GSMA

White Paper

February 2026

Mobile IoT Deployment Guide

This is a GSMA IoT Community Publication

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Executive Summary

NB-IoT and LTE-M are complementary radio access technologies specified by 3GPP in Releases 13 to 17 to address the fast-expanding market for low power wide area (LPWA) connectivity for IoT. To achieve global coverage and wide adoption of LPWA services, mobile network operators must ensure that devices and end-to-end services from various providers will connect to the LPWA systems that have been deployed and that the data transport capability and connection modes are well understood.

This document contains non-binding guidelines intended to help mobile operators and solution developers to ensure interoperability and smooth roaming. The recommendations have been developed by members of the GSMA 5G IoT Forum based on significant global deployment experience gained since 2017 and practical insight regarding which features have gained market traction. The guide categorises the myriad of features specified in multiple releases of the 3GPP standard into three distinct groups; (1) minimum baseline features required for interoperability, (2) new and emerging features, and (3) features not widely adopted.

The GSMA plans to maintain and update this guide on a regular basis, particularly with respect to the adoption of new and emerging features which may become part of the minimum baseline recommendations.

1. Introduction

1.1 Overview

NB-IoT and LTE-M are cellular radio access technologies specified by 3GPP to address the rapidly growing market for IoT devices requiring low power wide area connectivity. The two technologies have complementary performance characteristics and are often deployed side by side in the same network. They form part of the global 5G standard and are expected to remain in service well into the 2030's and beyond.

1.1 Scope

This document considers and categorises the features associated with NB-IoT and LTE-M up to and including Release 17, with a view to helping both mobile network operators and solution developers to differentiate between essential features needed for performance and interoperability and newer features which are still emerging – and those which have never been deployed.

Out of scope are non-3GPP LPWA technologies, such as SigFox or LoRa.

Definitions

TERMS	DESCRIPTION
IoT	Internet of Things, a generic term for the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment. IoT offers functions and services which go beyond the pure M2M scope. MIoT is a subset of the far bigger IoT concept, for example a bunch of sensors connected together via Wi-Fi or Bluetooth are a part of IoT but not MIoT.
M2M	Machine-to-Machine, a general term referring to any network technology allowing devices to communicate with each other. For example, two industrial robots connected to each other via Ethernet in a factory is a part of M2M but not MIoT.
MIoT	Mobile Internet of Things, a GSMA term which refers to the 3GPP standardised LPWA technologies using the licenced band (aka LTE-M, NB-IoT and EC-GSM-IoT). From 3GPP Release 13 and the following Releases, the Category of UEs that support power consumption optimisations, extended coverage and lower complexity are part of MIoT (CAT M1, CAT NB1 from Release 13 and CAT M2, CAT NB2 from Release 14). As this particular term is widely used throughout GSMA, it is utilised also in this document.
LTE-M	LTE-M is the simplified industry term for the LTE-MTC low power wide area (LPWA) technology standard published by 3GPP in the Release 13 specification. It specifically refers to LTE Cat M, suitable for the IoT. LTE-M is a low power wide area technology which supports IoT through lower device complexity and provides extended coverage, while allowing the reuse of the LTE installed base.
CAT-M NTN	Generic category for CAT-M NTN devices supporting Release-17 or later, as specified in 3GPP TS 36.306[14].
CAT-NB NTN	Generic category for NB-IOT NTN devices supporting Release-17 or later, as specified in 3GPP TS 36.306[14].

Abbreviations

TERMS	DESCRIPTION
3GPP	3rd Generation Partnership Project
API	Application Programming Interface
AS	Application Server
BS	Base Station
BTS	Base Transceiver Station
CDF	Charging Data Function
CGF	Charging Gateway Function
CIoT	Cellular Internet of Things
CMM	Connected Mode Mobility
dB	Decibel
DRX	Discontinuous Reception
DL	Downlink
eDRX	Extended Discontinuous Reception
eNB	Evolved Node B
EPS	Evolved Packet System
GSM	Global System for Mobile Communications
GSMA	GSM Association
GTP	GPRS Tunnelling Protocol
HLCom	High Latency Communication
HPLMN	Home Public Land Mobile Network
HSS	Home Subscriber Server
IoT	Internet of Things
IP	Internet Protocol
IP-SM-GW	Internet Protocol Short Message Gateway
IPX	Internetwork Packet Exchange
IWF	InterWorking Function
IWK-SCEF	InterWorking Service Capabilities Exposure Function

TERMS	DESCRIPTION
LPWA	Low Power Wide Area
LTE	Long-Term Evolution
LTE-M	Long-Term Evolution Machine Type Communications
M2M	Machine-to-Machine.
MFBI	Multi Frequency Band Indicator
MIoT	Mobile Internet of Things
MME	Mobile Management Entity
MNO	Mobile Network Operator
MO	Mobile Originated
MSC	Mobile Switching Centre
MT	Mobile Terminated
MTC	Machine Type Communications
NB-IoT	Narrowband IoT
NTN	Non-Terrestrial Network
O&M	Operation and Maintenance
OTA	Over The Air
PDN	Packet Data Network
PGW	Packet Gateway
PRB	Physical Resource Block
PSM	Power Saving Mode
RAN	Radio Access Network
SCEF	Service Capabilities Exposure Function
SCS	Services Capabilities Server
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SI	System Information
SIM	Subscriber Identity Module

Abbreviations

TERMS	DESCRIPTION
SMS	Short Message Service
SMS SC	Short Message Service Centre
TAU	Tracking Area Updating
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UE	User Equipment (User Device)
UICC	Universal Integrated Circuit Card (sometimes known as the SIM card)
UL	Uplink
VPLMN	Visited Public Land Mobile Network

References

TERMS	DOC NUMBER	DOC NUMBER
[1]	IOTTF07_DOC004	MIoT Roaming Whitepaper Draft. GSMA NG working group
[2]	3GPP TS 23.682	TS 23.682 (clause 4.5.4): Architecture enhancements to facilitate communications with packet data networks and applications
[3]	3GPP TS 24.008	Mobile radio interface Layer 3 specification; Core network protocols; Stage 3
[4]	3GPP TS 24.301	Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS); Stage 3
[5]	3GPP TS 23.401	General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access
[6]	3GPP TS 36.201	Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description
[7]	GSMA IR.92	IMS Profile for Voice and SMS; Section 3.2.1
[8]	3GPP TS 36.101	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception
[9]	3GPP TS 23.682	TS 23.682 (clause 4.5.4): Architecture enhancements to facilitate communications with packet data networks and applications
[10]	3GPP TS 36.307	Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements on User Equipment's (UEs) supporting a release-independent frequency band
[11]	3GPP TS 36.331	Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification
[12]	3GPP TS 29.272	Evolved Packet System (EPS); Mobility Management Entity (MME) and Serving GPRS Support Node (SGSN) related interfaces based on Diameter protocol
[13]	3GPP TS 29.212	Policy and Charging Control (PCC); Reference points
[14]	3GPP TS 36.306	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio access capabilities
[15]	3GPP TS 36.102	Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception for satellite access
[16]	3GPP TS 38.101-5	NR; User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements

2. Enabling Global Deployments

NB-IoT and LTE-M are low-power wide-area network (LPWAN) radio technologies that have once been specified and standardised in a very short timeframe, in response to customer requirements and emerging competition from non-3GPP proprietary technologies.

Both technologies are now established with **global coverage**, enabling application service providers to deploy and operate their solutions worldwide in a smooth and predictable manner. As of Oct 2025 there were more than 140 NB-IoT and 129 LTE-M networks deployed. Further details of these launches can be found at the GSMA's IoT deployment website https://www.gsma.com/solutions-and-impact/technologies/internet-of-things/deployment-map/

Both the mobile industry and its customers benefit from the **ability of devices to roam** and to interconnect to all mobile networks. However, each MNO's setup of NB-IoT and LTE-M frequency bands, data architecture and key features can affect the performance of a device, its cost and even its ability to roam. Below are some examples:

- If PSM and eDRX timers were set differently in different networks, device and service behaviour would change, impacting responsiveness to backend-originated commands and the longevity of the battery.
- If some (optional) features are not enabled, there could be negative implications for end-to-end security.
- Certifying roaming devices for all existing bands globally, which will have potentially significant cost implications.

Consistent deployment configuration settings, or at least transparency on them, are required to achieve a common deployment experience for IoT developers and users globally, independent of the MNO network being accessed. For any given IoT solution, application logic should be as constant as possible regardless of which RAN is used. From the IoT developer perspective, their devices need to work the same way and utilize the same minimum feature set. Ideally, the "write once, run in any network" rule should be applied, to avoid adapting the actual application to account for a device switching between NB-IoT and LTE-M, for example, when roaming across Europe.

Moreover, in order to reduce device costs, developers need to know which **bands** have been deployed by MNOs in territories where they intend to operate. To this end, MNOs can provide details of the bands in which they have deployed or intend to deploy.

Since the first deployment of Mobile IoT networks in 2017, several MNOs and network providers have gained extensive insights and experience with NB-IoT and LTE-M features. **This document** will help to share that experience and learning with all MNOs, network providers and chipset providers deploying and supporting NB-IoT and/or LTE-M. Specifically, it also assists MNOs' forthcoming decisions relating to deployment architectures and feature selection.

The Mobile IoT Deployment Guide builds up a picture of global deployment architectures, from the roaming and interconnect perspective, to realise the benefits of the development and deployment of a global telecommunications standard.

3. Feature Deployment Guide

Features covered in this Deployment Guide

For a Mobile IoT device to operate in a network, both the network and the device need to support numerous features. To connect to a mobile network, just like a regular mobile handset, a Mobile IoT device needs to support a range of features that have been standardised by the 3GPP.

In this deployment guidelines document, we have taken those fundamental features of connecting to the network and other functions that are common with mobile handsets, as a given. Instead, the document focusses on features that in some ways, are unique to Mobile IoT. The document then categorises those unique features into three distinct groups:

1. Minimal baseline features
2. New and emerging features
3. Features not widely adopted

3.1 Minimal baseline features

Features in this grouping are widely supported by MNOs and devices. To some extent, a Mobile IoT device may not operate optimally without them. For example, a battery powered water meter deployed into the field for potentially ten plus years may not achieve its service lifetime without relying upon energy reduction features like Power Savings Mode (PSM), extended discontinuous reception (eDRX) and R14 Release Assistance Indication (RAI).

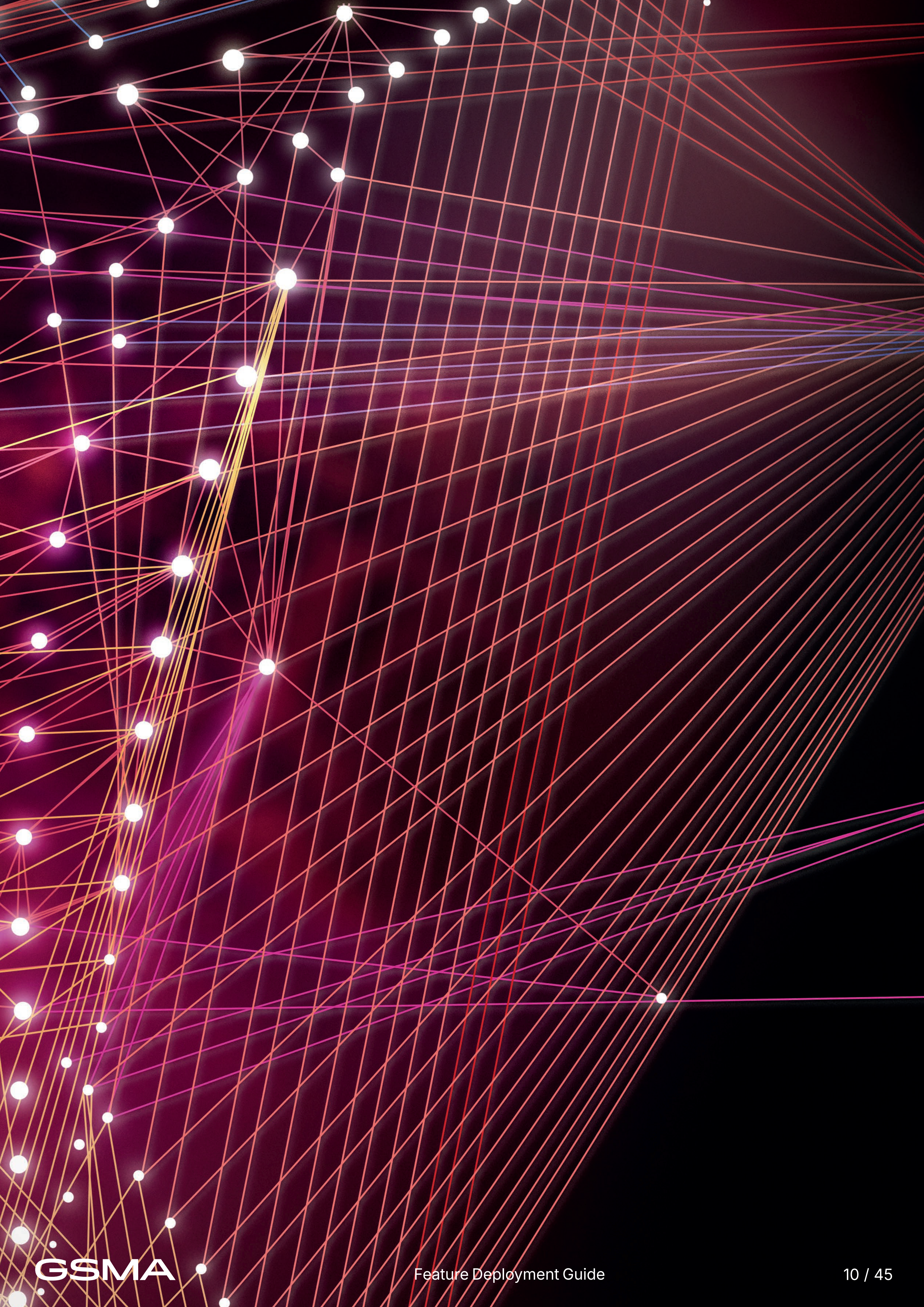
New and emerging features

As the name suggests, new features are just that, features that may have been standardised by 3GPP but it may be too soon for them to have been implemented into commercial networks and devices. That is, upon completion of standardisation activities it may take at least two to three years before a 3GPP standardised feature is implemented into commercial networks and/or devices. For these features, it's then a matter of monitoring the industry situation until that theoretical capability is realised in commercial networks and devices.

Emerging features are those that may have some limited support, but it is too soon to know whether adoption of the feature will grow further to become widely adopted or not. For example, LTE-M can support VoLTE voice services. Indeed, some chipset and infrastructure vendors have implemented a limited VoLTE capability in their products to support VoLTE for LTE-M. In some markets, mobile network operators have enabled this capability. In other markets, the regulatory environment mandates an emergency calling capability which is currently excluded from that limited VoLTE implementation, so VoLTE for LTE-M is not currently a possibility in those markets. For emerging features, it's usually a case of monitoring the market and technology evolution.

Features not widely adopted

This group of features includes device and network capabilities that have not been taken up even though they may have been standardised by 3GPP. There may be many reasons why a feature has been standardised but not been realised commercially. In some instances, it may be because alternate mobile device categories or capabilities are able to service the need already. For example, LTE-M device Category M2 has been standardised but will likely not be implemented in the world market. The performance characteristics of Cat M2 are not that dissimilar to those of Cat 1 and therefore there is little incentive to take Cat M2 from a technical standard to a commercial reality. While some carriers have deployed VoLTE on LTE-M devices, it is not widely deployed in the world market.



4. Minimal baseline features

4.1 Common features

Deployment bands

Whilst strictly speaking not a feature unique to Mobile IoT, the choice of operating may have a significant impact on the performance of Mobile IoT applications. That is, to achieve the maximum possible depth and breadth of coverage, it is preferable to use the lowest possible frequency band available. Often this means that at least one sub 1GHz band is used for Mobile IoT in a market.

From a Mobile Network Operator's perspective, the regulatory environment in each market dictates what frequency bands are available to them. So too does the amount of spectrum a MNO holds in specific frequency bands and the need to not significantly compromise the traffic carrying capacity of that spectrum for mobile broadband applications.

From an application developer's perspective, the radio module within their product needs to support the operating frequencies used in their target market(s). Additionally, if they are to maximise the coverage potential of their product, the antenna used by the product needs to support those same operating frequencies. For products intended for roaming applications, this could represent quite a challenge. For example, a product may operate in one market where the Mobile IoT operating frequency is band 20 but then roam into other markets where band 3 needs to be supported. If the antenna in the product is not able to adequately support each of these bands, coverage would be compromised.

3GPP Technical Specification TS36.101 defines the frequency bands that have been standardised for use by Mobile IoT. Release 17 of TS36.101 defines the following bands:

4.1.1 LTE-M

UE Categories M1 and M2 are designed to operate in the frequency bands 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 14, 18, 19, 20, 21, 24, 25, 26, 27, 28, 31, 66, 71, 72, 73, 74, 85, 87 and 88 in both half duplex FDD mode and full-duplex FDD mode and in bands 39, 40, 41, 42, 43 and 48 in TDD mode.

4.1.2 NB-IoT

UE Categories NB1 and NB2 are designed to operate in the frequency bands 1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 14, 17, 18, 19, 20, 21, 24, 25, 26, 28, 31, 41, 42, 43, 48, 65, 66, 70, 71, 72, 73, 74, 85, 87, 88, and 103. Additionally, UE Categories NB1 and NB2 are designed to operate in the NR operating frequency bands n1, n2, n3, n5, n7, n8, n12, n14, n18, n20, n25, n26, n28, n41, n65, n66, n70, n71, n74 and n90. Whilst initially NB-IoT Release 13 NB-IoT devices could only operate in HD-FDD mode, today Category NB1 and NB2 systems can operate in HD-FDD duplex mode or in TDD mode.

Whilst the above defines what frequency bands could be used, it does not define what frequency bands are being used or where. By surveying its member MNOs, the GSMA identified at a high level the frequency bands used in different regions. This information is summarised in Table 1

REGION	BAND
Europe	3, 8, 20
Commonwealth of Independent States	3, 8, 20
North America	2, 4, 5, 12, 66, 71, 26
Asia Pacific	1, 3, 5, 8, 18, 20, 26, 28
Sub-Saharan Africa	3, 8
Middle East and North America	8, 20
Latin America	2, 3, 5, 28

Table 1, Mobile IoT Regional Frequency usage

3GPP Technical Specification TS 36.102 [15] and TS 38.101-5 [16] defines the frequency bands that have been standardised for use by NTN devices. Release 17 or later versions of 3GPP TS 36.102 [15] and 3GPP TS 38.101-5 [16] defines the following NTN bands:

NTN UEs are designed to operate in the frequency bands 253, 254, 255 and 256. Additionally, NR NTN UEs are designed to operate in the NR operating frequency bands n254, n255 and n256.

* – trials/planned/consideration

REGION	BAND
Europe	256, 255, 254*, 253*
USA	256, 255, 254*
Canada	256, 255
India	256*, 255*
Australia	256*, 255*
Japan	254*
China	254*
Brazil	256*, 255
Africa	256*

Table 2, Mobile IoT Regional Frequency usage

Additional information specific to a market and MNO can be found at the GSMA's Mobile IoT Deployment Map website. https://www.gsma.com/iot/deployment-map/

Recommendations

MNOs should endeavour to maximise their coverage potential by deploying Mobile IoT into at least one sub 1GHz frequency band. They should openly publish the frequency bands they are using for Mobile IoT including publishing onto the GSMA's Mobile IoT Deployment Map website. https://www.gsma.com/solutions-and-impact/technologies/internet-of-things/deployment-map/

Application developers should investigate the frequency bands in use for their current and future target markets to ensure both the radio module and antenna system used by their product can adequately support those frequency bands.

Neither NB-IoT nor LTE-M have been deployed in TDD mode by any public carrier in the world market. It is instead recommended to deploy in FDD spectrum.

Network attachment

Whilst every mobile device needs to attach to the network, for Mobile IoT additional ways of working were introduced to streamline operation and reduce energy consumption. That is, there are two main network attach options to support connectivity:

1. **Attach with PDN (Packet Data Network) connection:** the UE (User Equipment) is required to establish a PDN connection as part of the attach procedure. This has been the case for all 3GPP EPS (Evolved Packet System) releases up to Rel-13.
2. **Attach without PDN connection:** this is a new capability that has been introduced in Rel-13 to allow UEs supporting CIoT (Cellular Internet of Things) optimisations to remain attached without PDN connection, which may be useful for cases where huge numbers of devices would keep a connection inactive for very long period of time and seldom transmit data over it.

PDN connection establishment options

There are different data connectivity options for PDN connections available to IoT devices using the EPS:

1. **IP over Control Plane:** both User Datagram Protocol (UDP) and Transmission Control Protocol (TCP) from 3GPP Rel-13 using the Control Plane CIoT EPS optimisation with IP PDN types
2. **IP over User Plane** (both UDP and TCP), including User Plane Optimisation and user Plane Original), available since Rel-8 with IP PDN types
3. **Non-IP over Control Plane**, from 3GPP Rel-13 using the Control Plane CIoT EPS optimisation with Non-IP PDN type
4. **Non-IP over User Plane** (including User Plane Optimisation and User Plane Original), from 3GPP Rel-13 using the User Plane CIoT EPS optimisation with Non-IP PDN type

Each of these options has advantages and disadvantages. The traditional mechanism for transporting information over LTE is to attach with a PDN connection and use IP over User Plane (most commonly TCP) and/or SMS.

4.1.3 Control Plane vs User Plane

Control Plane CIoT EPS Optimisation transports user data or SMS messages via MME by encapsulating them in NAS (Non-Access-Stratum), thus reducing the total number of control plane messages when handling a short data transaction.

For services that occasionally transmit reasonably small amounts of data, the utilisation of the Control Plane will optimise the power consumption due to the fact that the amount of signalling required and the "air time" is reduced. Services that need to send more information could benefit from User Plane connection, which can be used to send multiple packages. Overall, this approach might consume less power than sending multiple messages over the Control Plane. On the other hand, using non-IP over the User Plane might be unrealistic simply because the benefits of using efficient protocols are nullified by using a user plane connection.

4.1.4 IP vs non-IP

Power consumption can be optimised using either non-IP, or UDP and TCP over IP. Non-IP allows for the use of protocols that have been optimised for a specific use. UDP is asynchronous, which reduces the time of the connection, while TCP will keep the connection open until an acknowledgment is received.

In the case of non-IP communication over the Control Plane, the MNO has two options, either through the PGW (Packet Gateway) (requiring support for the SGi interface to the application server) or by utilising SCEF. For the latter case, the visited network will direct the message to the IWF (InterWorking Function) -SCEF which will connect to the SCEF of the home network (via the new T7 interface).

Recommendations

For LTE-M, it is recommended that MNO's support IP traffic over User Plane as a minimum requirement to support roaming, optionally using the User Plane CIoT EPS Optimisation.

LTE-M implementation over Control Plane isn't supported by the vast majority of LTE-M MNO's and therefore does not form part of the minimum feature baseline.

For NB-IoT, it is recommended that MNO's support IP traffic over Control Plane and Control Plane CIoT EPS optimisation as a minimum requirement to start supporting roaming. This option is the best solution for supporting devices that need to consume as little power as possible.

Since many MNO's that have already deployed NB-IoT do not support Non-IP over Control Plane, this implementation is optional. However, if non-IP traffic is to be supported, it is recommended to start by utilising the SGi interface and later on by utilising SCEF.

NB-IoT implementation over User Plane isn't supported by most NB-IoT MNO's and therefore does not form part of the minimum feature baseline.

PSM – Power Saving Mode

Introduced in 3GPP Release 12, Power Saving Mode (PSM) is designed to help IoT devices conserve battery power and potentially achieve up to 10-years battery life.

Whilst it has always been possible for a device's application to turn its radio module off to conserve battery power, the device would subsequently have to reattach to the network when the radio module was turned back on. The reattach procedure consumes a small amount of energy, but the cumulative energy consumption of reattaches can become significant over the lifetime of a device. Therefore, battery life could be extended if this procedure could be avoided.

When a device initiates PSM with the network, it provides two preferred timers (T3324 and T3412), configurable by customers through AT Commands embedded within the Customer's device software:

- **T3324 Active Timer** – Determines how long the User Equipment (UE) stays in idle mode listening to paging messages following a Periodic Tracking Area Update or a Mobile Origination event.
- **T3412 Extended Timer** – Extended time between two Periodic Tracking Area Updates (pTAU). pTAU are used by the UE to inform the network that it is still registered and should not be detached by the network.

The duration after T3324 Timer expires and before the next pTAU, is the PSM time or HIBERNATE period, a period during which the UE/Device is not reachable by a Mobile Terminated message/SMS.

PSM effectively turns off monitoring of Paging Instances on the device and increases the time periods of devices sending Periodic Tracking Area Updates (pTAUs) to extended intervals.

As a result, the device is able to save battery current drain and drop power consumption into the micro-Ampere range by disabling parts of the chipset protocol stack and decreasing device-to-network signalling while remaining registered with the network. If a device awakens before the expiration of the time interval to send data, a reattach procedure is not required, and energy is saved.

This timer T3324 has a trade-off between lower values and maximum values. Lower values save more battery life by allowing the UE to go into hibernate state quicker. Higher values of T3324 will allow a longer time for the application server (AS) to respond to UE/MO data (e.g. acknowledgements, network initiated data). Customers are advised to test out this parameter to determine a value that best fits their Use Case.

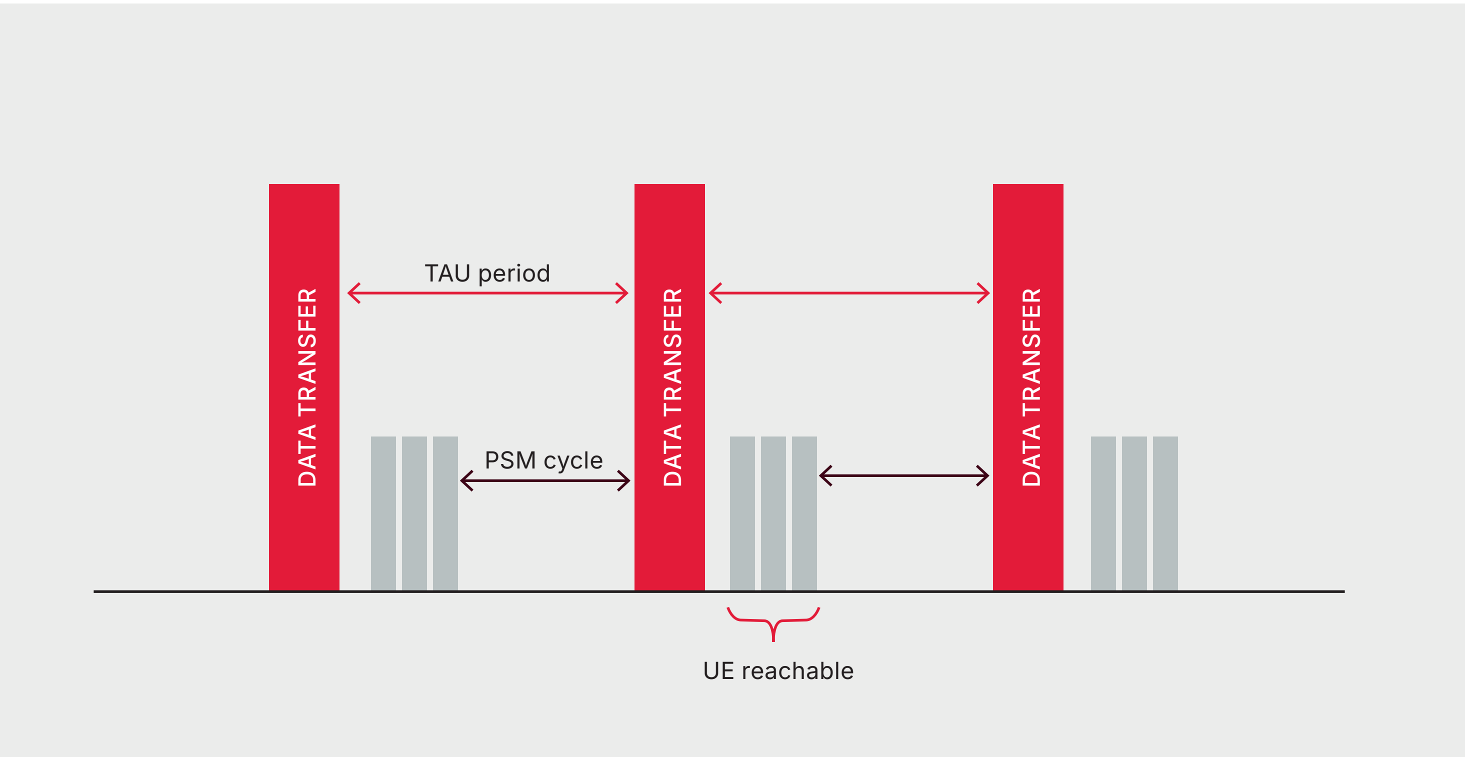


Figure 1, TAU (Tracking Area Updating) period and PSM cycle

For example, for a monitoring application, the radio module in a device might be configured by an application to enable PSM, negotiate a 24-hour time interval with the network and provide a daily status update to a centralised monitoring point. If the device's monitoring application were to detect an alarm condition, irrespective of any agreed sleep interval, the application could wake the radio module instantly and send vital information to the centralised monitoring point without the need to execute a reattach procedure.

In a similar manner to a radio module that has been powered off, a radio module with PSM enabled cannot be contacted by the network whilst it is asleep. The inability to be contacted whilst asleep may preclude the use of PSM for some applications.

The network may accept both timer values or set different ones. If a UE requested value is lower than the minimum recommended value, the network may override with the minimum value. If the UE requested value is higher than the maximum recommended value, the network may override with the maximum value as set in Release 13. Some networks also add an additional random amount of time to the requested T3412 value. This is done to reduce the potential for multiple devices in the same radio cell consistently sending a pTAU at the same instant in time.

For detailed information, refer to:

— TS 23.682 (clause 4.5.4) [2]: Architecture enhancements to facilitate communications with packet data networks and applications.
— TS 24.301 [4]: provides the timers used and their default values.
— TS 24.008 [3]: provides the coding detail for the timers (GPRS Timer 2 and 3)

PSM in combination with custom APNs

There are specific recommendations to the use of PSM in combination with custom APNs to ensure the APN idle timer is set such that it is in-sync with what the customers PSM timers are set to. Upon expiration of the APN idle timer, the UE is implicitly detached from the network. If a customer wants to use PSM, their T3412 Extended Timer value should not be greater than their APN Idle Timer, since the device would otherwise need to reattach after resuming from its PSM state, therefore defeating the main purpose of the PSM feature.

Summary:

- PSM is a UE mechanism to reduce the energy used by the UE.
- The UE reports how often and for how long it needs to be active in order to transmit and receive data. However, the final values are determined by the network.
- PSM mode is similar to power-off, but the UE remains registered with the network. When the UE becomes active, again there is no need to re-attach or re-establish PDN connections.
- UE requests PSM simply by including a timer with the desired value in the attach request or TAU tracking area update.
- The maximum time a device may sleep is approximately 413 days (maximum value of the T3412 Extended timer). The maximum time a device may be reachable is 186 minutes for both NB-IoT and LTE-M (maximum value of the active timer T3324).
- The network may accept both requested timer values or set different ones.

Note: On mobile originations: An application running on a UE, controlling the UE radio module, can initiate a mobile origination at any time, even if the device is within a PSM state. Therefore, mobile originations are not governed by the use of PSM. Furthermore, T3412 resets after mobile originated events.

Recommendations

This guide recommends that MNOs and UE should support PSM for Mobile IoT deployments.

No further restrictions should be set to timers based on 3GPP Release 13 [2], [3] & [4], and the device requested values used wherever possible.

It is recommended that a "store and forward" policy be supported for PSM. For more details, please refer to the "High-Latency Communications" section of this document.

eDRX - Extended Discontinuous Reception

A 3GPP Release 13 feature, Extended Discontinuous Reception (eDRX) is an extension of an existing LTE feature, which can be used by IoT devices to reduce power consumption.

Today, many smartphones use discontinuous reception (DRX) to extend battery life between recharges. By momentarily switching off the receive section of the radio module for a fraction of a second, the smartphone is able to save power. The smartphone cannot be contacted by the network whilst it is not listening, but if the period of time is kept to a brief moment, the smartphone user will not experience a noticeable degradation of service. For example, if called, the smartphone might simply ring a fraction of a second later than if DRX was not enabled. As the name suggests, eDRX takes this concept of discontinuous reception and further extends it.

eDRX has been designed for downlink-centric applications (e.g. actuators) that usually receive rather than send data. eDRX is especially useful when it is not critical for the device to be unreachable from several seconds to a few hours. For such applications, the device wakes up from it's momentary slumber and listens to the network at regular intervals for any incoming data (so-called paging procedure).

eDRX allows the time interval during which a device is not listening to the network to be greatly extended, thus strongly reducing the power consumption of the device while remaining reachable from the network.

eDRX can be used without PSM or in conjunction with PSM to obtain additional power savings. Although it does not provide the same level of power reduction as PSM, eDRX provides a good compromise between device reachability and power consumption.

When a device application program initiates eDRX, it can provide via AT commands, two preferred timer values to the network:

- Paging Transmission Window (T PTW): Time during which the device performs the DRX procedure.
- eDRX Cycle (T eDRX): Time between the start of two consecutive PTW windows.

Note: T PTW value is optional, when omitted, a default value is provided by the network.

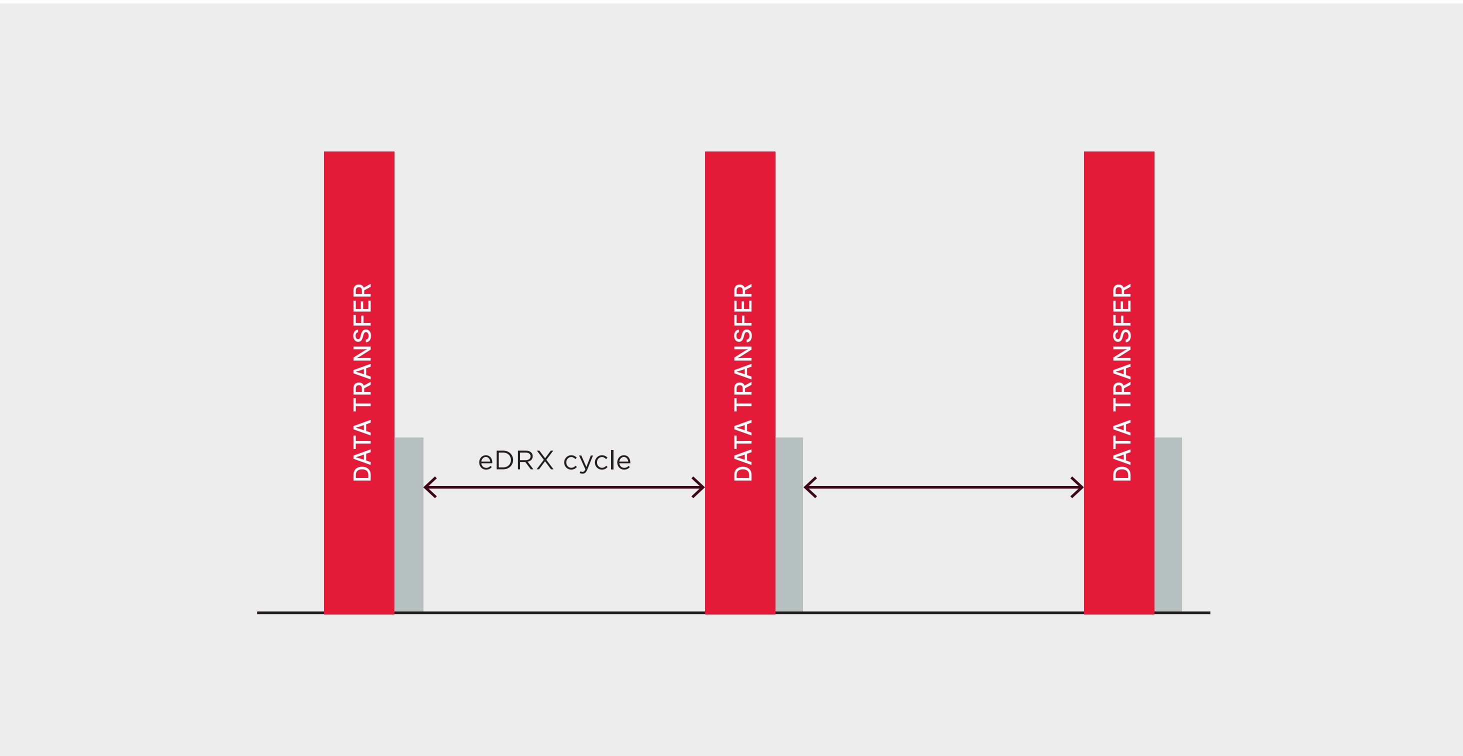


Figure 2, eDRX Cycle

Between two consecutive PTW windows, the IoT device module or chipset enters a so-called “Sleep Mode” during which the receive path of the radio chipset is deactivated. Note: On mobile originations: An application running on a UE, controlling the UE radio module, can initiate a mobile origination at any time , regardless of DRX/eDRX settings. Therefore, mobile originations are not governed by the use of eDRX.

As for PSM, the details of this feature can be found in 3GPP TS 23.682 [2] and 3GPP TS 24.301 [4].

Summary:

- eDRX is a mechanism to save device energy, particularly for mobile-terminated traffic.
- Networks and devices negotiate when devices can sleep.
- The device keeps its receiver circuitry switched off for a defined period of time; during this time, the device is not listening for paging or downlink control channels and therefore saves energy.
- When the UE wakes up, the receiver will listen for the Physical Control Channel.

Recommendations

It is recommended Mobile IoT deployments support idle-mode eDRX.

It is recommended that a “store and forward” policy be supported for eDRX. For more details, please refer to the “High-Latency Communications” section of this document.

This guide also recommends that customers should be informed about the implications of their choice for power consumption versus reachability.

In case of combined use of PSM and e-DRX, a careful alignment is needed between the different configuration parameters (PSM timers and e-DRX paging cycle length) in order to ensure paging success by the network.

Note: The device can request the use of both PSM and eDRX during an attach or TAU procedure, but it is up to the network to decide to enable none, one of them or both (see 3GPP TS 23.682 [2] and 3GPP TS 23.401 [5]).

High Latency Communication

The High Latency Communications (HLCom) feature can be used to handle mobile terminated (MT) communication, when the UE is unreachable while using PSM or eDRX. “High latency” refers to the initial response time before normal exchange of packets is established. The feature introduced in Release 13, is described in 3GPP TS 23.682. High latency communications may be handled by two main mechanisms:

1. **Extended data packet buffering (DPB):** Extended data packet buffering is done at the Serving-GW (S-GW) and it is controlled by the MME/SGSN, which explicitly informs the S-GW to buffer downlink packets related to a specific UE until it is reachable.
2. **Explicit notification towards the SCS/AS:** By using explicit notifications, the S-GW simply discards the downlink packets when the device is not reachable and the MME/SGSN issues a notification towards the SCS/AS once the device becomes available.

Recommendations

It is recommended that operators implement Data Packet Buffering to store incoming data packets whilst the device is asleep (using either PSM or eDRX), to be forwarded to the device once it awakens. This guide recommends the MNO sets aside storage for at least the last packet of 100 bytes, to allow the customer to send simple messages to the device, for example an update to the clock. Any storage limitations will need to be communicated to the customer and the roaming partner to establish a clear agreement on the operator’s store and forward policy for UE utilising PSM or eDRX. As the packets are stored in the S-GW of the visited network, limitations on downlink information retention however may vary depending on the roaming network over which the IoT device has attached.

In a GSMA survey of operators’ PSM policies, the majority of MNOs reported that they support Data Packet Buffering and store and forward for at least the last received packet. However, customers should be aware that Data Packet Buffering may not always be supported while roaming.

Note regarding SMS MT messages

There is currently no recommendation to implement any SMS MT buffering in addition to the existing legacy SMS store and forward mechanism in the home network’s SMS-Centre.

As a consequence, to prevent loss of information, devices using PSM and for which SMS MT are expected, should not request a PSM timer of higher value than the standard SMS expiry timer from the SMS Centre (typically 7 days).

Nevertheless, in networks implementing SMS delivery over the SGs interface, a high risk remains that SMS MT messages never get delivered within the configured SMS retention period of the SMS-C since SMS delivery attempts by the SMS-C are likely to occur while the IoT device is in deep-sleep mode (PSM) or in sleep mode (eDRX). Customers shall therefore be made aware of this limitation and recommended not to implement SMS MT in combination with PSM and/or eDRX.

In the future, the implementation of the SMS delivery over the SGd interface (aka SMS over MME) will enable the visited network MMEs to inform the home network’s SMS-Center about the next SMS MT message delivery opportunity according to the IoT device PSM and/or eDRX cycle (see “requested-retransmission-time” AVP in 3GPP TS 29.338 for more details). Since most operators currently do not support this SMS over MME interface, this implementation option will be considered in a future version of this deployment guide. However, SMS over MME is expected to become more widely supported with the sunset of 2G/3G infrastructure.

4.1.5 IPX Firewall

GTP-IDLE Timer on IPX Firewall

Some MNOs employ a firewall on the 3GPP S8 interface towards IPX (Internetwork Packet Exchange) network in order to protect their network. These firewalls are not part of the 3GPP standards, but some of the settings could have an impact on the performance of the service. These firewalls typically supervise the GPRS Tunneling Protocol (GTP) tunnel (session) of each device that is roaming on the network. To clean up the firewall from unused GTP sessions, an idle timer is used, such that, if no traffic is transferred, this GTP Tunnel is deleted.

In PSM, the device may sleep for very long periods of time and hence not send any data. If the firewall deletes the GTP session, this could lead to a new registration of the UE once it wakes up (if it is using Attach with PDN connection) or to the need to re-establish the PDN connection. This process will reduce battery lifetime.

Recommendations

It is recommended that operators operating an IPX Firewall implement a minimum GTP-IDLE timer value for Mobile-IoT traffic to prevent idle IoT devices from losing their PDN connection or end up in a contradictory EMM-state.

For NB-IoT, the recommended GTP-Idle timer value should be at least 31 days.
For LTE-M, the recommended GTP-Idle timer value should be at least 24 hours. This recommended minimum value for LTE-M might be increased in the future in the case that LTE-M traffic can be distinguished from the standard LTE traffic (e.g. after the implementation of the LTE-M RAT-Type as defined in 3GPP Release 15).

Coverage Enhancement

Some IoT applications require devices to be positioned in areas not readily accessible by radio coverage, such as underground parking garages and in ground pits. The 3GPP Coverage Enhancement feature introduced in Release 13, is an integral characteristic of NB-IoT and LTE-M networks. It increases the depth and breadth of radio coverage to enable IoT devices to operate in locations that would otherwise not be possible.

The 3GPP Enhanced Coverage feature increases the power levels of signalling channels together with the ability to repeat transmissions. Repeated transmission improves the ability of receivers to correctly resolve the message sent.

The trade-off is that repeating signal transmissions consumes additional power and the time between battery recharge or replacement may be reduced.

4.1.6 LTE-M CE Mode A / B

The LTE-M standard supports two Coverage Enhancement (CE) Modes, each consisting of 2 CE Levels: CE Mode A (Level 0 & 1) and CE Mode B (Level 2 & 3). Both CE Modes enable coverage enhancement using repetition techniques for both data channels and control channels. Support for CE Mode A by UE is mandated in the 3GPP standards.

The CE feature essentially increases maximum coupling loss by approximately:

— up to +5dB with CE Mode A
— up to +15dB with CE Mode B

For data channels, CE Mode A supports up to 32 times repetition and CE Mode B supports up to 2048 times repetition. CE Mode A is the default mode of operation for LTE-M devices and LTE-M networks, providing efficient operation in coverage scenarios where moderate coverage enhancement is needed. It is designed to maintain the LTE-M advantages of higher data rates, voice call possibility, and connected mode mobility.

CE Mode B is an optional extension providing even further coverage enhancement at the expense of throughput and latency. It was mainly designed to provide coverage deep within buildings. For this reason, Mode B is intended more for stationary or pedestrian speeds applications that require limited data rates and limited volumes of data per month. The maximum coverage Mode B provides is highly configurable by the MNO (from 192 to 2048 repetitions).

Recommendations

It is recommended that Coverage Enhancement Mode A be supported by all operators deploying LTE-M. CE Mode A is the mandatory coverage extension mode, to be supported by all LTE-M devices.

For MNOs considering adding CE Mode B in the future, additional testing by MNOs is required to understand its effects on data throughput, and other features deployed within the network. It is recommended that MNO's that have deployed Mode B, provide this information to its roaming partners to allow them to inform their customers of the availability of the feature. If CE Mode B is not enabled on a visited network, the roaming device will revert to CE Mode A and revert to the coverage benefits offered by CE Mode A. As of 2025, no MNO is known to have implemented CE Mode B and no devices are known to support CE Mode B.

4.1.7 NB-IoT Extension of coverage features (CE Level 0 / 1 / 2)

As of 2022, the NB-IoT standard supports 3 Coverage Enhancement (CE) Levels. A fourth level (CE level 3) is currently reserved.

In a manner similar to LTE-M, each CE Level of NB-IoT determines the number of times downlink and uplink messages can be repeated to reach devices in poor coverage and the number of repetitions in each CE-Level is predefined by the network.

The CE feature essentially increases the maximum coupling loss (MCL) from 144dB to up to 164dB:

— +0dB vs. GSM signal with CE Level 0 (used when coverage is good)
— up to +10dB with CE Level 1 (with moderate repetitions)
— up to +20dB with CE Level 2 (with up to 128 repetitions)

Note that a higher power density (e.g. of 23 dBm for devices of Power Class 3) is also used in CE-Level 1 and CE-Level 2 instead of power control, which leads to an additional increase in power consumption by the NB-IoT device.

Recommendations

It is recommended that all three CE levels be supported by all operators deploying NB-IoT.

SMS

SMS is a ubiquitous feature of the mobile network and used extensively by mobile handsets every day. With such wide support for SMS in the mobile network, it is not surprising to see many IoT applications leveraging SMS as part of an IoT solution. SMS has been around for many years having been introduced during the initial 2G deployments.

For some IoT solutions, it is not uncommon for the application to send SMS messages to a remote device as a trigger for the device to establish a connection back to a centralised point. Whilst a mobile terminated SMS is one mechanism that can be used to trigger the device, an IoT device could also send alerts directly to a mobile phone using SMS (mobile originated SMS).

Both LTE-M and NB-IoT are technically capable of supporting SMS although many MNOs have elected to support SMS for LTE-M but have not enabled support of SMS for NB-IoT.

Currently within a mobile core network, many MNOs however still make use of the 3GPP SGs interface to transport SMS to/from the SMS-C via a mobile Switching centre (MSC) to/from the IoT device.

As 2G and 3G networks are being shut down across the world, this poses a thread to SMS service continuity for IoT devices after 2G/3G shutdown, since a MNO may no longer have a MSC in their network and thus no longer be able to support SMS delivery over SGs.

Fortunately, an alternative solution for SMS delivery to IoT devices exists that relies on the direct and 4G-native Diameter interface SGd between the Core SMS-Center and the local MME entities.

https://www.gsma.com/solutions-and-impact/technologies/internet-of-things/gsma_resources/ensuring-sms-continuity-for-iot-after-2g-3g-shutdown/

Recommendations

Application developers should consider whether they wish to use SMS for their application or if some an alternate approach like sending a UDP or NIDD message might be more appropriate. If SMS is the preferred approach, developers need to work with their home MNO to understand on which technologies SMS has been deployed and the extent of roaming support for SMS if their application is to be used outside of their home market.

MNOs should consider whether they support SMS on their LTE-M network, NB-IoT network or both networks. With the sunsetting of 2G and 3G networks, MNOs should follow the recommendations provided in the whitepaper "SMS for IoT after 2G/3G shutdown" to ensure the smooth and timely migration of their existing SMS traffic from the SGs interface over the 2G/3G infrastructure to the SGd interface native over the 4G network. This applies both to their internal SMS traffic and to the inbound and outbound roaming traffic with their LTE-M, respectively NB-IoT Roaming Partners.

Connected-Mode (Extended) DRX Support

When a UE is in connected mode, it consumes it's maximum amount of energy. Therefore, just as a UE in idle mode reduces energy consumption by using discontinuous reception, so too is it advantageous for a UE to adopt a similar approach when in connected mode. Configuration of C-DRX has a dramatically large effect on UE battery consumption. Connected DRX (C-DRX) was added in Release 8 and connected-mode extended DRX (C-eDRX) was added in Release 13. Both C-DRX and C-eDRX operate similarly where the UE can periodically enter a low power state except the maximum DRX cycle for C-DRX is 2.54sec and for C-eDRX it is 10.24sec.

C-DRX and C-eDRX have a configurable "ON duration" which controls the amount of time the UE will listen to the downlink control channel each cycle and a configurable "DRX Inactivity time" which determines the amount of time without data before UE enter C-DRX/C-eDRX. The time the UE must stay in C-DRX/C-eDRX before releasing to idle mode is called the "RRC inactivity Timer". Figure 3 illustrates this mechanism and the above C-DRX/C-eDRX parameters.

Note that if a large C-DRX period is configured, the access delay increases greatly. If supported by the network, Release Assistance Indication maybe a better option to reduce power consumption.

Recommendations:

— Network should support C-DRX or C-eDRX (where C-DRX is a subset of C-eDRX)
— To maximise battery life for latency tolerant applications, the maximum C-DRX or C-eDRX cycle and minimum onDurationTimer should be configured

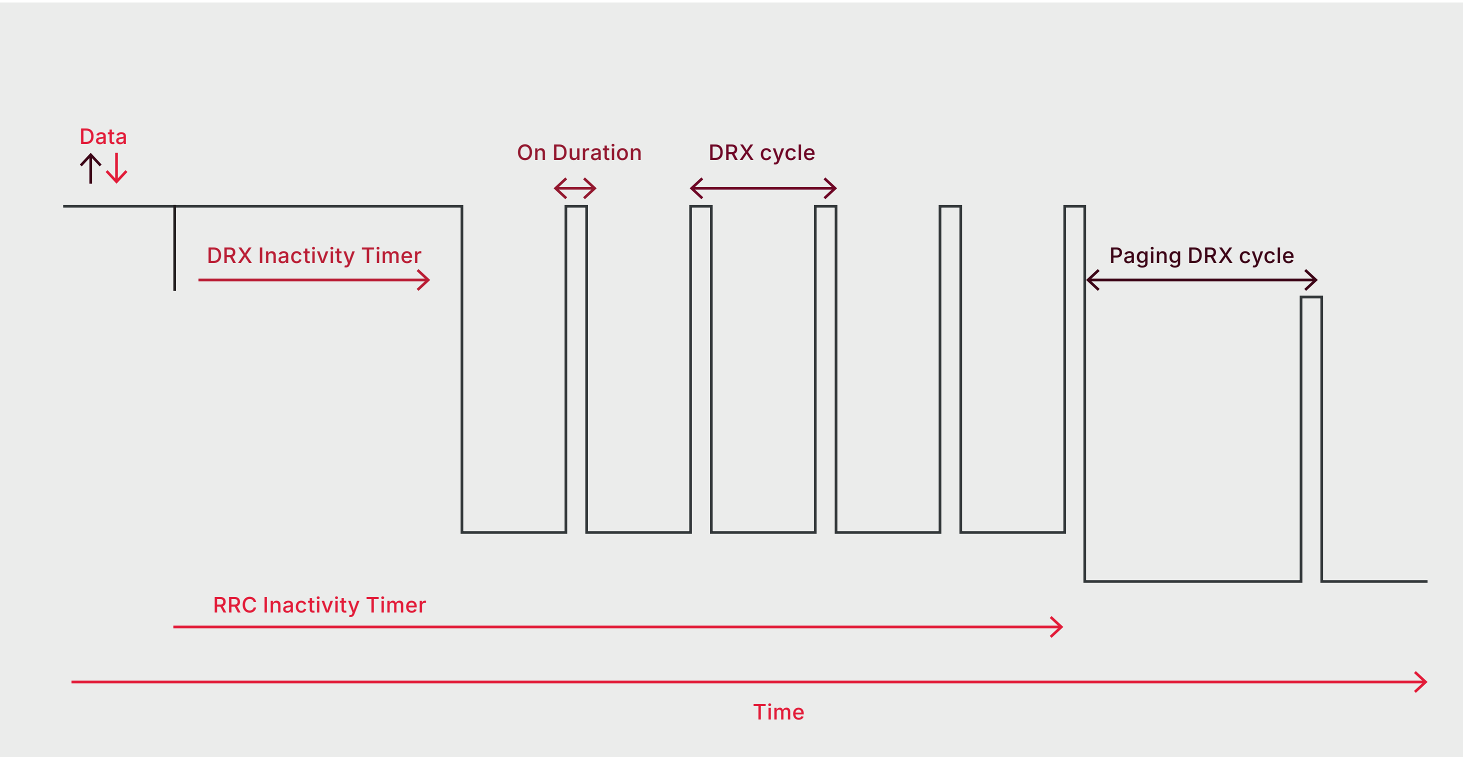


Figure 3, Connected-Mode (Extended) DRX Support

4.1.8 CIoT Optimisations

Control Plane CIoT Optimisations

Control Plane CIoT EPS optimisation is an optional feature introduced in 3GPP Release 13 allowing transport of user data (IP, Non-IP) via control plane signalling to the MME (aka Data over NAS (DoNAS)). This feature reduces the signalling overhead by approximately half when moving from idle to connected mode which improves network efficiency and UE battery life. This procedure is suited for UDP where only a few packets are sent per connection.

Recommendations:

Whilst theoretically available for use by both LTE-M and NB-IoT, the feature is widely used by NB-IoT with little if any support by LTE-M networks or LTE-M devices.

UICC Deactivation During eDRX

To reduce power consumption when the UE uses idle mode eDRX, the UE may deactivate the UICC during idle eDRX. The UE may only deactivate the UICC if the UICC supports deactivation and is configured to allow it. UICC configuration requires elementary files (EF's) within the UICC to be set (e.g. the Administrative Data EF) (see section 4.2.18 in 3GPP TS 31.102). This capability was introduced in 3GPP Release 13.

Recommendations:

The UICC should support deactivation and be configured to allow the UE to deactivate the UICC while in idle mode eDRX mode.

Power class

Some IoT applications are particularly sensitive to power consumption. Mobile LTE devices typically operate with a device RF power output of 23 dBm (Power Class 3) and indeed a large number of mobile IoT devices support this capability. To minimise the impact of connectivity on the device battery life, for mobile IoT additional power class options could be used. That is, later 3GPP Releases allow a mobile IoT device to operate with an RF power output level of 23dBm (Power Class 3) or with less power output, at 20dBm (Power Class 5) or 14dBm (Power Class 6).

The main benefit with the lower power classes is that they facilitate integration of the power amplifier (PA) in a single-chip implementation and in addition, especially for the 14 dBm power class, it may be more compatible with simpler battery technologies that can only sustain a low battery discharge power. These lower power classes are primarily intended for devices with stringent requirements on manufacturing cost and device form factor, but with less stringent requirements on battery life and coverage.

The introduction of lower power output UEs presents a challenge for operators to effectively communicate to end customers that not all mobile IoT devices will deliver the same performance for coverage and battery life and challenge existing operator network designs.

Operators need to carefully consider their situation if they are to support lower power class devices in their networks. LTE cellular networks are likely to have been planned assuming the UE can transmit at up to 23dBm. A reduction in power output from a UE will lead to a reduction in coverage. Depending on how an operator has performed their cell planning, a 3 dB or 9 dB reduction in UE power output may introduce areas of the network where the lower power devices may go out of coverage that did not previously exist or limit the ability for a UE to operate below ground in parking garages or the like. Operators with extended range cells providing coverage at up to 120 km range may find that distance is no longer achievable. Where an operator presents maps for end customers to self-assess coverage at a specific location, operators may need to provide multiple coverage maps to reflect the different coverage levels available from each power class.

A reduction in coverage may mean a mobile IoT device enters increased Coverage Enhancement levels sooner than a power class 3 device. The impact may mean for some UEs, any energy savings gained through reduced power output are lost or exceeded by the signal repetitions required to deliver a message. This early onset of signal repetitions may lead to cell congestion as the number of power class 5 and power class 6 devices increase within a single reduced size cell.

The introduction of lower power output UEs shifts the burden of understanding the intricacies of their chosen UE to the customer, further complicating an already complex decision process.

Recommendations

MNOs should, at a minimum, support 23dBm. Power levels of less than 23 dBm should be considered where it makes sense for an operator and their local market. For roaming, MNOs should expect to negotiate support for lower power output levels as part of their IoT roaming agreement.

Application developers should carefully consider the coverage impact that may be experienced using a lower powered device. Whilst selecting a slightly lower cost item may seem attractive, depending on where the device is used, it could lead to higher customer care costs and increased customer dissatisfaction if customer coverage expectations are not realised. It needs to be remembered that the Power Class defines the maximum power output and depending on the coverage, a mobile IoT device may be operating well below the maximum power output level anyway.

2RAT-Type and Home Subscriber Server

Radio Access Technology (RAT) types are defined by 3GPP to identify the radio access technology that is serving the UE. This RAT-Type is a mandatory parameter used in the interface S6a between the MME/SGSN and the HSS, as described in 3GPP TS 29.272 [12].

With the introduction of NB-IoT in 3GPP Release 13, a new value for the RAT type attribute-value pair (AVP code 1032) was defined: EUTRAN-NB-IoT (1005), see 3GPP TS 29.212 [13] to be used instead of the standard EUTRAN RAT-Type (1004). In addition, a new value (bit '6' for "NB-IoT Not Allowed") was defined for parameter "Access-Restriction-Data" to restrict access to NB-IoT.

Note: Although LTE-M was also introduced in 3GPP Release 13, a dedicated LTE-M RAT-Type AVP value (1007) was not defined until 3GPP Release 15. As a result, most LTE-M networks already deployed currently do not differentiate between LTE-M and standard LTE categories (i.e. cat 1 and above) in the S6a interface and standard EUTRAN RAT-Type value (1004) is used in the update-location-request to the HSS.

Recommendations

It is recommended that the NB-IoT RAT-Type be supported on the S6a interface at launch to guarantee a seamless experience in Roaming. This will ensure that roaming users whose HPLMN HSS profile includes an access restriction to NB-IoT be prevented access to the VPLMN's NB-IoT network.

It is recommended MNOs introduce the dedicated LTE-M RAT type introduced in 3GPP Release 15.

Relaxed monitoring for cell reselection

When this feature is enabled and the criteria for relaxed monitoring are fulfilled, the UE can reduce its neighbour cell measurements to as seldom as every 24 hours.

The network configures the UE with a 'RSRP delta' threshold, and while the change in RSRP in its current cell is less than the threshold, the UE does not need to monitor neighbouring cells for 24 hours.

This can reduce the power consumption substantially especially for stationary UEs in challenging coverage conditions. This feature is specified in Release 15 but is early implementable in Release 14.

Recommendations

It is recommended that relaxed monitoring for cell reselection be supported, in particular for NB-IoT use cases to increase the lifetime of battery-powered stationary devices.

Release Assistance Indication

When the UE has no more data to transmit, it waits for the network to release the connection to enter Idle mode.
In order for the network to release the UE to idle mode quickly to save power, Release Assistance Indication (RAI) was introduced in Release 13 for Control Plane CIoT EPS optimisation. The UE may include RAI in non-access stratum (NAS) signalling to indicate that after that uplink data transmission, no further uplink or downlink data transmission is expected or that only a single downlink data transmission and no further uplink data transmission subsequent to the uplink data transmission is expected, thus helping the network to decide if the connection can be released.

Release 14 introduces RAI for access stratum (AS) for both Control and User Plane CIoT EPS optimisations. When AS RAI is configured, the UE may trigger a buffer status report (BSR) with zero byte size, indicating to eNB that no further data is expected in UL or DL in the near future and the connection may be released.

Recommendations

It is recommended that this release 14 version of the RAI feature be supported by both the network and devices.

Improved access control

The legacy access barring mechanisms (ACB and EAB) do not distinguish between different coverage enhancement (CE) levels. In high load situations, it may be desired to temporarily bar access e.g. to the highest CE levels, since UEs in high CE levels may be associated with higher resource consumption due to dozens, hundreds or even thousands of repetitions.

A new mechanism for CE-level-based access barring is introduced in Release 15, which enables eNB to bar access per CE level. Note that if access is barred to a CE level, then access is also barred to all higher CE levels. The legacy barring mechanisms (ACB and EAB) are not affected by the new mechanism and they can be configured independently.

Recommendations

It is recommended introducing support for this feature so that during brief periods of high traffic load, UEs in deep coverage requiring the highest levels of resources to service, are momentarily delayed until the traffic peak subsides.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4.2 LTE-M Specific features

4.2.1 Deployment mode

The LTE-M standard supports FDD and TDD operation for LTE-M deployment in paired and unpaired bands, respectively. An LTE-M device in FDD operation can either employ full-duplex operation, which means that the device supports simultaneous transmission and reception, or half-duplex operation, which means that the device alternates between transmission and reception. Devices that only support half-duplex operation are associated with a lower peak rate compared to devices that support full-duplex operation, but devices that only support half-duplex operation are less complex and less costly since they may be implemented with fewer and/or less expensive components.

Recommendations

It is recommended that Half Duplex Mode is supported.

4.2.2 Connected Mode Mobility

There are two main mobility modes: Idle Mode Mobility and Connected Mode Mobility. In Idle Mode the UE has the decision to perform cell reselection. While in the Connected Mode, the network controls UE mobility, the network decides when the UE shall move, to which cell and triggers the handover procedure.

Connected Mode Mobility (CMM) is important especially for VoLTE in combination with mobility. Stationary VoLTE use cases will not require CMM. However, VoLTE use cases requiring mobility (i.e.: Wearables) will want to combine VoLTE with CMM to retain the session during movement between eNB's.

Recommendations

There is clear requirement for Connected Mode Mobility with VoLTE. It is also recommended that both Intra-Frequency (since Release 13) and Inter-Frequency Handovers (since Release 14) be supported for all data traffic.

4.2.3 Higher UL peak rate

This Release 14 feature introduces support for a larger transport block size (TBS) of 2984 bits instead of 1000 bits in order to increase the UL peak rate for Cat-M1. Increasing the UL TBS is not expected to increase the UE complexity significantly but will provide an UL peak rate boost which may be particularly useful in DL-heavy TDD configurations.

Recommendations

It is recommended Higher UL peak rate for LTE-M be supported by both the network and devices.

4.2.4 10 DL HARQ processes

To enable UEs supporting full-duplex FDD operation to do continuous DL data transmission, the number of DL HARQ processes is increased from 8 to 10, increasing the DL peak rate with 25%. This will also benefit half-duplex FDD UEs configured with HARQ-ACK bundling. This improved capability was introduced in 3GPP Release 14.

Recommendations

Whilst full duplex operation is not widely adopted, this feature brings additional benefit to half duplex devices and is therefore recommended.

4.2.5 HARQ-ACK bundling in HD-FDD

In half-duplex FDD operation, the DL peak rate is limited by the fact that the UE needs to switch to UL in order to transmit HARQ-ACK feedback. HARQ-ACK bundling enables a UE to transmit a single HARQ-ACK feedback message for multiple DL transport blocks, thereby enabling the UE to increase the portion of subframes that can be used for DL data transmission from 30% to 53% (or to 59% using 10 DL HARQ processes). This improved capability was introduced in 3GPP Release 14.

Recommendations

By improving utilisation of radio resources, this feature is recommended.

4.2.6 New PUSCH repetition factors

For the LTE-M physical uplink shared channel (PUSCH), two new subframe repetition factors (12, 24) were included in the existing range (1, 2, 4, 8, 16, 32) in order to allow more efficient use of available subframes. These additional PUSCH repetition factors were introduced in 3GPP Release 14.

Recommendations

By improving utilisation of radio resources, this feature is recommended.

4.2.7 Dynamic HARQ-ACK delays

For LTE-M, a field indicating a HARQ-ACK delay was introduced in the downlink control information (DCI) to allow more flexible scheduling of the HARQ-ACK feedback for DL data transmissions. This more flexible scheduling of HARQ-ACK feedback was introduced in 3GPP Release 14.

Recommendations

By improving utilisation of radio resources, this feature is recommended.

4.2.8 Mobility enhancement in Connected Mode

Release 13 supports intra-frequency RSRP measurements in idle and connected mode for Cat-M1 and other UEs in CE mode and similar mobility procedures as LTE. Release 14 introduces full mobility support in idle and connected mode including both intra- and inter-frequency RSRP/RSRQ measurements.

Recommendations

It is recommended to support this feature especially in markets where multiple IoT frequency bands are in use.

4.3 NB-IoT Specific features

4.3.1 Deployment mode

MNOs surveyed by the GSMA plan to deploy NB-IoT in all three deployment modes specified by 3GPP – standalone deployment, LTE guardband deployment and LTE in-band deployment.

Recommendations

In order to fully support roaming, any NB-IoT device should be able to attach to the visited NB-IoT network regardless of the deployment mode.

— **Standalone Deployment:** Standalone deployment is a deployment scenario in which operators deploy NB-IoT using existing idle spectrum resources. These resources can be the operator's spectrum fragments with non-standard bandwidths or spared from other radio access technologies (RATs) by refarming.
— **LTE Guardband Deployment:** Guardband deployment is a deployment scenario in which operators deploy NB-IoT in guard bands within existing LTE spectrum resources. Regulatory issues in some markets may limit the ability to deploy NB-IoT into the guardband.
— **LTE In-band Deployment:** In-band deployment is a deployment scenario in which operators deploy NB-IoT using existing LTE in-band resource blocks (RBs).

4.3.2 Downlink channel quality reporting

This 3GPP Release 14 feature allows the UE to measure the downlink quality of the anchor carrier and report it in Msg3 during the random access procedure. The report can be used by eNB for optimising the scheduling of downlink data transmission and consequently the energy consumption of the UE.

Recommendations

It is recommended that this feature be supported by operators deploying NB-IoT.

4.3.3 Narrowband measurement accuracy improvement

For NB-IoT, the narrowband secondary synchronisation signal (NSSS) or, on the serving cell, transmissions of MIB-NB on the narrowband physical broadcast channel (NPBCH) can be used for making NRSRP measurements, as alternatives to using narrowband reference signals (NRS). NSSS and NPBCH use more resource elements for their transmission than NRS, and this should reduce the amount of subframes the UE needs to process to achieve a given measurement.

Recommendations

It is recommended that this feature be supported because by reducing the number of subframes required to achieve a given measurement, greater device efficiencies may be obtained.

4.3.4 Power headroom reporting enhancement

In Release 13, power headroom reports (PHR) are made by the UE from one of two tables depending on coverage, each containing four entries. This feature improves the granularity of PHR transmitted in Msg3 to have 16 levels.

Recommendations

It is recommended that this feature be supported because it should improve the granularity of measurement reporting.

4.3.5 Release Assistance Indication

In Release 14, RAI for access stratum (AS) was introduced for both Control and User Plane CIoT optimisation. This functionality allows the UE to signal to the eNB that no data is expected in the DL or UL direction, so the connection may be released.

Recommendations

It is recommended that this feature be supported because it should improve the battery life performance.

4.3.6 Relaxed Monitoring for Cell Reselection

This Release 14 feature allows a UE to reduces its neighbour cell measurement frequency. The network will configure the UE with a RSRP delta threshold. While the change in RSRP in its current cell is less than the threshiold, the UE does not need to monitor neighbouring cells for 24 hours.

Recommendations

It is recommended that this feature be supported because it should improve the battery life performance.

4.4 New & emerging features

4.4.1 Common features

User Plane Optimisations

User Plane CIoT EPS optimisation is an optional feature that allows the transfer of the user plane data without the need for the Service Request procedure to establish the Access Stratum (AS) when the user is in ECM-IDLE mode (also called RRC Suspend/Resume procedure). This feature introduced in 3GPP Release 13, significantly reduces the signalling overhead to go from idle to connected mode by approximately 75% which improves network efficiency and UE battery life. Since the UE ends up in connected mode, the only difference compared to conventional connection establishment is during the state transition which is more efficient from signalling (and power) point of view.

There is no limit on packet size or number of transactions per connection, so this procedure is well suited for both TCP and UDP. At present there is minimal support for the RRC suspend/resume feature.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature as it has the potential to improve network efficiency and reduce UE energy consumption.

Positioning: E-CID and OTDOA

LPP (Location and Positioning Protocol) signalling is used as the positioning protocol for Mobile IoT. LPP supports several positioning methods, and among these methods, observed time difference of arrival (OTDOA) and enhanced cell identity (E-CID) are specified in 3GPP. Signalling for the LTE positioning methods E-CID and OTDOA were introduced in Release 13. Release 14 introduced full standard support by also including measurement performance requirements and additional OTDOA enhancements.

For E-CID, the positioning is based on received signal power and quality measurements[1] by the UE and Rx-Tx time difference measurements by eNB along with the cell identity (CID).

For OTDOA, LTE's positioning reference signal (PRS) is re-used for LTE-M and an equivalent narrowband positioning reference signal (NPRS) was introduced for NB-IoT – based on LTE's PRS in one PRB. PRS are configured to occur periodically in the time domain. In each case, the UE measures the reference signal time difference (RSTD) between PRS signals transmitted from three or more synchronised eNBs and reports the result to a positioning server which uses this information to estimate the location. Additional OTDOA enhancements were introduced in Release 14 to allow for the limited UE bandwidth and the low signal-to-noise ratio (SNR) operating point of UEs. Each cell and UE can be configured with up to three positioning reference signals (PRS) instead of just one, each PRS with its own configured transmission interval, duration and bandwidth, with or without frequency hopping.

Recommendations

There has been limited uptake of these features to date, hence they do not currently form part of the minimum feature baseline. Since this feature requires international alignment to work in roaming mode, several mobile operators have been hesitant to be among the first to invest into it.

Nevertheless, it is widely recognised that the combination of LPWA with positioning is a compelling enabler for a host of Mobile IoT services and market adoption will be monitored.

1 For LTE-M, this measurement is based on reference signal received power and quality (RSRP/RSRQ); for NB-IoT the measurement is based on the narrowband reference signal received power and quality (NRSRP/NRSRQ)

Wake-up signals (WUS)

When a UE is in DRX or eDRX, it must regularly check if a paging message is arriving from the core network. At most possible occasions for paging, no message arrives for the UE and the power the UE consumed could have been saved. This feature allows the eNB to send the UE a 'wake-up signal' (WUS) to instruct the UE that it must monitor physical downlink control channel for paging. Otherwise the UE can ignore the paging procedures.

This allows the UE to potentially keep parts of its hardware switched off for longer and save the power by not unnecessarily decoding physical downlink control and/or shared channel for paging messages. Depending on how long the network allows for the UE to 'wake up' after receiving a WUS, the UE may be able to keep switched on only a receiver dedicated to WUS detection, allowing much of the UE's conventional hardware to remain in a very low-power state.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this 3GPP Release 15 feature as it has the potential to reduce UE energy consumption.

Early data transmission (EDT)

This 3GPP Release 15 feature allows an idle mode UE to transmit data in Msg3 of the random-access procedure, carrying between 328 and 1000 bits. After successful reception by base station, the random-access procedure terminates and the UE does not transition to connected mode unless the MME or the eNodeB decides to move the UE to connected mode.

If its pending data is smaller than a maximum permitted size configured by the network, the UE requests a grant for EDT by using a pre-configured set of physical random access channel resources for its preamble transmission. The base station can allow the UE to transmit a smaller amount of data than the maximum permitted size, to reduce the power spent transmitting padding bits. If needed, the base station can order fallback to legacy random-access procedure during the EDT procedure.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature as it has the potential to improve network efficiency and reduce UE energy consumption.

EARFCN pre-provisioning

Around the world, Mobile Network Operators transmit Radio signals for IoT on discrete predefined radio frequencies. Each of these predefined frequencies is allocated a E-UTRA absolute radio frequency channel number (EARFCN) and devices must seek out these EARFCNs in each country to be able to connect. This feature allows that initial cell search to be sped up by pre-provisioning the UE with the EARFCN and the geographical area where the EARFCN pre-provisioning configuration is applicable.

Recommendations

Application developers should monitor industry development and support for this feature as it has the potential to reduce connection time especially for roaming devices and in doing so, reduce UE energy consumption.

Resynchronisation Signal (RSS)

The new Resynchronisation Signal (RSS) is a dense synchronisation signal of 2 Physical Resource Blocks (PRBs) wide and up to 40 ms long which can be transmitted anywhere within the system bandwidth. The RSS is transmitted much less frequently than PSS/SSS (primary synchronization signal/secondary synchronization signal), but each RSS transmission contains more energy as it is much longer. Given the large energy density in the RSS, UE may be able to acquire synchronisation from even the deepest coverage conditions with a single attempt (i.e. acquisition time is <= 40 ms) where if the PSS/SSS is used, many more PSS/SSS attempts are often needed taking >1 second. The RSS also communicates the new flag for unchanged SI (see below).

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature as it has the potential to reduce resynchronisation time and in doing so, reduce UE energy consumption.

Improved MIB and SIB demodulation performance

To connect to a network, the UE needs to know a bit about the network before it connects. Radio base stations transmit this network information at regular intervals with the Master Information Block (MIB) as the first piece in the chain of network information transmitted by a base station followed by System Information Blocks (SIB) containing the bulk of the network information.

Reduced MIB acquisition time is enabled by enhanced CGI (i.e. cell global identity) reading delay requirements based on accumulation of transmissions within two 40-ms MIB periods.

Reduced SIB1/SIB2 acquisition time is enabled by enhanced CGI reading delay requirements based on accumulation of transmissions within one modification period.

Recommendations

Application developers should monitor industry development and support for this feature as by reducing the time to acquire the MIB and SIBs, it would reduce the time to connect to the network. In doing so it may improve the end user experience and reduce UE energy consumption.

Flag for unchanged system information (SI)

In previous releases, after long sleep periods, the UE must decode the SIB1 to determine if any system information (SI) has changed before it can send data. In Release 15, an SI Unchanged flag bit is introduced in MIB to let the UE know whether the SIB information has been updated during the last N hours (where N is the system information validity time, which is 3 or 24 hours). This typically means that the UE can save time and energy since it does not need to re-acquire SIB1 as often. The SI update indication is also replicated in RSS, implying that the UE may also be able to re-acquire MIB less often.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature as by reducing the need to read the MIB and SIBs, it may reduce UE energy consumption.

4.5 LTE-M Specific features

4.5.1 Faster frequency retuning

Since the UE bandwidth of Cat-M UEs can be smaller than the system bandwidth, a guard period of 2 OFDM symbols is applied in CE mode to allow these UEs to do frequency retuning within the system bandwidth. This feature introduces support for shorter guard periods of 1 symbol (for Cat-M) and 0 symbols (for normal LTE UEs in CE mode), allowing for somewhat improved link performance.

Remarks

This feature is yet to see wide adoption.

4.5.2 Modulation scheme restriction

A possibility for eNB to restrict the modulation scheme for the data channels (PDSCH/PUSCH) to QPSK is introduced. This can improve the link performance when repetition is used. In the uplink case, it can also help reduce peak-to-average power ratio (PAPR), improving power consumption and coverage.

Recommendations

Mobile Network Operators should monitor industry development and support for this 3GPP Release 14 feature as it has the potential to reduce UE energy consumption whilst improving uplink performance.

4.5.3 Support for higher UE velocity

LTE-M can support devices on the move. With many countries around the world operating high speed trains for example, it is reasonable to expect that LTE-M devices may find their way onto high-speed vehicles.

To enable support of use cases associated with potentially relatively high velocity (e.g. logistics), enhanced performance requirements are introduced for CE mode A. These requirements are defined for 200 Hz Doppler spread, corresponding to around 240 km/h at 1 GHz and 120 km/h at 2 GHz.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature because by accommodating wider doppler spreads, device may operate more reliably on high velocity vehicles and improve the customer experience.

4.5.4 Spectral efficiency improvements

Increased spectral efficiency is achieved through higher order modulation, more efficient resource allocation and reduced inter-cell interference by the features listed in this section.

The features below have been defined by 3GPP but are yet to be implemented and supported commercially.

— **Flexible starting PRB:** To facilitate efficient scheduling of MTC-related data transmissions side by side with other transmissions (e.g. MBB-related PDSCH transmissions in downlink and PUCCH/PRACH in uplink), PDSCH/PUSCH resource allocation with a more flexible starting PRB (not restricted by 6-PRB narrowbands) is introduced for UEs that are configured in CE mode with max 1.4 MHz PDSCH/PUSCH channel bandwidth.

— **Downlink 64QAM support:** Support for 64QAM modulation is introduced for PDSCH unicast transmission without repetition in CE mode A to increase the downlink spectral efficiency. The UE peak rate is not increased.

— **CQI table with large range:** An alternative downlink channel quality information (CQI) table spanning a larger range is introduced. The new CQI table can be used by UEs configured with or without 64QAM support and even by UEs not supporting 64QAM. In the latter case, the large range of the CQI table can help reduce the need for RRC reconfigurations when the UE experiences varying channel conditions.

— U**plink sub-PRB allocation:** Uplink spectral efficiency is improved by the introduction of PUSCH sub-PRB resource allocation in connected mode. New allocation sizes are ½ PRB (6 subcarriers) or ¼ PRB (3 subcarriers). In the latter case, a new π/2-BPSK modulation using 1 at a time out of 2 of the 3 allocated subcarriers can be used to achieve near 0 dB baseband peak-to-average power ratio (PAPR), which may be beneficial for uplink data coverage and for UE power consumption.

— **Frequency-domain CRS muting:** Cat-M1 and Cat-M2 UEs can indicate support of CRS muting outside their 6-PRB narrowband or 24-PRB wideband, respectively, so that the network can take this information into account when deciding whether and how to perform CRS muting to reduce downlink inter-cell interference in the network.

— **Feedback for early termination:** A possibility to carry a positive HARQ-ACK in an UL DCI over MPDCCH is introduced, primarily for UE power consumption improvement. This allows eNB to indicate to a UE that UL data has been successfully received and may enable early termination of downlink (MPDCCH) monitoring and/or (in case of FD-FDD or TDD but not HD-FDD) early termination of uplink (PUSCH) transmission.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for these features because by improving spectral efficiency, a higher network traffic load may be supported which may lead to improved customer experience.


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4.6 NB-IoT Specific features

4.6.1 NB2

NB2 is a category that has been introduced in Release 14 to further improve the data rate of NB-IoT devices. This category consists in the following two features:

— Extended TBS size: To reduce the time and UE power required to transfer larger messages in more favourable coverage, the range of transport block sizes (TBS) the NB-IoT UE can support is increased from a maximum of 680 bits DL and 1000 bits UL to 2536 bits on both links. This establishes a Category NB2 UE.
— Dual HARQ: The Cat NB2 UE may optionally have 2 HARQ processes for UL and DL (compared to 1 each in Release 13), allowing further peak rate increases, in which case the time spacing between transmissions is reduced on the assumption the UE decoding capability has been increased.

Furthermore, the Multitone feature should be enabled as well in order to fully benefit from the improved transmission speed in uplink.

NB2 has been gaining traction in the operator community as it is now widely supported by module manufacturers and available for deployment by all major network vendors.

Recommendations

It is recommended that the new Category NB2 together with the Multitone feature be supported by operators and device manufacturers for NB-IoT.

4.6.2 Connected Mode Mobility

This feature is very useful for NB-IoT mobility.

For the Control Plane CIoT EPS optimisations, RRC Connection Re-establishment and S1 eNB CP Relocation Indication procedures are introduced, to allow the S1 connection to be maintained and retransmissions of the NAS PDUs by MME and UE NAS in case of radio rink failure.

Since AS security is not supported by these UEs, a security token based on NAS security is included in the RRC Connection Re-establishment Request and RRC Connection Re-establishment messages to allow authentication of the UE by the MME and authentication of the eNB by the UE. If the UE is successfully authenticated, the MME initiates a newly introduced S1 UE Context Release procedure to release the UE's S1-connection in the old eNB. The MME may initiate MME CP Relocation procedure before the release procedure in order to trigger the old eNB to return non-delivered NAS PDUs to the MME.

For User Plane CIoT EPS optimisations, the legacy handover procedure of data forwarding at handover is used at radio link failure.

Remarks

This feature is yet to see wide adoption.

4.6.3 Additional SIB1-NB repetition

For NB-IoT using FDD, when the SIB1-NB is being transmitted with 16 repetitions (the maximum supported), eNB can transmit additional subframes containing SIB1-NB repetitions on anchor carriers and non-anchor carriers to allow faster decoding of SIB1-NB and reduce the UE's power consumption during cell access. Compared to Release 13 which supports up to 8 SIB1-NB repetitions, Release 15 allows up to 16 repetitions.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature because by reducing the time to decode SIB1-NB, it may reduce UE energy consumption.

4.6.4 Local RRM Policy Information storage for UE differentiation

The network is able to collect and store in the MME information about the UE and its traffic profile. This can be used to improve the scheduling of the UE according to e.g. its battery life or power supply, mobility and when it tends to have traffic to transmit.

Recommendations

Mobile Network Operators should monitor industry development and support for this feature because it potentially tailors the scheduling for each UE individually.

4.6.5 NPRACH range enhancement

NB-IoT is sometimes deployed in cells with radius of up to around 100 km. Release 13 NPRACH supports cell radii up to 40 km with unambiguous determination of UE range. Beyond that distance, because NPRACH is a pure sine wave transmission, there can be ambiguities for the eNB to determine the UE's range. A new NPRACH format is introduced with a subcarrier spacing of 1.25 kHz and a cyclic prefix of 800 µs, together with frequency hopping, which is sufficient to allow unambiguous range determination up to 120 km.

Note due to geography constraints, deployment of this feature for some markets may be limited. That is, countries with small geographies may have little need for such large cell sizes.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for these features because by increasing NB-IoT cell range, mobile network operators can potentially offer greater coverage for devices.

4.6.6 Mixed standalone operation

In Release 13, a standalone anchor or non-anchor NB-IoT carrier can only be configured together with another standalone carrier. This feature allows configuration of standalone anchor carriers with in-band and guard-band non-anchor carriers, and of in-band and guard-band anchor carriers with standalone non-anchor carriers. This allows small slices of non-LTE spectrum to be used as a standalone NB-IoT carrier and be linked with NB-IoT carriers associated to LTE spectrum.

Recommendations

Mobile Network Operators should monitor industry development and support for this feature because it potentially allows for more flexible ways of increasing capacity.

4.6.7 Small-cell support

eNB power classes are defined in NB-IoT to allow deployment of eNBs as microcells, picocells and femtocells, which use lower maximum transmit power than macro eNBs.

Recommendations

Mobile Network Operators should monitor industry development and support for this feature because it potentially allows for more flexible ways of building out coverage.

4.6.8 RLC UM support

Release 15 adds support for RLC unacknowledged mode (UM) to complement the acknowledged mode (AM) and transparent mode (TM) introduced in Release 13. This reduces the need to send RLC signalling over the air for IoT traffic which may be latency and/or loss tolerant, or recoverable by the application layer.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature because by operating in unacknowledged mode and correcting problems at the higher level application layer if necessary, devices may reduce their energy consumption.

4.6.8 Scheduling request (SR)

In Release 13/14 NB-IoT, scheduling request (SR) exists only as a higher-layer procedure, which triggers a random access procedure to request sufficient UL resource to send a buffer status report (BSR). Release 15 has added new, more resource and power efficient, ways to achieve this goal which can be configured by the eNB.

For a connected mode UE, eNB can configure via RRC periodic NPUSCH resources, for the UE to send BSR. By doing so, the eNB is informed when pending traffic has arrived in the UE's buffer. The resources are activated and de-activated ('released') by dynamic signalling on NPDCCH.

A connected mode UE can send, in the physical layer, a request to the eNB to be granted NPUSCH resources to send a BSR. This can be done either by a dedicated signal using a pre-configured NPRACH transmission, or via 'piggybacking' the request onto HARQ ACK or NACK transmission from the UE if one is available, by applying a cover code to the ACK or NACK symbols.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for this feature because by simplifying the sending of BSRs via NPUSCH resources, NPRACH load may be reduced leading to potential higher cell densities and for the UE, a possible reduction in energy consumption may be achieved.

4.7 Release 16 features

The following sections describe new mobile IoT features introduced in 3GPP Release 16

4.7.1 Improved DL transmission efficiency and UE power consumption

Reduced UE power consumption is achieved through reduced downlink monitoring and reduced signalling, building on features introduced in earlier releases.

— **UE-group wake-up signals (GWUS)**
Reduced UE power consumption in idle mode was enabled in Rel-15 by the introduction of the wake-up signal (WUS), a compact signal transmitted a configurable time before the paging occasion (PO) when a UE is being paged, allowing the UE to maximise its sleep time during periods when there is no paging. In Rel-16, an enhancement is introduced that allows a WUS to wake up a configurable group of UEs rather than all UEs that happen to monitor the same PO. This helps reduce the power consumption even further.

— **Mobile-terminated early data transmission (MT-EDT)**
For scenarios where the UE only needs to transmit a small amount of data, the early data transmission (EDT) feature in Rel-15 enables the UE to transmit up to (slightly more than) 100 bytes of data already in Msg3 during the random-access procedure and to receive data already in Msg4. If needed, eNB can order fallback to legacy random-access procedure during the EDT procedure. In Rel-16, an enhancement is introduced that allows not only mobile-originated (MO) EDT access but also mobile-terminated (MT) EDT. When the MME triggers MT-EDT, an indication is included in the paging message, after which the UE triggers random access to resume the connection (in case the UP CIoT EPS optimisation is used) or initiate MO-EDT (in case the CP CIoT EPS optimisation is used). MT traffic is received in Msg4. MT-EDT is only supported when UE is connected to EPC (not 5GC).

— **LTE-M Improved DL quality reporting**
Legacy CE mode A supports both periodic and a periodic CSI reporting which can be used to assist PDSCH link adaptation. In Rel-16, a new type of DL quality reporting is introduced which reflects MPDCCH quality rather than PDSCH quality. The report represents the required number of MPDCCH subframe repetitions for reliable MPDCCH reception. It can be sent in connected mode but it can also be sent in Msg3 during the random access procedure. This means the report can be used for guiding the UE-specific MPDCCH configuration, which helps optimise power consumption, latency and spectral efficiency.

— **LTE-M MPDCCH performance improvement**
Pre Rel-16, MPDCCH demodulation is DMRS-based. With this feature, the UE can use a combination of DMRS and CRS for MPDCCH demodulation to improve the MPDCCH performance. The feature takes the configured DMRS-to-CRS power ratio into account. The feature can be used for transmissions in idle mode and/or connected mode. In idle mode, the DMRS-to-CRS mapping is based on precoder cycling, whereas in connected mode, it can be configured to be precoder cycling based, CSI-based, or (in case of TDD) reciprocity-based.

4.7.2 Preconfigured uplink resources (PUR)

In Rel-15, signalling overhead and power consumption reductions were introduced by the (mobile-originated) early data transmission (EDT) feature, where data can be transmitted in Msg3 during the random-access procedure.

In Rel-16, the earlier transmission of UL data payload has been further enhanced by introducing UL transmission using preconfigured uplink resources (PUR). When the feature is configured, both the random-access preamble transmission (Msg1) and the random-access response (Msg2) can be omitted, and the data transmission can be completed in only two messages (i.e., Msg3 and Msg4).

4.7.3 Scheduling of multiple transport blocks

For both LTE-M and NB-IoT, each DCI schedules a single downlink or uplink transport block (TB). In Rel-16, a possibility to schedule multiple TBs using a single DCI is introduced. This can help improve the resource utilisation by reducing DCI overhead for contiguous UL/DL transmissions.

4.7.4 Connection to 5GC

In Rel-16, support for connecting LTE-M UEs to 5GC is introduced.

4.7.5 LTE-M Mobility enhancements

In Rel-15, two new LTE-M signals were introduced, the resynchronisation signal (RSS) and the wake-up signal (WUS). In Rel-16 the following mobility enhancements are introduced which make use of those Rel-15 signals.

— **RSS-based measurements**
In Rel-15, support for a resynchronisation signal (RSS) was introduced and its configuration is provided by the serving cell. In Rel-16, signalling of RSS configurations for neighbour cells is introduced. Both broadcasted and dedicated signalling can be used to provide the configurations. The primary purpose of RSS is to improved synchronisation performance, but with the Rel-16 signalling, the UE may also use RSS for improved measurement performance for intra-frequency RSRP measurements for neighbour cells in both idle and connected mode.
— **RRM measurement relaxation**
The legacy LTE-M UE behaviour requires the UE to measure on the serving cell and evaluate the cell selection criterion at least every DRX cycle. The wake-up signal (WUS) introduced in Rel-15 would allow the UE to sleep for multiple paging cycles and wake up to receive paging after a configurable time duration but the UE power saving gain from WUS cannot be fully utilised since the UE is still required to wake up for measurements. Therefore, an RRM measurement relaxation is introduced in Rel-16, which allows the UE meet the requirements using a longer measurement cycle to save power, where the cycle is configurable under certain conditions.

4.7.6 LTE-M NR coexistence

Spectrum sharing with legacy (Rel-13/14/15) LTE-M is already supported in Rel-15 NR and the RF coexistence aspects described in TR 37.823. The following features are introduced in Rel-16 LTE-M in order to further improve the performance of the coexistence with NR.

— **DL/UL resource reservation**
Legacy LTE-M supports configuration of invalid DL/UL subframes, which can be used in order to avoid mapping LTE-M transmissions to subframes that are needed for NR transmissions. Rel-16 takes this a step further by introducing finer-granularity LTE-M resource reservation in both the time domain (with subframe, slot, or symbol level granularity) and the frequency domain (with LTE RBG level granularity) for unicast MPDCCH/PDSCH/PUSCH/PUCCH transmissions in connected mode in CE mode A/B.
— **DL subcarrier puncturing**
In order to achieve PRB alignment between LTE-M and NR, a possibility to puncture 1 or 2 DL subcarriers at the lower or higher edge of each 6-PRB narrowband is introduced. The puncturing affects MPDCCH/PDSCH transmissions in connected mode in CE mode A/B.

4.7.7 NB-IoT NR coexistence (FDD and TDD)

This feature allows the configuration of the DL/UL resource reservation in subframe/slot/symbol-levels on non-anchor carriers for unicast transmission to avoid resource overlapping with NR channels/signals.

The three deployment scenarios of in-band, guard-band and standalone have been studied and captured in 3GPP TR 37.824:

4.7.8 NB-IoT Network management tool enhancements - SON (FDD and TDD)

Rel-16 introduces SON features: RACH report, RLF report and ANR for network resource optimisation.

4.7.9 NB-IoT Improved multicarrier operations

— **Quality report in Msg3 and connected mode (FDD)**
In cells with interference, the coverage level corresponding to the estimate RSRP may be mismatched with the channel quality. This feature allows the eNB to configure a UE in IDLE mode to report the downlink channel quality in Msg3 for non-anchor access. It also allows the UE to report the downlink channel quality in connected mode other than Msg3 for anchor and non-anchor carriers. This allows the eNB to schedule NPDCCH and NPDSCH more accurately, especially in cases with mismatch between coverage level and channel quality.
— **Presence of NRS on a non-anchor carrier for paging (FDD)**
This feature allows eNB to transmit NRS in subframes on a non-anchor carrier for paging even when no paging NPDCCH is transmitted.

4.7.10 NB-IoT Idle mode inter-RAT cell selection to/from NB-IoT (FDD and TDD)

With this feature, NB-IoT can provide assistance information for inter-RAT cell selection to E-UTRAN/GERAN and E-UTRAN can provide assistance information for inter-RAT cell selection to NB-IoT. A UE may use the assistance information provided by the network for cell selection to/from NB-IoT.

4.7.11 NB-IoT UE Specific DRX (FDD and TDD)

Rel-16 introduces support for UE specific DRX to reduce paging latency. The eNB may broadcast a minimum UE specific DRX value shorter than the cell default DRX value. When UE specific DRX is configured by the upper layers and the minimum UE specific DRX value is broadcast, the UE monitors paging according to the longer of the two values.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for these Release 16 features as they potentially move from technical specifications into realisable product offerings.

4.8 Release 17 features

The following sections describe new mobile IoT features introduced in 3GPP Release 17

4.8.1 LTE-M Additional PDSCH scheduling delay for 14-HARQ processes in DL

This feature allows HD-FDD Cat. M1 UEs to use up to 14 HARQ processes in CE Mode A with an additional PDSCH scheduling delay to fully utilise the available BL/CE downlink and BL/CE uplink subframes.

4.8.2 LTE-M Maximum DL TBS of 1736 bits

From Rel-13 to Rel-16, the max DL TBS size for LTE-MTC Cat. M1 UEs is 1000 bits.

This feature allows HD-FDD Cat. M1 UEs to use a DL TBS of up to 1736 bits in CE Mode A, and the soft channel bits for UE supporting this feature is 43008 bits.

4.8.3 NB-IoT 16-QAM for unicast in UL and DL

From Rel-13 to Rel-16, an NB-IoT UE can use QPSK for unicast NPDSCH, and QPSK or BPSK for unicast NPUSCH.

This feature allows an NB-IoT UE to use 16-QAM for unicast NPDSCH with TBS up to 4968 bits for standalone and guard-band deployments and 3624 bits for in-band deployments; and allows an NB-IoT UE to use 16-QAM for unicast NPUSCH with TBS up to 2536 bits (which can be transmitted with up to half the time-domain resources with respect to QPSK).

4.8.4 NB-IoT Neighbour cell measurements and measurement triggering before RLF

This feature introduces measurements in RRC_CONNECTED for NB-IoT UEs to reduce the time taken for RRC connection re-establishment.

4.8.5 NB-IoT Carrier selection based on coverage level

This feature introduces coverage-based paging in NB-IoT to reduce the latency and the resource usage in the network.

Recommendations

Mobile Network Operators and application developers should monitor industry development and support for these Release 17 features as they potentially move from technical specifications into realisable product offerings.

NTN (Non-Terrestrial Network)

NTN refers to networks, or segments of networks, using an airborne or space-borne vehicle to embark a transmission equipment relay node or a Satellite Access Node i.e. involving satellites and Terrestrial Networks (TN) to provide seamless service continuity regardless of topography and potentially bridge coverage gaps. NTN infrastructure involves satellites in Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO) constellations, High-Altitude Platforms (HAPS) and Unmanned Aerial Systems (UAS). The emerging 5G NTN ecosystem combines the capabilities of satellites, Uncrewed Aircraft System (UAS) and High-Altitude Platforms (HAPS) with terrestrial networks and mobile devices, enabling new complementary coverage. Various NTN solutions can support a variety of use-cases including IoT applications, direct-to-device (D2D) satellite connectivity, agriculture and mobility applications, such as vehicle communications, and advanced maritime and aviation connectivity. In NTN, depending on the satellite's orbit, supported scenarios can be GSO scenario and/or NGSO scenario. NTN access is designed to operate in L, S, L/S band and Extended L band.

Recommendations

Different types of NTN terminals are being developed to serve different use cases: small low-power IoT devices based on NB-IoT; compact user terminals for individual and residential broadband connectivity, high capacity and high reliability terminals for use in enterprise and industrial applications, as well as terminals to connect moving platforms, such as airplanes or vehicles.

Mobile Network Operators and application developers should monitor industry development and support for these Release 17 features.

5. Features not widely adopted

5.1 Common features

5.1.1 Multicast transmission/Group messaging

For Mobile IoT, it's not inconceivable for large numbers of the same device to be deployed into the same radio cell. For example, if a utility deploys the same smart meter to every house. In that situation, there may be a need to send the same information to each and every one of those devices. That is, an electrical utility may wish to send a disconnect signal in times of power shortages to shed load for a brief period or the need to update the firmware in each device. In those group messaging situations, the use of unicast signalling where each device is addressed individually, may not be the best use of radio resources.

Multicast based on LTE's SC-PTM (Single Cell Point to Multipoint) feature was introduced with modifications to suit the low complexity of Mobile IoT UEs and enhanced coverage of UEs operating in CE mode. Requiring support in both the device and the network, the intent of this multicast feature was to provide a mechanism to more efficiently message to groups of devices within a single radio cell.

Remarks

This feature is yet to see wide adoption.

SCEF

The Service Capability Exposure Function (SCEF) provides a means to securely expose and discover the services and capabilities provided by 3GPP network interfaces. The SCEF provides access to network capabilities through homogenous network APIs (see 3GPP TS 23.682[2]).

Remarks

Currently there is limited support for SCEF within the mobile operator community or a consistent view on when it may be introduced. Operators deploying NB-IoT and LTE-M networks may benefit from deploying SCEF but it is an optional feature. Therefore, SCEF is not part of the minimum baseline and this edition of the guide does not make recommendations for the SCEF functions to be exposed through network APIs.

BEST (Battery Efficiency Security for low Throughput)

Network based end to middle or end to end (depends on the customer requirement) security solution for payload encryption with very low overhead which is an important requirement for battery driven devices. This solution can be used on the control plane and uses symmetrical cryptography based on 3GPP AKA run. The solution needs to be implemented on the core (HSE) and device side (chipset/module). Operators have full control on the tunnel establishment and payload encryption (for the countries that payload encryption is not allowed by government). BEST allows 3 different approaches:

— Key agreement only (just delivering the keys that can be used for the other type of cryptographies e.g. TLS)
— User plane integrity (traffic is not encrypted but integrity is protected
— User plane confidentiality (encryption + integrity)

Recommendations

Whilst a potentially valuable feature for devices limited power / battery constraints, BEST has yet to gain significant market adoption and does not currently form part of the minimum feature baseline.

Non-IP Data Delivery (NIDD)

Non-IP data delivery is an optional feature that allows a device to transfer data without adding an IP header or transport header and without the need to operate an IP stack and obtaining an IP address. Whilst it is technically possible for a LTE-M device to utilise NIDD, from an industry perspective, NIDD has so far only been a consideration for NB-IoT based devices. Two mechanisms (provisioned in HSS) are currently defined for the delivery of Non-IP data to the Service Capability Server / Application Server (SCS/AS):

— Delivery using SCEF;
— Delivery using a Point-to-Point (PtP) SGi tunnel

Neither option has enjoyed widespread deployment although some operators have performed customer trials using SCEF based delivery.

From an application perspective, NIDD has the potential to simplify application design by not requiring an IP protocol stack. This simplification may also extend to the application server as it is no longer required to maintain bindings from device identity to IP address/port. Note that it is possible for a device to support connection to the network using both NIDD and IP at the same time. Therefore, NIDD may also serve as an SMS alternative when operators are not offering SMS capability as part of their mobile IoT service offering. That is, an application server could send a NIDD message to a device as a trigger for it to establish an IP connection to the server in the same manner many applications today use an SMS to trigger the device to establish an IP connection.

Recommendations

Today, with limited support by operators in their home network and even less support in a roaming environment, it is too soon to know whether 3GPP Release 13 NIDD will see further acceptance and wider deployment.

5.2 LTE-M Specific features

5.2.1 New UE category M2

A new UE category (Cat-M2) is introduced with a UE bandwidth of 5 MHz and peak rates of approximately 4 Mbps in DL and 7 Mbps in UL. These peak rates apply for UEs supporting full-duplex FDD operation – the peak rates for UEs supporting half-duplex FDD are approximately half of these numbers and the peak rates for UEs supporting TDD depend on the DL/UL subframe configuration.

Remarks

This feature is yet to see wide adoption.

5.2.2 Wider bandwidth in CE mode

CE modes A and B are improved to support maximum data channel bandwidths of 5 or 20 MHz in DL, and CE mode A is improved to support a maximum data channel bandwidth of 5 MHz in UL. The control signalling (MPDCCH, system information, etc.) is still restricted to 1.4 MHz in order to re-use as much as possible of the Release 13 design.

Remarks

This feature is yet to see wide adoption.

5.2.3 UE transmit antenna selection

A possibility is introduced for eNB to control the UE transmit antenna selection for LTE UEs that happen to support two transmit antennas instead of just one in CE mode A.

Remarks

This feature is yet to see wide adoption.

5.2.4 SRS coverage enhancement

Support for sounding reference signal (SRS) repetition in the special subframe in TDD was introduced in order to enable improved link adaptation.

The SRS coverage enhancement can furthermore be supported also by LTE UEs that do not support CE mode.

Remarks

This feature is yet to see wide adoption.

5.2.5 New PUCCH repetition factors:

For LTE-M, large repetition factors (64 and 128) for transmission of HARQ-ACK feedback over PUCCH is introduced to improve coverage for UEs in the worse coverage in CE mode B. Support for large repetition factors was introduced in 3GPP Release 14.

Recommendations

This feature was introduced in support of LTE-M CE Mode B. CE Mode B is yet to see wide adoption.

5.2.6 VoLTE on LTE-M

The ability for LTE-M to support a voice service using VoLTE was introduced in 3GPP Release 13. Some chipset and infrastructure vendors have implemented a limited VoLTE capability in their products to support VoLTE for LTE-M. In some markets, mobile network operators have enabled this capability. In other markets, the regulatory environment mandates an emergency calling capability which is currently excluded from that limited VoLTE implementation, so VoLTE for LTE-M is not currently a possibility in those markets.   Most carriers worldwide are opting out of deploying VoLTE on LTE-M UEs.

Recommendations

VoLTE is not a mandatory recommendation for global LTE-M deployments, however if an operator deploys VoLTE, both the network and the device should support the GSMA PRD NG.108 “IMS Profile for Voice and SMS for UE category M1” to support voice and SMS for UE category M1.

For operators willing to support VoLTE on LTE-M, i they need to introduce the ability to flag emergency calls and support semi-persistent scheduling.

5.3 NB-IoT Specific features

5.3.1 Paging and random access on non-anchor carrier

Use of non-anchor carriers for paging and random access is introduced. There can be up to 15 DL and UL non-anchor carriers configured in a new NB-IoT SIB, used by paging, RAR, or SC-PTM, each identified by its centre frequency.¨

For paging purposes, paging occasions (POs) are distributed across the non-anchor carriers in a configurable uneven manner so that the eNB can decide what paging load each carrier should have.

For random access, each non-anchor UL carrier has a probability with which the UE may randomly select it for random access related UL transmissions (Msg1&3), and corresponds to a DL carrier for random access related DL transmissions (Msg2&4). For ordered random access the carrier for Msg1&3 is indicated by DCI. Contention free random access is supported for NPDCCH ordered random access.

On non-anchor carriers for receiving paging and random access response (RAR), the subframes which the UE can assume contain NRS are reduced, to benefit network power consumption and co-existence with LTE and NR in future. In addition to spanning a few valid subframes either side of the NPDSCH carrying paging or RAR, the NRS are reduced to start a few valid subframes before the paging NPDCCH search space or RAR window and continue until a few valid subframes after the NPDCCH candidate that contains the paging DCI, or after the RAR window respectively.

Remarks

This feature is yet to see wide adoption although will be required if future NB-IoT multi-carrier capacity scenarios eventuate.

5.3.2 TDD Support

Support for TDD is introduced, incorporating the Release 13 NB-IoT feature together with the following Release 14/15 features:

- Release 14 features:
  - OTDOA positioning
  - Release assistance indication
  - Paging and random access on non-anchor carrier
  - UE category NB2 with optional support for 2 UL/DL HARQ processes
  - Relaxed monitoring for cell reselection

- Release 15 features:
  - Local RRM policy information storage for UE differentiation
  - Improved access control
  - Small-cell support
  - RLC UM support

Remarks

This feature is yet to see wide adoption.

6. Conclusion

The recommendations provided in this guide aim to achieve the following:

- An accelerated realisation of the wider benefits of common standards and predictable interconnect, while ensuring that forthcoming decisions about deployment architectures are well informed, making it more straightforward to enable device interconnect and roaming.

The guide also recommends support for the following key minimum features to achieve a balance of roaming service continuity and power optimisation:

- PSM (Power Save Mode)
- eDRX (Extended Discontinuous Reception)
- Power class
- Rate control mechanisms
- Release Assistance Indication
- High Latency Communications
- For LTE-M
  - Cat M1
  - LTE-M Half Duplex Mode
  - Support for extended coverage mode A
  - LTE-M CMM
  - SMS
- For NB-IoT
  - Cat NB1 & NB2
  - Support for extended coverage
  - DoNAS

For other LTE-M features, such as VoLTE, MNOs do not yet have consistent deployment plans. Therefore, VoLTE is not a key feature in the short term.

Similarly, for SMS using NB-IoT, MNOs do not yet have consistent deployment plans. Therefore, SMS is not a key feature for NB-IoT in the short-term.

SCEF is also not included in the key minimum requirements of this edition of the Deployment Guide as some MNOs surveyed by the GSMA plan to support SCEF but others have not yet decided. Some are implementing it in phases, others going directly to full SCEF deployment. Those who will be deploying both NB-IoT and LTE-M networks might benefit from deploying SCEF, but it is an optional feature for LTE-M. Therefore, SCEF is not part of the minimum feature set required in the short-term.

Finally, Non Terrestrial Networks are also impacted by the listed features in the document and should therefore be closely monitored, as many of these are needed for the deployments currently being made in this technology.

The GSMA plans to update this Deployment Guide regularly to provide more specific recommendations once network operators have further Mobile IoT deployment experience.

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