

Network Energy Savings Implementation

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Release date: September 2026

Acknowledgements

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Executive summary

This Ecosystem Resource Publication explores detailed implementations for Energy Savings features defined in O-RAN. The publication discusses the use cases, end-to end-detailed implementation details, challenges, and considerations for each energy saving feature. Some of the case studies and best practices from current implementations are also specified. The Ecosystem Resource publication also covers the RF environment interdependencies with NES.

Definition of terms, symbols and abbreviations

Terms

BS: Base Station

ES mode 1: Energy saving feature driven in accordance with RAN OAM-configured background behavior

ES mode 2: Energy saving feature driven in accordance with policies information from the Non-RT RIC using A1 interface.

FILIP: Field Identified Levels of In-Objective Perception formula and its unit is designed to deliver a holistic and objective end-customer experience measure unbiased by a conventional approach to use a single-family type of indicators.

O1: Interface between management entities (NMS/EMS/MANO) and O-RAN managed elements, for operation and management by which FCAPS management, software management, and file management may be achieved.

O-CU: O-RAN Central Unit, a logical node hosting O-CU-CP and O-CU-UP.

O-DU: O-RAN Distributed Unit, a logical node hosting RLC/MAC/High-PHY layers based on a lower layer functional split.

O-RU: O-RAN Radio Unit, a logical node hosting Low-PHY layer and RF processing based on a lower layer functional split. This is similar to 3GPP's "RRH" but more specific in including the Low-PHY layer (FFT/iFFT, PRACH extraction).

RAN: Generally referred to as Radio Access Network. In terms of this document, any component below near-RT RIC per O-RAN architecture, including O-CU/O-DU/O-RU. **rAPP:** Non-RT RIC application: An application designed to consume and /or produce R1 Services.

TRX control: Disabling of some or all antenna array elements for a period of time to save energy.

Abbreviations

AI/ML Artificial Intelligence/ Machine Learning

BS Base Station

EE Energy Efficiency

EC	Energy Consumption
ES	Energy Saving
EUGT	End User Group Types
FILIP	Field Identified Levels of In-Objective Perception
NES	Network Energy Saving
Near-RT RIC	Near Real Time RAN Intelligent Controller
Non-RT RIC	Non Real Time RAN Intelligent Controller
OAM	Operation, Administration and Maintenance
O-RU	O-RAN Radio Unit
O-DU	O-RAN Distribute Unit
PA	Power Amplifier
PM	Performance Measurement
SU/MU MIMO	Single User/ Multi User MIMO
RF	Radio Frequency
RPC	Remote Procedure call
RRH:	Remote Radio Head
SMO	Service Management and Orchestration

Introduction

This Ecosystem Resource Publication offers a comprehensive overview of the Network Energy Saving capabilities defined within the O-RAN framework. It explains the key use cases in detail and describes how these features could be implemented across various O-RAN network components. The document also highlights the practical challenges and important considerations for deploying these energy-saving mechanisms in real-world networks. In addition, it includes selected case studies that illustrate the application and effectiveness of several key features.

The ecosystem resource publication is organized into dedicated sections for each NES feature. Each section includes an overview of the feature, its use cases, implementation considerations within O-RAN components, and the associated challenges and key considerations.

The Ecosystem Resource Publication covers some of the possible implementations. Other implementations are also possible.

Cell/Carrier shut down

Feature overview

NES features can be invoked in response to changes in traffic load or change in the cell/carrier shutdown policy.

When traffic load is below a certain threshold, energy savings may be achieved by shutdown of one or more carriers or entire cells without affecting user experience.

Use cases

Load based carrier/cell shutdown

Traffic load varies in mobile networks over the daytime, or even on different days of the week.

Traffic load is related to the users' mobility and behaviour, e.g., in a large city where many people commute from the surrounding suburbs into for working from Monday to Friday, usually BSs therein are highly loaded starting from the morning until the afternoon. On the other hand, during such days, BSs deployed in those suburban areas may be scarcely used until the late afternoon. This traffic load variation creates an opportunity to shutdown either entire cells or some of the operating frequencies (i.e., carriers) to provide energy savings. Thus, the most likely use case is across all capacity cells in the network during nighttime.

However, other scenarios exist, such as cells located in industrial parks or rural areas, where the active period can be extended beyond night hours, cells located in seasonal tourist areas that could extend their shutdown to the whole day, except for holiday periods. For a sporting event such as a popular Baseball Game/Stadium, where the "covering" BSs would be needed during the event and far less coverage would be needed when the event is not active.

End to end Carrier shutdown implementation approach

Figure 0-1 E2E Implementation Approach provides the functionalities of different nodes in O-RAN for implementing carrier cell shutdown feature.

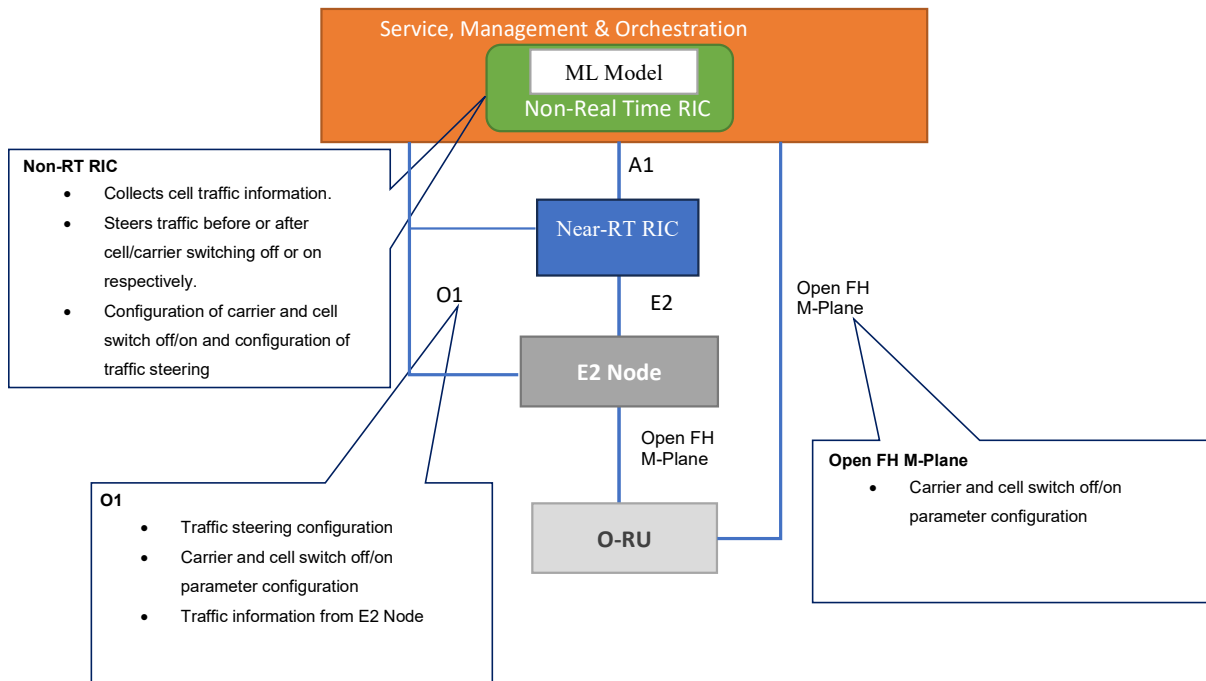


Figure 0-1 E2E Implementation Approach

O-RAN components implementation for cell/carrier shut down

Non-RT RIC Implementation

Non-RT RIC enables carrier and cell shutdown energy saving functions in the network by means of configuration parameter changes for the E2 nodes.

The SMO/Non-RT RIC performs following functions.

1. Collects the configuration performance indicators and measurement reports (e.g., cell load-related information and traffic information, EE/EC measurement reports) from E2 node(s) and trace records (e.g., per-UE measurement metrics and location information) through O1 Interface. These measurement reports are used for decision making, optionally for training and inference of AI/ML models that assist such EE/ES functions. It is assumed that configurations, performance indicators, and measurement reports collected from the O-DU contain the related information for the corresponding O-RU(s).
2. Transfers collected data (in step 1) to an rApp.
3. Signals updated configurations for EE/ES optimization towards E2 node(s) (O-CU) through an O1 Interface.
4. (Optionally) Retrain, update, and configure EE/ES AI/ML models in the Non-RT RIC.
5. Provides A1 policies to the Near-RT RIC, via an A1 interface, based on the request from an energy saving rApp (in the case of A1 policy-based solution).
6. The SMO/Non-RT RIC sends enrichment information via the A1 interface to the Near-RT RIC for

calculation of coverage overlap (in the case of A1 policy-based solution).

Near-RT RIC Implementation

The Near-RT RIC implementation for cell/carrier shut down enables the energy saving functions in accordance with RAN OAM-configured background behavior (ES mode 1) or policies information from the Non-RT RIC using A1 interface (ES mode 2).

Below are the key actors for Near-RT RIC based implementation of carrier cell shutdown feature.

1. A Non-RT RIC in SMO domain Creates and updates A1 policies and provides A1 enrichment information.
2. A Near-RT RIC: Enforces the A1 policies (of step 1) and generates RIC CONTROL and/or POLICY.
3. An E2 node the RIC CONTROL and POLICY execution and RIC REPORT creation.

Below steps explain how carrier cell shutdown could be implemented.

1. If the RAN is using ES mode 1, then
 - a. The Non-RT RIC receives the collected measurement data from the OAM function provided by the E2 Node through O1.
 - b. The Non-RT RIC trains the AI/ML models with the collected data. Trained AI/ML models are deployed, configured, and activated in the Near-RT RIC via the A1 interface. The Near-RT RIC constantly monitors performance and energy consumption.
 - c. The Near-RT RIC requests E2 Node, then E2 Node requests O-RU Node to execute cell shutdown.
2. If the RAN is using ES mode 2, then
 - a. A Near-RT RIC collects data from the E2 Node through the E2 interface and subscribes to an UE CTXT INFO and measurement metrics.
 - b. The E2 nodes report the UE context information and E2 measurements via RIC REPORT which could be periodically or event triggered.
 - c. The Near-RT RIC evaluates the performance data from E2 nodes and finds potential improvements to energy efficiency, which are indicated in the A1 policy.
 - d. Based on the UE context information, E2 measurement metrics (RIC REPORT), and A1 policy, Near-RT RIC may generate new or modify the existing E2 policies and send them to E2 nodes to achieve the NES objective

OAM Implementation

An OAM implementation consists of the following functionality:

1. An O-RU shares energy-saving capabilities with O-DU via the open fronthaul M-Plane.
2. An O-DU shares NES capabilities with SMO via O1.
3. The SMO sends configuration to O-DU via the O1.
4. The O-DU applies configuration internally and to O-RU (via fronthaul M-Plane).

5. The O-DU reports performance and energy consumption data of the O-RU to SMO.
6. The SMO analyzes the reported energy and performance data and may reconfigure O-DU or create new policies.
7. The O-DU receives cell activation/deactivation commands from F1.
8. The O-DU maps cells to carriers and activates/deactivates them via M-Plane.

Open Fronthaul Implementation

1. A NETCONF Client (SMO/O-DU) uses the existing YANG parameter **[tr]x-array-carrier::active** to activate or deactivate [tr]x-array-carriers.
2. When a specific [tr]x-array-carrier is set to “inactive”, this causes the YANG parameter **[tr]x-array-carrier::state** transition to “DISABLED”. As a result, the power consumption of O-RU may be reduced because O-RU does not need to process C-Plane and U-plane traffic.
3. Additionally, when [tr]x-array-carriers are inactive and when the YANG parameter **energy-saving-enabled** is set to “TRUE”, the O-RU may turn off circuitry associated with carrier processing to further reduce power consumption.

O-RAN specification reference

WG Reference	Clause
O-RAN.WG2.TS.Use-Case-Requirements	4.8.1
O-RAN.WG3.TS.UCR	4.6.1
O-RAN.WG4.MP	20.2
O-RAN.TS.WG10.OAM-Architecture-	Annex E.2

Challenges and considerations

The activation and deactivation of the NES feature could be governed by a set of key performance indicators (KPIs), including, but not limited to, cell load and resource block (RB) utilization. Additionally, continuous monitoring of the average cell throughput and user throughput is required. It is recommended to disable the NES feature proactively in scenarios where its operation adversely affects network performance. It is recommended that coverage-related cell carriers be excluded from the scope of the NES feature, as their deactivation is not permissible due to coverage preservation requirements.

RF channel reconfiguration

Feature overview

This NES feature is expected to reduce power consumption by switching off certain RF channels of the O-RU with massive MIMO deployment with large number of antennas.

The RF channel reconfiguration includes the following mechanisms for energy saving:

1. O-RU Array Rx/Tx ON/OFF e.g., 64Tx/Rx to 32Tx/Rx
2. Modify SU/MU MIMO spatial streams or data layers.

Use cases

Load-based RF channel switch off/on during daytime and nighttime

The traffic load in mobile networks varies over the daytime; usually it is lower during the night when most people are sleeping and rises during the day when people utilize data transfer for work purposes.

Considering the variations of the traffic load, the number of RF channels may be adjusted to provide NES gains while satisfying user's Quality of Service (QoS) demands.

As can be observed, during busy hours all RF channels remain active.

When the traffic load lowers to the level of a "medium load", a percent of the RF channels (for e.g. 40%) may be switched off to save energy. Finally, under "low load" traffic, some RF channels can be switched off. For example, if only 20% of active RF channels can provide users with a satisfying QoS, the rest can be switched off.

During nighttime, the number of RF channels could be switched off depending on the load of the cells. This use case may be used in high traffic areas during the day that are not so loaded during the nights, such as office areas.

In cells located in seasonal tourist areas, RF channel reconfiguration should be considered during the day, instead of switching off the cell completely and extend the night period for carrier/cell switch-off.

The switching off RF channels requires reconfiguration of the BS, e.g. while having fewer antennas, the number of the supported beams is reduced, and the beams themselves change their shape.

End to end RF channel shutdown implementation

Figure 0-1 E2E Implementation Approach provides the functionalities of different nodes in O-RAN for implementing RF channel reconfiguration feature

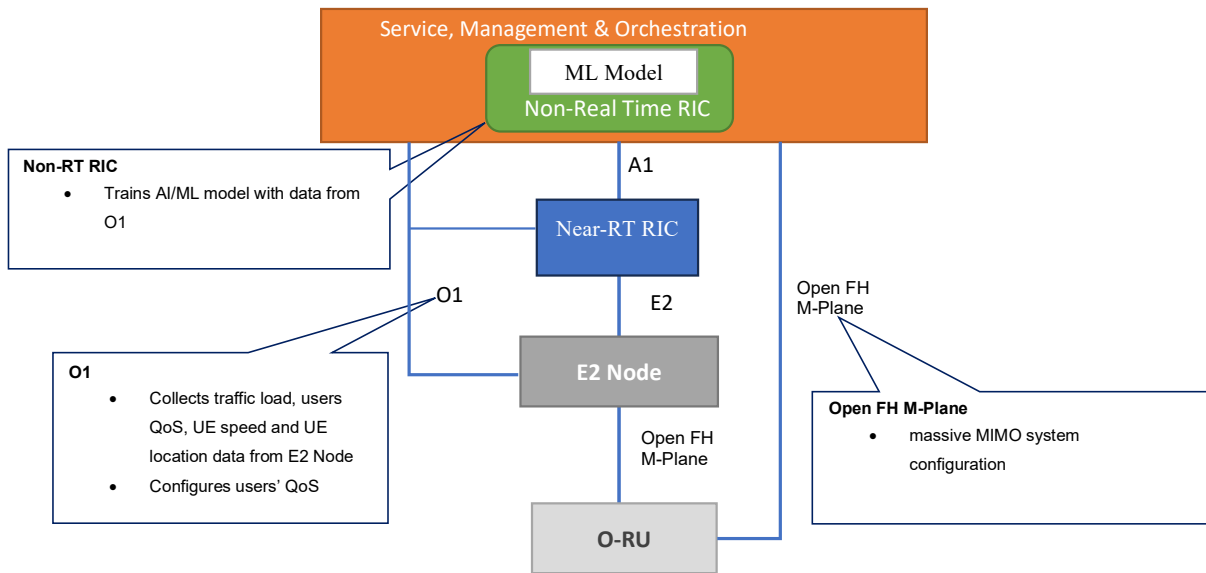


Figure 0-1 E2E Implementation Approach

O-RAN components implementation and reference

Non-RT RIC Implementation

This solution to RF Channel reconfiguration using a Non-RT RIC proposes a framework that allows the operator to flexibly configure RF channel reconfiguration parameters in a single cell or in a cluster of cells. Reconfiguration may be achieved in two ways. The first is through the O1 interface configuration, as formulated by an rApp to E2 node(s) and O-RU(s) through SMO/Non-RT RIC. The second method is achieved through A1 policies formulated by rApp towards Near-RT RIC through SMO/Non-RT RIC framework, which is assisted by Machine Learning (ML) techniques in the NON-RT RIC.

The functions of Non-RT RIC are mentioned below.

1. Collect the configurations, performance indicators, and measurement reports (e.g., cell load-related information and traffic information, EE/EC measurement reports) from E2 node(s), for the purpose of decision making, optionally using training and inference of AI/ML models that assist such EE/ES functions.
2. Transfer collected data towards rApp. It is assumed that configurations, performance indicators, and measurement reports collected from the O-DU contain the related information for the corresponding O-RU(s).
3. Signal updated configurations for EE/ES optimization towards E2 node(s) (O-CU) through O1 interface.
4. (Optionally) Retrain, update, and configure EE/ES AI/ML models in Non-RT RIC.
5. Provide A1 policies to Near-RT RIC via A1 interface based on the request from energy saving rApp in the case of A1 policy-based solution.

Near-RT RIC Implementation

The goal of Near-RT RIC energy saving using RF reconfiguration is to interpret the policies received over the A1 interface. Based on policy and the current or predicted traffic and channel conditions, the Near-RT RIC then derives the best choices for O-RU Tx/Rx array configurations. An Array configuration includes the number of active antenna elements, antenna element layout, SU/MU MIMO layers etc., The Near-RT RIC also provides guided configurations to the O-DU. Both ES mode 1 and ES mode 2 are supported.

The guided configurations may include:

1. Indication of the slot numbers, symbol numbers, and the conditions for the TRX control configuration to be applied.
2. Indication of the array elements to be switched off during the period indicated above, based on the TRX control capability information reported by the E2 node (O-DU)

Note that in ES mode 2, it is also possible to implement RF channel reconfiguration solely in the Near-RT RIC, without relying on the interpretation of policies received over A1 interface. Instead, xApp deployed in the Near-RT RIC operates independently of Non-RT RIC in a fast control loop, dynamically adapting Tx/Rx array configuration to the traffic demand or cell load based on internal logic or AI/ML models.

OAM Implementation of NES RF Channel Reconfiguration

TRX Control Capability Retrieval: O-RU shares TRX control capabilities with O-DU via open fronthaul M-Plane.

The following steps demonstrate how the Policy Configuration and Execution works:

1. The SMO sends TRX Control-based energy saving policies/configurations to O-DU.
2. The O-DU evaluates conditions in the policy and monitors cell load related data and traffic information.
3. When thresholds are met as defined in the policy, the O-DU sends antenna mask and sleep mode info to O-RU via Open Fronthaul C-Plane.
4. The O-RU applies TRX Control settings received from O-DU and could respond to O-DU with ACK/NACK.
5. The SMO is notified of execution via notification and counter by the O-DU.
6. The SMO analyses the policy status and PM data.
7. The SMO may remove some or all policies and is notified of policy status.
8. The process ends when all TRX Control-based policies/configurations are removed.

Open Fronthaul Implementation

WG4 has split this RF Channel reconfiguration NES feature into 2 sub-use-cases, classified as TRX Control and Data Layer Control:

1. **TRX Control** is used to achieve energy saving through disabling one or more O-RU antenna array elements. The TRX control feature can be C-Plane controlled or M-plane controlled. Both these techniques are explained below.

- For example, an O-DU can switch off 16 out of 32 antenna elements of an antenna array.
- i. TRX control – C-Plane controlled: The O-RU exposes the capability to support energy saving through disabling some or all the O-RU's array elements by including support of the feature **TRX-CONTROL** in its o-ran-wg4-features.yang YANG module. The capabilities include.
 - a) `trx-control-capability-info` (per `[tr]x-array`):
 - `supported-trx-control-masks`: Lists supported mask-name and antenna-mask values. If absent, any mask is supported.
 - `sleep-mode-type`: Indicates supported sleep modes.
 - `wake-up-duration`: Time (μ s) to wake from sleep; convertible to slots based on SCS.
 - `wake-up-duration-guaranteed`: TRUE if wake-up time is fixed; FALSE if minimum only. For `SLEEP_MODE_0`, always TRUE.
 - `defined-duration-sleep-supported`: Supports defined sleep.
 - `undefined-duration-sleep-supported`: Supports undefined sleep.
 - b) `energy-saving-capability-common-info` (via `o-ran-module.cap.yang`):
 - `ST8-ready-message-supported`: Indicates readiness after non-guaranteed wake-up via Section Type 8.
 - `sleep-duration-extension-supported`: Allows extending defined sleep.
 - `emergency-wake-up-command-supported`: Supports emergency wake-up.

The configuration is done using ST4 command using **st4CmdType**: `TRX_CONTROL`

- ii. TRX Control – M-Plane controlled is achieved via M-Plane YANG configuration:
 - a) O-RU supports energy-saving TRX control via `MPLANE-TRX-CONTROL` in `o-ran-wg4-features.yang`. The capabilities are:
 - `Tx-arr-capability-info`: Includes `mplane-trx-control-supp-antenna-masks` listing supported antenna-mask configurations. If absent, any mask is supported. If an antenna mask list is present, an all-ones antenna mask shall be included in the list to assure all array elements can be turned on.
 - `Rx-arr-capability-info`: Same structure and logic as `tx-arr-capability-info`.
 - b) O-RU uses `array-config-group` with `tx-array-antenna-mask-config` and `rx-array-antenna-mask-config` lists, indexed by `array-name`, with `antenna-bitmask` and `antenna-bitmask-index`.

2. **Data Layer Control** is used to achieve energy savings through reducing the number of data layers independent of TRX-Control (i.e., no antenna elements are switched off).

- 1. For example, the EC of O-RU can be reduced by turning off certain HW components like processing units of FPGA/GPUs or CPU/GPU cores or by running at a lower clock speed.

Below are the capabilities:

1. O-RU supports the feature MPLANE-DATA-LAYER-CONTROL via o-ran-wg4-features.yang.
2. Each static low-level [tr]x-endpoint advertises one or more energy-sharing-group-id values.

Configurations: O-RU controller disables data layers by adding group IDs to energy-sharing-groups-disabled in o-ran-uplane-conf.yang.

O-RAN specification references

WG Reference	Clause
O-RAN.WG2.TS.Use-Case-Requirements	4.8.2
O-RAN.WG3.TS.UCR	4.6.3
O-RAN.WG4.MP	20.3.1, 20.3.2, 20.3.3
O-RAN.WG4.TS.CUS	16.2
O-RAN.TS.WG10.OAM-Architecture	4.2.5.1

Challenges and considerations

The activation and deactivation of the RF channel reconfiguration NES feature is governed by a set of key performance indicators (KPIs) including, but not limited, to cell load and resource block (RB) utilization. Additionally, average cell throughput and user throughput has to be continuously monitored in conjunction with overall cell performance metrics. RF channel reconfiguration should be proactively disabled in scenarios where its operation adversely affects network performance.

Case study/best practices and results

Evaluation of the RF channel reconfiguration xApp by Rimedo Labs

One of the possible implementations of the RF channel reconfiguration NES feature is the Near-RT RIC implementation described in Clause 0. This approach is solely a Near-RT RIC approach; that is, there is no A1 policy guidance from Non-RT RIC. This Near-RT RIC-only was followed by Rimedo Labs demonstrating their RF Channel Reconfiguration xApp (RCR-xApp) during the O-RAN Virtual Exhibition at Mobile World Congress 2025 in Barcelona [1].

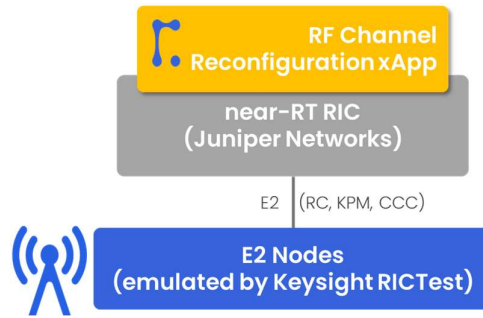


Figure 0-1 Evaluation setup exploiting RCR-xApp by Rimedo Labs, Near-RT RIC by Juniper Networks, and RICTest by Keysight. Based on [1].

As presented in Figure 0-1, the RCR-xApp is hosted on the Near-RT RIC platform provided by Juniper Networks and tested against the E2 Nodes emulated by the Keysight RICTest software. To provide the NES through RF channel reconfiguration, Rimedo Labs xApp utilizes a Service Model from the E2 interface, namely:

1. E2SM RAN Control (RC) [7], to retrieve the E2 Node information.
2. E2SM Key Performance Measurement (KPM) [8], to monitor network metrics for making a decision on the RF channel reconfiguration, e.g., PRB utilization, DL/UL cell/UE throughput, and power consumption.
3. E2SM Cell Configuration and Control (CCC) [9], which enables monitoring and modification of active RF channels through the O-NES policy structure.

To demonstrate energy saving benefits from an RCR-xApp, Keysight RICTest emulated 10 E2 Nodes along with related 3GPP and O-RAN protocol stacks, including E2SM-RC, E2SM-KPM, and E2SM-CCC. Each E2 Node is a 3-sector site equipped with 8x8 Massive MIMO antenna arrays, resulting in a total number of 30 cells as depicted in Figure 5.6-2. The subscribed emulated population is a few hundred UEs following an inverse bell curve traffic profile, as depicted in the top part of Figure 0-3 and shown as Baseline (no xApp). This creates an opportunity for the RCR-xApp to save energy during the low load period but also tests its robustness in accommodating the growing traffic demand without QoS degradation.

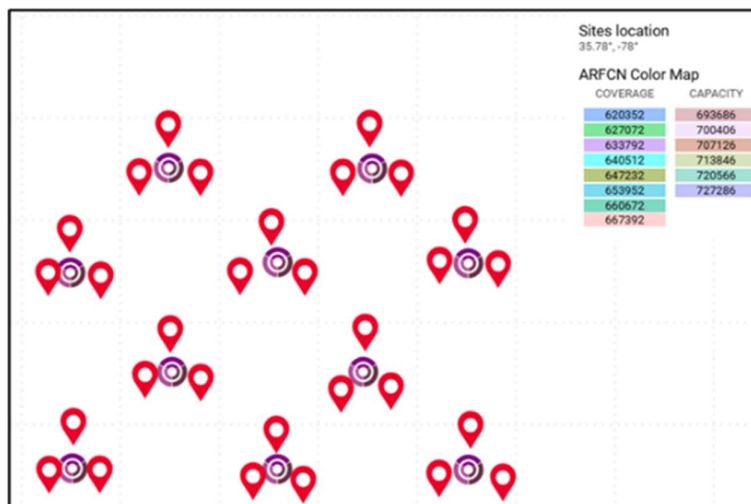
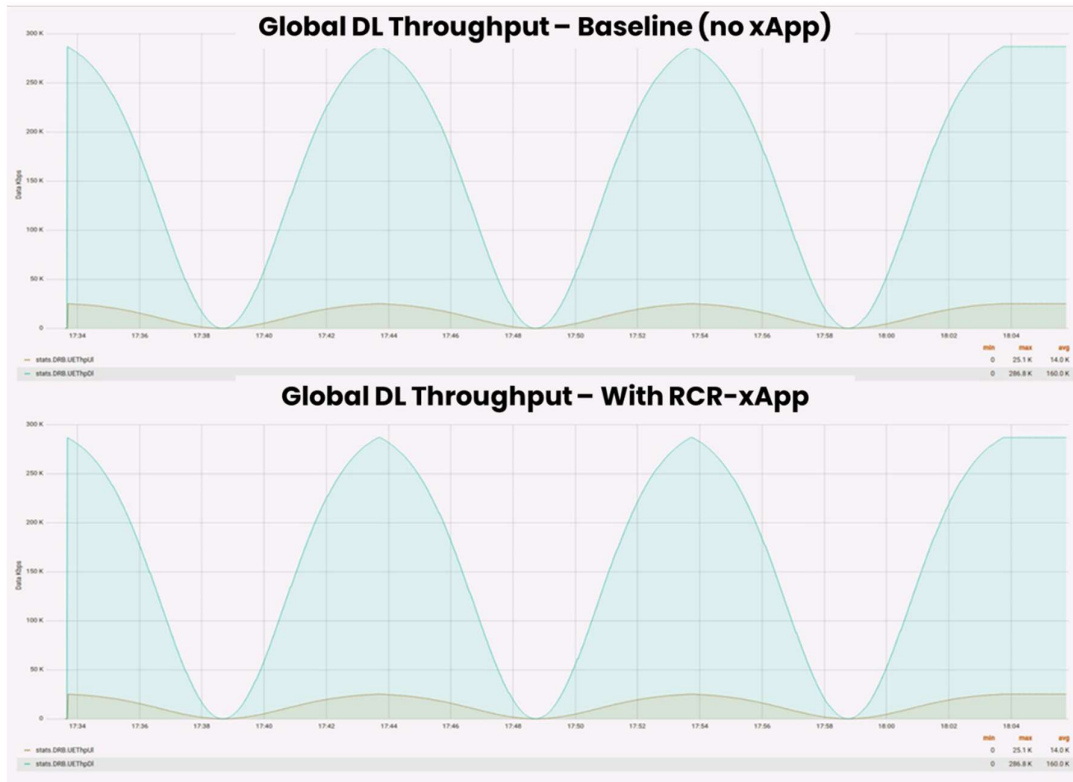


Figure 0-2 UE and E2 Nodes deployment. Based on [1].

The ability of RCR-xApp to follow with RF channel reconfiguration with UE traffic demand changes are presented in Figure 5.6-3. The Global DL throughput in the top plot, related to the baseline scenario (without the xApp), is almost identical to the bottom one achieved by the Rimedo Labs RCR-xApp. This means that dynamic scaling of the number of active RF channels done by the RCR-xApp is done without a negative impact on the UE QoS.

**Figure 0-3 Comparison of Global DL throughput between baseline scenario (without xApp), and when Rimedo Labs RCR-xApp is enabled. Based on [1].**

Finally, while being sure that the application of the RF channel reconfiguration NES feature by the RCR-xApp is not deteriorating network performance, the NES performance is analysed. The results presented in Table 5.6-1 show that by applying RF channel reconfiguration during the low load periods the network power consumption can be significantly reduced compared to the baseline (without the xApp). At the same time, during maximum load (of about 50% utilized PRBs per cell), the RCR-xApp keeps all the RF channels active to preserve system throughput. Specifically, at maximum load the consumed power is equal to about 48.2 kW for both baseline scenario and when the RCR-xApp is introduced. However, during minimum load period the power reduction range is from about 14.9 kW to 4.6 kW. This results in about 69% power savings achieved by reducing the number of RF Channels from 64 to 16. On average, in the considered scenario, thanks to the RCR-xApp, the power consumption can be reduced by about 30%.

Table: 5.6-1 Summary of NES provided by RCR-xApp. Based on [1].

Test	Description	Power Consumption at Maximum Load (kW)	Power Consumption at Minimum Load (kW)	Avg Power Consumption over 30-minute traffic model (kW)	Number of Active RF Channels during Minimum Load
1	Baseline	48.2	14.9	33.2	8x8 (64 in total)
2	With RCR-xApp	48.2	4.6	23.5	4x4 (16 in total)
	Analysis	-	~69% saving	~30% saving	75% reduction

The final remarks from testing the RCR-xApp can be formulated as follows:

1. The Near-RT RIC implementation of RF channel Reconfiguration NES features was successfully demonstrated on the example of the RCR-xApp deployed on Juniper Near-RT RIC.
2. The RCR-xApp to perform RF channel reconfiguration utilizes E2SM-RC, E2SM-KPM, and E2SM-CCC.
3. The RCR-xApp was verified against the O-RAN protocol stack using RAN emulated by Keysight RICTest.
4. The fast control loop and report period related to the Near-RT RIC and E2 interface enables the RCR-xApp to dynamically adjust the number of active RF channels to the varying network traffic.
5. For the considered network, the average power consumption gain is about 30%, and about 9.7 kW, meaning that yearly energy savings would be about 84.9 MWh.
6. At the same time, the RCR-xApp maintains global DL throughput.
7. Further studies based on the live-network data and field trials are necessary to push the RF channel reconfiguration NES feature for wide-network deployments.

Operator-led evaluation of RF channel reconfiguration using Non-RT RIC rApp (Rakuten Mobile, Japan OTIC PlugFest Fall 2023)

Rakuten Mobile evaluated the RF channel reconfiguration NES feature in a Japan OTIC / Rakuten Mobile Lab as an operator-led energy saving use case using a Non-RT RIC and rApp-based control framework. The purpose of the evaluation was to confirm whether reducing the active transmit chain configuration during low traffic periods can reduce RRH/O-RU power consumption while making the associated radio performance trade-off visible to the operator.

In PlugFest Fall 2023 evaluation, the RF channel configuration was changed from 4Tx/4Rx to 2Tx/4Rx. The rApp identified candidate periods for downlink transmit chain reduction using traffic and subscriber behavior analysis. The expected energy saving gain was estimated to be in the range of 10-15%, depending on the extent to which transmit chain components such as the PA can be switched off or placed into an energy saving mode. The same evaluation also confirmed an important service trade-off:

UEs that could originally use four downlink layers may be limited to two layers after RF channel reduction, and therefore user throughput and coverage impact need to be considered before activation.

In a later PlugFest Spring 2025 evaluation, the setup was extended into a more explicit measurement-oriented test using a 4G configuration. The RRH configuration was changed from 4T4R to 2T4R by Rakuten's rApp, and RRH power consumption was measured under three iPerf traffic scenarios. The measured power reduction was 38% for the 100 Mbps traffic scenario, 31% for the 200 Mbps traffic scenario, and 13% for the 400 Mbps traffic scenario. The absolute power values were intentionally masked in publicly available material, but the relative reductions show a clear dependency between traffic load and achievable saving: the gain is larger when the offered traffic is lower, and smaller when the radio chain is more heavily used.

These results indicate that RF channel reconfiguration can provide measurable RRH/O-RU power reduction, but this feature should not be applied as a simple time-of-day “switch”. The operator should evaluate the traffic load, expected MIMO layer usage, coverage role of the cell, and user throughput impact before activating this feature. The result also suggests that RF channel reconfiguration is most suitable for capacity-oriented cells or periods where the additional transmit layers are underutilized, while coverage-critical cells or high-rank traffic conditions may require more conservative thresholds or exclusion from the feature.

Figure 0-4 and Figure 0-5 shows the test setup and results of RF channel reconfiguration testing with rAPP.

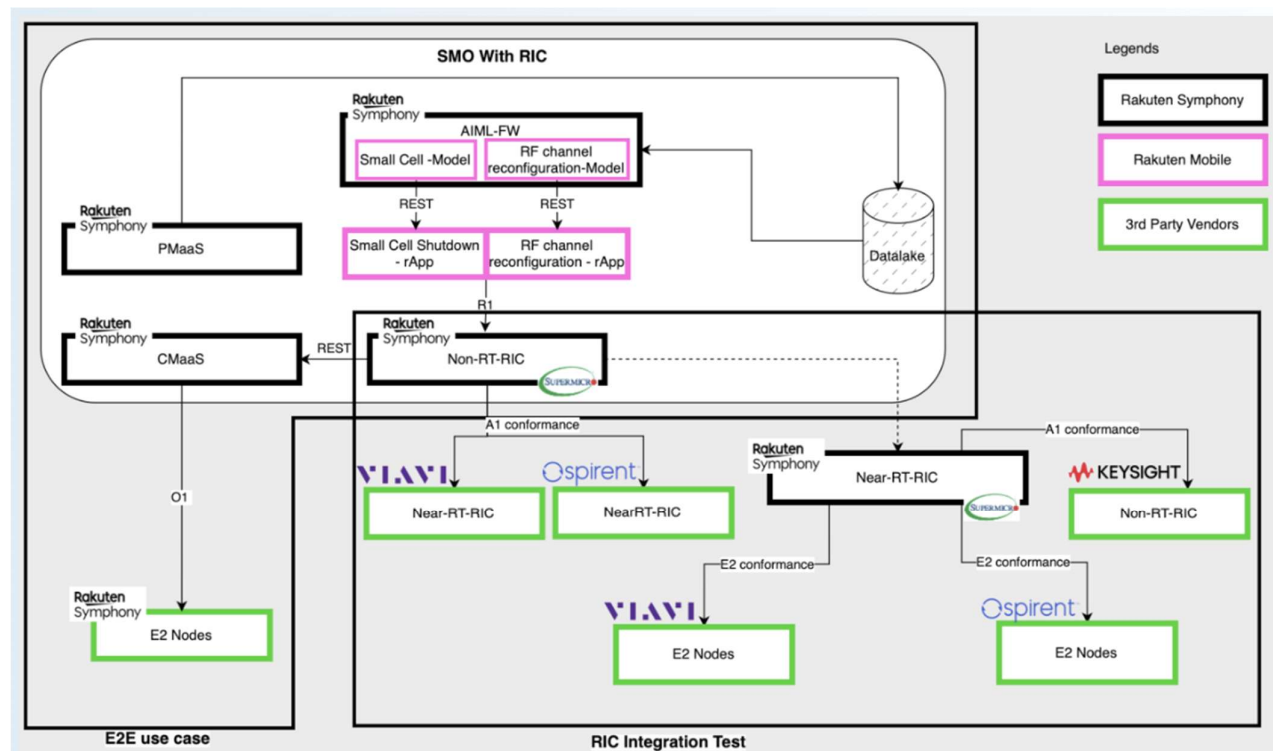


Figure 0-4 Test setup for RF channel reconfiguration testing with rAPP

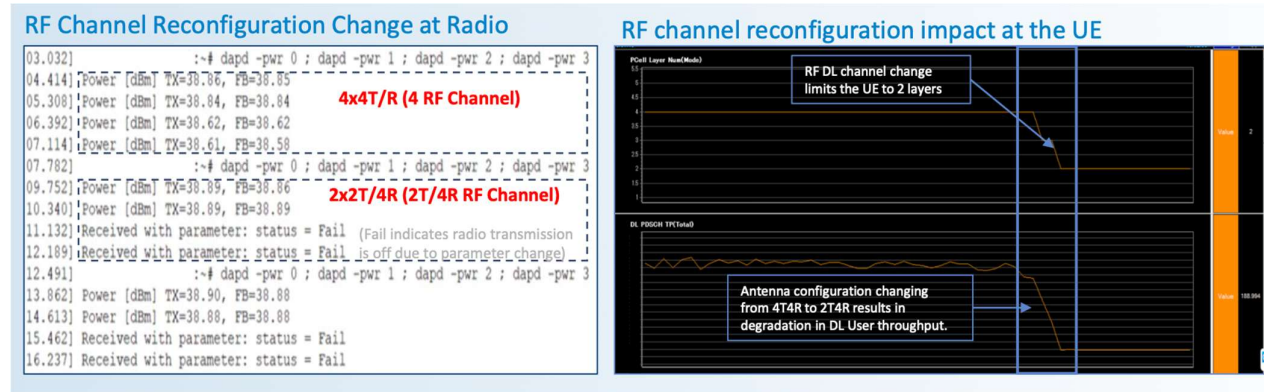


Figure 0-5 Test results for RF channel reconfiguration

Advanced sleep mode

Feature overview

Advanced sleep mode NES feature is expected to reduce power consumption by switching off certain O-RU components for a duration of time.

Use cases

Load traffic periods in urban areas

During off-peak hours (e.g., midnight to early morning), gNBs in urban areas experience minimal user activity.

The Advanced Sleep Mode dynamically deactivates specific components (e.g., power amplifiers, antenna ports) or transitions gNodeBs to an appropriate sleep mode during these periods.

The choice of sleep mode can be made by considering the sleep duration and the wake-up duration.

Event-driven traffic spikes

Stadiums or concert venues experience high traffic during events but remain nearly idle otherwise. The Advanced sleep mode uses predictive algorithms based on historical data or real-time traffic patterns to switch to light-sleep (e.g., reduced MIMO layers or bandwidth parts). Advance sleep mode feature involves dynamically switching off O-RU's components depending on the time needed for activation and deactivation of the O-RU's components. If the depth of sleep is higher, the wake-up time is longer. During events that require high traffic load, the system can quickly scale up resources, while post-event, it reverts to sleep modes to save energy. When traffic in hot spots is low because there is no event, both the cell/carrier shutdown and advanced sleep mode features could be used.

Seasonal traffic periods

Another possible use case could be cells located in seasonal tourist areas that could extend their switch-off to the whole day, except perhaps for holiday periods, advanced sleep mode feature should be used in conjunction with cell/carrier shutdown, as it goes one step further and switches off the electronic components of the cells/carriers.

End to end advanced sleep mode implementation approach

Figure 0-1 E2E Implementation Approach provides the functionalities of different nodes in O-RAN for implementing Advanced sleep mode NES feature.

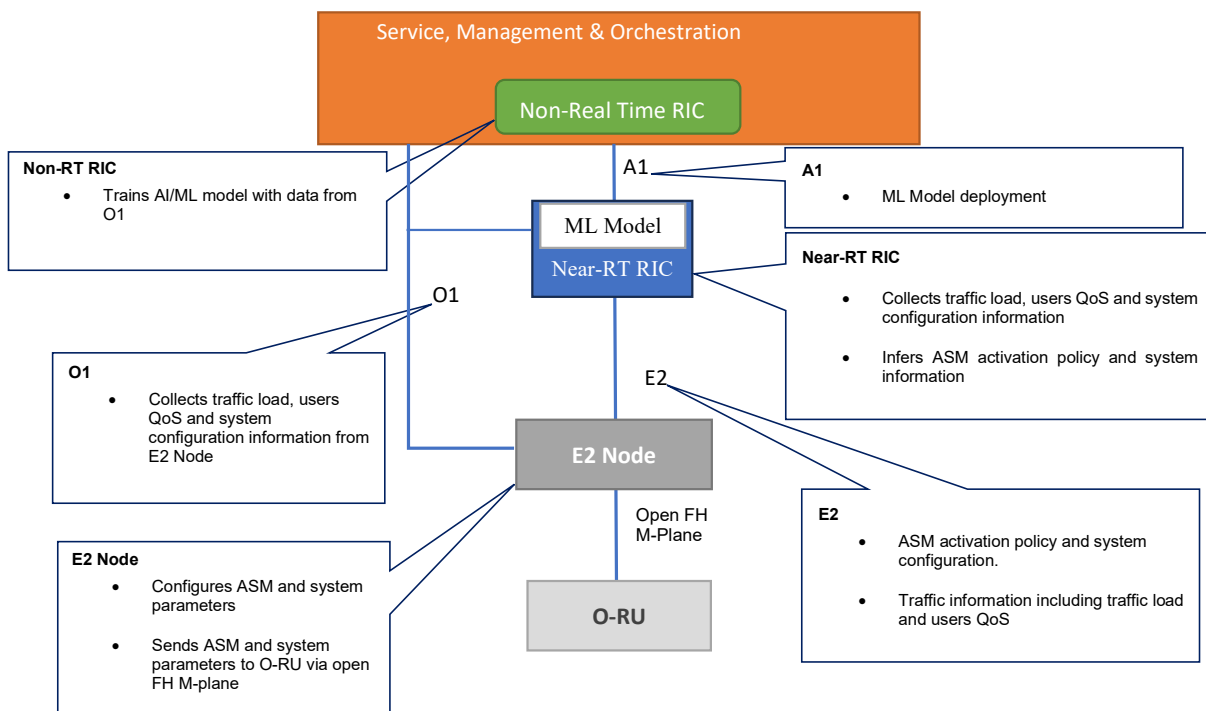


Figure 0-1 E2E Implementation Approach

O-RAN components implementation and reference

Non-RT RIC Implementation

This implementation proposes a framework that allows the operator to flexibly select various sleep mode parameters through an A1 policy formulated by an rApp to a Near-RT RIC through the SMO/Non-RT RIC framework, assisted by Machine Learning (ML) techniques.

The functions of Non-RT RIC are mentioned below:

1. Collects configurations, performance indicators, and measurement reports (e.g., cell load-related information and traffic information, EE/EC measurement reports) from E2 node(s) and

trace records (e.g., per-UE measurement metrics and location information) through the O1 interface. For decision making, the NON-RT RIC can optionally use training and inference of AI/ML models that assist such NES functions.

2. Transfers the collected data to the rApp. It is assumed that configurations, performance indicators and measurement reports collected from the O-DU, contain the related information for the corresponding O-RU(s).
3. Signals A1 policies for the Near-RT RIC for ASM optimization.
4. (Optionally) Retrain, update, configure AI/ML models in the Non-RT RIC.

Near-RT RIC Implementation

The goal of Near-RT RIC energy saving is to interpret the policies received over the A1 interface and to determine the optimum changes it can make according to these policies. More specifically, a Near-RT RIC triggers E2 procedures and related control/policies to obtain network performance information that would fulfill the criteria identified in the A1 policies.

Based on the UE context information, E2 measurement metrics (RIC REPORT), and A1 policy, Near-RT RIC may generate new or modify the existing E2 policies and send them to E2 nodes.

The guided configurations can include: - Indication of the slot numbers, symbol numbers and the conditions for the sleep mode configuration to be applied.

OAM Implementation

An implementation for the Advanced sleep mode NES capability within the OAM may be the following:

1. The SMO provides advanced sleep mode based energy saving related policy/configuration details to the O-DU
2. The O-DU examines the conditions(s) provided in configuration/policy related to Advanced Sleep Mode.
3. The O-DU monitors relevant data and watches for the thresholds configured/provided in the policy
4. Once conditions provided in the policy are satisfied, the O-DU activates or deactivates the appropriate Advanced Sleep Mode in O-RU using Open Fronthaul C-Plane message.
5. The O-RU processes the Open Fronthaul C-Plane or Open Fronthaul M-Plane message and activates/deactivates the corresponding Advanced Sleep Mode.
6. The O-RU sends the ACK/NACK message to O-DU via Open Fronthaul C-Plane.

Open Fronthaul Implementation

As part of the capability reporting to O-DU via M-Plane, an O-RU can report support for the below functionalities. It is reported per each **tx-array/rx-array**

1. Support for different types of sleep modes (SM0, SM1, SM2, SM3).
2. Details for each sleep mode,

- Wakeup Duration – Amount of time O-RU can take to wake-up from sleep and be ready for operation.
- 3. Wakeup Guarantee – Wakeup Duration can be a Guaranteed/Minimum Sleep duration control – can be any defined duration or can be an undefined duration-

The configuration is implemented using ST4 command using **st4CmdType**: Advanced Sleep Mode.

O-RAN specification reference

WG Reference	Clause
O-RAN.WG2.TS. Use-Case-Requirements	4.8.3
O-RAN.WG3.TS.UCR	4.6.2
O-RAN.WG4.MP	20.4
O-RAN.WG4.TS.CUS	16.3
O-RAN.TS.WG10.OAM-Architecture	4.2.5.2

Challenges and considerations

The activation and deactivation of advanced sleep mode feature is governed by a set of key performance indicators (KPIs) including, but not limited, to cell load and resource block (RB) utilization. Additionally, average cell throughput and user throughput may be continuously monitored in conjunction with overall cell performance metrics. It is recommended to disable this feature proactively in scenarios where its operation adversely affects network performance. It is also recommended that coverage-related cell carriers be excluded from the scope of this feature, as their deactivation is not permissible due to coverage preservation requirements.

Case study/best practices and results

Operator-led evaluation of O-RU micro-sleep behaviour with symbol-level blanking (Rakuten Mobile, Japan OTIC)

Rakuten Mobile evaluated O-RU micro-sleep behavior in Japan OTIC / Rakuten Mobile Lab as part of the PlugFest energy saving activities. The evaluation focused on a symbol-level energy saving mechanism where the O-DU generates an Open Fronthaul C-plane message using Section Type 0 to indicate idle or guard periods. When no resource elements are allocated in a given symbol region, the O-DU can indicate the relevant start-symbol and number-of-symbols information, allowing the O-RU to switch off the PA during the indicated no-data interval.

The evaluation used a power meter to measure the O-RU power consumption under different load conditions by varying the number of blanked symbols. The test was performed using both a real O-DU from Rakuten Symphony and a DU emulator from Keysight, allowing the same micro-sleep behavior to be checked in two different integration environments. The traffic/load model included full load, busy load, medium load, and low load cases. For symbol-based allocation, testing included a busy-load case with seven active symbols and seven blanked symbols, and a medium-load case with four active symbols and ten blanked symbols.

The reported result was that when micro-sleep mode was enabled an energy saving gain of 10-20% was observed depending on the traffic load. The evaluation also showed that the gain increases when the number of consecutive blanked symbols increases. A further useful observation is that similar gains were observed with both the real O-DU and the DU emulator, which gives confidence that the result is related to the O-RU micro-sleep behavior and the idle-symbol pattern, rather than being specific to a single integration setup.

The practical lesson is that micro-sleep is not only an O-RU hardware feature; it is also affected by O-DU scheduling behavior. The scheduler needs to create sufficiently long consecutive idle symbol regions for the O-RU to exploit the low-power state efficiently. Therefore, micro-sleep validation should include both power measurement and scheduler behavior observations. Any testing should document the load condition, the number of active and blanked symbols, the measurement method, and whether the result was obtained with a real O-DU, a DU emulator, or both.

Figure 0-1 and Figure 0-2 shows the test setup and results for micro sleep testing.

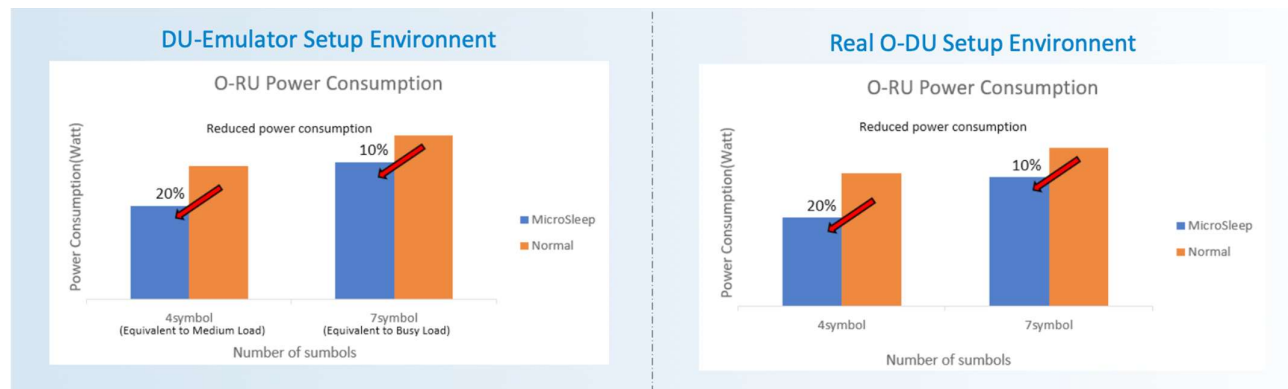


Figure 0-1 Power consumption results with DU emulator and real O-DU

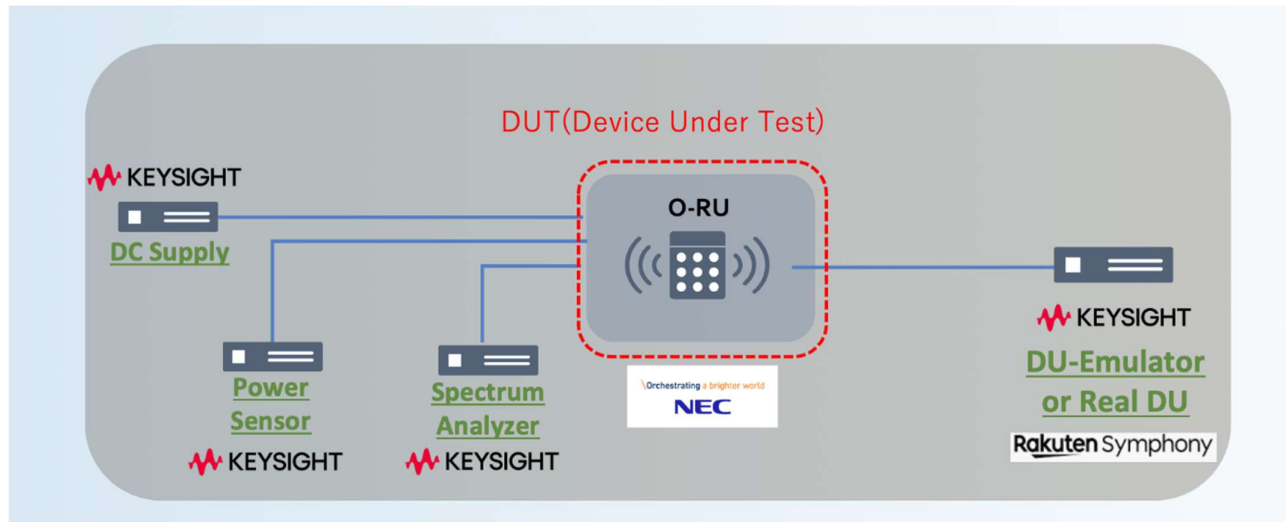


Figure 0-2 Test setup for O-RU micro sleep

Deep hibernate

Feature overview

During deep hibernate, the entire O-RU is switched off for a pre-determined duration of time. The O-RU switches on automatically after the end of the predetermined time. All the control, user, synchronization and management plane processing software and hardware can be switched off to give high energy savings.

Use cases

Low traffic periods in urban areas

In dense urban areas (e.g., city centre), traffic drops significantly during late-night or early-morning hours (e.g., 2–5 AM). For example, office districts or commercial areas have minimal UE activity during these times.

Deep hibernate sleep mode involves deactivating nearly all hardware components of the radio unit.

Deep hibernate should be used in conjunction with the cell/carrier shutdown, as it goes one step further than the previous one and switches off all the electronic components of the cells/carriers. This feature has the same use cases as in the carrier/cell shutdown will apply but the time to wake up should be very carefully analysed, as this feature needs more time than carrier/cell shutdown feature to switch on again the electronics.

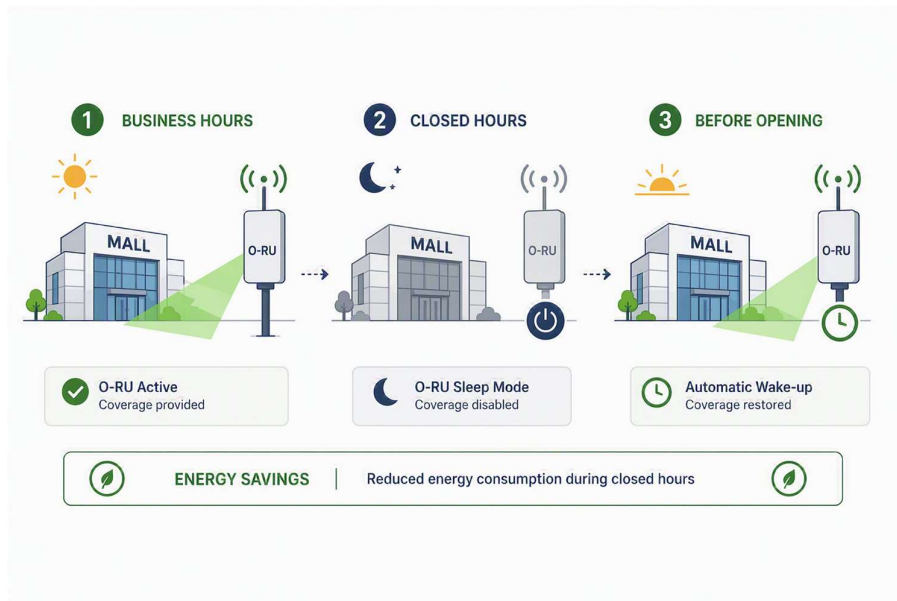


Figure 0-1 Use case for Deep hibernate

Event-driven traffic spikes

Stadiums or concert venues experience high traffic during events but remain nearly idle otherwise.

Deep hibernate sleep uses predictive algorithms based on historical data or real-time traffic patterns to switch to deep sleep when no event is scheduled.

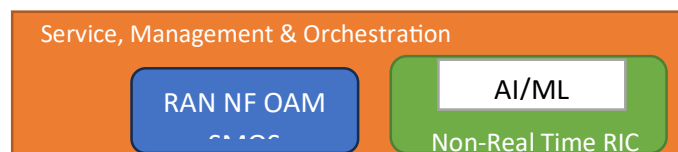
This involves switching off O-RU's components depending on the time needed for each of them to deactivate and reactivate again. The depth of sleep is higher, and the wake-up time is longer.

During events, the system can quickly scale up resources, while post-event, it reverts to deep sleep to save energy.

When traffic in hot spots is low because there is no event, deep hibernate features could be used. However, the time to wake up needs to be very carefully analysed, as this feature needs more time (than the carrier/cell shutdown feature) to switch on electronics again. It is also important to ensure that coverage from external cells will be maintained when the O-RU is put in deep hibernate mode.

End to end deep hibernate implementation

Figure 0-1 E2E Implementation Approach provides the functionalities of different nodes in O-RAN for implementing deep hibernate NES feature.



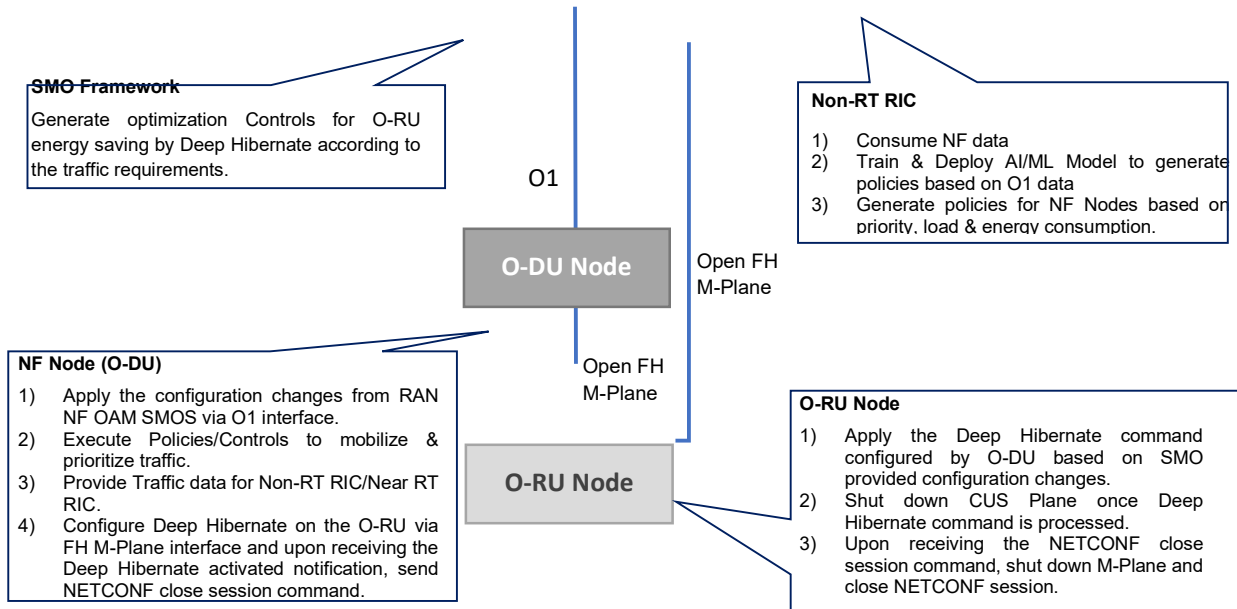


Figure 0-1 E2E Implementation Approach

O-RAN components implementation and reference

Near-RT RIC Implementation

The goal of Near-RT RIC energy saving is to interpret the policies received over an A1 interface and to determine the optimum changes it can make according to these policies. WG4 defines a standardized deep-hibernate mechanism on the O-RU M-plane that allows an O-RU to enter an extended low-power state with a controlled wake-up. Building on that device-level capability, this use case places the decision of when/where/how long to hibernate under policy-driven, near-real-time control in the RAN via the E2 interface, while keeping all WG4 procedures unchanged.

The Near-RT RIC evaluates live measurements and capabilities, determines eligible cells/sectors, and commands deep-hibernate via the E2 Node, which then realizes the action using existing WG4 mechanisms. For example, a mechanism defined by WG4 is invoking the standardized deep-hibernate RPC toward the O-RU after verifying prerequisites, such as carrier deactivation. Both ES mode 1 and ES mode 2 are supported by the O-RAN specifications.

OAM Implementation

A solution for the Deep hibernate implementation within the OAM may be the following:

1. The SMO uses O1 interface to provide the O-DU with configuration to trigger Deep-Hibernate of O-RU.
2. The O-DU triggers activation of Deep-Hibernate in O-RU using Open Fronthaul M-Plane interface.

3. Once O-RU enters Deep-Hibernate (which results in OFH M-Plane session termination between the O-DU and the O-RU), the O-DU updates its O-RU model to reflect the O-RU entering deep hibernate.
4. The O-DU sends O-RU model update notification to SMO.

Open Fronthaul Implementation

Capability reporting of O-RU: via M-Plane

Configuration of O-RU: via M-Plane

As part of the capability reporting via M-Plane, an O-RU can report Maximum Hibernate time and Minimum Hibernate time supported.

To achieve this, a new <deep-hibernate> RPC command via M-Plane is introduced.

The O-DU can use this RPC, along with the parameter “hibernate-time” to put the O-RU to deep hibernate mode.

O-RAN specification reference

WG Reference	Clause
O-RAN.WG4.MP	20.5

Challenges and considerations

The activation and deactivation of deep hibernate feature is governed by a set of key performance indicators (KPIs) including, but not limited to, cell load and resource block (RB) utilization. Additionally, it is recommended continuously monitor average cell throughput and user throughput in conjunction with overall cell performance metrics. It is also recommended to disable this feature proactively in scenarios where its operation adversely affects network performance. The coverage-related cell carriers should be excluded from the scope of this feature, as their deactivation is not permissible due to coverage preservation requirements.

Time to wake up needs to be carefully analysed, as this feature needs more time (than other NES features) to switch the electronics on again after shutting down. This is because wake-up should be before the designated operational window to ensure all components are fully functional and stable prior to the commencement of the defined period.

PA Power Optimization

Feature overview

PA optimization NES feature is expected to reduce O-RU power consumption by adjusting the parameters and the operating region of its power amplifier(s) for a certain duration of time.

Use cases

Load traffic periods in urban areas

During off-peak hours (e.g., midnight to early morning), gNBs in urban areas experience minimal user activity and throughput requirements. PA power optimization dynamically configures the power amplifier operating region or transitions gNodeBs to optimize their power amplifiers during these periods, thereby optimize O-RU power consumption. The choice of PA operating region can be made by considering traffic requirements and O-RU transition time. This feature should be used when the traffic pattern changes over a period of time, since the PA operating region needs to be adjusted according to the traffic requirements.

Event driven traffic spikes

Downtown areas experience high traffic during office hours but normally have less throughput requirements during the remaining time of the day. PA power optimization uses predictive algorithms based on historical data or real-time traffic patterns to adjust the O-RU maximum power, where O-RU adjusts its PA parameters according to the maximum power configured by O-DU. This involves dynamically adjusting the O-RU's maximum output power and, thereby, the PA power consumption can be reduced to achieve energy saving in gradual manner. If the PA transition time is high, the wake-up time is longer. During high traffic events, the system can quickly scale up resources. Post-event, it reduces the maximum output power to save energy. When traffic in hot spots is low, both the advanced sleep mode and PA power optimization features could be used.

Seasonal traffic periods

Another possible use case could be cells located in seasonal tourist areas that could extend their switch off or reduction of maximum power to the whole day, except perhaps for holiday periods. PA power optimization feature should be used in conjunction with the cell/carrier shutdown, advanced sleep mode, as it additionally adjusts the PA parameters that impact cells/carriers based on the utilization.

End to end PA power optimization implementation approach

The end-to-end PA power optimization can be implemented using two approaches, where one is based on non-RT RIC/O1 and the other is based on the Near-RT RIC/E2. The non-RT RIC/O1-based

implementation is shown in Figure 8.3-1. For more details, please refer to clause 4.21.3.5.1 of [10] and clause 4.21.3.5 of [11].

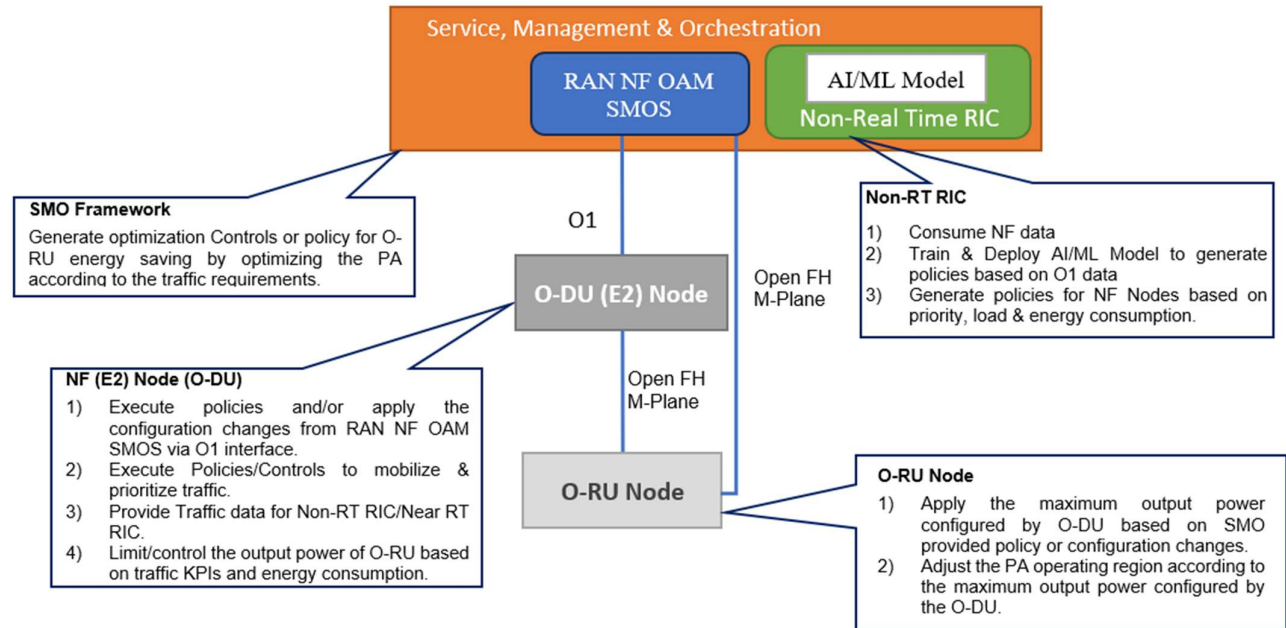


Figure 0-1 End to end PA power optimization implementation approach - Non-RT RIC and O1 based solution [Clause 4.21.3.5 of [11]].

The near-RT RIC/E2 based implementation is shown in Figure 8.3-2. For more details see clause 4.21.3.5.2 of [10] and clause 4.21.3.5 of [11].

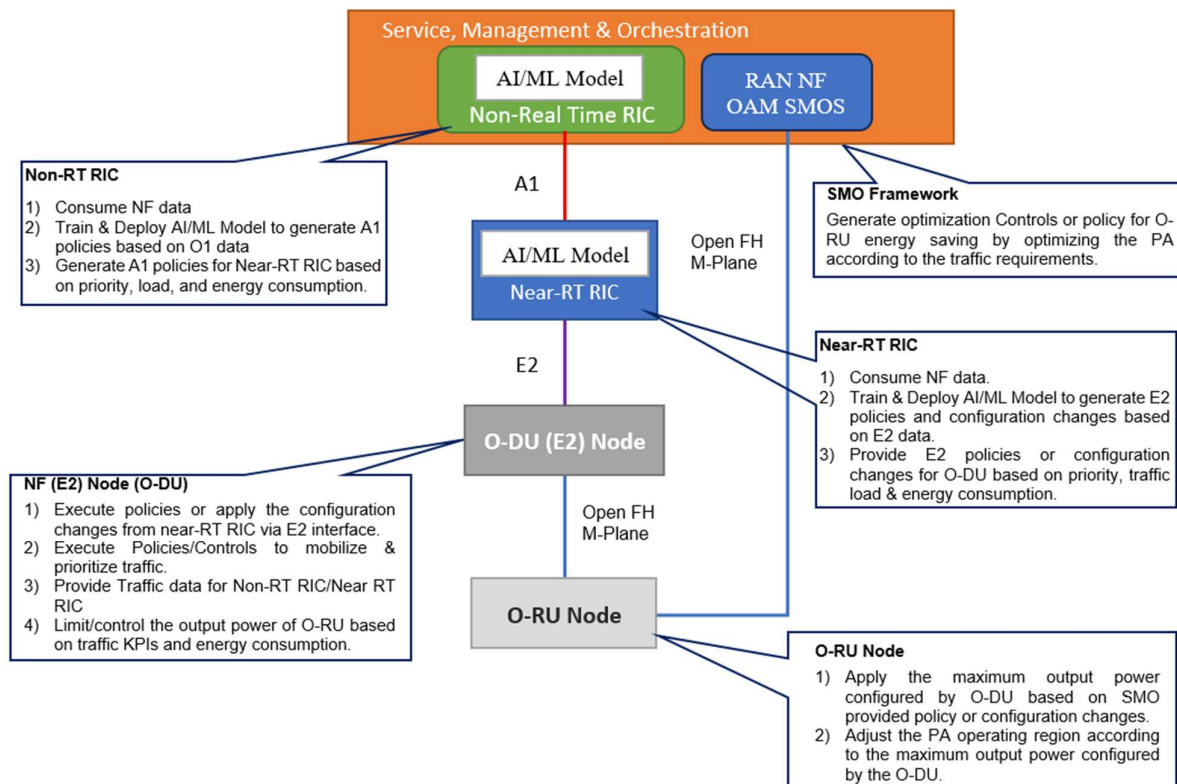


Figure 0-2: End to end PA power optimization implementation approach - Near-RT RIC and E2 based solution [Clause 4.21.3.5 of [11]].

O-RAN components implementation and O-RAN references

Non-RT RIC Implementation

The SMO/Non-RT RIC framework collects the configurations, performance indicators and measurement reports (e.g., cell load related information and traffic information, EE/EC measurement reports) from E2 node(s) through an O1 interface for the purpose of decision making.

An rApps collect the necessary configurations, performance indicators, and measurement reports from SMO/Non-RT RIC framework for the purpose of training and execution of relevant AI/ML models. The rApps consume the data for O-RU PA power optimization through an R1 interface and triggers EE/ES optimization through a RAN NF OAM SMOS via the O1 interface to execute the PA power optimization [10].

Near-RT RIC Implementation

The rApp triggers the EE/ES optimization through A1 policy based on the Operator's requirements using the PA power optimization feature. Non-RT RIC framework receives policy from rApp and also analyzes the performance data to provide the NES A1 policy and/or NES related A1 Enrichment information to a near-RT RIC via A1 interface. In this process, AI/ML inference may be used to make the decision.

The Near-RT RIC analyzes the A1 policy to determine the required data collection and E2 control/policies. An inferring AI/ML model to evaluate and generate E2 control or policies for PA power optimization in the specific O-RU.

The Near-RT RIC collects the performance data from E2 nodes (O-RAN NFs such as O-DU and O-CU) and configures E2 node i.e., O-DU via E2 interface for PA power optimization in the specific O-RU. Then the O-DU configures the maximum output power level in O-RU.

OAM Implementation

In this section, the OAM aspects of PA power optimization feature are described for both Non-RT RIC/O1 and Near-RT RIC/E2-based implementations.

In Non-RT RIC/O1 based implementation, the SMO analyzes the consumed performance data and provides the NES policy and/or configuration details to O-DU via O1 interface. Similarly, in Near-RT RIC/E2-based implementations, the Non-RT RIC provides the A1 policy to the Near-RT RIC via the A1 interface. The Near-RT RIC then translates the A1 policy to E2 policy or configurations and provides it to the O-DU via E2 interface.

The O-DU examines the conditions provided in the configuration/policy (received via O1 or E2 interfaces) related to PA power optimization, monitors relevant data, and watches for the thresholds configured/provided in the policy. Once conditions provided in the SMO or Near-RT RIC policy are satisfied the O-DU activates or deactivates the PA power optimization in the O-RU. The activation or

deactivation of PA is done using the Open Fronthaul M-Plane command or C-Plane ST4 Command. Once the maximum output power level is configured by the O-DU, via M-Plane or C-Plane ST4 command, and applied by the O-RU, then the O-DU may schedule the traffic (e.g., PRBs) according to the maximum output power configured in the O-RU [4-5]. In response to this, the O-RU sends the notification to the O-DU via Open Fronthaul M-Plane.

Open Fronthaul Implementation

As part of capability reporting via M-Plane, O-RU can report support for below functionalities,

All the capabilities below are reported per each **tx-array/tx-array-carrier**.

1. List of maximum power control methods supported (Maximum power per tx-array/tx-array-carrier)
2. List of supported maximum power levels

The configuration can be done either via M-Plane [Clause 20.6 of [5]] or via C-Plane ST4 Command [Clause 16.14 of [4]]

O-RAN specification reference

WG Reference	Clause
O-RAN.WG1.TS.Use-Cases-Detailed-Specification-R005	4.21.3.5, 4.21.4.5
O-RAN.WG2.TS.Use-Case-Requirements-R005	4.21.3.5
O-RAN.WG3.TS.UCR-R005	4.6.8
O-RAN.WG4.MP.0-R005	20.6
O-RAN.WG4.TS.CUS.0-R005	7.2.9.2.5, 7.4.6, 7.5.3.38, 7.5.3.125, 8.1.3.3, 10.2.6, 10.2.10, 16.1, 16.14
O-RAN.TS.WG10.OAM-Architecture-R005	4.2.5.4

Challenges and considerations

The activation and deactivation of the feature could be governed by a set of key performance indicators (KPIs) including, but not limited to, cell load and resource block (RB) utilization. Additionally, an average cell and user throughput and coverage range could be continuously monitored in conjunction with overall cell performance metrics. The feature could be disabled proactively in scenarios where its operation adversely affects network performance. It is recommended that coverage-related cell carriers be included for PA power optimization feature, as their activation does not affect the coverage preservation requirements.

NES RF Environment Variables

Understanding the RF Environment Interdependencies with NES

Implementation of Network Energy Saving features requires a holistic approach to assess the designated RF environment of the intended NES use. Various aspects need to be considered in order not to introduce any significant degradation in Customer Experience and implications in critical areas of the mobile network service provisioning. Some primary focus areas are discussed in the sections below.

Frequency Bands:

To understand mobile network operation, we need to start with the frequency layers used by specific mobile network operators. The complexity of live network operations depends on the number of activated bands per site (capacity driven dimensioning). Typically, NES features adaptation covers all operational frequency bands operations.

An example from the live network NES implementation for RF Environment definition. Assuming polygon of eight 3-sector mobile network sites in the vicinity with three frequency bands per sector. List of frequencies used are:

1. First Frequency Band: 18 (800MHz)
2. Second Frequency Band: 3 (1800MHz)
3. Third Frequency Band: 7 (2600MHz)

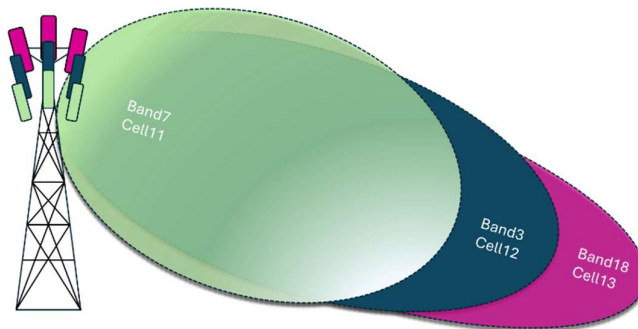


Figure 0-1 Frequency Bands vs Coverage

Applying NES features with a default configuration on all three frequencies may lead to coverage holes. Precisely, if Band18 is treated in the same manner as Band7, it is feasible that overlaying coverage is disturbed in the polygon in question. Band 7 is predominantly used as a capacity layer with a smaller coverage footprint due to shorter lambda. Respectively, lower frequency bands, such as Band18 can be characterized as coverage layers. Hence, NES settings have to be correlated with the Operator capacity and coverage strategies.

An example of how coverage can be degraded is presented below in three scenarios. Scenario A shows 8x3 polygon with all three frequency bands active without NES features enabled. Scenario B shows 8x3 polygon where the cells from replicated sector are treated in the same manner causing coverage gaps. Scenario C shows 8x3 polygon when NES feature carrier shutdown (load-driven) is only deployed on the capacity layer on the replicated sector.

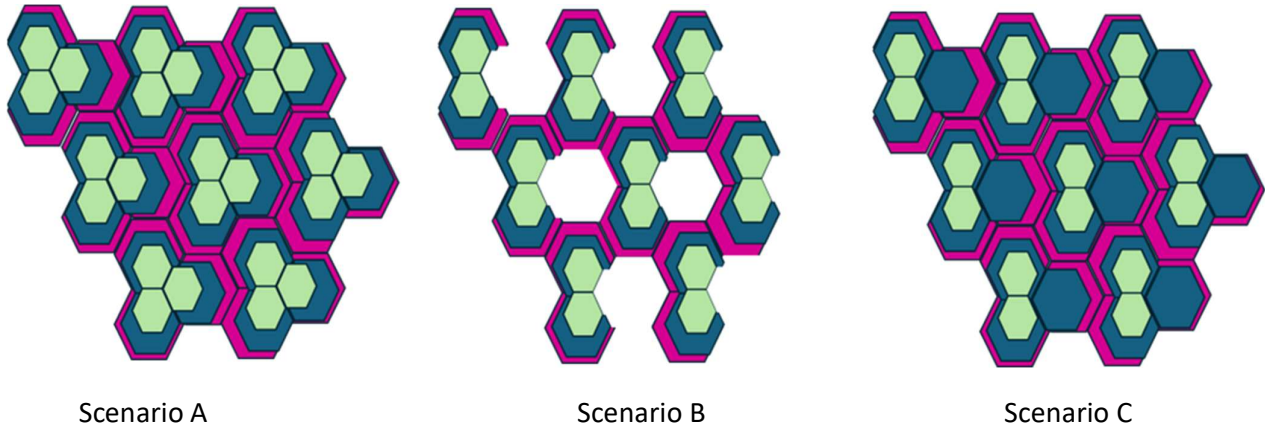


Figure 0-2 Polygon 8x3 Frequency Bands Visualization Top View

RAN parametrization:

RAN parametrization for NES adaptation area should reflect interdependencies between transmitted/enabled bands. Example of configuration parameters are TX Powers, antenna tilts, and Handover hysteresis. Furthermore, mobile operator strategies applied to various location types have to be addressed as multiple guidelines might be applicable per region/polygon exclusively.

Thresholds driven by parametrization in live networks focuses on two areas:

1. Events steering:
 - a. Signal strength
 - b. Signal quality
 - c. Handover-related thresholds
2. Statistics:
 - a. Call success rate
 - b. Handover quantity
 - c. Packet loss rate
 - d. Cell load levels

End User Group Types:

Additionally, different profiles of mobile user types could be addressed e.g. static mobility profiles of users, high level of mobility users, static metering-based subscribers. Understanding End User Group Types (EUGT) that populate different areas in the operator's subscriber database may play a significant role in selecting appropriate NES features per location. Recognition of capacity, speed, and network availability per EUGT improves overall NES energy efficiency by adopting appropriate strategies.

EUGT profiles example:

1. Metering type, low traffic volume: IoT, M2M
2. Stationary type, large traffic volume: Mobile Broadband
3. Mobile type, significant traffic volume: Hyper-connected

In reference to NES features, data-layer control implementation using an Open Fronthaul can be applied to regions populated by EUGT metering type subscriber. By doing so, the potential risk of customer experience degradation is significantly lower.

Key Performance Indicators:

End user network performance monitoring covers typically a set of regularly monitored KPIs (i.e. user throughput statistics, number of connected active users, resource blocks utilization). Deutsche Telekom AG has developed Field Identified Levels of In-Objective Perception unit (FILIP) to analyze those KPIs with a holistic approach. FILIP formula presented in this publication focuses on the delta of end user performance to be calculated before and after any NES features are switched on for uplink and downlink. The X factor in FILIP_{Delta} formula can be used to extend calculations by adding additional accessibility KPIs.

The following is a sample of performance indicators considered:

- Throughput peak and average values
- Sampling time of measured data
- PRB utilization
- number of active users
- data volume transmitted
- number of handovers CSR
- connection re/&/establishment CSR
- extendable accessibility KPIs factor X

$$\begin{aligned}
 & \mathbf{FILIP}_{DL\Delta} \\
 &= \left[\frac{\left(\frac{(THR_{DLMax} - THR_{DLave}) * T_{ST}}{TOT_{DLVol}} \right) + \left(\frac{HO_{CSR} + RRC_{SCSR} + RRC_{RECSR} + PRB_{DLAR}}{X * 100} \right)}{TOT_Users_{ASTR}} \right]
 \end{aligned}$$

Formula 10.1.4-1: Field Identified Levels of In-Objective Perception (FILIP) for DL direction

THR_{DLMax} – Peak DL throughput over sampling time

THR_{DLave} – Average DL throughput over sampling time

T_{ST} – Sampling Time

TOT_{DLVol} - Total DL Data Volume transmitted over sampling time

HO_{CSR} - Handover success rate Inter/Intra

RRC_{SCSR} - RRC setup success rate

- RRC_{RECSR} - RRC reestablishment success rate
- PRB_{DLAR} - Average allocation rate of PRBs in downlink
- TOT_Users_{ASTR} - Number of all active users reported over sampling time
- X - number of accessibility KPIs

$$FILIP_{ULDelta} = \left[\frac{\left(\frac{(THR_{ULMax} - THR_{ULave}) * T_{ST}}{TOT_{ULDVol}} \right) + \left(\frac{HO_{CSR} + RRC_{SCSR} + RRC_{RECSR} + PRB_{ULAR}}{X * 100} \right)}{TOT_Users_{ASTR}} \right]$$

Formula 10.1.4-2: Field Identified Levels of In-Objective Perception (FILIP) for UL direction

- THR_{ULMax} – Peak UL throughput over sampling time
- THR_{ULave} – Average UL throughput over sampling time
- T_{ST} – Sampling Time
- TOT_{ULDVol} - Total UL Data Volume transmitted over sampling time
- HO_{CSR} - Handover success rate Inter/Intra
- RRC_{SCSR} - RRC setup success rate
- RRC_{RECSR} - RRC reestablishment success rate
- PRB_{ULAR} - Average allocation rate of PRBs in uplink
- TOT_Users_{ASTR} - Number of all active users reported over sampling time
- X - number of accessibility KPIs

Interdependency - Network Features:

Mobile networks operate by delivering various services on top of their infrastructure. Awareness of key services provided or planned to be rolled out by the mobile operator is crucial to efficient operations of most of the NES features that are planned.

An example of a service that introduces a broader analysis of potential implications to all mobile network service delivery is Network Slicing. It has been introduced already in 4G and continued to be offered in both 5G NSA and 5G SA. Slicing can be deployed in various ways and types. The most simplistic approach is to designate a flexible and fixed share of Radio Resource Block per user groups where the EUGT definition may play key role in the overall NES adoption.

Therefore, default activation of NES features without detailed analysis on how Radio Resource Partitioning (RRP) may impact EUGT groups. Energy saving functions in the mobile network always have a tradeoff

between energy saved and service performance obtained by the end users. Decision of which NES features to enable and what is the best parametrization of these features imposes a detailed and a holistic analysis.

NES Decision logic example: Deploy chronological progression comparison of FILIP score in the tested polygon. Compare FILIP scores in DL and UL directions for three consecutive periods addressing comparable load periods, e.g.:

- 7 days sampling time before (no NES initiation yet)
- 7 days during parameters change (NES semi-state)
- 7 days after parametrization stability (NES stabilized)

Next, calculate the delta between different periods.

The example stated above can be used to calculate single and multiple NES features' impact on end user performance. Results for a single NES feature will have the highest impact on end user performance. Multiple NES features deployed and scored in parallel lower the impact on end user performance. However, it is good to allow mobile operators to test a number of features at once, saving time on trial.

Conclusion

This Ecosystem Resource Publication explored a range of Network Energy Saving (NES) features within the O-RAN framework. Through the examination of implementation approaches, deployment considerations, and case studies, it is evident that these features can significantly reduce network energy consumption while maintaining service performance when applied appropriately.

The study demonstrates that O-RAN's open and intelligent architecture provides a flexible foundation for implementing energy-saving mechanisms across different network components. At the same time, successful deployment requires careful consideration of traffic patterns, operational policies, network performance objectives, and interoperability requirements.

The implementations and case studies presented in this publication highlight the effectiveness and practical feasibility of NES features in real-world environments. While the publication covers several representative implementation approaches, other implementations are possible, allowing operators and vendors to adapt these capabilities to their specific network architectures and operational needs. As energy efficiency continues to be a key industry objective, the NES capabilities defined in O-RAN provide valuable tools for building more sustainable and cost-effective mobile networks.

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