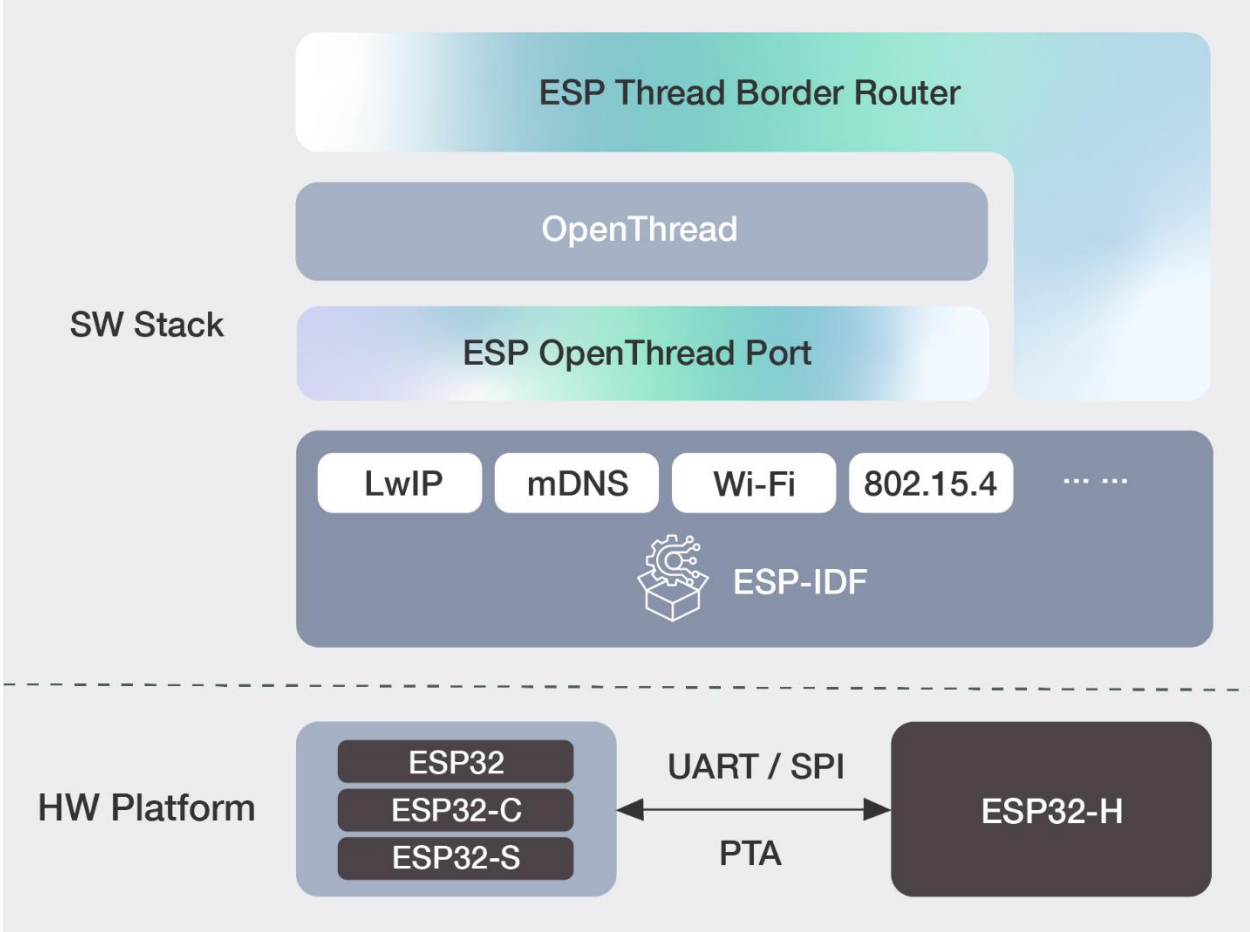
ESP Thread Border Router SDK

Espressif Thread Border Router solution is based on the combination of Espressif's Wi-Fi and 802.15.4 SoCs, built on the ESP-IDF and open-source OpenThread stack.



ESP-Thread-Border-Router Software Components

This solution has obtained the Thread 1.3 Certified Component Certificate issued by the Thread Group, complying with the latest Thread 1.3 standard, and supporting Matter application scenario.

It provides the following features:

- Bi-directional IPv6 Connectivity
- Service Discovery
- Multicast Forwarding

- NAT64
- RCP update
- RF coexistence
- Web GUI
- ...

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1. Hardware Platforms

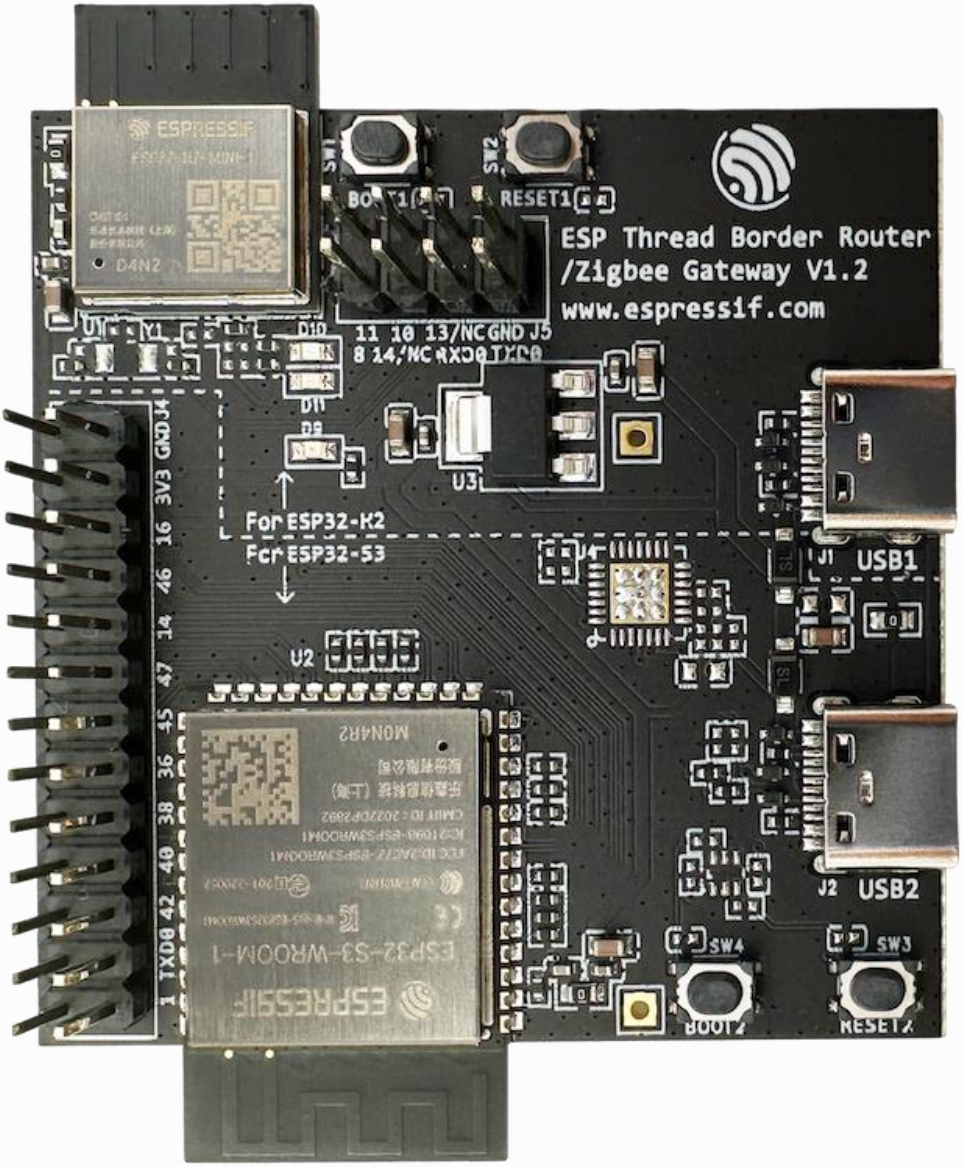
The Espressif Thread Border Router supports both Wi-Fi and Ethernet interfaces as backbone link.

1.1. Wi-Fi based Thread Border Router

The Wi-Fi based ESP Thread Border Router consists of two SoCs:

- The host Wi-Fi SoC, which can be ESP32, ESP32-S and ESP32-C series SoC.
- The radio co-processor (RCP), which is an ESP32-H series SoC. The RCP enables the Border Router to access the 802.15.4 physical and MAC layer.

Espressif provides a Border Router board which integrates the host SoC and the RCP into one module.

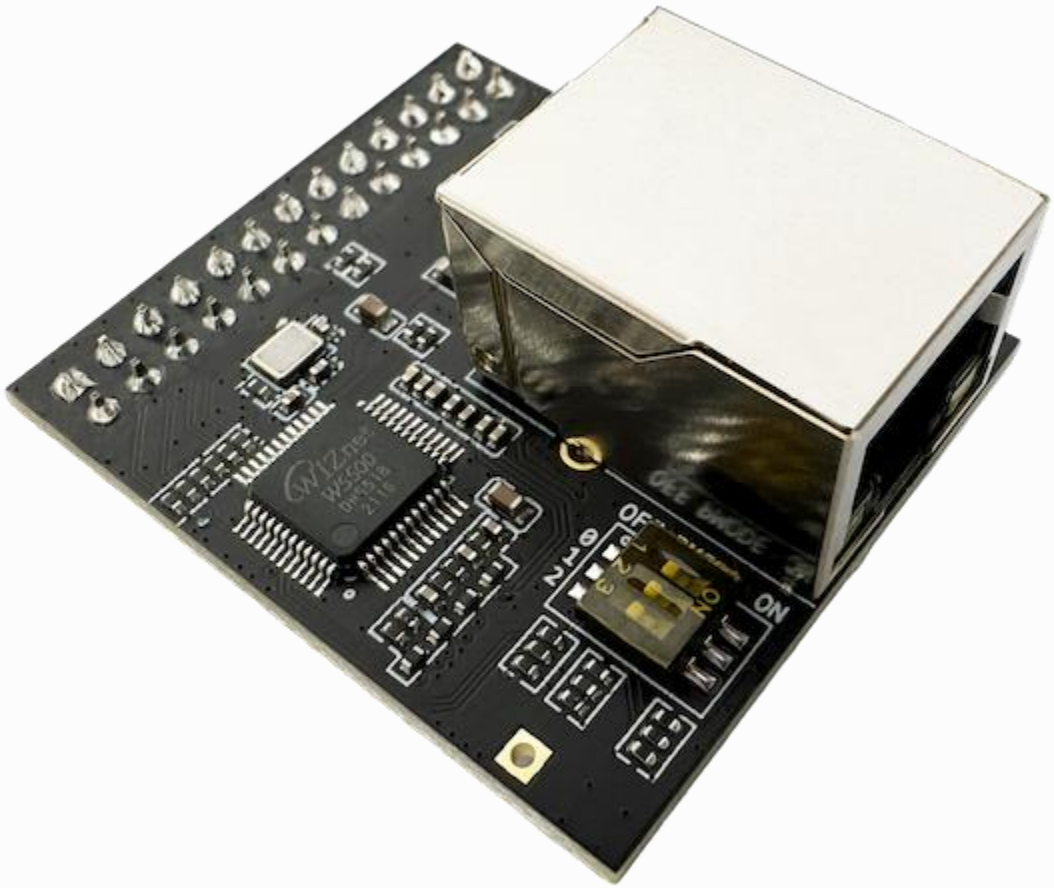


ESP Thread Border Router/Zigbee Gateway Board

1.2. Ethernet based Thread Border Router

Similar to the previous Wi-Fi based Thread Border Route setup, but a device with Ethernet interface is required.

Espressif provides a Sub-Ethernet daughter board, which works with the ESP Thread Border Router board to extend Ethernet interface.



ESP Thread Border Router/Zigbee Gateway Sub-Ethernet

1.3. Contents and Packaging

Ordering Information

The development board has a variety of variants to choose from, as shown in the table below.

Ordering Code	On-board Module	Flash [A]	PSRAM	Description
ESP Thread BR-Zigbee GW	ESP32-S3-WROOM-1 and ESP32-H2-MINI-1	4 MB	2 MB	ESP Thread Border Router/Zigbee Gateway Board
ESP Thread BR-Zigbee GW_SUB				ESP Thread Border Router/Zigbee Gateway Sub-Ethernet

A

The flash is integrated in the chip's package.

Retail Orders

If you order one or several samples, each board comes in an individual package in either antistatic bag or any packaging depending on your retailer.

For retail orders, please go to https://www.espressif.com/en/company/contact/buy-a-sample.

Wholesale Orders

If you order in bulk, the boards come in large cardboard boxes.

For wholesale orders, please go to https://www.espressif.com/en/contact-us/sales-questions.

1.4. Related Documents

- ESP Thread Border Router/Zigbee Gateway Board schematic (PDF)

- ESP Thread Border Router/Zigbee Gateway Sub-Ethernet (PDF)

2. Development Guide

2.1. Build and Run

This document contains instructions on building the images for ESP Thread Border Router and CLI device and forming a Thread network with the devices.

2.1.1. Set up the Repositories

Clone the esp-idf and the esp-thread-br repository.

```
git clone -b v5.1.1 --recursive https://github.com/espressif/esp-idf.git
cd esp-idf
./install.sh
. ./export.sh
cd ..
git clone --recursive https://github.com/espressif/esp-thread-br.git
```

If you are new to ESP-IDF, please follow the ESP-IDF getting started guide to set up the IDF development environment and get familiar with the IDF development tools.

2.1.2. Build the RCP Image

Build the `esp-idf/examples/openthread/ot_rcp` example. The firmware doesn't need to be explicitly flashed to a device. It will be included in the Border Router firmware and flashed to the ESP32-H2 chip upon first boot.

```
cd $IDF_PATH/examples/openthread/ot_rcp
```

Select the ESP32-H2 as the RCP.

```
idf.py set-target esp32h2
```

The default communication interface on the ESP Thread Border Router board is UART0 with 460800 baudrate, which can be configured in esp_ot_config.h.

```
idf.py menuconfig

idf.py build
```

2.1.3. Configure ESP Thread Border Router

Go to the `basic_thread_border_router` example folder.

```
cd esp-thread-br/examples/basic_thread_border_router
```

The default configuration works as is on ESP Thread Border Router board, the default SoC target is ESP32-S3.

To run the example on other SoCs, please configure the SoC target using command:

```
idf.py set-target <chip_name>
```

For any other customized settings, you can configure the project in menuconfig.

```
idf.py menuconfig
```

2.1.3.1. Wi-Fi based Thread Border Router

By default, it is configured as Wi-Fi based Thread Border Router.

The Wi-Fi SSID and password must be set in menuconfig. The corresponding options are `Example Connection Configuration -> WiFi SSID` and `Example Connection Configuration -> WiFi Password`.

The auto start mode is enabled by default, the device will connect to the configured Wi-Fi and form Thread network automatically, and then act as the border router.

Note

The following configuration options are all optional, jump to 2.1.4. Build and Run the Thread Border Router if you don't need any customized settings.

2.1.3.2. Ethernet based Thread Border Router

The border router can also be configured to connect to an Ethernet network. In this case, the daughter board `ESP Thread Border Router/Zigbee Gateway Sub-Ethernet` is required to extend the Ethernet interface.

The following options need to be set:

- Enable `EXAMPLE_CONNECT_ETHERNET`
- Disable `EXAMPLE_CONNECT_WIFI`

The configurations of `EXAMPLE_CONNECT_ETHERNET` as following:

Parameter	Value	Note
Type	W5500 Module	Mandatory
Stack Size	2048	Customized
SPI Host	SPI2	Mandatory
SPI SCLK	GPIO21	Mandatory
SPI MOSI	GPIO45	Mandatory
SPI MISO	GPIO38	Mandatory
SPI CS	GPIO41	Mandatory
SPI Interrupt	GPIO39	Mandatory
SPI SPEED	36 MHz	Customized
PHY Reset	GPIO40	Mandatory
PHY Address	1	Mandatory

The configuration result would look like this.

```
Espressif IoT Development Framework Configuration
[ ] connect using WiFi interface
[*] connect using Ethernet interface
(2048)  emac_rx task stack size
      Ethernet Type (W5500 Module)  --->
(2)     SPI Host Number
(21)    SPI SCLK GPIO number
(45)    SPI MOSI GPIO number
(38)    SPI MISO GPIO number
(41)    SPI CS GPIO number
(36)    SPI clock speed (MHz)
(39)    Interrupt GPIO number
```

```
(40)    PHY Reset GPIO number
(1)     PHY Address
[*] Obtain IPv6 address
     Preferred IPv6 Type (Local Link Address)  --->
```

2.1.3.3. Thread Network Parameters

The Thread network parameters could be pre-configured with `OPENTHREAD_NETWORK_xx` options.

2.1.3.4. Communication Interface

The default communication interface between host SoC and RCP is UART.

In order to use the SPI interface instead, the `OPENTHREAD_RCP_SPI` and `OPENTHREAD_RADIO_SPINEL_SPI` options should be enabled in `ot_rcp` and `basic_thread_border_router` example configurations, respectively. And set corresponding GPIO numbers in *esp_ot_config.h*.

2.1.3.5. Manual Mode

Disable `OPENTHREAD_BR_AUTO_START` option if you want to setup the network manually. Then the following CLI commands can be used to connect Wi-Fi and form a Thread network:

```
wifi connect -s <ssid> -p <psk>
dataset init new
dataset commit active
ifconfig up
thread start
```

2.1.3.6. RF External coexistence

Enable `EXTERNAL_COEX_ENABLE` option if you want to enable the RF External coexistence.

Note

To enable external coexistence of the Thread Border Router, enable the `EXTERNAL_COEX_ENABLE` option of `$IDF_PATH/examples/openthread/ot_rcp` before building the RCP Image.

2.1.4. Build and Run the Thread Border Router

Build and Flash the example to the host SoC.

```
idf.py -p ${PORT_TO_BR} flash monitor
```

The following result will be shown in your terminal:

Wi-Fi Border Router:

```
I (555) cpu_start: Starting scheduler on PRO CPU.
I (0) cpu_start: Starting scheduler on APP CPU.
I (719) example_connect: Start example_connect.
I (739) wifi:wifi firmware version: 4d93d42
I (899) wifi:mode : sta (84:f7:03:c0:d1:e8)
I (899) wifi:enable tsf
I (899) example_connect: Connecting to xxxx...
I (899) example_connect: Waiting for IP(s)
I (5719) example_connect: Got IPv6 event: Interface "example_netif_sta" address:
fe80:0000:0000:0000:86f7:03ff:fec0:d1e8, type: ESP_IP6_ADDR_IS_LINK_LOCAL
I (5719) esp_netif_handlers: example_netif_sta ip: 192.168.1.102, mask: 255.255.255.0, gw:
192.168.1.1
I (5729) example_connect: Got IPv4 event: Interface "example_netif_sta" address: 192.168.1.102
I (5739) example_common: Connected to example_netif_sta
I (5749) example_common: - IPv4 address: 192.168.1.102,
I (5749) example_common: - IPv6 address: fe80:0000:0000:0000:86f7:03ff:fec0:d1e8, type:
ESP_IP6_)
I(5779) OPENTHREAD:[I] Platform------: RCP reset: RESET_POWER_ON
I(5809) OPENTHREAD:[N] Platform------: RCP API Version: 6
I (5919) esp_ot_br: RCP Version in storage: openthread-esp32/8282dca796-e64ba13fa; esp32h2;
2022-10-10 06:01:35 UTC
I (5919) esp_ot_br: Running RCP Version: openthread-esp32/8282dca796-e64ba13fa; esp32h2;
2022-10-10 06:01:35 UTC
I (5929) OPENTHREAD: OpenThread attached to netif
I(5939) OPENTHREAD:[I] SrpServer-----: Selected port 53535
I(5949) OPENTHREAD:[I] NetDataPublshr: Publishing DNS/SRP service unicast (ml-eid, port:53535)
```

Ethernet Border Router:

```
I (793) cpu_start: Starting scheduler on PRO CPU.
I (793) cpu_start: Starting scheduler on APP CPU.
I (904) system_api: Base MAC address is not set
I (904) system_api: read default base MAC address from EFUSE
I (924) esp_eth.netif.netif_glue: 70:b8:f6:12:c5:5b
I (924) esp_eth.netif.netif_glue: ethernet attached to netif
I (2524) ethernet_connect: Waiting for IP(s).
I (2524) ethernet_connect: Ethernet Link Up
I (3884) ethernet_connect: Got IPv6 event: Interface "example_netif_eth" address:
fe80:0000:0000:0000:72b8:f6ff:fe12:c55b, type: ESP_IP6_ADDR_IS_LINK_LOCAL
I (3884) esp_netif_handlers: example_netif_eth ip: 192.168.8.148, mask: 255.255.255.0, gw:
192.168.8.1
I (3894) ethernet_connect: Got IPv4 event: Interface "example_netif_eth" address:
192.168.8.148
I (3904) example_common: Connected to example_netif_eth
```

```
I (3904) example_common: - IPv4 address: 192.168.8.148,
I (3914) example_common: - IPv6 address: fe80:0000:0000:0000:72b8:f6fI(3944) OPENTHREAD:[I]
Platform------: RCP reset: RESET_POWER_ON
I(3974) OPENTHREAD:[N] Platform------: RCP API Version: 6
I(4144) OPENTHREAD:[I] Settings------: Read NetworkInfo {rloc:0x4400,
extaddr:129f848762f1c578, role:leader, mode:0x0f, version:4, keyseq:0x0, ...
I(4154) OPENTHREAD:[I] Settings------: ... pid:0x18954426, mlecntr:0x7da7, maccntr:0x7d1c,
mliid:2874d9fa90dc8093}
I (4194) OPENTHREAD: OpenThread attached to netif
```

2.1.5. Build and Run the Thread CLI Device

Build the `esp-idf/examples/openthread/ot_cli` example and flash the firmware to another ESP32-H2 devkit.

```
cd $IDF_PATH/examples/openthread/ot_cli

idf.py -p ${PORT_TO_ESP32_H2} flash monitor
```

2.1.6. Attach the CLI Device to the Thread Network

First acquire the Thread network dataset on the Border Router:

```
dataset active -x
```

The network data will be printed on the Border Router:

```
> dataset active -x
0e080000000000010000000300001335060004001fffe00208dead00beef00cafe0708fdfaeb6813db063b05101122
33445566778899aabbccddeeff00030f4f70656e5468726561642d343964360102123404101048 10e2315100afd6bc
9215a6bfac530c0402a0f7f8
Done
```

Commit the dataset on the CLI device with the acquired dataset:

```
dataset set active
0e080000000000010000000300001335060004001fffe00208dead00beef00cafe0708fdfaeb6813db063b05101122
33445566778899aabbccddeeff00030f4f70656e5468726561642d343964360102123404101048 10e2315100afd6bc
9215a6bfac530c0402a0f7f8
```

Set the network data active on the CLI device:

```
dataset commit active
```

Set up the network interface on the CLI device:

```
ifconfig up
```

Start the thread network on the CLI device:

```
thread start
```

The CLI device will become a child or a router in the Thread network:

```
> dataset set active
0e080000000000010000000300001335060004001fffe00208dead00beef00cafe0708fdfaeb6813db063b05101122
33445566778899aabbccddeeff00030f4f70656e5468726561642d343964360102123404101048 10e2315100afd6bc
9215a6bfac530c0402a0f7f8
Done
> dataset commit active
Done
> ifconfig up
Done
I (1665530) OPENTHREAD: netif up
> thread start
I(1667730) OPENTHREAD:[N] Mle-----------: Role disabled -> detached
Done
> I(1669240) OPENTHREAD:[N] Mle-----------: RLOC16 5800 -> fffe
I(1669590) OPENTHREAD:[N] Mle-----------: Attempt to attach - attempt 1, AnyPartition
I(1670590) OPENTHREAD:[N] Mle-----------: RLOC16 fffe -> 6c01
I(1670590) OPENTHREAD:[N] Mle-----------: Role detached -> child
```

2.2. Setting up the Local OTA Server

This document contains instructions on setting up a self-signed HTTPS OTA server on the local host and configuring the Border Router to trust the server.

Generating the Server Certificate

Create a new directory `ota_server_storage` to host the server. Then generate the certificate in this directory:

```
mkdir ota_server_storage && cd ota_server_storage

openssl req -x509 -newkey rsa:2048 -keyout ca_key.pem -out ca_cert.pem -days 365 -nodes
```

Note that when prompted for the `Common Name (CN)`, the name entered shall match the hostname running the server.

The Border Router OTA image will be automatically generated when building the `basic_thread_border_router` example. Copy it to the previously created directory `ota_server_storage`:

```
cp esp-thread-br/examples/basic_thread_border_router/build/br_ota_image ota_server_storage
```

Rebuilding the Border Router Firmware with the New Certificate

The certificate `server_certs/ca_cert.pem` in the `basic_thread_border_router` example shall be replaced with the generated certificate. Perform a fullclean and build the application again:

```
cp path/to/ota_server_storage/ca_cert.pem server_certs/ca_cert.pem
idf.py fullclean
idf.py flash monitor
```

To download the image from the server and run the following command on the Border Router:

```
ota download https://${HOST_URL}:8070/br_ota_image
```

PreviousNext

2.3. OTA Update Mechanism

The ESP Thread Border Router supports building the RCP image into the Border Router image. Upon boot the RCP image will be automatically downloaded to the RCP if the Border Router detects the RCP chip failure to boot.

Hardware Prerequisites

To perform OTA update, the following devices are required:

- An ESP Thread Border Router
- A Linux Host machine

In addition to the UART connection to the RCP chip, two extra GPIO pins are required to control the RESET and the BOOT pin of the RCP. For ESP32-H2 the BOOT pin is GPIO8.

Download and Update the Border Router Firmware

Create a HTTPS server providing the OTA image file, excute the follow command on your Linux Host machine:

```
openssl s_server -WWW -key ca_key.pem -cert ca_cert.pem -port 8070
```

The private key and the certificate shall be accpetable for the Border Router. If they are self-signed, make sure to add the public key to the trusted key set of the Border Router.

Now the image can be downloaded on the Border Router:

```
ota download https://${HOST_URL}:8070/br_ota_image
```

- Tips 1: For optimizing the firmware of border router, *CONFIG_COMPILER_OPTIMIZATION_SIZE* and *CONFIG_NEWLIB_NANO_FORMAT* are enabled by default.
- Tips 2: If the OTA function is enabled, it is recommended to optimize the ot_rcp firmware size before building the OTA image. Please refer to ot_rcp README for detailed steps.

After downloading the Border Router will reboot and update itself with the new firmware. The RCP will also be updated if the firmware version changes.

The RCP Image Rollback Mechanism

The RCP image is stored in a configurable SPIFFS partition under a configurable prefix. Prefix *ot_rcp* will be used in as an example.

Two folders *ot_rcp_0* and *ot_rcp_1* will be used to store the current and the backup RCP image. The RCP image will be stored in *ot_rcp_0* upon first boot. An extra key-value pair will be added in the nvs for storing the current RCP image index.

When applying the RCP update, the RCP image with the current index will be downloaded. After the reboot, the Border Router will detect the status of the RCP. If the RCP fails to boot, the backup image will be flashed to the RCP to revert the change.

When downloading the OTA image from the server, the current RCP image will be marked as the backup image and the previous backup image will be overridden. After the download completes, the current image index will be updated.

The OTA Image File Structure

The OTA image is a single file containing the meta data of the RCP image, the RCP bootloader, the RCP partition table and the firmwares.

The image can be generated with script basic_thread_border_router/create_ota_image.py. By default this file is called automatically during build and packs the *ot_rcp* example image into the Border Router firmware.

The RCP image header is defined as the following diagram:

0xff	Header size	0
File Type 0	File size	File offset
File Type 1	File size	File offset

...

The file type is defined as the following table:

0	RCP version
1	RCP flash arguments
2	RCP bootloader
3	RCP partition table
4	RCP firmware
5	Border Router firmware

3. ESP Thread Border Router Codelab

3.1. Bi-directional IPv6 Connectivity

The ESP Thread Border Router allows the devices on the Wi-Fi/Ethernet and the Thread network to reach each other with IPv6 addresses.

Hardware Prerequisites

To perform bi-directional IPv6 connectivity, the following devices are required:

- An ESP Thread Border Router
- A Thread CLI device
- A Linux Host machine

The Border Router and the Linux Host machine shall be connected to the same Wi-Fi network and the Thread device shall join the Thread network formed by the Border Router.

Validate the IPv6 Connectivity

The Linux Host machine needs to be configured to accept the router advertisements from the Border Router:

Setting `accept_ra` to 2 allows all RAs to be accepted:

```
sudo sysctl -w net/ipv6/conf/wlan0/accept_ra=2
```

Setting `accept_ra_rt_info_max_plen` to 128 allows all kinds of prefix length in RAs to be accepted:

```
sudo sysctl -w net/ipv6/conf/wlan0/accept_ra_rt_info_max_plen=128
```

A global address will be assigned to the Thread CLI device. The Linux Host machine can reach the Thread device with an address that can be obtained by running the command *ipaddr* on the CLI device.

```
ipaddr
```

The command would produce the similar output:

```
> ipaddr
fd66:afad:575f:1:744d:573e:6e60:188a
fd87:8205:4651:27c8:0:ff:fe00:0
fd87:8205:4651:27c8:e65a:3138:745a:df06
fe80:0:0:0:2433:db2e:62c:b2e4
Done
```

The Linux Host reachable address is `fd66:afad:575f:1:744d:573e:6e60:188a`, you can ping this address from Linux Host using the following command:

```
ping fd66:afad:575f:1:744d:573e:6e60:188a
```

You well get these output:

```
$ ping fd66:afad:575f:1:744d:573e:6e60:188a

PING fd66:afad:575f:1:744d:573e:6e60:188a(fd66:afad:575f:1:744d:573e:6e60:188a) 56 data bytes
64 bytes from fd66:afad:575f:1:744d:573e:6e60:188a: icmp_seq=1 ttl=254 time=187 ms
64 bytes from fd66:afad:575f:1:744d:573e:6e60:188a: icmp_seq=2 ttl=254 time=167 ms
```

3.2. Multicast Forwarding

Multicast Forwarding allows reaching devices on the Thread and Wi-Fi network in the same multicast group from both sides.

Hardware Prerequisites

To perform Multicast Forwarding, the following devices are required:

- An ESP Thread Border Router
- A Thread CLI device
- A Linux Host machine

The Border Router and the Linux Host machine shall be connected to the same Wi-Fi network and the Thread device shall join the Thread network formed by the Border Router.

Limits on Multicast Groups

Note that to forward packets between the Thread and the Wi-Fi network, the multicast group scope shall be at least admin-local(ff04). Link-local and realm-local multicast packets will not be forwarded.

Reaching the Multicast Group from the Wi-Fi Network via ICMP

First, join the multicast group on the Thread CLI device:

```
mcast join ff04::123
```

Now you can ping Thread CLI device on your Linux Host:

```
ping -I wlan0 -t 64 ff04::123
```

The output similar to shown below may indicate that the device can be reached on the Wi-Fi network via the multicast group:

```
$ ping -I wlan0 -t 64 ff04::123
PING ff04::123(ff04::123) from fdde:ad00:beef:cafe:2eea:7fff:fe37:b4fb wlan0: 56 data bytes
64 bytes from fd66:afad:575f:1:744d:573e:6e60:188a: icmp_seq=1 ttl=254 time=132 ms
```

Reaching the Multicast Group from the Wi-Fi Network via UDP

First, join the multicast group and create a UDP socket on the Thread CLI device:

```
> mcast join ff04::123
Done
> udp open
Done
> udp bind :: 5083
Done
```

Use the following python script, which is named `multicast_udp_client.py`, to send UDP messages to the Thread CLI device via the multicast group:

```
import socket
import time

data = b'hello'
group = 'ff04::123'
REMOTE_PORT = 5083
network_interface = 'wlan0' # Change to the actual interface name

sock = socket.socket(socket.AF_INET6, socket.SOCK_DGRAM)
sock.setsockopt(socket.SOL_SOCKET, socket.SO_BINDTODEVICE, network_interface.encode())
sock.setsockopt(socket.IPPROTO_IPV6, socket.IPV6_MULTICAST_HOPS, 32)
sock.sendto(data, (group, REMOTE_PORT))
sock.close()
```

On the Linux Host machine, you need to start a UDP client by running this script:

```
python3 multicast_udp_client.py
```

On the Thread CLI device, the message will be printed:

```
> mcast join ff04::123
Done
> udp open
Done
> udp bind :: 5083
Done
5 bytes from fd11:1111:1122:2222:4a9e:272e:6a50:cf61 56024 hello
```

Reaching the Multicast Group from the Thread Network

Use the following python script, which is named `multicast_udp_server.py`, to join an admin-local group and set up a UDP server on the Linux machine:

```
import socket
import struct

if_index = socket.if_nametoindex('wlan0')
sock = socket.socket(socket.AF_INET6, socket.SOCK_DGRAM)
sock.bind(('::', 5083))
sock.setsockopt(
        socket.IPPROTO_IPV6, socket.IPV6_JOIN_GROUP,
        struct.pack('16si', socket.inet_pton(socket.AF_INET6, 'ff04::123'),
                                if_index))
while True:
        data, sender = sock.recvfrom(1024)
        print(data, sender)
```

On the Linux Host machine, you need to start a UDP server by running this script:

```
python3 multicast_udp_server.py
```

After launching the script and the Thread CLI device will be able to send UDP messages to the Linux Host via the multicast group:

```
udp open
udp send ff04::123 5083 hello
```

You will get a result `Done` after executing each of the commands, the expected output is below:

```
> udp open
Done
> udp send ff04::123 5083 hello
Done
```

On the Linux Host machine, the message will be printed:

```
$ python3 multicast_udp_server.py
b'hello' ('fd66:afad:575f:1:744d:573e:6e60:188a', 49154, 0, 0)
```

3.3. Service Discovery

The ESP Thread Border Router allows devices on the Thread and Wi-Fi/Ethernet network to discover services published on both the networks.

Hardware Prerequisites

To perform service discovery, the following devices are required:

- An ESP Thread Border Router
- A Thread CLI device
- A Linux Host machine

The Border Router and the Linux Host machine shall be connected to the same Wi-Fi network and the Thread device shall join the Thread network formed by the Border Router.

Publishing Services from the Thread Network

Thread uses the Service Registration Protocol (SRP) to register services. First, publish the service on the Thread CLI device.

Using this command line to set host name:

```
srp client host name thread-device
```

Using this command line to set host address, you can set default address with `auto`:

```
srp client host address auto
```

Using this command line to set parameter of the service:

```
srp client service add thread-service _test._tcp,_sub1,_sub2 12345 1 1 0778797a3d58595a
```

Using this command line to enable the service:

```
srp client autostart enable
```

You will get a result `Done` after executing each of the commands, the expected output is below:

```
> srp client host name thread-device
Done
> srp client host address auto
Done
> srp client service add thread-service _test._tcp,_sub1,_sub2 12345 1 1 0778797a3d58595a
Done
> srp client autostart enable
Done
```

You can execute this command on the Border Router to resolve the service:

```
srp server service
```

The service can be found on the Border Router:

```
> srp server service
```

```
thread-service._test._tcp.default.service.arpa.
    deleted: false
    subtypes: _sub2,_sub1
    port: 12345
    priority: 1
    weight: 1
    ttl: 7200
    TXT: [xyz=58595a]
    host: thread-device.default.service.arpa.
    addresses: [fd66:afad:575f:1:744d:573e:6e60:188a]
Done
```

The service can also be found on the Wi-Fi with the Linux Host machine by using this command:

```
avahi-browse -rt _test._tcp
```

The expected output is below:

```
$ avahi-browse -rt _test._tcp
+ enp1s0 IPv6 thread-service                             _test._tcp           local
+ enp1s0 IPv4 thread-service                             _test._tcp           local
= enp1s0 IPv6 thread-service                             _test._tcp           local
   hostname = [thread-device.local]
   address = [fd66:afad:575f:1:744d:573e:6e60:188a]
   port = [12345]
   txt = ["xyz=XYZ"]
= enp1s0 IPv4 thread-service                             _test._tcp           local
   hostname = [thread-device.local]
   address = [fd66:afad:575f:1:744d:573e:6e60:188a]
   port = [12345]
   txt = ["xyz=XYZ"]
```

Publishing Services from the Wi-Fi Network

First publish the service on the Linux Host machine with mDNS:

```
avahi-publish-service wifi-service _test._tcp 22222 test=1 dn="aabbbb"
```

If the service is established, you will get this output on your Linux Host machine:

```
$ avahi-publish-service wifi-service _test._tcp 22222 test=1 dn="aabbbb"
Established under name 'wifi-service'
```

Then get the Border Router's Mesh-Local Endpoint Identifier, and configure it on the Thread end device. On the Border Router:

```
ipaddr mleid
```

You will get:

```
> ipaddr mleid
fdde:ad00:beef:0:f891:287:866:776
Done
```

On the Thread CLI device:

```
dns config fdde:ad00:beef:0:f891:287:866:776
```

You will get:

```
> dns config fd9b:347f:93f7:1:1003:8f00:bcc1:3038
Done
```

The service can be resolved on the Thread CLI device by executing this command:

```
dns service wifi-service _test._tcp.default.service.arpa.
```

The expected output on the Thread CLI device is below:

```
> dns config fdde:ad00:beef:0:f891:287:866:776
Done
> dns service wifi-service _test._tcp.default.service.arpa.
DNS service resolution response for wifi-service for service _test._tcp.default.service.arpa.
Port:22222, Priority:0, Weight:0, TTL:120
Host:FA001388.default.service.arpa.
HostAddress:fd33:1cc4:a6ec:2e0:2eea:7fff:fe37:b4fb TTL:120
TXT:[test=31, dn=616162626262] TTL:120

Done
```

3.4. NAT64

The ESP Thread Border Router supports NAT64 which allows Thread devices to visit the IPv4 Internet.

Hardware Prerequisites

To perform NAT64, the following devices are required:

- An ESP Thread Border Router
- A Thread CLI device

The Thread device shall join the Thread network formed by the Border Router.

Visiting the IPv4 HTTP Servers

For visiting HTTP servers with domain names, the DNS server shall be first configured on the Thread CLI device:

```
dns64server 8.8.8.8
```

Then you can use `curl <website>` command to get the data form the specific website(for example `http://www.espressif.com`):

```
curl http://www.espressif.com
```

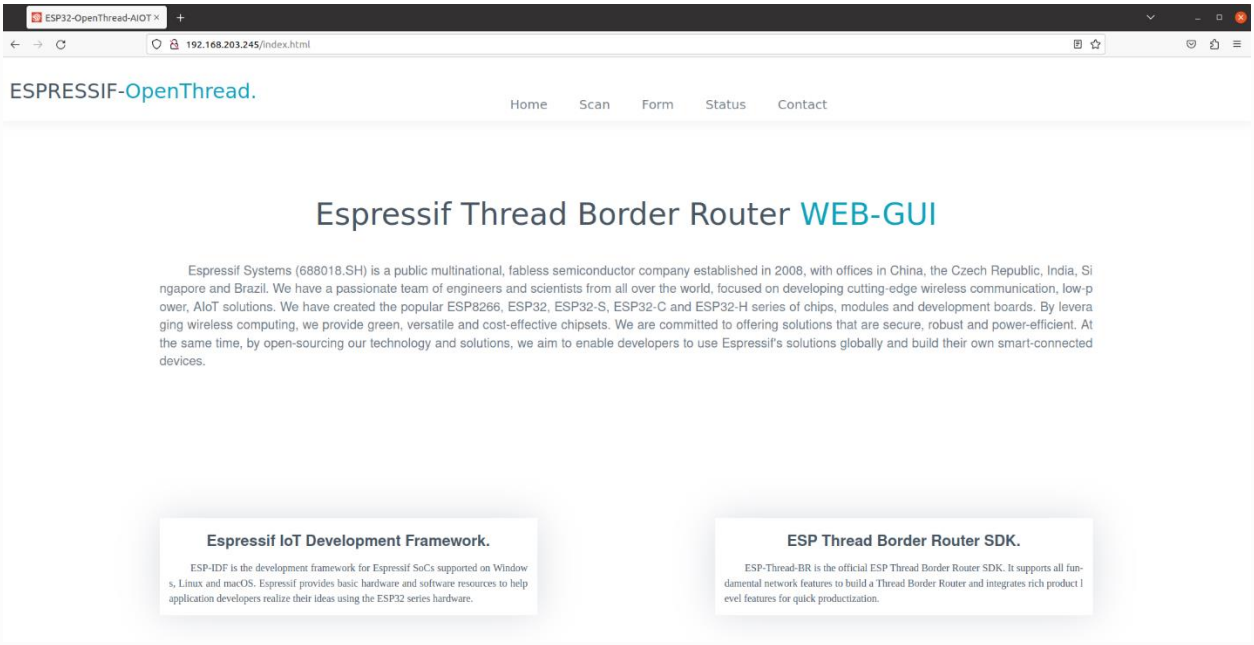
The Thread device will first resolve the host with UDP packets sent to the IPv4 DNS server. Then retrieve the page from the IPv4 HTTP server via TCP. The expected output is below:

```
> dns64server 8.8.8.8
Done
> curl http://www.espressif.com
Done
> I (22289) HTTP_CLIENT: Body received in fetch header state, 0x3fcca6b7, 183
<html>
<head><title>301 Moved Permanently</title></head>
<body bgcolor="white">
<center><h1>301 Moved Permanently</h1></center>
<hr><center>CloudFront</center>
</body>
</html>
```

3.5. WEB GUI

The ESP Thread Border Router is equipped with a user-friendly graphical user interface (GUI) that enables users to easily discover, configure, and monitor Thread networks through the web server.

To access the Web GUI, simply enter `the local IPv4 address` for the ESP Thread Border Router in your browser window with port `80` and the path `index.html`.



ESP-Thread-Border-Router GUI

Prerequisites

To perform web gui, the follow device are required:

- An ESP Thread Border Router
- A Linux host machine with browser

Enable the `CONFIG_OPENTHREAD_BR_START_SERVER` option to enable the Web Server feature.

The Thread Border Router and the Linux Host machine shall be connected to the same Wi-Fi network that has access to the Internet.

When the ESP Thread Border Router starts up, it will print the website's access address to terminal of the Linux host.

such as:

```
otbr_web: <=======================server start=======================>

otbr_web: http://192.168.200.98:80/index.html

otbr_web: <==========================================================>
```

All REST APIs can be accessed by visiting the IPv4 address of the Thread-Border-Router-Board using the `HTTP` on port 80 with the API field specified.

Thread REST APIs

The ESP Thread Border Router server provides the REST APIs that are compatible with ot-br-posix

The Thread REST APIs field include `/diagnostics`, `/node`, `/node/rloc`, `/node/rloc16`, `/node/ext-address`, `/node/state`, `/node/network-name`, `/node/leader-data`, `/node/num-of-router`, `/node/ext-panid` and `/node/active-dataset-tlvs`.

Entering this link to the browser of Linux machine:

```
http://192.168.200.98:80/node
```

The following feedback result will display on the browser:


```
{
    "NetworkName":  "OpenThread-4c68",
    "ExtPanId":     "f4f9437404558d34",
    "ExtAddress":   "caf97e6ee990b047",
    "RlocAddress":  "fd12:cb40:859f:287e:0:ff:fe00:3800",
    "LeaderData":   {
        "PartitionId":      61563841,
        "Weighting":        64,
        "DataVersion":      211,
        "StableDataVersion":        110,
        "LeaderRouterId":   14
    },
    "State":        4,
    "Rloc16":       14336,
    "NumOfRouter":  1
}
```


The access method for other APIs is similar to the one described above.

Web GUI REST APIs

The web server of ESP Thread Border Router provides the `avaiable_network` API to discover the all available Thread networks.

Entering this link to the browser of Linux machine:

```
http://192.168.200.98:80/available_network
```

The feedback result may appear as follows:


```
{
    "error":        0,
    "result":       [{
            "id":   1,
            "nn":   "OpenThread",
            "ep":   "dead00beef00cafe",
            "pi":   "0xa06d",
            "ha":   "5a1ee78f873814fc",
            "ch":   11,
            "ri":   -35,
            "li":   229
        }, {
            "id":   2,
            "nn":   "GRL",
            "ep":   "000db80000000000",
            "pi":   "0xfacf",
            "ha":   "166e0a0000000003",
            "ch":   17,
            "ri":   -70,
            "li":   51
        }, {
            "id":   3,
            "nn":   "NEST-PAN-3DDF",
            "ep":   "4500ddd4f9c1597d",
            "pi":   "0x3ddf",
            "ha":   "9e517ed148e81409",
            "ch":   20,
            "ri":   -39,
            "li":   209
        }],
    "message":      "Networks: Success"
}
```


The web server of ESP Thread Border Router provides the `get_properties` API to check the Thread network status.

Entering this link to the browser of Linux machine:

```
http://192.168.200.98:80/get_properties
```

The feedback result may appear as follows:


```
{
    "error":        0,
    "result":       {
        "IPv6:LinkLocalAddress":    "fe80:0:0:0:c8f9:7e6e:e990:b047",
        "IPv6:RoutingLocalAddress": "fd12:cb40:859f:287e:0:ff:fe00:3800",
        "IPv6:MeshLocalAddress":    "fd12:cb40:859f:287e:a8b5:c617:396b:a4c2",
```

```
        "IPv6:MeshLocalPrefix":     "fd12:cb40:859f:287e::/64",
        "Network:Name":     "OpenThread-4c68",
        "Network:PANID":    "0x1254",
        "Network:PartitionID":      "61563841",
        "Network:XPANID":   "f4f9437404558d34",
        "OpenThread:Version":       "openthread-esp32/f4446d8819-091f68ed7; esp32s3;  2023-05-
05 13:05:02 UTC",
        "OpenThread:Version API":   "292",
        "RCP:State":        "leader",
        "OpenThread:PSKc":  "e66d93364793c33985280abb639c214c",
        "RCP:Channel":      "12",
        "RCP:EUI64":        "6055f9f72eebfeff",
        "RCP:TxPower":      "10 dBm",
        "RCP:Version":      "openthread-esp32/f4446d8819-091f68ed7; esp32h2;  2023-05-04
08:35:37 UTC",
        "WPAN service":     "associated"
    },
    "message":      "Properties: Success"
}
```


The web server of ESP Thread Border Router provides the `node_information` API to otbain the Thread node information.

Entering this link to the browser of Linux machine:

```
http://192.168.200.98:80/node_information
```

The feedback result may appear as follows:


```
{
    "error":        0,
    "result":       {
        "NetworkName":      "OpenThread-4c68",
        "ExtPanId": "f4f9437404558d34",
        "ExtAddress":       "caf97e6ee990b047",
        "RlocAddress":      "fd12:cb40:859f:287e:0:ff:fe00:3800",
        "LeaderData":       {
            "PartitionId":  61563841,
            "Weighting":    64,
            "DataVersion":  225,
            "StableDataVersion":    124,
            "LeaderRouterId":       14
        },
        "State":    4,
        "Rloc16":   14336,
        "NumOfRouter":      1
    },
    "message":      "Get Node: Success"
}
```


The web server of ESP Thread Border Router provides the `topology` API to retrieve information about the relationship between Thread networks.

Entering this link to the browser of Linux machine:

```
http://192.168.200.98:80/topology
```

The feedback result may appear as follows:


```
{
        "error":    0,
    "result":       [{
            "ExtAddress":   "caf97e6ee990b047",
            "Rloc16":       14336,
            "Mode": {
                "RxOnWhenIdle":     1,
                "DeviceType":       1,
                "NetworkData":      1
            },
            "Connectivity": {
                "ParentPriority":   0,
                "LinkQuality3":     0,
                "LinkQuality2":     0,
                "LinkQuality1":     0,
                "LeaderCost":       0,
                "IdSequence":       131,
                "ActiveRouters":    1,
                "SedBufferSize":    1280,
                "SedDatagramCount": 1
            },
            "Route":        {
                "IdSequence":       131,
                "RouteData":        [{
                        "RouteId":  14,
                        "LinkQualityOut":   0,
                        "LinkQualityIn":    0,
                        "RouteCost":        1
                    }]
            },
            "LeaderData":   {
                "PartitionId":      61563841,
                "Weighting":        64,
                "DataVersion":      229,
                "StableDataVersion":        128,
                "LeaderRouterId":   14
            },
            "NetworkData":
"08040b02cca60b0e8001010d0938000000500000e1003140040fd634dc9496e000105043800f10007021140030f0
040fdf4f94374048d3401033800000b1981015d0d143800fd12cb40859f287ea8b5c617396ba4c2d11f03130060fd6
34dc9496e000200000000001033800e0",
            "IP6AddressList":       [
                                "fd12:cb40:859f:287e:0:ff:fe00:fc11",
                                "fd63:4dc9:496e:1:9967:1ba3:5fbf:f2e6",
                                "fd12:cb40:859f:287e:0:ff:fe00:fc10",
                                "fd12:cb40:859f:287e:0:ff:fe00:fc38",
                                "fd12:cb40:859f:287e:0:ff:fe00:fc00",
                                "fd12:cb40:859f:287e:0:ff:fe00:3800",
                                "fd12:cb40:859f:287e:a8b5:c617:396b:a4c2",
                                "fe80:0:0:0:c8f9:7e6e:e990:b047"
                                ],
            "MACCounters":  {
                "IfInUnknownProtos":        0,
                "IfInErrors":       0,
                "IfOutErrors":      0,
                "IfInUcastPkts":    13,
```

```
                "IfInBroadcastPkts":        56,
                "IfInDiscards":     0,
                "IfOutUcastPkts":   0,
                "IfOutBroadcastPkts":       201,
                "IfOutDiscards":    0
            },
            "ChildTable":   [],
            "ChannelPages": "00"
        }],
    "message":      "Topology: Success"
}
```

The web server provides an `HTTP_POST` entry that allows users to configure the Border Router to use either `networkKeyType` or `pskdType` for joining other networks.

The JSON format of `join_network` API appears as follow:

```
{
    "credentialType":   "networkKeyType",
    "networkKey"    :   "00112233445566778899aabbccddeeff",
    "pskd"          :   "12345678",
    "prefix"        :   "fd11:22::",
    "defaultRoute"  :   1,
    "index"         :   1
}
```

Note that the network to be joined MUST be the networks scanned by the `available_network` API, the `index` indicates the sequence of available networks.

The web server provides an `HTTP_POST` entry that allows users to configure the Border Router to use the parameter provided by user for forming a Thread network.

The JSON format of `form_network` API appears as follow:

```
{
    "networkName"   :   "OpenThread-0x99",
    "networkKey"    :   "00112233445566778899aabbccddeeff",
    "panId"         :   "0x1234",
    "channel"       :   16,
    "extPanId"      :   "1111111122222222",
    "passphrase"    :   "j01Nme",
    "prefix"        :   "fd11:22::",
    "defaultRoute"  :   1
}
```

The web server provides an `HTTP_POST` entry that allows users to configure the Border Router for setting current Thread network.

The JSON format of `add_prefix` API appears as follow:

```
{
    "prefix":       "fd11:22::",
    "defaultRoute":  1
}
```

The JSON format of `delete_prefix` API appears as follow:

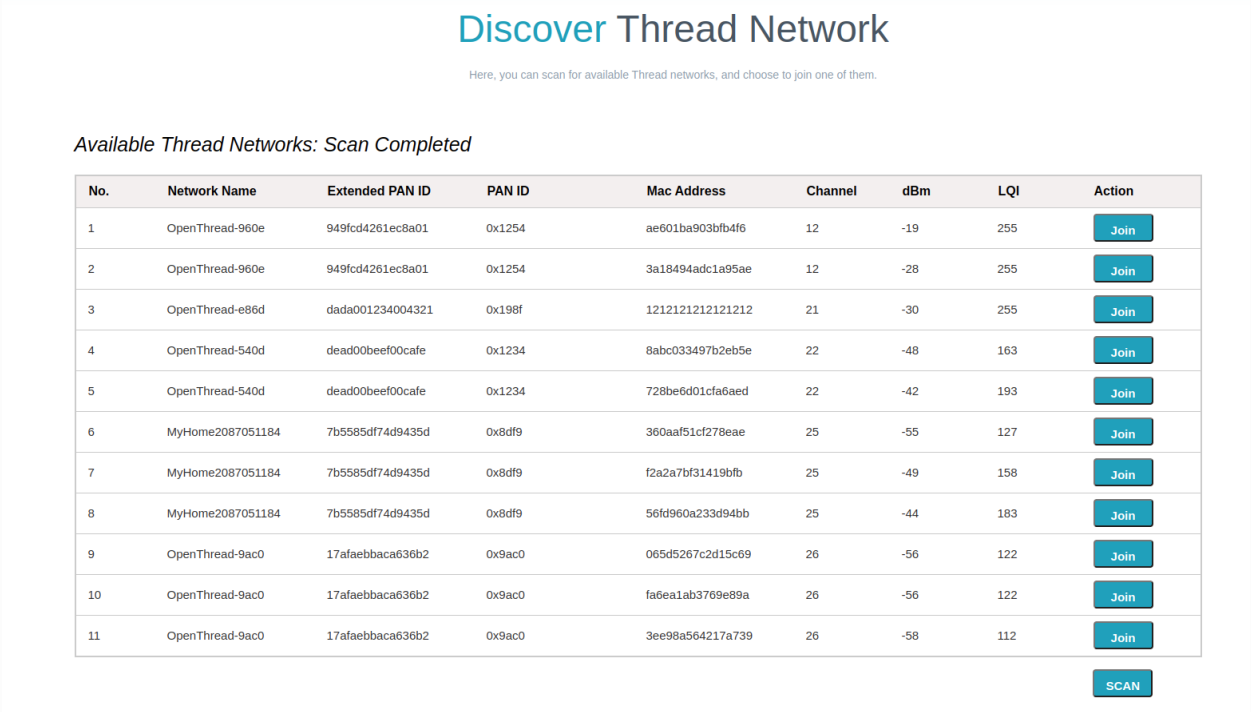
```
{
    "prefix":       "fd11:22::",
}
```

Web GUI Application Introduction

ESP Thread Border Router Web GUI provides practical functions including Thread network discovery, network formation, network settings, status query and network.

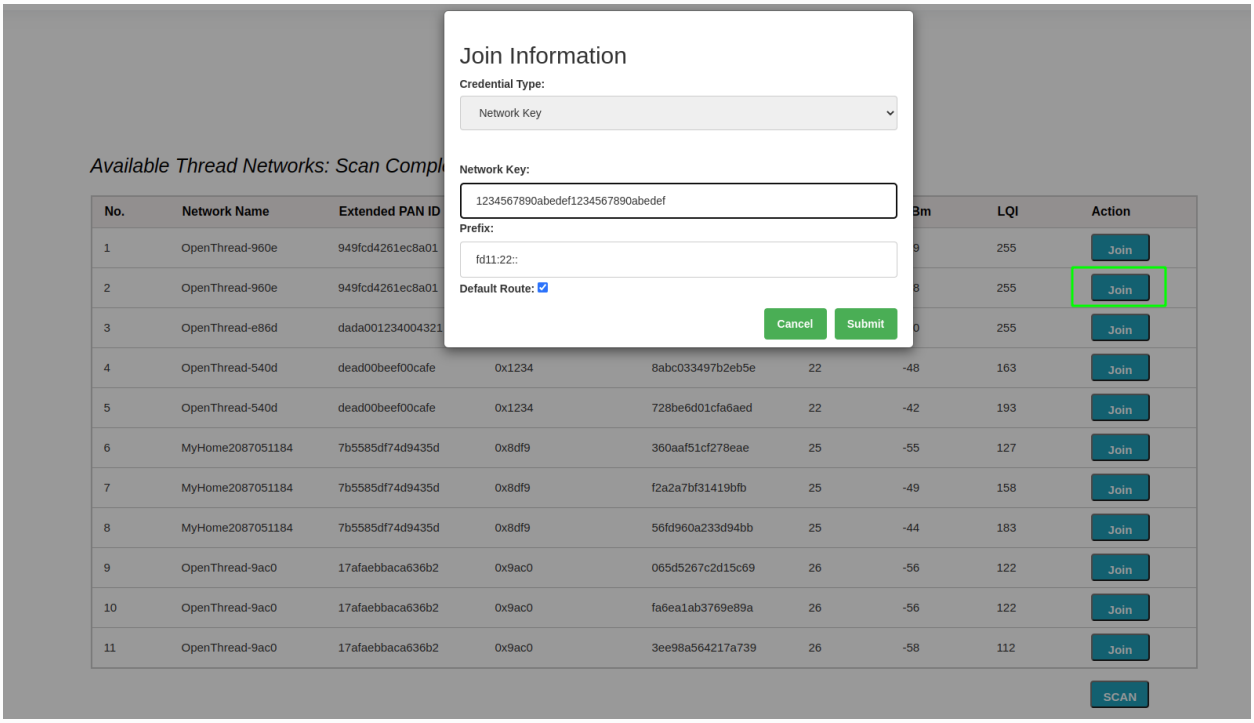
Discover

By clicking the `scan` button, you can discover for the available Thread networks. The networks will be shown in the table with their network name, channel, extended panid, panid, Mac address, txpower and so on.



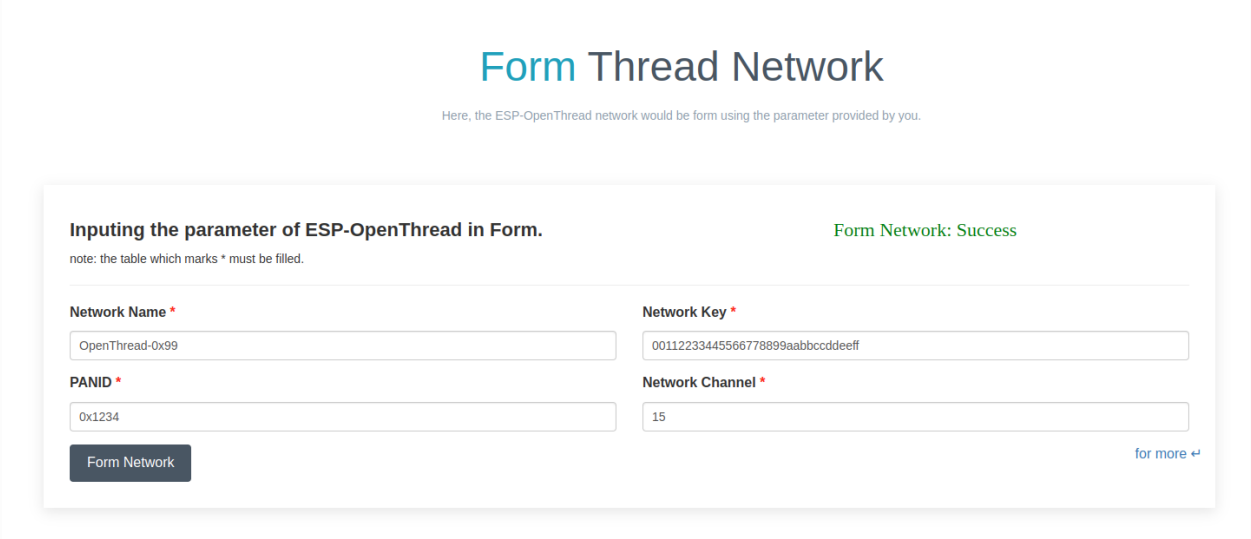
Join

You can select an available network to join by clicking the `join` button. Enter the relevant information into the pop-up dialog, submit it, and the result will be displayed for you after a moment.



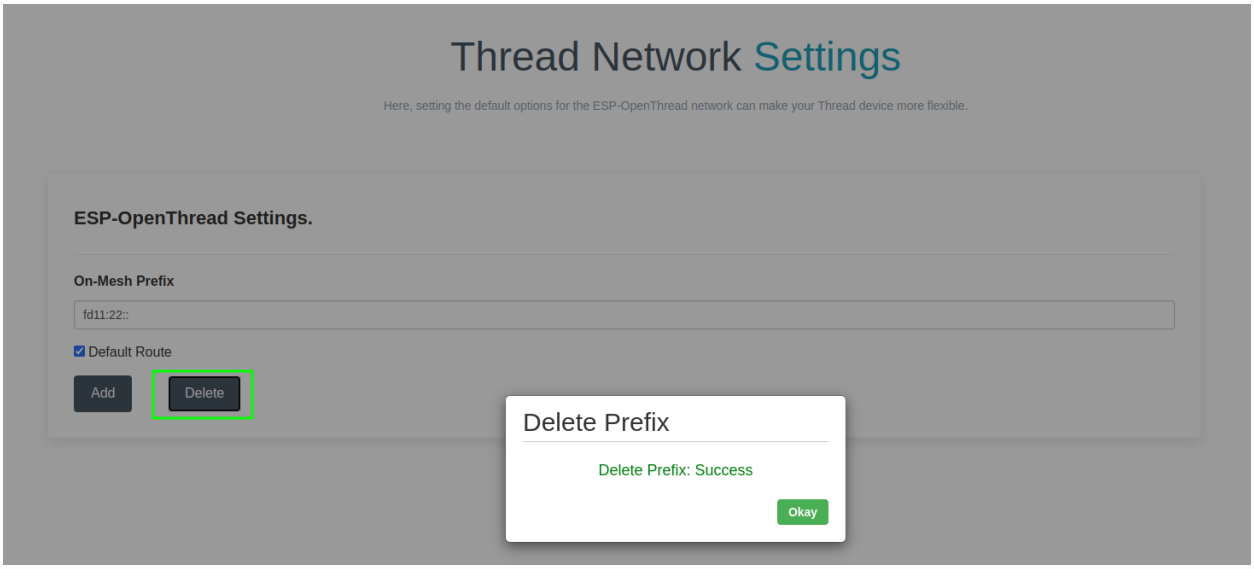
Form

You can form a Thread network in this section. First, you need to fill network's parameters in the following table. Then click the `Form Network` button to submit the message. The server will validate the network information and form the network on success.



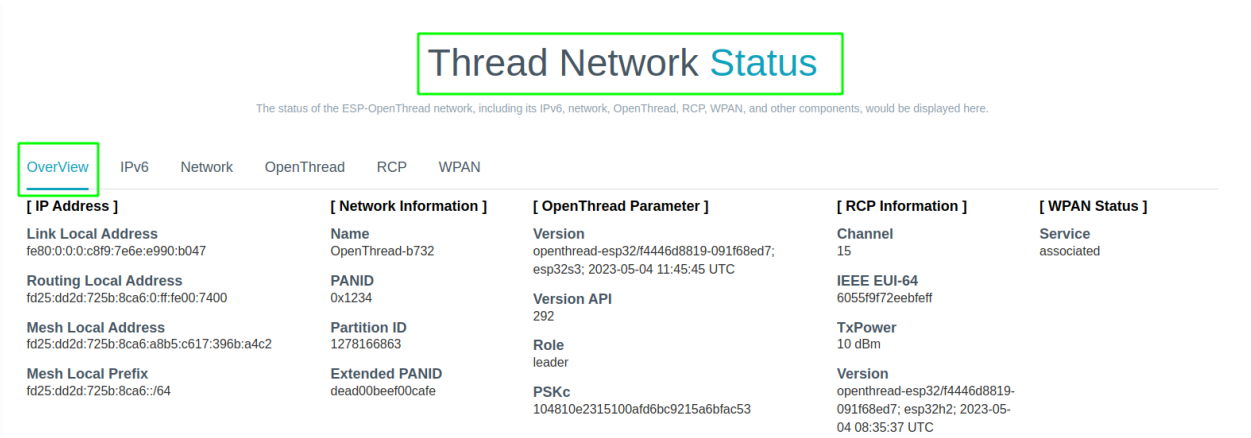
Settings

The IPv6 network prefix for Thread can be set in the Settings section. To add it, click `Add`, and to delete it, click `Delete`.



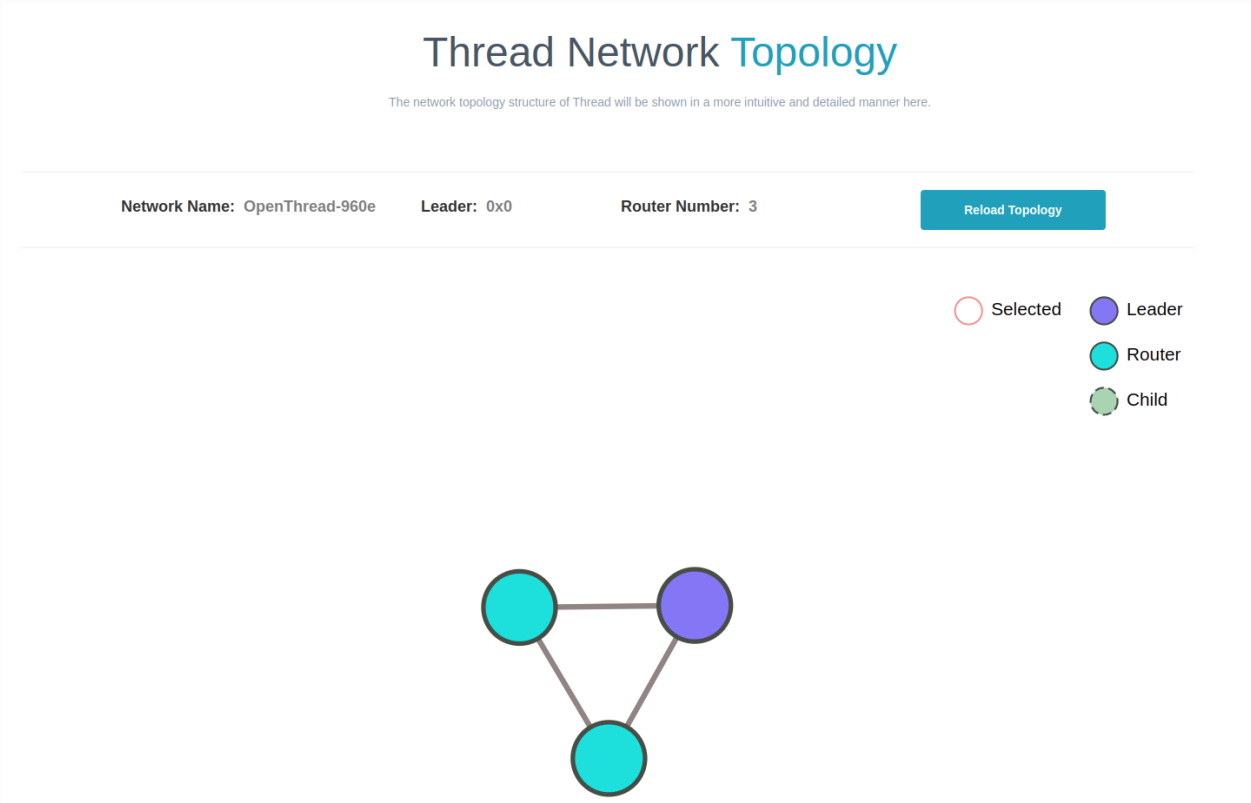
Status

By clicking the `OverView` bar, the properties of Thread network will been displayed in the corresponding section.



Topology

By clicking the `Start Topology` button, the topology of the current Thread node will be intuitively drawn and displayed.



4. API Reference

For manipulating the Thread network, the OpenThread API shall be used. The OpenThread API documentation can be found at the OpenThread official website.

For interacting with the ESP OpenThread port and Border Router library, the esp-openthread API shall be used. The esp-openthread API docs can be found at ESP-IDF API reference page.

The additional APIs are listed below:

4.1. RCP Update

The RCP update component updates the RCP from a local file on the host.

API reference

Header File

- components/esp_rcp_update/include/esp_rcp_update.h

Functions

esp_err_t **esp_rcp_update_init**(*const* esp_rcp_update_config_t *update_config)

This function initializes the RCP update process.

Parameters
update_config – **[in]** The RCP update specific config

Returns

- ESP_OK
- ESP_FAIL
- ESP_ERR_INVALID_ARG If the RCP type is not supported.

esp_err_t **esp_rcp_update**(void)

This function triggers an RCP firmware update.

Returns

- ESP_OK
- ESP_FAIL
- ESP_ERR_INVALID_STASTE If the RCP update is not initialized.
- ESP_ERR_NOT_FOUND RCP firmware not found in storage.

const char ***esp_rcp_get_firmware_dir**(void)*

This function acquires the RCP image base directory.

Note

The real RCP image directory should be suffixed the update sequence.

int8_t **esp_rcp_get_update_seq**(void)

This function retrieves the update image sequence.

The current update image sequence will be used to update the RCP.

int8_t **esp_rcp_get_next_update_seq**(void)

This function retrieves the next update image sequence.

The next update image sequence will be used for the downloaded image.

void **esp_rcp_reset**(void)

This function resets the RCP.

esp_err_t **esp_rcp_submit_new_image**(void)

This function marks the downloaded image as valid.

The image in the next update image sequence will then be used for RCP update.

Returns

- ESP_OK
- ESP_ERR_INVALID_STASTE If the RCP update is not initialized.

esp_err_t **esp_rcp_mark_image_verified**(bool verified)

This function marks previously downloaded image as valid.

Returns

- ESP_OK
- ESP_ERR_INVALID_STASTE If the RCP update is not initialized.

esp_err_t **esp_rcp_mark_image_unusable**(void)

This function marks previously downloaded image as unusable.

Returns

- ESP_OK
- ESP_ERR_INVALID_STASTE If the RCP update is not initialized.

esp_err_t **esp_rcp_load_version_in_storage**(char *version_str, size_t size)

This function loads the RCP version in the current update image.

Parameters

- **version_str** – **[out]** The RCP version string output.
- **size** – **[in]** Size of version_str.

Returns

- ESP_OK
- ESP_ERR_INVALID_STASTE If the RCP update is not initialized.
- ESP_ERR_NOT_FOUND RCP version not found in update image.

void **esp_rcp_update_deinit**(void)

This function deinitializes the RCP update process.

Structures

struct **esp_rcp_update_config_t**

The RCP update config for OpenThread.

Public Members

esp_rcp_type_t **rcp_type**

RCP type

int **uart_rx_pin**

UART rx pin

int **uart_tx_pin**

UART tx pin

int **uart_port**

UART port

int **uart_baudrate**

UART baudrate

int **reset_pin**

RESET pin

int **boot_pin**

Boot mode select pin

uint32_t **update_baudrate**

Baudrate when flashing the firmware

char **firmware_dir**[RCP_FIRMWARE_DIR_SIZE]

The directory storing the RCP firmware

target_chip_t **target_chip**

The target chip type

Macros

RCP_FIRMWARE_DIR_SIZE

RCP_FILENAME_MAX_SIZE

RCP_URL_MAX_SIZE

Enumerations

enum **esp_rcp_type_t**

Values:

enumerator **RCP_TYPE_INVALID**

enumerator **RCP_TYPE_ESP32H2_UART**

4.2. Border Router HTTP OTA

The ESP Thread Border Router HTTP OTA component provides helper functions to download firmware from the web server.

API reference

Header File

- components/esp_br_http_ota/include/esp_br_http_ota.h

Functions

esp_err_t **esp_br_http_ota**(esp_http_client_config_t *http_config)

This function performs Border Router OTA by downloading from a HTTPS server.

Parameters

http_config – **[in]** The HTTP server download config

Returns

- ESP_OK
- ESP_FAIL
- ESP_ERR_INVALID_STASTE If the RCP update is not initialized.
- ESP_ERR_INVALID_ARG If the http config is NULL or does not contain an url.

Macros

OTA_MAX_WRITE_SIZE