Improving Energy Efficiency for Mobile IoT

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Table of Contents

Table of Figures

Table of Tables

1. Introduction

1.1. Overview

The 5G Mobile IoT technologies LTE-M and NB-IoT are recognised Low Power Wide Area Network (LPWAN) technologies. Every day, devices based on these technologies are being deployed worldwide in support of a wide variety of applications. With many devices battery powered, it is imperative application developers configure their software to maximise the low power potential of these devices and deliver the best possible experience and longest battery life for customers.

The information provided in this white paper is based on input received from members of the 5G IoT Strategy Group who, having deployed 5G Mobile IoT devices across the globe, have shared their knowledge and experience.

1.2. Scope

This document provides insight into the energy efficiency capabilities of the 5G Mobile IoT technologies LTE-M and NB-IoT. It describes some of the key energy efficiency features available to devices using these technologies, tools and measurement scenarios used to assess performance, network parameters and values that may influence outcomes as well as typical use cases deployed using these technologies.

By studying the benefits of specific energy efficiency features of the 5G Mobile IoT technologies (LTE-M and NB-IoT), the document creates a baseline to guide application developers building low energy solutions using these technologies.

To achieve global coverage and wide adoption of NB-IoT and LTE-M services, Mobile Network Operators must ensure that devices and end-to-end services from various providers will connect to the NB-IoT and LTE-M systems that have been deployed, and that the data transport capability and connection modes are well understood. To these means, the GSMA has published the “NB-IoT Deployment Guide” and “LTE-M Deployment Guide”. These documents contain non-binding guidelines designed to help MNOs deploying LTE-M networks and devices globally to ensure interoperability and smooth roaming. They identify a minimum set of key features, details key configurations and considerations for deployments.

Although best practice guidelines for Mobile Network Operators can be helpful, customers increasingly need support in navigating the rich set of energy efficiency features that both 3GPP™ technologies provide.

1.3. References

Reference	Document	Name
1	3GPP TR 23.002	Network architecture; Release 13 or higher
2	3GPP TS 23.060	General Packet Radio Service (GPRS); Service description; Release 13 or higher
3	3GPP TS 23.401	General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial

Reference	Document	Name
		Radio Access Network (E-UTRAN) access; Release 13 or higher
4	3GPP TS 23.682	Architecture enhancements to facilitate communications with packet data networks and applications; Release 13 or higher
5	GSMA TS.09	Battery Life Measurement and Current Consumption Technique, version 11 or higher
6	3GPP TS45.820	Cellular system support for ultra-low complexity and low throughput Internet of Things (CIoT)
7	GSMA CLP.29	LTE-M Deployment Guide to Basic Feature Set Requirements
8	GSMA CLP.28	NB-IoT Deployment Guide to Basic Feature set Requirements

Table 1 – References

1.4. Abbreviations

Term	Description
3GPP	Third Generation Partnership Project
cDRX	Connected DRX
CoAP	Constrained Application Protocol
dB	Decibel
dBm	electrical power unit in decibels (dB), referenced to 1 milliwatt (mW)
DL	Down Link
DRX	Discontinuous Reception
DTLS	Datagram Transport Layer Security
DUT	Device Under Test
EDGE	Enhanced Data Rates for GSM Evolution
eDRX	Extended Discontinuous Reception
eMTC	Enhanced Machine Type Communications
eNodeB	Radio base station
eUICC	Embedded Universal Integrated Circuit Card
GPRS	General Packet Radio Service
HTTP	Hyper Text Transfer Protocol
Hz	Hertz
iDRX	Idle mode DRX

Term	Description
IE	Information Element
IoT	Internet of Things
IP	Internet Protocol
LPWA	Low Power Wide Area
LTE	Long Term Evolution
LTE-M	LTE for Machines – synonym for eMTC
LwM2M	Light weight Machine to Machine
Mobile IoT	LTE-M and NB-IoT technologies
MIoT	Mobile IoT
MNO	Mobile Network Operator
MQTT	Message Queuing Telemetry Transport
NB-IoT	Narrow Band Internet of Things
PA	Power Amplifier
PDCCH	Physical Downlink Control Channel
PSM	Power Saving Mode
PTW	Paging Time Window
RAI	Release Assistance Indication
RF	Radio Frequency
RRC	Radio Resource Control
RT	Recommended Test
Rx	Receive
TAU	Tracking Area Update
TCP	Transmission Control Protocol
TLS	Transport Layer Security
Tx	Transmit
UDP	User Datagram Protocol
UE	User Equipment
UL	Up Link

Table 2 – Abbreviations

2. Mobile IoT Energy Efficiency Features

2.1. Introduction

Mobile IoT refers to the standardised and secure 3GPP™ low power wide area (LPWA) operator managed IoT networks operating in licensed spectrum. In particular, mobile IoT networks are designed for low cost IoT applications using low data rates, requiring long battery lives and often operating in remote and hard to reach locations. Two mobile IoT technologies were specified by 3GPP™ in Release 13, Release 14 and Release 15. These have been subsequently commercially launched over the past years by mobile network operators: NarrowBand IoT (NB-IoT) and LTE-M. Both address the fast-expanding market for low power wide area connectivity.

This document on Mobile IoT Energy Efficiency is part of the GSMA mobile IoT initiative, designed to support service providers, developers and manufacturers using mobile IoT technology to accelerate commercial availability of low power wide area solutions in licensed spectrum.

Whereas classical LTE technology began introducing energy efficiencies with features such as Idle Mode DRX (iDRX), mobile IoT has brought in a myriad of new power saving capabilities allowing the battery life of optimised devices to last up to a decade. This document primarily focuses on Release 13 and Release 14 features, as most mobile network operators have deployed these specific releases of the 3GPP™ standard on their networks. These features, which are available for use in both NB-IoT and LTE-M, can be used individually or in combination for mobile IoT solutions to conserve battery power.

2.1.1. Energy consumption model

Models used for energy consumption vary on technology. Power consumption test methods and parameters can be found for many 3GPP system capable devices in GSMA document TS.09 [5].

Both lower 3GPP protocol layers and higher application layers must be taken into consideration when measuring the power consumption of these devices. Figure 1 illustrates a typical power profile for LPWA devices using LTE-M or NB-IoT technology:

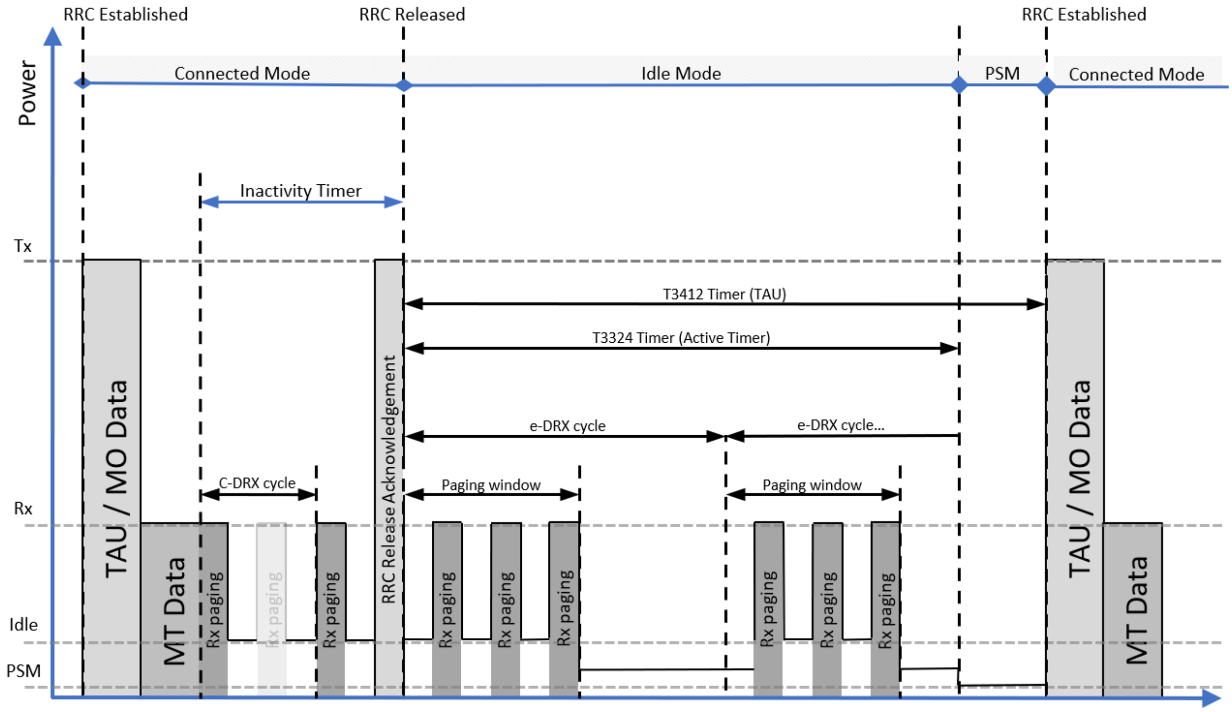

Figure 1 – Power profile

Figure 1 outlines the relative power consumption, the Tx and Rx signalling of the device and the lower power consumption of idle and PSM modes. Here we can see three modes of operation; Connected Mode, Idle Mode and Power Save Mode (PSM). Each mode has various features that can be used by the customer and network operator to provide an energy efficient application.

Figure 2 illustrates the typical power consumption profile of a wireless communication module during connected mode and idle mode. After a data transmission completes, an inactivity timer is started in the eNodeB. Upon the latter's expiration, a Radio Resource Control (RRC) release message is sent by the eNodeB down to the IoT device. Upon receiving this message, the device sends an acknowledgement back to the eNodeB (as illustrated), the radio bearer releases, putting the device into idle mode. Note that connected mode usually consumes far more energy than idle mode, especially if Discontinuous Reception (DRX) in connected mode is not be supported by the network. In idle mode, however, DRX is generally supported and activated on both networks and wireless communication modules.

An IoT device remains in idle mode until the either the next application message or a Tracking Area Update (TAU) message is sent. In each case, the module will re-enter connected mode but a TAU message does not trigger an inactivity timer. In this case, the wireless communication module drops directly back into idle mode. Successive transmissions of application messages will trigger the activity timer with RRC release.

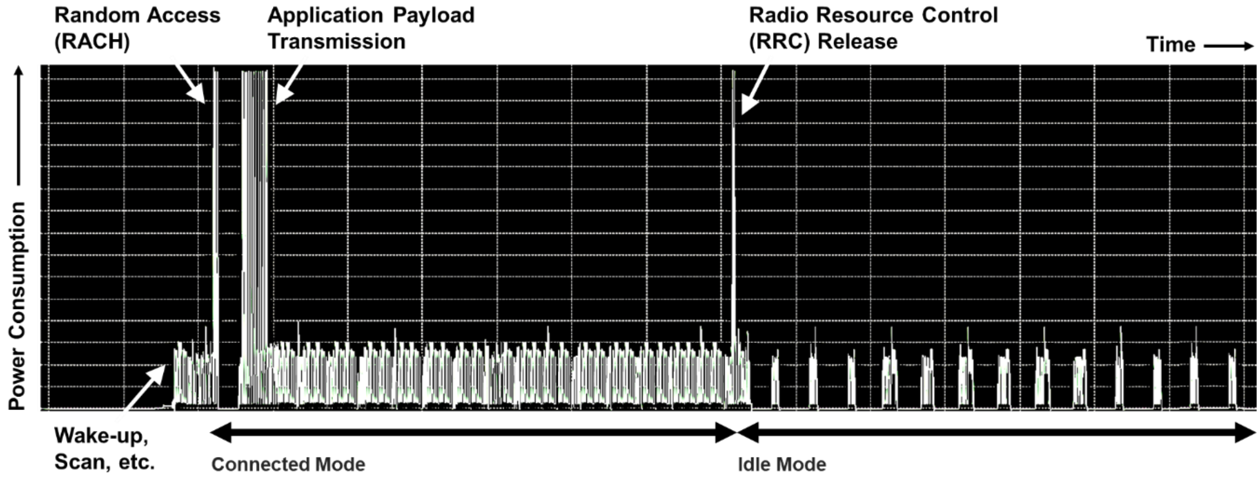

Figure 2 – Connected Mode & Idle Mode Procedures

Idle Mode power saving features:

- Long-Periodic Tracking Area Updates,
- Enhanced Discontinuous Reception (eDRX),
- Power Saving Mode (PSM).

Connected Mode power saving features:

- Connected Mode Discontinuous Reception (cDRX),
- Release Assistance Indication (RAI).

It is critical to note though that these power saving features must be used according to the specific IoT application use-case. Using these features inappropriately may in some cases, lead to wasting more battery life or even to a failing product design. Figure 3 indicates which combinations of power saving features are recommended for different scenarios.

	Long Periodic TAU	eDRX	PSM	RAI
Uplink-centric Application				
Very Regular Reporting (e.g. Asset Tracker)	Beneficial if reporting interval > 186 minutes	✗	✓	✓
Regular Reporting (e.g. Smart Parking)		✗	✓	✓
Irregular Reporting (e.g. Smart Metering)		✗	✓	✓
Downlink-centric Application				
Very Regular Reporting (e.g. Access Control)	Beneficial if reporting interval > 186 minutes	✗	✗	✗
Regular Reporting (e.g. Ventilation Valve)		✓	✗	✓
Irregular Reporting (e.g. Pet Tracker)		✓	✓	✓

Figure 3 – Power Saving Features use cases

2.1.2. Transmitter Power

Tx power output has a significant impact on the power consumption of mobile IoT devices. Older 2G systems have considerable energy consumption where PA output can be as high as 33 dBm. Low Power Wide Area (LPWA) devices address this issue and reduce the power output to a maximum of 23 dBm. Typical 2G devices can consume 2.5 A when transmitting, limiting choice for battery requirements, whereas LPWA LTE-M/NB-IoT devices typically consume less than 400 mA at their maximum +23 dBm output. With the lower power consumption and demand from LPWA devices, wider battery choices are available.

Some MIoT devices support multiple LPWA technologies including 2G as a fallback option. These modules are an option when the deployment is unknown and 2G might be the only connection available. Modules with 2G-fallback may have a PA which is not optimised for LPWA. When using modules with 2G-fallback, the power consumption of the LPWA technologies NB-IoT and LTE-M may be higher than they would be on non-2G enabled devices. Careful review of product datasheets should be taken in this case.

2.1.3. Application protocols

The choice of application protocol also impacts the overall power consumption of the device. The application protocol will dictate how long the module is in connected mode and how long it can go to sleep when using eDRX and PSM.

Applications can be designed to use basic UDP/IP communication with no acknowledgement of IP packets. Messaging can be quick using a “Fire & Forget” type design. If acknowledgements are required, CoAP can provide acknowledgements on top of UDP/IP. CoAP is designed for small messages. The entire message would need to be retransmitted if lost. For more complex applications LwM2M can build on top of CoAP to provide device management and a standard way of describing and updating resources.

For larger messages, TCP/IP communication would be used where the larger message size can be safely broken into smaller acknowledged chunks of data. MQTT and HTTP are protocols that use TCP/IP communication.

Security of application messages is a very important consideration for device design. Security options can cause the module to remain in connected mode for many seconds, transferring certificates between client and server. The impact of how security is implemented for both the client and server needs to be considered.

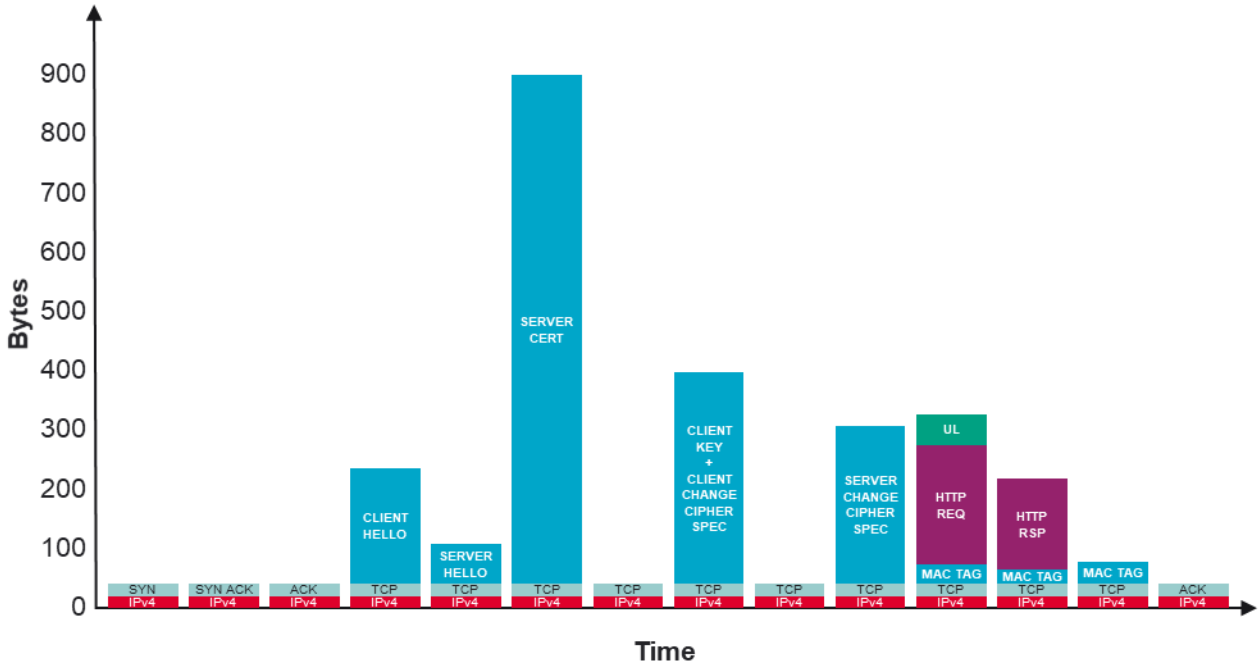

Figure 4 – HTTP with TLS (HTTPS) – using TLS_RSA_WITH_AES_256_CBC_SHA256

Figure 5 – CoAP with DTLS – using TLS_PSK_WITH_AES_256_CBC_SHA384

For applications requiring unsolicited downlink messaging, the device will have to periodically wake up. eDRX can be used to reduce energy consumption, but it is possible other application designs may be more energy efficient.

For chatty applications, where there are messages sent back and forth between client and server, the server's response time needs to be optimised. Any delay in the server responding back to the client will cause the device to stay in connected mode longer. There could be a chance the device will transition into idle mode if the server takes too long, incurring additional energy consumption by the device to re-enter connected mode.

2.2. Long Periodic Tracking Area Updates (TAU)

2.2.1. Overview

To understand the benefit of this idle mode power saving feature, it is important to understand the underlying "Tracking Area Update" (TAU) functionality. In conformance to 3GPP™ Layer 3 procedures, the chipset protocol stack transmits TAU messages at regular intervals to keep the network updated about the IoT device's location. If the IoT devices fails to send the TAU before the expiration of a TAU timer (T3412), the network considers that the device is no longer within its footprint. It is subsequently deregistered from the network. If the device sends a TAU in a timely manner, the data context is kept active and there is no need to reattach to the network. The T3412 timer is restarted when the device is released from connected mode

Please note that the IoT device's chipset protocol stack will trigger a TAU in any of the following cases:

- When a device moves to a new Tracking Area which is not included in its list of Tracking Areas with which it was registered,
- When the T3412 timer expires,
- When Enabling, disabling, or changing the eDRX, TAU or PSM parameters after an ATTACH.

A T3412 timer value is proposed by the IoT device to the network. The network can accept or reject this value. If the network rejects the value, then the IoT device does not perform periodic tracking area updates.

A major reason for moving IoT applications from legacy technologies, such as 2G or 3G, onto NB-IoT and LTE-M is the availability of an extended version of the long periodic TAU timer, T3412ext. As defined in 3GPP™ Technical Standard TS24.301 Release 14, the long periodic tracking area update feature allows this time interval between TAU events to be greatly increased, up to approximately 413 days. Depending on the feature support of the chipset and/or network infrastructure, T3412ext may be limited to 310 hours.

Figure 6 illustrates the typical power consumption profile of a wireless communication module when using the long periodic TAU feature. Prior to the expiration of the extended T3412 timer, the wireless communication module needs to temporarily enter connected mode to send a tracking area update. Upon sending its TAU, the module can re-enter idle mode without waiting for an inactivity timer to expire.

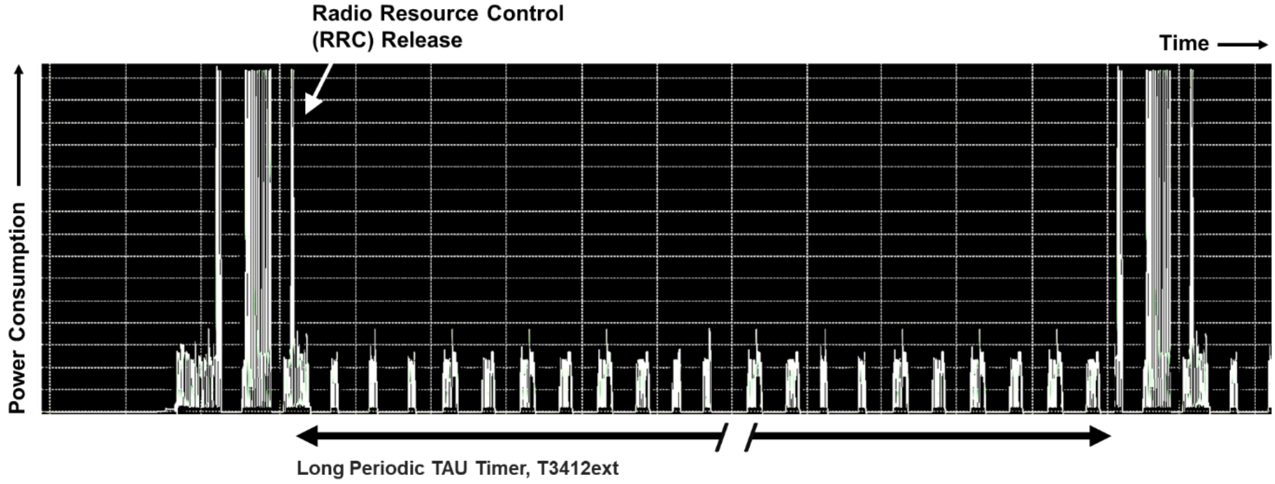

Figure 6 – Long Periodic Tracking Area Update (TAU)

2.2.2. Applicability

The benefit of the long periodic TAU is the chipset protocol stack can remain in deep sleep mode for a longer duration (refer to Section 2.4 Power Saving Mode) before it must wake up to send a TAU message.

2.3. Extended Discontinuous Reception (eDRX)

2.3.1. Short presentation

Another idle mode power saving feature is Extended Discontinuous Reception (eDRX), an extension of the existing LTE idle mode feature “Discontinuous Reception (DRX)”, which can be used by IoT devices to reduce power consumption. It is specified in 3GPP™ Technical Standards TS23.682 and TS24.301.

Today, millions of smartphones use discontinuous reception to extend battery life between recharges. By momentarily switching off the receive section of the radio chipset for a fraction of a second (the interval being controlled by the network defined DRX Timer parameter, TDRX), these smartphones can save power. When the device wakes up, the receiver will listen on the physical control channel. The smartphone cannot be contacted by the network during the period that it is not listening, but if the period is kept rather short, the smartphone user will not experience a noticeable degradation of service.

In a similar way, the Extended DRX feature allows this time interval during which a device is not listening to the network to be greatly increased. IoT devices perform the DRX procedure during fixed time windows whilst in idle mode, called Paging Time Windows (PTW). Between 4-16 paging reception slots can be accommodated within each Paging Time Window duration, or TPTW. The subsequent PTWs are further offset from each other by a second timer, TeDRX, which represents the eDRX Cycle. Both the size of the PTW and the TeDRX timer can be defined by the IoT application. In between PTW, the receive circuitry of the radio chipset is deactivated. For M2M or IoT applications, it might be quite acceptable for the device to not be reachable for many seconds, or even hours. Although it does not provide the same levels of power reduction as PSM, eDRX may provide a good compromise for many use cases between device reachability and power consumption.

In summary, there are three features which control how eDRX is configured:

- TDRX, the duration of a DRX period, as defined by the mobile network operator,

- TPTW, the duration of the Paging Time Window, as defined by the IoT application. The PTW controls the number of DRX cycles completed in series before the chipset receive circuitry is deactivated for a longer period until the next PTW,

- TeDRX, the duration between the start of a PTW and the proceeding one, as defined by the IoT application. The interval where the chipset has reduced its power consumption by deactivating it’s receive circuitry may be seen as a form of "Sleep Mode",

In Figure 7, one can see how extended DRX improves the power consumption profile of a wireless communication module during idle mode. Discrete time windows of discontinuous reception (representing the Paging Time Windows) are cyclically starting at the offset defined by the eDRX Timer. In between these PTWs, the module may typically consume less than a few microamps.

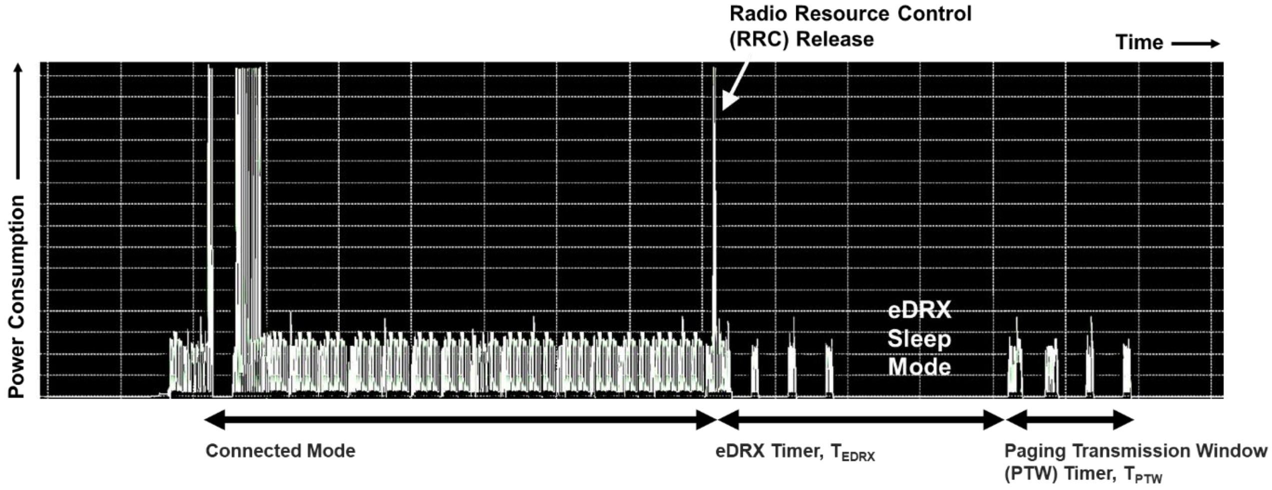

Figure 7 – Extended Discontinuous Reception (eDRX)

2.4. Power Saving Mode (PSM)

2.4.1. Short presentation

Although it is possible for an IoT device’s application to shut-down the radio module or chipset to conserve battery power between messages, the device would subsequently need to reattach to the network every time that the module or chipset is turned back on. This re-attach procedure consumes energy that can become significant over time and generates unnecessary signalling. As such, this procedure should be avoided if it would need to occur too frequently. The viable alternative is to use Power Saving Mode (PSM), as specified in 3GPP™ Release 12. Initially intended to help LTE devices conserve battery power during idle mode and potentially achieve longer battery life, the feature was subsequently inherited by the NB-IoT and LTE-M specifications.

PSM disables parts of the chipset protocol stack and drops power consumption into the micro-Ampere range.

The IoT device may request the use of Power Saving Mode (PSM) simply by including a timer with the desired value in an attach, TAU or routing area update message. The maximum time a device may be reachable after sending this message is 186 minutes (11160 seconds). This is often referred to as the “PSM Activity Timer”, T3324. The network may accept these values or set different ones. The network then retains the state information and the IoT device remains registered with the network during its hibernation.

Upon expiration of the T3324 timer, the chipset or module in the IoT device powers down many of its subsystems to enter a "Deep Sleep Mode”. The maximum time a device may stay in this hibernation state is approximately 413 days (as governed by the 3GPP™ Release 14 T3412 timer). Please note that some operator core networks support shorter T3412 timer values. For example, 310 hours.

If a device wakes before the expiration of the time interval to send data, a reattach procedure is not required. This wake-up procedure can be triggered by applying power to a pin of the module or chipset.

Power Saving Mode is visualised in Figure 8. The expiration of the activity timer triggers the RRC release message, placing the wireless communication module into Idle Mode so a PSM T3324 timer can be started. The network may only support a static timer or allow the IoT device to propose a dynamic value for T3324. Once the timer expires, the module silently drops into power saving mode, where it typically consumes a few microamps on average.

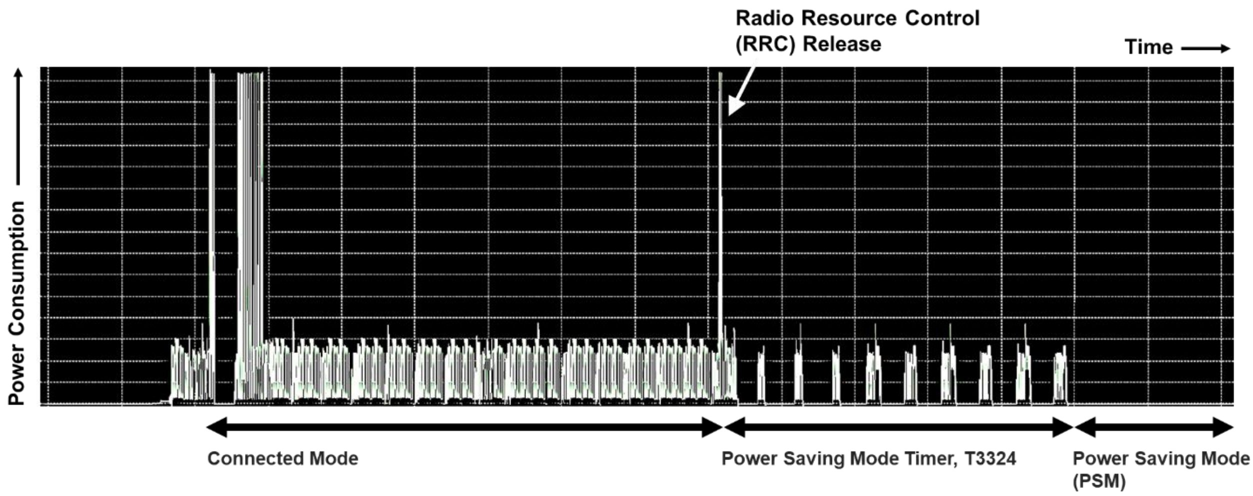

Figure 8 – Power Saving Mode (PSM)

As seen in Figure 8, the benefit of power saving mode is that the module can consume very low average currents in a sleep mode for a prolonged time. That is, until the next application message or scheduled TAU message triggers the wireless communication module to wake-up and re-enter connected mode, whichever comes first.

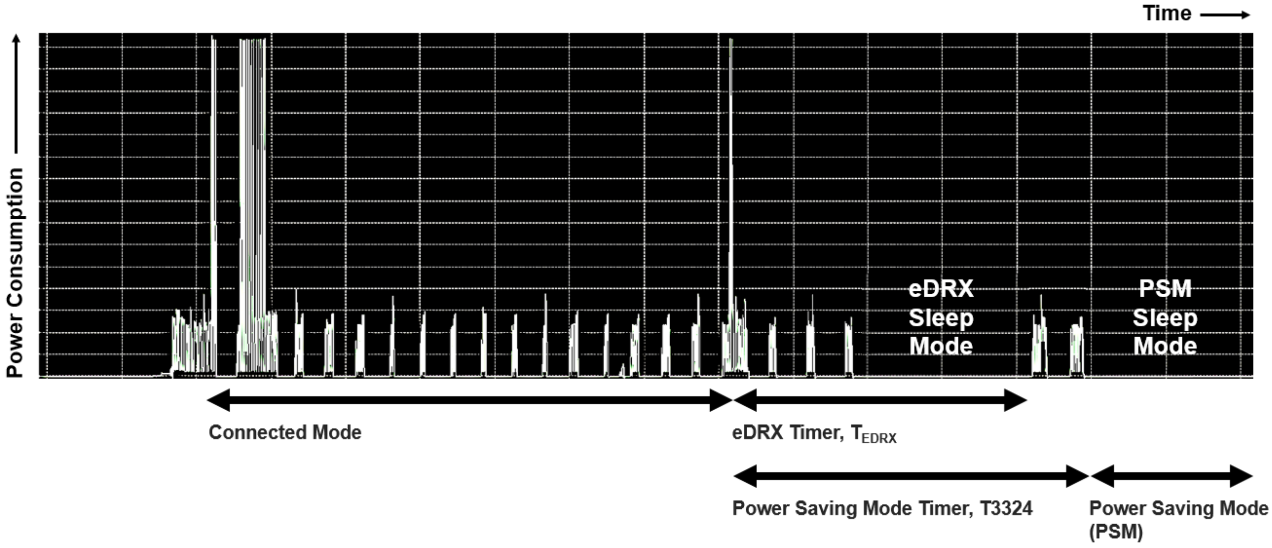

Figure 9 – Power Consumption Profile

2.4.2. Applicability

PSM brings a significant power reduction as shown in section 6.4 and enables long battery life. A drawback of using PSM is that the IoT device cannot be contacted by the network while its module or chipset is asleep. The inability to be contacted may preclude the use of PSM for downlink-centric applications requiring frequent or unscheduled communication to IoT devices (e.g., tracking solutions).

By default, many mobile network operators set T3324 values between 20 and 30 seconds. Setting the timer to a value lower than 10 seconds may be risky due to the higher latencies and turn-around times that may be experienced by devices in CE-Level 2 (deep indoor) coverage conditions. If the device prematurely enters PSM mode, a downlink message may not be able to be delivered to it.

The shutting down of a module or chipset is a non-standardised approach that may be used to conserve the power of the IoT device. It needs to be recognised when using PSM that this feature only puts the module into an ultra-low power dormant state; the rest of the device hardware continues consuming power, including sensors, actuators, microcontroller, etc. There are specific use cases, where a hard cut of voltage to the entire device may be the most preferred course of action.

That said, please note that some chipsets are not able to store the list of recently camped-on networks in permanent memory. As a consequence of this limitation:

- By pulling the current to those chipsets, the updated location of the network is purged from the volatile memory, resulting in a need to perform a full network scan,
- Depending on the radio access technology and band support of the selected chipset or module, AT commands used to restrict scanning may also be purged, resulting in a long scanning period of up to 15 minutes.

IoT application designers must therefore weigh the pros and cons of switching off the IoT device and then doing a full network scan, versus keeping the device powered with the module or chipset in deep sleep mode. Finally, if devices are regularly powered off and on, the amount of signalling to the mobile network operator's network will increase, as the chipset or module must perform a full attach procedure with the network to re-register.

2.5. Connected Mode Discontinuous Reception (cDRX)

2.5.1. Overview

Many Mobile IoT networks support the Connected Mode Discontinuous Reception (cDRX) feature to reduce power consumption on the IoT device. Unlike power saving mode, idle mode DRX and extended DRX, all of which improve power efficiency during the idle Mode (when there is no active radio connection in place between the IoT device and network). cDRX (occasionally referred to as "RRC Mode DRX") optimises device power consumption during connected mode, the state during and immediately after the transmission and/or reception of messages. During this period, a Radio Resource Control (RRC) logical connection is maintained with the eNodeB (cell site) until a network-configured inactivity timer expires, allowing for quick transfer of data between the device and the eNodeB.

Without cDRX, the IoT device's chipset is forced to monitor the Physical Downlink Control Channel (PDCCH) in every subframe to check if there is downlink data available. To do so would drain the battery quickly. The solution introduced in LTE standardisation involves monitoring the PDCCH channel discontinuously. In other words, the IoT device enters sleep and wake cycles. By momentarily switching off the receive section of the radio chipset for a fraction of a second (the interval being controlled by the network defined DRX Timer parameter, TDRX), IoT devices can save power. When the device wakes up, the receiver will listen for the PDCCH. The IoT device cannot be contacted by the network during the period that it is not listening but if the period is kept rather short, the IoT application will not experience a noticeable degradation of service. Connected mode DRX is configured by the network in the RRC connection setup request and RRC connection reconfiguration request.

Figure 8 illustrates how connected mode DRX can improve the power consumption profile of a wireless communication module during connected mode. In between these PTWs, the module may typically consume less than a few microamps. DRX average current consumption values can drop to around few milli amperes. As this feature is not supported by all networks, device manufacturers may need to consider that some operators reduce the duration of the connected mode inactivity timer to reduce the higher power consumption in connected mode.

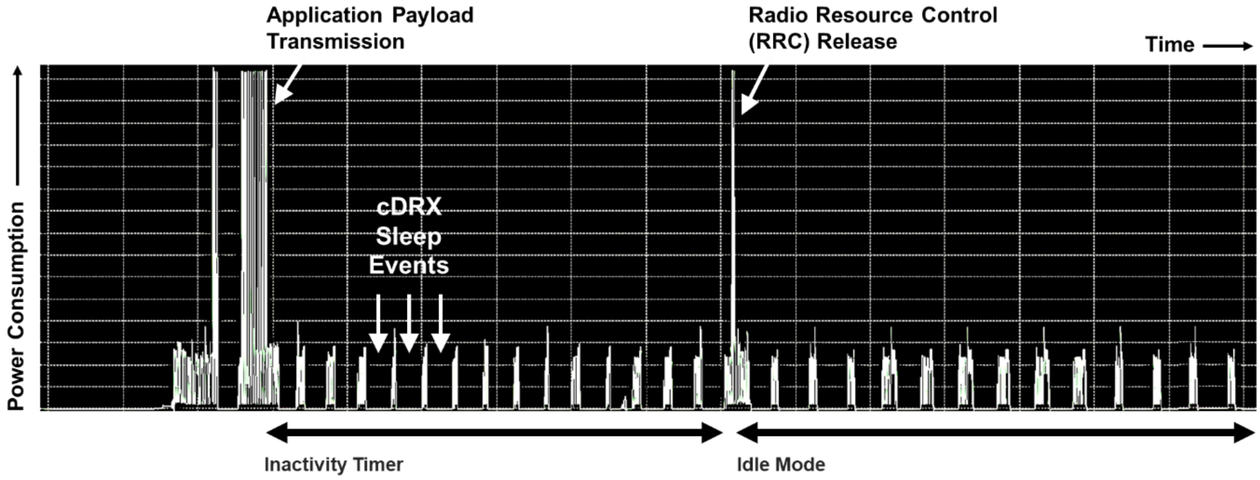

Figure 10 – Connected Mode Discontinuous Reception (cDRX)

2.5.2. Applicability

The IoT device and application cannot control this feature; essentially, use of the feature is dependent upon whether the network supports the feature or not.

2.6. Release Assistance Indication (RAI)

2.6.1. Overview

The 3GPP™ Release 13 Release Assistance Indication (RAI) feature defined in Technical Standard TS24.301 helps IoT applications further reduce device power consumption and improve control plane latency. This is achieved by allowing the IoT device to prematurely request release of the layer 3 Radio Resource Control (RRC) connection between itself and the eNodeB on the mobile network operator's radio access network. A Release Assistance Indicator IE is included with the last data message to inform the network no subsequent uplink or downlink data transmission (e.g., an acknowledgement or response from the application server) is expected. Without this feature, the IoT device is forced to remain in RRC_CONNECTED mode until the expiration of the eNodeB's RRC inactivity timer. Depending upon the network configuration, this could be as long as 20 to 30 seconds.

Through release assistance indication, an IoT device can go directly into the idle mode after data transmission and/or reception. Depending on the chipset solution being used, this means that up to 50mA of current may be saved by the IoT device. This quickly adds up over time to form a significant component of reduced battery lifetimes.

In Figure 11 and Figure 12, the benefit of RAI can be visualised. If an IoT application is certain that there are no further downlink messages from the server, a RRC release can be triggered with RAI. Please note that this feature may not be available on all wireless communication modules.

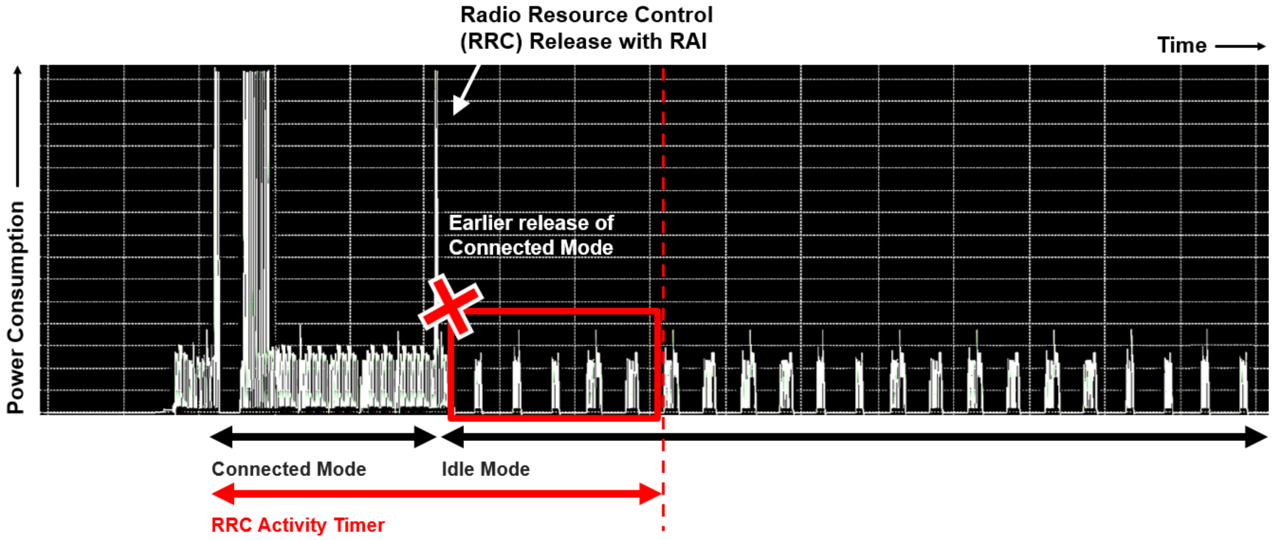

Figure 11 – Release Assistance Indication (RAI) - RRC Activity Timer

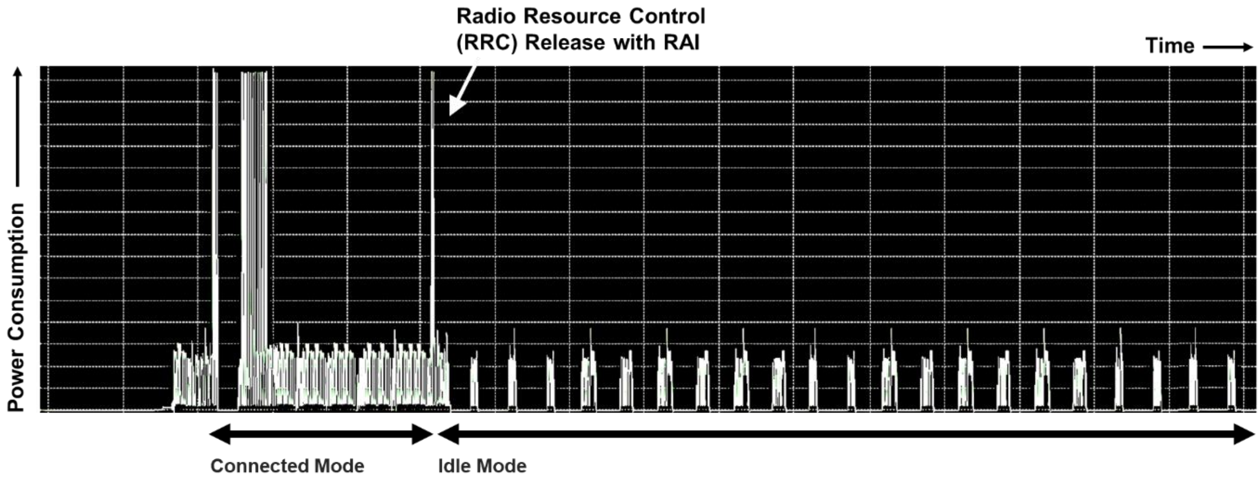

Figure 12 – Release Assistance Indication (RAI)

2.6.2. Applicability

Release assistance indication should only be initiated by an IoT application when no additional uplink or downlink traffic is expected in the near-term. Premature release of the RRC connection would require the IoT device to waste additional power to re-establish a RRC connection. This generally consumes more power than remaining RRC_CONNECTED for the duration of the RRC inactivity timer.

2.7. Combining energy efficiency features

2.7.1. Applicability

Given the richness of power saving features that 3GPPTM provides application developers, the question naturally arises how such capabilities can be combined? There are up to 32 combinations of power saving features available presented above.

Depending on the serving mobile network operator's feature support, some of these combinations may not apply. For example, if either eDRX or cDRX are not supported, 50% of the potential combinations are not available. This limitation may not be relevant for many IoT solutions but it may affect some specific IoT use cases.

The idle mode power saving features Extended Discontinuous Reception (eDRX) and Power Saving Mode (PSM) can be combined to obtain additional power savings. If an application is designed to only perform downlink communication during a predefined time period comprising multiple Paging Time Windows (PTW), the modem should be placed into PSM deep sleep mode after this period. The PSM T3324 timer could be set until after the last PTW has completed. Alternatively, the T3324 timer can be configured to initiate PSM during a PTW or in the eDRX sleep time between PTWs.

Similarly, the connected mode power saving features, Connected Mode Discontinuous Reception (cDRX) and Release Assistance Indication (RAI) can be combined. The RAI IE to release radio resources should never be sent if a pending downlink message is expected to arrive shortly thereafter. As previously stated, the energy required to re-establish a RRC connection from idle mode may exceed the power savings of the device made by dropping into idle mode.

Figure 11 illustrates a device combining the three power saving features: cDRX, eDRX, and PSM. Through this illustration, it is possible to appreciate the flexibility that 3GPPTM offers application developers to fine-tune their IoT device's power consumption profile. Figure 7 provides some indicative current consumption values for several power savings features.

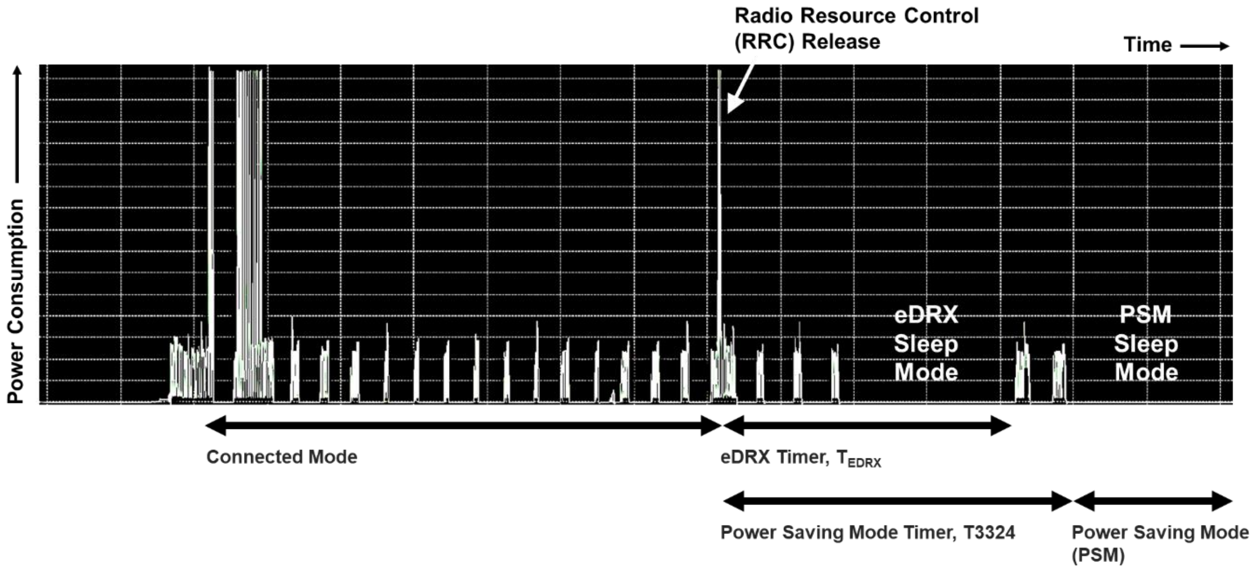

Figure 13 – Discontinuous Reception (cDRX, eDRX) with Power Saving Mode (PSM)

3. Measurement parameters

3.1. Measurement tools

Figure 12 illustrates a suggested measurement environment. An alternate configuration illustrated in Figure 14, is to directly connect the development board to the cellular base station using a coaxial cable and RF attenuators to emulate radio path loss. That is, a “conducted mode” connection.

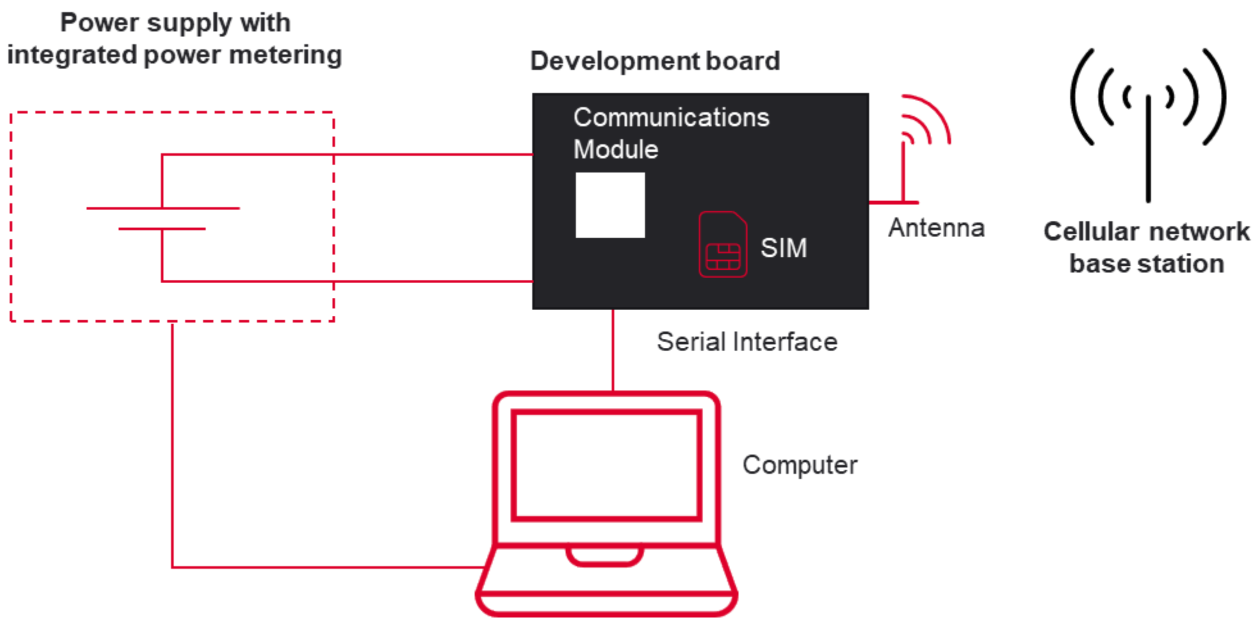

Figure 14 – Suggested measurement environment

The intent of the activity is to measure the energy consumption of the cellular communications module or chipset used in the development board. A consequence of which, it is imperative that any additional elements such as light emitting diodes, etc. are either removed or powered separately to ensure the energy required by those ancillary elements are not included in any measurement. Failure to do so will provide erroneous results.

The board is controlled by an external computer sending commands to the module according to predefined scripts. These scripts should implement the measurement scenarios described in Section 6.

A power supply with or without integrated power metering can be used. That is, any test equipment compliant with GSMA TS.09 Section 3.2.2 [5]. The supply and measurement system has to offer adequate precision. Sampling rate is relevant as some current peaks are extremely short.

External measurement devices should comply with GSMA TS.09 Section 3.2.4 [5]. E.g., As illustrated in Figure 13, an oscilloscope and a low value shunt resistor.

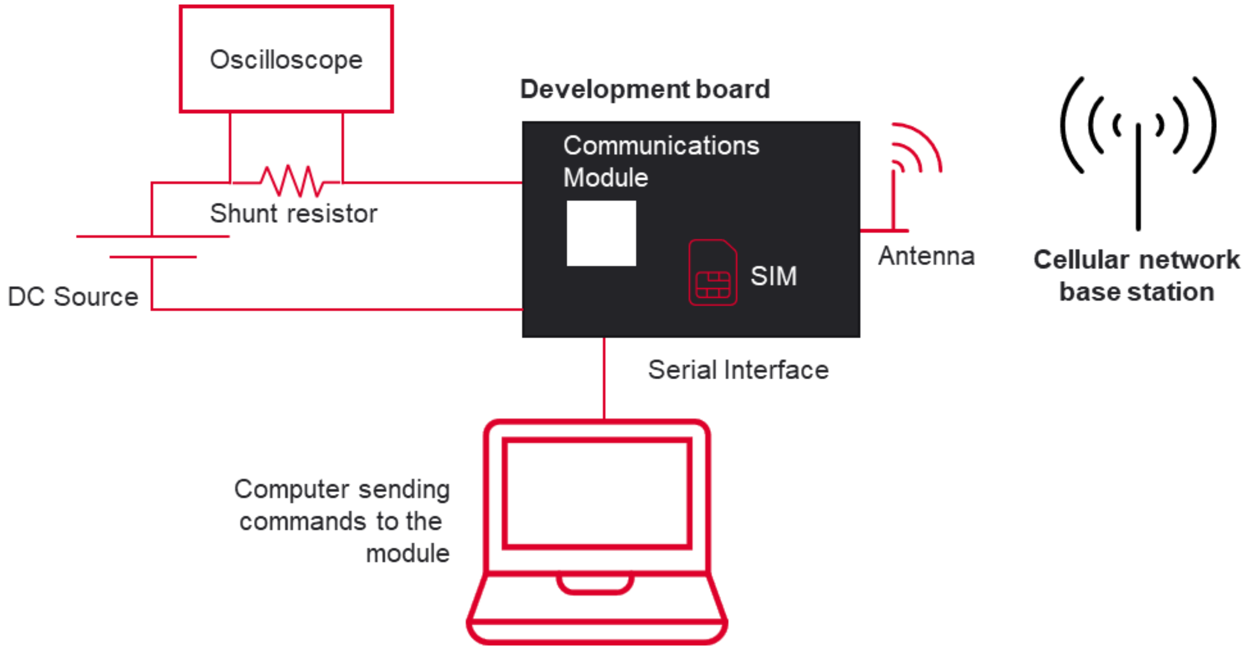

Figure 15 – External measurement device

In some cases, testers can test in *conducted* mode, connecting the radio base station directly to the board through a wire.

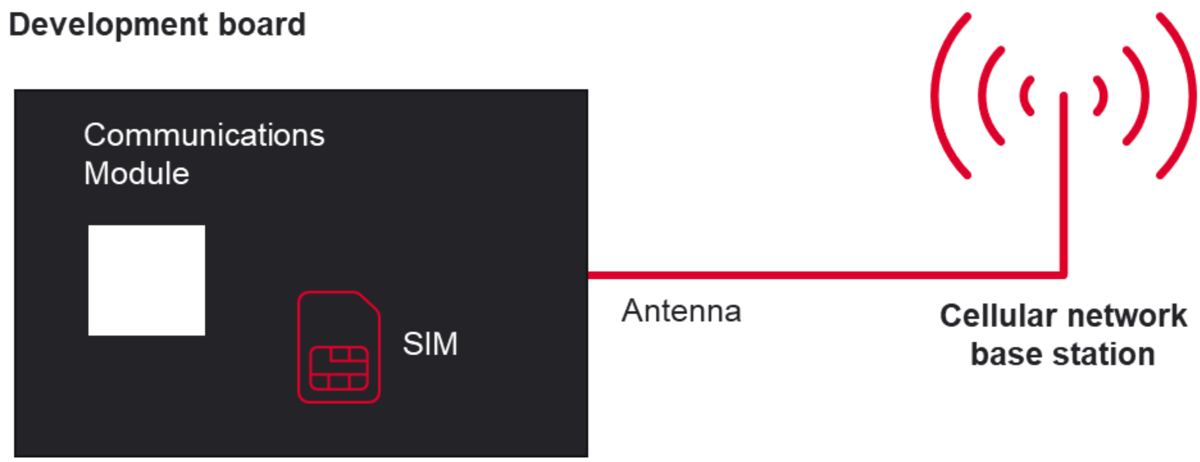

Figure 16 – "Conducted mode" connection

3.2. Device parameters

As defined in TS.09 Section 2.2 [5], device testing is normally performed at an ambient temperature range of 18 -25°C. Depending upon the specific device, it is common for the operating voltage to be 3.6V.

Additional tests can be performed at extreme conditions (-40C, -30C + 85C, etc.) depending upon the expected use of the end product.

3.3. Network parameters and conditions

The configuration of network parameters can also significantly impact the energy consumption of an IoT device. Table 1 provides an overview of the parameters that should be considered to achieve optimum device energy consumption.

3.3.1. NB-IoT typical parameters

Network Parameters	NB-IoT Applicability and example values	Comment
Test Case Parameters		
UL packet size and times	1-1358 Bytes	Longer messages will be split. The shortest messages will consume less energy to transmit.
DL packet size and times	1-1358 Bytes	Longer messages will be split. The shortest messages will consume less energy to transmit.
Long period TAU timers	T3412. 0-413 days, e.g.: 24 hours	The longer the TAU timer, the less energy spent in updates but the network will take more time to detect device area changes.
PSM timers	T3324. 0-186 min. e.g.: 1 minute	The device will consume more energy the longer the T3324 period, but will be able to receive messages for longer before going to sleep.
eDRX cycle	0-175 min. Ex: 40.96 seconds	A longer eDRX cycle will consume less energy but the device will take more time to receive a message from the network.
eDRX PTW	2.56-40.96 seconds. E.g.: 2.56 seconds	A Shorter PTW will consume less energy but the network will have less opportunity to send a message to the device.
RRC inactivity timer	Typically 5-30 seconds	Set by the network. Shorter times save energy but may delay DL messages (will

Network Parameters	NB-IoT Applicability and example values	Comment
		have to wait DRX cycles or even PSM duration).
UE DL RSRP	Typically -80 to -120 dBm	Depends on coverage condition. Energy consumption increases quickly if the device enters extended coverage modes and packets are repeated.
Parameter settings related to UE capabilities:		
UE category	NB1（R13）- NB2（R14）	NB2 allows for faster connections, saving time and energy.
UE power class	14, 20 and 23 dBm	Power Class 5 and 6 devices (20 and 14 dBm) require less energy but will have reduced coverage.
Basic network configuration parameters:		
Frequency Band	E.g.: 900MHz	Lower frequencies will have better penetration and less energy demand due to lower path loss.
Deployment Mode	Standalone, In-band, Guard-band	Energy consumption is not affected by deployment mode.
NB-IoT bandwidth	180 kHz	Defined by 3GPP standards.
ECL0	-114 dBm	Reference values, please contact your MNO for detailed values.
ECL1	-124 dBm	Reference values, please contact your MNO for detailed values.
ECL2	-130 dBm	Reference values, please contact your MNO for detailed values.

Network Parameters	NB-IoT Applicability and example values	Comment
NB-IoT Transmission Parameters		
RAI	Yes/No	If activated, the device will release the radio link sooner but downlink information may be delayed due to the need to return to connected mode.
c-DRX	Yes/No	cDRX saves energy in connected mode but increases DL latency.
DRX Cycle	1.28 or 2.56 seconds	Longer cycle saves more energy but increases DL latency.
UL multi-tone transmissions on NPUSCH	Single tone /Multi tone	Multi tone transmissions are faster, saving more time but are more sensitive to noise and coverage impacts.

Table 3 – NB-IoT typical parameters

Additional network related parameters and configurations may have to be considered when planning your device power budget. Please contact your network provider for further optimisation assistance.

3.3.2. LTE M

Network Parameters	LTE-M Applicability and example values	Comment
Test Case Parameters		
UL packet size and times	1-1358 bytes	Longer messages will be split. The shortest messages will consume less energy to transmit.
DL packet size and times	1-1358 bytes	Longer messages will be split. The shortest messages will consume less energy to transmit.
Long period TAU timers	T3412. 0-413 days ex: 24h	The longer the TAU timer, the less energy spent in updates but the network will

Network Parameters	LTE-M Applicability and example values	Comment
		take more time to detect device area changes.
PSM timers	T3324. 0-186 min. ex: 1min	The device will consume more energy the longer the T3324 period, but will be able to receive messages for longer before going to sleep.
eDRX cycle	0-43 min. Ex: 40.96 seconds	A longer eDRX cycle will take less energy but the device will take more time to receive a message from the network.
eDRX PTW	2.56-40.96 seconds. Ex: 2.56 seconds	A Shorter PTW will consume less energy but the network will have less opportunity to send a message to the device.
RRC inactivity timer	Typically 5-30 seconds	Set by the network. Shorter times save more energy but may delay DL messages (will have to wait DRX cycles or even PSM duration).
UE DL RSRP	Typically -80 - -120 dBm	Depends on coverage condition. Energy consumption increases quickly if device enters extended coverage modes and packets are repeated.
Parameter settings related to UE capabilities:		
UE category	Cat-M1	
UE power class	14, 20 and 23dBm	Power Class 5 and 6 devices (20 and 14 dBm) require less energy but will have reduced coverage.
Basic network configuration parameters:		
Frequency Band	Ex: 900Mhz	Lower frequencies will have better penetration and less

Network Parameters	LTE-M Applicability and example values	Comment
		energy demand due to lower path loss.
LTE-M bandwidth	1.4MHz (Cat-M1)	Defined by 3GPP standards.
CE Mode A, 1st threshold	-122 to -128dBm dBm	Lower thresholds will give better connection quality but will increase energy demand as coverage degrades.
CE Mode B, 2nd threshold	Depends on NW deployment	
CE Mode B, 3rd threshold	Depends on NW deployment	
LTE-M Transmission Parameters		
RAI	Yes/No	From Release 14, if activated, the device will release the radio link sooner. but downlink information may be delayed due to the need to return to connected mode.
c-DRX	Yes/No	cDRX saves energy in connected mode but increases DL latency.
DRX Cycle	1.28 or 2.56 s	Longer cycle saves more energy but increases DL latency.

Table 4 – LTE-M typical parameters

4. Power class

MIoT devices commonly implement a power class 3 (+23 dBm) transmitter. Whilst some devices implement a power class 5 (+20 dBm) transmitter, MNOs prefer power class 3 devices. Although lowering the output power means the PA can be better integrated into the device, managing a mixture of power class 3 and 5 devices on the network is difficult. Lower power devices will not have the same coverage and in difficult environments power class 5 devices will increase their messaging repetition rate, which will consume more power than if they had used a power output for a shorter period.

Power class 6 (+14 dBm) was introduced in 3GPP Release 14. These devices are intended for simple battery technologies that can only sustain a low battery discharge rate.

Further information on power classes can be found in the LTE-M Deployment Guide to Basic Feature Set Requirements [7] - Section 7.17 and NB-IoT Deployment Guide to Basic Feature set Requirements [8] - Section 7.10.

5. Applicable use cases

5.1. Smart Metering

5.1.1. Overview

The ever-increasing demands for resources coupled with dwindling supplies have posed great challenges for society to efficiently manage resources. After decades of inadequate metering, society has realised that accurate, adequate and reliable measurement and monitoring practices of energy and water consumption are essential for long term resource sustainability. The saying "if you can't measure it, you can't manage it" has never been truer and this is where smart metering comes to the fore.

Somewhat simplistically, a smart meter is a normal meter connected to a data logger that allows for the continuous monitoring of water or energy consumption. Compared to existing systems where users get information on usage months after events occurred, a smart metering system can deliver near real-time consumption profiles that can be used to determine and improve usage patterns.

For users to access this near real-time information, the smart meter needs to send information at regular intervals to platforms often located in the cloud. With ubiquitous coverage, cellular networks and more specifically the IoT technologies LTE-M and NB-IoT, are well placed to transport this information from the widely dispersed monitoring points sometimes placed in challenging to reach locations.

Deployed to monitor electricity, water, gas or even heat flow consumption with a service life expectation of 10, 15 or more years, the energy consumption of the smart meter can become a critical factor in achieving that service lifetime. That is, whilst an electrical smart meter has access to a ready source of energy, a water meter may typically be deployed with a primary cell battery that needs to power the meter throughout its lifetime.

A consequence of which, the underlying use case and radio parameter profiles associated with each meter type may be different leading to different energy consumption test cases.

For the purposes of this document, we will assess the requirements of a more interactive smart meter that may be powered directly but still uses eDRX to save some energy (e.g., electrical smart meter) as well as a battery powered smart meter that is less interactive and from a radio perspective spends most of its time asleep using PSM to maximise battery life (e.g., smart water meter).

For some smart metering, low latency downlink messaging may be required by the country's regulations body to be able to control the supply. This could be as low as 1 second for electric grids. In this situation eDRX and PSM would not be used and the smart device would be powered by a mains supply.

5.1.2. Use case parameters

Smart electricity meter

- 81.92 second eDRX cycle time

- Sending 50B/100B/200B of uplink data once a day
- Sending 32B / 64B of downlink data (e.g., for acknowledgement)
- Downlink data for firmware over the air (module) and/or software over the air (metering application): 3 times over 10 years (typically: about 10kB and 200kB)

Smart water meter

- PSM T3412Ext=24h; T3324=1min
- Sending 50B/100B/200B of uplink data once a day
- Sending 32B / 64B of downlink data (e.g., for acknowledgement)
- Downlink data for firmware over the air (module) and/or software over the air (metering application): 3 times over 10 years (typically: about 10kB and 200kB)

5.2. Consumer tracker use case

5.2.1. Overview

Tracking of physical assets had always been a pain point in both our personal and professional lives. Misplacing our valuables or even our beloved pets is very common in our daily lives, damaging our sense of security and increasing uncertainty. On the business side, keeping inventories up to date and registering asset location with limited visibility has traditionally been a manual, time consuming, error prone activity, leading to sub-optimal supply chains and mediocre customer experience.

In the last years, tremendous technology progress combined with integration of positioning and the dedicated IoT cellular standards of LTE-M and NB-IoT, has revolutionised the tracking industry. By building devices that attach to assets to continuously track and report position over the network, providing near real-time visibility on the asset's location, has increased our overall sense of comfort on the personal level and unlocked new ways to manage business supply chains.

The first asset trackers in the market showed a lot of promise but encountered genuine difficulties. The hurdles of ensuring consistent network coverage globally with regional bands, with the use of higher LTE categories and expensive data plans, combined with the bulky form factor dominated by the large battery required to operate these devices, yielded a poor user experience, requiring quite some effort and additional costs to utilise them in a practical way.

The widely deployed cellular IoT standards (LTE-M and NB-IoT), allowing ultra-low power communication and ubiquitous worldwide coverage finally delivers small size, battery operated, cost-effective solutions to track and report multiple parameters, improving customer experience and delivering on the initial promise.

Today, we have ways to use compact trackers to locate our pets and personal items, providing us with greater sense of comfort, as well as track business assets easily and accurately to shed light on blind spots in the business supply chain, unlocking multiple opportunities to significantly reduce costs, set higher customer experience standards, improve efficiency and better comply with regulations alongside other potential supply chain optimisations

Furthermore, the easy, affordable and power optimised data communication made possible by the new LTE-M and NB-IoT cellular standards, encouraged more and more applications to extend their scope beyond location data only, collecting other valuable usage data and generating comprehensive tools based on the analysis of this data, unlocking a range of new use cases.

Applications for managing large fleets of vehicles are a good example. These applications monitor in real-time several in-vehicle indicators dubbed telematics, to be analysed and provide useful insights on location as well as vehicle condition for predictive maintenance. Patterns of driving habits emerge from this analysis which can be used to properly educate drivers, enhancing safety and best practice across the business.

5.2.2. Use case parameters

5.2.2.1. Pet Tracker Use Case

- Expected battery lifetime 2-3 years,
- Operational typical use case: 82 seconds eDRX cycle time,
- Data upload – Once per day within geo-fencing zone, ~100 Byte,
- Continuous location tracking and data upload is activated once the device is crossing a predefined based Geo-fencing (based on Cellular/GPS/Wi-Fi),
- Downlink data for firmware over the air (module) and/or software over the air (tracking application): 1-2 times over 2-3 years (typically: about 10kB and 200kB).

5.2.2.2. Telematics/Asset Tracker Use Case

- Expected battery lifetime 5-7 years,
- Operational typical use case: 82 seconds eDRX cycle time when moving and PSM for stationary (cycle 12hour/24hour),
- Data upload – Multiple times per day, ~100 Byte,
- Continuous location tracking and data upload can be activated depending on device status,
- Downlink data for firmware over the air (module) and/or software over the air (tracking application): 1-3 times over 5-7 years (typically: about 10kB and 200kB).

6. Summary and recommendations

6.1. Summary

3GPP releases R13 and R14 introduced multiple power saving features for network operators and device manufacturers to utilise and reduce power consumption of a MIoT device. Each feature should be considered when developing a MIoT application recognising some power saving features may not be suitable for certain applications.

Power saving features can be split into two categories. That is, network operator settings which the MIoT device must follow and 3GPP options that the device can request from the network to save power.

From a network perspective, it is in the network operator's own interest to configure their mobile IoT network to reduce power consumption, as this will generally mean less resources consumed on their network. Note that MIoT networks may not grant every request from the MIoT device, so the MIoT application needs to accommodate this situation when the device's battery consumption model requires a specific power saving feature. Also, recognise that not all R13 and R14 power saving features are deployed in every MIoT network.

From a device perspective, the practical realisation of these features may vary widely. The MIoT device designer needs to carefully consider their choice of radio module as not all features are implemented in every module. Even when features are supported by radio modules, optimisation of the feature by manufacturers may vary, resulting in a wide range of energy consumption to perform the same task. Designers should carefully review each radio module manufacturer's product literature to determine suitability of that product for their application.

6.2. Recommendations

LTE-M and NB-IoT power optimisations provide the opportunity to significantly reduce power consumption and increase device's battery life compared to 2G devices through reduction in hardware requirements for MIoT modules, reduction in transmitter output and optimised MIoT protocol stacks.

This document highlights there are multiple factors affecting battery life of a mobile IoT device. Factors include message size, messaging period, message protocol, network parameters, overall application design and cloud latency.

Summarised below are considerations for lowering the power consumption of the MIoT device

Power consumption optimisation	Consideration
Minimise power on/off and Registration	Use 3GPP Power Save Mode (PSM) to minimise the powering cycling of the MIoT device which causes re-registration each time. Powering on some modules may take more time and energy compared to waking up from PSM

Power consumption optimisation	Consideration
Reduce Connected Mode consumption	Use Release Assistance Indication (RAI) to request t.he network to release the MIoT device from Connected Mode after communication has completed instead of waiting for the network's inactivity timer to expire.
Reduce Idle Mode consumption	Use eDRX to allow the MIoT device to sleep for short periods of time while in idle mode to further reduce consumption. Note: Latency for unsolicited downlink messages will increase with increasing eDRX cycle period.
Reduce power consumption between uplink messages	Use PSM to put the MIoT device into a deep sleep mode which significantly reduces the power consumption. Wake the device up from PSM when the next message needs to be sent. Note: Downlink messages will not be received while the MIoT device is in PSM.
Avoid chatty protocols	Carefully select the communications protocol used to reduce the application protocol communication to/from the cloud service. For example, split regular 'metering' messages from 'service' type message which may require more communication. Optimise cloud responses/acknowledgements to minimise the time a MIoT device is left waiting for a response/acknowledgement.
Consider device centric application design	Applications waiting for an unknown time for unsolicited downlink messages will consume more energy than applications obtaining a response from their uplink messages.
Consider power consumption when securing message transfer.	There are many options to secure device messages and some will consume more energy than others. For example; TCP/TLS base security consumes more than UDP/DTLS security. Features like Session Resumption will allow devices to reuse security tokens to reduce the security handshake.

Table 5 –Recommendations

Annex A Measurement scenarios

To predict the performance of devices in some common use cases, lab tests are proposed. Each test corresponds to a specific real-world scenario.

Each test investigates the impact of a given parameter for a scenario. Some common Recommended Tests (RT) are described. However, organisations are encouraged to design and execute their own testing scenarios to investigate other parameters of interest.

* Note: Measured results explained in Paragraphs 6.4-6.9 may vary depending on chipset and module vendor, please consult your supplier.

A.1 Measurement points

For each of the scenarios, measurements will be taken between certain points representing stages of the device's activity. CIoT devices may have shorter durations for some stages. For example, when the device wakes up from PSM compared to when it initially powers on.

Listed here are the points of interest:

- P1. Power on / wake up from PSM,
- P2. Start protocol stack,
- P3. Scan for previous cell,
- P4. Establish RRC connection (Connected Mode),
- P5. Register on cellular network, if required,
- P6. Send message(s) / TAU,
- P7. Release RRC connection (Idle Mode),
- P8. Power off / enter in to PSM.

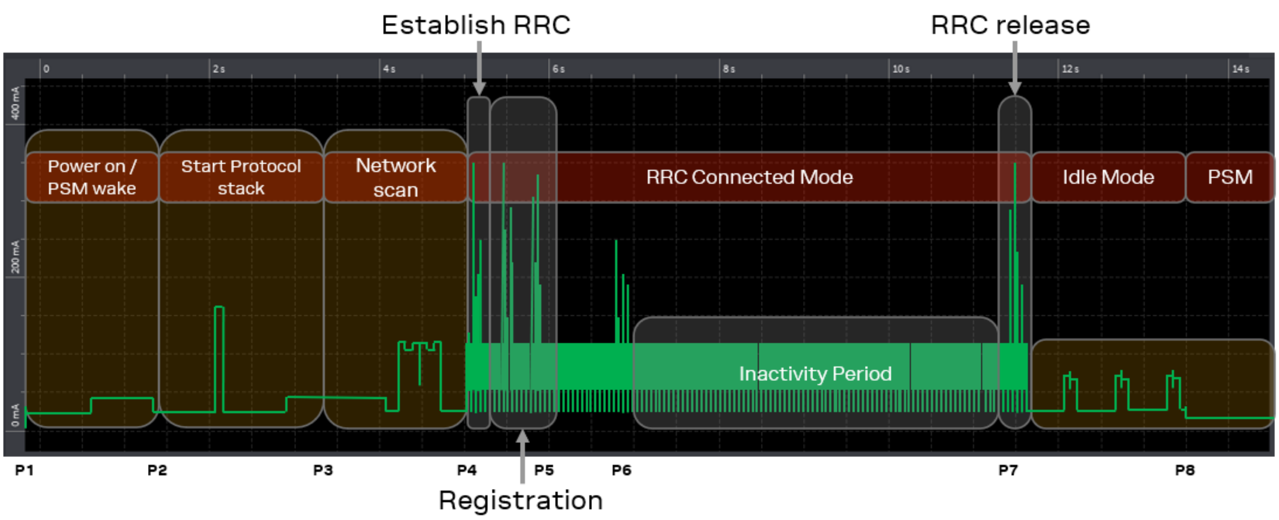

Figure 17 – PSM and TAU test energy profile

A.2 Test structure

For each of these scenarios the recommend tests are:

- RT1: Use of LTE-M,
- RT2: Use of NB-IoT,
- RT3: Comparison with GPRS (as baseline).

A.2.1 PSM and TAU

This test models a device sleeping to save as much energy as possible. The device is in PSM mode and occasionally connects to the network to perform a TAU.

A.2.2 Data transmission to/from PSM

This test models a typical metering application. A device stays asleep, wakes up briefly and transmits a short burst of data.

A.2.3 Reception in eDRX

This test models a remotely controlled device, such as a valve in a fluid management system. The device waits for server commands using eDRX, a mode optimised for network reception. At some time, the server sends a command to the device.

A.2.4 Connection to network and change to PSM

This test measures the energy consumed by the device booting up from a powered down state. This is an important test as designers need to decide whether to power down devices completely or use sleep mode.

A.2.5 Always on transmission

This test emulates a device connected to the network and periodically transmitting short bursts of information. For example, a wearable measuring and transmitting vital constants or a tracker following an asset in real time.

A.2.6 Profile swap

Remote management of eUICCs is a relevant feature of cellular IoT devices. This test helps to understand the impact of a profile management operation in the device battery life. We have selected the profile swap operation, as it will be the most critical of eUICC management operations. Of course, the energy required by this operation will depend on many factors, especially the transmitted profile size, so any data obtained will be for guidance only.

A.3 Test parameters

The following parameters shall be defined in each test:

Test setup: Conducted mode environment using test equipment.

Deployment model: in band/guard band and anchor carrier – no significant power impact is expected in either operation mode.

Band: Operating frequency to suit market or operator deployment (Please refer to mobile IoT commercial launches page https://www.gsma.com/iot/mobile-iot-commercial-launches/).

Cellular technology: Either Narrowband IoT (Cat-NB1 or Cat-NB2), LTE-M (Cat-M1), or other technologies to be compared such as GPRS, LTE Cat-1, etc…Cellular technology selection is a key factor for power management, also impacting device cost, size, development process, etc.

For the next five parameters see Figure 1:

Inactivity timer: Fixed by the network operator, typically ranges between 5 and 30 seconds.

T3324: Duration of time a device will remain in idle mode before entering PSM. Proposed by the device and accepted by the network.

T3412: Duration of time before a device sends a Tracking Area Update (TAU) after exiting connected mode. Proposed by the device and accepted by the network. T3412 timer is reset each time the device enters connected mode.

cDRX: Yes/No. Allows the device to listen discontinuously whilst in connected mode.

Paging Time Window: Duration of time when paging messages may be expected from the network. The time between PTWs determines the delay before a device is reachable in DRX.

Coverage Enhancement (CE): The coverage enhancement feature allows devices to operate at locations beyond the coverage of regular LTE. Coverage enhancement makes use of signal repetitions to enhance signal reception but doing so has a big impact on energy consumption.

- For LTE-M the device can operate in a range of modes (A/B) and levels (0-3),
- For NB-IoT the possible modes are CE0, CE1, and CE2.

Number of bytes transmitted/received (NBYTES): The number of bytes transmitted and received which in turn impacts the energy spent communicating.

Application protocols: The protocols employed to transport the final business payload also impact energy consumption. Organisations may want to execute tests comparing different protocols such as UDP (with or without acknowledgement messages), raw TCP, MQTT, MQTT on TLS, DTLS, etc.

RAI, Release Assistance Indication: Using RAI a device can leave connected mode before the inactivity timer expires. This saves a lot of energy, as the device is not waiting for further network messages. Usually, devices can request for release after sending one packet, or after receiving one packet. RAI use depends on the application protocols employed.

A.4 PSM and TAU Energy profile

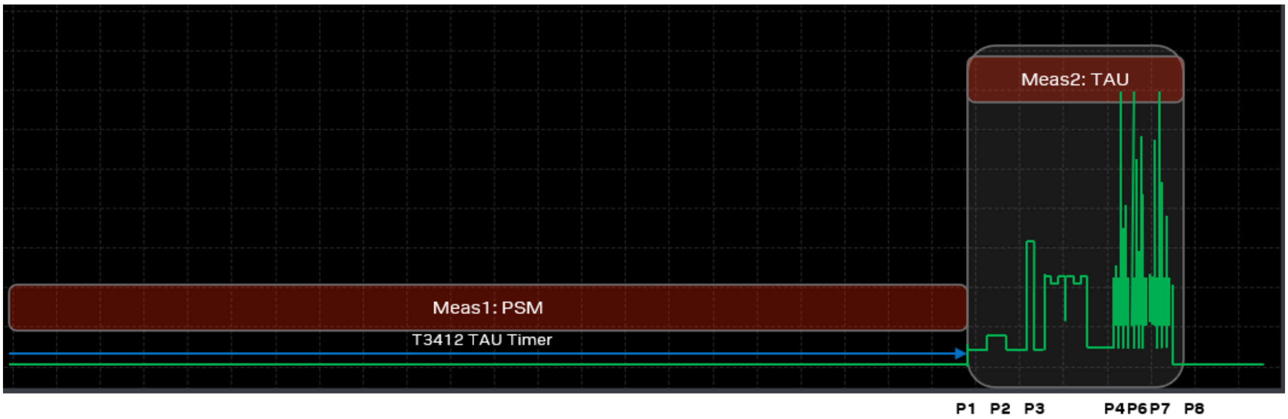

Figure 18 – PSM and TAU test energy profile

Action	Outcome	Measurement
Initial state: device connected to the network PSM status, with known TAU update time		
Device stays in PSM status		Meas1. Energy (Wh)
TAU timer expires	Device executes TAU procedure	Meas2 Energy in TAU update (Wh)
Device goes back to PSM status		

Table 6 – Test Procedure: PSM and TAU

PSM and TAU	Recommended Tests	
Parameters	**RT1: LTE-M1**	**RT2: NB-IoT**
Device	LTE-M device	NB-IoT Device
Band	3	20
Deployment model	-	in-band
Network	Cat-M1 R13	Cat-NB1 R13
T3412	60 minutes	60 minutes

PSM and TAU	Recommended Tests	
T3324	0 seconds	0 seconds
RSRP (dBm)	-100	-100
Extended Coverage	Mode A Level 0	ECL0
Results		
Meas1: Energy in PSM	6.5 – 15 uWh	6.5 – 15 uWh
Meas2: Energy in TAU	140 - 430uWh	110 - 410 µWh

Table 7 – Test results: PSM and TAU

A.5 Data transmission to/from PSM

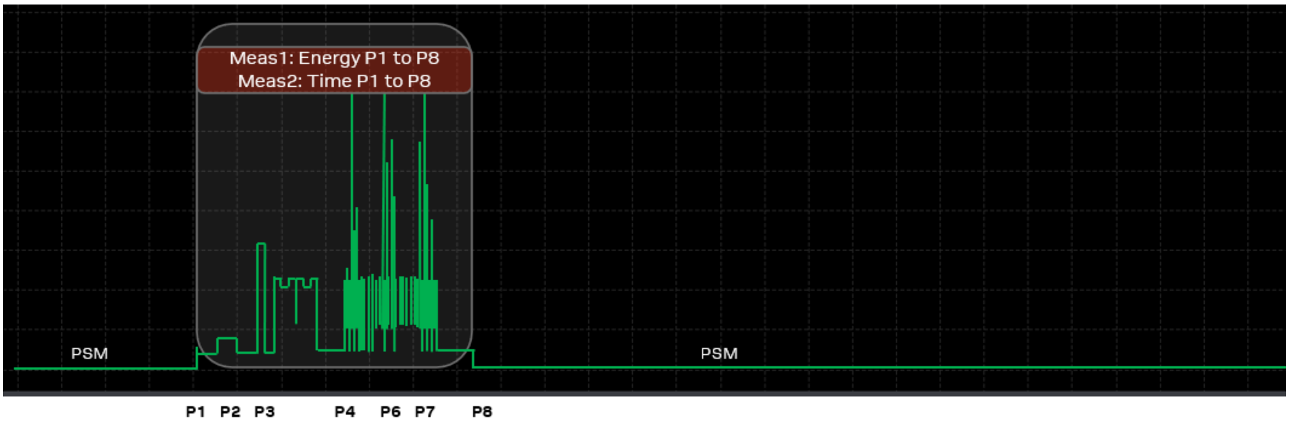

Figure 19 – Data transmission to/from PSM test profile

Action	Outcome	Measurement
Initial state: device connected to the network PSM status, with known TAU update time (shut down in GPRS)		
Device leaves PSM status (boot up and connection in GPRS)		
Device transmits [NBYTES] to server in fixed IP address using [CXMETHOD]	Bytes received by server.	
Device goes back to PSM status for LTE-M/NB-IoT (shut down in GPRS)		Meas1 Energy consumed while in active status

Action	Outcome	Measurement
		Meas2 Time in active status

Table 8 – Test Procedure: Data transmission to/from PSM test profile

Data transmission to/from PSM	**Recommended Tests**		
Parameters	**RT1: LTE-M**	**RT2: NB-IoT**	**RT3: GPRS**
Device	LTE-M device	NB-IoT Device	2G device
Band	3	20	8
Deployment model	-	in-band	-
Network	Cat-M1 R14	Cat-NB1 R14	GPRS
T3324	0 seconds	0 seconds	-
RSRP/RSSI (dBm)	-100	-100	-80
Inactivity timer	5 seconds	5 seconds	-
RAI	Yes	Yes	Module shut down after transmission
Application protocol	UDP, no ACK	UDP, no ACK	UDP, no ACK
Number of bytes	10	10	10
Extended Coverage	No	ECL0	-
Results			
Meas1: Energy consumed while in Active status.	120 - 580 µWh	45 – 480 µWh	643 µWh
Meas2: Active status time.	5.5 seconds	1.61 seconds	6.32 seconds

Table 9 – Test Results: Data transmission to/from PSM test profile

A.6 Reception in eDRX (RAI enabled)

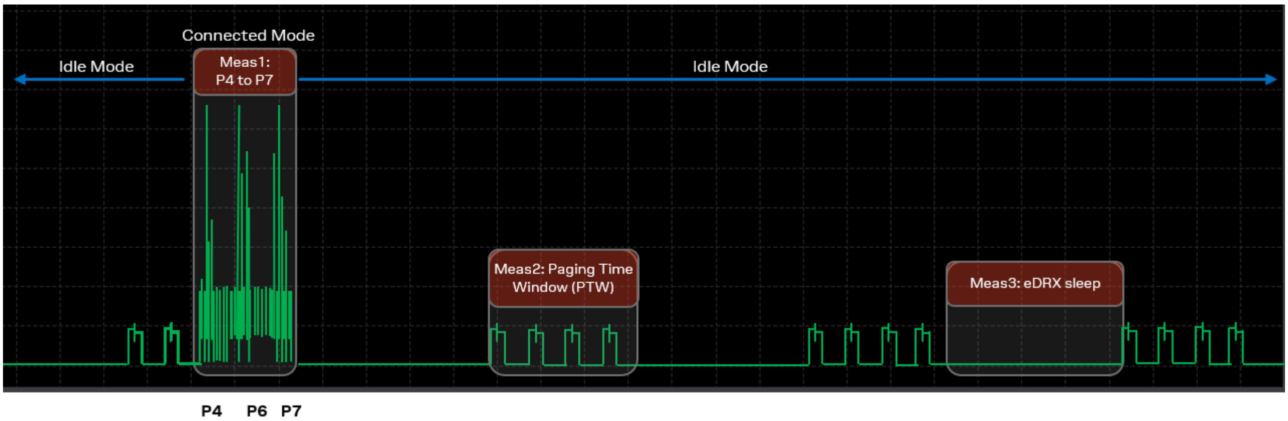

Figure 20 – Reception in eDRX test profile

Action	Outcome	Measurement
Initial state: device connected to the network in idle status (active and connected in GPRS)		
Device listens for network paging every [eDRX value] (does not apply in GPRS)		Meas1 Energy consumed between paging windows (Wh) Meas2 Energy consumed during a paging window (Wh)
Application transmits [NBYTES] to device in fixed IP address using [CXMETHOD]	Device is notified in next paging window and receives information	Meas3 Energy consumed while in active status (Wh)
Device goes back to idle status (active and connected in GPRS)		

Table 10 – Test Procedure: Reception in eDRX

Reception in eDRX	Recommended Tests	
Parameters	**RT1: LTE-M**	**RT2: NB-IoT**
Device	LTE-M device	NB-IoT Device
Band	3	20
Deployment model	-	in-band
Network	Cat-M1 R13	Cat-NB1 R13
eDRX value	40.96 seconds	40.96 seconds
cDRX	Yes	No
Paging time window	5.12 seconds	5.12 seconds
Inactivity timer	5 seconds	5 seconds
RAI	Yes	Yes
Application protocol	UDP	UDP
Number of bytes	10	10
Extended Coverage	Mode A Level 0	ECL0
RSRP (dBm)	-100	-100
Results		
Meas1: Energy consumed while in Active status	50 - 719 µWh	70- 100 µWh
Meas2: Energy consumed between paging windows	26 - 121 µWh	0.9 - 26 µWh
Meas3: Energy consumed during a paging window	3.5 - 3.8 µWh	1.77 - 5 µWh

Table 11 – Test Results: Reception in eDRX

A.7 Connection to network then to PSM

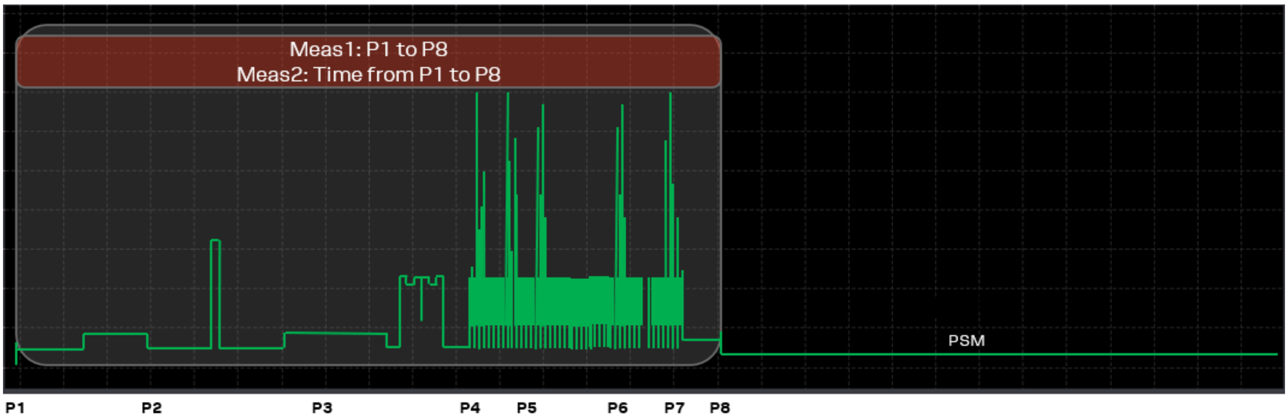

Figure 21 – Connection to network then to PSM Test Profile

Action	Outcome	Measurement
Initial state: device switched off, no power		
Device is powered on	Device begins connection to network	
Device connects to network	Device connected to network	
Device transmits [NBYTES] to server in fixed IP address using [CXMETHOD]	Bytes received by server	
Device goes back to PSM status (in GPRS, shut down device)		Meas1 Energy consumed while in Connecting and Active status Meas2 Time negotiating and in active status

Table 12 – Test Procedure: Connection to network and change to PSM.

Connection to network then to PSM	Recommended Tests		
Parameters	**RT1: LTE-M**	**RT1: NB-IoT**	**RT2: GPRS**
Device	LTE-M device	NB-IoT Device	2G device
Band	3	20	8
Deployment model	in-band	in-band	-

Connection to network then to PSM	Recommended Tests		
Network	Cat-M1 R13	Cat-NB1 R13	GPRS
T3324	0 seconds	0 seconds	-
T3412	60 seconds	60 seconds	-
Inactivity Timer	5 seconds	5 seconds	-
RAI	Yes	Yes	-
Application protocol	UDP. Unconfirmed	UDP. Unconfirmed	UDP. Unconfirmed
Number of bytes	10	10	-
Extended Coverage	Mode A Level 1	ECL0	-
RSRP/RSSI (dBm)	-100	-100	-80
Results			
Meas1: Energy consumed while in connecting and active status	158 - 1620 µWh	200 - 700 µWh	559 µWh
Meas2: Time negotiating and in active status	4.5 - 25.7 seconds	16.4 – 19 seconds	6.04 seconds

Table 13 – Test Results: Connection to network and change to PSM

A.8 Always ON transmission

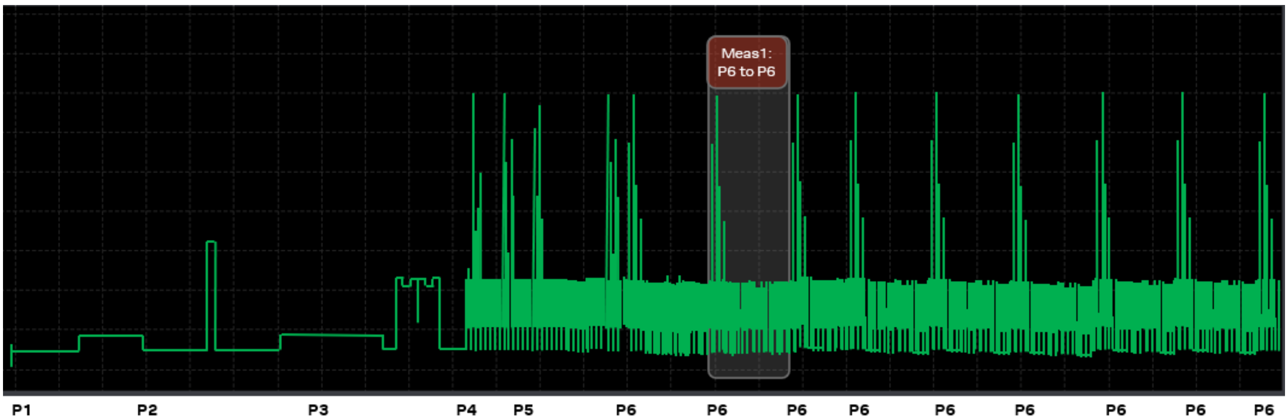

Figure 22 – Always ON transmission. Test Profile if transmission period < Inactivity Timer

Action	Outcome	Measurement
Initial state: device switched off, no power		
Device is powered on	Device begins connection to network	
Device connects to network	Device connected to network	
(only if TCP) Device connects to server in fixed IP address	Device connected to server	
Device transmits [NBYTES] to server in fixed IP address using [CXMETHOD] every [PERIOD] seconds	Bytes received by server	Meas1 Energy consumed while in [PERIOD]

Table 14 – Test Procedure: Always ON transmission (TON < Inactivity Timer)

SCENARIO 1

Always on transmission	Recommended Tests		
Parameters	**RT1: LTE-M**	**RT2: NB-IoT**	**RT3: GPRS**
Device	LTE-M device	NB-IoT Device	2G device
Band	3	20	8
Deployment model	-	in-band	-
Network	Cat-M1 R13	Cat-NB1 R13	GPRS
eDRX value	40.96 seconds	40.96 seconds	-
cDRX	Yes	No	-
Inactivity timer	5 seconds	5 seconds	-
Connection period	3 seconds	3 seconds	3 seconds
Application protocol	UDP. Unconfirmed	UDP. Unconfirmed	UDP. Unconfirmed
Number of bytes	100	100	100
Extended Coverage	Mode A Level 0	ECL0	-
RSRP/RSSI (dBm)	-100	-100	-80
Results			
Meas1: Average energy consumed while in Connecting and Active status when transmission period is less than the inactivity timer (9 data packets)	119 - 159.22 µWh	110 - 179 µWh	237.22 µWh

Table 15 – Test Result: Always ON Transmission (Ton < Inactivity Timer)

SCENARIO 2

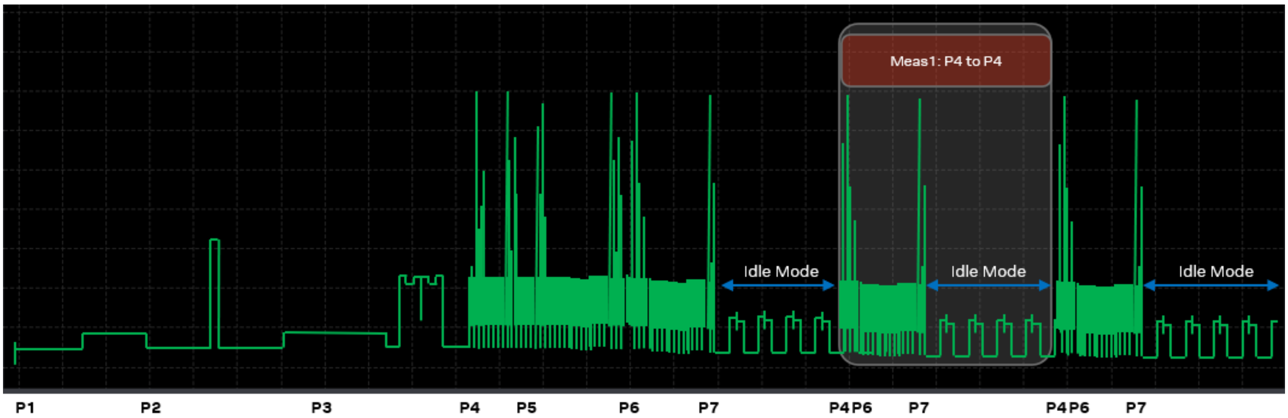

Figure 23 – Always on Transmission. Test Profile if transmission period > Inactivity Timer

Always on transmission	**Recommended Tests**		
Parameters	**RT1: LTE-M**	**RT2: NB-IoT**	**RT3: GPRS**
Device	LTE-M device	NB-IoT device	2G device
Band	3	20	8
Deployment model	-	in-band	-
Network	Cat-M1 R13	Cat-NB1 R13	GPRS
eDRX value	40.96 seconds	40.96 seconds	-
Paging time window	2.56 seconds	5.12 seconds	
cDRX	Yes	No	-
Inactivity timer	5 seconds	5 seconds	-
Connection period	30 seconds	30 seconds	30 seconds
Application protocol	UDP. Unconfirmed	UDP. Unconfirmed	UDP. Unconfirmed
Number of bytes	100	100	100
Extended Coverage	Mode A Level 1	ECL0	-
RSRP/RSSI (dBm)	-100	-100	-80
Results			

Always on transmission	Recommended Tests		
Meas1 : Average energy consumed while in Connecting and Active status when transmission period is greater than the inactivity timer	350 - 960.89 µWh	140 - 261.67 µWh	1.17 mWh

Table 16 – Test Result: Always ON Transmission (Ton > Inactivity Timer)

A.9 eUICC Profile swap

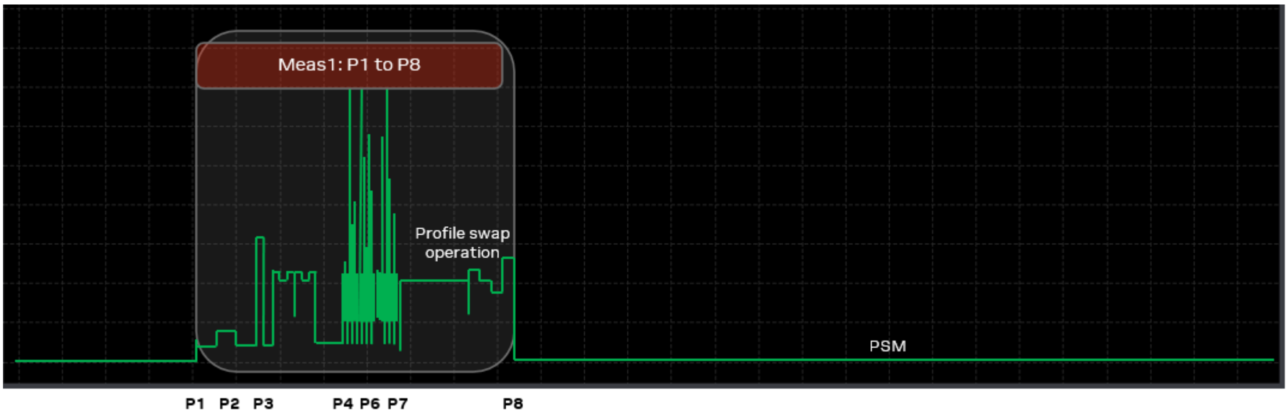

Figure 24 – eUICC Profile swap, Test Profile

Action	Outcome	Measurement
Initial state: device connected to the network PSM status, with known TAU update time (in GPRS, device starts from off state)		
SM-SR launches profile swap		
TAU timer expires (in GPRS, switch device on)	Device executes TAU procedure	
Device and SM-SR execute full profile swap	SIM profile changed	

Device goes back to PSM status (in GPRS, switch device off)		Meas1 Energy consumed before getting back to PSM status

Table 17 – Test Procedure: eUICC Profile Swap, Test Profile

Profile swap	**Recommended Tests**		
Parameters	**RT1: LTE-M**	**RT2: NB-IoT**	**RT3: GPRS**
Device	LTE-M device	NB-IoT Device	2G device
Band	3	20	8
Deployment model	-	in-band	-
Network	Cat-M1 R13	Cat-NB1 R13	GPRS
T3324	2 seconds	2 seconds	-
T3412	60 seconds	60 seconds	-
Inactivity timer	5 seconds	5 seconds	-
RAI	No	Yes	-
Extended Coverage	Mode A Level 0	ECL0	-
RSRP/RSSI (dBm)	-100	-100	-80
Results			
Meas1: Energy consumed before getting back to PSM status	2.83 mWh	1.77 mWh	15.9 mWh

Table 18 – Test Result: eUICC Profile Swap, Test Profile

Annex B Document Management

B.1 Document History

Version	Date	Brief Description of Change	Approval Authority	Editor / Company
0.1.0	24 Feb. 2021	Initial draft skeleton		

Table 19 – Document History

B.2 Other Information

Type	Description
Document Owner	GSMA 5G IoT Strategy Group
Editor / Company	Igor Tovberg - Sony
Editor / Company	Nicolas Damour – Sierra Wireless

Table 20 – Document Owner

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