

# Network Energy Saving Technologies in 3GPP Standards Towards 6G

Takeo Ohseki  
Wireless Technology Division  
KDDI Research, Inc.  
Saitama, Japan  
ta-ooseki@kddi.com

Shunsuke Kamiwatari  
Wireless Technology Division  
KDDI Research, Inc.  
Saitama, Japan  
sh-kamiwatari@kddi.com

Issei Kanno  
Wireless Technology Division  
KDDI Research, Inc.  
Saitama, Japan  
is-kanno@kddi.com

**Abstract**—The rapid deployment of the fifth-generation mobile communication system (5G) to support advanced use cases has led to a significant increase in network-wide energy consumption. In response, the Third Generation Partnership Project (3GPP) initiated the standardization of Network Energy Saving (NES) technologies starting from Release 18 (Rel-18) and extending into Release 19 (Rel-19) to establish unified energy consumption models, evaluation key performance indicators (KPIs), and power-saving mechanisms across the time, frequency, spatial, and power domains. This paper provides a comprehensive technical review of these standardized NES technologies, which are expected to serve as a crucial foundation for future 6G networks. Furthermore, as a concrete application to 6G, we present evaluation results for a spatial-domain “Massive MIMO (mMIMO) muting” technology operating in the FR3 band (7–24 GHz). Radio wave propagation simulations based on real-world structural data demonstrate that dynamically disabling unnecessary RF chains can improve network energy efficiency by up to 30.2% compared to conventional mMIMO systems. Finally, we discuss the outlook toward 6G Radio standardization in Release 20, where power efficiency is envisioned as a fundamental design premise from the initial specifications.

**Index Terms**—Network Energy Saving (NES), 3GPP standards, 6G Radio, Massive MIMO (mMIMO), FR3, Energy Efficiency.

## I. INTRODUCTION

The fifth-generation mobile communication system (5G) is designed to support three key use cases—high-speed, high-capacity, ultra-reliable low-latency, and massive device connectivity—and is currently being deployed commercially worldwide [1] [2]. However, these performance improvements are leading to an increase in energy consumption across the entire network [3]. In response, the Third Generation Partnership Project (3GPP) has standardized Network Energy Saving (NES) technologies—power-saving technologies for wireless networks (primarily base stations (gNB))—starting with Release 18 (Rel-18). This paper introduces NES technologies standardized by 3GPP since Rel-18 that could serve as the foundation for 6G. Furthermore, as a concrete example of the application of NES technologies to 6G, we present the results of evaluations conducted by the authors.

The remainder of this paper is organized as follows. Section II provides a technical review of the NES framework defined in 3GPP. Sections III and IV describe the specific NES technologies standardized in Release 18 and Release 19,

respectively. Section V summarizes the evaluation results and benefits of these technologies based on 3GPP technical reports. Section VI presents our evaluation results of the spatial-domain NES technology applied to 6G networks. Finally, Section VII discusses the future outlook toward 6G Radio standardization.

## II. TECHNICAL REVIEW OF NES IN 3GPP

The study of NES technologies within 3GPP began in Rel-18 with a study item (SI) titled “Study on Network Energy Savings for NR,” and the results of that study were compiled in Technical Report TR 38.864 [4] [5]. The objective of TR 38.864 was to define an energy consumption model for the gNB, establish an evaluation methodology and KPIs for assessing the effectiveness of NES technologies, and then examine and identify NES technologies.

### A. Definition of the gNB Energy Consumption Model

To quantitatively evaluate the effectiveness of NES technologies, a vendor-neutral, unified energy consumption model is required. In the SI, an energy consumption model for gNB was defined, consisting primarily of the following three elements.

**Reference Configuration** These are the gNB specifications that form the basis for evaluation. Based on factors such as frequency bands (FR1/FR2), duplexing mode (TDD/FDD), system bandwidth, and the number of transmitter / receiver radio units (Tx/Rx RU), the following three sets have been defined.

**Set 1 (FR1 TDD):** 100 MHz BW, 30 kHz SCS, 55 dBm, 64 Tx/Rx RU.

**Set 2 (FR1 FDD):** 20 MHz BW, 15 kHz SCS, 49 dBm, 32 Tx/Rx RU.

**Set 3 (FR2 TDD):** 100 MHz BW, 120 kHz SCS, 33 dBm (EIRP limit is 63 dBm), 2 Tx/Rx RU.

**Power states** The power consumption relative to the deep sleep state described below, as well as the time and energy required for state transitions, were defined for each reference configuration.

**Sleep mode:** The state in which no data is being sent or received. Three levels are defined: “Deep sleep”

(which consumes the least power but takes time to resume), “Light sleep,” and “Micro sleep” (which resumes quickly).

**Active mode:** The state in which data is being transmitted or received. Defines “Active DL” (downlink transmission in progress) and “Active UL” (uplink reception in progress).

**Scaling Method** Power consumption during active operation was modeled as the sum of static and dynamic parts of power for a gNB.

**Static power ( $P_{static}$ ):** The base power consumption, regardless of traffic.

**Dynamic power ( $P_{dynamic}$ ):** The power that varies with load. It is calculated using the following scaling factors:

$s_a$  (**Spatial domain**): Active antenna/TxRU ratio.

$s_f$  (**Frequency domain**): Ratio of used bandwidth to resource allocation.

$s_p$  (**Power domain**): Ratio of transmitted power spectral density.

### B. KPIs for measuring energy savings and communication performance

In general, while NES technologies contribute to reducing energy consumption in gNB, it also carries the risk of degrading communication performance. Therefore, in the SI, each NES technology was evaluated using multiple KPIs to assess not only “how much energy was saved,” but also the trade-offs involved, specifically “what kind of impact (degradation) this has on the performance of the network and user equipment (UE).” The main KPIs used can be broadly categorized into two aspects: the energy consumption reduction effect (NES Gain) and the impact on performance.

**NES Gain** A KPI calculated by comparing the energy consumption resulting from the application of the technology under evaluation with the baseline energy consumption over the same period.

**Performance Impact KPIs** KPIs used to verify that user experience and communication quality do not deteriorate significantly: UPT (User Perceived Throughput), UE Power Consumption, Access Delay / Latency.

## III. NES TECHNOLOGIES AS DEFINED IN REL-18

In Rel-18, standardization was carried out for NES technologies in the four domains of time, frequency, space, and power, based on the results of the SI review summarized in TR 38.864 [6].

### A. Time-domain technology

Prior to Rel-18, UE Connected Discontinuous Reception (C-DRX) was standardized to conserve battery power in UEs during communication, but in Rel-18, network-side discontinuous transmission and reception (Cell Discontinuous Transmission (DTX)/DRX) was introduced. This is a technology in which the gNB stops transmitting and receiving during traffic pauses. However, if a UE transmits data while the gNB is in DRX

mode, there is an issue where power consumption by the UE increases due to connection failures or retransmissions.

To prevent this, the gNB uses upper-layer (Radio Resource Control (RRC)) signaling to appropriately set the period and offset so that the active periods of the gNB (Cell DTX/DRX) and the UE (C-DRX) overlap. In addition to control via RRC, Cell DTX/DRX can be dynamically activated and deactivated for a group of UEs using group-common downlink control information (DCI) at the physical layer. This enables control in response to traffic fluctuations with minimal overhead.

Note that since this feature was introduced in Rel-18, restricting access by Rel-18 non-compliant UEs (or legacy UEs) is necessary for its actual network deployment. To achieve this, a mechanism has been standardized that prohibits access for all UEs via the Master Information Block (MIB) while granting access exclusively to Rel-18-compliant UEs through a new parameter in System Information Block 1 (SIB1). In addition, functional enhancements were made to conditional handover, with the aim of efficiently relocating connected UEs to adjacent cells immediately before the gNB initiates Cell DTX/DRX or switches off the cell.

### B. Frequency-domain technology

In 5G NR systems, synchronization signal blocks (SSBs) are transmitted periodically, and UEs use them to discover cells, synchronize, and perform measurements. However, because these SSBs are transmitted continuously regardless of whether traffic is present, they have been a factor preventing the gNB from entering deep sleep.

Therefore, in Rel-18, a technology called “SSB-less SCell Operation” was introduced, which omits SSB transmission by the secondary cell (SCell) in a carrier aggregation (CA) environment. In this case, the UE uses the PCell’s SSB as a reference for synchronization with the SCell and as a source for automatic gain control (AGC). Specifically, up to Release 17 (Rel-17), it was possible to reuse the PCell’s synchronization information for the SCells only if they were co-located with the PCell and operated on consecutive carriers within the same band. However, in Rel-18, by having the gNB explicitly set the cell ID that serves as the synchronization reference for the UE, it became possible to reuse synchronization information even across different frequency bands, provided the cells are located in the same physical location.

### C. Spatial and Power Domain Technologies

While Massive MIMO gNBs have a large number of antennas (e.g., 64T64R), keeping all of them active during periods of low load is a waste of energy. Therefore, in Rel-18, standard specifications were considered to dynamically reduce the number of gNB transmit antennas based on factors such as traffic volume and UE spatial distribution. Additionally, to reduce energy consumption associated with downlink transmission itself, standard specifications were also considered to dynamically reduce the transmission power of the Physical Downlink Shared Channel (PDSCH) to a level sufficient to meet required communication quality, for example.

Specifically, changing the number of transmit antennas on the gNB or the PDSCH transmit power alters the conditions under which the UE should measure Channel State Information (CSI). Therefore, a “Sub-configuration”—a set of parameters defining how the UE should measure the Channel State Information Reference Signal (CSI-RS) for each antenna or power configuration—has been standardized to enable CSI reporting. By having the UE report the CSI Report in accordance with each Sub-configuration, the gNB can now accurately evaluate the impact on downlink quality when reducing the number of antenna ports or transmit power to reduce energy consumption.

#### IV. NES TECHNOLOGIES AS DEFINED IN REL-19

In Release 19 (Rel-19), technologies that had been discussed in the SI and compiled in TR 38.864 but had not been standardized in Rel-18 were standardized [7].

##### A. Dynamic Synchronization Signal Control in SCell

In Rel-18, “SSB-less SCell Operation” was standardized as a frequency-domain NES technology; however, this was intended for CA between different frequency bands deployed at the same location. To extend this capability to non-co-located cells and reduce energy consumption overhead from SSB transmissions, Rel-19 standardized “On-demand SSB (OD-SSB) SCell Operation.”

The basic operation of this technology involves configuring this feature (including its initial activation/deactivation state) via RRC signaling during the process of configuring an SCell for Carrier Aggregation (CA) for a UE in the RRC\_CONNECTED state. Furthermore, if necessary, its dynamic activation/deactivation can be instructed via MAC layer control. This allows the UE to recognize the start, end, and period of the SSB transmitted on demand. Through this information notification mechanism, the gNB can completely stop SSB transmission when it is not required, thereby achieving maximum reduction in energy consumption.

##### B. Dynamic SIB1 Control for Idle/Inactive UE

The 5G NR system continues to broadcast SIB1 periodically (e.g., every 160 ms) for newly connecting UEs, regardless of whether any UEs are present in the cell. This results in a waste of energy, particularly at night and in sparsely populated areas. Therefore, Rel-19 introduced the “On-demand SIB1” mechanism, in which the gNB does not normally transmit SIB1, but instead responds to requests for SIB1 transmission from UEs in the idle (RRC\_IDLE), inactive (RRC\_INACTIVE), or RRC\_CONNECTED states that are in the process of reconnecting to the cell.

The challenge with on-demand SIB1 lies in how a UE requests a gNB that is not transmitting SIB1 to do so. If a gNB is not transmitting SIB1, the UE cannot receive the configuration information necessary for establishing an initial connection with that gNB and is therefore unable to access the network. To resolve this issue, Rel-19 standardized an approach in which, even in cells implementing On-demand

SIB1, the UE establishes synchronization using the minimum required SSB—which is assumed to be transmitted—and then transmits a physical layer signal (UL wakeup signal (WUS)) to request the transmission of SIB1.

Here, for the UL WUS requesting the transmission of SIB1, a random access preamble (Msg1) transmitted over a Physical Random Access Channel (PRACH) resource allocated exclusively for SIB1 requests is used. Unlike a normal connection request, using a resource dedicated to SIB1 requests allows the gNB to identify this as a “request for SIB1 transmission.” To notify UEs of the configuration information for this resource, a new SIB called SIB26 has been defined. The UE obtains SIB26 from the PCell or other SCells (including cells operating On-demand SIB1), and transmits a UL WUS based on the configuration contained therein to request the transmission of SIB1.

##### C. Adaptation of common signal/channel transmissions

Another pillar of Rel-19 NES technologies is the evolution of common signal/channel resources—such as paging, PRACH, and SSB—from static configurations to dynamic and adaptive configurations that respond to load conditions. If such adaptation of common signals can be achieved, it will be possible to balance wireless system performance and power savings through control that responds to temporal fluctuations in traffic, while avoiding coverage holes caused by disabling them to reduce gNB energy consumption.

1) *Time-domain adaptation of paging*: This control mechanism (paging adaptation) extends the interval between paging frames (PFs) during which a paging message (Paging Downlink Control Information (Paging DCI)) may be transmitted, thereby allowing the gNB to remain in sleep mode for a longer period. However, since simply explaining the PF interval would reduce paging capacity, the Rel-19 specification also allows for an increase in the number of paging occasions (PO) contained within a single PF. Parameters enabling such paging adaptation are provided within SIB1, and compatible UEs use these new parameters to calculate PFs and POs and await paging. Furthermore, Paging Early Indication (PEI), introduced in Rel-17 to reduce UE power consumption during paging monitoring, has also been extended to allow for parameter settings compatible with paging adaptation.

2) *PRACH Time-Domain adaptation*: PRACH resources (RACH Occasion (RO)) are reserved periodically even when there is no access from the UE, and the gNB must monitor them. In Rel-19, the density of PRACH resources in the time domain became dynamically adjustable (PRACH Adaptation). Specifically, in addition to the PRACH resources that are always available, the definition of additional PRACH resources that are activated as needed is configured via RRC signaling. Furthermore, the availability of these additional PRACH resources is notified via DCI. Consequently, when traffic is light, the gNB notifies the UE that the additional PRACH resources are unavailable, thereby eliminating the need for PRACH reception processing and reducing energy consumption.

TABLE I  
KEY FINDINGS FROM THE NES TECHNOLOGIES EVALUATION [5]

| Domain    | NES Technologies                              | NES Gain    | Performance impacts                                                                                                                                                                                |
|-----------|-----------------------------------------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Time      | Lengthening of the SSB/SIB1 cycle             | 0.9 %~84.8% | UPT degradation. As the cycle length increases, access delay, latency, and UE power consumption increase.                                                                                          |
|           | Lengthening of the PF interval                | 0.2 %~42.3% | -                                                                                                                                                                                                  |
|           | Lengthening of the PRACH cycle                | 14.4%~24.9% | Access latency has increased by 10 to 70 ms.                                                                                                                                                       |
|           | Alignment of UE C-DRX Settings (Cell DTX/DRX) | 0.2%~71.4%  | UPT degraded by up to 15.5%.<br>Access latency increased by up to 50%.                                                                                                                             |
|           | On-demand SSB/SIB1                            | 2.6%~43.4%  | -                                                                                                                                                                                                  |
| Frequency | SSB-less SCell                                | 0.3%~98.4%  | A 2.3% to 18.9% increase in gNB energy consumption on the anchor carrier. No degradation in UPT/UE power consumption (one study reports a slight increase in UPT). Reduced SCell activation delay. |
| Spatial   | Adaptation of Spatial Elements                | 0%~48.2%    | The UPT deteriorated from less than 10% to a maximum of 87.08%.                                                                                                                                    |
| Power     | Reduction of PDSCH Transmission Power         | 2.3%~51.5%  | UPT degraded by 0~19.49%, latency increased by up to 24.21%, and UE power consumption increased by up to 14.78%.                                                                                   |

3) *Time-domain adaptation of SSB*: As described in Section IV-A, OD-SSB is a technology that completely stops unnecessary transmissions by sending SSB signals only when necessary to achieve maximum power savings. However, in Rel-19, a technology was also standardized that dynamically switches the SSB transmission cycle to adjust the transmission frequency according to traffic load and UE measurement needs, thereby dynamically balancing the maintenance of connection quality with the reduction of energy consumption. Like OD-SSB, this technology applies only to SCells of UEs in the RRC\_CONNECTED state.

Specifically, in addition to the default SSB cycle transmitted via SCell, up to two additional cycles (and their timing on the time axis) are configured for the UE via RRC signaling. By dynamically switching between these up to three cycles using DCI, it becomes possible to control the SSB cycle via gNB. This allows for the suppression of unnecessary SSB transmissions.

## V. THE BENEFITS OF STANDARDIZED NES TECHNOLOGIES

The evaluation of NES technologies in TR 38.864 was conducted primarily through system-level simulations of various traffic load scenarios, based on the gNB energy consumption model described in Section II-A. In this section, Table I presents the evaluation results summarized in TR 38.864, specifically those that formed the basis for the standardization technologies in Rel-18 and Rel-19.

## VI. AN EVALUATION OF THE EFFECTS OF STANDARDIZED NES TECHNOLOGY [8]

In this section, we present our evaluation results on the application of spatial-domain NES technology to 6G. In 6G, the utilization of FR3, the frequency band ranging from 7 GHz to 24 GHz, is attracting significant attention. While the use of Massive MIMO (mMIMO) in FR3 is expected to enable both wide-area coverage and high-speed, high-capacity communication, there are concerns that the use of a large number of

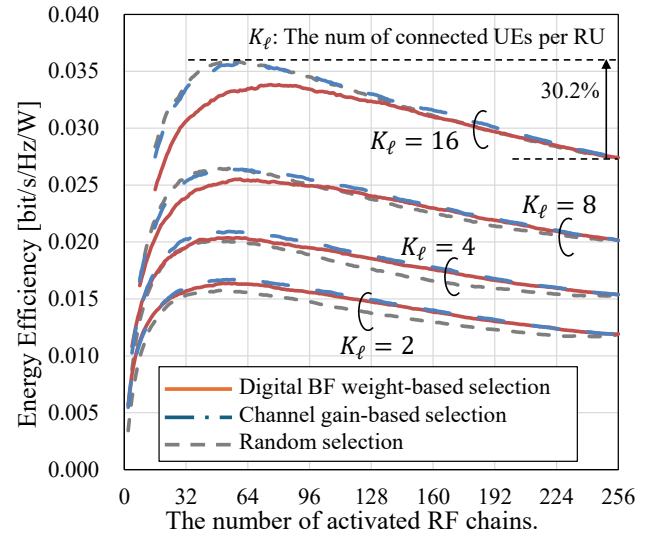


Fig. 1. Energy efficiency v.s. the num. of activated RF chains with UE fairness-aware analog beam selection.

transceivers (RF chains) will significantly increase the energy consumption of the gNB and reduce energy efficiency. We focused on “mMIMO muting” technology (corresponding to the spatial domain technology described in Section III-C), which improves energy efficiency by disabling unnecessary RF chains and antennas during off-peak traffic periods, and evaluated the energy-saving effects of this technology.

An example of the evaluation results is shown in Figure 2. In this evaluation, we performed a radio wave propagation simulation using ray tracing based on real-world structural data from Shibuya Ward, Tokyo. For analog beam selection, we performed selection that took fairness among UEs into account, and for the selection of RF chains to be disabled via mMIMO muting, we compared three methods: digital beamformer-based [9], channel gain maximization, and random selection. The simulation results revealed that there exists an optimal number of active antennas that maximizes energy efficiency,

and that this number increases as the number of spatially multiplexed UEs increases. Furthermore, we demonstrated that it is possible to improve energy efficiency by 30.2% compared to conventional mMIMO systems that do not disable antennas.

## VII. TOWARD THE STANDARDIZATION OF 6G NES-RELATED TECHNOLOGIES

In Release 20, the SI process for 6G Radio began. Building on the NES technical standardization efforts of Rel-18 and Rel-19, power efficiency for networks and devices has been identified as a key requirement [10]. With concrete discussions set to begin in June 2025, efforts are currently underway to establish evaluation criteria and other related matters. In contrast to 5G, 6G Radio is expected to be designed with power efficiency as a fundamental premise from the initial specifications, and the NES technologies are anticipated to be utilized more extensively in real-world environments.

## REFERENCES

- [1] ITU-R Rec. M.2083-0, "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond," Sept. 2015.
- [2] GSA, "5G Market Snapshot," November 2025.
- [3] <https://www.ericsson.com/en/blog/2019/2/breaking-the-energy-curve-5g-energy-efficiency>
- [4] RP-220297, "Revised SI: Study on network energy savings for NR," March, 2022.
- [5] 3GPP TR 38.864, "Study on network energy savings for NR," v18.1.0, March, 2023.
- [6] RP-234009, "Revised WID on Network energy savings for NR," December, 2023.
- [7] RP-252332, "Revised WID on enhancements of network energy savings for NR," September, 2025.
- [8] S. Kamiwatari, et al., "Towards Energy-Efficient FR3 Massive MIMO: Antenna Muting and Hybrid Beamforming Evaluation," IEICE Tech. Rep., vol. 125, no. 214, RCS2025-131, pp. 47–52, Oct. 2025.
- [9] F. Sohrabi, et al., "Energy-Efficient Flat Precoding for MIMO Systems," IEEE Trans. on Signal Process., vol.73, pp.795–810, 2025.
- [10] RP-253876, "Revised SID: Study on 6G Radio," December, 2025.