External Coexistence Design (Application Note)

Related Products

All ESP chip series, except ESP8266 and ESP32 series

Version 1.0
Espressif Systems

About This Document

This document provides information about 1-wire, 2-wire, and 3-wire Wi-Fi coexistence schemes for Espressif customers when configuring devices equipped with ESP Wi-Fi SoCs (including all ESP chip series except ESP8266 and ESP32 series).

Release notes

Date	Version	Release Notes
Jan 2022	V1.0	Initial release.

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1. Introduction

In the 2.4 GHz ISM band, the availability of channels is regulated per country. There are mainly three communication protocols worldwide: Bluetooth® (BLE & BT), 15.4 (Zigbee & Thread), and Wi-Fi.

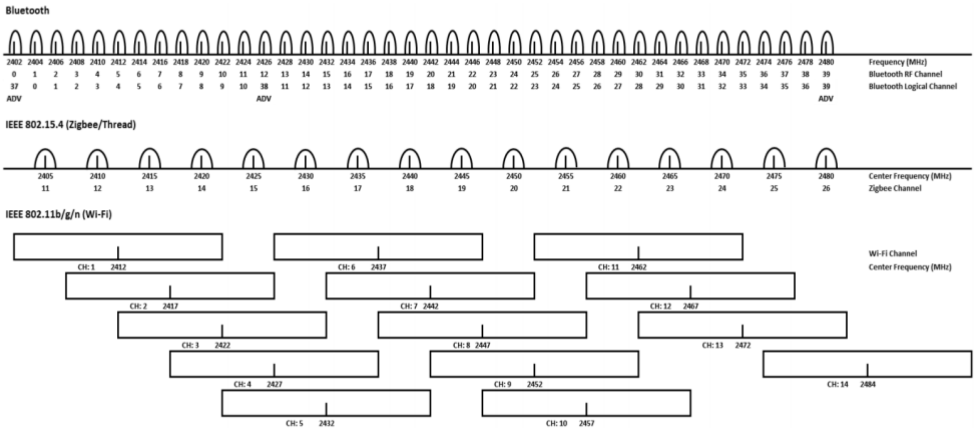

Figure 1-1. 2.4 GHz Channel Map

Nowadays, more and more Espressif's Wi-Fi SoCs share the 2.4 GHz frequency band with other devices, such as BLE, BT, and Zigbee. In this case, Espressif implemented a hardware interface and protocol to arbitrate and notify Peer devices whether there is interference with its normal transmitting and receiving of packets. The protocol is available for ESP32-S2 and the following series of SoCs (ESP Wi-Fi).

To implement the protocol, it is necessary to adopt a reasonable external coexistence priority policy and determine the timing duration of key packets, to ensure proper operation of ESP Wi-Fi and to limit the interference with the interaction behavior of Peer devices.

Implementation of coexistence of Peer devices using different communication protocol specifications is similar to implementation on a single dual-mode, dual-baseband SoC. In other words, two sets of RF modules and baseband modules can receive packets of different protocols in the 2.4 GHz ISM simultaneously. So, there will be less interference compared with the coexistence of single-mode SoC.

If separate devices are used, there are two design differences from internal coexistence.

- Internal interface needs to be called to check if the current Wi-Fi channel conflicts with the communication channel of the Peer device, and decide whether to enable the function of external coexistence.

- Since there are two sets of basebands, Wi-Fi sleep mode is optional and it is possible that both devices transmit packets at the same time. Then it is necessary to configure the internal coexistence timer to set the PTI (Packet Type Identifier) of the 2.4 GHz band coexistence to achieve the function of arbitrating and transmitting packets with the Peer device.

2. Architecture Design

Currently Espressif offers three coexistence modes with Peer devices: 1-wire, 2-wire and 3-wire. For detailed description of these three modes, please refer to the table below.

Table 2-1. Three Coexistence Modes

Coexistence Mode	PTA Signals			PTI Level
	Request	Grant	Priority	
1-wire	☑	✕	✕	Always high level
2-wire	☑	☑	✕	Always low level
3-wire	☑	☑	☑	Selectable low/high level

2.1. Mapping of Coexistence Modes and PTA (Packet Traffic Arbitration) Signals

2.1.1. 1-wire mode

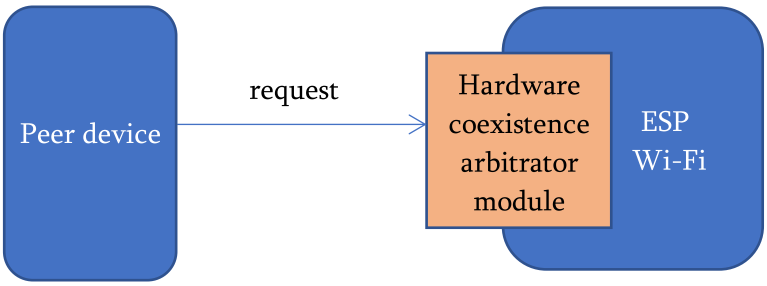

Figure 2-1. 1-wire Mode

In 1-wire mode，Peer device transmits a request signal to ESP Wi-Fi, where Peer device triggers request whenever it needs the 2.4 GHz ISM band and expects ESP Wi-Fi to always yield. This mode works very well for the Peer device, but high priority ESP Wi-Fi traffic can be compromised which impacts ESP Wi-Fi performance.

Since PTI level for 1-wire mode is always high level, arbitration results are not required after Peer device triggers a request.

2.1.2. 2-wire mode

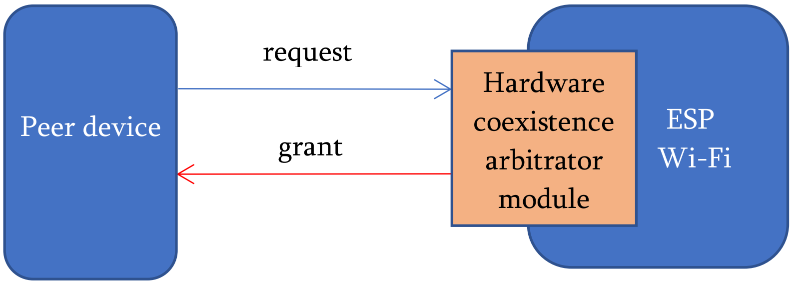

Figure 2-2. 2-wire Mode

In 2-wire mode, the request is extended with the grant signal, allowing the Peer device to request the 2.4 GHz ISM band. The arbitration results are received through grant signal.

The ESP Wi-Fi internally controls the prioritization with the Peer device, and on a conflict, the Hardware coexistence arbitrator module can analyze which device (Peer device or ESP Wi-Fi) is permitted to access to the ISM band.

2.1.3. 3-wire mode

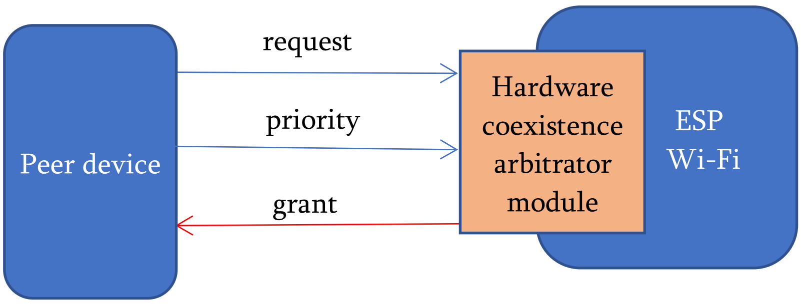

Figure 2-3. 3-wire Mode

In 3-wire mode, the priority signal is added, allowing the Peer device to signify a high or middle level behavior being performed.

The table below shows how to set PTI level through controlling the level of request and priority signals:

Table 2-2. Set PTI Level Through Request and Priority Signals

PTI Level	Request	Priority
Middle Level	GPIO voltage high	GPIO voltage low
High Level	GPIO voltage high	GPIO voltage high

> **Note:**
> *GPIO voltage is high when 3.3 V are supplied to the related GPIO pin.*

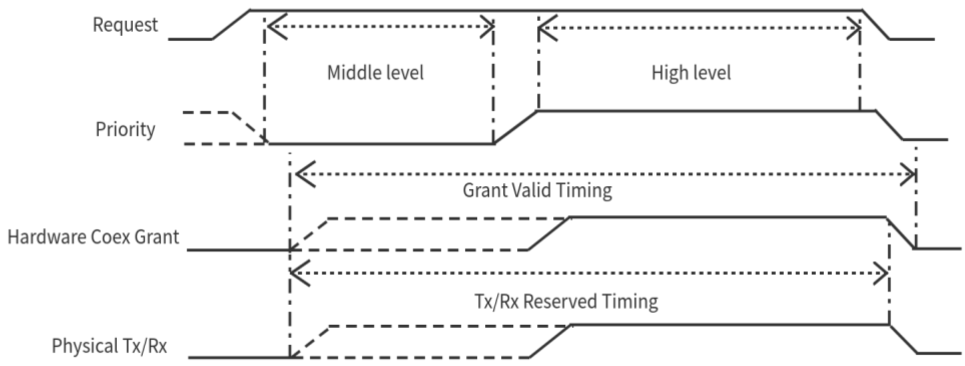

Figure 2-4. 3-wire Timing Sequence

The above figure shows that the ESP Wi-Fi compares this external priority request, which may be Middle/High level, against the internal Wi-Fi priority and can choose to grant access to ISM band to either Peer device or ESP Wi-Fi.

2.1.4. Coexistence Signaling Timing Information

For 1-wire/2-wire/3-wire mode, the typical time delay from triggering request signal by peer device to de-asserting the PHY signal by ESP Wi-Fi device can be in the range of 350 ns ~ 450 ns.

For 3-wire mode, the typical time delay from PTI signal assertion to grant signal output can be in the range of 50 ns ~ 150 ns. The screenshot below shows that when PTI level is high in 3-wire mode, the time delay between PTI signal assertion by Peer device and grant signal output by ESP Wi-Fi device is 50 ns.

When the grant signal is high, Peer device can perform RF activity. And when the grant signal is low, ESP Wi-Fi device can transmit/receive packets.

In contrast, when the PHY signal is high, it means ESP Wi-Fi device is able to transmit/receive packets. When the PHY signal is low, it means ESP Wi-Fi device cannot transmit/receive packets. ESP Wi-Fi will start working again until PHY signal goes high. Please note that PHY signal is ESP Wi-Fi's internal signal, which is not available for the Peer device. When grant signal goes high, the PHY signal will go low at the same time and vice versa.

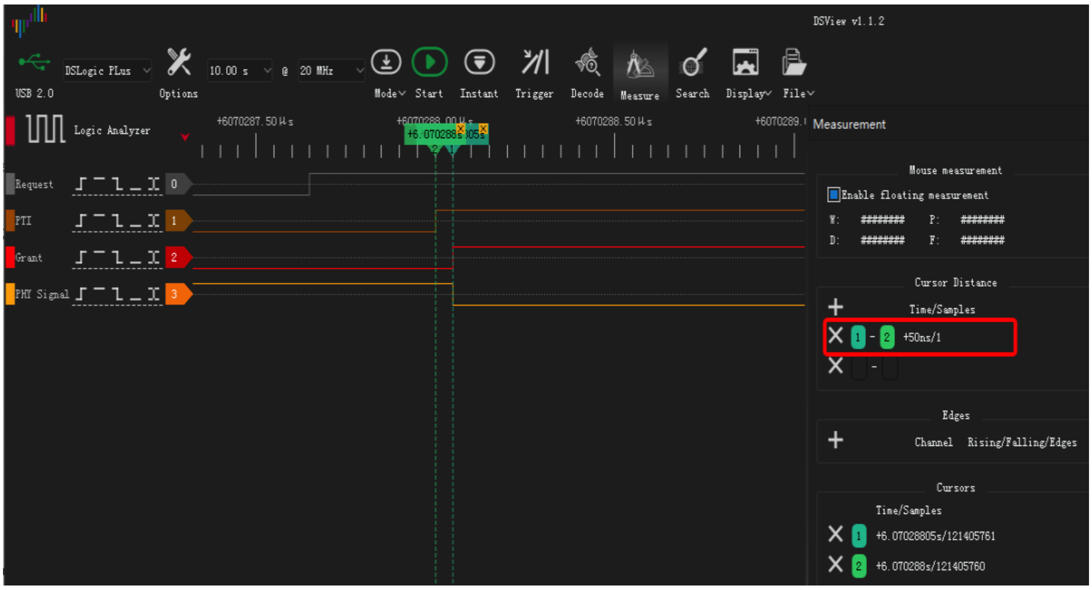

Figure 2-5. 3-wire Timing Diagram

> **Note:**
>
> *The test above is conducted with ESP32-S2 chip. The same result can be expected when the PTI level is middle or high in 3-wire mode.*

2.2. Coexistence PTA (Packet Traffic Arbitration) Flow

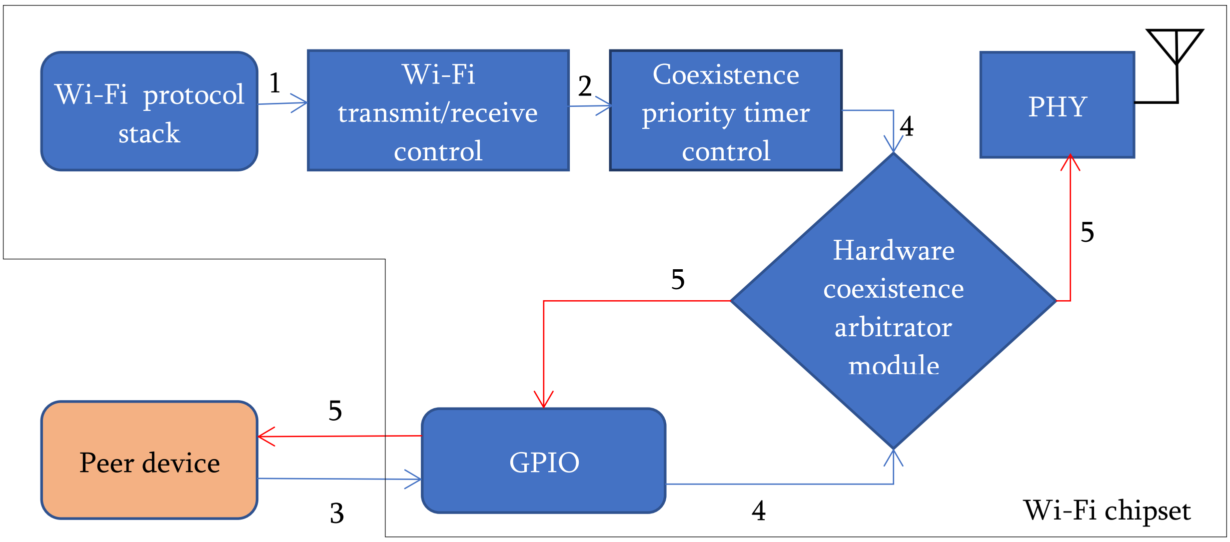

Figure 2-6. Coexistence PTA Flow

1. Wi-Fi protocol stack triggers the request of transmit/receive to Wi-Fi transmit/receive control.

2. Wi-Fi protocol stack uses the coexistence priority timer control in ESP Wi-Fi to set proper PTI value based on specific scenario. The PTI value will be transferred to corresponding PTI level automatically later.

3. The Peer device outputs either high or low level through a GPIO pin to select PTI level and obtains arbitration results from ESP Wi-Fi by reading signal from another GPIO pin. The number of GPIOs offered by ESP Wi-Fi to communicate with the Peer device is in the range of one to three depending on the chosen mode.

4. ESP Wi-Fi internal hardware coexistence arbitration module compares internal PTI level with the level obtained from the Peer device.

5. Arbitration results are provided to PHY and the GPIO at the same time. Based on arbitration results, PHY will decide whether to transmit/receive packets and GPIO will output high/low level to the Peer device. High level means that the Peer device can transmit/receive packets, and low level means that ESP Wi-Fi can transmit/receive packets.

2.3. Wi-Fi Key Packets

To ensure that the ESP Wi-Fi stays connected and works properly, an internal default priority has been set.

When the ESP Wi-Fi is connecting, the priority of this process will be higher than the middle level and lower than the high level request from Peer device.

When the ESP Wi-Fi is connected, the priority of the receiving beacon will be lower than the high level request from Peer device.

It should be noted that the highest PTI value for Wi-Fi is less than the high level PTI value of external coexistence.

3. Design Implementation

3.1. Software interfaces in ESP-IDF

When configuring for the coexistence feature, please make sure to use release/v4.3 or newer release of ESP-IDF. The following screenshot shows how to configure external hardware coexistence in menuconfig:

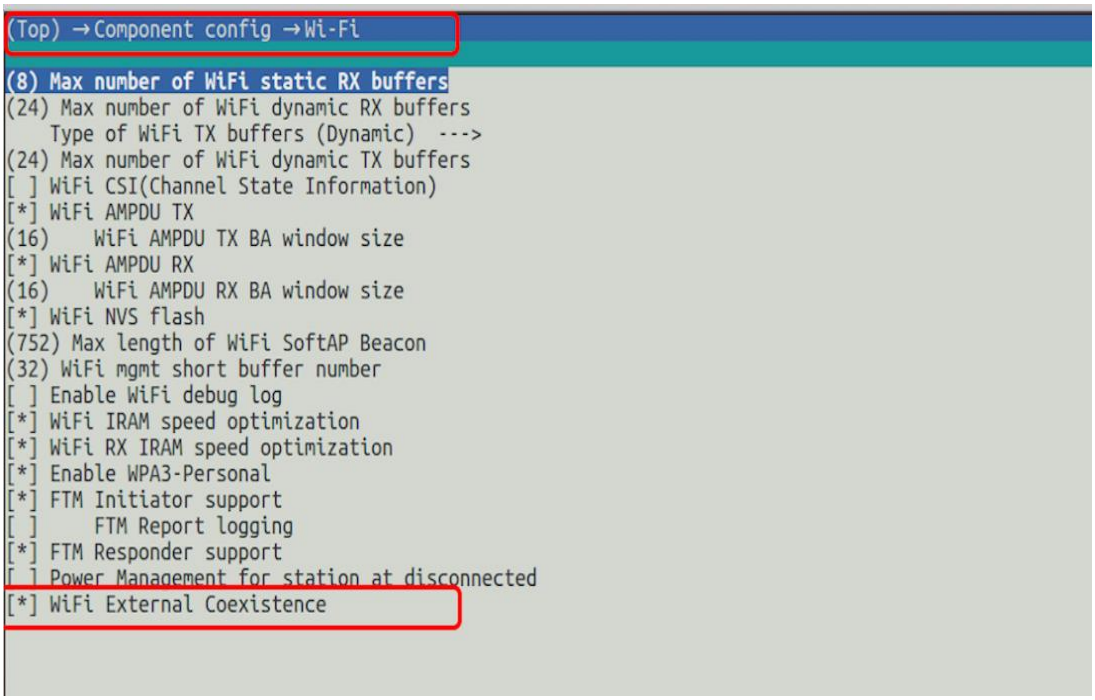

Figure 3-1. Configure External Hardware Coexistence in Menuconfig

After the hardware external coexistence is configured in menuconfig, it is still necessary to set the relevant GPIO pins and PTI level by calling the following interfaces:

- `esp_enable_extern_coex_gpio_pin`:

By calling on the function `esp_err_t esp_enable_extern_coex_gpio_pin(wire_type, gpio_pin),` you can input 1-wire/2-wire/3-wire for the “wire_type”, and the available pin number for “gpio_pin”. For available pin numbers, please refer to the [ESP-IDF Programming Guide > API Reference > Peripherals API > GPIO & RTC GPIO.]

1. Enable GPIO pin;
2. Set GPIO pin in/out direction. By configuring the high and low level of pin *in*, Peer device can transmit request and PTI level to ESP Wi-Fi. By configuring GPIO pin *out*, the ESP Wi-Fi's hardware coexistence arbitrator module will provide feedback on the current arbitration result based on the PTI level and the Wi-Fi internal priority. If pin *out* outputs low level (0), it indicates that the ESP Wi-Fi can communicate properly. If pin *out* outputs high level (1), it indicates that the Peer device can communicate properly.
3. Establish the map between PTI value and PTI level.

> ⚠ ***Notice:***
>
> - For specific scenario of Peer device, if users want to keep the duration time of PTI level, they can set related GPIO pin high/low through their alarm/timer or other similar function unit.

- `esp_disable_extern_coex_gpio_pin`:

By calling on the function `esp_err_t esp_disable_extern_coex_gpio_pin()`, users can clear the configured priority for external coexistence and disable all configured pins.

4. Q&A

If there are any other questions regarding the software interaction between the Wi-Fi device and the Peer device, please feel free to contact us.

Appendix A. Terminology

Table A-1. Terminology

Term	Description
Coexistence priority timer control	Part of ESP Wi-Fi hardware which keeps PTI value for configurable duration time.
ESP Wi-Fi	Espressif's SoC (All chip series, except ESP8266 and ESP32 series).
Hardware coexistence arbitrator module	Part of ESP Wi-Fi hardware. It compares the PTI value from Peer device and Wi-Fi scenario module to select device to access the ISM band.
ISM	The Industrial, Scientific, and Medical (ISM) frequency bands.
Peer device	The 2.4 GHz device that shares ISM band with ESP Wi-Fi and communicates priority information through GPIO interface.
PTA	Packet Traffic Arbitration. PTA is described in IEEE 802.15.2 (2003) Clause 6 and is a recommendation, not a standard.
PTI	Packet Type Identifier.
PTI value & PTI level	The Packet Type Identifier value will be used as raw data for hardware coexistence arbitrator module. PTI level is mapped to corresponding PTI value.