GTI MIoT Device Solution White Paper

Version	V1.0.0
Deliverable Type	□ **Procedural Document** ☑ **Working Document**
Confidential Level	□ **Open to GTI Operator Members** ☑ **Open to GTI Partners** □ **Open to Public**
Working Group	**Terminal WG**
Task	**PM3-PJ4: IoT Program / Device Solution Project**
Source members	CMCC, MTK, Qualcomm, Qorvo, Skyworks, Hisilicon, Unisoc
Support members	
Last Edit Date	2-3-2019
Approval Date	

Document History

Date	Meeting #	Version #	Revision Contents
2-3-2019		V1.0.0	

Contents

1 Executive Summary

In order to meet the requirements of LPWA IoT scenarios, MIoT(NB-IoT/eMTC) technologies have been developed by 3GPP to realize more reduced complexity, lower power consumption and deeper coverage. It's exciting times that many of new market opportunities are appearing as more than 80 MIoT networks around the world have been deployed. In this situation, the issue on MIoT device solution has aroused wide concern.

This whitepaper will provide the overview of MIoT device solution from the following aspects.

- **MIoT RFFE Design**

Broad global adoption of MIoT needs RF ecosystem ready to support low cost, low power and cost-effective RFFE products. And RFFE with low voltage capability is recommended.

- **MIoT Chipset Requirements and Architecture**

For MIoT Chipset Requirements, NB-IoT and eMTC are complementary LPWA solution, they work together to address a wide range of MIoT use cases and applications. Considering the service requirement of MIoT application, network deployment and the market status quo, the typical multi-mode RAT combinations will be analyzed.

For MIoT Chipset Architecture, the key advantage of the MIoT technology is its simplicity. The low memory and processing requirement, with a simple modem and single antenna design is ultra-power efficient, giving the option of battery powered for extended periods. Therefore, Chipset Architecture can be highly integrated, which may include Baseband, MCU, RAM, FLASH, PMIC, RFIC, PA and GNSS.

- **Optimized MIoT solution on low power**

Typical working models and usage scenarios for MIoT products will be analyzed, and power consumption consideration and battery life evaluation will be discussed.

- **eUICC based implementation solution for MIoT devices**

General eUICC Architecture of MIoT device will be described, and eUICC remote provisioning procedures and the use of Bearer Independent Protocol will be introduced.

2 References

[1] TS 136 101 - V14.4.0 - ETSI www.etsi.org/deliver/etsi_ts/136100.../14.04.../ts_136101v140400p.pdf

[2] 3GPP R4-163189 Simulation on the effect of nonlinear PA to EVM in NB-IOT uplink

[3] 3GPP TR 45.820 V13.1.0. "Cellular system support for ultra-low complexity and low throughput Internet of Things (CIoT)," November 2015.

[4] 3GPP TS 23.401 V14.3.0. "General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access," March 2017.

[5] https://www.rohde-schwarz.com/uk/applications/narrowband-internet-of-things-white-paper_230854-314242.html

[6] http://www.tsmc.com

[7] SGP.01: Embedded SIM Remote Provisioning architecture v1.12

[8] SGP.02: Remote SIM Provisioning Architecture for Embedded UICC Technical Specification v3.1

[9] ETSI TS 102 223 Smart Cards; Card Application Toolkit (CAT) V14.0.0
[10] ETSI TS 101 220 Smart Cards; ETSI numbering system for telecommunication application providers V12.0.0

3 Abbreviations

Abbreviation	Definitions
AMR	Adaptive Multi-Rate Compression
ANT	Antenna
ASM	Antenna Switch Module
BIP	Bearer Independent Protocol
BLE	Bluetooth Low Energy
BPF	Band Pass Filter
BW	Band Width
CMOS	Complementary Metal-Oxide Semiconductor
CS	Circuit Switched
DDR	Double Data Rate
DL	Downlink
DRAM	Dynamic Random Access Memory
eDRX	Extended Discontinuous Reception
eMTC	Enhanced Machine-type Communication
eUICC	Embedded UICC
EUM	eUICC Manufacturer
FDD	Frequency Division Duplexing
FD-FDD	Full Duplex FDD
FEM	Front End Module
GaAs	Gallium Arsenide
GNSS	Global Navigation Satellite System
GP	Global Platform
GPIO	General-Purpose Input Output
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GSMA	GSM Association
HARQ	Hybrid Automatic Repeat request
HB	High Band
HD	Half Duplex
HD-FDD	Half Duplex FDD
IoT	Internet of Things
IPD	Integrated Passive Device
ISD-P	Issuer Security Domain Profile
ISD-R	Issuer Security Domain Root

LB	Low Band
LPF	Low Pass Filter
LTE	Refer to both TD-LTE and FDD LTE
M2M	Machine to Machine
MB	Middle Band
MCL	Maximum Coupling Loss
MCP	Multi-Chip Package
MCU	Micro Computer Unit
MIB	Master information block
MME	Mobility Management Entity
MMMB	Multi Mode Multi Band
MO call	Mobile Originated Call
MT call	Mobile Terminated Call
NAS	None-Access-Stratum
NB-IoT	Narrow Band Internet of Things
OEM	Original Equipment Manufacturer
OTDOA	Observed Time Difference of Arrival
PA	Power Amplifier
PAE	Power Amplifier Efficiency
PAPR	Peak-to-Average Power Ratio
PC	Power Class
PCB	Printed Circuit Board
PCM	Pulse-coded modulation
PDCCH	Physical Downlink Control Channel
PDU	Protocol Data Unit
PMU	Power Management Unit
PS	Packet Switched
PSRAM	Pseudo Static Random Access Memory
QB	Quad Band
RB	Resource Blocks
RFFE	RF Front End
Rx	Reception
SAS	Security Accreditation Scheme
SAT	SIM Application Toolkit
SAW	Surface Acoustic Wave Filters
SIM	Subscriber Identity Module
SiP	System-in-Package
SKU	Stock Keeping Unit
SMD	Surface Mount Device
SM-DP	Subscription Manager - Data Preparation for Machine to Machine
SM-SR	Subscription Manager Secure Routing
SoC	System on a Chip
SPI	Serial Peripheral Interface

SRAM	Static Random Access Memory
TDD	Time Division Duplexing
TTM	Time To Market
Tx	Transmission
UART	Universal Asynchronous Receiver/Transmitter
UE	User Equipment
UL	Uplink
ULB	Ultra-low Band
Xcvr	Transceiver

4 Introduction

Nowadays, there are more than 80 MIoT networks deployed all over the world. To accommodate the rapid development of M-IoT technologies (NB-IoT/eMTC), this whitepaper will focus on the following key points of MIoT device solution.

- MIoT RFFE Design
- MIoT Chipset Requirements and Architecture
- Optimized MIoT solution on low power
- eUICC based implementation solution for MIoT devices

Based on the technical exploration, this whitepaper will give the guidance for MIoT device research and development.

5 MIoT RFFE Design

5.1 Overview

It's exciting times that many of new market opportunities are appearing as Operators around the world deploy MIoT network; eMTC primarily in N.A. and NB-IoT in EU/APAC. However, looking not far into the future, a combination of both standards will likely occur and create products optimized to the specific needs of a multitude of vertical segments leveraging overall MIoT volumes with reduced SKUs. The band implementation decision can have a profound impact on RFFE cost in a MIoT device, so an understanding of which bands to include is very important. Low bands (<1GHz) provide the benefit of range, B8 is the primary candidate with usage of B5/26 significant and regional pockets of B20/B28. Mid Bands (<2GHz) are predominating B3 across Asia and Europe, with B2/4 in the Americas. Optimizing a cost effective solution (with future flexibility) is important for product planning given the long life cycles expected for mMTC products.

Mobile Handset RFFE vendors are familiar with this problem, some smartphones implementing >20 bands in one device. Utilizing this experience and best practices… how can we create a cost effective, scalable RFFE for the MIoT market? Using broad-banding techniques common in smartphones one amplifier and filter can address several bands eliminating redundancy. In order to address the Low Band (5,8,20,28) and Mid-band (1,2,3,4) needs, an optimized 2in1 broadband PA + LPF can address the Tx requirements. In some cases, a 2in1 BPF can provide global coverage on the Rx. When mated with a SP6T, a low cost MIoT RFFE with some future flexibility can address the global market needs (resembling that of a QB 2G RFFE having shipped in the billions of units).

The approach for RFFE in NB-IoT and all half duplex systems is to simplify requirements to minimize cost overhead. Half duplex systems eliminate duplexers, and can operate at lower power than a full duplex system. The trade-off for band coverage is to utilize popular readily available LTE bands without putting too many additional bands. Both those approaches help reducing cost.

Please refer to below Global MIoT RFFE System Architecture.

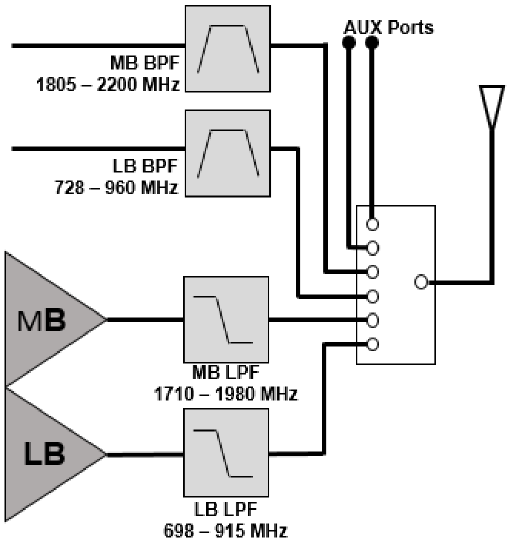


Figure 5-1 Global MIoT RFFE System Architecture

5.2 RFFE Design challenge

Understanding the configuration and specific performance requirements, the next decision is how to implement the PA in the system – on chip CMOS (SoC) vs. discrete (GaAs). Similar to planning filtering for a global SKU configuration, selecting a PA to address the widest range of applications without sacrificing cost/performance is important. Range and cost are very important for MIoT applications, at both PC3 and PC5 Pout levels a discrete GaAs amplifier beats that of CMOS in cost, size as well as performance as expected. On chip CMOS integration is challenged by transistor limitations, heating, TTM and VCO pulling. Despite having an advantage in cost per area, total implementation cost is higher on chip vs. discrete given the volume/technical advantages leveraged from the smartphone industry. For PC6, SoC integration can provide an advantage in cost. Like handsets, a discrete PA implementation for >+20dBm is superior to SoC for cost, performance, area and TTM (design flexibility).

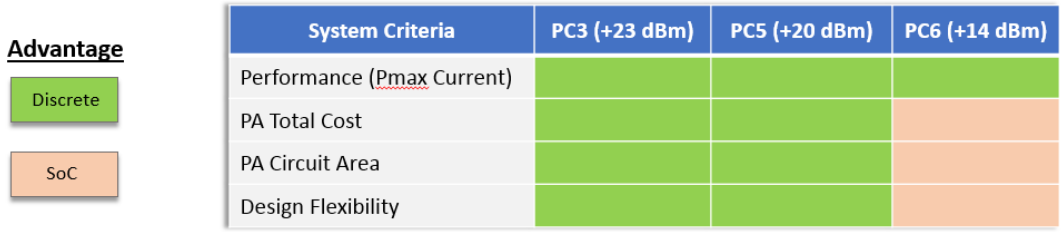
Optimized Discrete RF Architecture Provides System Benefits

- PC3 & PC5 can Benefit in Size, Performance, Price and Flexibility
- PC6 can Potentially Benefit from SoC CMOS PA’s with performance trade-offs

- Smaller CMOS nodes for SoC and Mid-Band frequency Operation Diminishes Advantages

- Most Products Traditional PA Technology (3Vmin; 5.5Vmax with charger)
- Some Interest for Non-Traditional PA Technology (3V to 1.8V)
- Potential Benefits
  - Enables Alternate Battery Options (Examples: 2-AA Cells; 3V Lithium Cell; Etc.)
  - Common Power MGMT Unit Voltage (1.8V) to Isolate SoC and PA from the Battery
  - Lower Breakdown/Ruggedness Requirements vs. 5.5Vmax with charger
- Potential Challenges
  - PA Bias Circuit Process and Temperature Compensation
  - Higher Current Draw Through DC-DC Inductors; Larger Case Size Inductors (z-Height)
  - Optimal Balance Voltage/Current Clouded by Range of Use Cases & Battery Options

Please refer to below Discrete Vs SoC RF Performance Comparison Matrix.



Estimates based on SWKS & QRVO PA Test Data, SoC System Measurements Courtesy of Cat-M1 Chipset Vendor

Figure 5-2 Discrete Vs SoC RF Performance Comparison Matrix

5.3 RFFE solution evolution

The RF-Front End for MIoT devices adopting NB-IoT/eMTC have a specific set of requirements that differ from a commercial mobile phone. MIoT devices typically only require less data to be transmitted and received, but need to operate over a wide coverage area. As such, the RFFE solution needs to evolve from a high performance, high data rate centric solution to one that is low cost, low data rate centric that can accommodate a wide range of MIoT applications. As such, as NB-IoT/eMTC proliferates, end devices will increasingly require an RFFE solution that is robust, flexible, and designed from the ground up rather that a re-use of an existing mobile phone solution.

5.3.1Discrete Solution

A Discrete RFFE is implemented using existing, off the shelf parts that operate over specific frequency bands and are combined together as separate pieces. The PA function will be separate from the filtering function and antenna switching function. Discrete designs are a simple, cost-effective way to build an RFFE if the end product is only going to be deployed in a specific region with extremely limited band coverage.

As shown in figure 5-3, a discrete single-band RFFE device using a commercially available 3 x 3 mm Power Amplifier Module (PAM) and SPDT switch.

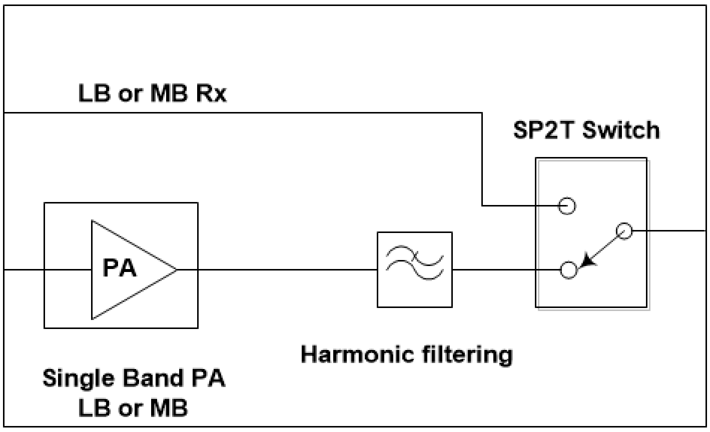


Figure 5-3 Block diagram of a discrete single-band RFFE device

There are also discrete solutions being implemented using Multi-mode multi-band (MMMB) PAs and higher throw count switches (SPnT).

As shown in figure 5-4, a discrete multi-band RFFE device using a commercially available 3.0 x 4.2 mm MMMB PA and 1.1 x 1.1 mm SP4T switch. This solution uses components originally designed for 3G mobile phones to build a half-duplex HD-FDD front-end.

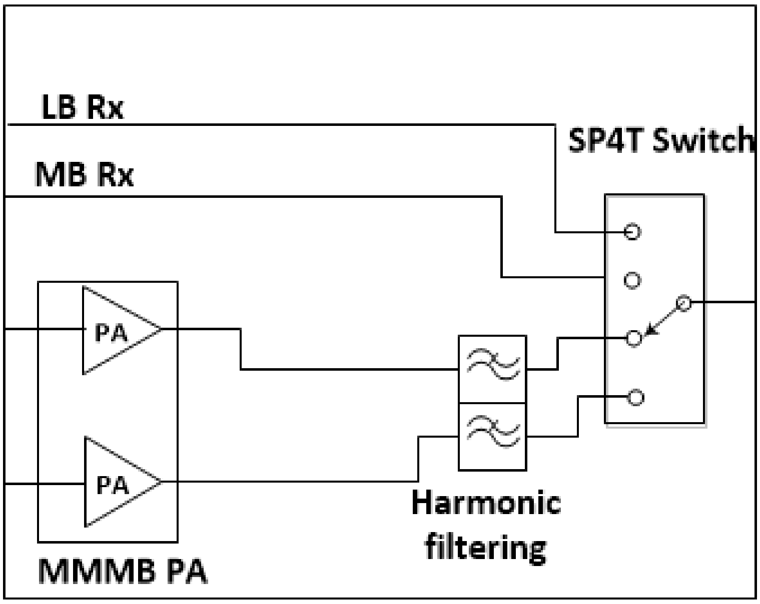


Figure 5-4 Block diagram of a discrete multi-band RFFE device

5.3.2Integrated Solution

As network operators worldwide continue to deploy NB-IoT/eMTC, and new use cases emerge in both consumer and industrial MIoT applications, moving to a fully-integrated RFFE solution has significant advantages.

An NB-IoT/eMTC FEM integrates all the RF and analog content between the transceiver and antenna, providing a turnkey RFFE that reduces complexity, size and time-to-market for MIoT device makers. More importantly, co-designing the PA with filtering and switching functions reduces the likelihood that the module or end device will fail certification, be it with the network operators, mobile industry or government standards bodies.

As shown in figure 5-5, a 15+ band fully integrated RFFE using a commercially available 4 x 5 mm half-duplex FEM.

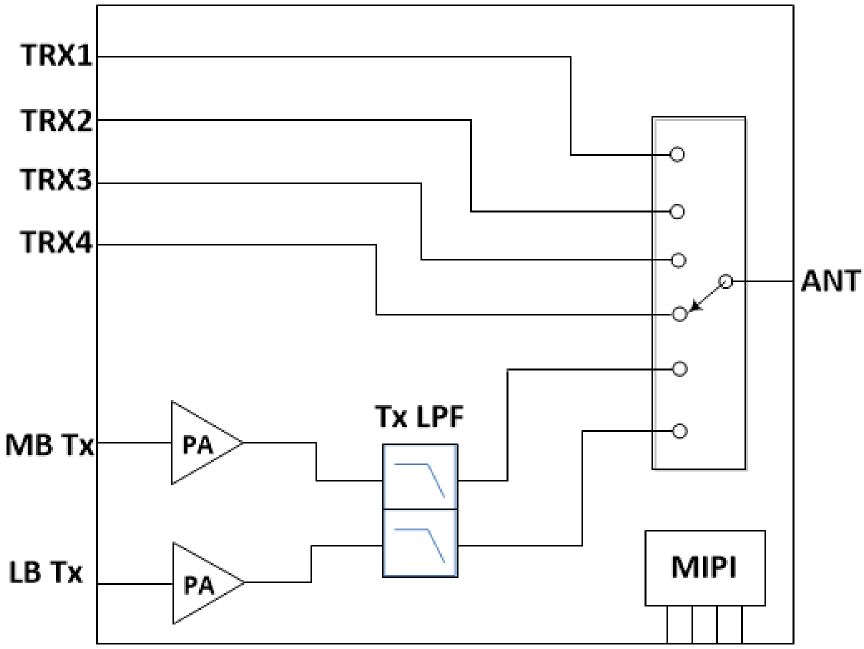


Figure 5-5 Block diagram of an integrated multi-band RFFE device

The NB-IoT/eMTC FEM is designed and optimized to deliver +23dBm at the Antenna port, and can operate over a wide 2.85 to 4.5V supply voltage range to support a direct battery connection. The use of a multi-throw antenna switch offering 4 auxiliary ports enables module makers to support 2G fallback or additional band deployments.

5.3.3High Performance Low Voltage

IoT devices by definition have to be low cost and operate from available battery voltages. Many MIoT devices such as asset trackers operate in a remote area need to support 10 years battery life. This requires extremely low leakage current in shutdown mode and low power consumption in active transmission mode. As a result, low Power-added-efficiency (PAE) is more important than cellular phones where the battery can be easily recharged by the user.

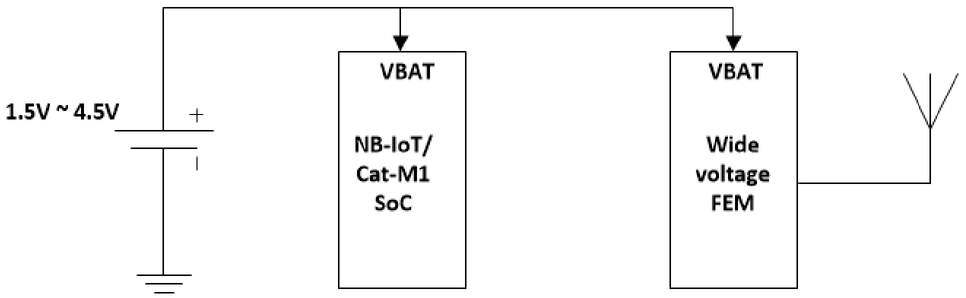
Part of the cost of an RFFE solution comes from using a DC-DC converter. The DC-DC converter is used to supply a regulated voltage to the FEM. If this component can be eliminated with the FEM directly connected to the battery, it will reduce overall device BOM costs.

The challenge comes in designing a power class 5 half-duplex FEM to cover a wide enough voltage range to operate directly from all types of available battery voltages. A common lithium coin cell battery has nominal voltage of 3V. Lithium Polymer (LiPo) batteries have a nominal voltage of 3.7V (with fully charged battery voltage can be as high as 4.5V). Alkaline batteries operate from 1.5V.

Batteries also discharge their voltage over time, requiring the FEM to be able to operate under the lowest rated battery voltage.

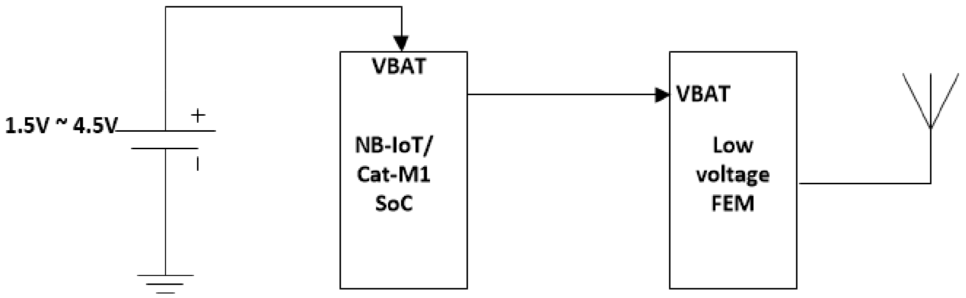
This requires the FEM to be able to operate over a very wide range of voltages while maintaining Gain, Output Power and harmonic performance. As seen in the use case 1 illustrated in the diagram below, this poses a significant challenge for the FEM design.

Use case 1: direct battery connection



Some NB-IoT SoC platforms feature an internal regulator that can be used to drive an external FEM, as low as 1.8V. As seen in the use case 2 shown below, the battery voltage can be as low as 2.1V - the internal regulator is used to drive the low voltage FEM. From the FEM design standpoint, to meet the same +23dBm output power with reduced operating voltage, the current consumption increases. This becomes even more of a challenge if the FEM has to operate over a wide frequency range and meet band specific spurious emissions requirements. As such, voltage range and current consumption become key factors in the FEM component selection.

Use case 2: driven by supply from SoC



5.3.4System-in-Package

A SiP(System-in-Package) system integrates the baseband, transceiver, RFFE, memory, crystals, and all associated passive components. It is a complete BB to RF solution that enables a MIoT device maker to add NB-IoT/eMTC connectivity with a minimal development cost. The SiP also comes pre-certified, which further reduces time to market. Most significantly, using a SiP enables size reduction, a key benefit for space constrained devices such as wearable devices and personal trackers.

The SiP is essentially a turnkey module solution that can be implemented in a few different ways. Some SiP vendors do not fully integrate all components such as the Flash Memory or Crystals, providing flexibility - in component placement and component sourcing. In addition, the large inductors typically required for the power management function will significantly increase the Z-height of the SiP if integrated into the package along with the other core pieces.

Using a SiP vs. a discrete, chip-on-board solution is attractive for MIoT device makers that are really looking for a simple and easy way to deploy a connected device using NB-IoT/eMTC. Without the SiP, the device maker has to take on the burden of completing not only the design and certification, but also obtain Intellectual Property (IP) indemnity.

Please refer to below NB-IoT/eMTC System in Package content.

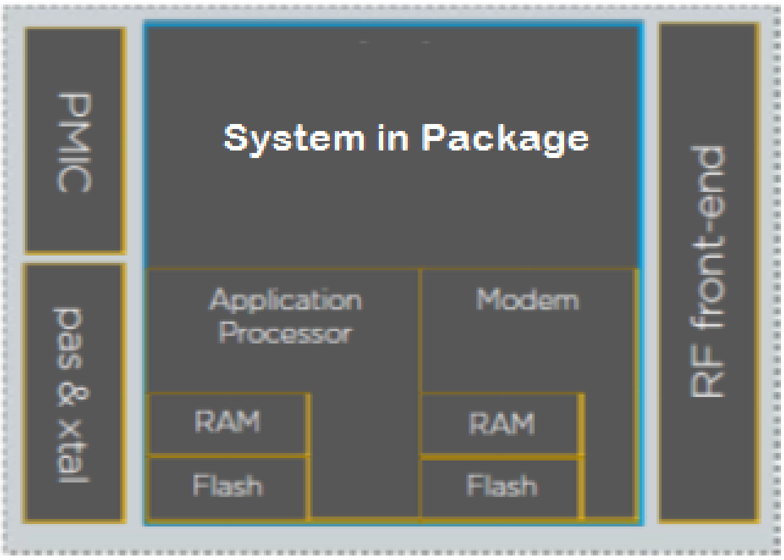


Figure 5-6 NB-IoT/eMTC System in Package content

5.4 Conclusion

MIoT adoption enables new markets, suppliers and customers, mass market adoption requires a simple, robust solution, broad, cost effective enablement for all regions and eliminates entry barriers for OEMs.

Broad global adoption of NB-IoT and eMTC needs RF ecosystem ready to support low cost, low power products. Global SKU RFFE configuration is possible for low band and mid band market adoption including flexibility for future use cases.

RFFE with low voltage capability is recommended. SiP Solution optimizes RF packaging technology combined with system support.

6 MIoT Chipset Requirements and Architecture

6.1 MIoT Technology Defined by 3GPP

6.1.1Overview

In 3GPP Release 13, two complementary narrowband technologies — NB-IoT (Cat-NB1) & eMTC (Cat-M1) — were introduced to reduce complexity, lower power consumption, deepen coverage, and increase user density. LTE IoT continued evolution with Rel 14 & 15 that allow LTE IoT to add new capabilities such as single-cell multicast and device positioning, further enhancing efficiency with energy reduction, coverage deepening, higher density, new UE categories of Cat-M2/NB2 to more efficiently address broader set of use cases. LTE IoT will serve as the initial 5G NR massive IoT solution by supporting in-band 5G NR deployments.

Coexists with today's services, eMTC can run on upgraded existing legacy LTE networks. It can be deployed in-band, utilizing resource blocks within normal LTE carrier. NB-IoT supports flexible deployment options: standalone, in-band, in guard-band. After refarming the GSM spectrum to LTE, the residual small spectrum blocks can be used for stand-alone deployment. NB-IoT can also be deployed into existing LTE bands, either in in-band or guard band. It can leverage the existing LTE infrastructure - in order to reduce deployment costs, it's possible to upgrade LTE infrastructures to provide the NB-IoT services.

To optimize the network for MIoT data transfer, meet the MIoT device requirement, data traffic was designed to be carried over control plane, which significantly improves efficiency for small data delivery in 3GPP systems and results in reduced signalling and conserves the battery life of the UE. The user data is transported via the MME by encapsulating user data in NAS PDUs. This results in a reduced total number of control plane messages to send a short data transaction.

6.1.2MIoT Bands

3GPP Release-13 specifications defined frequency bands 1, 2, 3, 5, 8, 12, 13, 17, 18, 19, 20, 26, 28, 66 for NB-IoT. 3GPP Release-14 added the support of the following bands: Band 11 (1.5GHz), Band 21(1.5GHz), Band 25 (850 MHz), Band 31 (450 MHz) and Band70 (Dish 1.7/1.9 GHz), as described in Table 6-1.

Table 6-1 NB-IoT Bands Definition in Release-13 and Release-14

Band	UL, Low (MHz)	UL, High (MHz)	DL, Low (MHz)	DL, High (MHz)	NB-IoT	Release Version
1	1920	1980	2110	2170	V	R-13
2	1850	1910	1930	1990	V	R-13
3	1710	1785	1805	1880	V	R-13
5	824	849	869	894	V	R-13

8	880	915	925	960	V	R-13
11	1427.9	1447.9	1475.9	1495.9	V	R-14
12	699	716	729	746	V	R-13
13	777	787	746	756	V	R-13
17	704	716	734	746	V	R-13
18	815	830	860	875	V	R-13
19	830	845	875	890	V	R-13
20	832	862	791	821	V	R-13
21	1447.9	1462.9	1495.9	1510.9	V	R-14
25	814	849	859	894	V	R-14
26	814	849	859	894	V	R-13
28	703	748	758	803	V	R-13
31	452.5	457.5	462.5	467.5	V	R-14
66	1710	1780	2110	2200	V	R-13
70	1695	1710	1995	2020	V	R-14

All Bands defined in Release-13 and Release-14 for NB-IoT are grouped into 4 groups:

UL RF frequency

- ULB: 452.5~457.5MHz
- LB: 699~915MHz
- MB1: 1427.9~1462.9MHz
- MB2: 1695~1980MHz

DL RF frequency

- ULB: 462.5~467.5MHz
- LB: 729~960MHz
- MB1: 1475.9~1510.9MHz
- MB2: 1805~2200MHz

LB/MB2 groups can cover all the R13 NB-IoT bands and all the R14 NB-IoT bands can be supported by using all the groups. The new low frequency band (ULB: 452.5~457.5MHz) can give better coverage, but device support is also needed.

UE category M1 and M2 is designed to operate in the operating bands 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 18, 19, 20, 21, 25, 26, 27, 28, 31 and 66 in both half duplex FDD mode and full-duplex FDD mode, and in bands 39, 40 and 41 in TDD mode. The bands are described in Table 6-2.

Table 6-2 eMTC Bands Definition in Release-13 and Release-14

E-UTRA Operating Band	Uplink (UL) operating band BS receive & UE transmit	Downlink (DL) operating band BS transmit & UE receive	Duplex Mode
	F_{UL_low} – F_{UL_high}	F_{DL_low} – F_{DL_high}	
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD

4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
66	1710 MHz	–	1780 MHz	2110 MHz	–	2200 MHz	FDD[1]
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
NOTE 1: The range 2180-2200 MHz of the DL operating band is restricted to E-UTRA operation when carrier aggregation is configured.							

6.1.3MIoT UE Capability Summarization

Table 6-3 compares the physical layer in terms of usable bandwidth, MCL (minimum coupling loss) as an indication of coverage, Downlink and Uplink peak data rate, Antenna numbers, UE Transmission Power.

Table 6-3 Cat 4/Cat 1/Cat 0/Cat M1/Cat NB1/Cat NB2 Physical Layer Comparison

Category[1]	**Cat 4**	**Cat 1(1bis)**	**Cat 0**	**Cat M1 (Rel. 13)**	**Cat M1 （Rel. 14）**	**Cat NB1 (NB-IoT)**	**Cat NB2 (NB-IoT)**
BW	20MHz	20MHz	20MHz	1.08 MHz	1.08MHz	180 KHz	180 KHz
MCL	140.7	140.7	140.7	155.7 dB	155.7 dB	164 dB	164 dB
DL Peak Rate	150Mbps	10Mbps	1Mbps	800kbps (FD-FDD) 300 kbps (HD-FDD)	588kbps (HD-FDD)	Anchor PRB:25.5 kbps Non-Anchor PRB:26.15kbps	Anchor PRB[2]: 100 kbps Non-Anchor PRB[3]: 126.8 kbps
UL Peak Rate	50Mbps	5Mbps	1Mbps	1 Mbps (FD-FDD) 375 kbps	1.1Mbps (HD-FDD)	62.53 kbps	150kbps

				(HD-FDD)			
ANT #	2	2 (1)	1	1	1	1	1
Modulation schemes	64 QAM (DL)[4] 16QAM (UL)[4]	64 QAM (DL)[4] 16QAM (UL)[4]	64 QAM (DL)[4] 16QAM (UL)[4]	QPSK, 16QAM	QPSK, 16QAM	BPSK, QPSK	BPSK, QPSK
Duplex Mode	FDD/TDD	FDD/TDD	FDD/TDD	HD-FDD / FD-FDD /TDD	HD-FDD / FD-FDD /TDD	HD FDD	HD FDD
UE Tx Power	23dBm	23dBm	23dBm	23/20dBm	23/20/14dBm	23/20dBm	23/20/14dBm

Note:
1. 3GPP TS 36.306
2. 2536bit TBS, 2 HARQ process
3. 2536bit TBS, 2 HARQ process
4. Highest Modulation Scheme

The downlink and uplink peak data rate summary for NB-IoT and eMTC is described in Table 6-4:

Table 6-4 Peak Data Rate Summarization

	Rel-13 NB-IoT	**Rel-14 NB-IoT**	**Rel-13 eMTC (HD-FDD)**	**Rel-13 eMTC (FD-FDD)**	**Rel-14 eMTC (Cat.M1 HD-FDD)**
Bandwidth	180 kHz	180 kHz	1.08 MHz	1.08 MHz	1.08MHz
UL Peak Rate	62.5[1] kbps	158.5[2] kbps	375 kbps	1 Mbps	1.1Mbps
UL HARQ No.	1	2	3	8	3
DL Peak Rate	26.15[3] kbps	126.8[4] kbps	300 kbps	800 kbps	588kbps
DL HARQ No.	1	2	3	8	10

Note:
1. 1000bits TBS with Single HARQ
2. 2536 bits TBS with 2HARQs
3. Non-Anchor PRB, 680bits TBS with Single HARQ
4. Non-Anchor PRB, 2536bits TBS with 2HARQs

6.1.4Other Features Summary

Table 6-5 summarizes other features of the NB-IoT and eMTC defined by 3GPP.

Table 6-5 Comparison of NB-IoT and eMTC

	Positioning	Mobility	VoLTE	PSM	eDRX
R13 NB-IoT	X	O[1]	X	O	O
R14 NB-IoT	O[2]	O[3]	X	O	O
eMTC	O[2]	O[4]	O[5]	O	O

Note:

1. Only support cell reselect
2. ECID/OTDOA
3. Support Control plane connection re-establishment in R14, handover is not supported
4. Handover is supported by eMTC
5. VoLTE is supported under CE Mode A.

6.2 MIoT Solutions

6.2.1 Overview

MIoT as a low power, wide area (LWPA) technology is designed to empower the explosive growth of MIoT devices. The key advantage of the MIoT technology over alternatives is its simplicity and the cellular ecosystem. The low memory and processing requirement, with a simple modem and single antenna design is ultra-power efficient, giving the option of battery powered for extended periods. Products can be highly cost and size effective; suitable for large scale roll-out.

6.2.2 Application Scenarios

NB-IoT and eMTC are complementary LPWA solution, they work together to address a wide range of MIoT use cases and applications. The following tables have shown the typical applications for NB-IoT and eMTC.

Table 6-6 NB-IoT single mode applications

	M2M Module	Bicycle, Asset Tracker	Smart Door	Smart Meter
Usage	• Data Module • In POS, Meter, Industrial Control	• Low Speed Transportation (Bus/Bicycle) • Asset Tracker	• Remote Control Management, Key exchange	• Part of Metering configuration

Table 6-7 NB-IoT dual mode/multi-mode applications

	M2M Module	Bicycle, Asset Tracker	Personal Tracker	POS Machine
Usage	• Data Module • In POS, Meter, Industrial Control	• Low Speed Transportation (Bus/Bicycle)	• Regular Data Update • Personal	• Pure Low Data POS

		• Asset Tracker	Tracking	

Table 6-8 eMTC applications

	Wearables	Car Tracker	Remote fire/dam monitoring	Pet/VIP tracking
Usage	• Watches used by children/adults	• Track whereabouts of cars	• Monitor dam for flood, and special places for fire	• Monitor pet/the old for their locations

6.2.3Multi-Mode Solution for MIoT Device

The use cases of MIoT are very diverse. Considering the service requirement of MIoT application, network deployment and the market status quo, below are typical types of multi-RAT combinations that can provide the MIoT devices with packet data delivery capability and voice capability.

- **NB-IoT + GPRS**

For some potential applications such as Smart Grid, Sensor Nodes, Smart Architecture and Existing M2M Applications, a more appropriate solution is NB-IoT + GPRS. The typical characteristics of these devices are described in Table 6-9.

Table 6-9 Typical characteristics of NB-IoT + GPRS suitable devices

Data Throughput	Report Frequency	Mobility Support	Power Consumption	Feature Extension	Voice
<10Kbps	Minute to Hour	Static	Years	Sensor I/O Extension	No Need

GPRS is adopted to cover the coverage holes for NB-IoT in early deployment stage. NB-IoT aims to address massive connection requirements with power consumption optimized. Tune to GPRS when being out of NB-IoT coverage.

- **NB-IoT + GSM**

For some potential applications such as Smart Tracker, Light Wearable, IVI OBD and existing M2M Devices, a more appropriate solution is NB-IoT + GSM. The typical characteristics of these devices are described in Table 6-10:

Table 6-10 Typical characteristics of NB-IoT + GSM suitable devices

Data Throughput	Report Frequency	Mobility Support	Power Consumption	Feature Extension	Voice
120Kbps if 8K PCM Mono Voice 12.2Kbps by AMR Encode	Sec	Walking, Biking, Car, Bus Movable Assets	Months	Regular Data Sync up	Message Emergency Call

NB-IoT network does not support voice service, while GSM network can support voice call.

➢ **eMTC + NB-IoT + GPRS**

This RAT combination is well adapted to the gradual evolution of this network deployment, which provides global solutions to carriers' customers who need MIoT solutions work seamlessly across the globe, across standards, across different spectrum bands etc. This type of solution also benefits the end-users with the simplicity of using global solutions without the hindrances of cost and complexities to adapt to the technologies/standards/bands where they deploy these solutions. Fewer designs/SKUs that address multiple global markets, results in overall cost savings in terms of research/development and customization vs. multiple designs/SKUs for different regions, technologies/bands. Such multimode LTE modem allow adopters to reduce power consumption and module footprint giving MIoT device end customers the ability to design and deploy smaller, battery-powered devices that work worldwide on virtually any cellular IoT network.

Table 6-11 Typical characteristics of eMTC devices[1]

Data Throughput	Report Frequency	Mobility Support	Power Consumption	Feature Extension	Voice
10 kpbs ~ 1Mbps	Second Milliseconds	Pedestrian, Cycling, Vehicle	Months ~ Year[2]	Regular Data Sync up	Message Voice Call

Note 1: The characteristics support by NB-IoT and GSM/GPRS is referred to Table 6-9, 6-10.

Note 2: Application and use scenarios dependent

According to different network deployment status, the Multi-mode capable terminal can select to work in a specific MIoT mode or a combination of them. Typical types multi-mode MIoT Terminals are listed as below:

- Type 1: GSM/GPRS/EDGE/NB-IoT, Single Card, Dual mode Dual Standby
  - Mainly for wearable devices and smart home application.

- Type 2: GSM/GPRS/EDGE/NB-IoT, Single Card, Dual mode Single Standby
  - Mainly for sharing bike, Tracker, Smart metering.

- Type 3: eMTC/NB-IoT/GPRS, Single card, Triple mode, Single Standby
  - Addressed most of the IoT applications under the diverse network deployment status.

The Network selection policy of the three types is described in Table 6-12, Table 6-13 and Table 6-14 respectively.

Table 6-12 Network selection policy of Dual mode Dual Standby device

Type 1: Dual Standby	GSM/GPRS/EDGE and NB-IoT	GSM/GPRS/EDGE Only	NB-IoT Only
Standby	GSM/GPRS/EDGE + NB-IoT	GSM/GPRS/EDGE	NB-IoT
CS	GSM	GSM	N/A
PS	NB-IoT	GSM/GPRS/EDGE	NB-IoT

Table 6-13 Network selection policy of Dual mode Single Standby device

Type 2： Single Standby	**GSM/GPRS/EDGE and NB-IoT**	**GSM/GPRS/EDGE Only**	**NB-IoT Only**
Standby	NB-IoT	GSM/GPRS/EDGE	NB-IoT
CS	Optional GSM	Optional GSM	No
PS	NB-IoT (SMS available)	GSM/GPRS/EDGE	NB-IoT (SMS available)

Table 6-14 Network selection policy of Type 3

Type 3： Single Standby	**eMTC + NB-IoT + GSM/GPRS/EDGE**	**eMTC+NB-IoT**	**eMTC Only**
Standby	eMTC or NB-IoT or GSM/GPRS/EDGE	eMTC or NB-IoT	eMTC
CS	eMTC or GSM	eMTC	eMTC
PS	eMTC or NB-IoT or GSM/GPRS/EDGE	eMTC or NB-IoT	eMTC

6.3 MIoT Chipset Architecture

6.3.1Overview

According to chapter 6.2, the complexity of MIoT(NB-IoT or eMTC) modem is much lower than that of LTE. In practical application, MIoT chipset will usually be made into a smaller general-purpose module, and then integrated into the end product. This chapter will introduce the feasibility of integrated design of MIoT chipset and system design for single-mode/dual-mode and multi-mode applications, as well as battery options that can be collocated with MIoT system.

6.3.2Chipset Architecture

➢ **MIoT Single mode / Dual mode**

For single mode and dual mode application, the complexity of the modem and system is relatively low. Therefore, the chipset and system integration can be relatively high, as shown in Figure 6-1.

In addition to the baseband, the low-end MCU, RF Transceiver and PMU can be integrated. Small memory size RAM and Flash can also be integrated into the chip for simple applications to save external components. For feature richer application, interface is reserved to connect to external RAM or Flash. Whether to choose SRAM or DRAM depends on performance requirement of application processor and modem. BLE/WiFi/GNSS can be integrated at chip level or board level depending on product orientation and market demand considering the acceptable cost and ship volume. The RF PA is usually not integrated into the chip, mainly due to technical difficulties or cost considerations.

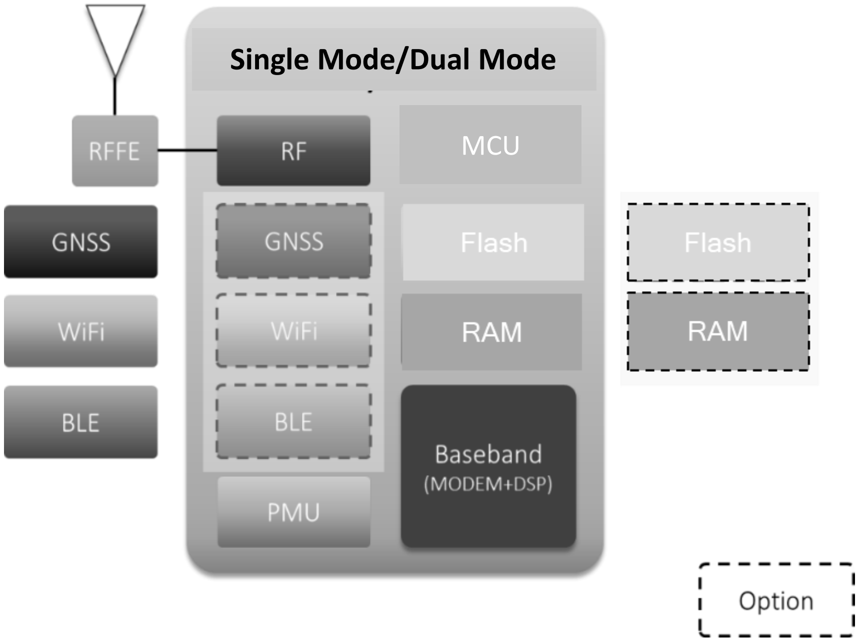


Figure 6-1 Single mode and Dual mode chipset architecture

- **MIoT Multi-mode**

For Multi-mode application, except NB-IoT/eMTC/2G, the modem may support LTE Cat 1 or higher capability, and the corresponding modem and system complexity are relatively high, so the chipset and system integration will not be as high as single-mode/dual mode products, as shown in Figure 6-2. For chipsets of this type of product, the main chip, in addition to the modem, usually integrates a powerful application processor.

The complexity of modem and applications require more memory capacity and faster memory, off-chip memory has become a better choice. In order to increase the integration to reduce PCB size, off-chip memory is usually selected MCP memory, DRAM and Flash in one package. Multi-mode modem corresponding RF transceiver will be more complex, need to support more modes and bands. In order to improve the versatility of RF transceivers while ensuring better RF performance, RF transceivers are often not integrated into the main IC. As for the part of power management, due to the increased complexity of AP, modem and system, the number of power supplies and the power consumption demands are correspondingly increased. So for power consumption and thermal considerations, PMIC is usually a single one.

The Integration of BLE/WiFi/GNSS is optional, for it depends on product orientation and market demand. The RF PA is usually not integrated into the chip, mainly due to technical difficulties or cost considerations, while with stacked memory in baseband chip and RFFE integrated with RF transceiver, smaller module size can be achieved and save the big efforts of RF design and debugging from module ODMs side.

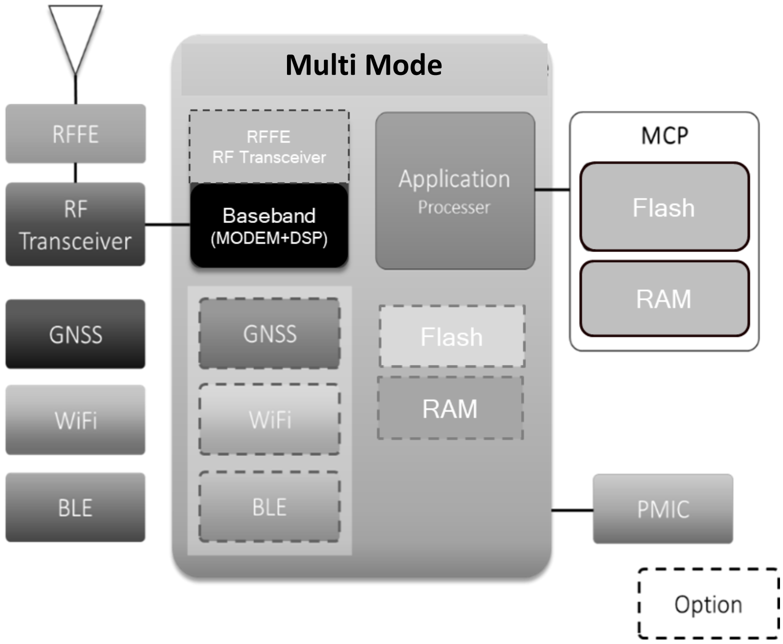


Figure 6-2 Multi-mode chipset architecture

6.3.3SoC-wise Consideration

The summarization of the key factors in chip producing for NB-IoT and eMTC are listed in Table 6-15.

Table 6-15 SoC-wise Summarization

	eMTC	NB-IoT	Notes
Fab Process	28/20 nm	90/55/40 nm	The fab process used by NB-IoT single mode chip can save cost during manufacturing.
RF Front End	No duplexer required for HD-FDD Duplexer needed for FD-FDD	No duplexer required	Half duplex can save cost and reduce insertion loss.

Compared with eMTC, NB-IoT with the bandwidth of 180 kHz BW also reduces the die size requirement for DL/UL processing block and HARQ buffer size in SoC design.

6.3.4Battery Consideration

Unlike smartphones, MIoT devices consume less power and can use non-rechargeable batteries in addition to rechargeable lithium batteries. The chemical composition of the battery determines its voltage rating:

- Non-chargeable Battery (Self-discharge : 1%~3% per year)
  - Li-SOCL2 (2.1V~3.9V)

- Li-MnO2 (2.1V~3.63V)
- 2-Series AA Battery (2.1V~3V)
- Chargeable Battery (Self-discharge : >15% per year)
  - Li-ion Battery (3.0V~4.3V) : Rechargeable

Self-discharge rate of the battery requires special attention, which means the annual loss of battery power when not in use. Non-chargeable battery self-discharge rate is about 1%~3% per year, while chargeable battery self-discharge rate is more than 15% per year. The self-discharge rate of non-rechargeable batteries is generally much lower than that of rechargeable batteries. This should be taken into account when estimating the battery life of MIoT devices.

6.4 MIoT Chip Integration (SoC Design) Considerations

6.4.1Overview

As described in Chapter 6.3, MIoT single mode/dual mode chips will probably have a high degree of integration. This chapter will analyze the advantages and disadvantages of integrating different modules into the chip and give some precautions when designing.

6.4.2The Advantages of Chip Integration

- Integrated SARM can effectively reduce costs while delivering guaranteed performance. As we all know, the performance of off-chip memory is greatly affected by PCB layout and PCB production process.
- Flash can be integrated to achieve security boot-up and storage, can prevent malicious copy or clone, so as to improve system security.
- Integrated power management unit compared to the use of general-purpose power supply chip to build system power supply circuit can significantly reduce costs and save PCB size. Simplify power control while making control more flexible. At the same time, due to system requirements being fully considered in the design of the power management unit, the use of an integrated power management unit will also result in a more stable power quality.
- Integrated RFIC can effectively reduce the PCB design difficulty, such as reducing the PCB stack and size. This is because RF signal lines usually require special protection and shielding when doing PCB layout and have strict impedance control. RF circuit PCB design cannot be as flexible as digital circuits. It is also because of such difficulties, the RF circuit design and production also need a lot of manpower and time to debug. The consistency of circuit performance is often affected by the process of production. As a result, integrated RFIC can reliably address these difficulties while providing guaranteed RF performance, resulting in significantly lower design and debugging costs.

- Integrated PA saves PCB area while reducing path loss of RFFE, improving PA efficiency, reducing RF power consumption to some extent.
- Integrated GNSS / BT can effectively reduce the PCB area and thus significantly reduce system design costs

6.4.3Chip Integration Process

➢ **Comparison of SoC and Die Stacking**

There are two ways to integrate the chip, design SoC and die stacking.

- The way to integrate chips through SoC requires that each integrated module have a corresponding IP core and require them to have the same process. In other words, the final design of the chip will only have one die. But in fact, if you do not have the ability to design each module, the purchase of IP core often requires high license fees, and cannot be customized to modify. At the same time, the process of PMIC and RFIC is usually larger than that of AP due to the requirements of power consumption and performance, which also brings difficulties to SoC design.
- IC Integrated by Die stacking allows direct use of other IC's die, without the need to purchase IP core, such as the integration of external memory chip. Thus greatly reducing the cost. At the same time, the different die used in the integration allow different processes, which makes it possible and convenient for the integration of the PMIC and the RFIC. However, Die stacking also requires special attention to the possibility of wire bonding. This is because the signal lead location of each die is not necessarily all around the die, there may be at the bottom of the die. At the same time, not all signals are connected to the substrate and some signals are internal connections between different die. In addition, the die stacking is bound to increase the height of the chip package. Special attention should also be paid to the design of the chip with certain requirements.

➢ **Die Stacking Introduction**

Die Stacking is placing two or more discrete die in one common package. There are three stacking options: MCP, SiP and PoP.

- MCP: Multi-Chip Package. Multiple chip (die) in a single package. Available in a small, thin package. All signals are connected to the substrate and there are no internal connections between different die.
- SiP: System in a Package. Not all signals are connected to the substrate and some signals are internal connections between different die.
- PoP: Package on a Package. The stacking of two or more packages on top of one another. Signals are routed between the packages through standard package interfaces.

The above three type diagrams are shown in Figure 6-3, and their attribute comparison is shown in Table 6-16.

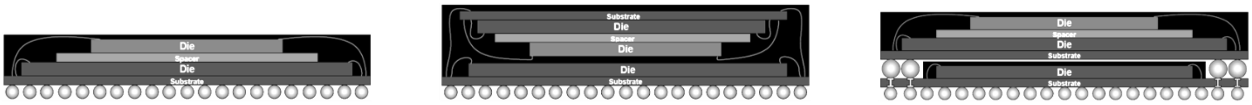


Figure 6-3 Die Stacking Diagrams

Table 6-16 Die Stacking Feature Comparison

Attribute	SiP	MCP	PoP
Cost	Good	Best	Better
Reliability	Best	Better	Good
Performance	Best	Good	Best
Height	Better	Best	Good
Board Space	Best	Good	Better
Standardization	Good	Better	Best
Availability	Good	Better	Best
Testability	Good	Better	Best
Flexibility	Good	Better	Best
Long-term viability	Good	Better	Best

➢ **Summary**

Generally speaking, the chip integration design needs to consider the following factors: Cost, Complexity, De-sense, Yield, Power Consumption and Thermal.

Chip manufacturers only consider the chip integration design when the product meets the following conditions: a simple system, a mature product design, a sufficiently large amount of shipping, and a competitive cost.

6.4.4PA Integration Consideration

RF PA has two processes of GaAs and CMOS, CMOS process can work at lower voltage in order to achieve the system's low-power design. Since the digital circuit of the SoC is implemented using a CMOS process, the PA of the CMOS process will be easier to integrate into the main IC. However, special CMOS processes are still required, and the following issues need to be considered and addressed:

- Thick metal process
- High voltage CMOS device
- SMD R/L/C replaced by CMOS IPD
- PA linearity should be guaranteed
- Cannot implement SW and harmonics filter using standard CMOS

As a result, SoC complexity and cost will increase. At the same time, due to PA's larger power consumption and higher heat generation, package design complexity and cost are also increased in order to prevent PA from affecting other parts of the IC. On the one hand, for thermal and power consumption reasons, low package thermal resistance is required. On the other hand, PA high-power signals may affect other RF signals, so low in-package signal coupling is required. What's more, PA's ability of wide band support and PA linearity should be taken into account for multi-mode application.

In summary, although integrated PA saves PCB area while reducing path loss of RFFE, improving PA efficiency, reducing RF power consumption to some extent. And reducing the maximum power can help reduce PA design difficulty as well. But the reduction of the integration area is at the expense of greater cost of other parts. Most chip vendors still adopt external PA.

6.4.5MIoT and WiFi/BT Coexistence

If you need to integrate WiFi/BT chip into MIoT chip, or just MIoT chips need external WiFi/BT chip extension, then the interference between MIoT and WiFi/BT must be considered and solved. Please pay attention to solution of WiFi/BT Rx interfered by MIoT Tx. An example of NB-IoT and WiFi/BT Coexistence is shown in Figure 6-4.

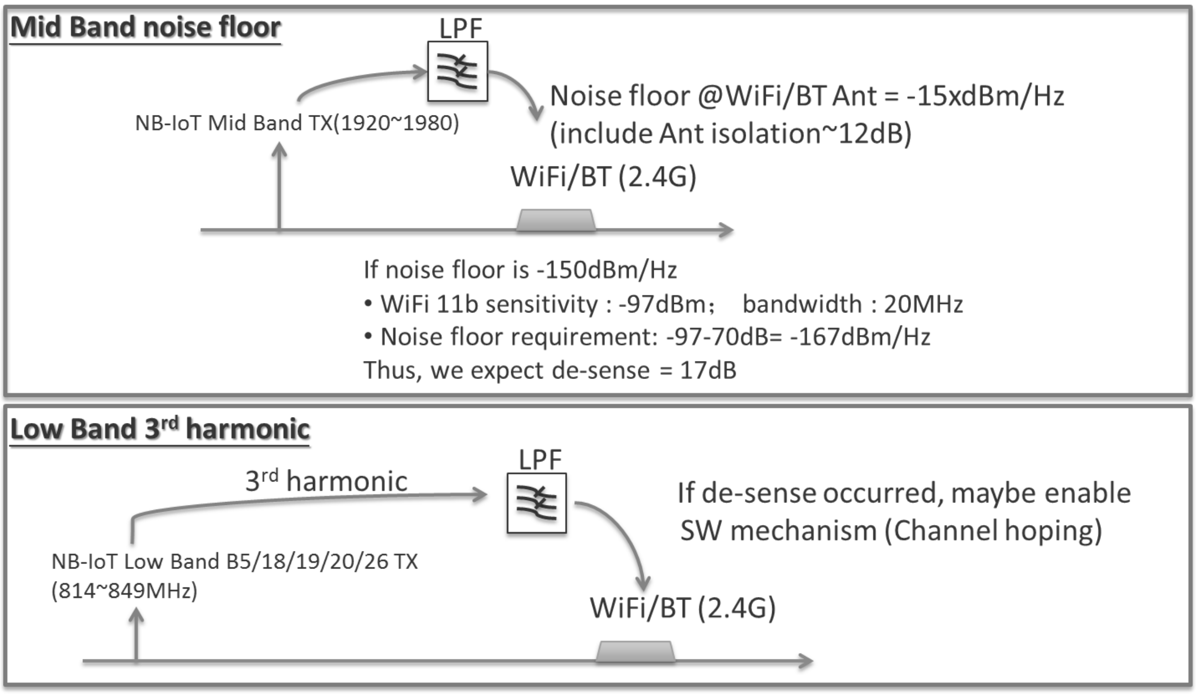


Figure 6-4 NB-IoT and WiFi/BT Coexistence

NB-IoT Rx can also suffer interference from WiFi Tx, such as NB-IoT B20 (791~821MHz). Three times the frequency of NB-IoT B20 Rx LO will fall in WiFi 2.4GHz band. Therefore, it is recommended to add a low pass filter to the B20 Rx input, when WiFi and NB-IoT B20 co-exist.

6.4.6MIoT and GPS Coexistence

If you need to integrate GPS chip into MIoT chip, or MIoT chips need external GPS chip extension, then the interference between MIoT and GPS must be considered and solved. The following is the example of NB-IoT and GPS Coexistence.

- For NB-IoT band 13 (777~787MHz)
  - The 2nd harmonic(1554~1574MHz) will enter GPS in-band(1575.42±1MHz)
- For NB-IoT mid band (Band1,2,3: 1710~1980MHz)
  - The out of band noise generated by PA will leakage to GPS in-band

7 Optimized MIoT solution on low power

7.1 How is an MIoT Device Different from a Smartphone

MIoT(NB-IoT/eMTC) technology is a narrowband radio technology designed for LPWA scenarios and is one of a range of Mobile IoT technologies standardized by the 3GPP.The characteristics of MIoT technologies determine its hardware and software implementation, and is different from smartphone.

In the MIoT product design process, chipset will usually be made into a smaller general-purpose module, and then integrated into the end product. Therefore, the demand for high integration of the chipset will be much higher than that of the smartphone chipset. The battery life of MIoT products is expected to be far greater than the smartphone, or even 10 years. As a result, MIoT products face the challenge of low cost and low power consumption.

7.2 Power Consumption Evaluation Methodology

7.2.1Control Plane CIoT EPS Optimization Model

In order to send data to an application, two optimizations for the cellular internet of things (CIoT) in the evolved packet system (EPS) were defined in 3GPP Rel-13 CIoT specification, the User Plane CIoT EPS optimization and the Control Plane CIoT EPS optimization. Both optimizations may be used for C-IoT devices. As described in Figure 7-1, in red, the Control Plane CIoT EPS optimization is indicated, in blue the User Plane CIoT EPS optimization.

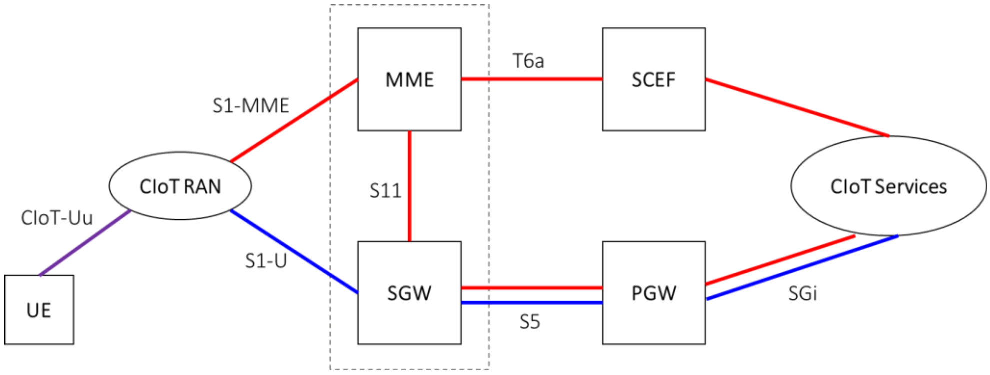


Figure 7-1 Network for the C-IoT Data Transmission and Reception

In existing LTE networks, the control signals and application data are transmitted separately via the control and user planes, and a radio bearer setup is necessary to send application data. On the other hand, the small data can be sent over the non-access stratum (NAS) signalling message. This scheme improves the transmission efficiency by skipping the bearer setup. Despite these features, there has been no progress in the scheduling request procedure to reduce power consumption. Given that the C-IoT is developed based on LTE, auxiliary procedures are necessary for the uplink radio resource allocation that is performed only by a random-access procedure.

Thus, at least 9 messages are required before the transmission of the first application packet in existing LTE, as shown Figure 7-2. On the other hand, the C-IoT CP EPS optimization allows to transmit application data packets after 4 messages, as shown in Figure 7-3.

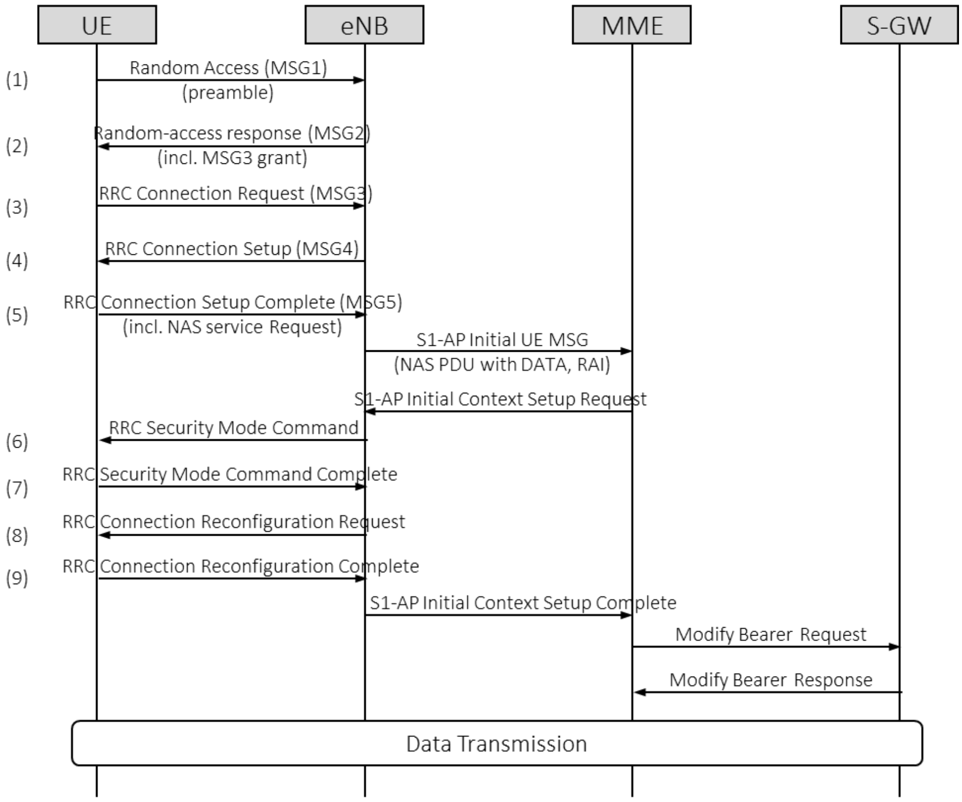


Figure 7-2 Packet Transmission Scheme: Existing Long-Term Evolution (LTE)

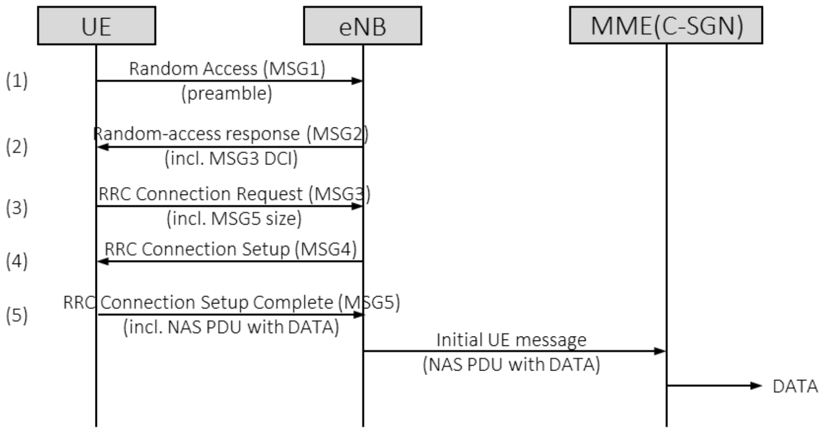


Figure 7-3 Packet Transmission Scheme: NB-IoT with control-plane cellular IoT optimization

7.2.2Tx, Rx and Idle Time Breakdown

Take the Control Plane CIoT EPS optimization (CP) for example. The Tx, Rx and Idle Time breakdown is described in table 7-1. It is useful for the analysis of power consumption.

Table 7-1 Time Breakdown of CP CIoT EPS Optimization

	Signalling and Data	**State**
1	NPSS, NSSS/PSS,SSS	Rx
2	MIB	Rx
3	NPRACH/PRACH	Tx
4	NPDCCH/PDCCH	Rx
5	RAR	Rx
6	RRC Connection Request (Msg3)	Tx
7	NPDCCH/PDCCH	Rx
8	RRC Connection Setup (Msg4)	Rx
9	HARQ ACK	Tx
10	NPDCCH/PDCCH	Rx
11	RRC Connection Setup complete + NAS E5M Data Transport (Msg5)	Tx
12	NPDCCH/PDCCH	Rx
13	RLC ACK	Rx
14	HARQ ACK	Tx
15	NPDCCH/PDCCH	Rx
16	RLC Status Report	Tx
17	RRC Idle	Idle
18	Enter PSM	Idle

7.2.3Power Consumption Evaluation Methodology

The purpose of energy consumption analysis is to calculate the achievable battery life for an MIoT device using a specific candidate solution. The battery leakage impact can be ignored since this depends on battery technology.

PSM denotes a Power Saving Mode State such as that achieved with the Rel-12 Power Save Mode feature. In Idle, the device may be consuming more power than in the PSM state because, for example, it is maintaining more accurate time/frequency synchronization with the network.

The energy consumption methodology comprises of two steps:

1) Declaration of key input parameters is shown in Table 7-2.

Table 7-2 Key Input Parameters for Power Consumption Analysis

(1)	Battery capacity (Wh)	
(2)	Battery power during Tx (mW)	Note1
(3)	Battery power for Rx (mW)	Note1

(4)	Battery power when Idle but not in PSM (mW)	Note1
(5)	Battery power in Power Save Mode (mW)	Note1
(6)	Number of reports per day	Note2
(7)	Rx time from PSM exit to re-entry into PSM (ms)	Table 7-1: 1+2+4+5+7+8+10+12+13+15
(8)	Idle time from PSM exit to re-entry into PSM (ms)	Table 7-1:17
(9)	Tx time from PSM exit to re-entry into PSM (ms)	Table 7-1:3+6+9+11+14+16
(10)	Time from last Rx or Tx activity to entry into PSM (ms)	Table 7-1:18

Note1: The power consumption according to the UE state can refer to 3GPP/Operator's specification or the real measurement result.

2) The battery life is calculated as follows, using the power and the duration of each state:

a. Power consumed per data report:

e1 (mW × ms) = energy for Tx + energy for Rx + energy for tasks in idle
= (9) × (2) + (7) × (3) + (8) × (4)

E1 (Joules) = e1 / 1000000

b. Power consumed per day:

E2 (Joules) = energy consumed per report × reports per day + energy in PSS per day
= E1 × (6) + (5) × 3600 × 24 / 1000

e2 (Watt Hours) = E2 / 3600

c. Days of battery life:

D = battery energy capacity / energy consumed per day
= (1) / e2

d. Years of battery life:

Y = D / 365

Note2: The power consumed per day by each device is also dependent on the reporting interval (Table 7-2 (6)). Table 7-3 provides an example of how the battery life analysis can be evaluated based on three application scenario.

Table 7-3: Application Scenario for Battery Life Analysis Evaluation

	Metering	**Kid Tracker**	**Bike Tracker**
Typical Context	Report Data	Kid's Status	Vehicle Unlock
Packet size, reporting interval combination	(Uplink) 100bytes, 12 hours	(Uplink) 1Kbytes, 1 min	Waiting for DL data, eDRX: 20sec

7.3 Chip Process and Power Consumption

7.3.1Ultra-Low Power Technology Definition

- Technology
  - Device optimized for 0.7 ~ 0.5V range
  - Device enhancement for extremely low leakage
    - High-Vt device for leakage reduction
    - Low-Vt device to achieve target speed
  - SRAM bit cell enhancement and innovation for low Vcc_{min}
- Ecosystem
  - EDA tool accuracy at 0.5V
  - Sign-off corner tightening to reduce conservatism
  - Low-Vdd design methodology
  - Low-Vdd foundation IP’s: standard cells, SRAM, RF

7.3.2Ultra-Low-Power Processes

In the field of semiconductor manufacturing, many IC foundries can offer multiple processes to provide significant power reduction benefits for MIoT and wearable products and a comprehensive design ecosystem to accelerate time-to-market for customers.

For an example, TSMC's ultra-low power process lineup expands from the existing 0.18-micron extremely low leakage (0.18eLL) and 90-nanometer ultra-low leakage (90uLL) nodes, to 55-nanometer ultra-low power (55ULP), 40ULP and 28ULP, which support processing speeds of up to 1.2GHz. The wide spectrum of ultra-low power processes is ideally suited for a variety of smart and power-efficient applications in the MIoT and wearable device markets. Radio frequency and embedded Flash memory capabilities are also available in 0.18um to 40nm ultra-low power technologies, enabling system level integration for smaller form factors as well as facilitating wireless connections among MIoT products.

Compared with their previous low power generations, TSMC's ultra-low power processes can further reduce operating voltages by 20% to 30% to lower both active power and standby power consumption and enable significant increases in battery life by 2x to 10x , when much smaller batteries are demanded in MIoT/wearable applications.

7.3.3The Relationship between Process and Power Consumption

Explain from the transistor structure that makes up the semiconductor integrated circuit, the leakage occurs because the drain and source are physically closer in a narrower transistor. The narrower a transistor is, the larger this leakage becomes. Therefore, choosing small process technology will get low active current but high leakage current, while choosing large process technology will get low leakage current but high active current.

For MIoT Chips, different application scenarios have different ratio of sleep, Tx and Rx duration. For high Tx/Rx ratio scenarios, small process technology is better for low active current. For sleep ratio scenarios, large process technology is better for low leakage current. From the description in section 7.2.3, if MIoT device upload data at a lower frequency, then over 50% (Deep sleep + Light Sleep) of energy spent doing nothing. Therefore, designer should pay more attention to leakage current, and the small process may not be a good choice.

7.4 Power Consumption Consideration and Battery life Evaluation

7.4.1Power Consumption Consideration in System Design

In MIoT chip and system low-power design process, there are three types of power consumption need special attention:

- Dynamic Power

As is described in section 7.3.3, choosing small process technology will get low active current. Active current is the main contributor to dynamic power. At the same time, lower clock frequencies will result in lower dynamic current under a specific process. But low frequency does not directly equal to low power consumption. Execution speed is also a factor in power consumption. In some cases, it may be optimal to run at a higher frequency and finish an operation more quickly to allow the system return to sleep for minimal power use. Therefore, choose a suitable clock frequency for MCU is important.

- Static Power

Static Power typically includes bias currents for analog circuits, low-power timekeeping oscillators and leakage current. It is a major concern for battery-based systems, which spend significant portions of the application lifetime in sleep mode. Therefore, in low power system design, designer should choose devices with low-power mode and low leakage current.

- Battery Power Leakage over Time

Battery Power Leakage over Time depends on battery self-discharge rate. It means the annual loss of battery power when not in use. This should be taken into account when estimating the battery life of MIoT devices. This part will be described in section 7.4.2.

In addition to the above three types of power consumption, there are other parts that require special consideration in software and hardware design for low-power system design.

In hardware design, in addition to the chip's own leakage, there are other sources of leakage, such as push buttons, led indicators, unused port pins, Pull-up/Pull-down resistor resistance, and capacitor leakage current, etc.

In software design, conditional code execution is recommended. When the program enters Idle or Doze, need to enter the low-power sleep mode as much as possible. Switching from polling-based system to interrupt-based system is highly recommended.

In addition, the trade-off between performance and power consumption must be taken into account: The ratio of the duration the program wakes up and sleeps needs to be optimized. A higher clock frequency can get higher instruction execution speed, but at the same time it also brings about a rise in power consumption. Instruction Set Architecture (ISA) determines the execution mode and speed of the instruction, not only related to the performance of the chip, but also the power consumption. Program running from RAM or Flash is also related to performance and power consumption. Program execution from RAM is fast and consumes low power. But copy program from Flash to RAM consumes significant time and power. In order to reduce power consumption, properly utilizing peripherals is also very important. Take the contrast of UART and SPI communication as an example, The UART and SPI data transfer speed and power consumption are shown in Table 7-4.

Table 7-4 The Power Consumption Comparison of UART and SPI Interface

Serial Communication	Current(uA)	Time to Send 10 Bytes(ms)	Total Charge (uA*ms)
UART (57.6K)	200	1.74	347.22
I2C (400kHz)	1000	0.25	250.00
SPI (4 MHz)	700	0.02	14.00

As described in the previous paragraph, a higher clock frequency brings about a rise in power consumption. Therefore, many engineers intuitively believe that choosing a UART for data communications will save even more power, for UART data transfer rate is far lower than the SPI. But in fact the power consumption = current * time. Lower data rates mean that the same amount of data requires longer transfer times. As shown in table 7-4, although the SPI current is larger, the amount of power consumed to transmit 10 bytes of data is less than that of the UART, because SPI transfers faster. The system can enter sleep mode after completing the transfer in order to achieve the purpose of further power saving.

7.4.2Battery Selection and Power Supply Design

➢ **Battery Selection based on Application**

Unlike smartphones, MIoT devices consume less power and can use non-rechargeable batteries in addition to rechargeable lithium batteries. The chemical composition of the battery determines its voltage rating:

- Non-chargeable Battery (Self-discharge : 1%~3% per year)
  - Li-SOCL2 (2.1V~3.9V)
  - Li-MnO2 (2.1V~3.63V)
  - 2-Series AA Battery (2.1V~3V)
- Chargeable Battery (Self-discharge : >15% per year)
  - Li-ion Battery (3.0V~4.3V) : Rechargeable

The characteristics of commonly used battery are shown in table 7-5.

Table 7-5 Commonly Used Battery Characteristics

Chemistry	Typical Form Factor	Nominal Voltage	Voltage Profile	Self-Discharge	Nominal Internal Resistance

Alkaline	AA/AAA	1.5V	Sloped	0.08%	150-300 mΩ
Li/MnO2	Coin Cell	3.0V	Flat	0.05%	10k-40k mΩ
Lithium-ion	Varies	3.6V	Flat	20%	30-40 mΩ
Ni/MH	AA/AAA	1.2V	Sloped	30%	30-40 mΩ

Self-discharge rate of the battery requires special attention. It means the annual loss of battery power when not in use. Non-chargeable battery self-discharge rate is about 1%~3% per year, while chargeable battery self-discharge rate is more than 15% per year. The self-discharge rate of non-rechargeable batteries is generally much lower than that of rechargeable batteries. This should be taken into account when estimating the battery life of MIoT devices. The recommended battery types for different categories MIoT devices are described in table 7-6.

Table 7-6 Battery selection advice for MIoT device

	Function	Wearable	Tracker	Smart door/meter	Data Module
Battery	Chargeable: Li-ion	○	x	x	x
	Non-chargeable: Li-MnO2	x	○	○	○
	Non-chargeable: AA Battery	x	○	○	○
Operation Temp.	Consumer Grade	-20~65C	-20~65C	-20~65C	-20~65C
	Industrial Grade	-40~85C	-40~85C	-40~85C	-40~85C

➢ **Battery Life Evaluation base on Application**

The characteristics of common MIoT applications and battery life evaluation are shown in Table 7-7

Table 7-7 Battery Life Evaluation base on Application

	Metering	Parking, Street	Kid Tracker	Health Wrist Band	Bike/ Car Tracker	Logistic
Typical Context	Report Data	Report Status	Kid's Status	Health Status	Vehicle Status	Cargo Status
Suggested Traffic Model (MO)	50bytes, 1day	50bytes, 1day	200bytes, 10sec	200bytes, 10 sec	200bytes, 2.5sec	200bytes, 2.5sec
Suggested (e)DRX Paging Delay (MT)	20s – 2min	20s – 2min	5.12s or 10.24s	5.12s or 10.24s	1.28s or 2.56s	1.28s or 2.56s
Max. Data Throughput	<10Kbps	<10Kbps	50~70Kbps (Voice)	~50Kbps (Voice)	~50Kbps (Voice)	~50Kbps (Voice)
Mobility[1]	-	-	<30Km	<30Km	<90Km	<90Km
Power Consumption (3600mA Battery	10 Years achievable	10Years achievable	Application dependent	Application dependent	Static Power Supply	Static Power Supply

with 50% Efficiency)						
Note 1: Definition of mobility refers to section 6.1.4						

- **System Power Supply Design**

Switching regulators (DC-DC) and linear regulator (LDO) are very common power supply components in power design for hardware systems. Switching regulators usually provide greater efficiency for applications. But they tend to have very low efficiency at low loading currents. A low-power system, which may spend most of its time asleep, a linear regulator should be a more efficient choice, even there is power consumption on itself. By designing a system capable of operating directly from the battery to avoid power loss caused by power conversion, and it will have a significant help in improving the system's battery life.

From the analysis in Section 7.4.2, it can be seen that different applications suggest different types of batteries to choose from. The effective voltage range of non-rechargeable and rechargeable batteries is different. Rechargeable lithium battery voltage up to 4.3V, but at the same time its discharge cut-off voltage is higher, not less than 3V. The non-rechargeable battery discharge cut-off voltage is usually low, can be as low as 2.1V. So for different battery options, MIoT system power supply design can be optimized.

At present, the common IO voltage of MIoT chip and hardware system is 1.8V, the core voltage is 1.2V or even lower, and the required voltage for PA is typically 1.8V to 4.3V.

If a rechargeable battery is adopted, the battery voltage needs to step down by PMIC to generate the core and IO power supply. Usually, the battery voltage is reduced to a voltage slightly higher than the target voltage by DC-DC, and then the voltage is stepped down by LDO to generate target voltage for different requirement. The purpose of this is that direct use of LDO for voltage step down will introduce excessive power loss on the LDO due to larger dropout, resulting in increased system power consumption. However, the voltage step down of DC-DC and LDO will inevitably cause loss of power. By dynamically adjusting the power on and off of these power sources can minimize power consumption.

If a non-rechargeable battery is adopted, and the PMIC using the same step-down scheme, the power loss on the power supply will be relatively lower，because of its relatively low supply voltage (2.1V-3.xV). At the same time if the PA can also work in the lower voltage range (such as 1.8V), it will be very helpful to reduce the power consumption of the entire system.

Therefore, for low-power required chip and system designs such as MIoT, it is highly recommended that the PMIC can directly support lower voltage (e.g. 2.1V-3.6V) inputs without additional power conversion (non-rechargeable batteries directly power). Low voltage and less power conversion means less power loss, while the lower discharge cut-off voltage provided by non-rechargeable batteries also provides a longer battery life.

7.4.3Memory Selection: PSRAM vs. DRAM

If the system complexity, the RAM capacity and read/write speed requirement of application are not high, the PSRAM (Pseudo SRAM) is a better choice than DRAM, especially in low-power system design.

PSRAM is a combinational form of a dynamic RAM that incorporates various refresh and control circuit on-chip (e.g., refresh address counter and multiplexer, interval timer, and arbiter). These circuits allow the PSRAM operating characteristics to closely resemble those of an SRAM. It's a random-access memory. In the standby mode, it can mimic the function of a static memory. Note in practice, unlike so-called self-refresh DRAMs, PSRAMs have non-multiplexed address lines and pinouts similar to those of SRAMs. For power consumption, PSRAM has the same or lower driving current as SRAM, and a much lower current hold current than DRAM.

In conclusion, PSRAM is DRAM core designs with SRAM interface, as shown in figure 7-4

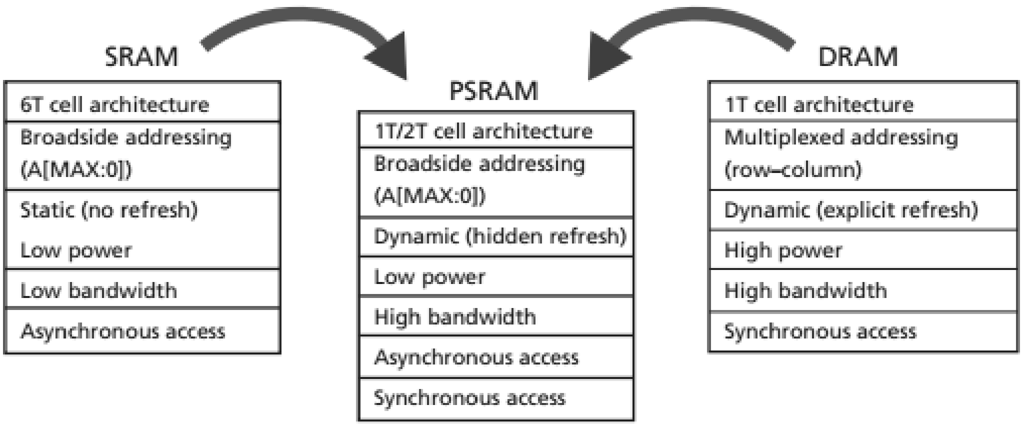


Figure 7-4 PSRAM Architecture and Characteristics

7.4.4RFFE Design for Power Consumption Optimization

In low-power design, adopting RF front end module in MIoT system design instead of discrete RF front end component is recommended. Firstly, it can reduce the power consumption and increase battery life at the same time. Because RF front end module can improve PA efficiency and reduce the front end loss by integration. Secondly, it is easy to use. RF front module is good for all applications and can be widely adopted. In RF front end module, all RF components are integrated in one module, and there is no need to tune the RF matching, which guarantees good RF performance.

8 eUICC based implementation solution for MIoT devices

8.1 Overview

eUICC means a UICC which is not easily accessible or replaceable, is not intended to be removed or replaced in the device, and enables the secure changing of Profiles. And MIoT Devices in this chapter indicate machine-to-machine devices where the consumer does not have a direct contract or relationship with a Service Provider of their choice to operate the Device.

8.2 General Architecture

eUICC Profile Data is prepared by Operators and eUICC Manufacturers. With Subscription Manager Servers, eUICC Profiles are downloaded to eUICCs through OTA. SM-SR(triggered by MNO) sends ISD-R a MT-SMS to trigger HTTPs session. MIoT device uses ENVELOPE (SMS-PP Download) command to forward SMS-PP to eUICC, then eUICC uses PROACTIVE command (OPEN CHANNEL) to request MIoT device to establish a HTTPs session with SM-SR. SM-SR sends INSTALL, STORE DATA commands through OTA platform. Figure 8-1 represents the General Architecture of eUICC terminal, and Figure 8-2 outlines a schematic representation of the eUICC.

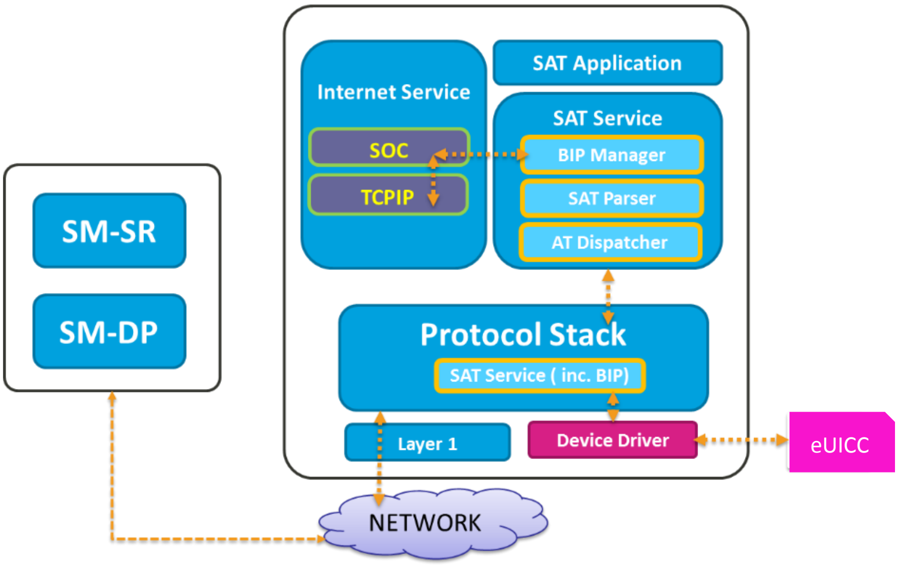


Figure 8-1 General Architecture of eUICC terminal

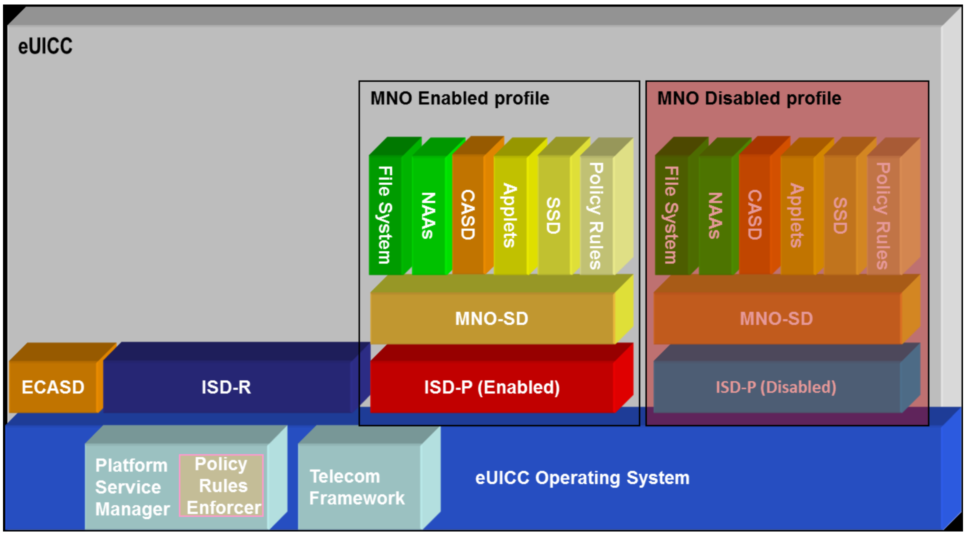


Figure 8-2 Schematic Representation of the eUICC

8.3 eUICC Remote Provisioning Implementation solution

8.3.1Overview

eUICC Remote Provisioning is defined as the capability to download, install, activate, deactivate, and delete an operator Profile/Subscription, switch between two Profiles, on an eUICC remotely. It should be noted that although the eUICC can hold multiple profiles/subscriptions, only one active profile/subscription will be possible at any point of time. The ecosystem includes different players: the eUICC manufacturers, the Device manufacturers, the Operators, Service Providers, the subscribers, end users and the Certificate Issuers. Figure 8-3 represents the eUICC Remote Provisioning system.

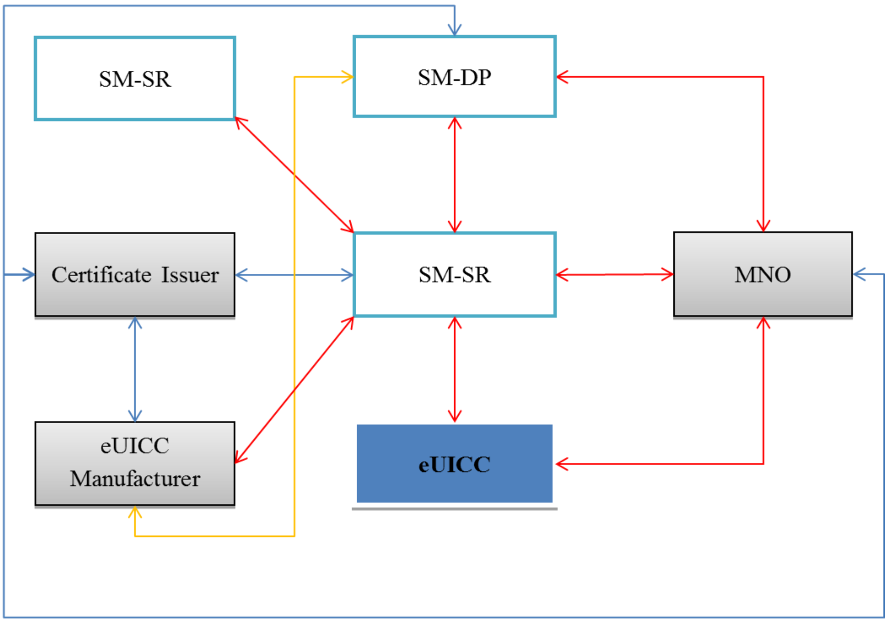


Figure 8-3 eUICC Remote Provisioning System

8.3.2eUICC Remote Provisioning Procedures

The procedures described in this section involve both interactions between the Roles of the business environment (e.g. between a Customer and a Service Provider) and between entities of the remote Provisioning architecture (e.g. between eUICC and SM-SR).

The following main procedures for the Provisioning and lifecycle management of eUICCs and related Profiles are identified (According to GSMA SGP.01-v1.12).

Table 8-1 eUICC Remote Provisioning Procedures

No	Name	Purpose
1	eUICC Registration at SM-SR	To register a newly manufactured eUICC at a given SM-SR as a prerequisite for subsequent remote management
2	Profile Ordering	For the MNO to order at the SM-DP a quantity of Profiles ready for download
3	Profile Download and Installation	To download a Profile to a given eUICC
4	Master Delete	To delete an Orphaned Profile in a given eUICC
5	Profile Enabling	To enable a Profile in a given eUICC via SM-SR
6	Profile Enabling via SM-DP	To enable a Profile in a given eUICC via SM-DP
7	Profile Disabling	To disable the Enabled Profile and enable the Profile with Fall-back Attribute set.
8	ISD-P Deletion	To delete a Profile and its ISD-P from a given eUICC via SM-SR.
9	ISD-P Deletion via SM-DP	To delete a Profile and its ISD-P from a given eUICC via SM-DP.
10	SM-SR Change	To change the SM-SR of a given eUICC
11	ISD-P Key Establishment	Key establishment procedure between the SM-DP and the ISD-P
12	Fall-back Mechanism	To enable the Profile with Fall-Back Attribute set in a given eUICC
13	eUICC Certificate Check	To verify whether the targeted eUICC is certified.

- **eUICC Registration at SM-SR**

As a mandatory step in the production process and prior to shipment, the EUM registers the eUICC at a selected SM-SR. This means that related information which is relevant throughout its further lifetime, in particular the Platform Management Credentials, Provisioning MSISDN, are stored in the SM-SR database. Without this step, remote access to the eUICC will be impossible.

The eUICC registration comprises the following steps, as shown in Figure 8-4.

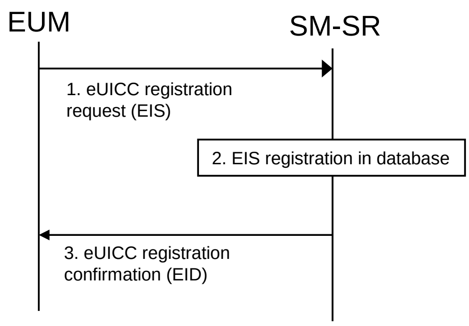


Figure 8-4 eUICC Registration at SM-SR

- **Profile Download and Installation**

In order for MIoT Device to be used for communication services, the eUICC must be loaded with at least one Operational Profile. In general, this will be done over-the-air, using the Subscription represented by the currently Enabled Profile.

The Profile download and installation procedure is shown in Figure 8-5.

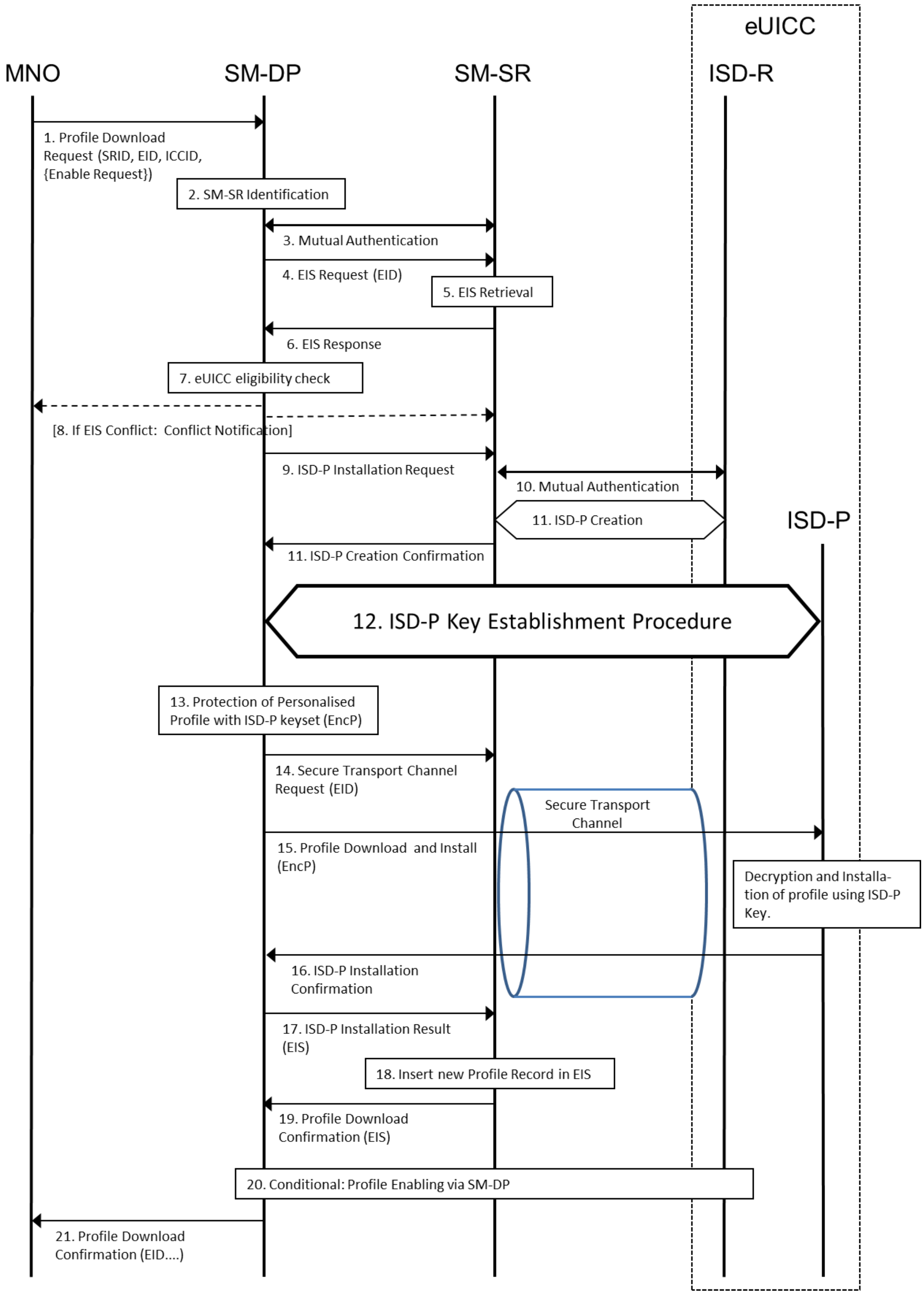


Figure 8-5 Profile Download

- **Master Delete**

This procedure deletes an Orphaned Profile without the Fall-back Attribute set regardless of the Profile's policy rules. The successful execution of this procedure requires the authorisation of both the Initiator and the SM-DP.

- **Profile Enabling**

A switch between two Profiles can be achieved by the following dedicated procedure, as shown in Figure 8-6. In this case the request is issued directly by the MNO to the SM-SR associated with the target eUICC.

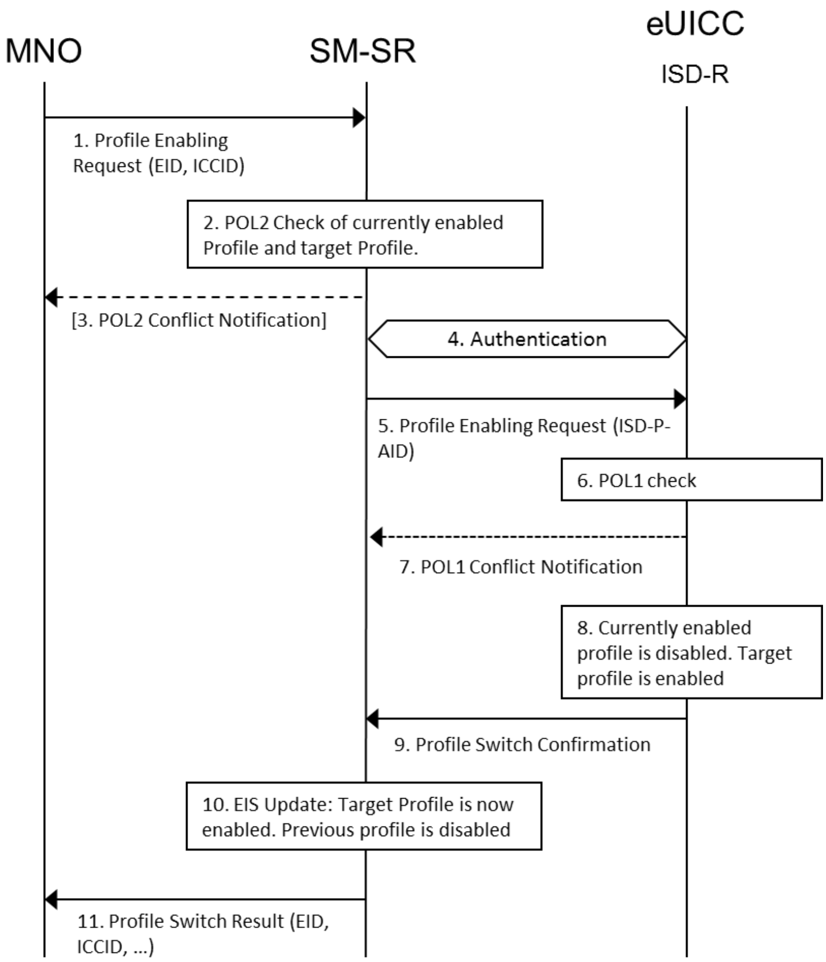


Figure 8-6 Profile Enabling

- **Profile Enabling via SM-DP**

A switch between two Profiles can be achieved by the following dedicated procedure. In this case, the request is issued by the MNO to the SM-DP which forwards it to the SM-SR associated with the target eUICC. This way, the MNO does not have to be linked to the SM-SR and relies on the SM-DP to make the connection.

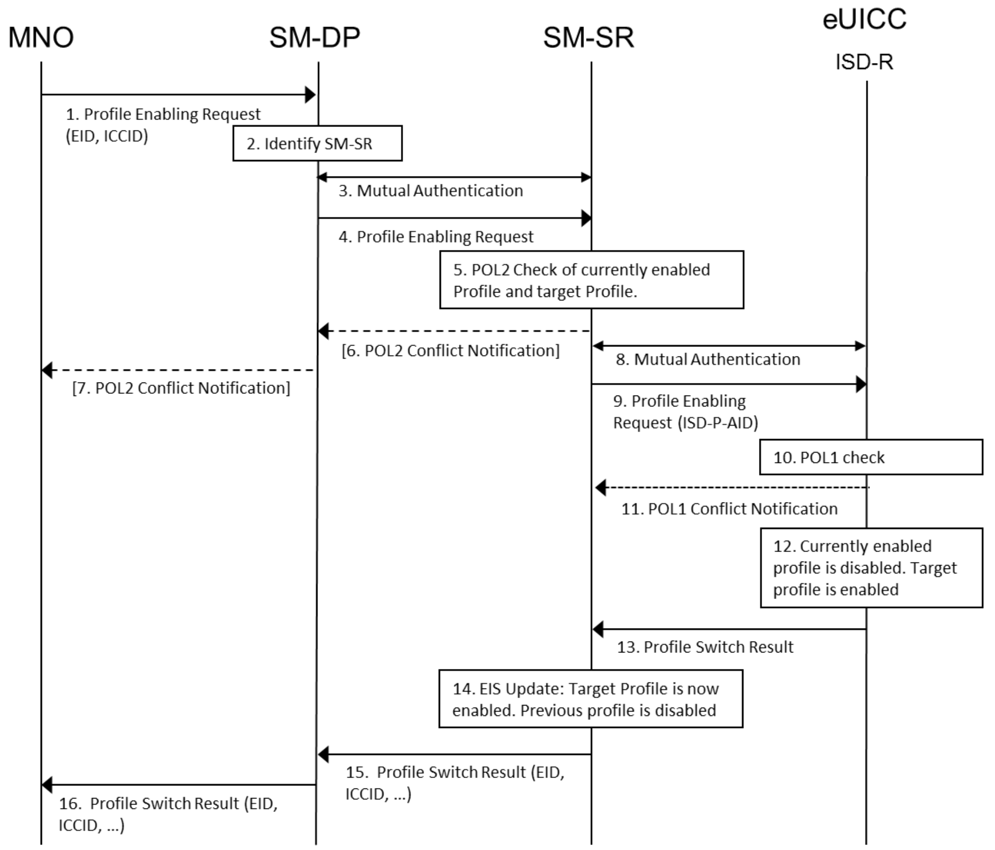


Figure 8-7 Profile Enabling via SM-DP

- **Profile Disabling**

Profile disabling can be achieved by the following procedure, as shown in Figure 8-8. The request is issued directly by the MNO to the SM-SR associated with the target eUICC.

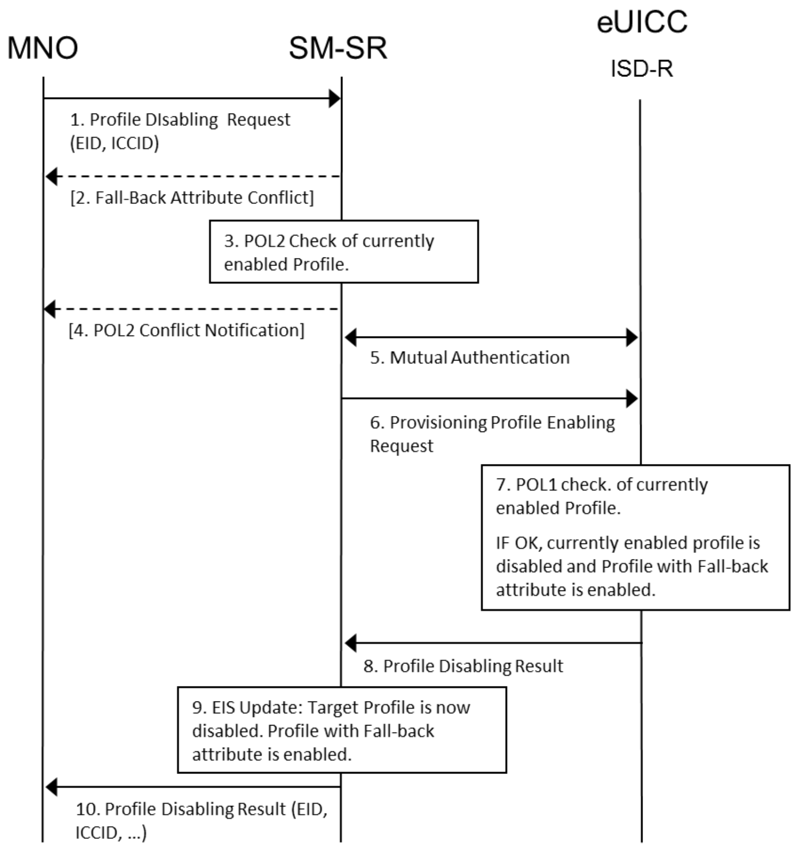


Figure 8-8 Profile Disabling

➢ **ISD-P Deletion**

A Profile can be deleted by its MNO. The SM-SR sends the ISD-P Deletion request to the ISD-R on the eUICC. The request includes the ISD-P AID of the target Profile. The target Profile is deleted from the eUICC.

➢ **ISD-P Deletion via SM-DP**

ISD-P deletion would be requested via the SM-DP. In this case, the MNO does not have to be linked to all SM-SRs and relies on the SM-DP to make the connection.

➢ **SM-SR Change**

This procedure assumes that, prior to the procedure being executed, the MNOs with installed Profiles on the concerned eUICC might request to be informed of the change by the current SM-SR (SM-SR1) and be allowed to take action as it relates to the desired disposition of their Profile (e.g. do nothing, update Policy rules, deletion of the Profile).

In the case where the SM-SR has to be changed, the credentials of the individual eUICCs must remain confidential.

➢ **ISD-P Key Establishment Procedure**

This procedure details the establishment of the keyset in the Secure Download and Installation process.

➢ **Fall-Back Mechanism**

In the event of loss of network connectivity, as detected by MIoT Device, there is a need to change to the Profile with Fall-back attribute set. In this case the eUICC disables the currently Enabled Profile (Profile A) and enables the Profile with Fall-back Attribute set (Profile B).

8.3.3Bearer Independent Protocol

The CAT provides mechanisms which allow applications, resident on the eUICC, to interact and operate with any terminal which supports the specific mechanism(s) required by the application.

The set of proactive commands (OPEN CHANNEL, CLOSE CHANNEL, SEND DATA, RECEIVE DATA, and GET CHANNEL STATUS) and events (Data available, Channel status) allow the eUICC to establish a data channel with the MIoT device, and through the MIoT device to a remote Server in the Network. The eUICC provides information for the MIoT device to select an available bearer at the time of channel establishment. The MIoT device then allows the eUICC and the Server to exchange data on this channel transparently. The eUICC uses service of MIoT device lower layer to send data. Figure 8-9 and Figure 8-10 represent how the BIP works.

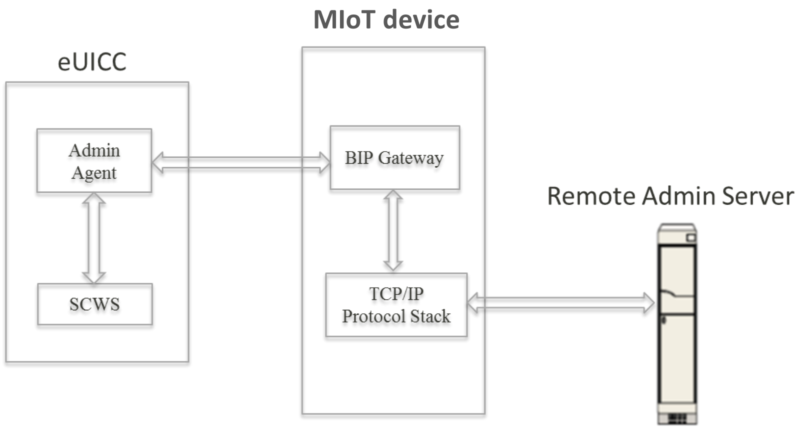


Figure 8-9 MIoT device forwards TCP/IP socket data from/to eUICC

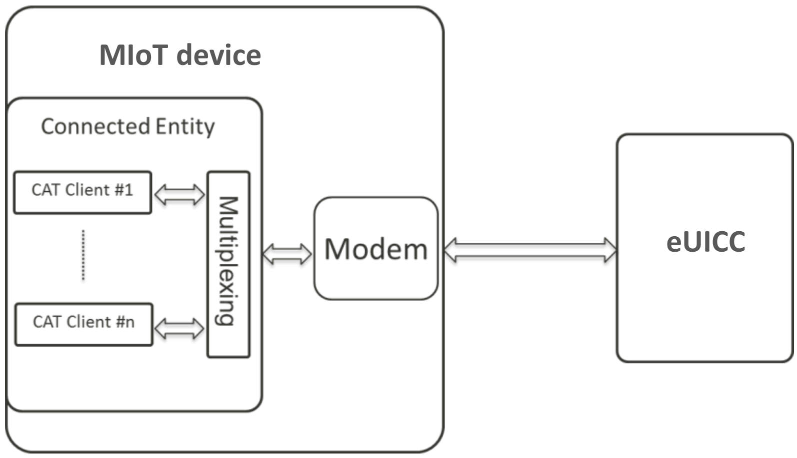


Figure 8-10 Interface between MIoT device and eUICC

- **BIP Command**

1. OPEN CHANNEL

Upon receiving this command, the MIoT device shall decide if it is able to execute the command. The eUICC shall indicate whether the MIoT device should establish the link immediately or upon receiving the first transmitted data (on demand).

The eUICC provides to the MIoT device a list of parameters necessary to establish a link. The eUICC may request the use of an automatic reconnection mechanism. The eUICC may also request an optional maximum duration for the reconnection mechanism. The MIoT device shall attempt at least one link establishment set-up.

2. CLOSE CHANNEL

This command requests the MIoT device to close the channel corresponding to the Channel identifier as indicated in the Device identities.

3. RECEIVE DATA

This command requests the MIoT device to return data from a dedicated Channel identifier (indicated in the Device identities) according to the number of bytes specified by the eUICC.

Upon receiving this command, the MIoT device shall return the data available in the Rx buffer corresponding to the Channel identifier. Examples are given below, but the list is not exhaustive.

4. SEND DATA

This command requests the MIoT device to send data through a previously set up data channel corresponding to a dedicated Channel identifier (indicated in the Device identities).

5. GET CHANNEL STATUS

This command requests the MIoT device to return a Channel status data object for each dedicated Channel identifier. The terminal shall return the requested information concerning the channel(s) within a TERMINAL RESPONSE command.