

AN13940

将 i.MX RT1060 连接到 USB 4G 模块 (RNDIS 模式)

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应用笔记

文档信息

信息	内容
关键词	i.MX RT, RT, USB, 4G, LTE
摘要	这篇应用笔记介绍了如何通过 USB 4G 模块 (例如 Quectel 的 EC200A-CN) 将 i.MX RT1060 EVK 连接到互联网。



1 介绍

在 i.MX RT1060 评估套件 (EVK, Evaluation Kit) 的软件开发套件 (SDK, Software Development Kit) 中，有一个 SDK 例程 `evkbmimxrt1060_lwip_dhcp_usb_bm`。该例程使用指南中提到的三部手机将 USB 连接到互联网。但是，如果客户想要使用 USB 4G 模块而不是指南中列出的手机来连接互联网，在这种情况下，这个例程可能无法实现。因此，我们必须调整这个例程以适配新的 USB 4G 模块。

这篇应用笔记介绍了当终端变成一个 USB 4G 模块 (如 Quectel 的 EC200A-CN) 时，如何实现适配，继而用这个 USB 4G 模块连接到互联网。

2 基本知识

2.1 RNDIS 介绍

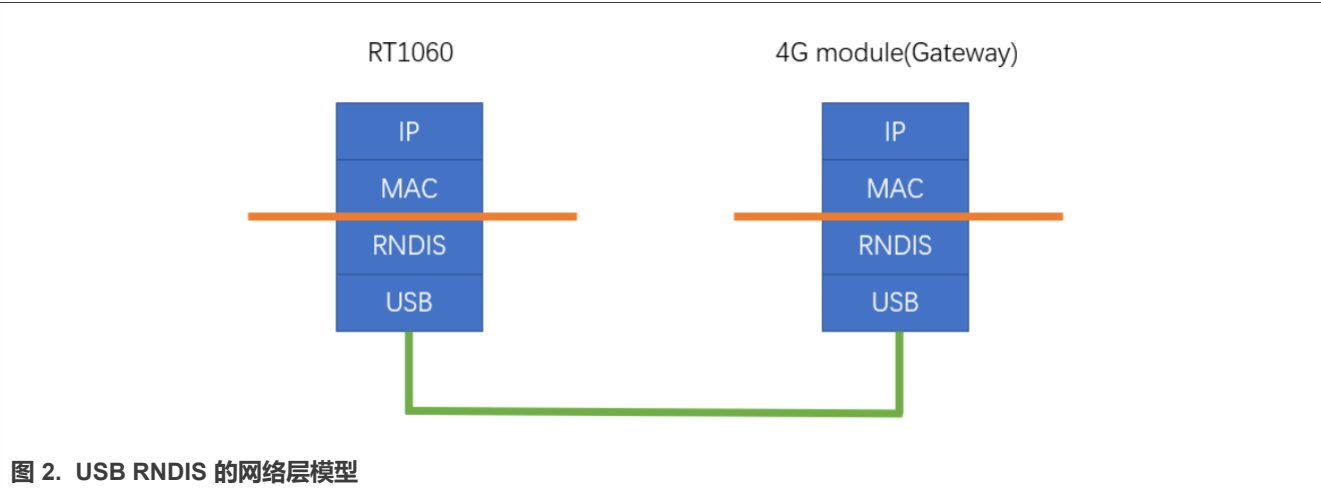
远程网络驱动接口规范 (RNDIS) 是由微软定义的一个 USB 协议。Windows 操作系统能够自动识别遵循该规范的 USB 设备，并将其视为一个网络设备，如 [图 1](#) 所示。

Name	Status	Device Name	Connectivity	Network Category
Bluetooth Network ...	Not connected	Bluetooth Device (Personal Area Net...		
Wi-Fi	wbi.nxp.com	Intel(R) Dual Band Wireless-AC 8265	Internet access	Domain network
Ethernet	Network cable unplugged	Intel(R) Ethernet Connection (4) I219...		
Ethernet 2	Identifying...	Remote NDIS based Internet Sharing...	No Internet access	Public network

图 1. USB 4G 模块连接到 Windows

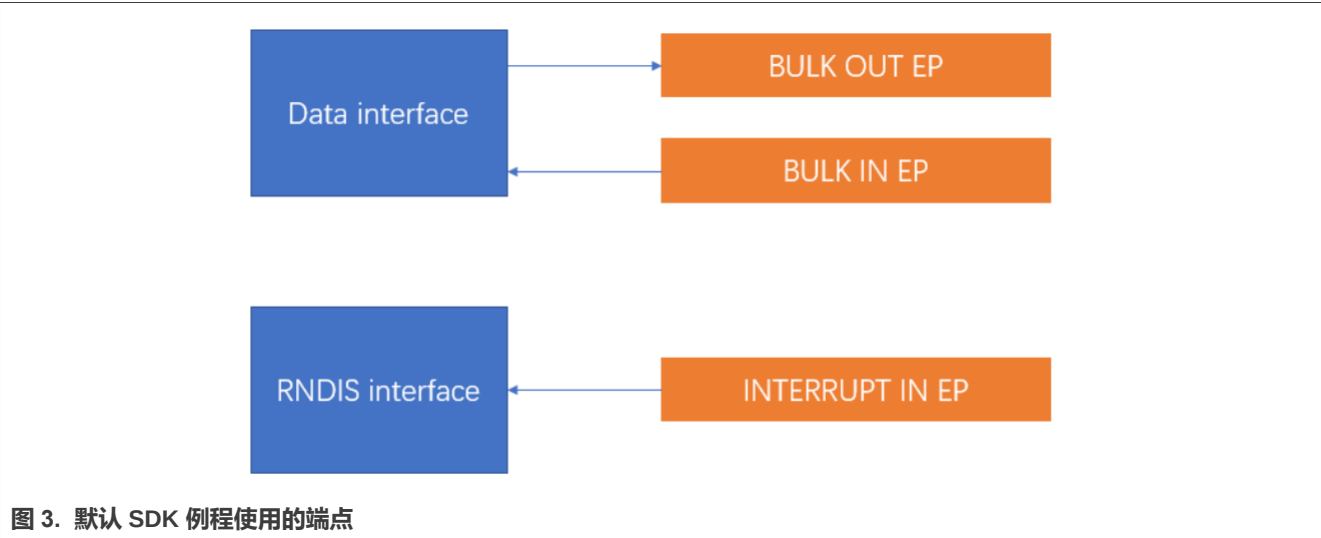
2.2 USB RNDIS 的网络层模型

[图 2](#) 所示为 USB RNDIS 的网络层模型。



2.3 RNDIS 的接口/端点分析

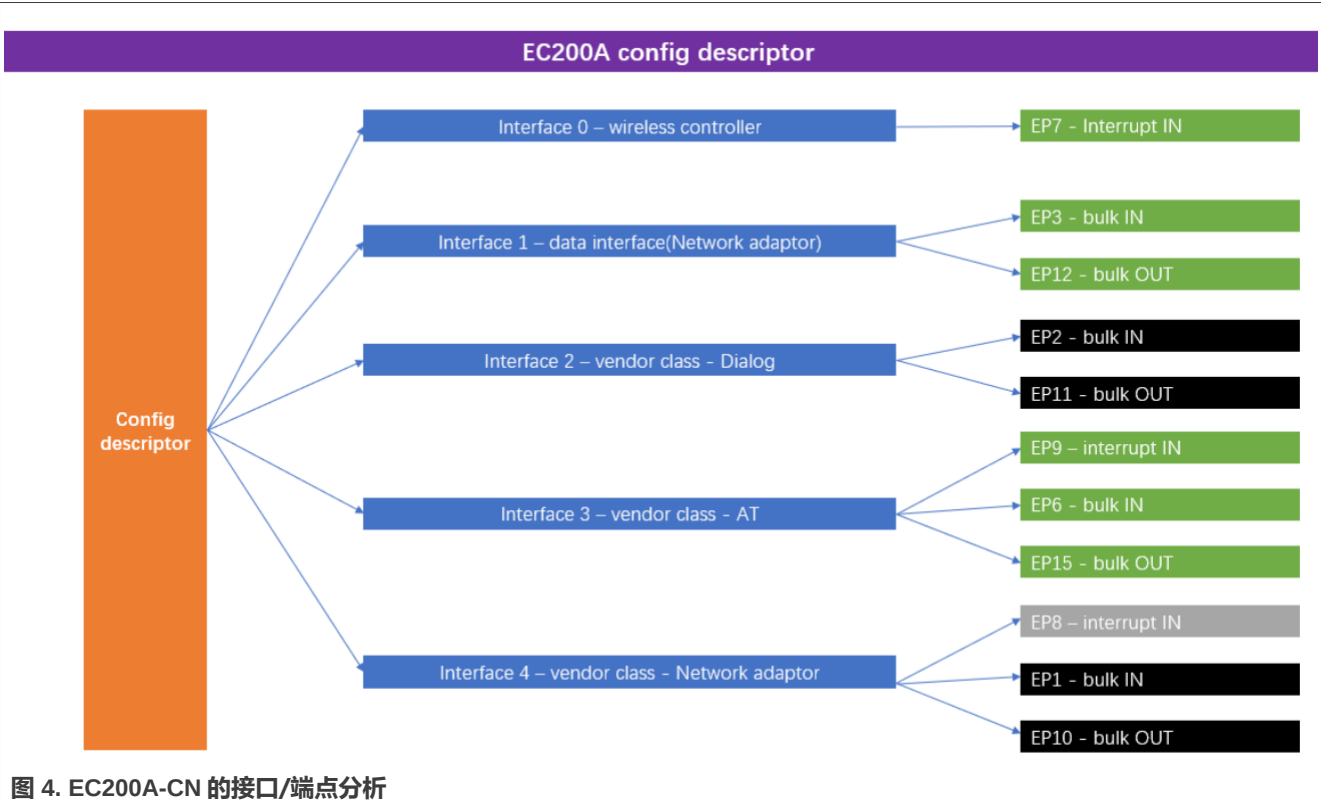
原本的 SDK 例程使用两个接口和三个端点。



此处，数据接口用于以太网包通信，每个方向都有一个端点。RNDIS 接口用于设备状态轮询。

2.4 EC200A-CN 的接口/端点分析

EC200A-CN 实现了五个接口，其中包括上面介绍过的接口。



此处使用的附加接口是 AT 接口。

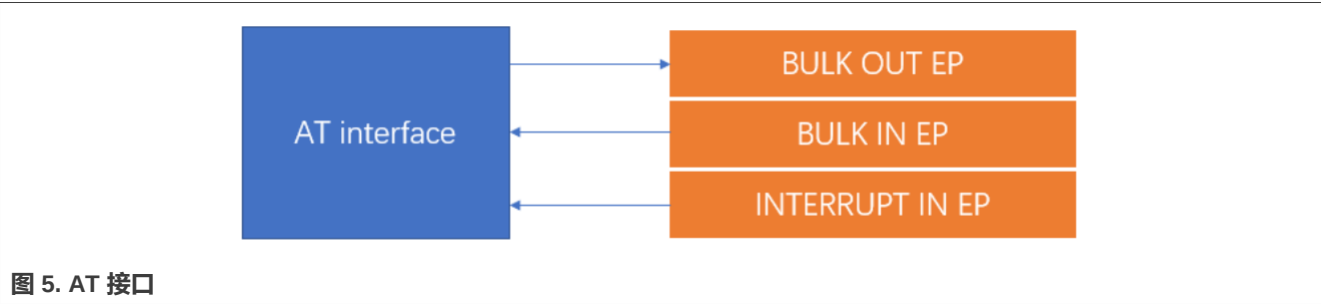


图 5. AT 接口

AT 接口用于拨号（发送 AT 命令并获取响应）、轮询和控制 USB 4G 模块。使用者需要轮询 USB 4G 模块的状态，并向它发送命令，将其设置为在线模式。接着，来自于或发送到 RT1060 EVK 的 IP 包就可以发送到互联网或从互联网接收。

为了启用/适配新的 4G 模块，我们必须：

- 启用 AT 接口
- 在 AT 接口上拨号

EC200A-CN 定义的其他接口此时对我们来说并不重要，所以在本文档中不做介绍。

2.5 通过恩智浦 SDK 实现 USB 主机应用的一些基础知识

- 恩智浦 SDK USB 协议栈会自动解码配置描述符。它可以识别配置描述符中的所有接口和端点。详情参见 `usb/host/usb_host_devices.c` 中的 `USB_HostParseDeviceConfigurationDescriptor()`。[图 6](#) 所示为相关的调用栈。调用栈的分析对我们理解 SDK USB 协议栈的组织方式很有帮助。



图 6. `USB_HostParseDeviceConfigurationDescriptor()` 的调用栈

- 关于事件回调，请参见 `lwip/port/usb_ethernetif_bm.c` 中的 `USB_HostEvent()`。[图 7](#) 所示为相关的调用栈。

```
≡ USB_HostEvent() at usb_ethernetif_bm.c:312 0x60012f78
≡ USB_HostNotifyDevice() at usb_host_devices.c:609 0x60017c4c
≡ USB_HostProcessCallback() at usb_host_devices.c:535 0x60004c4a
≡ USB_HostEnumerationTransferCallback() at usb_host_devices.c:239 0x600047ce
≡ USB_HostEhciTransactionDone() at usb_host_ehci.c:3,926 0x600192b8
≡ USB_HostEhciTaskFunction() at usb_host_ehci.c:5,058 0x60019b2e
≡ USB_HostTaskFn() at lwip_dhcp_usb_bm.c:137 0x6001a692
≡ USB_HostApplicationInit() at usb_ethernetif_bm.c:360 0x60013044
≡ USB_EthernetIfInit() at usb_ethernetif_bm.c:382 0x600130ca
≡ netif_add() at netif.c:388 0x6000c504
```

图 7. USB_HostEvent() 的调用栈

- 打开每个接口的管道。
详情参见 `usb_host_cdc.c` 中的 `USB_HostCdcOpenDataInterface()` 和 `USB_HostCdcOpenControlInterface()`。

图 8 所示为相关的调用栈。

```
≡ USB_HostOpenPipe() at usb_host_hci.c:356 0x60019e4a
≡ USB_HostCdcOpenDataInterface() at usb_host_cdc.c:339 0x60002836
≡ USB_HostCdcSetDataInterface() at usb_host_cdc.c:838 0x60002dbe
≡ USB_HosCdcRndisTask() at usb_ethernetif_bm.c:844 0x60013940
≡ USB_HostApplicationInit() at usb_ethernetif_bm.c:361 0x6001304a
≡ USB_EthernetIfInit() at usb_ethernetif_bm.c:382 0x600130ca
≡ netif_add() at netif.c:388 0x6000c504
≡ main() at lwip_dhcp_usb_bm.c:279 0x60006da4
```

图 8. USB_HostCdcOpenDataInterface() 的调用栈

- 状态机维护
关于状态机维护，请参见 `lwip/port/usb_ethernetif_bm.c` 中的 `USB_HosCdcRndisTask()` 和 `USB_HostCdcRndisControlCallback()`。

图 9 所示为默认状态机。调整它以启用 AT 接口并在 AT 接口上拨号。

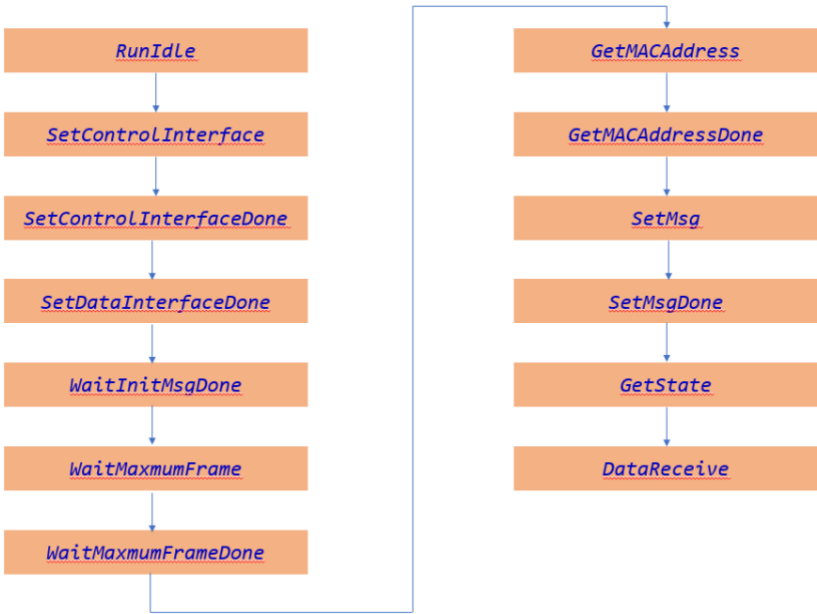


图 9. 状态机维护

3 实现细节

基于上述介绍，本节将讨论实现细节。此处给出一些代码，更多详情，请参见 AN13940SW。

主要的代码变化在于：

- `usb_ethernet_bm.c`
- `usb_ethernet.h`

一些关键的代码变化包括：

- 为 AT 接口添加数据结构。

此部分在 `sdk_root\lwip\port\usb_ethernetif.h` 中。

```
typedef struct _usb_host_rndis_instance_struct
{
    usb_device_handle deviceHandle;
    usb_host_class_handle classHandle;
    usb_host_interface_handle controlInterfaceHandle;
    usb_host_interface_handle dataInterfaceHandle;
    usb_host_class_handle classHandle_at;
    usb_host_interface_handle dataInterfaceHandle_at;
}
```

图 10. 为 AT 接口添加数据结构

- 在附加事件中添加类初始化代码。

此部分在 `lwip\port\usb_ethernetif_bm.c` 中。

```
case kStatus_DEV_Attached:
    rndisInstance->runState = kUSB_HostCdcRndisRunSetControlInterface;
    status = USB_HostCdcInit(rndisInstance->deviceHandle, &rndisInstance->classHandle);
    if(status == kStatus_USB_Success)
    {
        usb_echo("init cdc classHandle done. \r\n");
    }
    status = USB_HostCdcInit(rndisInstance->deviceHandle, &rndisInstance->classHandle_at);
    if(status == kStatus_USB_Success)
    {
        usb_echo("init cdc classHandle_at done. \r\n");
    }
```

图 11. 添加类初始化代码

- 在拔出事件中添加去初始化代码。

此部分在 `lwip\port\usb_ethernetif_bm.c` 中。

```
case kStatus_DEV_Detached:
    rndisInstance->deviceState = kStatus_DEV_Idle;
    rndisInstance->runState = kUSB_HostCdcRndisRunIdle;
    USB_HostCdcDeinit(rndisInstance->deviceHandle, rndisInstance->classHandle);
    USB_HostCdcDeinit(rndisInstance->deviceHandle, rndisInstance->classHandle_at);
    rndisInstance->classHandle = NULL;
    rndisInstance->controlInterfaceHandle = NULL;
    rndisInstance->dataInterfaceHandle = NULL;
    rndisInstance->classHandle_at = NULL;
    rndisInstance->dataInterfaceHandle_at = NULL;
    rndisInstance->deviceHandle = NULL;
    rndisInstance->interruptRunState = kUSB_HostCdcRndisRunIdle;
    usb_echo("rndis device detached\r\n");
    break;
```

图 12. 在拔出事件中添加去初始化代码

- 更新状态机枚举 (enum) 变量。
此部分在 `lwip\port\usb_ethernetif.h` 中。

```
typedef enum HostCdcRndisRunState
{
    kUSB_HostCdcRndisRunIdle = 0,

    kUSB_HostCdcRndisRunSetControlInterface,
    kUSB_HostCdcRndisRunWaitSetControlInterface,
    kUSB_HostCdcRndisRunSetControlInterfaceDone,

    kUSB_HostCdcRndisRunSetDataInterface,
    kUSB_HostCdcRndisRunWaitSetDataInterface,
    kUSB_HostCdcRndisRunSetDataInterfaceDone,

    kUSB_HostCdcRndisRunSetATDataInterface,
    kUSB_HostCdcRndisRunWaitSetATDataInterface,
    kUSB_HostCdcRndisRunSetATDataInterfaceDone,

    kUSB_HostCdcRndisRunWaitInitMsg,
    kUSB_HostCdcRndisRunWaitInitMsgDone,
    kUSB_HostCdcRndisRunWaitGetMACAddress,
    kUSB_HostCdcRndisRunWaitGetMACAddressDone,
    kUSB_HostCdcRndisRunWaitMaxumFrame,
    kUSB_HostCdcRndisRunWaitMaxumFrameDone,
    kUSB_HostCdcRndisRunWaitSetMsg,
    kUSB_HostCdcRndisRunWaitSetMsgDone,

    // kUSB_HostCdcRndisRunEC200AInit,
    kUSB_HostCdcRndisRunWaitEC200AInit,
    kUSB_HostCdcRndisRunEC200AInitDone,

    // kUSB_HostCdcRndisRunDial,
    kUSB_HostCdcRndisRunWaitDial,
    kUSB_HostCdcRndisRunDialDone,
```

图 13. 更新状态机

- 更新状态机实现函数。
此部分在 `lwip\port\usb_ethernetif_bm.c` 中。

```
case kUSB_HostCdcRndisRunSetDataInterfaceDone:
    rndisInstance->runWaitState = kUSB_HostCdcRndisRunWaitSetATDataInterface;
    rndisInstance->runState = kUSB_HostCdcRndisRunIdle;
    if (USB_HostCdcSetDataInterface(rndisInstance->classHandle_at,
                                    rndisInstance->dataInterfaceHandle_at,
                                    0,
                                    USB_HostCdcRndisControlCallback,
                                    rndisInstance) != kStatus_USB_Success)
    {
        usb_echo("set at interface error\r\n");
    }
    break;
```

图 14. 更新状态机实现函数

- 添加相关的 API 和回调。函数参数此处不作显示。更多细节，请参见 AN13940SW。

```
USB_HostCdcRndisATInCallback();
USB_HostCdcRndisATOutCallback();
dial_tx(); // Send command on AT interface
dial_rx(); // Receive message from AT interface
lte_dial(); // Dial, then USB 4G module can connect to internet
USB_HostCdcRndisEC200ACallback();
ep0_communicate(); // API used for AT interface enablement, to send/receive
                    command/message to/from EP0
init_ec200a(); // Initiate EC200A, then AT interface communication is available
```

- 支持的最大接口数。
连接不同的 USB 4G 模块时，最大接口数是不同的。需要更新接口数。
例如，如果使用 LE910C1-EU，应将接口数更新为 8。

```
#define USB_HOST_CONFIG_CONFIGURATION_MAX_INTERFACE (8U)
```

图 15. 支持的最大接口数。

而对于本文档中使用的 EC200A-CN，默认值 5 就可以直接工作。

- 实现面向 AT 接口使能和拨号功能的新状态机。
主要的代码变化在 `lwip\port\usb_etherntif_bm.c` 中的 `USB_HostCdcRndisControlCallback()` 和 `USB_HosCdcRndisTask()` 函数中。更多细节，请参见 AN13940SW。
- 适配 AT 接口。
AT 数据接口索引是在把 USB 4G 模块连接到 PC 时，从 USB 分析器中解码出来的。代码来自 `lwip\port\usb_etherntif_bm.c` 中的 `USB_HostCdcRndisEvent()` 函数，它把 `interfaceList[3]` 赋值给 `g_RndisInstance`, `dataInterfaceHandle_at`，并实现绑定。

```
// at interface.  
hostInterface = &configuration->interfaceList[3];  
g_RndisInstance.dataInterfaceHandle_at = hostInterface;  
  
g_RndisInstance.deviceHandle = deviceHandle;  
if ((NULL != g_RndisInstance.dataInterfaceHandle) &&  
    (NULL != g_RndisInstance.controlInterfaceHandle) &&  
    (NULL != g_RndisInstance.dataInterfaceHandle_at)  
)  
{  
    status = kStatus_USB_Success;  
}  
else  
{  
    usb_echo("- 0001 \r\n");  
    status = kStatus_USB_NotSupported;  
}  
break;
```

图 16. 绑定 AT 接口

在所有代码更改完成后，运行该代码，可以看到 i.MX RT1060 EVK 通过 USB 4G 模块 EC200A-CN 成功地连接到了互联网。

```
+QIND: PB DONE

ec200a_rx_index = 3
PB DONE detected.
dial_state = 100.
AT+qnetdevctl=1,1,1
>>>TX: AT+qnetdevctl=1,1,1

dial_state = 101.
>>>RX: AT+qnetdevctl=1,1,1
ec200a_rx_index = 4
dial_state = 102.
>>>RX:
OK
tdevctl=1,1,1
ec200a_rx_index = 5
dial_state = 103.
>>>RX:
+QNETDEVSTATUS: 1

ec200a_rx_index = 6
end do not need to rx again.
dial done.

*****
DHCP example
*****
DHCP state      : SELECTING
DHCP state      : REQUESTING
DHCP state      : BOUND

IPv4 Address    : 192.168.43.100
IPv4 Subnet mask : 255.255.255.0
IPv4 Gateway    : 192.168.43.1

    waiting for getting the IP Address....

    the IP Address of nxp.com is    : 223.119.214.147
ping: send
223.119.214.147

ping: recv
223.119.214.147
60 ms
```

图 17. 通过 USB 4G 模块 EC200A-CN 连接到互联网

4 注意

确保 USB 4G 模块的电源供电充足。在本例中，i.MX RT1060 EVK 使用外部电源适配器供电，而不是 USB 线。否则，当 USB 4G 模块试图启用射频 (RF) 连接到互联网时，该模块将会复位。

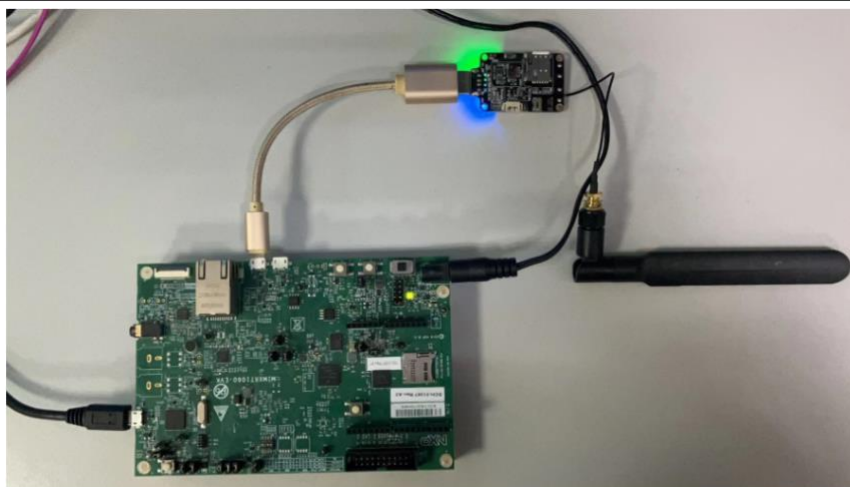


图 18. 用外部电源适配器给 i.MX RT1060 EVK 供电

5 结论

本应用笔记介绍了通过 USB 4G 模块 EC200A-CN 将 i.MX RT1060 EVK 连接到互联网的基本知识和细节。当用户想要用相同的或其他 USB 4G 模块连接到互联网时，可以参考此笔记并从中获得帮助。

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