How network adaptations for 5G devices will lead to superior battery life

The essential guide to device energy saving in 5G NR

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White paper

Contents

Executive summary

5G mobile operators aim to deliver a superior user experience to their smartphone subscribers. This experience is not only about features like bandwidth, coverage and reliability, but also how long they can use their devices over the course of the day. Longer battery life can be achieved by reducing the energy consumption of the 5G mobile device, which is equally critical to sustainability goals. 3GPP has introduced a comprehensive toolbox of device energy saving features in the 5G New Radio (NR) Releases 15–17 that can increase battery life, thus providing a superior user experience. The toolbox is the focus of this paper, with an emphasis on the recent enhancements defined in NR Release 17.

The toolbox, in essence, can save device energy by providing the network with greater flexibility to implement fast adaptation according to device traffic and QoS needs. Whereas Release 16 enhancements focused entirely on increasing energy-efficient operations in the RRC Connected state, Release 17 improves the RRC Inactive and Idle states, thus ensuring more energy-efficient operations for network synchronization, paging and small data handling. In this paper, we also provide recommendations on how to select the optimal energy saving features in the toolbox to balance device energy with latency and other relevant KPIs. We conclude that for optimal energy efficiency, it is best to take an all-embracing perspective that accounts for the multitude of devices and traffic profiles that exist in a network.

Moreover, in our outlook to 5G-Advanced (3GPP Release 18 and beyond), we anticipate that additional device energy saving features may be expected to be developed by 3GPP with the aim of reducing the energy use of new applications, services and device types such as extended reality (XR) and gaming devices of reduced capability (RedCap), as well as to foster novel network energy saving techniques according to traffic and channel conditions.

Introduction

The efficient utilization of energy by 5G mobile devices and networks plays a pivotal role in 5G development because it increases customer satisfaction and reduces operation costs. It also helps to meet environmental goals, to which consumers are paying increasingly more attention as they focus on climate protection and sustainability.

The majority of 5G devices in the market right now are smartphones, equipped with more advanced technological features than in any previous radio technology, including, for example, support for much wider bandwidth (100 MHz rather than 20 MHz in 4G LTE) and a larger number of receiver antennas (four rather than two in 4G LTE). These features make the devices more power-hungry and increase the absolute energy consumption, which has generated concerns that 5G smartphone battery life may be shorter than 4G LTE. But the very same features allow the devices to obtain much higher energy efficiency (in terms of energy per bit) than in 4G LTE, thus shortening the active time of the device and reducing energy consumption per data session. Further energy savings will be achieved after the transition from non-standalone to standalone 5G, as devices need no longer maintain simultaneous 4G LTE and NR radio connections.

The development of the 5G New Radio (NR) standard, moreover, has been improving battery life of 5G smartphones ever since the first release of NR (Release 15). This development has been primarily targeted but not limited to smartphones and is generally applicable to any device type. As part of this development, the network has increased flexibility to implement adaptation in different domains (e.g., time, frequency and space) according to the actual requirements and traffic needs of the end user. The aim is to achieve an optimal balance between device energy savings and other KPIs such as end-user QoS and network energy efficiency. The mobile device benefits by intelligently adapting to the network configuration.

In this white paper, we provide an overview of the essential energy saving features for the devices supported by the 5G NR standard in its evolution from Release 15 to 17. We examine in detail the newest set of features introduced in Release 17, provide recommendations on how to best leverage the energy saving features, and give an outlook on further enhancements we expect in Release 18.

Device energy saving features in 3GPP toolbox

Features defined in 5G NR Releases 15 and 16

The energy savings in mobile devices can be achieved by **five different enablers** that aim primarily at receiver activity reduction:

1. **Control channel monitoring reduction** enables the device to monitor the control information that schedules user data more infrequently so that the device can sleep. Such reduction must be done carefully since it impacts the actual delay performance; the more infrequently the device monitors the control information, the larger the impact on data delay.
2. **Use of different RRC states** and faster transitioning between states enables the device to be in a low-power mode during long data inactivity periods whenever the QoS targets allow this.
3. **Faster user data transfer to and from the network**, for instance, by using larger bandwidth and more MIMO layers so that the device can sleep longer.
4. **Reduced measurement activity** enables the device to omit certain energy-consuming measurements in some scenarios without causing mobility issues and QoS degradation.
5. **Energy-efficient paging** enables the device to efficiently monitor for potential paging from the network, which occurs frequently during daily device use. This entails longer sleep while the device is in low-power mode.

Release 15 features

The first version of the 5G NR standard (Release 15) inherited many valuable energy efficiency principles from 4G LTE for the above-mentioned energy saving enablers. The best example is discontinuous reception (DRX). The device must monitor the physical downlink control channel (PDCCH) that carries its downlink and uplink scheduling grants according to the network configuration. Such monitoring is associated with unnecessary energy consumption whenever no scheduling grants are targeted to the device, which occurs often. The DRX mechanism enables the device to monitor the PDCCH only periodically (during the on-duration period of each DRX cycle) rather than continuously. If the device can sleep in between the defined monitoring periods, it saves energy.

Another example is the introduction of a third RRC state, RRC Inactive, in addition to RRC Connected and Idle. This is similar to 4G LTE IoT technologies, which suspend and resume the RRC connection in a faster and more energy-efficient way. 5G devices can also save energy by reducing their radio resource management (RRM) measurement activity as in 4G LTE. The RRM measurements assist the network to perform intelligent mobility decisions, but the need for them depends on whether mobility events are necessary. The devices are allowed to omit certain RRM measurements of neighboring cells if the serving cells' reference signal receive power (RSRP) is above a network-defined threshold. In this case, the relaxation is deemed safe because there is a low likelihood for the device to experience a mobility event such as a cell reselection or handover.

There are also new principles in NR Release 15. To effectively manage the wide bandwidths supported by 5G NR, the bandwidth part (BWP) approach was specified. It allows the network to configure the device to communicate in a BWP that is smaller than the full channel bandwidth when the demand for data activity is lower, thus saving energy. This addresses both efficient data transfer and control channel monitoring reduction, because a smaller BWP is associated with a smaller dedicated search space and reduced control channel monitoring. The first 5G NR release also facilitates cross-slot scheduling, where the scheduling information points to radio resource assignments of data transmission located in a future slot instead of the same scheduling slot. This enables the device to skip data reception in any slot with no prior assignment and sleep in the remainder of the slot after receiving the control channel.

Release 16 features

In addition to the above features, 3GPP has defined further device energy saving mechanisms in Release 16 that allow additional adaptations to user traffic and channel conditions. The key feature of Release 16 for RRC Connected devices operating with DRX is the wake-up signal (WUS), which can be used to further reduce PDCCH monitoring. With DRX, the device wakes up to monitor for data during the defined on-duration period for each DRX cycle, whether or not there is pending data for the device. The WUS is designed to avoid unnecessary energy consumption in case of no data. In short, the WUS is sent from the network prior to the start of the DRX active time (on-duration period) of the device to inform the device whether the network intends to schedule data to the device within this active time. If there is no data to be scheduled, then the device can skip the PDCCH monitoring in that active time and remain in a low-energy sleep mode.

Release 16 also includes energy saving optimizations for data transmission for carrier aggregation (CA) and dual connectivity (DC) scenarios. Among others, it introduces a secondary DRX for CA that is applied to a secondary cell (SCell), in addition to the primary DRX that is applied to the primary cell (PCell). This enables coordination of the active times on both cells. It further defines faster frequency adaptation of an SCell (larger bandwidth) when the data amount requires it. This makes use of the concept of the SCell's BWP dormancy state, in which the device can skip the PDCCH monitoring but must perform measurements to assist the network for fast activation of a dormant BWP to enable energy-efficient data transfer. Moreover, the maximum number of MIMO layers is made configurable per downlink BWP, allowing the device to reduce, at the same time, the active number of antennas and bandwidth to jointly save energy in both domains. Finally, the cross-slot scheduling feature was improved allowing the network to configure a minimum offset between the scheduling resource and the data resource, so that the device can be made aware upfront whether it can skip data reception in a slot.

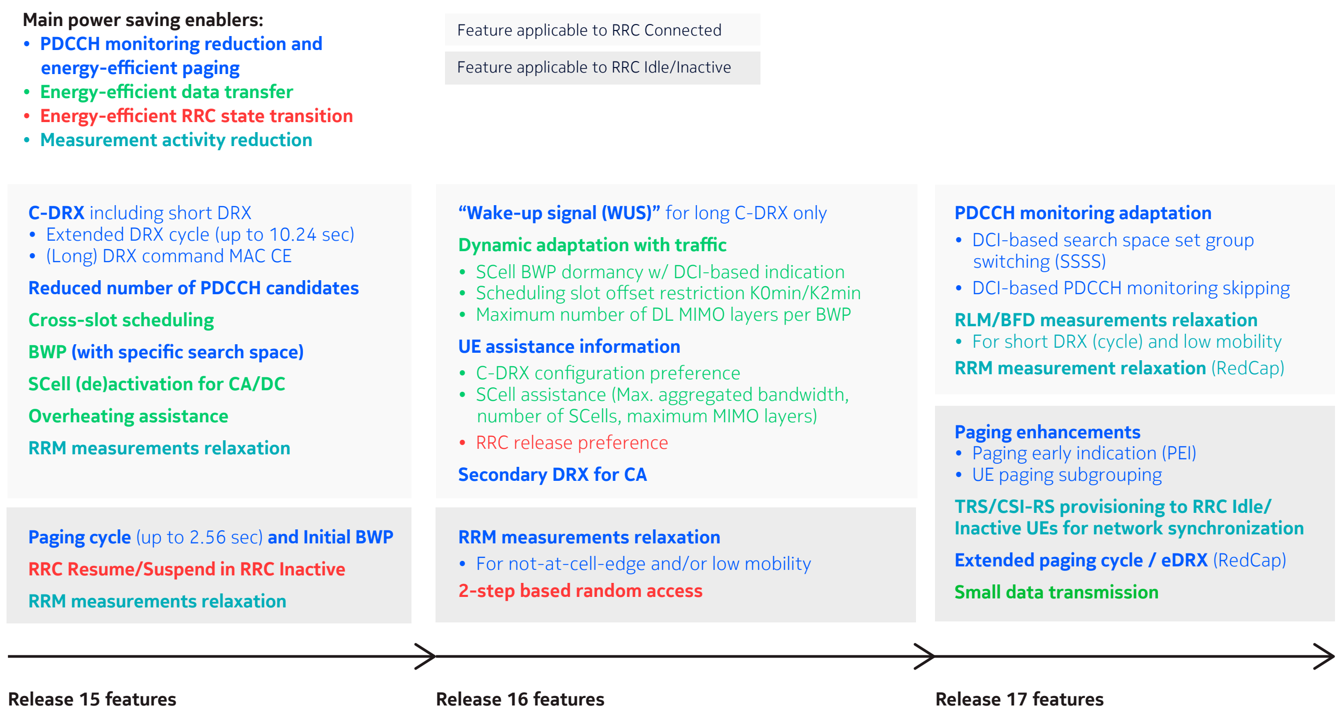
Release 16 enhances the relaxation of the RRM measurements of neighboring cells. These measurements are required by devices in RRC Idle and Inactive states for cell reselection. Whenever the device evaluates itself in a low mobility state and/or not-at-cell edge, based on the network-defined conditions, it is allowed to further relax these RRM measurements compared to Release 15.

Based on the large number of parameters that impact the energy consumption of the device, Release 16 also introduces device assistance information, which enables the device to inform the network about its preferred settings — note that it is up to network to decide whether to accommodate the preferred configurations indicated by the device. The device can indicate its preference for connected DRX configuration, maximum aggregated bandwidth, number of component carriers, minimum cross-slot scheduling offset, and the number of MIMO layers. Finally, the device can also indicate its preferred RRC state along with its wish to be released from the RRC Connected state.

When a device attempts to establish or resume an RRC connection, it will perform the random access procedure. In Release 16, the conventional four-step procedure, which was also applied in 4G LTE, was complemented with a two-step version. In the latter, the usual two uplink transmissions (preamble and scheduled message 3) are merged into one transmission to reduce the time and energy required by the procedure. Likewise, the usual two downlink messages are merged into one message.

To summarize, Figure 1 provides the overview of the entire device energy saving toolbox covering the features of Release 15 and 16 outlined above and lists the new enhancements introduced in Release 17, which will be discussed in the next section. The features are grouped per 3GPP release, highlighting which of the five energy saving enablers introduced above is underneath each feature and the RRC state to which each feature is applicable.

Figure 1. The device energy saving toolbox of 3GPP 5G NR and the standard development across Releases 15–17

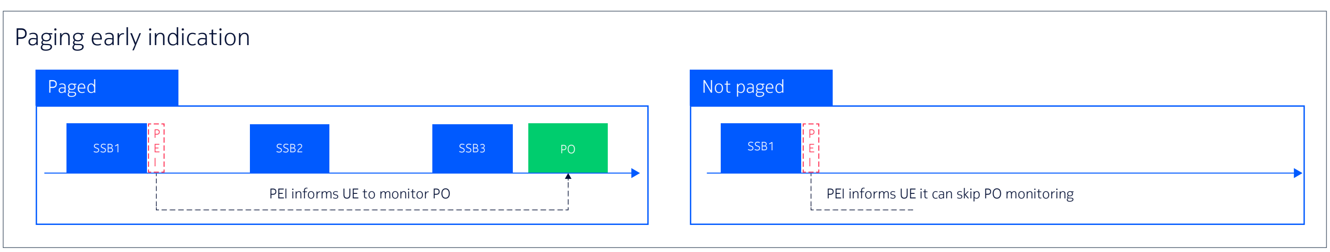


Five energy saving enhancements in Release 17

Paging early indication and paging subgrouping

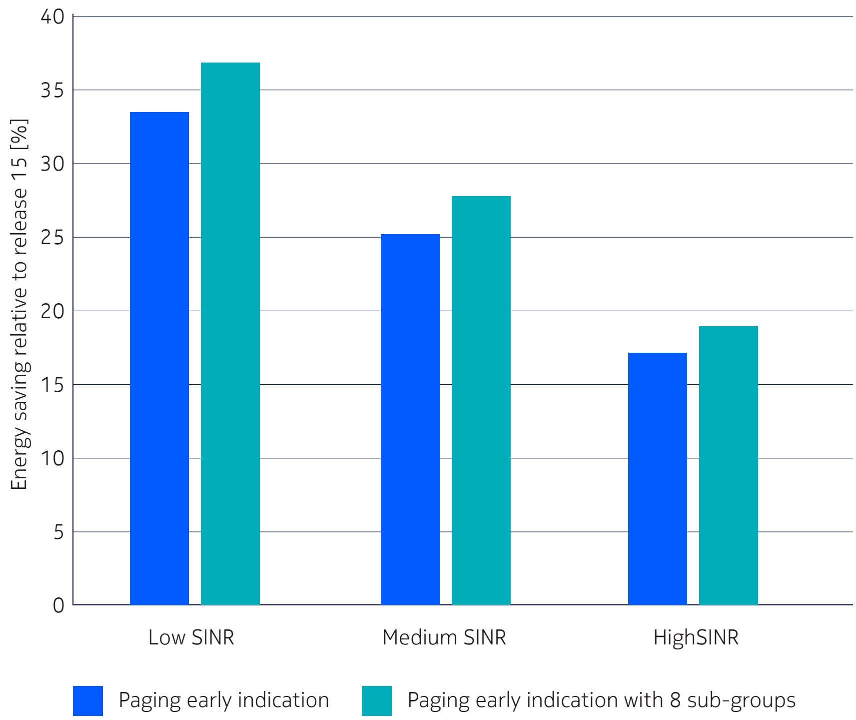
While Release 16 mainly focuses on RRC Connected mobile devices, Release 17 also considers optimizations for the RRC Idle and Inactive states, and, specifically, enablers for energy-efficient paging. The work standardizes paging early indication (PEI) — a wake-up signal for paging. The basic principle is illustrated in Figure 2. In each paging cycle, the mobile device will monitor for the PEI transmission from the network. The PEI indicates whether the device should monitor the paging occasion in the given paging cycle. This feature helps the mobile device save energy when the PEI indicates no paging, because the device can stop the SSB-based downlink synchronization procedure and, in turn, can omit further SSB and paging reception. Such synchronization is otherwise needed to ensure reliable paging message decoding performance. The PEI is provided in a downlink control information (DCI) format of the PDCCH dedicated for this purpose. The network may reduce the PDCCH utilization by associating a single PEI to up to four paging occasions. The PEI, furthermore, can include a paging subgrouping indication so that mobile devices can be split into subgroups, e.g., based on their paging activity. This reduces the false paging rate, as the devices, waking up to monitor for PEI with subgrouping indication, can determine that their subgroup is not paged and return to sleep, i.e., they need not decode the paging message. The PEI can indicate up to eight paging subgroups per paging occasion.

Figure 2. The paging early indication (PEI) principle using an example of a low SINR mobile device, where PEI is located right after the first SSB



As noted, the energy saving potential of PEI depends on the downlink synchronization procedure. In Figure 3, the gain compared to the Release 15 paging procedure is illustrated for mobile devices in low, medium and high SINR conditions, where it is assumed that the device would receive three, two and one SSB burst prior to the paging occasion, respectively. The savings are in the order of 17–34%, while the subgrouping indication results in 10% additional savings. The high SINR device may save the least amount of energy because it only skips the paging occasion monitoring, i.e., it has no additional SSB reception to skip because the first SSB burst is always received for RRM measurement purposes. Note that the energy saving gain also depends on the paging cycle length; a smaller length results in more frequent paging procedures, thus a larger saving potential. Note that means for avoiding paging collision have also been defined in Release 17 for multi-SIM devices. Although designed for a different purpose, they may be leveraged for aligning the paging timing across multiple SIMs in a device, thus allowing the device to sleep longer and save energy.

Figure 3. Device energy saving gain of PEI with paging subgrouping compared to the Release 15 paging procedure

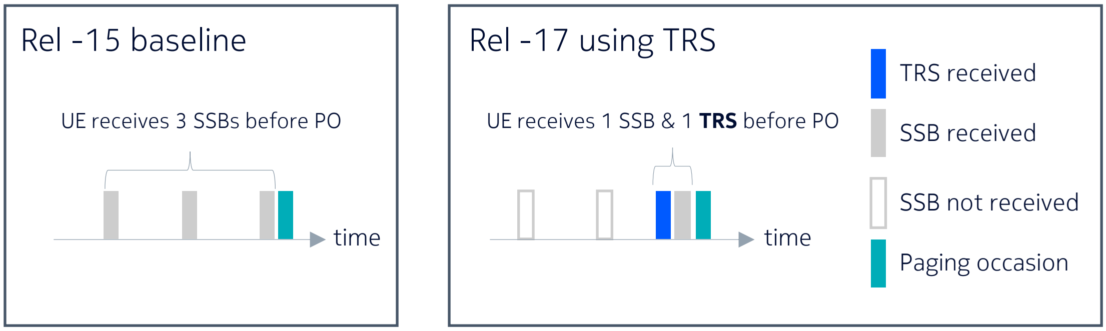


Reference signals provisioning in RRC Idle and Inactive

As discussed in the previous section, the RRC Idle and Inactive mobile device monitoring for paging will receive several SSB bursts to obtain synchronization with the network. Typically, the SSB periodicity is 20 ms, thus a device in need of more than one SSB burst prior to the paging occasion will wake up before it needs to, wasting energy. Because the minimum SSB periodicity is 5 ms, the network could assist the device by configuring more frequent SSB transmissions, but this would impact network energy consumption and signaling overhead. Hence, a different solution was developed in Release 17 to facilitate faster synchronization of RRC Idle and Inactive mobile devices to enable longer sleep durations. Because the network can provide different reference signals to the RRC Connected mobile devices, these signals can in principle also be received by the RRC Idle and Inactive devices if they are made aware of the configuration.

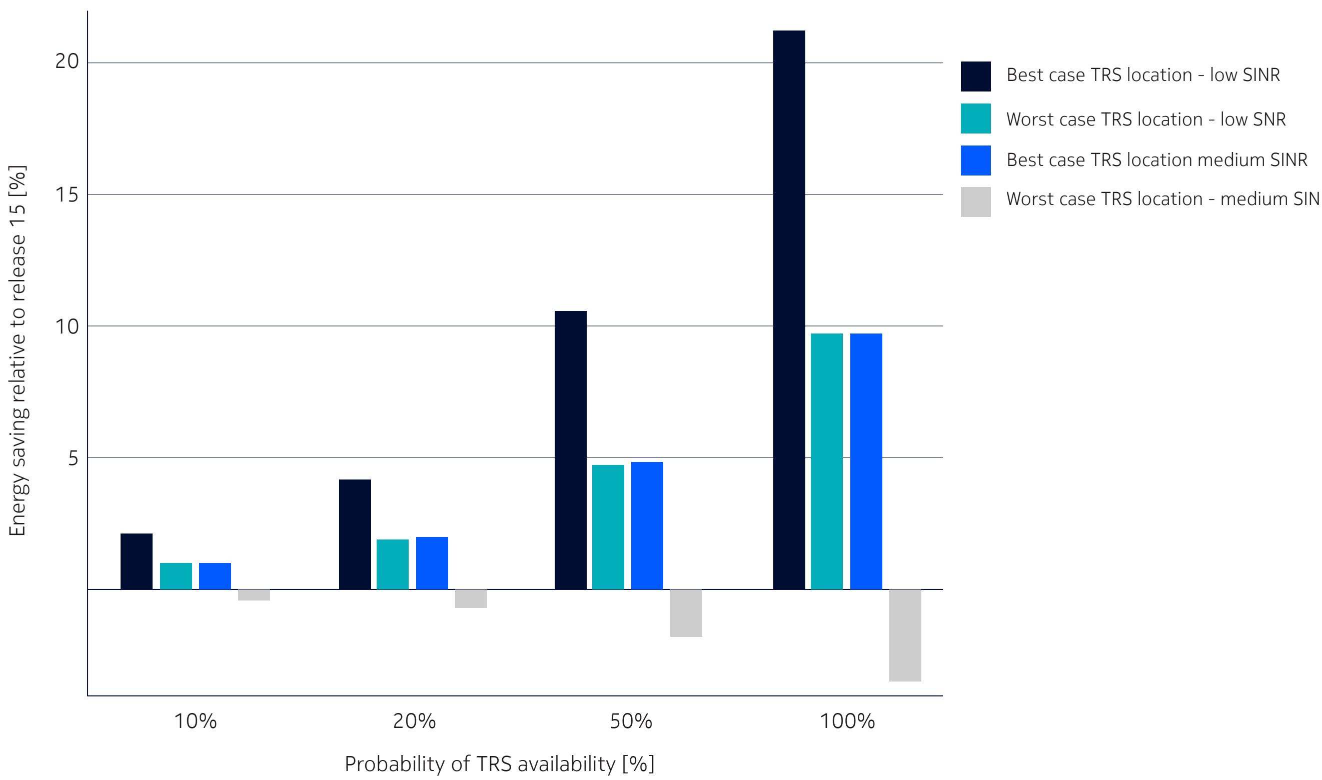
The new standard enables the network to provide the configuration of one or more tracking reference signals (TRSs) to the RRC Idle and Inactive mobile devices. It can also indicate the actual availability of the TRS in the paging DCI or PEI. This allows the network, for example, to stop transmitting the TRSs when there are no RRC Connected mobile devices in need of it. The TRSs are likely to be transmitted much more frequently than the SSBs and thus the RRC Idle and Inactive devices can utilize the TRSs to shorten the synchronization time and extend sleep duration. The principle of TRS reception is illustrated in Figure 4, where the left subfigure shows the Release 15 baseline, while the right subfigure is an example scenario, where the mobile device skips reception of some SSBs and instead receives one SSB burst and one TRS before the paging occasion.

Figure 4. SSB monitoring and tracking reference signals provisioning in RRC Idle and Inactive device paging



The potential energy saving gain of utilizing TRSs, in addition to SSBs, for RRC Idle and Inactive mobile devices is illustrated in Figure 5. The gain is compared to the Release 15 baseline in Figure 4 for low and medium SINR devices. Note that a high SINR device would only need to receive one SSB burst, thus there is no saving potential in receiving the TRS instead. The energy saving potential is evaluated for best- and worst-case locations of the TRS, i.e., the TRS being located right before the paging occasion and about one SSB period away, respectively.

Figure 5. Energy saving gains for mobile devices using TRS provisioning in RRC Idle and Inactive devices for different TRS locations and availability probabilities. The gain shown is relative to the Release 15 baseline paging procedure.



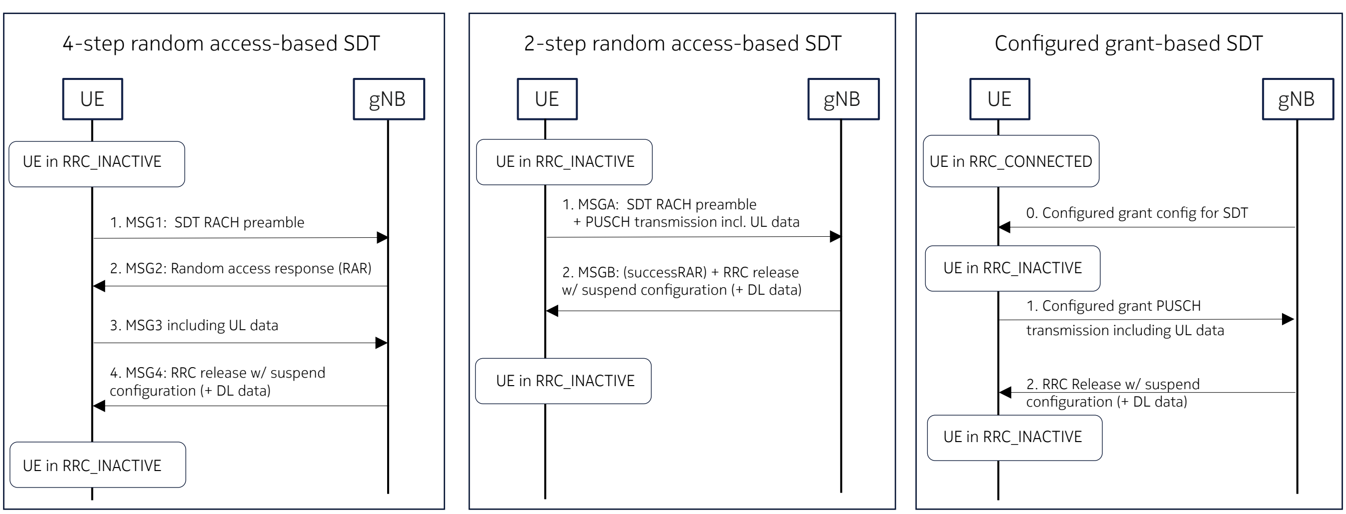
Since the network is not mandated to always send the TRSs, we also include the probability of TRS availability. If the TRS is not available, the device will apply the Release 15 baseline procedure. The results show that when TRSs are always available, the energy saving gain is 10–20%, except for the medium SINR device, which will suffer a small energy consumption penalty if the TRS is placed far from the paging occasion. For lower TRS availability the potential energy saving gain reduces, but the low SINR device will always be able to achieve some savings due to skipping reception of two SSB bursts, as shown in Figure 4.

Small data transmission in RRC Inactive

Typically, a 5G smartphone today performs from 300 to 700 RRC setups per day depending on the running applications. During the peak traffic hour, the smartphone may perform close to an RRC setup per minute. A large part of this traffic is small data generated by smartphone applications such as instant messaging and heartbeats. Non-smartphone IoT applications such as wearables, sensors and smart meters also generate small and infrequent data. But currently, small data can be served only in the RRC Connected state resulting in a high overhead relative to the small payload because of the RRC connection establishment or resume. Release 17 handles low throughput and short data more efficiently by supporting small data transmissions from the RRC Inactive state.

The three small data transmission types defined in Release 17 are shown in Figure 6. The small data transmission can leverage the random access procedure, using four-step or two-step random access. In addition, it can leverage the configured grant framework of NR, enabling the uplink small data to be sent on uplink resources that are preconfigured to the device and can be used only in the last serving cell, without random access. Any of these three small data procedures removes the need for the device to first switch to the RRC Connected state before transferring small data, which reduces the radio signalling overhead and, in turn, the device energy consumption and packet latency.

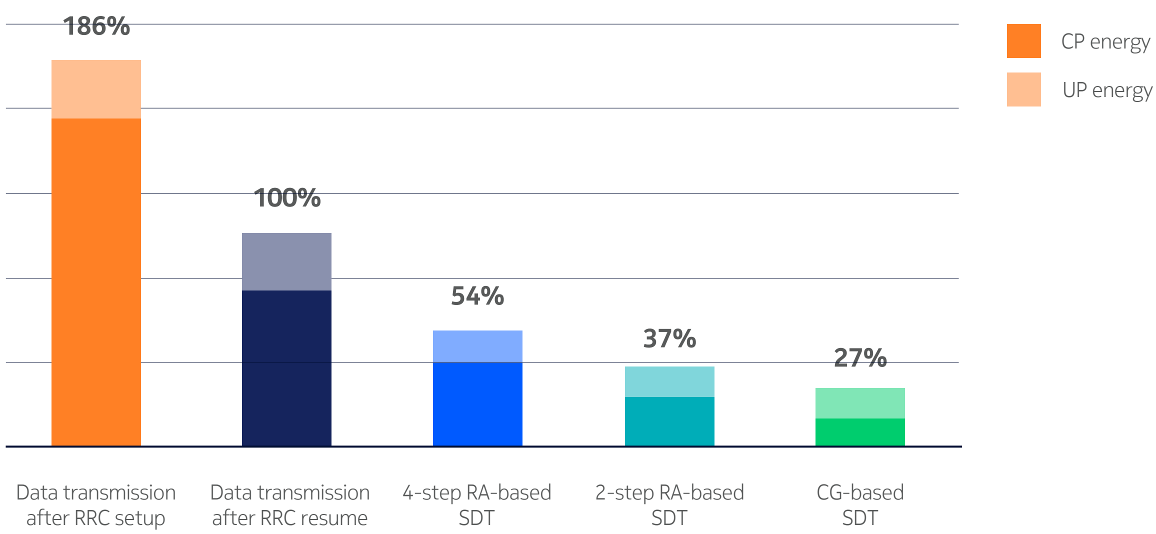
Figure 6. The three small data transmission (SDT) procedure types defined in Release 17.



The energy consumption of a small data transmission procedure has been compared to a single small uplink data payload transfer after either the RRC resume procedure (baseline) or the RRC setup procedure as per Release 15. From Figure 7, we observe that the energy saving gains obtained with small data transmissions, relative to the baseline, range between 46% and 73%, depending on which of the three small data transmission types is considered.

Note that the small data procedure allows more than just one uplink and/or downlink data packet as shown in Figure 6. It also allows the transfer of multiple small uplink or downlink data within a single small data procedure — the network enables these subsequent data transmissions according to its own strategies. Likewise, control channel messages (e.g., for the positioning use case) can also be transferred using the small data transmission.

Figure 7. Device energy consumption of the three SDT procedures as well as of uplink data transfer after both Release 15 RRC resume (baseline) and Release 15 RRC setup. The energy consumption is split between control plane (CP) and user plane (UP) contributions.

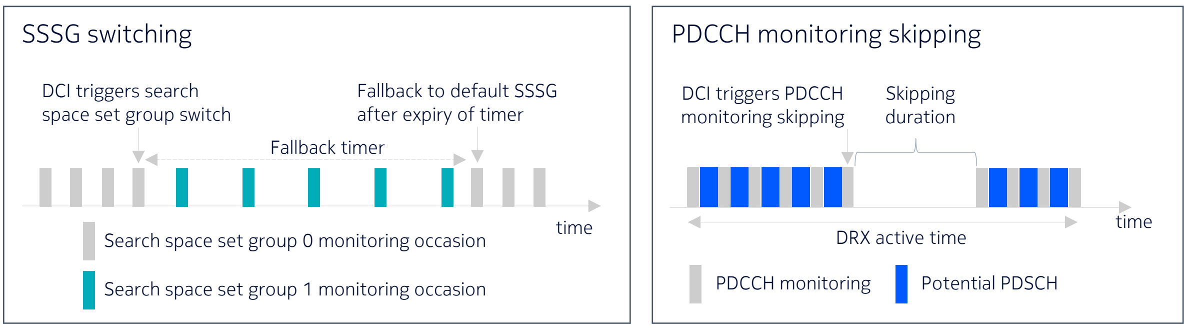


Active-time PDCCH monitoring adaptation

While the three features above addressed RRC Idle and Inactive mode enhancements, Release 17 improves device energy efficiency in the RRC Connected state as well. The Release 15 DRX feature enables mobile devices to only monitor PDCCH periodically during the active time of the DRX cycle, otherwise they sleep. Further energy savings can be attained by adapting the PDCCH monitoring behavior during the active time with a trade-off of latency. This is partially feasible in Release 15 by use of the short DRX feature and the DRX command (MAC command element signaling), which can end the active time prematurely if no further data is present or expected. Likewise, a similar monitoring adaptation can be achieved by switching to a smaller BWP configured with an infrequent PDCCH monitoring period, as per Release 15.

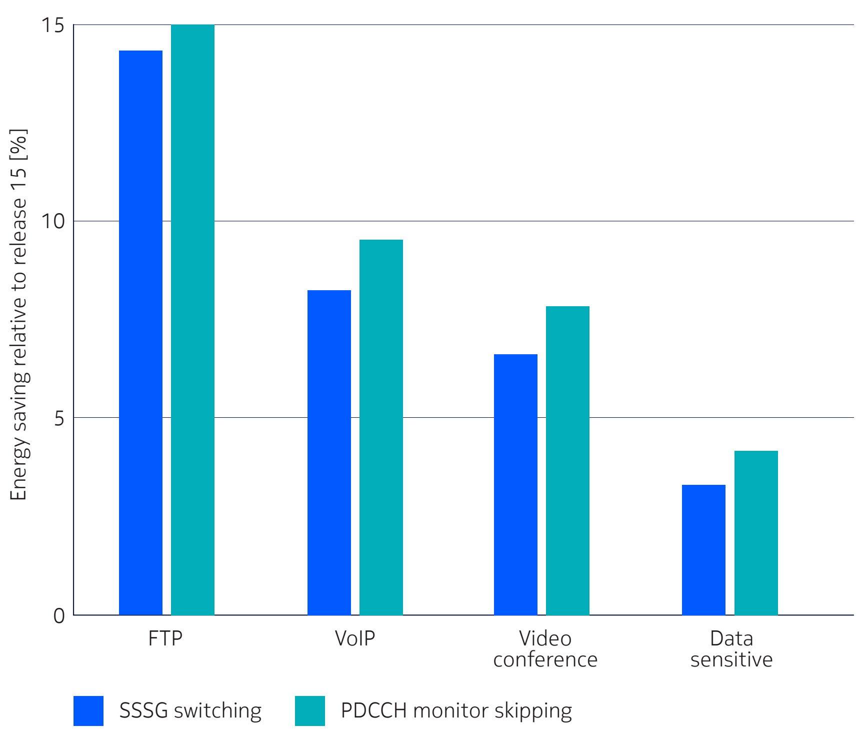
In Release 17 a more dynamic adaptation is defined, where up to three search space set groups can be configured on the device. Each has a specific PDCCH monitoring periodicity. The adaptation is achieved by switching between these groups based on traffic activity. This is illustrated in the left-hand part of Figure 8 for two search space set groups (SSSGs). The network may order the device to switch groups by indicating the target group in a PDCCH DCI, while the mobile device can also be configured to fallback to a default group according to a timer. Likewise, the network may signal in the DCI of a PDCCH that the device can skip PDCCH monitoring for a short, pre-configured period if there is no incoming data. This feature is denoted PDCCH monitoring skipping and is illustrated in the right-hand part of Figure 8.

Figure 8. Search space set group (SSSG) switching and PDCCH monitoring skipping features for active time adaptation.



In Figure 9, the performance of both Release 17 features (search space set groups switching and PDCCH monitoring skipping) is compared with the Release 15 baseline, which relies on DRX. The evaluation is made for multiple traffic types and under different data activity patterns. As the data activity increases and the DRX cycle is made correspondingly shorter, the potential energy savings of the new features reduce from around 15% to less than 5%.

Figure 9. Mobile device energy saving gain of PDCCH monitoring skipping and SSSG switching relative to the Release 15 baseline using DRX.



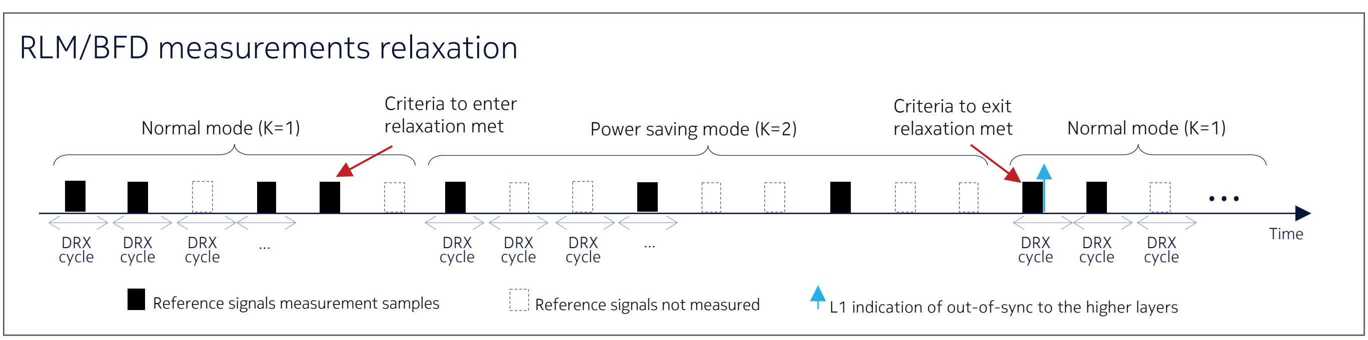
RLM and BFD measurements relaxation

Inherited from 4G LTE and included in 5G NR, the device is allowed to relax radio measurements such as reference signal received power (RSRP) to save device energy by leveraging the DRX operations. Specifically, the measurement of the serving cell(s) and neighbor cell(s) need not be performed continuously; the device need only take measurement samples about once per DRX cycle. This is shown during normal mode in Figure 10, where certain measurements are skipped. Until Release 17, further relaxation has only targeted the RRM measurements of neighbor cells (in any RRC state) based on the serving cell RSRP level and its variation.

In Release 17 measurements relaxation additionally targets the serving cell and specifically the radio link monitoring (RLM) and beam failure detection (BFD) measurements, which the RRC Connected device performs to ensure a good serving radio link and serving beam quality. The aim is to decrease the associated energy consumption for devices in low mobility and at cell center, which are configured with a short value of the DRX cycle length, thus they cannot benefit from the DRX-based relaxation.

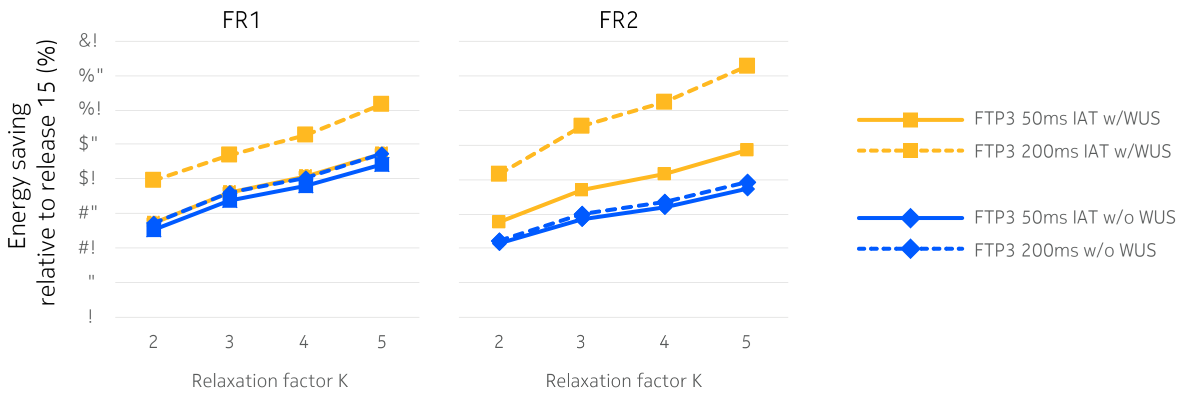
Figure 10 shows how the relaxation can be realized through a relaxation factor K applied to the measurement evaluation period, which allows the device to omit measurement samples when K > 1 (e.g., during power saving mode). Note that to enable energy saving, all measurement types derived from the same reference signal measurement samples must be omitted when RLM or BFD measurements are omitted. This also includes the need to relax RRM measurements. Also note that the device is assumed capable of autonomously applying RRM measurements relaxation under the low mobility and cell center conditions — this is device dependent and not in scope for Release 17. To ensure a minimum risk for delayed detection of cell and beam failures and to avoid QoS degradation, the network determines the conditions under which the device is allowed to enable such relaxation. For example, the device should immediately revert from power saving mode to normal mode whenever it observes an out-of-sync status, as shown in Figure 10.

Figure 10. Illustration of RLM/BFD measurements relaxation through a relaxation factor K (example for FR1 scenarios).



The attainable energy saving gains are significant (see Figure 11). They range from 10–35% compared to Release 15 requirements for serving cell measurements. The gains depend on various scenarios in terms of relaxation factor, frequency range, traffic type and wake-up signal usage. In general, the gains are lower if the wake-up signal is not used, since the device must wake up anyway to monitor for the DRX On duration, even when measurements can be skipped. Although it is not shown in Figure 11, note that gains highly depend on the location of the reference signals in the time domain compared to the defined DRX On duration.

Figure 11. Device energy saving gain of RLM and BFD measurements relaxation vs. relaxation factor K — results are relative to the Release 15 baseline, where serving cell measurements are relaxed according to Release 15 requirements.



It is also noteworthy that the gain attainable from such relaxation is similar in FR1 and FR2. More measurements might be expected in FR2 compared to FR1 because of the larger grid of beams deployed at FR2. Moreover, the FR2 capable device may employ multiple antenna panels to compensate for the higher path attenuation incurred at the FR2 bands, which may further increase the number of measurements to be performed. However, this affects both the baseline and relaxation scenario in FR2. Thus, when employing relaxation, similar gains are observed in FR1 and FR2 since a similar number of measurements can be omitted in FR1 and FR2 relative to their corresponding baselines.

Leveraging the 3GPP toolbox

Balance energy saving with latency and other relevant KPIs

The energy saving features of Release 15–17 rely on the five key enablers introduced earlier. The applicability of each feature, however, is greatly influenced by multi-dimensional considerations that depend on the current traffic profile, QoS targets and mobility scenario of the mobile device. In this section, the features, and their applicability individually and in combination, are reviewed. We provide recommendations on how to balance mobile device energy savings with data latency, QoS and other network KPIs such as network signaling overhead and network energy consumption.

Control channel monitoring reduction and energy-efficient data transfer

As previously noted, the monitoring of the PDCCH results in large and wasteful energy consumption for the device, as typically the device is not frequently scheduled. With that in mind, the highly recommended and key energy saving enabler is a proper configuration of DRX, because it can tailor periodic PDCCH monitoring behavior to the current traffic characteristics of the mobile device. Release 16 capable devices may even assist by providing information concerning their preferred DRX configuration.

The optimal DRX configuration will realize most of the energy savings of the control channel monitoring reduction enabler. Additional features may be enabled, depending on the mobile device's latency requirements, although these might only bring incremental gains. For example, the Release 16 wake-up signal can be configured in scenarios where the traffic is arriving infrequently. Or, another example, the dynamic monitoring adaptation (SSSG switching or PDCCH monitoring skipping) can be applied for traffic profiles that are less delay tolerant, such as when running a short DRX cycle or under unpredictable traffic arrival, which would mandate a longer DRX inactivity timer.

Another example is the use of BWPs and SCell's BWP dormancy, which can be efficient for bursty and high-volume traffic to quickly adapt the bandwidth available for the device to the actual traffic amount. The BWPs also allow configuration of the maximum number of MIMO layers. This would be beneficial in low data rate scenarios, where the device could more efficiently operate on a small BWP combined with a reduced number of MIMO layers. A final example is the cross-slot scheduling feature, which is also an effective means to save energy in the active time, but it requires that the mobile device's traffic profile can accommodate the increased latency caused by the delayed transmission of data.

Energy-efficient RRC state

Once the mobile device has completed the data transfer, the use of the energy efficient RRC Idle and Inactive states is recommended to allow the device to benefit from longer deep sleep. This also applies to scenarios where the amount of data is limited and infrequent and can be accommodated in the small data transmission procedure of RRC Inactive. To ensure energy-efficient data transmission, such small data transmission features can always be beneficial, if the mobile device's traffic profile is suitable. The RRC Inactive state also enables fast RRC connection suspend and resume, so that the latency impact on the mobile device is minimized, while the energy saving benefit of the low-activity inactive state is obtained.

The RRC Idle mode state is especially applicable for fast moving devices because the device can autonomously reselect to the most suitable cell, which may entail less signaling overhead towards the network as compared to RRC Inactive, depending on network configuration.

Energy-efficient paging

The RRC Idle and Inactive states rely on mobile device monitoring for paging, which is an energy-efficient mechanism to monitor for incoming traffic, but it has larger delay compared to active time monitoring. The paging procedure can be complemented with the PEI in Release 17, but the network impact in terms of PDCCH load and energy consumption must be considered. In addition, if the paging load is high, the use of paging subgrouping can bring additional energy savings for the mobile device. The use of TRSs for idle and inactive UEs must be conditional on the reuse of these reference signals from RRC Connected UEs so that signaling overhead is minimized. If TRSs are available, e.g., during the day, when many devices are connected to the network, the network can consider not utilizing the PEI. In contrast, at night, the network can disable TRSs for connected devices, thus for idle and inactive devices as well, choosing to configure the PEI instead.

Measurement activity reduction

The final key energy saving enabler is the relaxation of mobile device measurements. Most of the potential savings are obtained if the mobile device can skip the neighbor cell measurements, for example, when the device is in a low mobility state or at the cell center. To avoid poor mobility performance and degradation of QoS, the network must carefully configure the corresponding neighbor cell measurements relaxation thresholds. The connected mobile device may also be able to save some additional energy by relaxing RLM and BFD measurements, although, in this scenario, careful network control is required.

Final remarks

Table 1 recommends the key device energy saving features that can be leveraged for typical device profiles. It is important to note that the discussed features must be considered in an all-embracing perspective to account for the multitude of devices and traffic profiles that exist in a network. Machine learning (ML) could be beneficial in handling such diversity when selecting and configuring the energy saving features.

The presented energy saving gains were compared to the baseline for each feature, although these gains cannot always be obtained in practice. When multiple features addressing the same gain enabler are activated, they may "eat from the same cake", thus the observed gains will not necessarily be additive. However, it will always be worthwhile to configure at least one feature per energy saving enabler. Furthermore, the contribution of each feature to reduce the total device energy consumption will vary based on the device profile. For example, the energy consumption in RRC Idle only constitutes a fraction of a mobile device's total daily energy budget, and hence the enhancements targeting the RRC Idle state only save energy for that portion of the budget.

Table 1 Examples of device energy saving features recommended for typical smartphone device profiles. The DRX and paging cycle configurations are assumed to be optimized for the current scenario/device profile, especially to match the most stringent delay target.

Example scenario	Device profile	Key device energy saving features
Mostly application heartbeats during the night	Low data activity Latency tolerant Low mobility	The device will be kept mostly in RRC Inactive and leverage early paging indication with subgrouping and small data transmissions. The device can be also allowed to relax the RRM measurements. For larger data transfers, the device can be briefly in RRC Connected using a small BWP and long DRX.
Mostly application heartbeats while the end user is commuting	Low data activity Latency tolerant High mobility	The device will be kept mostly in RRC Idle and leverage TRS-based synchronization for paging or early paging indications with subgrouping. For data transfers, the device can be briefly in RRC Connected using a small BWP and long DRX.
Video streaming at home	High data activity Latency tolerant Low mobility	The device will be kept mostly in RRC Connected, which can be made energy efficient by using long DRX and BWP switch to match the actual data activity (e.g., BWPs with optimized PDCCH monitoring periods, bandwidth and number of MIMO layers). The device may further benefit from SCell dormancy and SSSG switching.
Gaming at home	High data activity Latency critical Low mobility	The device will be kept mostly in RRC Connected, which can be made energy efficient by using long and short DRX and BWP switch to match the actual data activity (e.g., BWPs with optimized PDCCH monitoring periods, bandwidth and number of MIMO layers). The device may further benefit from SCell dormancy. The device may be also allowed to relax the RLM/BFD measurements.

What's next?

Device energy saving enhancements expected in Release 18

The existing device energy saving toolbox is compelling and fully fledged, thus enabling energy-efficient device operations today. But it is targeted primarily at 5G smartphones. Release 18 will define additional device energy saving features that may be crucial for the adoption of new traffic applications (like XR) and device types (like RedCap), which cannot tolerate overheating and poor battery life.

For example, XR traffic is characterized by tight delay constraints and by quasi-deterministic and frequent packet arrival with relatively large jitter. Due to the frequent traffic arrivals, a short DRX cycle can be beneficial with a relatively long DRX On duration to accommodate the tight delays and jitter. But this may result in frequent but unnecessary PDCCH monitoring and large device energy consumption, because the device must remain awake for the entire on-duration period. Instead, the XR device may benefit from making the existing DRX operations and the PDCCH monitoring adaptations (per Release 17) more flexible and dynamic according to the XR characteristics. The means to introduce such flexibility will be defined in Release 18 if the potential energy savings justify it.

Basic RedCap functionality is already introduced in Release 17, entailing reduced operations including, for instance, lower bandwidth (20 MHz), fewer receive antennas (1–2) and fewer MIMO layers (1–2). For energy consumption reduction, the enhanced extended DRX (eDRX) is also defined for RedCap defining paging cycles larger than 10.24s, but it is limited to RRC Idle in Release 17. As a next step, the support of enhanced eDRX will be defined in Release 18 to include RRC Inactive. To expand RedCap use cases and applications further, the need to enable longer battery life has also been identified.

Therefore, Release 18 will study the design of a low power wake-up signal (WUS) to be employed by the RedCap devices primarily for the RRC Idle and Inactive states. In contrast to the Release 16 WUS that makes use of the PDCCH DCI, the low power WUS is not restricted to the existing signals of NR. Essentially, 3GPP wants to dramatically reduce the device energy consumption by enabling the reception of the low power WUS through a dedicated low-power wake-up receiver while the device's main receiver sleeps. However, its design should still ensure an adequate detection performance, coverage and device complexity as well as justifiable energy saving gains.

Standard impacts (expected) for network energy savings in Release 18

The 5G NR standard is designed with great flexibility and provides the ability for the network to adapt different requirements and trade-offs according to the traffic conditions and channel conditions. To name one example, the lean carrier design allows the network to operate with high energy efficiency and low energy consumption under low traffic. Enabled by the NR design, most network energy efficiency techniques are implementation matters rather than standard-impacting. These techniques can also be tailored and benefit from ML-based prediction and analytics. To this end, NG-RAN data collection and analytics are also being studied in 3GPP to facilitate AI/ML-based energy savings such as smart traffic predictions.

The network energy saving techniques 3GPP aims to study in Release 18, such as RAN adaptations in time, frequency, spatial and power domains, may have standard impacts for the device and in-network signaling. The focus will be on assessing the potential energy saving gains of these techniques and their impact on system and user performance according to the defined evaluation methodology. The evaluation will be carried out in target scenarios such as FR2 massive MIMO scenarios and urban and rural macro scenarios in FR1 with different forms of NR coexistence with LTE (e.g., with and without dynamic spectrum sharing or dual connectivity).

To further increase the attention on energy efficiency, it has recently been proposed to introduce network energy efficiency as a criterion for selection of solutions across all Release 18 features (where relevant). This objective will be enabled by the definition of a BS power model and energy efficiency KPIs as part of the network energy saving study.

Conclusion

The compelling device energy saving toolbox of 5G NR has been progressively developed in 3GPP since the first standard version of NR, with the most recent enhancements being introduced in Release 17. Although it is also applicable to IoT and other devices, the primary aim of the standard evolution has been to increase the energy efficiency of smartphone radio operations. The various device energy saving features enable network adaptations based on the traffic characteristics and mobility conditions of the given device and can extend the battery life of smartphones under various daily use cases.

In general, the optimal combination of features must balance energy savings against latency and QoS impact and depends on actual device implementation, network configuration and daily use of the device by the end user. This balancing will determine the actual energy saving potential achievable from these features. Release 17 advances energy savings under low daily utilization (thanks to its paging enhancements and small data handling), as well as under very high daily utilization with intense traffic activity (thanks to the fast PDCCH monitoring adaptation). Looking ahead, the standard development of device energy savings is promised to continue in 5G-Advanced bringing tailored enhancements to new applications and device types.

Abbreviations

AI	Artificial Intelligence
BFD	Beam Failure Detection
BS	Base Station
BWP	Bandwidth Part
CA	Carrier Aggregation
CP	Control Plane
DC	Dual Connectivity
DCI	Downlink Control Information
DRX	Discontinuous Reception
DSS	Dynamic Spectrum Sharing
FR1	Frequency Range 1
FR2	Frequency Range 2
FTP	File Transfer Protocol
IAT	Inter Arrival Time
IoT	Internet of Things
KPI	Key Performance Indicator
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
ML	Machine Learning
LTE	Long Term Evolution
NR	New Radio
PBCH	Physical Broadcast Channel Block
PCell	Primary Cell
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PEI	Paging Early Indication
QoS	Quality of Service
RAN	Radio Access Network
RedCap	Reduced Capability
RLM	Radio Link Monitoring
RRC	Radio Resource Control
RRM	Radio Resource Management
RS	Reference Signals
RSRP	Reference Signal Received Power
SCell	Secondary Cell
SDT	Small Data Transmission
SSB	Synchronization Signal and PBCH block
SSSG	Search Space Set Group
TRS	Tracking Reference Signal
WUS	Wake Up Signal
UP	User Plane
UE	User Equipment
XR	Extended Reality

Further reading

3GPP TR 38.840 Study on User Equipment (UE) power saving in NR (Release 16)

3GPP RP-200494 UE power saving in NR (Release 16)

3GPP RP-200085 2-step RACH for NR (Release 16)

3GPP RP-212630 UE power saving enhancements for NR (Release 17)

3GPP RP-212594 NR small data transmissions in INACTIVE state (Release 17)

3GPP RP-211574 Support of reduced capability NR devices (Release 17)

3GPP TR 38.875 Study on support of reduced capability NR devices (Release 17)

3GPP RP-212709 New study on network energy savings for 5G (Release 18)

Whitepaper “5G Massive MIMO Innovations. Boosting Spectral, Energy and Site Efficiency” https://onestore.nokia.com/asset/210389

A. Khlass, D. Laselva and R. Jarvela, “On the Flexible and Performance-Enhanced Radio Resource Control for 5G NR Networks,” 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall), 2019

A. Khlass and D. Laselva, “Efficient Handling of Small Data Transmission for RRC Inactive UEs in 5G Networks,” 2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring), 2021

D. Laselva, L. Sanchez, F. Sabouri-S, Q. Zhao, J. Kaikkonen, L. Dalsgaard and P. Kinnunen, “UE Measurements Relaxation for UE Power Saving in 5G New Radio,” 2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall), 2021

M. Lauridsen, D. Laselva, F. Frederiksen and J. Kaikkonen, “5G New Radio User Equipment Power Modeling and Potential Energy Savings,” 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall), 2019

M. Lauridsen, L. L. Sanchez, D. Laselva and J. Kaikkonen, “Study of Paging Enhancements for UE Energy Saving in 5G New Radio,” 2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring), 2021

Y. R. Li, M. Chen, J. Xu, L. Tian and K. Huang, “Power Saving Techniques for 5G and Beyond,” in IEEE Access, vol. 8, 2020

Whitepaper “How 5G is bringing an energy efficiency revolution” https://onestore.nokia.com/asset/207360

Whitepaper “5G network energy efficiency” https://onestore.nokia.com/asset/200876

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