AN13940

将 i.MX RT1060 连接到 USB 4G 模块（RNDIS 模式）

第 0 版 — 2023 年 4 月 18 日 **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。

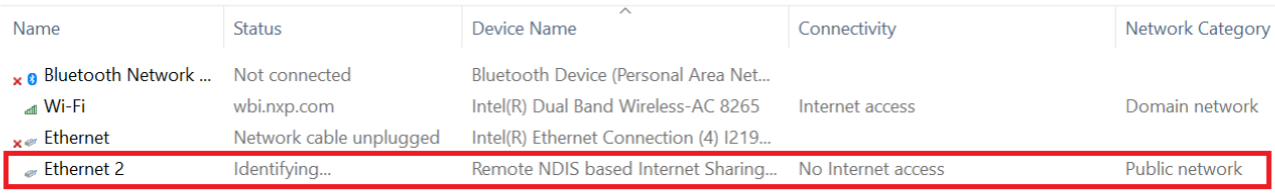

图 1. USB 4G 模块连接到 Windows

2.2 USB RNDIS 的网络层模型

图 2 所示为 USB RNDIS 的网络层模型。

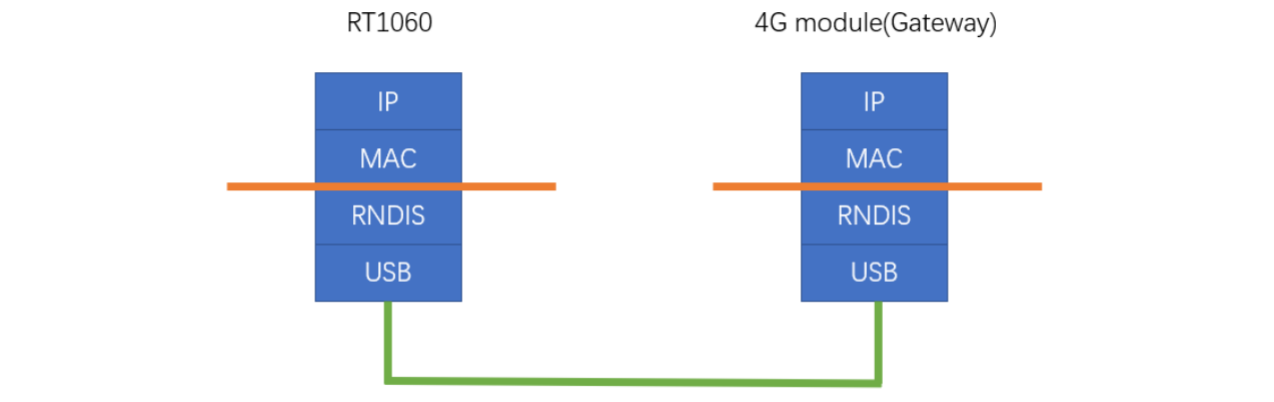

图 2. USB RNDIS 的网络层模型

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。

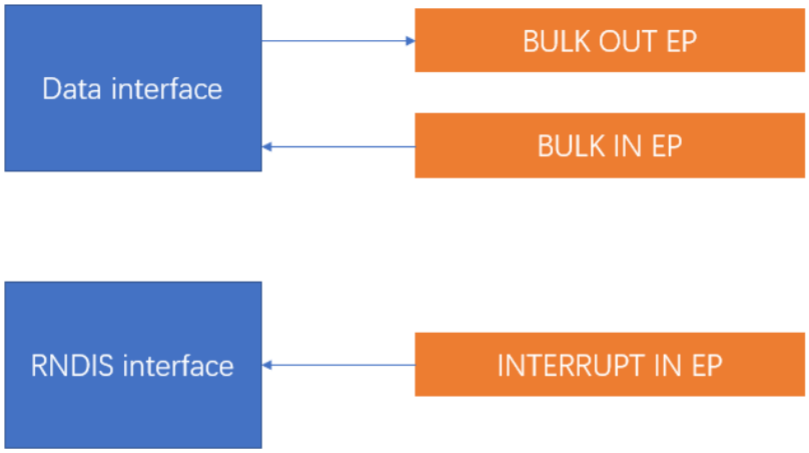

图 3. 默认 SDK 例程使用的端点

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。

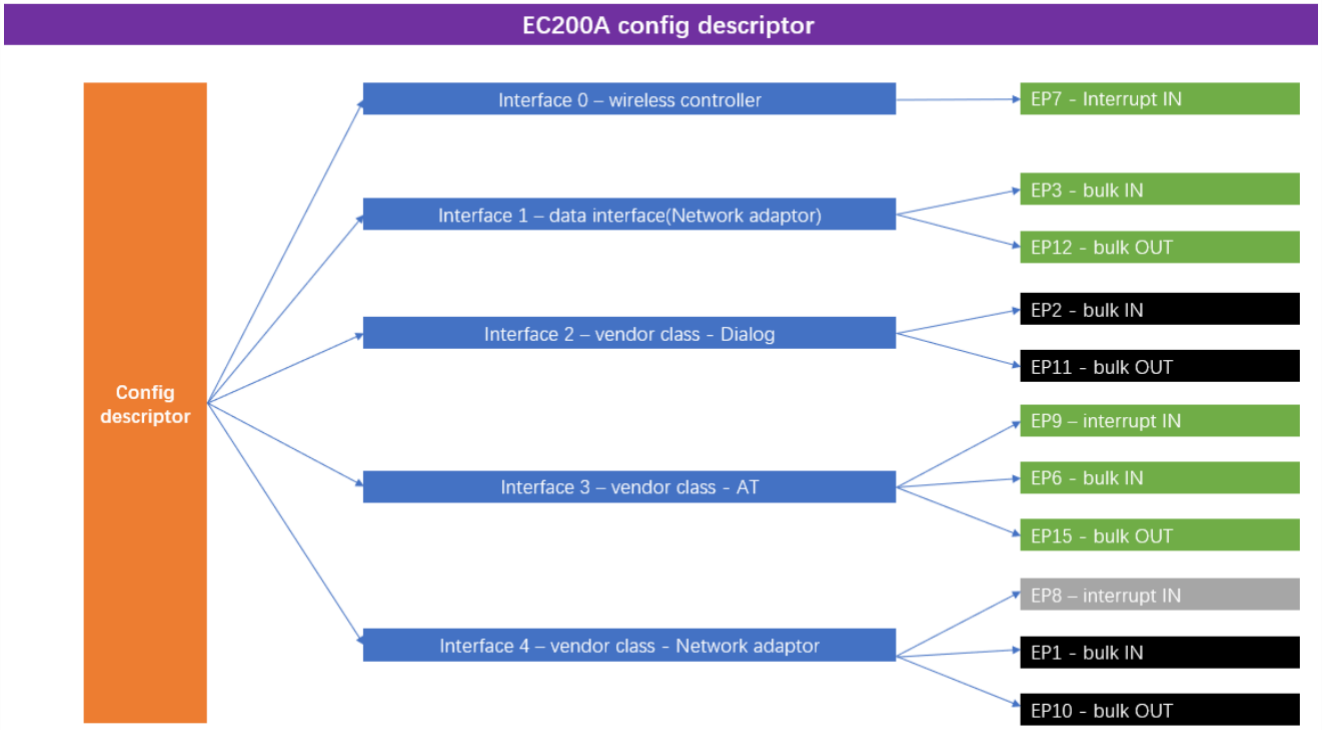

图 4. EC200A-CN 的接口/端点分析

此处使用的附加接口是 AT 接口。

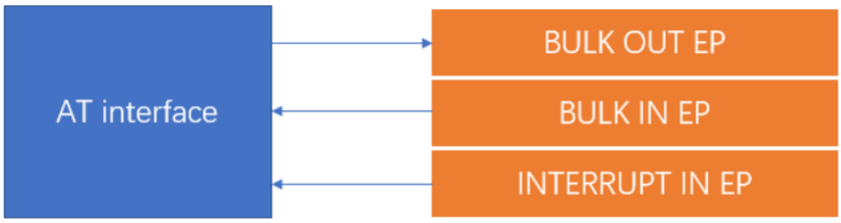

图 5. AT 接口

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。

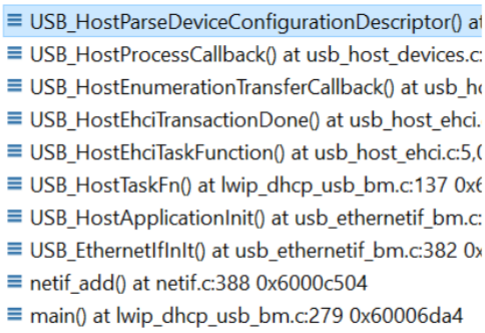

图 6. `USB_HostParseDeviceConfigurationDescriptor()` 的调用栈

- 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。

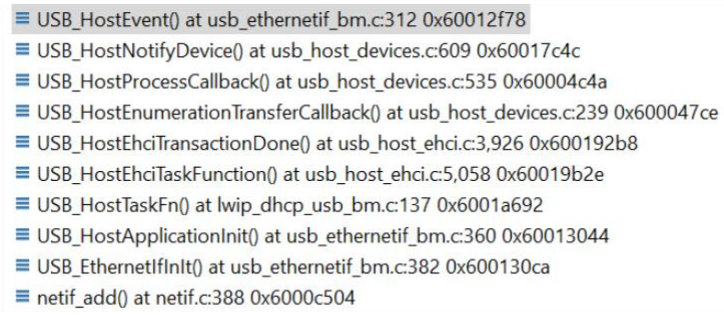

图 7. `USB_HostEvent()`的调用栈

- 打开每个接口的管道。
  详情参见 *usb_host_cdc.c* 中的 `USB_HostCdcOpenDataInterfac()`和 `USB_HostCdcOpenControlInterface()`。
  图 8 所示为相关的调用栈。

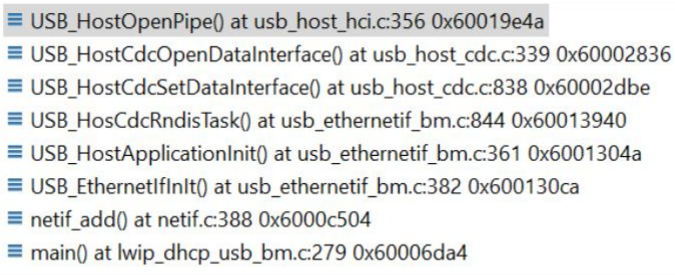

图 8. `USB_HostCdcOpenDataInterfac()`的调用栈

- 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。

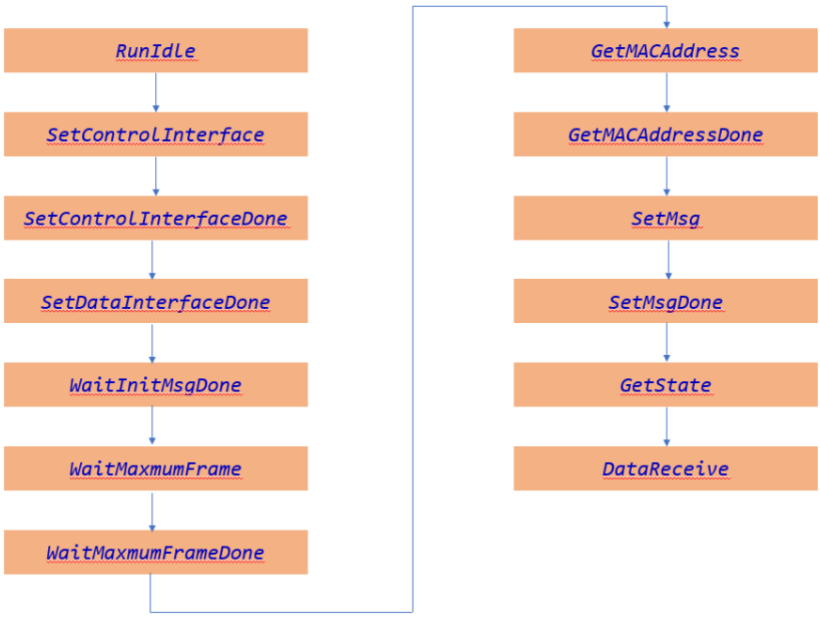

图 9. 状态机维护

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_HostCdcRndisRunWaitMaxmumFrame,
    kUSB_HostCdcRndisRunWaitMaxmumFrameDone,
    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_ethernetif_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_ethernetif_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。

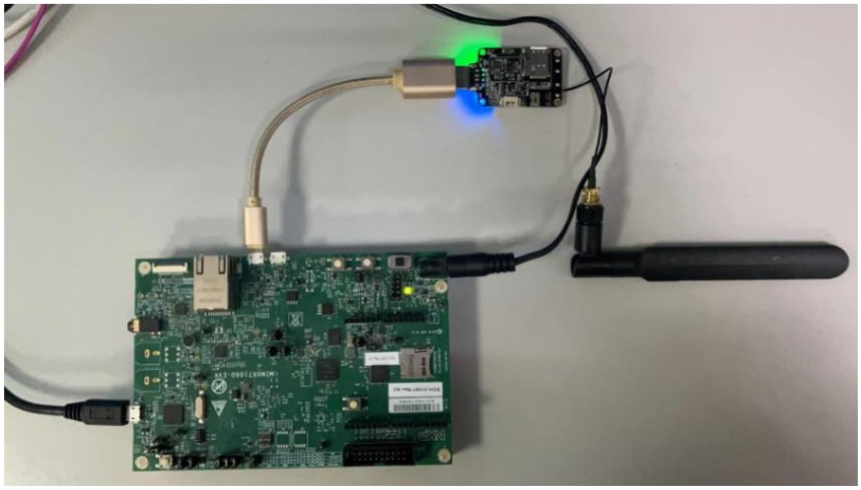

图 18. 用外部电源适配器给 i.MX RT1060 EVK 供电

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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