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4. LoRa和LoRaWAN介绍
5. STM32WL LoRa 例程介绍
6. STM32WL 使用STM32 CubeMX 创建LoRa 节点应用
7. STM32WL LoRa RF 测试
8. STM32WL 安全特性介绍
9. STM32WL FUOTA 应用设计

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STM32WL 软件简介

David Liu

课程目录

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4 LoRaWAN 协议层介绍

5 LoRa SubGHz层介绍

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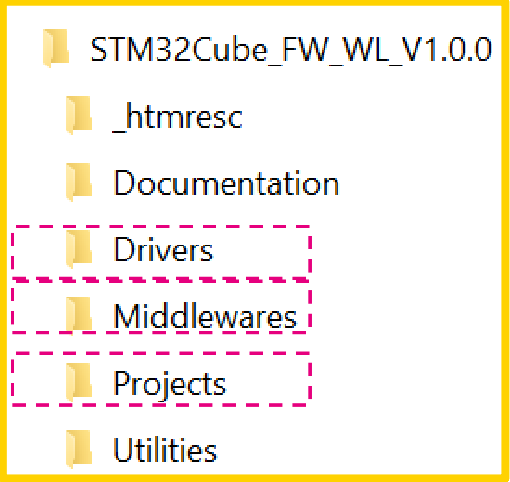
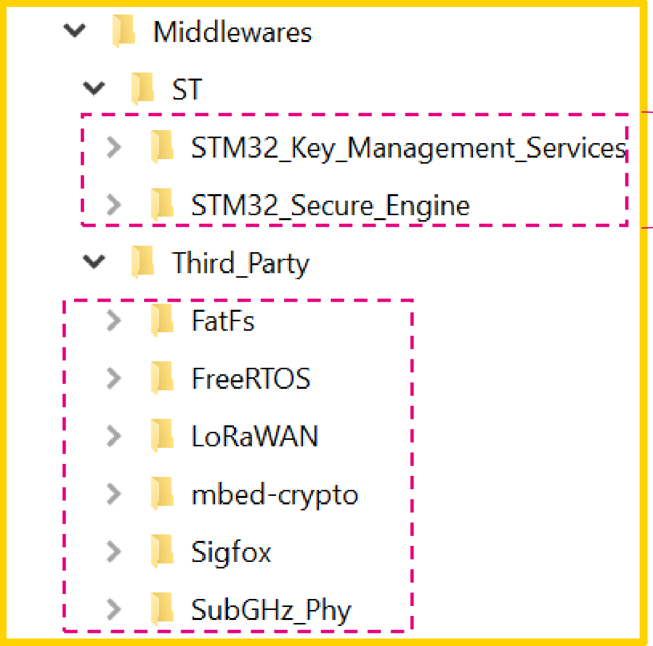
STM32WL 软件包

STM32Cube_FW_WL_V1.0.0



```
STM32Cube_FW_WL_V1.0.0
    _htmresc
    Documentation
    Drivers
    Middlewares
    Projects
    Utilities
```

Middleware

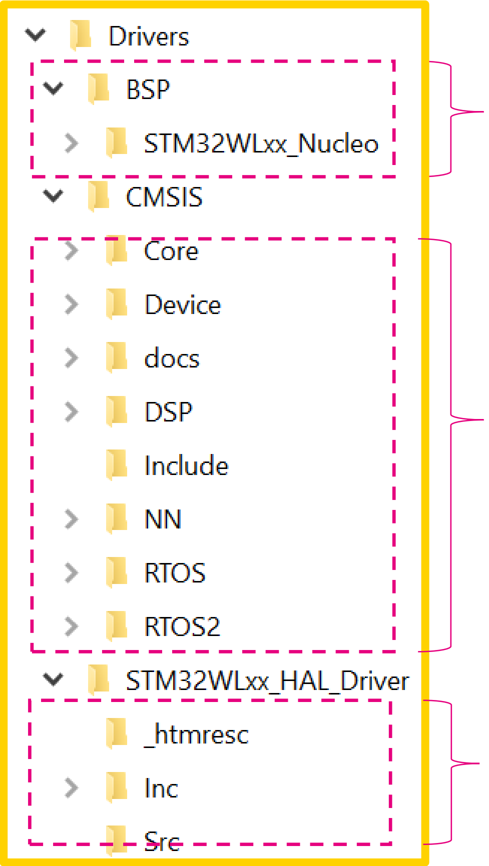


```
v Middlewares
    v ST
        > STM32_Key_Management_Services
        > STM32_Secure_Engine
    v Third_Party
        > FatFs
        > FreeRTOS
        > LoRaWAN
        > mbed-crypto
        > Sigfox
        > SubGHz_Phy
```

Middleware
- KMS
- SE

Third party
- FreeRTOS
- FatFs
- LoRaWAN
- Mbed-crypto
- Sigfox
- SubGHz_Phy

Driver



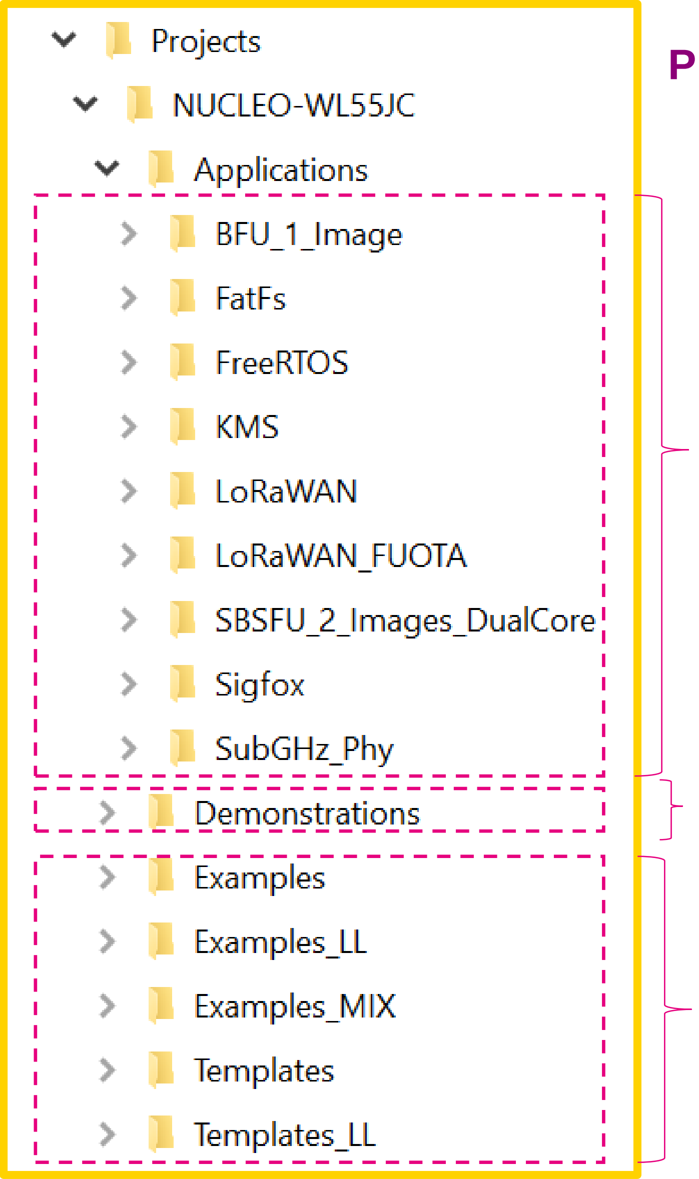
```
v Drivers
    v BSP
        > STM32WLxx_Nucleo
    v CMSIS
        > Core
        > Device
        > docs
        > DSP
          Include
        > NN
        > RTOS
        > RTOS2
    v STM32WLxx_HAL_Driver
          _htmresc
        > Inc
          Src
```

BSP

CMSIS

HAL Driver

Projects



```
v Projects
    v NUCLEO-WL55JC
        v Applications
            > BFU_1_Image
            > FatFs
            > FreeRTOS
            > KMS
            > LoRaWAN
            > LoRaWAN_FUOTA
            > SBSFU_2_Images_DualCore
            > Sigfox
            > SubGHz_Phy
        > Demonstrations
        > Examples
        > Examples_LL
        > Examples_MIX
        > Templates
        > Templates_LL
```

STM32WL Application
- LoRa
- Sigfox
- SubGHz
- SBSFU
- KMS
- FUOTA
- FreeRTOS

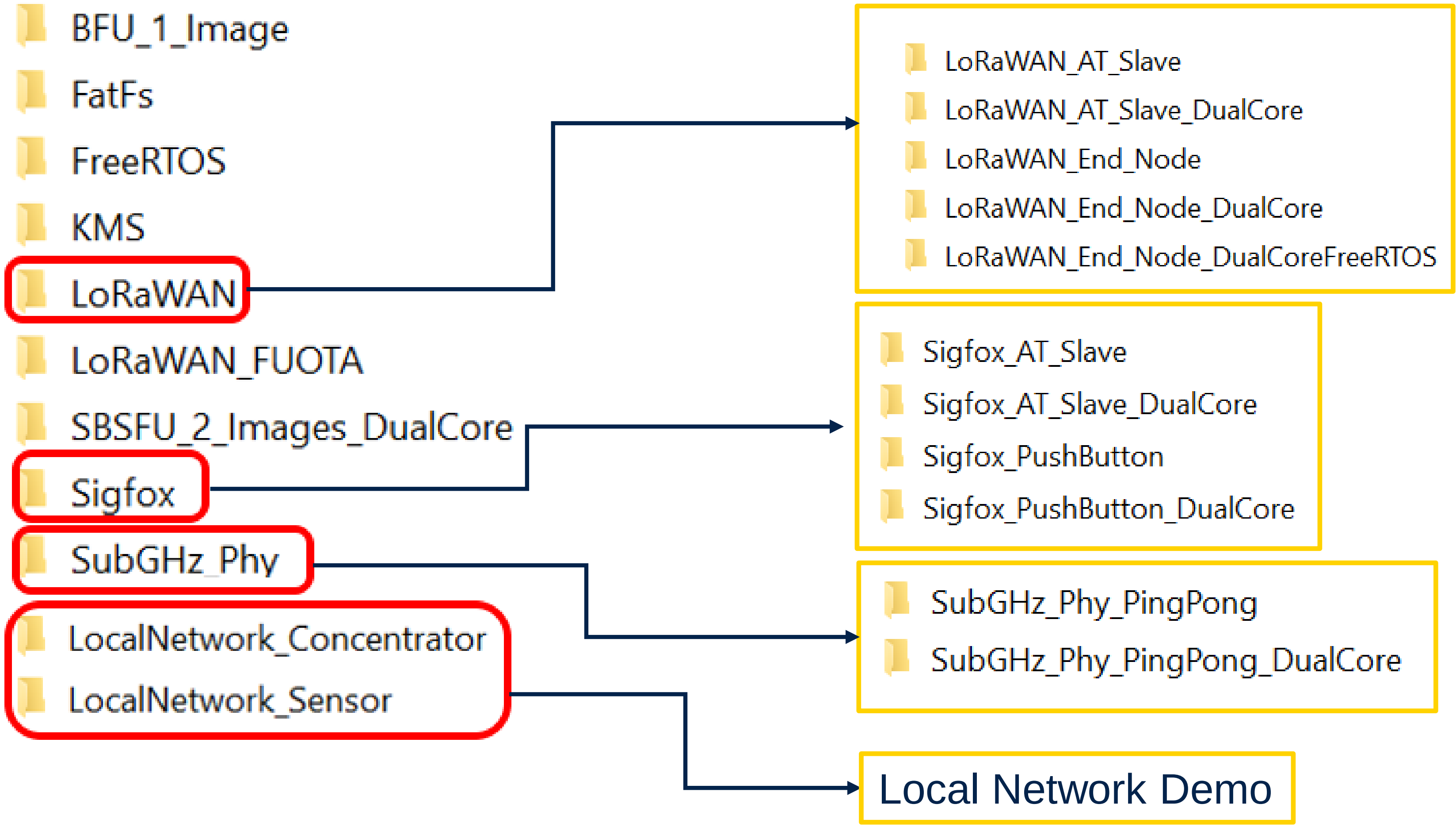
Local Network Demo

Peripheral Examples

下载链接：Here

STM32WL 无线Demo

- STM32Cube_FW_WL_V1.0.0



- BFU_1_Image
- FatFs
- FreeRTOS
- KMS
- LoRaWAN
- LoRaWAN_FUOTA
- SBSFU_2_Images_DualCore
- Sigfox
- SubGHz_Phy
- LocalNetwork_Concentrator
- LocalNetwork_Sensor

LoRaWAN:

- LoRaWAN_AT_Slave
- LoRaWAN_AT_Slave_DualCore
- LoRaWAN_End_Node
- LoRaWAN_End_Node_DualCore
- LoRaWAN_End_Node_DualCoreFreeRTOS

Sigfox:

- Sigfox_AT_Slave
- Sigfox_AT_Slave_DualCore
- Sigfox_PushButton
- Sigfox_PushButton_DualCore

SubGHz_Phy:

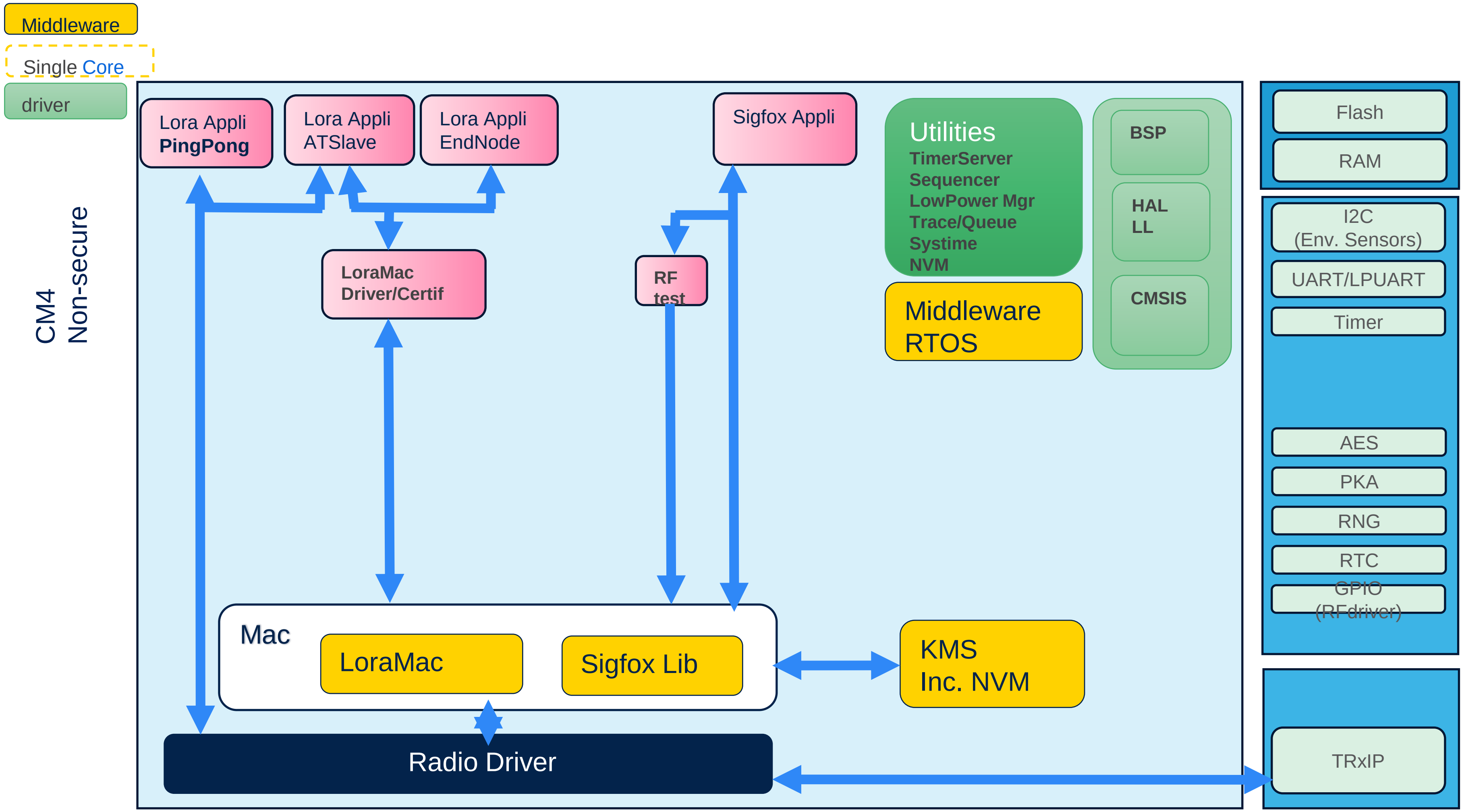
- SubGHz_Phy_PingPong
- SubGHz_Phy_PingPong_DualCore

LocalNetwork_Concentrator, LocalNetwork_Sensor:

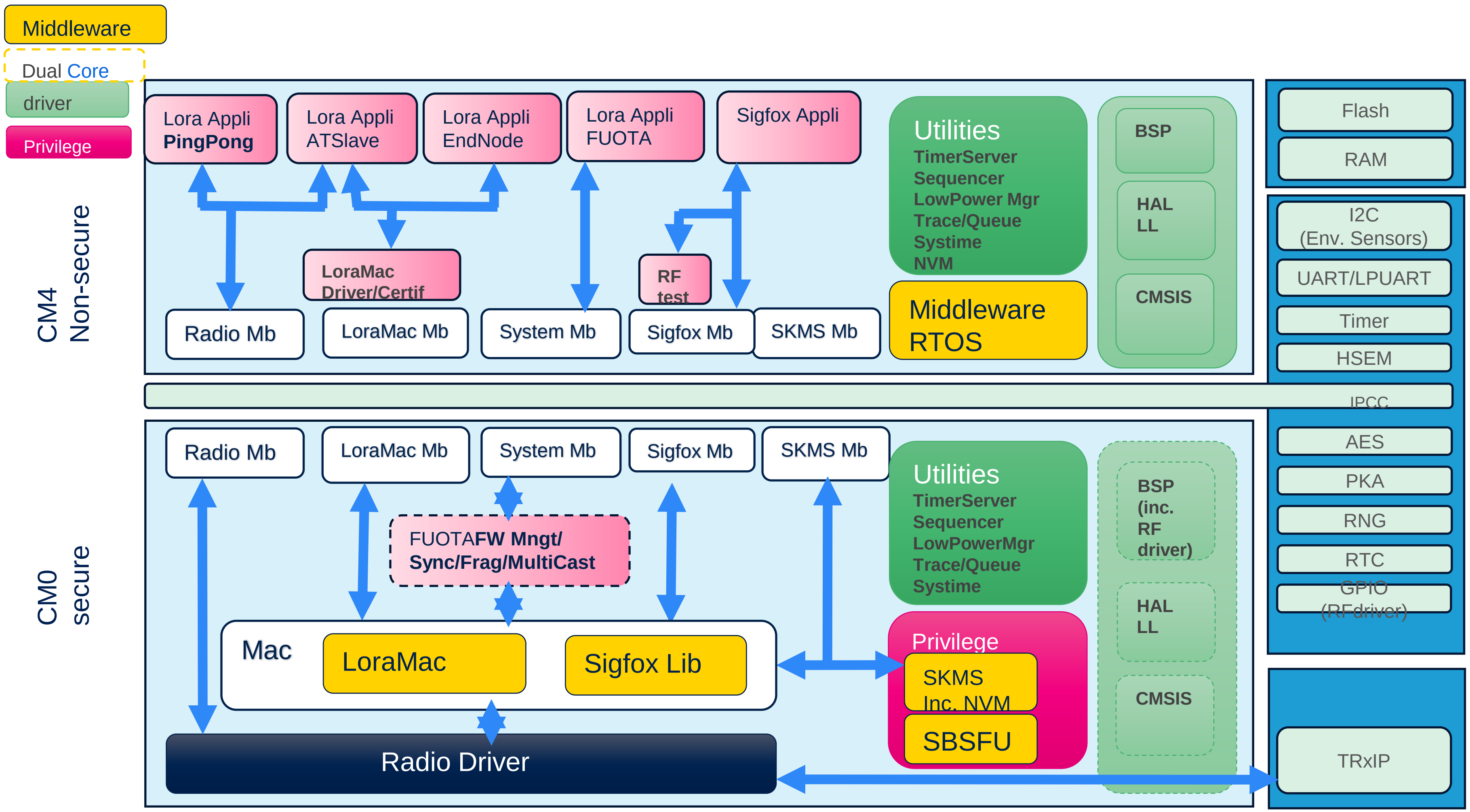
Local Network Demo

STM32WL 软件架构

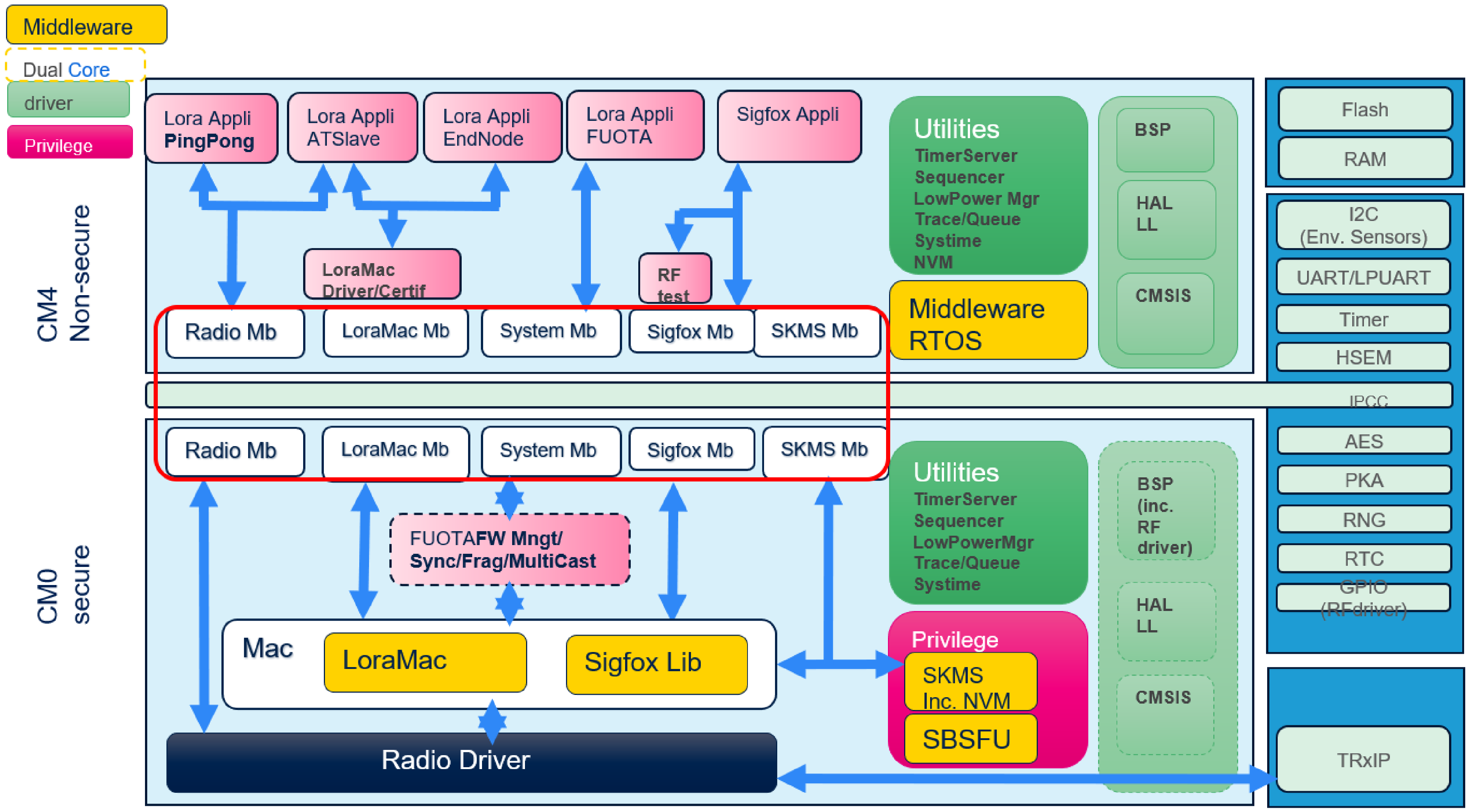
STM32WL 软件架构(单核)



STM32WL 软件架构(双核)

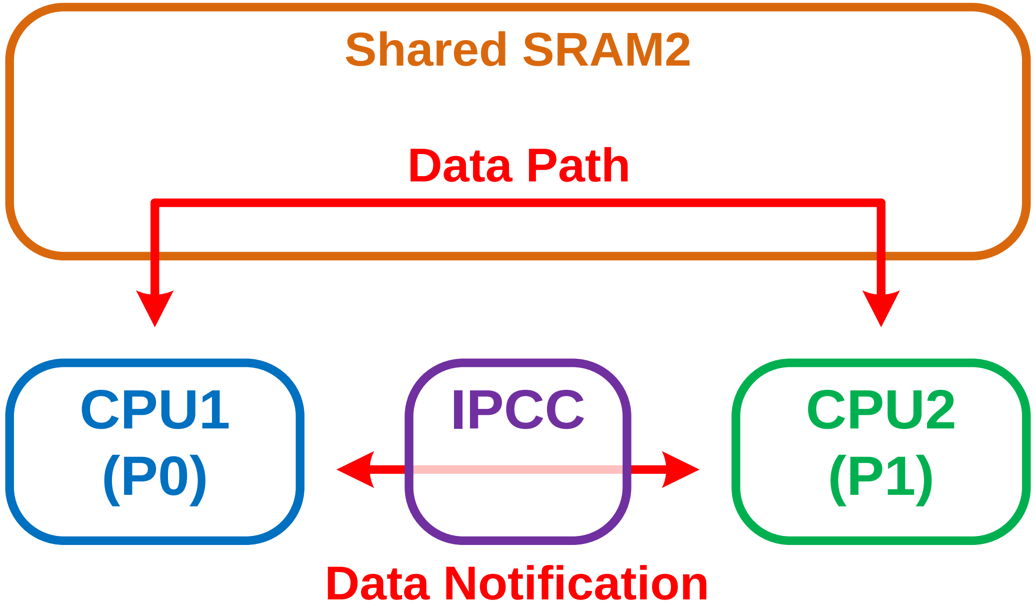


STM32WL Mailbox概览



什么是Mailbox

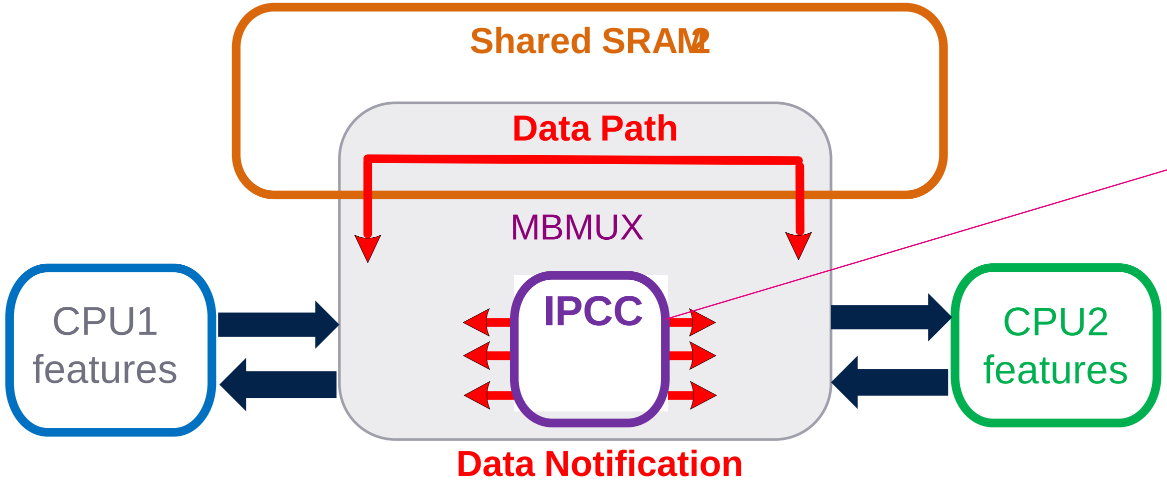
- **Mailbox**是一项SW服务，实现了一种在两个处理器之间交换数据的方式。 它建立在两种资源之上：
  - **IPCC**：这是一个HW IP，其唯一目的是触发到远程CPU的中断并从远程CPU接收中断
  - **SRAM2**：RAM2_SH1两个CPU都可以读取/写入共享存储器。 它用于存储所有缓冲区，这些缓冲区将包含两个CPU之间要交换的数据。

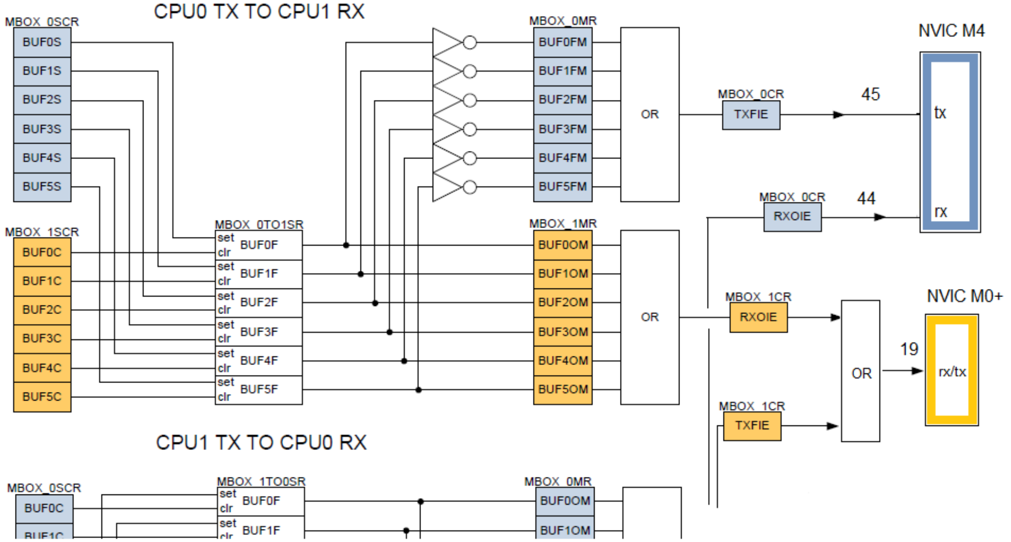


什么是MBMUX?

- MBMUX是Mailbox软件服务的一层，它将IPCC通道irq与共享内存缓冲区结合在一起，以允许两个CPU之间进行消息交换

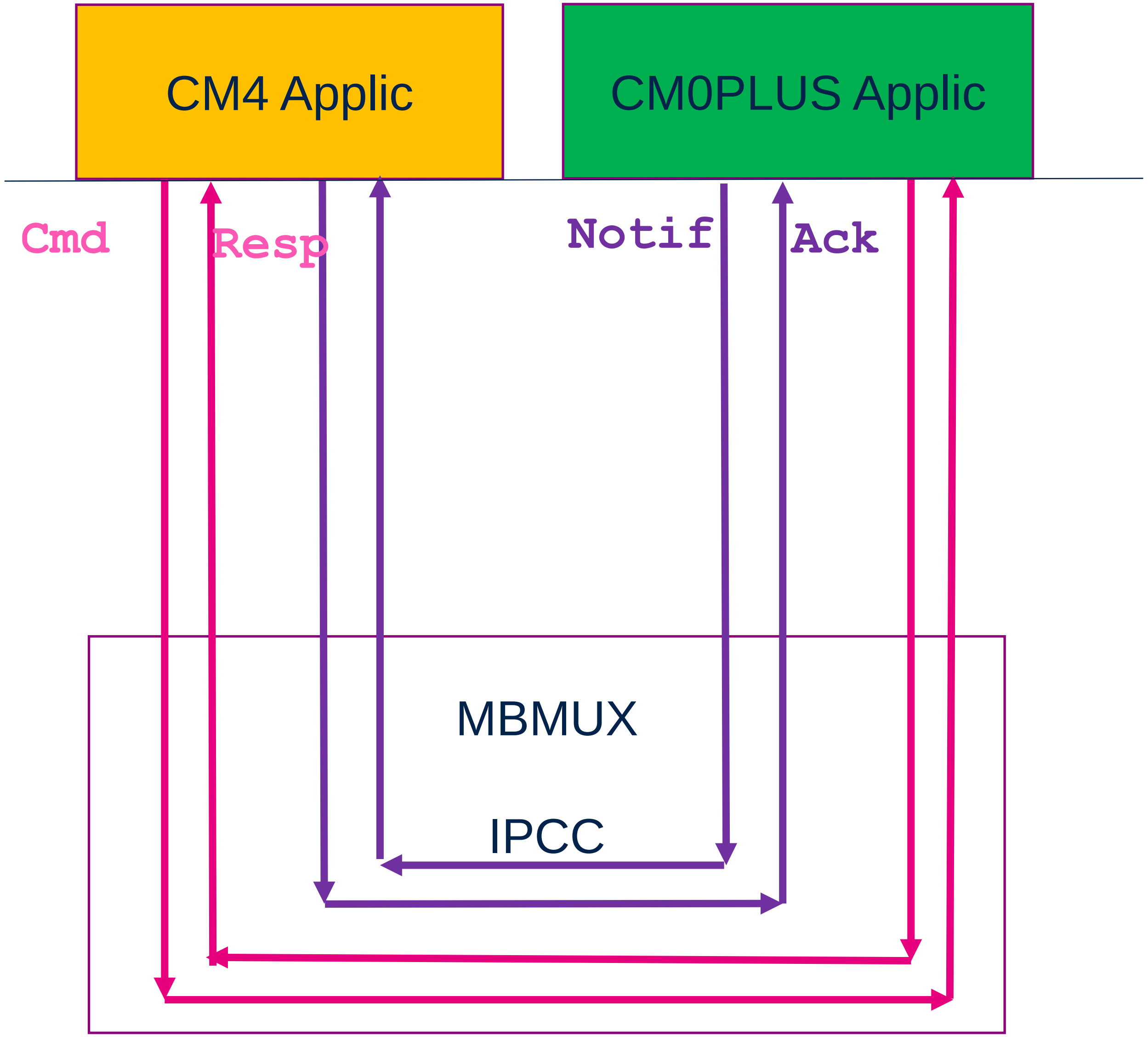
- MBMUX还是一个多路复用器，允许在2x6 IPCC通道上映射功能（Lora，Sigfox，Radio，Mwbus， Kms（SKS），Trace等）





STM32WL Mailbox和MBMUX 工作模式

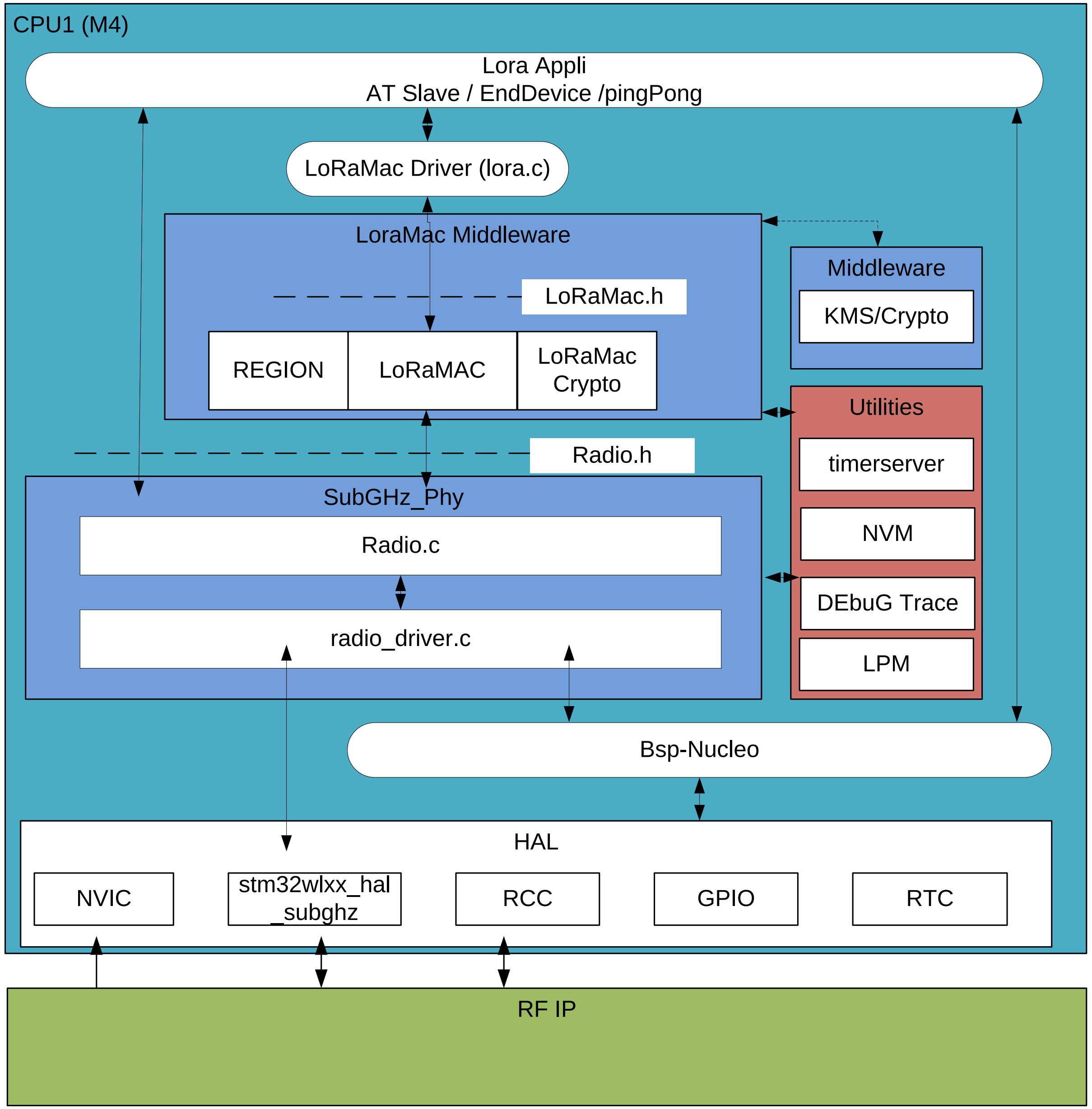
- Cmd: CM4 发送给CM0PLUS 的命令.
  - 用于调用在CM0PLUS上实现的函数
- Resp: CM0PLUS 给CM4响应.
  - 告诉CM4函数已经被执行，并返回可用的返回值
- Notif: 由CM0PLUS 发给CM4的通知.
  - 用于调用在CM4上实现的函数
- Ack: CM4 给 CM0PLUS的应答.
  - 告诉CM0PLUS函数已经被执行，并返回可用的返回值



STM32WL LoRa 软件架构

LoRa软件架构

- **Application:**
  - Ping-Pong 应用
  - End-Node 应用
  - AT-Slave 应用
- **Middleware**
  - LoRaWAN 包含LoRa Mac 层
  - SubGHz_Phy 包含Phy 层
  - KMS
    - 密钥管理系统
- **Utilities**
  - 低功耗管理器. 调度器 .定时服务器
- **BSP**
  - RF 开关, 板级配置



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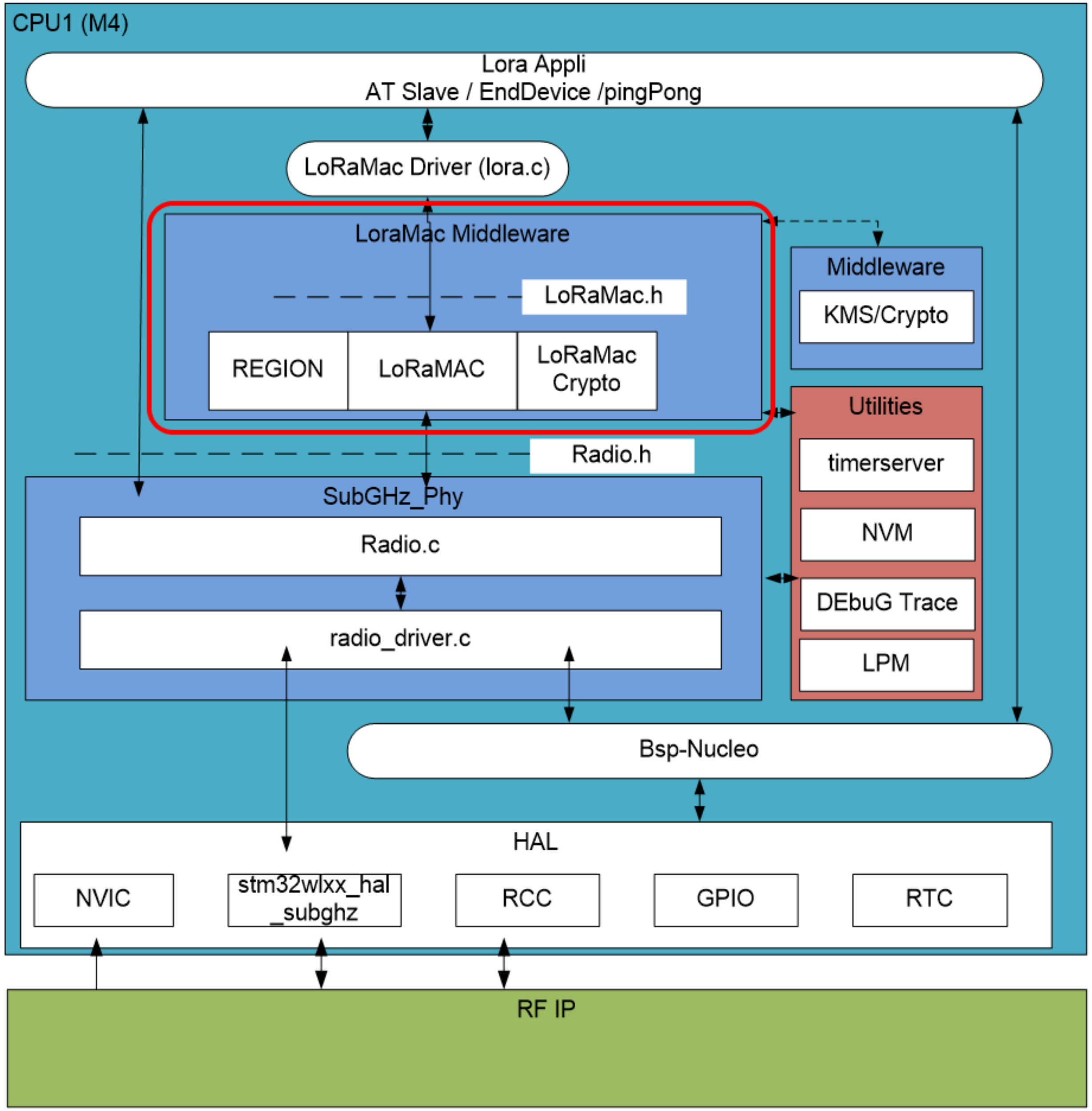
LoRaWAN 协议层介绍

LoRaWAN

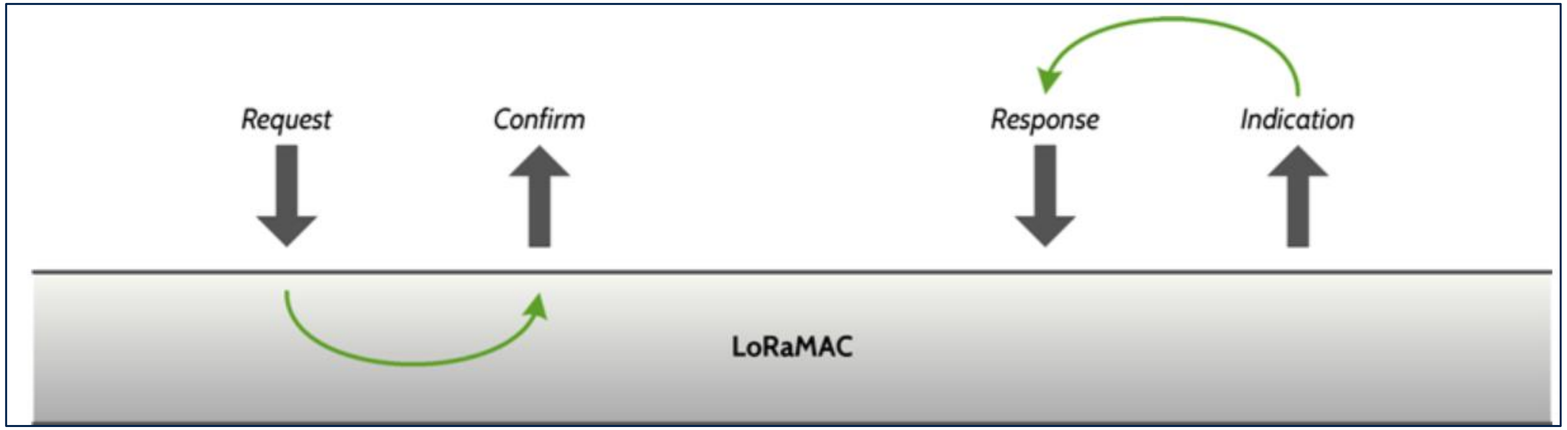
- LoRaWAN
  - **LoRaMAC层**
  - SubGHz_Phy 层



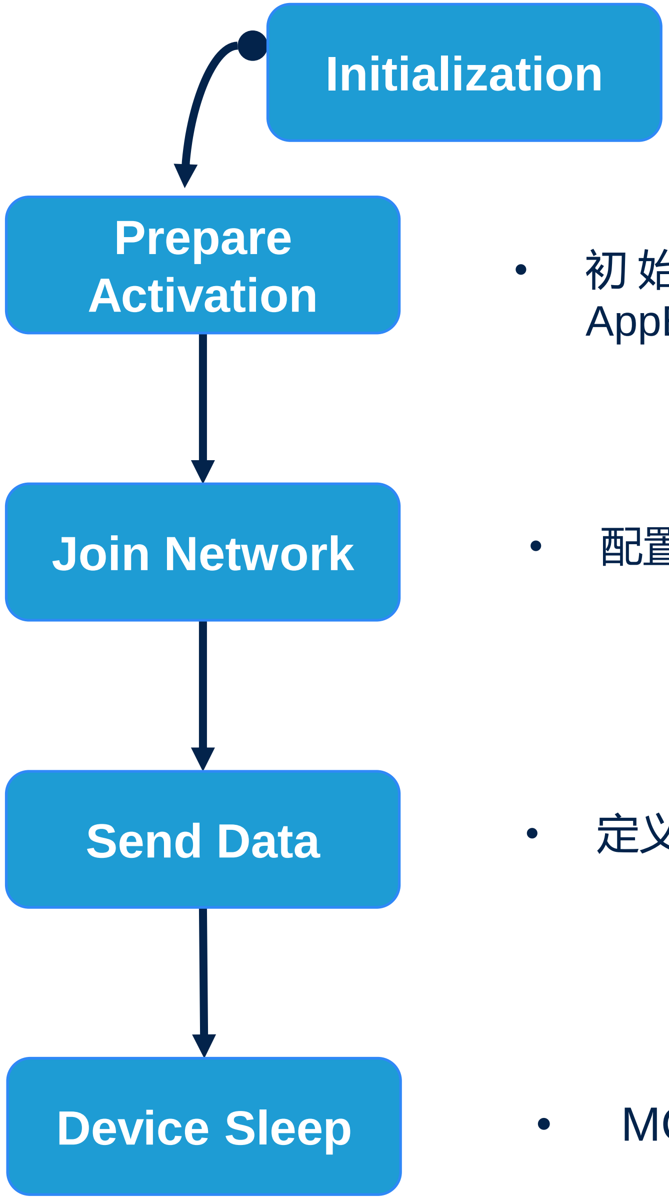
LoRaMAC 工作模式

LoRaMAC层提供MCPS（MAC公共部分子层）服务，MLME（MAC层管理实体）服务和MIB（MAC信息库）。该概念遵循请求确认和指示响应体系结构。

- **MCPS** 用于数据收发
- **MLME** 用于管理LoRaWAN 网络
- **MIB** 负责存储重要的运行时信息，并保存LoRaMAC层的配置



LoRaWAN 工作流程



Initialization

Prepare Activation

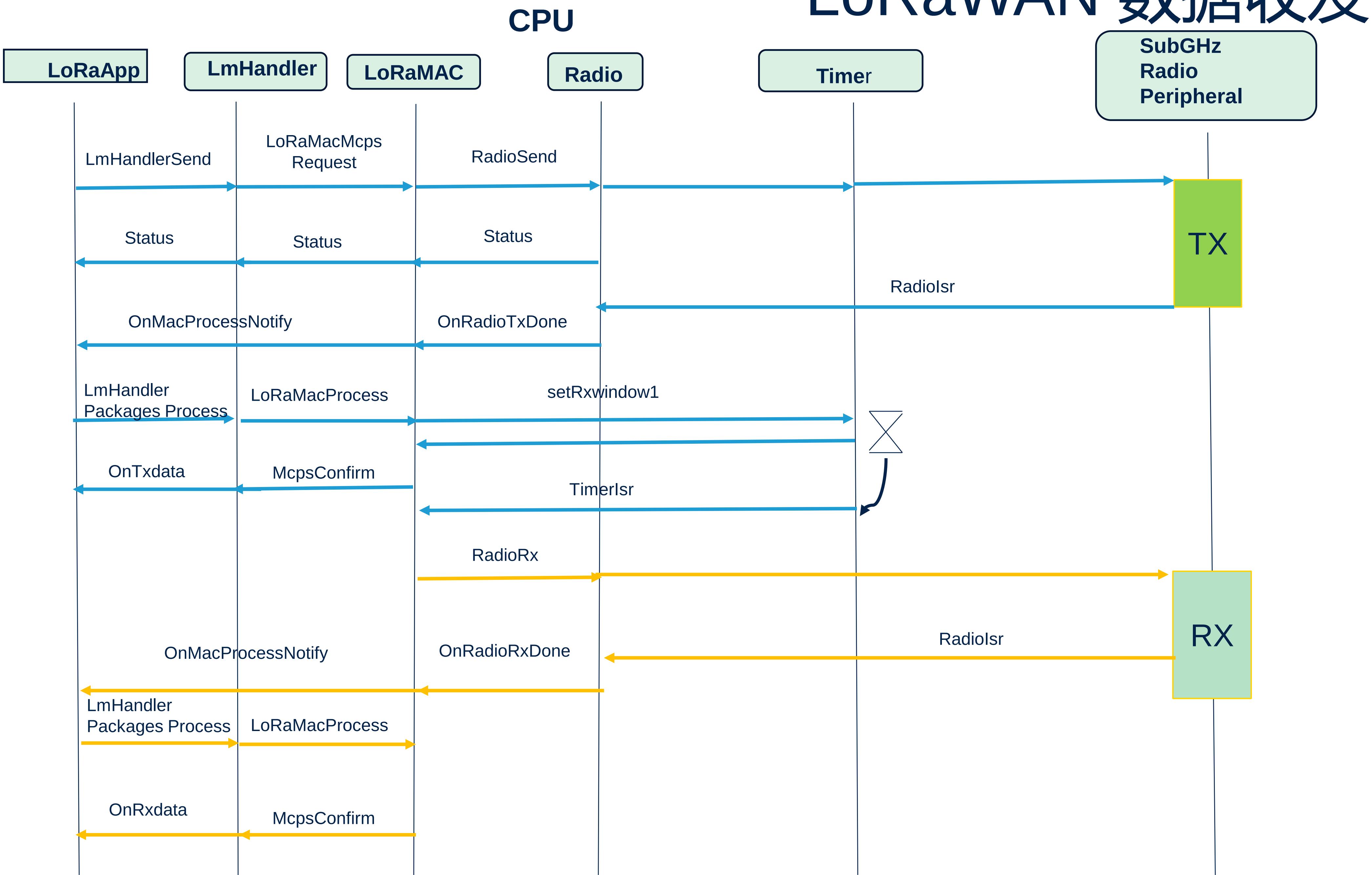
Join Network

Send Data

Device Sleep

- 初始化，定义回调函数
- 初始化LoRaWAN 设备的 unique ID, DevEUI, AppEUI, Region, ADR, DutyCycle.(**MIB**) 参数
- 配置入网方式OTAA o或者 ABP(**MLME**)
- 定义数据的格式, 端口, 数据缓存,速率(**MCPS**)
- MCU进入低功耗

LoRaWAN 数据收发流程



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初始化示例代码

```
static void McpsConfirm( McpsConfirm_t *mcpsConfirm )
{
// Implementation of the MCPS-Confirm primitive
}
static void McpsIndication( McpsIndication_t *mcpsIndication )
{
// Implementation of the MCPS-Indication primitive
}
static void MlmeConfirm( MlmeConfirm_t *mlmeConfirm )
{
// Implementation of the MLME-Confirm primitive
}
static void MlmeIndication( MlmeIndication_t *mlmeIndication )
{
// Implementation of the MLME-Indication primitive
}
static void OnMacProcessNotify( void )
{
// Mac notification. Process run function
}
LoRaMacPrimitives_t LoRaMacPrimitives;
LoRaMacCallback_t LoRaMacCallbacks;
LoRaMacStatus_t Status;
```

```
int main( void )
{
LoRaMacPrimitives.MacMcpsConfirm = McpsConfirm;
LoRaMacPrimitives.MacMcpsIndication = McpsIndication;
LoRaMacPrimitives.MacMlmeConfirm = MlmeConfirm;
LoRaMacPrimitives.MacMlmeIndication = MlmeIndication;
LoRaMacCallbacks.GetBatteryLevel = BoardGetBatteryLevel;
LoRaMacCallbacks.GetTemperatureLevel = NULL; // apply
board specific temperature reading
LoRaMacCallbacks.NvmContextChange = NvmCtxMgmtEvent;
LoRaMacCallbacks.MacProcessNotify = OnMacProcessNotify;
// Initialization for the region EU868
Status = LoRaMacInitialization( &LoRaMacPrimitives,
&LoRaMacCallbacks, LORAMAC_REGION_EU868 );
if( Status == LORAMAC_STATUS_OK )
{
// Initialization successful
}
}
```

入网操作示例代码

```
MlmeReq_t mlmeReq;
LoRaMacStatus_t status;
MibRequestConfirm_t mibReq;
uint8_t devEui[] = LORAWAN_DEVICE_EUI;
uint8_t joinEui[] = LORAWAN_JOIN_EUI;
// This comment is a placeholder for the initialization of the LoRaMAC layer. Set dev eui
mibReq.Type = MIB_DEV_EUI;
mibReq.Param.DevEui = devEui;
LoRaMacMibSetRequestConfirm( &mibReq );
// Set join eui
mibReq.Type = MIB_JOIN_EUI;
mibReq.Param.JoinEui = joinEui;
LoRaMacMibSetRequestConfirm( &mibReq );
// Setup the request type
mlmeReq.Type = MLME_JOIN;
// Fill the join parameters
mlmeReq.Req.Join.Datarate = DR_0;
status = LoRaMacMlmeRequest( &mlmeReq );
if( status == LORAMAC_STATUS_OK )
{
// Join request was send successfully
}
```

数据发送示例代码

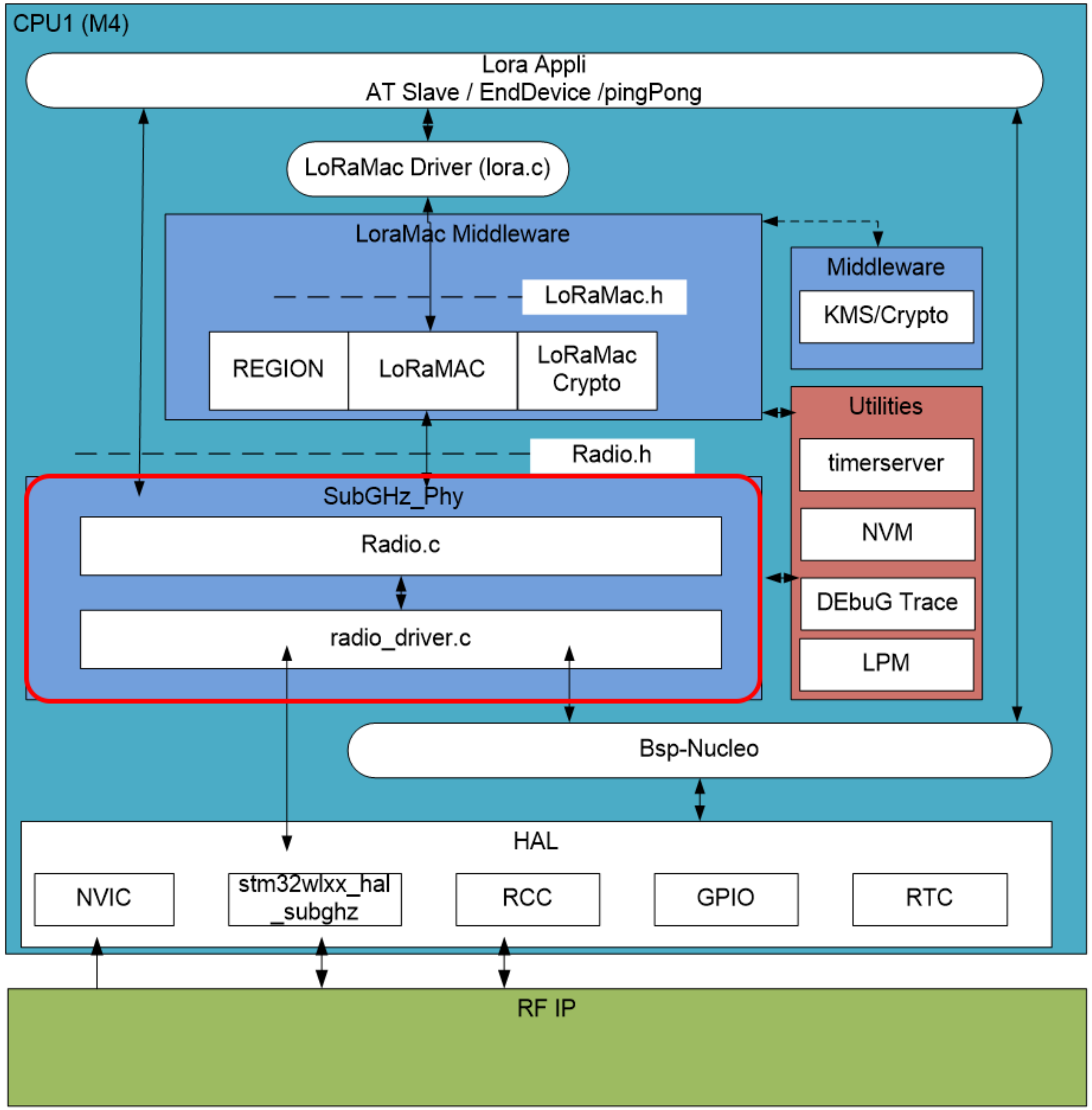
```
if( IsTxConfirmed == false )
{
mcpsReq.Type = MCPS_UNCONFIRMED;
mcpsReq.Req.Unconfirmed.fPort = AppPort;
mcpsReq.Req.Unconfirmed.fBuffer = AppDataBuffer;
mcpsReq.Req.Unconfirmed.fBufferSize = AppDataSize;
mcpsReq.Req.Unconfirmed.Datarate =
LORAWAN_DEFAULT_DATARATE;
}
else
{
mcpsReq.Type = MCPS_CONFIRMED;
mcpsReq.Req.Confirmed.fPort = AppPort;
mcpsReq.Req.Confirmed.fBuffer = AppDataBuffer;
mcpsReq.Req.Confirmed.fBufferSize = AppDataSize;
mcpsReq.Req.Confirmed.Datarate = LORAWAN_DEFAULT_DATARATE;
}
```

```
// Update global variable
AppData.MsgType = ( mcpsReq.Type == MCPS_CONFIRMED )
? LORAMAC_HANDLER_CONFIRMED_MSG :
LORAMAC_HANDLER_UNCONFIRMED_MSG;
AppData.Port = mcpsReq.Req.Unconfirmed.fPort;
AppData.Buffer = mcpsReq.Req.Unconfirmed.fBuffer;
AppData.BufferSize = mcpsReq.Req.Unconfirmed.fBufferSize;
LoRaMacStatus_t status;
// Data Send
status = LoRaMacMcpsRequest( &mcpsReq );
```

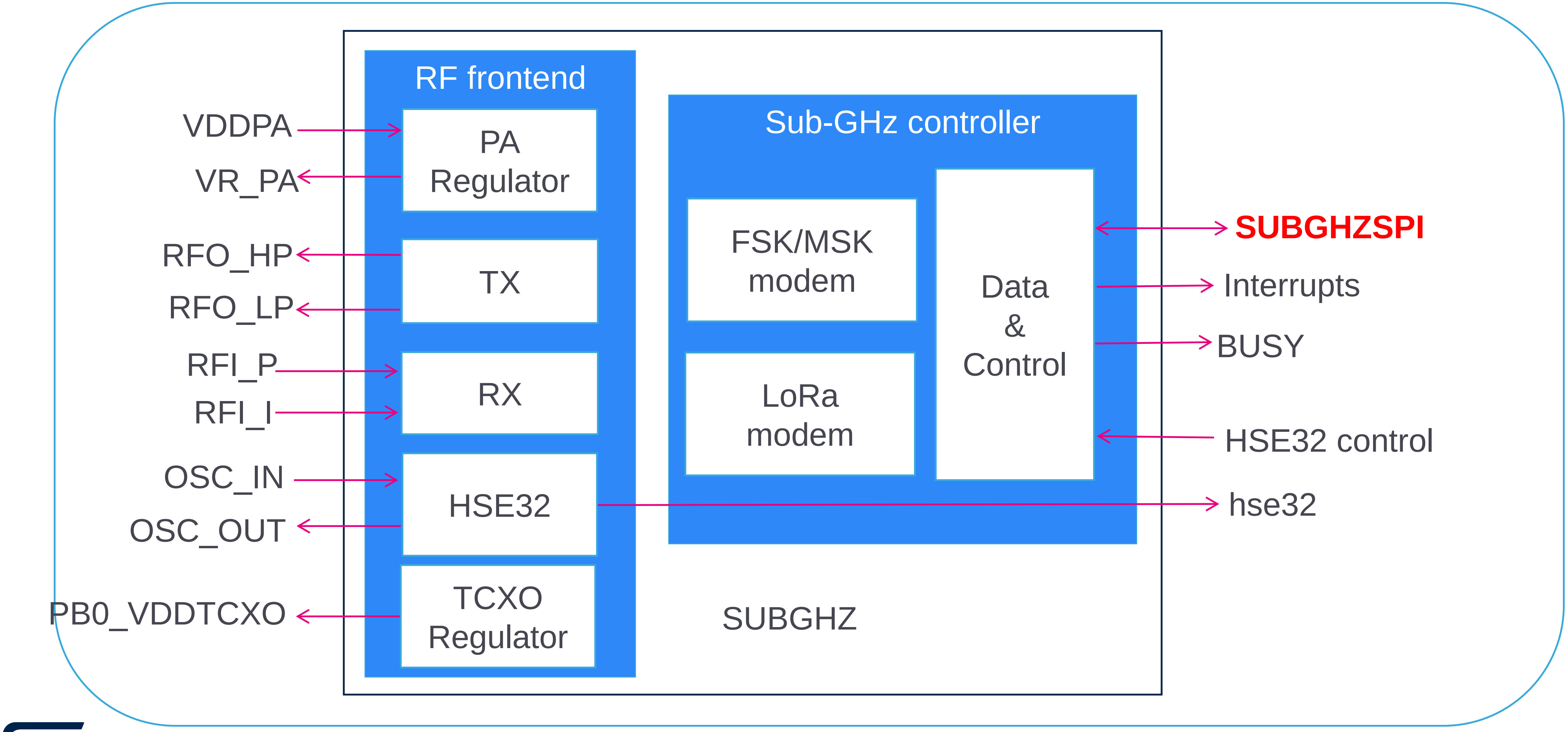
LoRa SubGHz层介绍

SubGHz_Phy层

- Middleware
  - LoRaWAN 包含Mac 层
  - **SubGHz_Phy 包含Phy 层**



SubGHz 内部结构



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SubGHz 概要

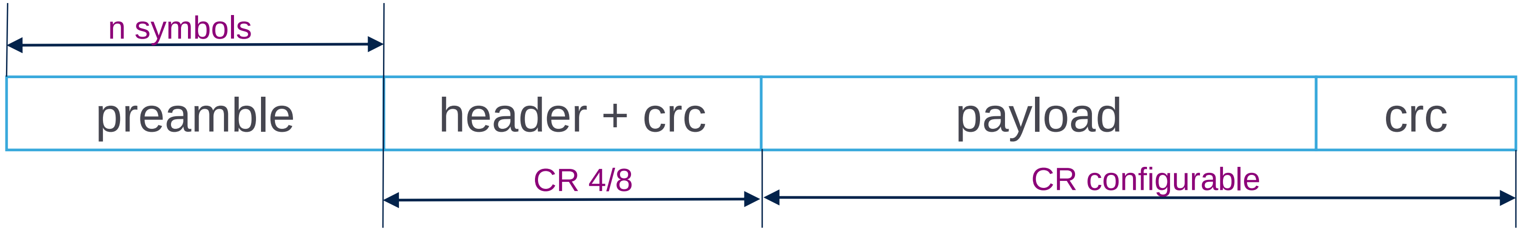
- Sub-GHz 主要特征:
  - ISM 频率范围150 – 960 MHz
  - 调制模式和速率:
    - LoRa™, 速率从 0.013 到 17.4 kbps
    - (G)FSK, 速率 从0.6 t到 300 kbps
    - (G)MSK, 速率 从0.1 到10 kbps
    - BPSK,速率从100 bps 到600 bps
  - 规范
    - ETSI EN 300 220, EN 300 113, EN 301 166
    - FCC CFR 47 part 15, 24, 90, 101
    - ARIB STD-T30, T67, T108
  - 协议标准:
    - LoRaWAN™, Sigfox, ….
    - Proprietary protocols

应用优势

- 多协议支持
- 超低功耗
- 功率输出高达+22 dBm
- 自动校准

LoRa™ 调制

- 数据帧
  - 带有报头和可变长度有效载荷的显式包
  - 没有报头和固定长度有效载荷的隐式数据包

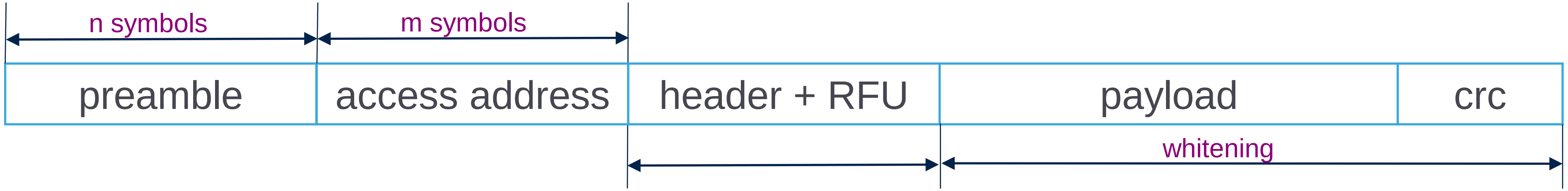


- 调制解调器配置：
  - 调制带宽BW7.81 kHz至500 kHz
  - 扩展因子SF 32个码片/符号）最多4096个码片/符号）
  - 编码率CR 4/4至4/8
- 通道活动检测

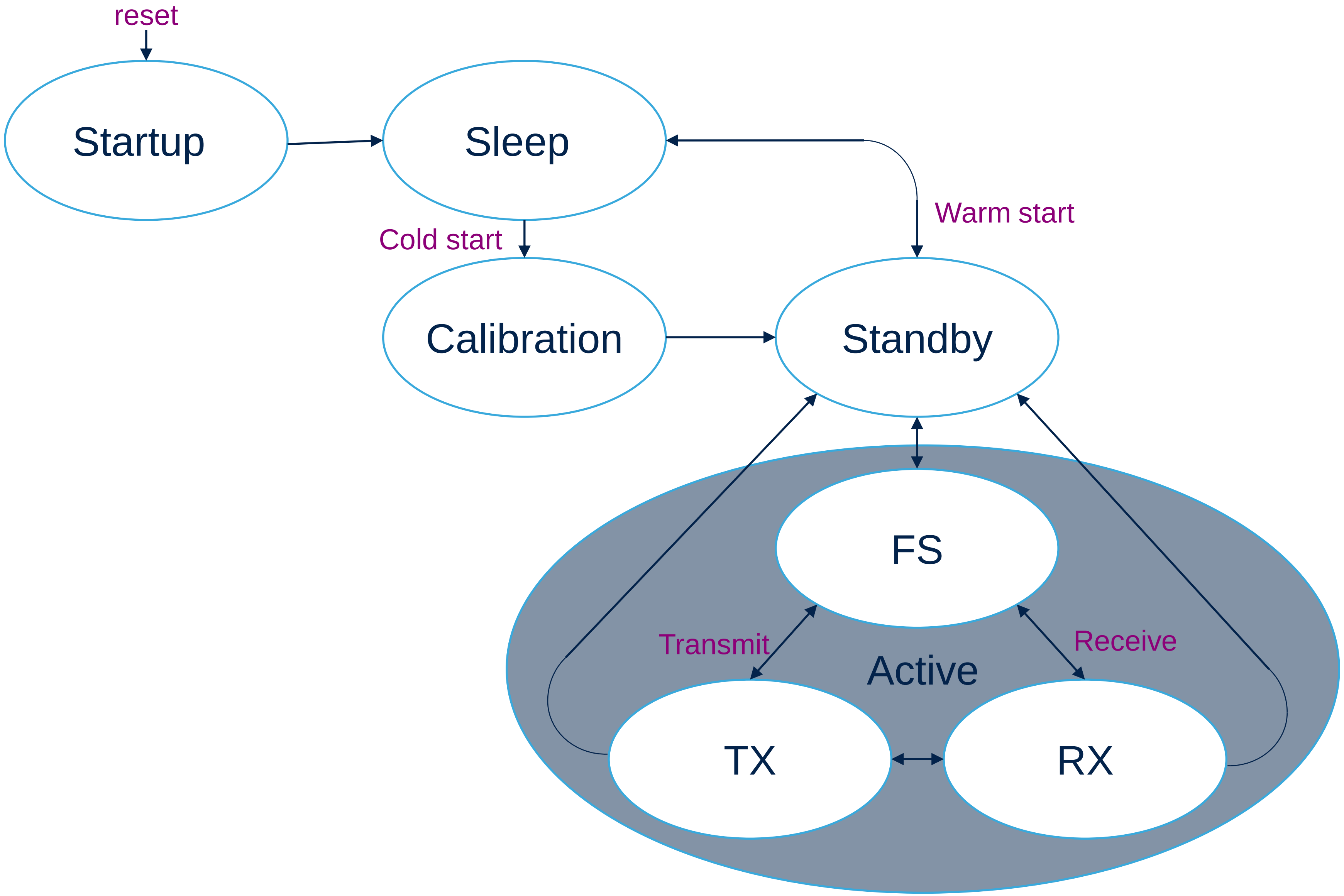
FSK/MSK调制

数据帧

- FSK和MSK调制解调器一起使用
- NRZ编码
- 可编程前导码长度
- 长度可选的访问地址
- 具有报头和可变长度有效载荷的可变长度数据包
- 不含报头和固定长度有效载荷的固定长度数据包
- 可选的白化（9位LFSR x9 + x5 + x1，可编程初始化值）
- 有效载荷CRC（可编程多项式，初始化值，取反和长度）

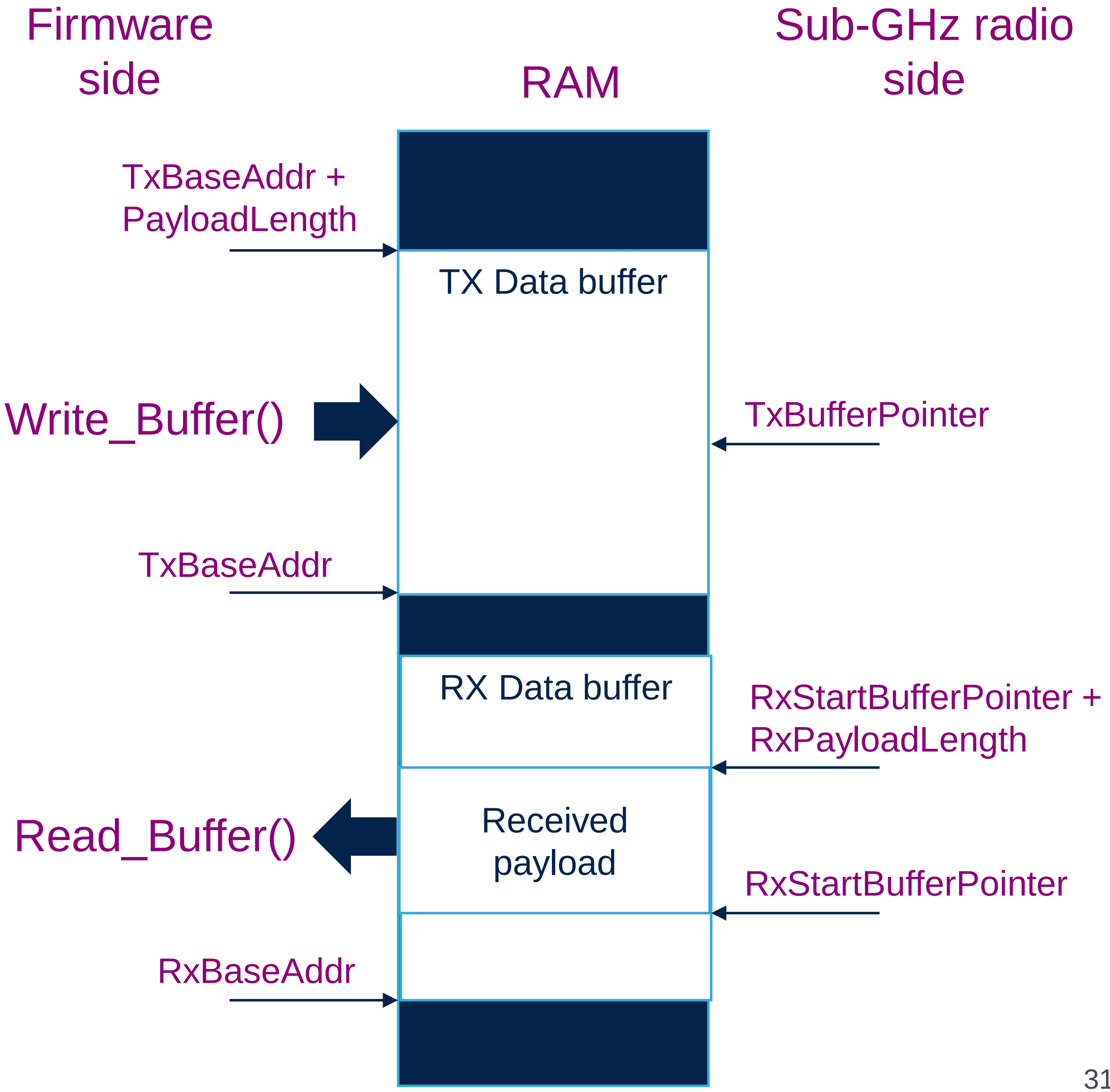


Sub-GHz radio 工作模式

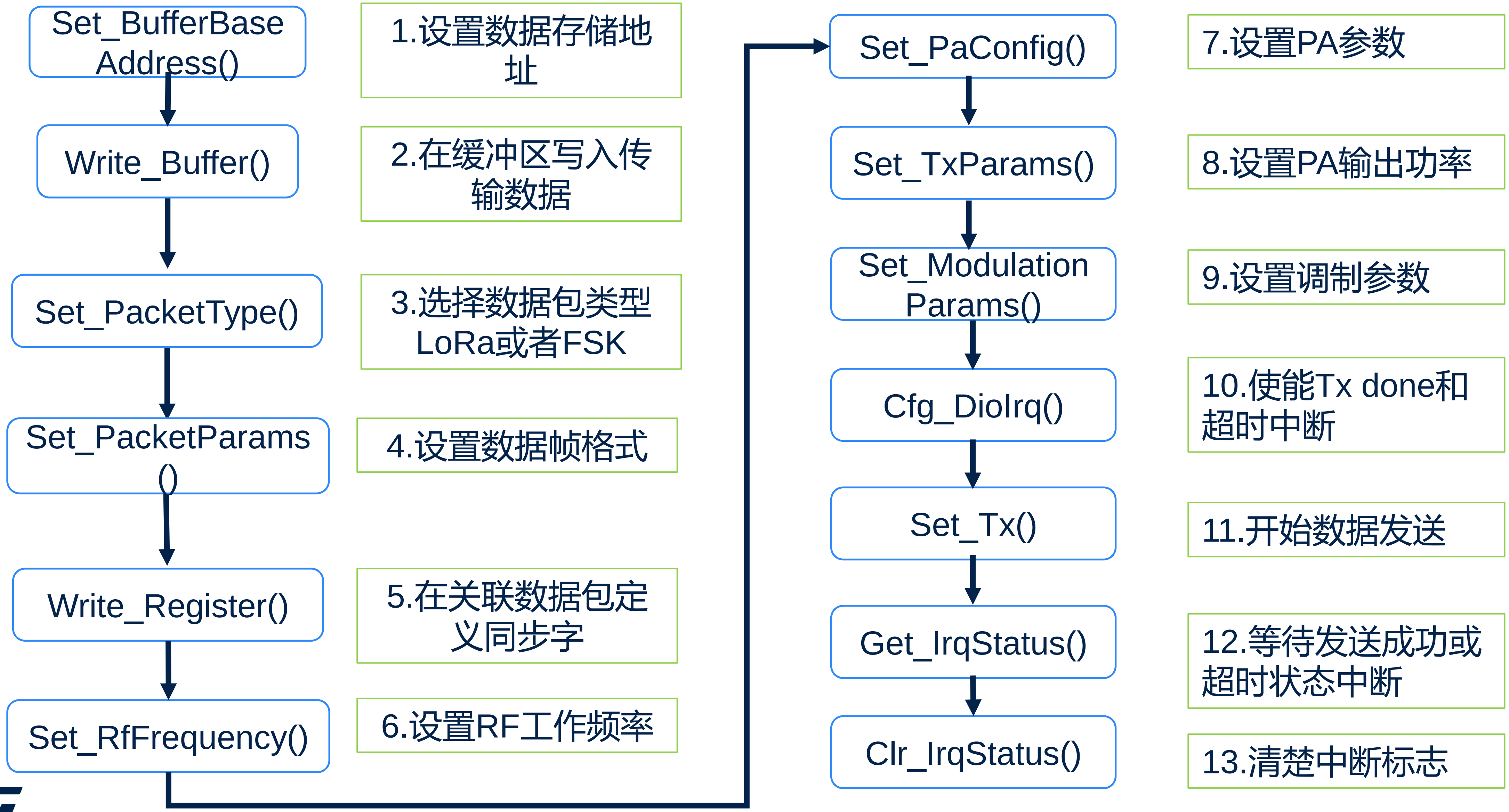


SubGHz 的数据缓冲区

- 256 字节的 RAM
- **TX 数据缓冲区**
  - 由软件写入，硬件读取
  - 参数:
    - TxBaseAddr,
    - TxBufferPointer
    - PayloadLength
- **RX 数据缓冲区**
  - 由硬件写入，软件读取
  - 参数:
    - RxBaseAddr,
    - RxStartBufferPointer
    - RxPayloadLength

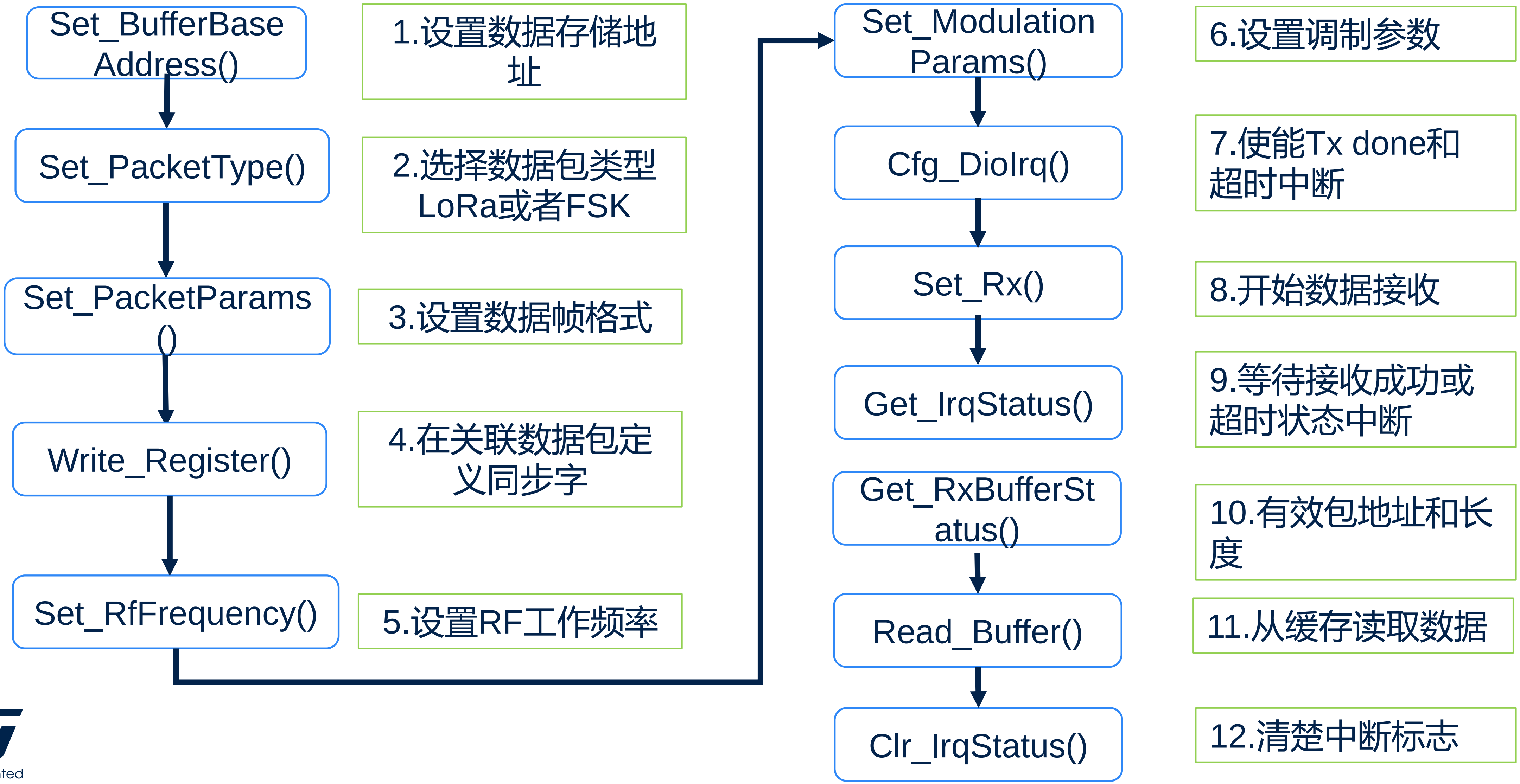


LoRa™, (G)FSK, (G)MSK 发送操作顺序



Set_BufferBase Address()	1.设置数据存储地址
Write_Buffer()	2.在缓冲区写入传输数据
Set_PacketType()	3.选择数据包类型LoRa或者FSK
Set_PacketParams ()	4.设置数据帧格式
Write_Register()	5.在关联数据包定义同步字
Set_RfFrequency()	6.设置RF工作频率
Set_PaConfig()	7.设置PA参数
Set_TxParams()	8.设置PA输出功率
Set_Modulation Params()	9.设置调制参数
Cfg_DioIrq()	10.使能Tx done和超时中断
Set_Tx()	11.开始数据发送
Get_IrqStatus()	12.等待发送成功或超时状态中断
Clr_IrqStatus()	13.清楚中断标志

LoRa™, (G)FSK接收操作顺序



Set_BufferBase Address()

1.设置数据存储地址

Set_PacketType()

2.选择数据包类型LoRa或者FSK

Set_PacketParams()

3.设置数据帧格式

Write_Register()

4.在关联数据包定义同步字

Set_RfFrequency()

5.设置RF工作频率

Set_Modulation Params()

6.设置调制参数

Cfg_DioIrq()

7.使能Tx done和超时中断

Set_Rx()

8.开始数据接收

Get_IrqStatus()

9.等待接收成功或超时状态中断

Get_RxBufferStatus()

10.有效包地址和长度

Read_Buffer()

11.从缓存读取数据

Clr_IrqStatus()

12.清楚中断标志

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使用射频接口发送数据示例代码

```
// Radio initialization
RadioEvents.TxDone = OnTxDone;
RadioEvents.RxDone = OnRxDone;
RadioEvents.TxTimeout = OnTxTimeout;
RadioEvents.RxTimeout = OnRxTimeout;
RadioEvents.RxError = OnRxError;
Radio.Init( &RadioEvents );

// Radio Tx Configuation in Lora mode
Radio.SetTxConfig( MODEM_LORA, TX_OUTPUT_POWER, 0, LORA_BANDWIDTH,
                   LORA_SPREADING_FACTOR, LORA_CODINGRATE,
                   LORA_PREAMBLE_LENGTH, LORA_FIX_LENGTH_PAYLOAD_ON,
                   true, 0, 0, LORA_IQ_INVERSION_ON, 3000 );

// Radio Set Rf frequency
Radio.SetChannel( RF_FREQUENCY );

// Radio send a buffer
Radio.Send( Buffer, BufferSize );
```

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使用射频接口接收数据示例代码

```
// Radio initialization
RadioEvents.TxDone = OnTxDone;
RadioEvents.RxDone = OnRxDone;
RadioEvents.TxTimeout = OnTxTimeout;
RadioEvents.RxTimeout = OnRxTimeout;
RadioEvents.RxError = OnRxError;
Radio.Init( &RadioEvents );

// Radio Rx Configuation in FSK mode
Radio.SetRxConfig( MODEM_FSK, FSK_BANDWIDTH, FSK_DATARATE,
         0, FSK_AFC_BANDWIDTH, FSK_PREAMBLE_LENGTH,
         0, FSK_FIX_LENGTH_PAYLOAD_ON, 0, true,
         0, 0,false, true );

// Radio Set Rf frequency
Radio.SetChannel( RF_FREQUENCY );

// Radio set in Rx mode a buffer
Radio.Rx( RX_TIMEOUT_VALUE );
```

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- community.st.com
- www.st.com/STM32WL
- wiki.st.com/stm32mcu
- github.com/意法半导体
- STM32无线模块 – 视频播放列表
- STM32WL博客文章

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Thank you

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