Power saving methods for LTE-M and NB-IoT devices
White paper

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ROHDE&SCHWARZ

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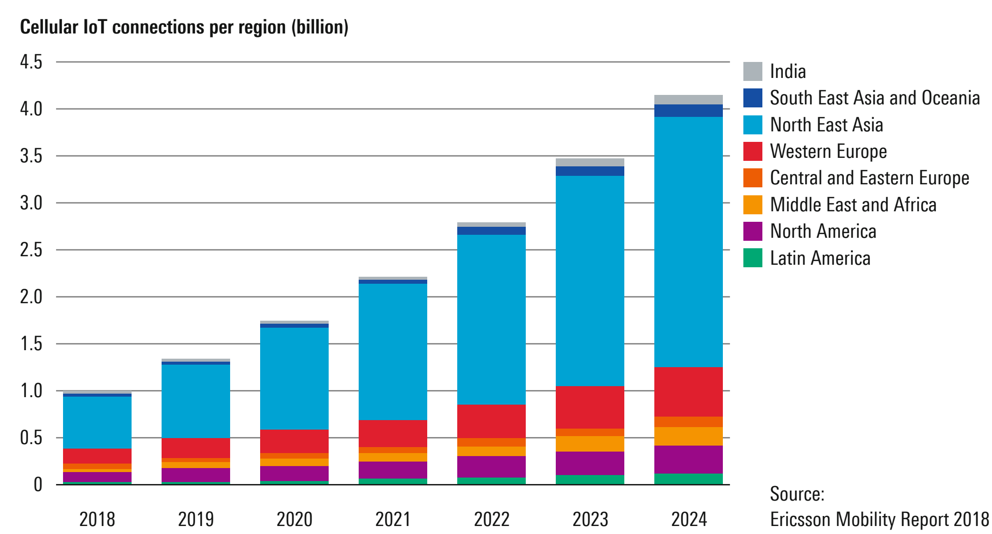
LTE-M and NB-IoT are LTE based internet of things (IoT) technologies. Both require long battery lifetime to ensure IoT services and minimize maintenance costs in the future. This technical white paper describes the possible power saving methods that can be applied to LTE-M and NB-IoT devices and gives a guideline of the applicability of the power saving methods.

1 Overview

In the past decades, the internet has been booming and connecting people with each other. Nowadays, technology trends tell us that not only people, but also machine type devices, e.g. house equipment and street facilities will be connected and can communicate with each other. The term internet of things (IoT) is becoming a buzzword throughout all vertical industries. We are now so to speak in the dawn of the IoT era. With IoT technology, the world is becoming smarter and smarter. Smart as in smart city, smart home, smart agriculture, etc. is penetrating people's everyday lives and gradually changing their lifestyle.

From the technology perspective, there is a plethora of radio telecommunications technologies available for IoT. For instance, communications can be based on Bluetooth®, Zigbee, LoRa, Sigfox or cellular technology. Cellular IoT (cIoT) is considered one of the most attractive approaches in the IoT industry. cIoT is licensed spectrum based low-power wide-area (LPWA) access technology deployed in the GSM, LTE network or later 5G network. It offers benefits with respect to QoS, reliability, latency and coverage range and provides the opportunity for enterprises to enhance efficiency and improve customer value. With widespread cIoT service deployment, the entire mobile ecosystem will experience a revolutionary change. Fig. 1-1 indicates that the number of cIoT connections is expected to reach over 4 billion in 2024, a rapid increase of approximately 30% growth compared with 2018.

Fig. 1-1: Cellular IoT connections forecast



In this white paper, we will be focusing on two cIoT main streams based on LTE technology: LTE-M and NB-IoT. Both of these LTE based IoT technologies were initially specified in 3GPP Rel. 13 in 2016. They are currently deployed worldwide in parallel and LTE-M/NB-IoT devices should possess the following characteristics:

- Low power consumption allowing operation for many years on a single charge
- Low device costs
- Enhanced coverage both outdoors and indoors
- Secure connectivity
- Optimized data transfer for small amounts of infrequent data

Beyond the common requirements listed above, LTE-M should additionally fulfill the following requirements:

- Speech function over VoLTE
- Full mobility

Table 1-1 gives an overview of the differences between LTE-M and NB-IoT in terms of the physical layer definition.

Table 1-1: Comparison of LTE-M and NB-IoT

	LTE-M		NB-IoT	
	LTE CAT M1 (since Rel. 13)	**LTE CAT M2 (since Rel. 14)**	**LTE CAT NB1 (since Rel. 13)**	**LTE CAT NB2 (since Rel. 14)**
Deployment	in-band LTE		in-band LTE, guard band LTE, standalone	
Downlink OFDMA subcarriers	72 (i.e. 6 resource blocks)	288 (i.e. 24 resource blocks)	12 (i.e. 1 resource block)	
Downlink subcarrier spacing	15 kHz		15 kHz	
Uplink SC-FDMA subcarriers	72 (i.e. 6 resource blocks)	288 (i.e. 24 resource blocks)	single-tone (1 subcarrier at 15 kHz/ 3.75 kHz subcarrier spacing); multi-tone (3, 6 or 12 subcarriers at 15 kHz subcarrier spacing)	
Uplink subcarrier spacing	15 kHz		15 kHz/3.75 kHz	
Peak rate	DL: 1 Mbps UL: 1 Mbps	DL: 4 Mbps UL: 6 Mbps	DL: 27 kbps UL: 60 kbps	DL: 79 kbps UL: 106 kbps
Duplex mode	full/half-duplex FDD/TDD		half-duplex FDD	
UE receiver bandwidth	1.4 MHz	5 MHz	200 kHz	
UE TX power	23/20 dBm		23/20 dBm	23/20/14 dBm
Power saving	PSM, eDRX		PSM, eDRX	
Antenna(s)	1 RX/TX		1 RX/TX	

Basically, LTE-M is a kind of downsized LTE network operating at a narrower bandwidth but inheriting the signaling details of LTE. NB-IoT can be simplified as a new radio communications technology for machine type communications based on the known LTE radio technology. Note that an LTE cell would not be visible to an NB-IoT device. In addition, NB-IoT introduced new features like single tone operation and reduced subcarrier spacing, either for enabling a higher number of simultaneously transmitting devices or for better coverage, especially for indoor operations with the resulting higher power density at narrower bandwidth.

Whether LTE-M or NB-IoT technology should be rolled out depends on the general use case that the end user demands. LTE-M is best suited to time-critical applications and applications requiring a slightly higher data rate to meet user experience needs, e.g. emergency services in a smart city. NB-IoT is better in a delay tolerant application with less demand for data communications, typically in a stationary application, e.g. smart meter. Apparently LTE-M use cases can cover most of the use cases provided by NB-IoT.

As we can observe in Table 1-1, both LTE-M and NB-IoT technology need to support power saving features, i.e. eDRX and PSM. This is due to the fact that LTE-M/NB-IoT devices have a very wide deployment base. In most cases, the devices are powered by battery and supplied as a single-charge version. The maintenance cost for replacing the several thousand batteries can be very high. Therefore, the entire industry has a great interest in IoT devices having a long battery life, say minimally 10 years. With this as an incentive, 3GPP specifies power saving procedures and also extends the existing LTE power saving mechanism to minimize LTE-M/NB-IoT device power consumption.

The data rate in Table 1-1 represents the peak data rate under the assumption of neglected control overhead and maximum transportation block sizes. The exact data rate that can be achieved depends on many configuration details like transport block size, scheduling time, HARQ operation, TTI bundling and CE level to name only a few of the influencing parameters.

In this white paper, the power saving methods utilized by LTE-M/NB-IoT devices are discussed as follows:

- Chapter 2 explains the fundamentals of discontinuous reception (DRX), which is a generic procedure for power saving in the mobile communications world
- Chapter 3 describes the principle of extended discontinuous reception (eDRX) and shows how it differs from legacy DRX
- Chapter 4 covers the key parameters of the power save mode (PSM)
- Chapter 5 explains other power saving mechanisms (RAI, EDT and WUS) introduced in 3GPP Rel. 14 and Rel. 15
- Chapter 6 briefly summaries the power saving mechanisms

Rohde & Schwarz provides test solutions to measure the power consumption of LTE-M/NB-IoT devices based on R&S®CMW, R&S®CMWrun and Rohde & Schwarz oscilloscopes. This solution is out of the scope of this white paper, but further reading is available in [14].

2 Discontinuous reception

In radiocommunications, there are two general operating modes or RRC states when the UE is switched on:

- Connected mode, allowing transmission and reception of user data over an established connection
- Idle mode or camping on a cell

In the latter mode, the UE has to periodically update its knowledge about system information broadcast by the network. And to enable mobile terminated traffic, the UE has to monitor the physical downlink control channel (PDCCH) for paging messages and decode the paging message on its allocated physical downlink shared channel (PDSCH). This consumes electric energy.

Discontinuous reception (DRX) is a generic mobile communications mechanism that allows the device to stop monitoring the radio channel, e.g. PDCCH, and enter low power consumption mode or sleep mode for a certain period of time.

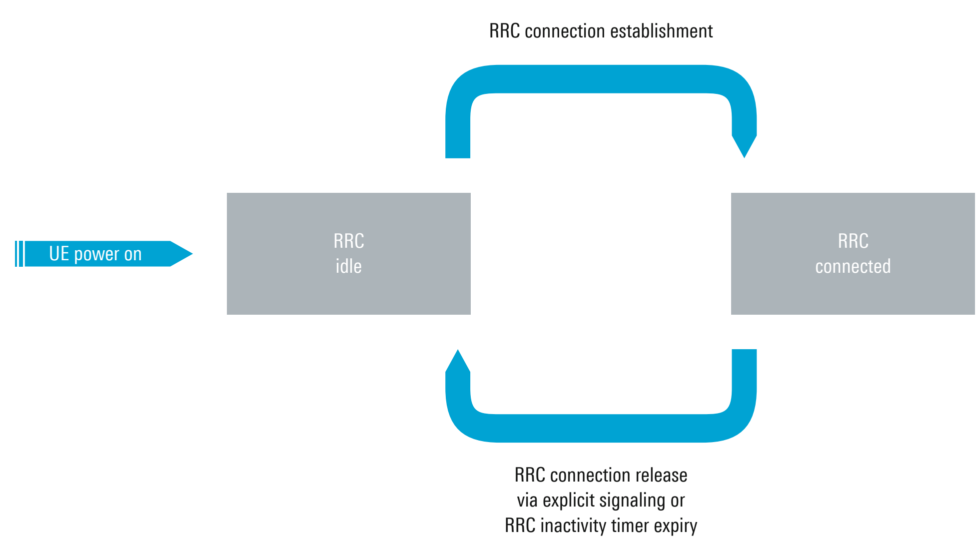
Two types of DRX deployments have been adopted by LTE: connected DRX (c-DRX) and idle DRX (i-DRX). They are differentiated by the UE RRC state, and the procedures also differ.

Since the DRX functions are similar for LTE and LTE-M/NB-IoT devices, the generic DRX methodology is explained in the following chapters unless otherwise stated.

Accordingly, the physical downlink control channel (PDCCH) that carries the resource scheduling and other control information is referred to in its general purpose. For simplicity, PDCCH refers to PDCCH in the case of LTE, MPDCCH in the case of LTE-M and NPDCCH in the case of NB-IoT.

Fig. 2-1 illustrates the general RRC state transition. Right after the UE is powered on, it enters the RRC idle state. In RRC idle state, the UE does not have an established physical connection to eNodeB. However, the RRC idle state corresponds to the mobility management state MM-REGISTERED, so the UE identity is known to the network and the location of the UE is known based on the tracking area. When the data arrives in the downlink, the network will initiate a paging process to address the relevant UE. As soon as the UE receives its own paging message, it starts the random access procedure (RAP) followed by establishment of the RRC connection. The RRC state is changed to "connected" only after a RRC connection is established. In the RRC connected state, the UE needs to listen to the PDCCH in every subframe for the downlink scheduling information and also the resource assignment for its uplink transmission. In addition, the UE has to send control information in the uplink to remain synchronized with the network and also send feedback about the channel quality status. In order to save resources on the air interface and due to power saving requirements from the UE end, the UE will return to idle state after the RRC connection is released, either via an explicit signaling message or due to expiry of the RRC inactivity timer. The RRC inactivity timer is a configurable timer defined in eNodeB to indicate that the UE does not have any downlink and uplink traffic within the defined period of time. Expiration of the RRC inactivity timer is specified as a valid release cause in the RRC connection release message.

Fig. 2-1: RRC state transition



Depending on the RRC state, certain procedures can be carried out as summarized in Table 2-1. In both RRC states, DRX operation can be deployed: idle DRX (i-DRX) and connected DRX (c-DRX).

Table 2 1: Summary of RRC idle and connected state

UE in RRC idle	UE in RRC connected
Inactive radio	Active radio
UE is known in the core network, i.e. IP address is assigned to UE, but UE is not known to eNodeB.	UE is known to both the core network and eNodeB.
RRC IDLE procedures: ▪ PLMN selection ▪ Cell selection and reselection (neighbor cell measurement) ▪ Cell reservation and access restrictions ▪ Tracking area registration ▪ Reception of MIB and SIB ▪ Monitor the paging opportunities (PO) on paging channel ▪ UE is aware of the random access channel configuration ▪ Monitor control channel ▪ Report feedback information, e.g. CQI, to eNodeB ▪ Receive/transmit date from/to eNodeB ▪ Connected mode DRX	RRC CONNECTED procedures: ▪ Monitor control channel ▪ Report feedback information, e.g. CQI, to eNodeB ▪ Receive/transmit date from/to eNodeB ▪ Connected mode DRX ▪ Neighbor cell measurement

2.1 DRX in RRC idle state

UE is in the RRC idle state when it is tracked by the network with a paging mechanism even though it has no activated radio connection to eNodeB. Paging can be initiated by:

- Incoming downlink data
- Change of system information
- Incoming earthquake or tsunami warning

Fig. 2-2: Scheduling of paging information in LTE

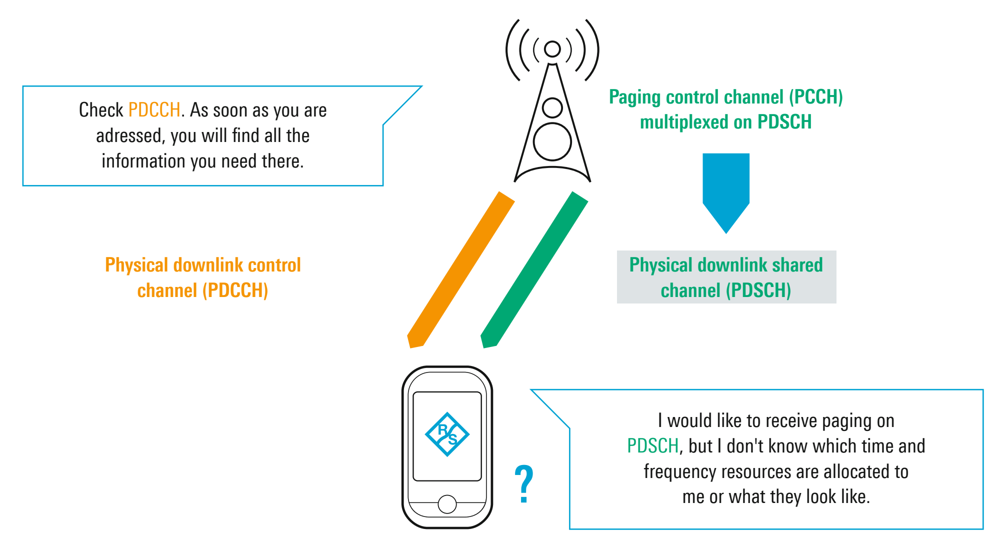


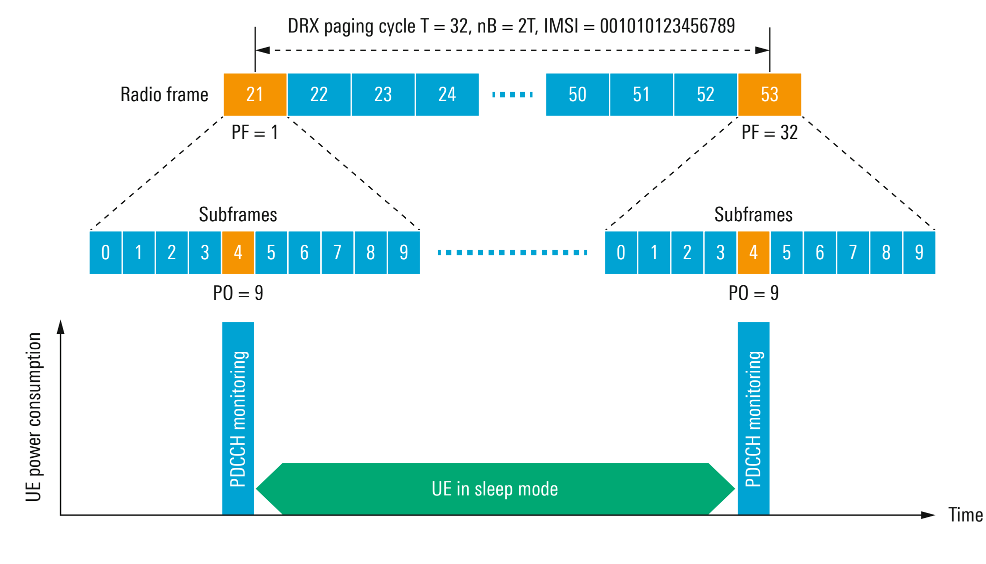
Fig. 2-2 shows the general paging mechanism in LTE. In the downlink direction, the paging message for each individual UE carried by the PCCH logical channel is multiplexed on PDSCH. The PDCCH allocates the resource for PDSCH.

A UE in idle mode needs to monitor the PDCCH in order to check whether there are any paging messages on PDSCH. The UE searches for P-RNTI within the PDCCH. If P-RNTI is found, then the downlink control indicator (DCI) that carries PDSCH resource scheduling information is decoded. This DCI information will redirect the UE to the associated PDSCH resource blocks (RB) to decode the higher layer paging message as to its relevant UE identity (i.e. TMSI or IMSI). If the UE does not find its identity in the paging record, it will return to check PDCCH for P-RNTI at another time. This paging process repeats.

A UE operating in DRX mode only monitors the PDCCH at defined time intervals, i.e. within a paging cycle, for instance every 40 ms or 100 ms. The UE will enter sleep mode the rest of the time. Without DRX, the UE would have needed to monitor PDCCH continuously for each radio subframe (i.e. every 1 ms) which significantly drains the battery in RRC idle state. Applying the DRX mechanism in RRC idle state conserves the battery life of the device.

Fig. 2-3 gives an example of i-DRX in LTE FDD mode. The UE (IMSI 001010123456789) only needs to monitor its paging occasion (PO) in subframe 4 starting from radio frame 21 every 32 paging cycles or 320 ms. The UE is in sleep mode during the consecutive radio frames before the next paging frame arrives.

Fig. 2-3: Example of idle mode DRX in LTE FDD



Paging occasion (PO) and paging frame (PF) are two key terminologies that need to be understood when we talk about i-DRX operation. They are crucial for the UE to be synchronized with eNodeB to detect its paging message.

Paging occasion (PO) is the subframe where P-RNTI may be transmitted on the PDCCH addressing the paging message. There is only one PO for each UE in a DRX paging cycle.

Paging frame (PF) is one radio frame containing one or multiple POs.

The calculation of PF and determination of the PO should follow the parameters given in Tables 2-2 to 2-6 depending on the deployed RAT, i.e. LTE FDD/TDD, LTE-M or NB-IoT.

Below, we will look at how DRX or paging in RRC idle state works.

The UE receives the cell-specific DRX parameters default paging cycle (T_c) and nB that were broadcasted in system information block 2 (SIB2) or the UE-specific DRX cycle length (T_{ue}) from the NAS signaling, if there is any.

The DRX paging cycle T takes the shorter paging cycle value between the default paging cycle T_c and the UE-specific DRX paging cycle T_{ue}. This parameter defines the number of radio frames in the paging cycle. The larger the paging cycle, the less the UE will wake up to monitor the paging occasion. The UE will also consume less battery power, but a possible mobile terminated call setup would take longer. The value sets of the paging cycle for LTE CAT-M and NB-IoT are given in Table 2-2. nB is another DRX parameter that gives the number of paging occasions (PO) per DRX paging cycle. It indicates the paging capacity of the cell and shows the density of the paging. Like the parameter paging cycle, a different value set for nB shown in Table 2-2 can be applied depending on the IoT technology.

In addition to the above-mentioned DRX parameters, an UE identity index (UE_ID) is required. It is calculated based on the UE IMSI stored on the UE SIM card. The calculation of the UE_ID is RAT dependent and in the case of NB-IoT, the UE_ID also depends on whether the UE is paged on an anchor carrier or a non-anchor carrier (details are given in Table 2-2).

With all the parameters (T_{ue} or T_c, nB and UE_ID) in place, the paging frame (PF) is then derived according to the formula shown in Table 2-2.

The PO is determined in one of the lookup tables (Tables 2-3 to 2-6) by considering the Ns value and i_s index calculated by the formulas given in Table 2-2. In the case of LTE-M, it also depends on the operating bandwidth. If an LTE-M UE operates in a very narrow bandwidth smaller than 3 MHz, lookup tables Table 2-4 and Table 2-6 are used to determine the PO.

Table 2-2: DRX parameters (LTE, LTE-M and NB-IoT) and paging frame calculation

DRX parameter	Description	Value set/calculation formula
T_{ue}	UE-specific DRX cycle length allocated by upper layers in radio frame	LTE-M: 32, 64, 128, 256; NB-IoT: 128, 256, 512 and 1024
T_c	default paging cycle (cell-specific DRX cycle) length in radio frames broadcasted in the SIB2 message	LTE-M: 32, 64, 128, 256; NB-IoT: 128, 256, 512 and 1024
T	UE DRX paging cycle length in radio frames based on T_{ue} and T_c	min (T_{ue}, T_c)
nB	number of POs per DRX cycle across all UEs in the cell. This parameter is broadcasted in the SIB2 message.	LTE-M [1]: 4T, 2T, T, T/2, T/4, T/8, T/16, T/32, T/64, T/128, and T/256; NB-IoT: 4T, 2T, T, T/2, T/4, T/8, T/16, T/32, T/64, T/128, T/256, T/512 and T/1024
N	number of PFs within the UE DRX cycle	min. (T, nB)
N_s	number of paging subframes used within a PF	max. (1, nB/T)
UE_ID	UE identity	IMSI mod 1024 (for LTE), IMSI mod 16384 (for LTE-M), IMSI mod 4096 (for NB-IoT anchor carrier), IMSI mod 16384 (for NB-IoT non-anchor carrier)
PF	paging frame number	SFN mod T = (T div N) × (UE_ID mod N)
i_s	index position of PO within a PF	i_s = floor (UE_ID div N) mod N_s

Table 2-3: Subframe pattern in FDD to determine the paging occasion (valid for LTE, LTE-M with bandwidth > 3 MHz and NB-IoT) [2]

N_s	PO if i_s = 0	PO if i_s = 1	PO if i_s = 2	PO if i_s = 3
1	9	NA	NA	NA
2	4	9	NA	NA
4	0	4	5	9

Table 2-4: Subframe pattern in FDD to determine the paging occasion (valid for LTE-M with bandwidth ≤ 3 MHz) [2]

N_s	PO if i_s = 0	PO if i_s = 1	PO if i_s = 2	PO if i_s = 3
1	5	NA	NA	NA
2	5	5	NA	NA
4	5	5	5	5

Table 2-5: Subframe pattern in TDD to determine the paging occasion (valid for LTE, LTE-M with bandwidth > 3 MHz and NB-IoT) [2]

N_s	PO if i_s = 0	PO if i_s = 1	PO if i_s = 2	PO if i_s = 3
1	0	NA	NA	NA
2	0	5	NA	NA
4	0	1	5	6

[1] T/64, T/128 and T/256 are only allowed if the default paging cycle Tc has the same or a greater value. For example, T/64 needs default paging cycle $T_c \geq 64$.

[2] N_s and i_s are calculated in Table 2-2.

Table 2-6: Subframe pattern in TDD to determine the paging occasion (valid for LTE-M with bandwidth ≤ 3 MHz)[3)]

N_s	PO if i_s = 0	PO if i_s = 1	PO if i_s = 2	PO if i_s = 3
1	1	NA	NA	NA
2	1	6	NA	NA
4	1	1	6	6

3) N_s and i_s are calculated in Table 2-2.

Detailed information about the determination of the PF and PO is provided in [1].

To verify the i-DRX of the UE, the R&S®CMW500/R&S®CMW290 can easily set up the DRX parameters: default paging cycle T and nB as shown in Fig. 2-4.

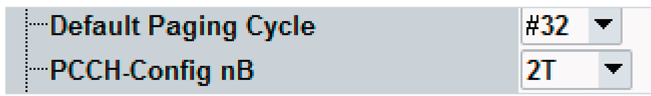


Fig. 2-4: Idle DRX cell-specific settings on the R&S®CMW500/R&S®CMW290

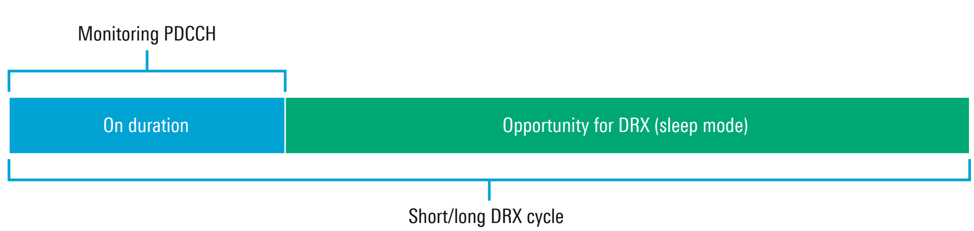
2.2 DRX in RRC connected state

In addition to the idle state DRX explained in chapter 2.1, the connected DRX (cDRX) operated in RRC connected state is another approach taken to conserve the battery life of the device. In cDRX mode, the UE is allowed to monitor the PDCCH discontinuously to check if the scheduling messages can be detected by its C-RNTI on PDCCH.

To operate the DRX in RRC connected state, there are basically two possibilities, either through a timer based mechanism or via explicit DRX commands from the eNodeB MAC layer. This white paper only looks at the timer based approach.

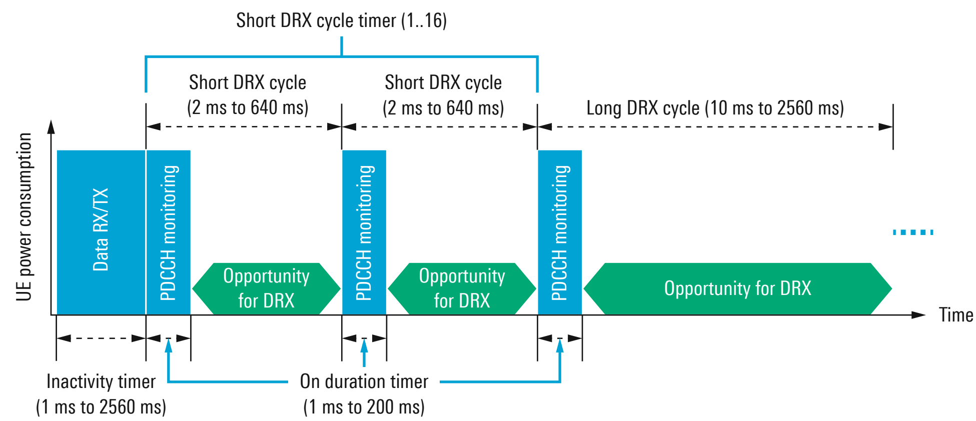
The connected DRX procedure generally contains two types of DRX cycles: a short DRX cycle and a long DRX cycle, where the short DRX cycle is defined as optional by the specification and is only applicable for LTE devices. Regardless of whether the UE supports the short or long DRX cycle, it needs to be reported to the eNodeB in bits 4 and 5, respectively, of the feature group indicator (FGI) in the UE capability information. For an LTE-M and NB-IoT device, short DRX is not required [8].

Fig. 2-5: Connected DRX cycle



A DRX cycle as shown in Fig. 2-5 consists of an on duration period when the UE monitors PDCCH continuously and an opportunity for DRX period or sleep mode in which the UE can skip reception of downlink channels to save battery power. However, in sleep mode, the UE always has the possibility to send a scheduling request (SR) through PUCCH in the uplink.

Fig. 2-6: Connected DRX for LTE



A general cDRX mechanism is depicted in Fig. 2-6. The UE continuously monitors the PDCCH in RRC connected state. As long as DL scheduling or a UL grant is detected in the PDCCH, the UE's DRX inactivity timer and RRC inactivity timer are both restarted. After the DRX inactivity timer expires, the UE optionally (for LTE) enters a short DRX cycle or otherwise directly enters a long DRX cycle. The UE keeps on monitoring the PDCCH on the number of the subframes specified by the on duration parameter. UE power saving will only start after the on duration timer expires. After a short DRX cycle expires, another short DRX cycle may start depending on the given number of short DRX cycle timers. The UE will enter the long DRX cycle when the complete short DRX cycle has terminated due to expiration of the short DRX cycle timer.

Below are the details of the DRX configuration parameters contained in the RRCConnectionSetup or RRCConnectionReconfiguration message that determine the behavior of the UE DRX. This ensures that the UE wake-up timing and network transmission timing are synchronized. This means that the UE should not be in sleep mode while the network sends data or vice versa.

- **DRX cycle:** Refers to either a short DRX cycle or a long DRX cycle. It consists of an on duration in which the UE monitors the paging messages on the PDCCH and an opportunity for DRX period during which the UE skips reception of the downlink control channels, i.e. sleep mode.
- **DRX inactivity timer:** Specifies the number of consecutive PDCCH subframe(s) after successfully decoding a PDCCH, indicating an initial UL or DL user data transmission for this UE with up to 2560 subframes. While this timer is active, the UE can be considered as being operated in continuous reception mode and therefore there is no power saving effect. This timer is restarted when a new transmission for DL or UL is received on PDCCH. After this timer expires, the UE should enter DRX mode. Optionally short DRX prior to long DRX.
- **On duration timer:** Specifies the number of consecutive PDCCH subframe(s) in a DRX cycle. During the validity of this timer, the UE monitors the PDCCH to detect any associated scheduling message. It has a duration of up to 200 subframes.
- **Short DRX cycle** (not relevant for LTE CAT-M and NB-IoT device): Specifies the number of consecutive subframe(s) the UE should follow the short DRX cycle. It is the first DRX cycle that the UE enters after the DRX inactivity timer expires and it ranges from 2 subframes to 640 subframes. The UE is in the short DRX cycle until the short DRX cycle timer expires. After that it will enter a long DRX cycle.

The main reason for introducing the short DRX cycle is to compromise between power saving and communication responsiveness, particularly in a bursty communications scenario or in an irregular data transmission pattern, e.g. web surfing.

- **Short DRX cycle timer** (not relevant for LTE CAT-M and NB-IoT device): Specifies the number of short DRX cycles the UE should follow after the DRX inactivity timer has expired. The timer value can be up to 16
- **Long DRX cycle:** The value of long DRX cycle is in number of subframes, which is in the range of 10 subframes to 2560 subframes. If the short DRX cycle is configured, the value of the long DRX cycle should be a multiple of the short DRX cycle value.
- **DRX start offset:** Specifies the subframe where the DRX cycle starts.

The starting of short DRX and long DRX with respect to system frame number (SFN) and subframe number depends on the formulas below.

Formula 2-1: Starting time grid of short DRX

$$\left[\left(SFN \times subframeNumber\right)\right] mod\left(short\ DRX\ cycle\right) = \left(DRX\ start\ offset\right) mod\left(short\ DRX\ cycle\right)$$

Formula 2-2: Starting time grid of long DRX

$$\left[\left(SFN \times 10\right) + subframeNumber\right] mod\left(long\ DRX\ cycle\right) = DRX\ start\ offset$$

- **DRX retransmission timer:** Specifies the maximum number of consecutive PDCCH subframe(s) where a DL retransmission is expected by the UE after the first available retransmission time.

Table 2-7 lists the value set for each cDRX parameter defined in 3GPP Rel. 11. These parameters are relevant for LTE devices. The cDRX value set defined in Rel. 13 (mostly relevant for LTE-M/NB-IoT) is shown later in Table 3-3. In the table, psf and sf stand for PDCCH subframe respectively subframe. Bear in mind that the PDCCH subframe based timer in TDD mode only counts the DL subframes and special subframes.

Table 2-7: cDRX parameter value set defined in 3GPP TC36.331 [8]

Parameters	Value set (cDRX)
DRX inactivity timer	psf1, psf2, psf3, psf4, psf5, psf6, psf8, psf10, psf20, psf30, psf40, psf50, psf60, psf80, psf100, psf200, psf300, psf500, psf750, psf1280, psf1920, psf2560
On duration timer	psf1, psf2, psf3, psf4, psf5, psf6, psf8, psf10, psf20, psf30, psf40, psf8, psf10, psf20, psf30, psf40, psf50, psf60, psf80, psf100, psf200
Short DRX cycle	sf2, sf4, sf5, sf8, sf10, sf16, sf20, sf32, sf40, sf64, sf80, sf128, sf160, sf256, sf320, sf512, sf640
DRX short cycle timer	1 to 16
Long DRX cycle	sf10, sf20, sf32, sf40, sf60, sf64, sf70, sf80, sf128, sf160, sf256, sf320, sf512, sf640, sf1024, sf1280, sf2048, sf2560
DRX start offset	0 to (long DRX cycle – 1)
DRX retransmission timer	psf0, psf1, psf2, psf4, psf6, psf8, psf16, psf24, psf33

For more details about DRX in connected mode, see the 3GPP specification [4].

Fig. 2-7 illustrates an example of the LTE UE behavior in cDRX mode with respect to the system frame number (SFN) and subframe based on the cDRX parameters given in Table 2-8.

Fig. 2-7: Example of connected DRX (cDRX) for an LTE device

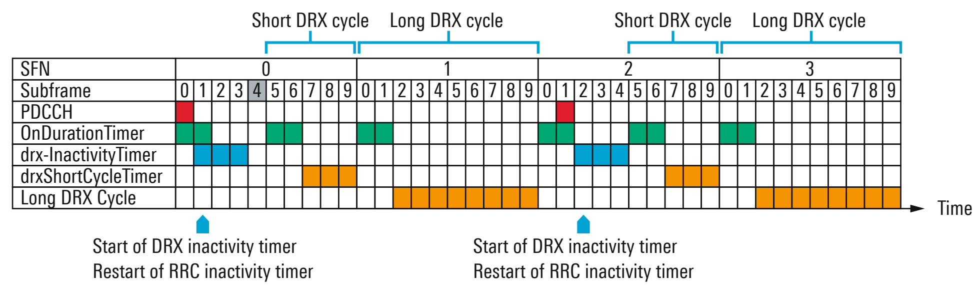


Table 2-8: cDRX parameters, see example in Fig. 2-7

cDRX parameter	
drx-InactivityTimer	3 psf (PDCCH subframes)
OnDurationTimer	2 psf (PDCCH subframes)
Short DRX cycle	5 sf (subframes)
Long DRX cycle	10 sf (subframes)
DRX start offset	0 sf (subframes)
drxShortCycleTimer	1

Table 2-9: List of UE behavior of the cDRX, see example in Fig. 2-7

(SFN, subframe)	UE behavior
(0, 0)	The UE detects the PDCCH while the on duration timer is active.
(0, 1)	DRX inactivity timer is started immediately after the PDCCH is detected; the RRC inactivity timer is also restarted.
(0, 5)	Short DRX cycle is started. Since the DRX short cycle timer is set to 1, the short DRX cycle terminates at (0, 9).
(1, 0)	Long DRX cycle is started.
(2, 1)	New PDCCH resource allocation occurs while the on duration timer is active.
(2, 2)	DRX inactivity timer is started immediately after the PDCCH is detected; the RRC inactivity timer is also restarted.
(2, 5)	Short DRX cycle is started. Since the DRX short cycle timer is set to 1, the short DRX cycle terminates at (2, 9).
(3, 0)	Long DRX cycle is started.

In Fig. 2-7, time grid notation is defined as (SFN, subframe). For example, the first PDCCH detection occurs at time grid position (0, 0).

On the time axis, the UE behavior described in Table 2-9 can be observed.

The following points need to be highlighted here:
- The UE starts the short DRX cycle at (SFN, subframe) = (0, 5) instead of subframe 4 due to formula 2-1
- The short DRX cycle occurs 1 time due to the DRX short cycle timer parameter
- When the DRX inactivity timer is (re)started, the entire RRC inactivity timer is reset. Just keep in mind that if the RRC inactivity timer expires, the RRC connection will be released and the RRC state changes to idle mode. In RRC idle mode, the idle DRX described in chapter 2.1 applies.

Fig. 2-8 shows the DRX parameter implementation on R&S®CMW500/R&S®CMW290. It enables verification of the cDRX behavior of the UE either against the 3GPP predefined cDRX pattern, including long cDRX and short cDRX, or against a user-defined cDRX pattern.

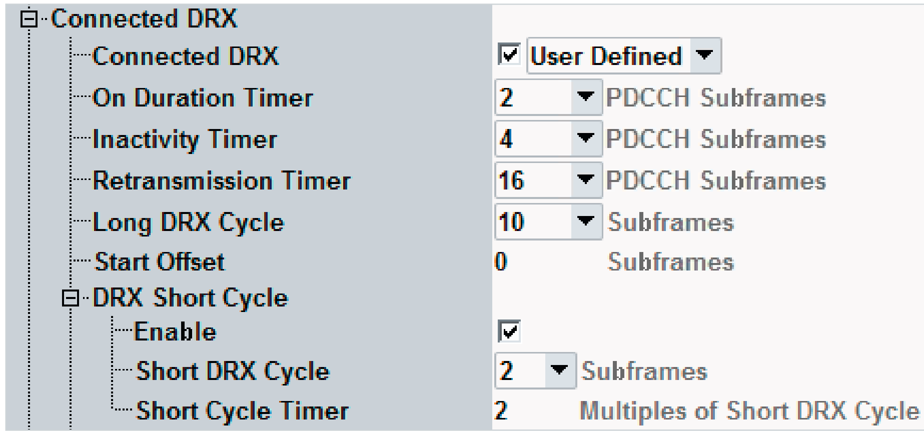


Fig. 2-8: Connected DRX on R&S®CMW500/R&S®CMW290

3 Extended discontinuous reception

Extended discontinuous reception (eDRX) is a power saving optimization feature introduced in 3GPP Rel. 13. As the name implies, it supports a longer DRX cycle than the legacy DRX power saving features described in chapter 2.

Fig. 3-1: Comparison of DRX and eDRX in RRC idle state

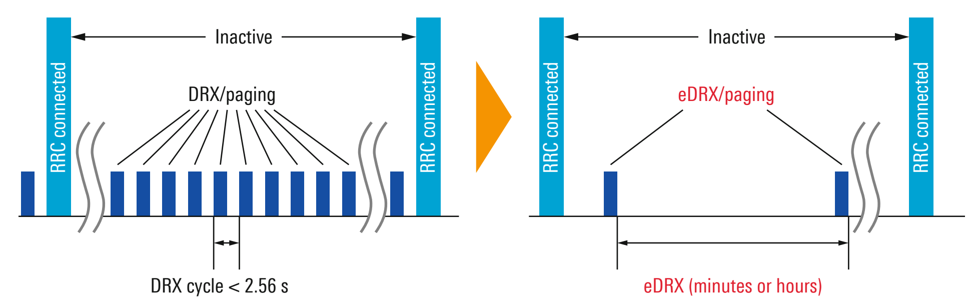


Fig. 3-1 shows the basics of eDRX versus legacy DRX where in the RRC idle state the paging cycle is extended from 2.56 s to minutes or even hours, more precisely, approx. 44 min in LTE-M and approx. 3 h in NB-IoT.

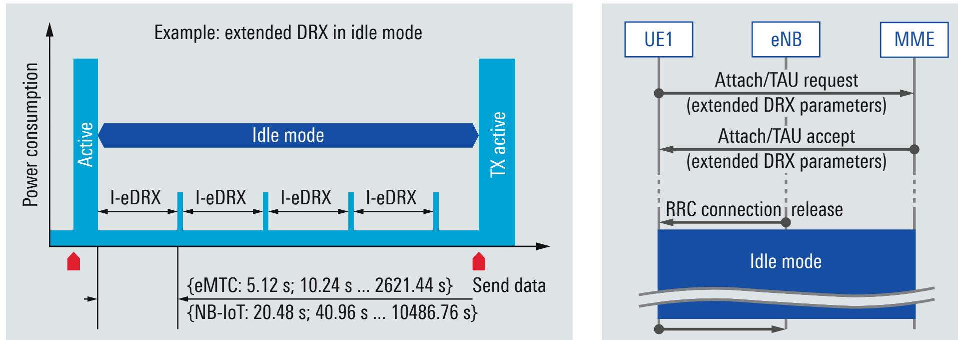
The typical use case for eDRX is LTE-M and NB-IoT devices. Since these IoT devices send little data and the data that is sent or received is not so time critical, there is more delay tolerance compared to LTE devices. It is also assumed that LTE-M and NB-IoT devices have more uplink data traffic than downlink data traffic. The tradeoff between device reachability and power consumption in the IoT application is therefore more in favor of energy consumption reduction. Long battery lifetime, say minimally 10 years, is required for LTE-M and NB-IoT devices. To achieve this, the eDRX approach is highly recommended.

Like legacy DRX, eDRX can be deployed in both RRC idle and connected state. This gives us the terms idle eDRX (I-eDRX) and connected eDRX (C-eDRX).

3.1 eDRX in RRC idle state

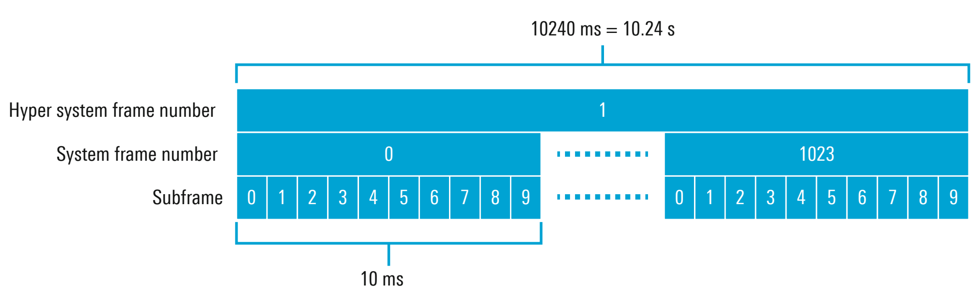
Fig. 3-2 demonstrates the idle eDRX principle and its message flow. The UE can request the use of idle eDRX during the initial attach procedure or tracking area update (TAU) by including the eDRX parameters IE. The network entity MME accepts the request from the UE by providing the eDRX parameters IE according to the network policy when accepting the attach or TAU procedure. The UE will then use the received eDRX parameters for the subsequent procedures. If the UE does not receive any eDRX values from the network, it effectively means that the network rejects the eDRX request, probably due to the fact that the network does not have eDRX support. In that case, the eDRX parameter is not applied, and legacy DRX as described in chapter 2.1 is used instead.

Fig. 3-2: Idle eDRX (I-eDRX) concept and procedure flow



To achieve the longer paging cycle over minutes or hours, the system frame number (SFN) that is used to synchronize the UE and eNodeB prior to 3GPP Rel. 13 is no longer sufficient. Since SFN rolls over to 0 after 1024 LTE system frames, the maximum SFN duration is 10240 ms. In legacy DRX operation, most of the time parameters are not allowed to exceed the maximum SFN duration. Starting with Rel. 13, 3GPP introduced a hyper system frame number (Hyper SFN or H-SFN) to extend the time span of the time parameters, e.g. the timer used for eDRX. One H-SFN consists of 1024 SFNs, and H-SFN rolls over to 0 after 1024 hyper frames (HF). This results in a maximum H-SFN duration of 29127 h (1024 × 10240 ms = 10485769 ms = 29127 h). The introduction of H-SFN timing makes the longer paging cycle possible. Fig. 3-3 gives an overview of the system frame hierarchy right up to the hyper system frame level.

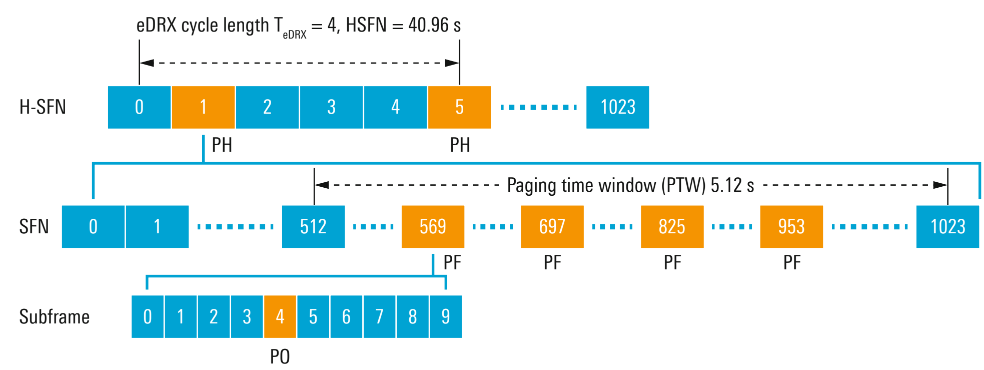
Fig. 3-3: Hyper system frame number (H-SFN) hierarchy



Recall that in legacy DRX explained in chapter 2.1, the UE needs to monitor the paging on the PDCCH in the given PF and PO, which corresponds to the SFN and subframe, respectively. In comparison to I-DRX, I-eDRX has to additionally determine the paging hyperframe (PH). The UE is reachable for paging in a paging hyperframe (PH), which is a specific set of H-SFN values. Within the PH, the UE monitors the PF and PO in the given paging time window (PTW) .

Fig. 3-4 illustrates an example of eDRX paging. By signaling the eDRX cycle length T_{eDRX} = 40.96 s, paging time window (PTW) = 5.12 s and UE_ID = 57, the paging frame (PF) and paging occasion (PO) are calculated (time grid of the PF and PO is indicated in the SFN and subframe, respectively). For instance, in the second paging hyperframe (H-SFN = 1), a PO can be expected in subframe 4 of SFN 569.

Fig. 3-4: Example of eDRX paging



The eDRX parameters and determination of the PH, PF and PO are explained below.

I-eDRX parameters [3] contain I-eDRX cycle length (T_{eDRX}) and paging time window (PTW).

I-eDRX cycle length (T_{eDRX}) gives the value for the paging cycles in number of H-SFNs.

PTW is the time period configured for a UE in the I-eDRX cycle during which the UE monitors paging occasions (PO) on the PDCCH. In the remaining cycle time, the UE does not monitor the PDCCH. Thus, the network considers the UE unreachable for paging until the next paging hyperfame (PH) comes along.

Given the I-eDRX cycle length (T_{eDRX}), PTW and UE_ID (IMSI, TMSI or S-TMSI), the I-eDRX PH, PF and PO are derived using the calculation defined in [1], chapter 7.3.

A high-level summary of the PH, PF and PO calculation is explained as follows:

- UE_ID_H (the 12 most significant bits of the UE_ID for NB-IoT devices, the 10 most significant bits of the UE_ID for LTE-M devices) and T_{eDRX} determine the PH and PTW_start (the start position of the PTW in SFN)

  Formula 3-1:

  $$H\text{-}SFN \bmod T_{eDRX} = (UE\_ID\_H \bmod T_{eDRX})$$

  Formula 3-2:

  $$PTW\_start = 256 \times i_{eDRX}, \text{ where } i_{eDRX} = floor\,(UE\_ID\_H \;div\; T_{eDRX}) \bmod 4$$

- PTW_stop position is determined by applying PTW_start and PTW length

  Formula 3-3:

  $$PTW\_stop = (PTW\_start\ SFN + PTW\ length \times 100 - 1) \bmod 1024$$

- From now on, the PF and PO occur between PTW_start and PTW_stop. Determination of the PF and PO within the given PTW follows the same calculation as for legacy DRX as described in chapter 2.1.

By knowing the PH, PF and PO, the UE is now able to wake up at the right time to monitor its paging message.

Table 3 1 lists possible I-eDRX parameter value sets by IoT technology. The maximum achievable I-eDRX cycle length for an LTE-M device is about 44 min (HF256 = 256 × 10.24 s = 2621.44 s = 43.69 min, 1HF = 10.24 s), whereas for NB-IoT devices, it can reach approx. 3 h (HF1024 = 1024 × 10.24 s = 10485.76 s = 2.91 h).

Table 3-1: I-eDRX parameter value set comparison between LTE-M and NB-IoT

IoT technology	eDRX cycle length (T_{eDRX}) in s	Paging time window (PTW) in s
LTE-M	5.12/10.24/20.48/40.96/61.44/ 81.92/102.40/122.88/143.36/ 163.84/327.68/655.36/1310.72/ 2621.44	1.28/2.56/3.84/5.12/6.40/7.68/8.96/ 10.24/11.52/12.80/14.08/15.36/ 16.64/17.92/19.20/20.48
NB-IoT	20.48/40.96/81.92/163.84/327.68/ 655.36/1310.72/2621.44/5242.88/ 10485.76	2.56/5.12/7.68/10.24/12.80/15.36/ 17.92/20.48/23.04/25.60/28.16/ 30.72/33.28/35.84/38.40/40.96

Table 3-2 compares legacy I-DRX and I-eDRX in terms of the paging cycle. We can easily identify that due to the introduction of the H-SFN, the paging cycle length in I-eDRX has considerably increased compared to legacy DRX.

Table 3-2: LTE-M/NB-IoT paging cycle length value set comparison: legacy DRX versus eDRX in idle state

IoT technology	Legacy DRX paging cycle (T) in s	eDRX cycle length (TeDRX) in s
LTE-M	0.32/0.64/1.28/2.56	5.12/10.24/20.48/40.96/61.44/ 81.92/102.40/122.88/143.36/ 163.84/327.68/655.36/1310.72/ 2621.44
NB-IoT	1.28/2.56/5.12/10.24	20.48/40.96/81.92/163.84/327.68/ 655.36/1310.72/2621.44/5242.88/ 10485.76

Fig. 3-5 shows how easy it is to verify idle mode eDRX on the R&S®CMW500/ R&S®CMW290 with the configurable extended cycle length and paging time window.

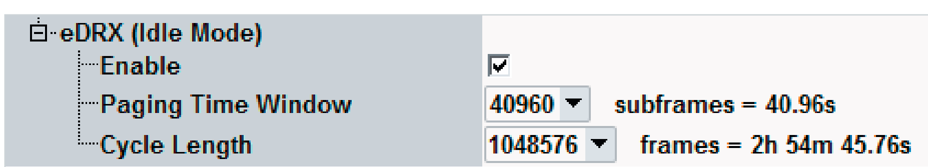


Fig. 3-5: I-eDRX on R&S®CMW500/R&S®CMW290

3.2 eDRX in RRC connected state

eDRX in RRC connected state is applicable only in the long DRX cycle. The overall working principle is the same as legacy cDRX. A different extended DRX cycle timer is applied based on the IoT technology. Table 3-3 shows the comparison of the connected eDRX cycle length value set by IoT technology as well as the comparison to legacy connected DRX. A long DRX cycle of an LTE-M is extended to 10.24 s, whereas NB-IoT is specified to have a maximum long DRX cycle of 9.216 s.

Table 3-3: Timer comparison between legacy cDRX and connected-eDRX in RRC connected state

Parameters	Value set (Legacy cDRX until Rel. 11)	Value set (C-eDRX Rel. 13)	
	LTE	**LTE-M**	**NB-IoT**
DRX inactivity timer	psf1, psf2, psf3, psf4, psf5, psf6, psf8, psf10, psf20, psf30, psf40, psf50, psf60, psf80, psf100, psf200, psf300, psf500, psf750, psf1280, psf1920, psf2560		pp0, pp1, pp2, pp3, pp4, pp8, pp16, pp32
On duration timer	psf1, psf2, psf3, psf4, psf5, psf6, psf8, psf10, psf20, psf30, psf40, psf50, psf60, psf80, psf100, psf200	psf300, psf400, psf500, psf600, psf800, psf1000, psf1200, psf1600	pp1, pp2, pp3, pp4, pp8, pp16, pp32
Short DRX cycle	sf2, sf4, sf5, sf8, sf10, sf16, sf20, sf32, sf40, sf64, sf80, sf128, sf160, sf256, sf320, sf512, sf640	not applicable	not applicable
DRX short cycle timer	1 to 16	not applicable	not applicable
Long DRX cycle	sf10, sf20, sf32, sf40, sf60, sf64, sf70, sf80, sf128, sf160, sf256, sf320, sf512, sf640, sf1024, sf1280, sf2048, sf2560	sf5120, sf10240	sf256, sf512, sf1024, sf1536, sf2048, sf3072, sf4096, sf4608, sf6144, sf7680, sf8192, sf9216
DRX start offset	0 to (long DRX cycle – 1)	0 to (long DRX cycle – 1)	0 to 255
DRX retransmission timer	psf0, psf1, psf2, psf4, psf6, psf8, psf16, psf24, psf33	psf40, psf64, psf80, psf96, psf112, psf128, psf160, psf320	pp0, pp1, pp2, pp4, pp6, pp8, pp16, pp24, pp33

Note:

- psf = PDCCH subframe
- sf = subframe
- pp = PDCCH period; the number of PDCCH subframes for the timer is calculated by multiplying the number of PDCCH periods by npdcch-NumRepetitions-RA when the UE uses the common search space or by npdcch-NumRepetitions when the UE uses the UE-specific search space

4 Power saving mode

Power saving mode (PSM) is the power saving feature designed for LTE-M/NB-IoT devices to help them conserve more battery power. This feature was first introduced in 3GPP Rel. 12 [5] [7].

To update the network about its availability, the UE performs periodic tracking area updates (TAU) after a configurable TAU timer has expired. The UE then remains reachable for paging during the paging time window (PTW, a configurable window explained in chapter 3.1) of the idle state. Once the PTW expires, it enters deep sleep mode (PSM mode) and becomes dormant and unreachable until the next periodic TAU occurs. During PSM mode, the UE turns off its circuitry yet is still registered in the network, meaning that the UE closes the AS connection yet keeps the NAS status. The advantage of such an approach lies in the fact that the UE can wake up immediately from PSM without having to re-attach or re-establish the PDN connections. This avoids extra power consumption due to additional signaling messages transmission for the higher layer connection establishment procedure. PSM maximizes the downtime of the UE, which significantly reduces battery consumption.

Fig. 4-1: Principle of power save mode

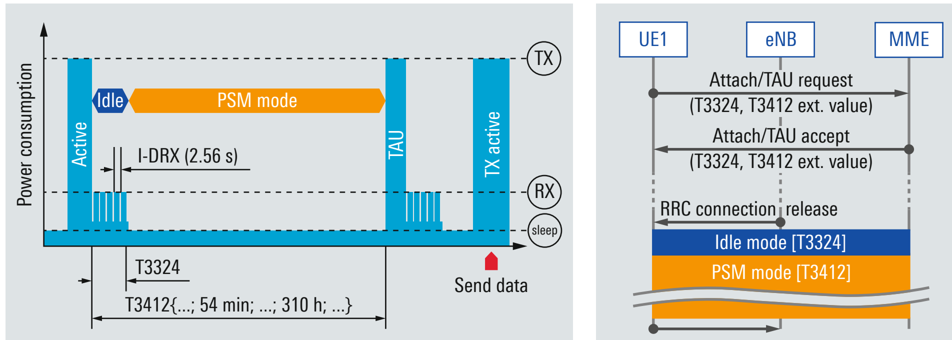


Fig. 4-1 shows the principle of PSM and its message flow. The UE can exit PSM either after the T3412 timer expires, i.e. renewed TAU, or the UE initiates a mobile originated (MO) service or detach. The UE can use this to proactively exit PSM and enter into the RRC idle state and connected state later on to request the service.

In the NAS messages Attach request, Attach accept, TAU request and TAU accept, there are two configurable timers that play an important role in PSM: T3324 and T3412 extended timer [2].

T3324 is an active timer that is started immediately after the UE releases the RRC connection and enters the idle state. The value of T3324 can be in the range of 0 s to 11 160 s, or roughly 3.1 h. After this timer expires, the UE enters PSM, i.e. the dormant state. The timer value greatly affects the battery power consumption. Apparently, the lower the timer value, the faster the UE will go into the dormant state.

The T3412 extended timer is the extension of the T3412 timer which is between the periodic TAU whose value is given by attach TAU messages. It controls the initiation of the periodic TAU by the UE. The T3412 extended timer gives the UE up to 35 712 000 s, i.e. 413 days.

The use of PSM is particularly interesting for use cases that require infrequent mobile terminated or mobile originated events that allow a certain latency for the services, such as a water meter that sends the counter once a month. With the PSM mechanism, the 10-year battery lifetime as recommended for LTE-M and NB-IoT devices becomes possible.

As shown in Fig. 4-2, the PSM feature can be easily verified with the R&S®CMW500/R&S®CMW290 radio tester. Simply activate the PSM allowed checkbox to enable PSM mode. The T3324 and T3412 extended timers are all configurable on the tester and signaled to the UE via layer 3 messages.

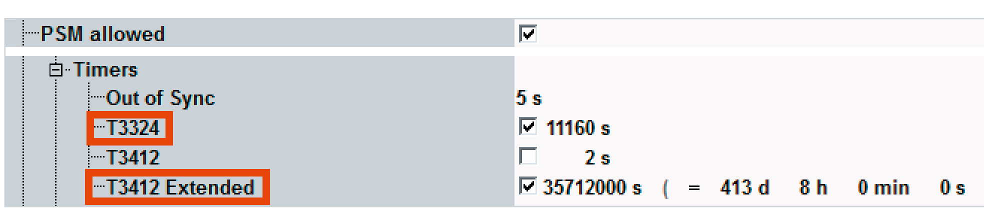


Fig. 4-2: Enabling PSM mode and timer configurations on R&S®CMW500/R&S®CMW290

Applying PSM, eDRX or a combination of both reduces IoT device power consumption. However, due to the unresponsiveness of the device during the sleep period or during the paging cycle, there is always a tradeoff between the device reachability and battery lifetime. This side effect has to be taken into account in IoT service deployment and needs to be optimized based on the individual use case.

As explained in the previous chapters, eDRX and PSM are the key power saving schemes adopted by LTE-M and NB-IoT. Which power saving method is used depends heavily on the real use scenario. The rule of thumb is that eDRX is the suitable approach for device terminated applications such as asset tracking, smart grid, etc. or if the IoT application needs to often listen to the network for incoming messages. eDRX reduces power consumption thanks to the long eDRX cycles, yet still maintains relatively fast service responsiveness compared to PSM. For more uplink driven data applications, device originated applications and non-realtime requirements, PSM might be a better choice, e.g. for smart meters, smart sensors etc. that periodically push data up to the network [10]. Certainly, eDRX can be used in conjunction with PSM to find the balance between battery lifetime and service responsiveness.

If we use current drain to quantize the device energy consumption, then PSM-only operation is approximately at the microampere level when the device is in the deep sleep mode whereas the eDRX current drain is in the range of milliampere and microampere depending on the applied paging cycle length.

The Rohde & Schwarz test solution that enables benchmarking, verification and optimization of the IoT device power consumption measurement is described in detail in the application note 1MA281 [14].

5 Other power saving mechanisms

5.1 Release assistance indication (RAI)

Release assistance indication (RAI), a 3GPP Rel. 14 feature, allows the LTE-M/NB-IoT device to indicate to the eNB that it has no more UL data and that the device does not anticipate receiving further DL data, thereby enabling an early transition from RRC connected to RRC idle state. Without RAI, the UE would have to wait for the eNB to release the connection via explicit signaling. Since the eNB is not fully aware of the UE data buffer or the expected DL traffic, it sends a connection release message that forces the UE to enter idle state after the RRC inactivity timer expires. This mechanism further improves the UE battery lifetime.

5.2 Early data transmission (EDT)

A good compromise between battery lifetime and message latency is achieved by the early data transmission (EDT) mechanism, which was introduced in 3GPP Rel. 15 and allows the UE to send uplink data during the random access procedure. This mechanism improves the battery lifetime by almost 3 years and reduces the message latency by more than 3 s compared to the Rel. 13 performance, particularly under poor radio conditions [11].

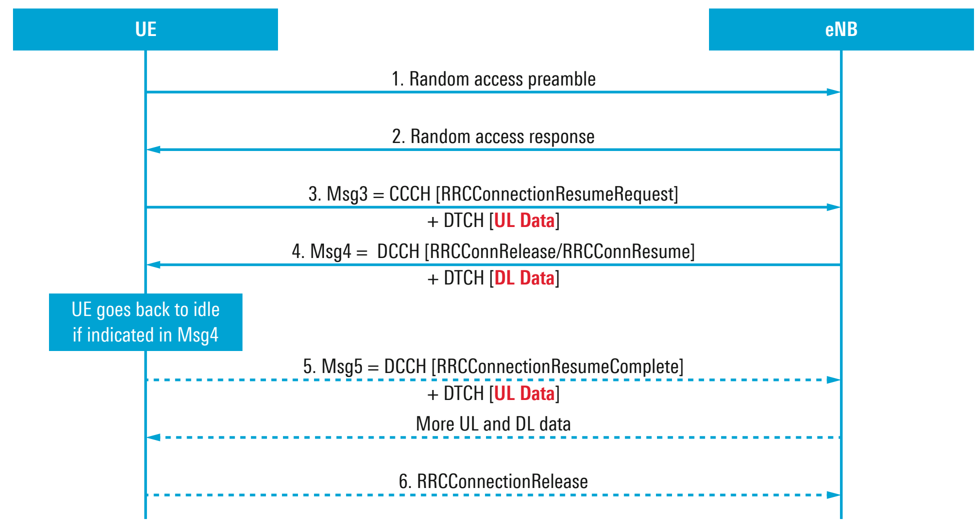
Before EDT was introduced, LTE-M/NB-IoT devices utilized one of two ways to transfer small data: control plane (CP) or user plane (UP) cIoT EPS optimization. Without applying these mechanisms, the signaling overhead to the transmitted data is over proportional, which leads to inefficiency or latency in the data transmission. For CP cIoT EPS optimization, transmitted data is piggybacked in the RRCConnectionSetup message and RRCConnectionSetupComplete message for DL and UL, respectively. For UP cIoT EPS optimization, the RRC connection of the previous data transmission is not released – it is suspended. By the next data transfer, the preserved RRC connection is resumed [15].

In 3GPP Rel. 15, cIoT data transfer in CP and UP mode was further enhanced to CP-EDT and UP-EDT respectively. In contrast to CP and UP data transfer, the core concept of EDT is that the UL and DL data is transmitted early in the contention based random access (RA) procedure. More precisely, the UL and DL data is transferred in message 3 respectively message 4 of the RA procedure.

For LTE-M devices, the maximum TBS size given in message 3 depends on the coverage enhancement (CE) level. For CE0 and CE1, the UE can utilize the maximum TBS size of 1000 bits to transmit data, whereas for CE2 and CE3, the UE is only allowed to apply the maximum TBS size of 456 bit. For NB-IoT devices, the maximum TBS size is about 1000 bits. If the entire data transmission is completed in message 3, the eNodeB will signal the UE in message 4 to enter the RRC idle state. This shortens the overall data transmission time. Since the entire transmission and reception time is shortened, the battery life of the device is prolonged as a result.

Figs. 5-1 and 5-2 show the signaling flow of the UP-EDT and CP-EDT. The message flow plotted in dotted lines indicates the Rel. 13 cIoT UP and CP that serves as the fallback procedure for data transmission.

Fig. 5-1: Signaling flow of UP-EDT [8]



1. The UE initiates EDT by selecting a random access preamble configured for EDT in the system information as well as the maximum transport block size (TBS) for EDT.

2. eNodeB receives the EDT preamble and responds with the random access response, including the granting of Msg3 with an appropriate TBS.

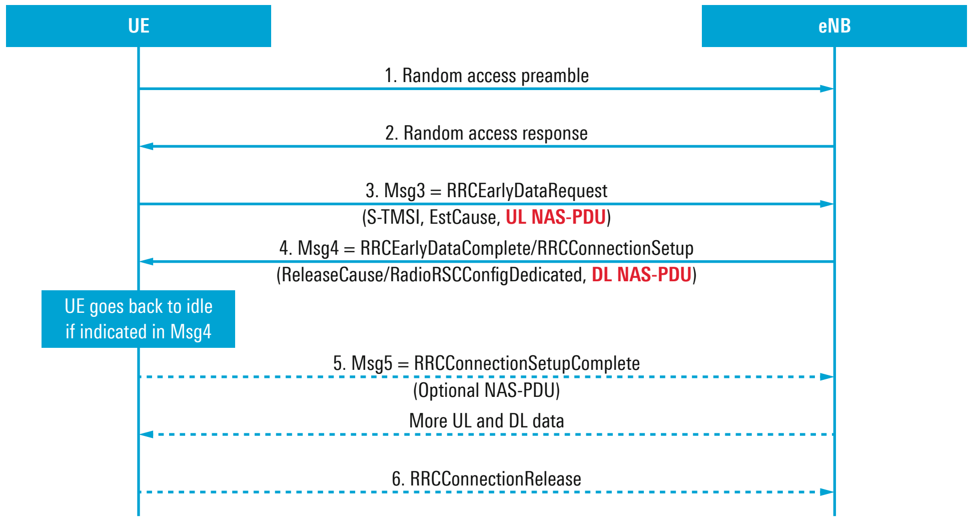
3. The UE sends RRCConnectionResumeRequest to eNodeB including the resume ID, establishment cause and an authentication token. The UE resumes all signaling radio bearers (SRB) and data radio bearers (DRB), derives new security keys and re-establishes the AS security. The UL data is ciphered and transmitted on DTCH multiplexed with the RRCConnectionResumeRequest message on CCCH

4. eNodeB sends the RRCConnectionRelease message to keep the UE in RRC idle state and indicating the completion of the UP-EDT procedure. DL data can also be optionally sent to the UE on DTCH multiplexed with RRCConnectionRelease message on DCCH. Otherwise, if more UE data transfer is expected, eNodeB sends the RRCConnection-Resume message to the UE to revoke the RRC connection resume procedure and fall back to Rel. 13 cIoT UP data transfer.

5. The UE enters the RRC connected state and informs eNodeB about its RRC state. More UL and DL data is transferred in the subsequent message exchanges.

6. eNodeB commands the release of the RRC connection by sending the RRCConnectionRelease message to the UE.

Fig. 5-2: Signaling flow of CP-EDT [8]



1. The UE initiates the EDT by selecting a random access preamble configured for EDT in the system information as well as the maximum transport block size (TBS) for EDT.

2. eNodeB receives the EDT preamble and responds with the random access response, including the granting of Msg3 with an appropriate TBS.

3. In Msg3, the UE transmits the data in the NAS-PDU that is encapsulated in RRC message RRCEarlyDataRequest on CCCH.

4. In Msg4, eNodeB optionally encapsulates the DL data in the NAS-PDU of the RRC message RRCEarlyDataComplete on CCCH and confirms successful completion of the CP-EDT procedure. In this case, the UE moves to RRC idle state and continues its idle state procedures. Otherwise, if eNodeB decides to transfer more data, the RRCConnectionSetup message needs to be sent to the UE to fall back to the Rel. 13 cIoT CP data transfer.

5. The UE enters RRC connected state and informs eNodeB about its RRC state. More UL and DL data is transferred in the subsequent message exchanges.

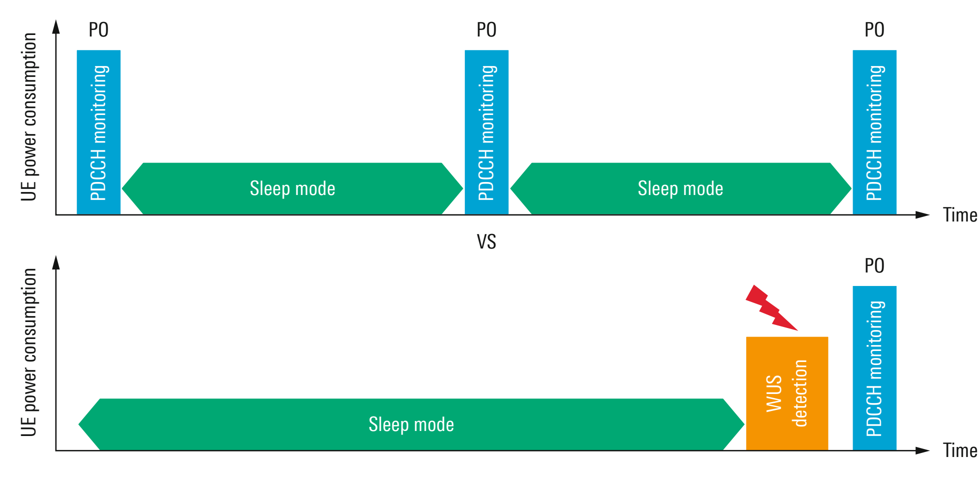
6. eNodeB commands the release of the RRC connection by sending the RRCConnectionRelease message to the UE.

5.3 Wake-up signal (WUS)

A wake-up signal (WUS) was introduced in 3GPP Rel. 15 and at first glimpse, it looks like a repetition of the paging indicator channel introduced in 3GPP Rel. 99 (UMTS). With the paging indicator channel, the network sends physical layer information that indicates whether the UE should read the higher layer control information on the respective control channels. The advantage is that recognition of the paging indicator channel is based on a matched filter or correlation metric, a sort of low power receiver, and does not require more energy consuming demodulation and decoding operations with the main baseband receiver.

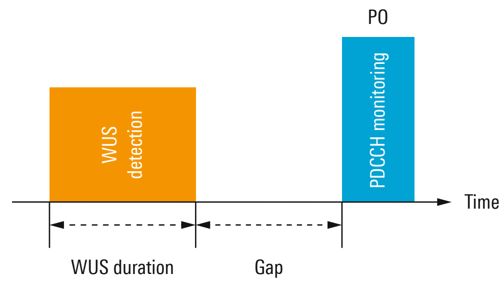
Similar to the UMTS paging indicator channel, 3GPP now specifies a physical signal in conjunction with I-(e)DRX or C-(e)DRX operation that can be decoded or detected before the UE decodes paging on PDCCH and PDSCH. The benefit of introducing WUS is that it reduces the unnecessary power consumption related to PDCCH monitoring. Without WUS, the UE would have to monitor the PDCCH for paging at each PO. With the WUS approach, the UE only needs to decode the PDCCH when WUS is detected, otherwise, the UE will stay in sleep mode. This represents an efficiency improvement, especially when considering low activity on the control channels within a cell, e.g. at nighttime. Fig. 5-3 compares the WUS principle with the conventional I-DRX operation, where the upper section shows I-DRX and the lower section shows DRX with WUS. This technical improvement enhances the UE battery lifetime.

Fig. 5-3: DRX versus DRX with WUS detection



The timing of the WUS with respect to the associated PO is shown in Fig. 5-4. WUS duration is the maximum time duration configured by the network for the UE to detect the WUS. After WUS is detected, the network leaves a time gap to allow the UE to resynchronize to the network and eventually switch from the low-power wake-up receiver to the main baseband circuitry in order to be ready to decode the PDCCH.

Fig. 5-4: Timing of WUS



WUS is an optional feature for the UE. From the eNB perspective, WUS operation can be enabled or disabled by the cell. If the feature is disabled, the UE will not detect WUS and normal PDCCH monitoring for paging messages is necessary.

To ensure that the UE does not miss any paging messages, the robustness of the WUS plays a very important role. The missed detection rate of the signal should be kept as low as possible, say below 1 %. To achieve a highly reliable signal, WUS adopts a Zadoff-Chu sequence of length 131. This provides very good cross correlation and auto correlation properties.

6 Summary

The power consumption of an LTE-M/NB-IoT device has to be kept as low as possible in order to achieve the minimum 10-year battery lifetime. To meet that design goal, several power saving mechanisms are described in this white paper.

In the legacy world, idle DRX and connected DRX are the common power saving mechanisms used by LTE devices. LTE-M/NB-IoT devices can also use this common approach. With this approach, PDCCH is monitored discontinuously by the UE, allowing the UE to enter sleep mode the rest of the time.

eDRX, an extension based on the legacy DRX concept, allows a longer cycle timer. This enables the UE to be in sleep mode longer than the legacy DRX principle. Due to the nature of the longer sleep time, this approach has the side effect of message latency and slow responsiveness in information exchange. Therefore, eDRX is commonly used by LTE-M/NB-IoT technologies that are not as time critical as LTE service.

Power saving mode (PSM) provides a further power saving possibility where the UE enters a sort of deep sleep mode, meaning the UE receiver circuitry is switched off during that certain period of time. This helps extend the device battery lifetime, but causes more latency in service responsiveness. Therefore, it definitively makes more sense to use PSM for non-time-critical services.

Other power saving mechanisms such as RAI, EDT and WUS were specified by 3GPP in Rel. 14 and 15. RAI allows the UE to return RRC idle state before the RRC inactivity timer expires as long as no further UL and/or DL transmission is expected. With EDT, the UE can transmit the data early in the random access procedure phase. This has the advantage that it shortens the message latency and decreases the signaling overhead for each data transmission in the IoT application. In addition, the UE can waive unnecessary PDCCH monitoring by detecting WUS only, which further extends the battery lifetime.

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