 11 00 99 88 77 66 55 44 33 22 11 00

- Enable advertising.

  hcitool -i hci0 cmd 08 0A 01
Expected results

After receiving the Bluetooth LE advertising packet from the peer device (from the allowlist, scan filter), the firmware generates an interrupt on the configured GPIO pin.
4.3 Host wake-up over Rx data packet and active Bluetooth LE connection

In this case, the Bluetooth LE connection is active, and the host is asleep.

**Step 1** - Add the peer device to the DUT allowlist.

```
hcitoi -i hci0 cmd 0x08 0x0011 <Address_Type> <BD_Address>
```

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address_Type</td>
<td>The device address type 0x00 = public device address</td>
</tr>
<tr>
<td></td>
<td>0x01 = random device address</td>
</tr>
<tr>
<td>BD_Address</td>
<td>The public or random Bluetooth device address to be</td>
</tr>
<tr>
<td></td>
<td>added to the allowlist</td>
</tr>
</tbody>
</table>

**Step 2** - Configure the GPIO pin.

Refer to [Section 5](#) for the commands to configure the GPIO pin of the supported products. The firmware will generate an interrupt on the configured GPIO pin.

**Step 3** - Start advertising on the DUT.

- Set the advertising parameter.

```
hcitoi -i hci0 cmd 08 06 00 02 00 02 00 00 00 00 00 00 07 03
```

Where 00 is the advertising type set to connectable and scannable undirected advertisement, 07 is the advertising policy set to scan, and 03 is for connection requests allowed only from devices in the allowlist.

- Set the advertising data.

```
hcitoi -i hci0 cmd 08 08 1F 00 99 88 77 66 55 44 33 22 11 00 99 88 77 66 55 44 33 22 11 00
```

- Enable advertising.

```
hcitoi -i hci0 cmd 08 0A 01
```

**Step 4** - Establish the Bluetooth LE connection with the remote device.

**Step 5** - Send Bluetooth LE data packets from the remote device.

When the connection is established and host sleep is enabled, the firmware sends an interrupt on the configured GPIO pin.

Example of command on Bluez stack to send a single data packet:

```
hcitoi -i hci1 acldat -p dcd -d 0x5454 -c 1 -s 10 -P i <BD_Addr_Dut> -H 128
```

**Expected results**

After receiving any data packet from the remote device, the firmware generates the interrupt on the configured GPIO pin.
5 Commands to configure GPIO pins

The configuration command is specific to the wireless SoC and host interface. The first interface is for Wi-Fi, and the second is for Bluetooth. For example:

- PCIe-UART: the Wi-Fi interface uses PCIe and the Bluetooth interface uses UART.
- SD-UART: the Wi-Fi interface uses SDIO and the Bluetooth interface uses UART.

Table 6. Commands to configure GPIO pin using UART interface

<table>
<thead>
<tr>
<th>SoC</th>
<th>Interface</th>
<th>Command</th>
<th>GPIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>88W8987</td>
<td>SD-UART</td>
<td>hctool -i hci0 cmd 0x3F 0x53 0x03 0x04 0x01 0xFF</td>
<td>GPIO[4]</td>
</tr>
<tr>
<td>IW416</td>
<td>SD-UART</td>
<td>hctool -i hci0 cmd 0x3F 0x53 0x03 0x04 0x01 0xFF</td>
<td>GPIO[4]</td>
</tr>
<tr>
<td>88W9098</td>
<td>SD-UART/PCIe-UART (88W9098)</td>
<td>hctool -i hci0 cmd 0x3F 0x53 0x03 0x10 0x01 0xFF</td>
<td>GPIO[16]</td>
</tr>
<tr>
<td>IW612</td>
<td>SD-UART (IW612)</td>
<td>hctool -i hci0 cmd 0x3F 0x53 0x03 0x13 0x01 0xFF</td>
<td>GPIO[19]</td>
</tr>
</tbody>
</table>
6 Command to configure host sleep

The configuration command is specific to the wireless SoC and host interface. The first interface is for Wi-Fi, and the second is for Bluetooth.

For example:

- PCIe-UART: the Wi-Fi interface uses PCIe, and Bluetooth interface uses UART.
- SD-UART: the Wi-Fi interface uses SDIO, and Bluetooth interface uses UART.

Table 7. Commands to configure host sleep using UART interface

<table>
<thead>
<tr>
<th>SoC</th>
<th>Interface</th>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>IW416</td>
<td>SD-UART</td>
<td></td>
</tr>
<tr>
<td>88W9098</td>
<td>SD–UART/PCIe-UART (88W9098)</td>
<td>echo &quot;psmode=1&quot; &gt; /proc/mbt_uart/hci0/config</td>
</tr>
<tr>
<td>IW612</td>
<td>SD-UART (IW612)</td>
<td></td>
</tr>
</tbody>
</table>
7 Examples

7.1 Host wake-up over 88W8987 SD-UART with Rx data packet and active Bluetooth LE connection

In this example, the Bluetooth LE connection is active and the host is asleep.

**Step 1** - Add the peer device to the DUT allowlist.

```
hcitool -i hci0 cmd 0x08 0x0011 00 F7 EE 6B 83 15 00
```

Where 00 is the address type of the public device, and F7 EE 6B 83 15 00 is the Bluetooth device address.

**Step 2** - Configure the GPIO pin.

```
hcitool -i hci0 cmd 0x3F 0x53 0x03 0x04 0x01 0xFF // Configure GPIO[4] for interrupt
```

The firmware will generate the interrupt on the configured GPIO[4] pin.

**Step 3** - Start advertising on the DUT.

- Set the advertising parameter

  ```
  hcitool -i hci0 cmd 08 06 00 02 00 02 00 00 00 00 00 00 00 00 07 03
  ```

- Set the advertising data

  ```
  hcitool -i hci0 cmd 08 08 1F 00 99 88 77 66 55 44 33 22 11 00 99 88 77 66 55 44 33 22 11 00 99 88 77 66 55 44 33 22 11 00
  ```

- Enable advertising

  ```
  hcitool -i hci0 cmd 08 0A 01
  ```

**Step 4** - Set the Bluetooth LE connection from the remote device

```
hcitool -i hci1 lecc 00:50:43:21:30:CF
```

Where 00:50:43:21:30:CF is the DUT address.

**Step 5** - Enable Host sleep with keeping LE connection active.

```
echo "psmode=1" >/proc/mbt_uart/hci0/config
```

**Step 6** - Send Bluetooth LE data packet from the remote device to the DUT

```
hcitool -i hci1 acldat -p dcd -d 0x5454 -c 1 -s 10 -P i 00:50:43:21:30:CF -H 128
```

Where 00:50:43:21:30:CF is the DUT address.

**Expected results**

Upon receiving a data packet from the remote device, the firmware generates the interrupt on the configured GPIO[4] pin.
7.2 Host wake-up over Bluetooth LE connection on 88W9098 SD-UART

In this example, the Bluetooth controller is advertising and the host is asleep.

Step 1 - Add the peer device to the DUT allowlist.

\[\text{hcitool -i hci0 cmd 0x08 0x0011 <Address_Type> <BD_Address>}\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
</table>
| Address_Type| The device address type 0x00 = public device address  
              0x01 = random device address                  |
| BD_Address  | The public or random Bluetooth device address to be added to the allowlist |

Step 2 - Configure the GPIO pin.

\[\text{hcitool -i hci0 cmd 0x3F 0x53 0x03 0x10 0x01 0xFF // Configure GPIO[16] for interrupt} \]

Step 3 - Start advertising on the DUT

- Set the advertising parameter

\[\text{hcitool -i hci0 cmd 08 06 00 02 00 02 00 00 00 00 00 00 00 07 03} \]

Where 00 is the advertising type set to connectable and scannable undirected advertisement , 07 is the advertising policy set to scan, and 03 is for connection requests allowed only from devices in the allowlist.

- Set the advertising data

\[\text{hcitool -i hci0 cmd 08 08 1F 00 99 88 77 66 55 44 33 22 11 00 99 88 77 66 55 44 33 22 11 00} \]

- Enable advertising

\[\text{hcitool -i hci0 cmd 08 0A 01} \]

Step 4 - Enable host sleep

\[\text{echo "psmode=1" > /proc/mbt_uart/hci0/config} \]

Step 5 - Establish the Bluetooth LE connection from the remote device

\[\text{hcitool -i hci1 lecc 00:50:43:21:30:CF} \]

Where 00:50:43:21:30:CF is the DUT address

Expected result

After receiving the Bluetooth LE connection request from the remote device, the controller accepts the Bluetooth LE connection request. The firmware generates an interrupt on the configured GPIO[16] pin.
8 References

Table 9. References

<table>
<thead>
<tr>
<th>Reference type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data sheet</td>
<td>88W8987 - Wi-Fi 5 and Bluetooth 5 Single-chip SoC</td>
</tr>
<tr>
<td>Data sheet</td>
<td>IW416 - Wi-Fi 4 and Bluetooth 5.2 Combo SoC</td>
</tr>
<tr>
<td>Data sheet</td>
<td>88W9098 - Wi-Fi 6 Concurrent Dual Wi-Fi (CDW) and Bluetooth 5.3 Combo SoC</td>
</tr>
<tr>
<td>Data sheet</td>
<td>IW612 - Wi-Fi 6 Concurrent Dual Wi-Fi (CDW), Bluetooth 5.2 and 802.15.4 Tri-Radio SoC</td>
</tr>
</tbody>
</table>

9 Acronyms and abbreviations

Table 10. Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACK</td>
<td>Acknowledgment</td>
</tr>
<tr>
<td>ACL</td>
<td>Asynchronous connectionless link</td>
</tr>
<tr>
<td>BR</td>
<td>Basic rate</td>
</tr>
<tr>
<td>CPU</td>
<td>Central processor unit</td>
</tr>
<tr>
<td>DUT</td>
<td>Device under test</td>
</tr>
<tr>
<td>EDR</td>
<td>Enhanced data rate</td>
</tr>
<tr>
<td>GPIO</td>
<td>General Purpose Input/Output</td>
</tr>
<tr>
<td>HCI</td>
<td>Host controller interface</td>
</tr>
<tr>
<td>HID</td>
<td>Human interface device</td>
</tr>
<tr>
<td>L2CAP</td>
<td>Logical link control and adaptation protocol</td>
</tr>
<tr>
<td>LE</td>
<td>Low energy</td>
</tr>
<tr>
<td>LMP</td>
<td>Link manager protocol</td>
</tr>
<tr>
<td>PSM</td>
<td>Protocol service multiplexer</td>
</tr>
<tr>
<td>SD</td>
<td>Secure digital</td>
</tr>
<tr>
<td>SDIO</td>
<td>Secure digital input/output</td>
</tr>
<tr>
<td>SoC</td>
<td>System-on-Chip</td>
</tr>
<tr>
<td>PCIe</td>
<td>Peripheral component interconnect express</td>
</tr>
<tr>
<td>UART</td>
<td>Universal asynchronous receiver/transmitter</td>
</tr>
<tr>
<td>USB</td>
<td>Universal serial bus</td>
</tr>
</tbody>
</table>
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10.1 Definitions

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Date of release: 14 August 2023
Document identifier: AN13958