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| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Radio Access Network;  Study on network energy savings for NR  (Release 18) | |
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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

3 or greater indicates TSG approved document under change control.

y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# 1 Scope

The present document captures the findings from the study item of "Study on network energy savings for NR" [2].

The study includes how to model network energy consumption especially for a base station, and evaluations of network energy saving gains as well as impact to network and user performance, by reusing existing KPI whenever applicable or new KPIs as needed. The study is also to identify techniques on gNB and UE side that can improve the network energy savings in various domains, potentially with UE feedback/assistance information and information exchange over network interfaces.

The study prioritizes idle/empty and low/medium load scenarios, allow different loads among carriers and neighbor cells, allows legacy UEs to be able to continue accessing a network implementing Rel-18 network energy savings techniques, with the possible exception of techniques developed specifically for greenfield deployments. The study does not include aspects related to IAB.

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP RP-220297: "Revised SI: Study on network energy savings for NR".

[3] GSMA, 5G energy efficiencies: Green is the new black, <https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=54165956&file=241120-5G-energy.pdf>.

[4] 3GPP R1-2205551: "FL summary#4 for performance evaluation for NR NW energy savings".

[5] 3GPP R1-2208216: "FL summary#3 for EVM for NR NW energy savings".

[6] 3GPP R1-2213006: "FL summary for Post-110-R18- NW\_ES2".

[7] 3GPP R1-2210592: "FL summary#4 for R18 NW\_ES".

[8] 3GPP R1-2213013: "Simulation results summary for NW Energy Savings".

[9] 3GPP R1-2210858: "Evaluation results and other performance aspects for network energy savings".

[10] 3GPP R1-2211018: "Discussions on NW energy savings performance evaluation".

[11] 3GPP R1-2211085: "Discussion on NW energy saving performance evaluation".

[12] 3GPP R1-2211097: "NW energy savings performance evaluation".

[13] 3GPP R1-2211241: "Discussion on performance evaluation of network energy savings".

[14] 3GPP R1-2211458: "Discussion on NW energy savings performance evaluation".

[15] 3GPP R1-2211903: "Evaluation results of NW energy saving techniques".

[16] 3GPP R1-2211994: "Discussion on NW energy saving performance evaluation".

[17] 3GPP R1-2212128: "NW energy savings performance evaluation".

[18] 3GPP R1-2212154: "Evaluations for network energy savings techniques".

[19] 3GPP R1-2212259: "NW energy savings performance evaluation".

[20] 3GPP R1-2212541: "Discussions on NW energy savings performance evaluation".

[21] 3GPP R1-2212543: "NW energy savings performance evaluation".

[22] 3GPP R1-2212563: "Discussion on Network energy saving performance evaluations".

[23] 3GPP R1-2211692: "Discussion on network energy saving techniques".

[24] 3GPP R1-2212429: "Discussion on Network energy saving techniques".

[25] 3GPP R1-2211210: "Network energy saving techniques in time, frequency, and spatial domain".

[26] 3GPP R1-2212129: "Network energy saving techniques".

[27] 3GPP R1-2212765: "Discussion on Network energy saving techniques".

[28] 3GPP R1-2212745: "NW energy savings performance evaluation".

[29] 3GPP R1-2209996: "NW energy savings performance evaluation".

[30] 3GPP R1-2213000: "NW energy savings performance evaluation".

[31] 3GPP R1-2212814: "Discussion on Network energy saving techniques".

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

**example:** text used to clarify abstract rules by applying them literally.

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol> <Explanation>

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1]

AAU Active Antenna Unit

BS Base Station

CC Component Carrier

CHO Conditional Handover

EIRP Effective Isotropic Radiated Power

(N)ES (Network) Energy Saving

OPEX Operating Expenses

UPT User Perceived Throughput

XR Extended Reality

# 4 Introduction

Network energy saving is of great importance for environmental sustainability, to reduce environmental impact (greenhouse gas emissions), and for operational cost savings. As 5G is becoming pervasive across industries and geographical areas, handling more advanced services and applications requiring very high data rates (e.g. XR), networks are being denser, use more antennas, larger bandwidths and more frequency bands. The environmental impact of 5G needs to stay under control, and novel solutions to improve network energy savings need to be developed.

Energy consumption has become a key part of the operators' OPEX. According to the report from GSMA [3], the energy cost on mobile networks accounts for ~23% of the total operator cost. Most of the energy consumption comes from the radio access network and in particular from the AAU, with data centres and fibre transport accounting for a smaller share. The power consumption of a radio access can be split into two parts: the dynamic part which is only consumed when data transmission/reception is ongoing, and the static part which is consumed all the time to maintain the necessary operation of the radio access devices, even when the data transmission/reception is not on-going.

Therefore, there is a need to study and develop a network energy consumption model especially for the base station (a UE power consumption model was already defined in TR38.840), KPIs, an evaluation methodology and to identify and study network energy savings techniques in targeted deployment scenarios. The study investigates how to achieve more efficient operation dynamically and/or semi-statically and finer granularity adaptation of transmissions and/or receptions in one or more of network energy saving techniques in time, frequency, spatial, and power domains, with potential support/feedback from UE, potential UE assistance information, and information exchange/coordination over network interfaces.

The study not only evaluates the potential network energy consumption gains, but also assesses and balances the impact on network and user performance, e.g. by looking at KPIs such as spectral efficiency, capacity, UPT, latency, UE power consumption, complexity, handover performance, call drop rate, initial access performance, SLA assurance related KPIs, etc. The techniques studied could avoid having a large impact to such KPIs.

# 5 Modeling and evaluation methodology

## 5.1 Energy consumption model for BS

For evaluation purpose, the energy consumption modeling for a BS for evaluation includes:

* Reference configuration
* Multiple power state(s) including sleep or non-sleep modes with relative power, and associated transition time/energy
* Scaling method to be applied.

For reference configuration, the following is considered for single CC case.

Table 5.1-1: Reference configuration for BS power consumption model

|  |  |  |  |
| --- | --- | --- | --- |
|  | Set 1 FR1 | Set 2 FR1 | Set 3 FR2 |
| Duplex | TDD | FDD | TDD |
| System BW | 100 MHz | 20 MHz | 100 MHz |
| SCS | 30 kHz | 15 kHz | 120 kHz |
| Number of TRP | 1 | 1 | 1 |
| Total number of DL TX RUs | 64 | 32 | 2 |
| Total DL power level | 55 dBm | 49 dBm | 33 dBm\* |
| Total number of UL Rx RUs | 64 | 32 | 2 |

\*Note: EIRP limit is 63 dBm for the reference configuration. The EIRP value is scaled with the number of TxRUs.

For power states, for non-sleep mode and TDD, the BS power consumption for DL and UL are separately modelled, allowing DL-only transmission or UL-only reception. The relative power value in power consumption model tables for UL reception and/or DL transmission is provided based on the reference configurations. For simultaneous DL and UL transmission for FDD, the power for UL reception is neglected in this study.

The power states of power consumption model are provided as Table 5.1-2. Note: The BS power model defined in this study is a simplified model for the purposes of evaluations, considering single-RAT NR BSs only. This does not mean a BS cannot benefit from the identified techniques when serving multi-RAT. Transition among power states, transition time, are implementation specific, and different BS types may support a different number of power states with different characteristics, i.e., power consumption values and required transition time.

During the transition time period, relative power of sleep mode *i* is assumed to be consumed. For RAN1 evaluation purpose, the values of relative power *P* for BS Category 1 and BS Category 2 for respective set of reference configurations are provided in Table 5.1-3.

Additional transition energy *E* and total transition time *T* also include energy and time for both ramping down and ramping up. The values of total transition time for BS power state transition are given in Table 5.1-4, which are the same across different sets of reference configurations for a given BS Category. The values of additional transition energy for reference configuration Set 1, Set 2 and Set 3, with unit in (relative power) \* (duration in msec), are provided in Table 5.1-5.

For background and discussion related to the power models as well as the corresponding values for relative power, transition time and additional transition energy, see [4][5][6][7] and references therein.

Table 5.1-2: Power states of BS power consumption model

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Power state** | **Characteristic** | Relative Power *P* | Additional transition energy2 *E* | **Total transition time*****T*** |
| Deep sleep1 | There is neither DL transmission nor UL reception.  Time interval for the sleep should be larger than the total transition time entering and leaving this state. | P1 | E1 | T1 |
| Light sleep | There is neither DL transmission nor UL reception.  Time interval for the sleep should be larger than the total transition time entering and leaving this state. | P2 | E2 | T2 |
| Micro sleep | There is neither DL transmission nor UL reception.  Immediate transition is assumed for network energy saving study purpose from or to a non-sleep state. | P3 | 0 | 0 |
| Active DL | There is only DL transmission. | P4 | N.A. | |
| Active UL | There is only UL reception. | P5 |
| Note 1: Depending on implementations, there could be a state that the power is lower than deep sleep and requires larger total transition time, e.g. hibernating sleep or Quasi-off, which is not explicitly modeled in this study for evaluation purpose.  Note 2: Unit in relative power times duration. | | | | |

Table 5.1-3: Relative power values P for reference configuration Set 1, Set 2 and Set 3

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Power state** | **BS Category 1** | | | **BS Category 2** | | |
| **Set 1** | **Set 2** | **Set 3** | **Set 1** | **Set 2** | **Set 3** |
| Deep sleep | 1 | | | 1 | | |
| Light sleep | 25 | | | 2.1 | | |
| Micro sleep | 55 | 50 | 38 | 5.5 | 5 | 3 |
| Active DL | 280 | 200 | 152 | 32 | 26 | 17.6 |
| Active UL | 110 | 90 | 80 | 6.5 | 5.8 | 4.2 |

Table 5.1-4: Total transition time *T* for reference configuration Set 1, Set 2 and Set 3

|  |  |  |
| --- | --- | --- |
| **Power state** | **BS Category 1** | **BS Category 2** |
| Deep sleep | 50 ms | 10 s |
| Light sleep | 6 ms | 640 ms |

Table 5.1-5: Additional transition energy *E* for reference configuration Set 1, Set 2 and Set 3

|  |  |  |
| --- | --- | --- |
| **Power state** | **BS Category 1** | **BS Category 2** |
| Deep sleep | 1000 | 17000 |
| Light sleep | 90 | 1088 |

For scaling method, for non-sleep mode, the scaling can be based on one or more of the following:

* number of used physical antenna elements, or TX/RX RUs
* occupied BW/RBs for DL and/or UL in a slot/symbol in one CC
* number of CCs in CA
* number of TRPs
* PSD or transmit power
* number of DL and/or UL symbols occupied within a slot.

For active DL transmission, the BS power consumption is provided by

where

* is a static part of power for BS in active, which is not scaled based on reference configurations.
  + - Baseline:
    - Optional:
* is a dynamic part of power for BS in active, which is scaled based on reference configuration.
  + - Baseline: , where ,, is the fraction of active TRxRUs, the ratio between the RF bandwidth and the maximum system BW, and the ratio of PSD per TxRU between the DL transmission and reference configuration, respectively.
      * + is the power part related to PA.
        + For simplicity
      * A = baseline: 0.4; optional: 0.1, 0.7;
      * For , in evaluation, company to report the assumption from below:

If one value of is used for evaluation, for any ;

If two values of are used for evaluation, if ; otherwise,

For active UL transmission, the BS power consumption for is provided by

where

* + is a static part of power for BS in active, which is not scaled based on reference configurations.
  + is a dynamic part of power for BS in active, which is scaled based on reference configuration, and is the fraction of active TRxRUs.
  + Baseline:
    - when no scaling is applied (i.e. scaling factor is 1).

Note,

* For multi-carrier, the total power consumption of BS is calculated as is the sum of the power consumption of each CC; for intra-band multi-carrier with contiguous CCs, the power consumption of each additional CC is scaled by 0.7.
* For multi-TRP, the total power consumption of BS is assumed as is the sum of the power consumption of each TRP. Company to report whether is shared among TRPs (if shared, is accounted once).
* Company to additionally report the assumption for antenna adaptation delay, e.g. immediate adaptation, or with a transition time of 1-3 ms, etc.
* In time domain, the power consumption in a slot is the sum of the power consumption associated with symbols in the slot. The symbol may correspond to uplink symbol, downlink symbol, or symbol without uplink and downlink. Company to report how the summation is performed along with evaluation results.

Other values for the above scaling formula, and other scaling approaches can be optionally reported, including

* At least = 1 is supported.
* , with being the ratio of RF BW to the maximum system BW.

## 5.2 Evaluation methodology

For evaluation, the BS energy consumption model at least include the power consumption of BS on slot-level, and symbol-level power consumption to reflect different BW (or RB utilization)/time-occupancy/tx-rx direction of different symbols in a slot is considered. System simulation evaluations can be per slot regardless of detailed approach for calculating symbol-level power consumption. All calculation of energy consumption is to use the same time unit. Companies are to indicate which time unit is used.

The evaluation baseline includes at least NR R15 mandatory without capability features. Optional features from R15 onwards (e.g. CA, MIMO) as well as implementation-based energy saving techniques are to be explicitly reported and described if used in the evaluation baseline.

SLS is considered as baseline evaluation method. Other method, including numerical analysis and LLS can also be considered. At least one of the methods is to be selected and used for evaluation of a specific technique (selection and criteria is up to proponent).

For evaluation purpose, network energy saving gain is computed based on the energy consumptions for a technique and the baseline over the same duration. Percentage of energy consumption reduction from the baseline is used to express BS energy saving gain. In addition to the BS energy saving gain, at least UPT/UE power consumption/access delay/latency is to be considered for performance impact evaluation. Other KPIs can be optionally reported, conditioned with clear definition/descriptions provided. Note for potential new channel/signals, e.g. WUS from UE, the assumption for detection reliability at BS side is to be reported (performance and complexity impact would subject to results and further discussion).

For initial evaluations, there is always a non-sleep mode assumed between adjacent sleep modes.

System level evaluation assumptions are provided in Annex A and B.

Companies are to report the assumption details for the reception of a low-power UL channel/signal, if used, including power states, additional transition energy, and transition times, receiver details (e.g. architecture and receiver sensitivity), and other impact/change on the power consumption model.

# 6 Techniques to improve network energy savings

Various techniques in time, frequency, spatial and power domains are studied. Companies’ simulation results as well as evaluation assumption details are gathered in [8]. In this document, results as well as some notable assumptions and setting are explicitly present in relevant tables. Also, the categorization of techniques in terms of technical domain and results presentation/tabulation are for study/evaluation purpose. This does not preclude to further merge or combine certain techniques.

For analysis of impact on legacy UE and RAN1 specification, the list described in corresponding sub-sections is not an exhaustive list. RAN1 may identify additional impact and determine that the listed impact may no longer apply to the described technique(s) as specification is further developed.

## 6.1 Techniques in time domain

### 6.1.1 Technique A-1 Adapting transmission/reception of common channels/signals

#### 6.1.1.1 Description of technique

In Rel-15 NR, time-domain positions of transmitted SSBs within a half frame are semi-statically configured. Further, UE assumes a single periodicity for the transmitted SSBs. The transmission of common signal and channels or reception of random-access signals may limit the gNB ability to use (deeper) sleep modes to save energy. Currently, system information (SI) update mechanism can adapt the parameters in the cell, such as those associated with downlink common and broadcast signals, such as SSB/SI/paging/cell common PDCCH, and/or the periodicity/availability of uplink random access resources.

Technique A-1 adapts the transmission pattern (when applicable) of downlink common and broadcast signals, such as SSB/SI/paging/cell common PDCCH, and/or the transmission pattern/availability of uplink random access opportunities. Adaptation of the transmission pattern includes changes to periodicity, time resource locations, and omitting of specific signals/channels. The transmission pattern can be adapted semi-statically or dynamically.

#### 6.1.1.2 Analysis of NW energy saving and performance impact



The following table captures the simulation results for the technique A-1-1 that use simplified version of SSB, such as only PSS, only PSS and SSS without PBCH, or PSS and SSS with partial PBCH.

Based on the simulation results, at empty load, one source shows that BS energy saving gain can be achieved by 15.7%~28.3% with only PSS and SSS transmitted from SSB, and half-reduced SIB1 transmission. One source shows that the gain from light SSB only ranges from 0.7% to 4.4%, which slightly increases as the listening periodicity of WUS from UE becomes larger. One source shows that with simplified SSB of PSS, SSS and partial PBCH, for empty load and Set 1 reference configuration, 2.4% BS energy savings can be achieved. One source shows 30.49% BS energy savings with 2-symbol simplified SSB for FR2.

No impact on UPT was observed due to empty load.

Table 6.1.1.2-1: BS energy savings by simplified SSB

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT/access delay/latency/UE power consumption (%: loss w.r.t. baseline)** | **Reference configuration** | **Baseline configuration/assumption** |
| **CMCC**  **[9]** | SSB and SIB1 repetition period 40ms, for other 20ms occasions, only PSS and SSS are transmitted. | cat.2 | Zero | 15.7% | / | Set 1 | Baseline: normal SSB/SIB1 transmission, with 20ms repetition period for both. |
| SSB and SIB1 repetition period 40ms, for other 20ms occasions, only PSS and SSS are transmitted. | cat.1 | Zero | 28.3% | / | Baseline: normal SSB/SIB1 transmission, with 20ms repetition period for both. |
| **vivo**  **[10] [20]** | SSB structure adaptation including light SSB (ES scheme: 20ms light-SSB and SIB1, 20ms RACH listening only PSS and SSS for light-SSB) | Cat1 | Zero | 0.9% | 0% | Set 1 | Baseline scheme: 20ms SSB and SIB1, 20ms RACH listening |
| SSB structure adaptation including light SSB (ES scheme: 160ms light-SSB, 20ms UEWUS listening only PSS and SSS for light-SSB) | Cat1 | Zero | 1.2% | 0% | Set 1 | Baseline scheme: 160ms SSB, 20ms UEWUS listening |
| SSB structure adaptation including light SSB (ES scheme: 160ms light-SSB, 80ms UEWUS listening only PSS and SSS for light-SSB) | Cat1 | Zero | 2.4% | 0% | Baseline scheme: 160ms SSB, 80ms UEWUS listening |
| SSB structure adaptation including light SSB (ES scheme: 160ms light-SSB, 160ms UEWUS listening only PSS and SSS for light-SSB) | Cat1 | Zero | 4.4% | 0% | Baseline scheme: 160ms SSB, 160ms UEWUS listening |
| SSB structure adaptation including light SSB (ES scheme: 20ms light-SSB and SIB1, 20ms RACH listening only PSS and SSS for light-SSB) | Cat2 | Zero | 0.7% | 0% | Baseline scheme: 20ms SSB and SIB1, 20ms RACH listening |
| SSB structure adaptation including light SSB (ES scheme: 160ms light-SSB, 20 UEWUS listening only PSS and SSS for light-SSB) | Cat2 | Zero | 0.8% | 0% | Baseline scheme: 160ms SSB, 20ms UEWUS listening |
| SSB structure adaptation including light SSB (ES scheme: 160ms light-SSB, 80ms UEWUS listening only PSS and SSS for light-SSB) | Cat2 | Zero | 0.8% | 0% | Baseline scheme: 160ms SSB, 80ms UEWUS listening |
| SSB structure adaptation including light SSB (ES scheme: 160ms light-SSB, 160ms UEWUS listening only PSS and SSS for light-SSB) | Cat2 | Zero | 0.8% | 0% | Baseline scheme: 160ms SSB, 160ms UEWUS listening |
| **CEWiT**  **[24]** | simplified SSB with repetition period 20ms, only PSS and SSS with partial PBCH are transmitted in simplified SSB | Cat.1 | Zero | 2.4% |  | Set 1 | Baseline: normal SSB/SIB1 transmission, with 20ms repetition period for both. |
| **Qualcomm [30]** | Simple SSB with 2 OFDM symbols and a transmission period of 20 ms | Cat 1 | Zero | 30.49% | / | Set 3 | Baseline: normal SSB with 20ms repetition period; FR2 with 32 beams per cell. |

The following table captures the simulation results for the technique A-1-2 by which transmission occasion of one or more common signals/channels, which are SIB1 and SSB based on the submitted results, can be skipped.

Based on the results,

* One source observed that statically skipping certain SIB1 transmission occasions under Set 1 reference configuration for BS Category 1 can achieve energy saving gain by 2.6%~3.9% compared to the baseline of 20ms SSB&SIB1 repetition periodicity at low load. No impact to UPT was observed. There is no random-access procedure modelled in the simulation, therefore the impact on access delay/latency is not shown.
* One source observed that static adaptation of number of SSB can achieve energy saving gain by 0.3%~25.4% at different scenarios with FTP3 model. The gain generally increases when the traffic load becomes lighter while decreases as the SSB periodicity becomes larger. For a same traffic load and SSB periodicity, the gain increases as the number of SSB can be reduced. For FR2 with larger number of SSB for baseline, there is generally larger gain observed than FR1. Due to reduced number of SSB, access delay is increased. Performance of dynamic adaptation of SSB numbers is not provided. There is no random-access procedure modelled in the simulation, therefore the impact on access delay/latency is not shown.

Table 6.1.1.2-2: BS energy savings by skipping one or more common signals/channels

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **Load scenario** | **ES gain (%)** |  | **BS Category/Reference configuration/Baseline configuration/assumption** | **Other evaluation methodology/assumption details/other performance impact** |
| **OPPO [14]** | Transmission occasion of SIB1 with 24 RBs for 20 ms periodicity is skipped | low load(RU-10%) | 2.6% | Cat 1  Set 1  SIB1 with 24 RBs for 20 ms periodicity, SSB with 20 RBs for 20 ms periodicity | | SLS FTP3 (0.5MB as packet size, 200ms as mean inter-arrival time)  UPT/Access delay/Latency: almost similar with the baseline |
| low load(RU-0.2%) | 3.9% | SLS IM (0.1MB as packet size, 2s as mean inter-arrival time)  UPT/Access delay/Latency: almost similar with the baseline |
| **Samsung [21]** | the number of SSB adaptation | Medium load: 42 % RU | 1.9%, 2.8%, 3.3% | Cat 1  Set 1  8 SSBs for FR1 and ssb-periodicity = 20 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 3.1%, 6.1%, 7.6% |
| Low load: 7.5 % RU | 5.5%, 11.0%, 13.8% |
| Low load: 2 % RU | 7.2%, 14.3%, 17.9% |
| Medium load: 42 % RU | 2.0%, 3.0%, 3.5% | Cat 2  Set 1  8 SSBs for FR1 and ssb-periodicity = 20 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 2.8%, 4.2%, 4.9% |
| Low load: 7.5 % RU | 4.4%, 6.6%, 7.7% |
| Low load: 2 % RU | 5.3%, 7.9%, 9.2% |
| Medium load: 42 % RU | 3.3%, 5.0%, 5.8%, 6.3%, 6.5%, 6.6% | Cat 1  Set 3  64 SSBs for FR2 and ssb-periodicity = 20 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 4.3%, 17.6%, 19.5%, 20.5%, 21.0%, 21.3% |
| Low load: 7.5 % RU | 7.1%, 13.6%, 16.9%, 18.5%, 19.3%, 19.7% |
| Low load: 2 % RU | 8.3%, 15.9%, 19.7%, 21.6%, 22.6%, 23.0% |
| Medium load: 42 % RU | 4.0%, 5.9%, 6.9%, 7.4%, 7.7%, 7.8% | Cat 2  Set 3  64 SSBs for FR2 and ssb-periodicity = 20 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 5.4%, 8.1%, 9.5%, 10.2%, 10.5%, 10.7% |
| Low load: 7.5 % RU | 8.2%, 12.2%, 14.3%, 15.3%, 15.8%, 16.1% |
| Low load: 2 % RU | 9.6%, 14.4%, 16.8%, 18.0%, 18.6%, 18.9% |
| Medium load: 42 % RU | 1.1%, 2.2%, 2.7% | Cat 1  Set 1  8 SSBs for FR1 and ssb-periodicity = 40 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 1.6%, 3.2%, 4.0% |
| Low load: 7.5 % RU | 3.1%, 6.1%, 7.7% |
| Low load: 2 % RU | 4.2%, 8.3%, 10.3% |
| Medium load: 42 % RU | 1.0%, 1.6%, 1.8% | Cat 2  Set 1  8 SSBs for FR1 and ssb-periodicity = 40 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 1.5%, 2.2%, 2.5% |
| Low load: 7.5 % RU | 2.3%, 3.5%, 4.0% |
| Low load: 2 % RU | 2.8%, 4.2%, 4.9% |
| Medium load: 42 % RU | 1.9%, 3.6%, 4.4%, 4.8%, 5.0%, 5.2% | Cat 1  Set 3  64 SSBs for FR2 and ssb-periodicity = 40 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 2.6%, 5.0%, 6.1%, 6.7%, 7.0%, 7.2% |
| Low load: 7.5 % RU | 4.0%, 7.6%, 9.4%, 10.4%, 10.8%, 11.0% |
| Low load: 2 % RU | 4.8%, 9.2%, 11.4%, 12.5%, 13.1%, 13.3% |
| Medium load: 42 % RU | 2.1%, 3.1%, 3.6%, 3.9%, 4.0%, 4.1% | Cat 2  Set 3  64 SSBs for FR2 and ssb-periodicity = 40 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 2.9%, 4.3%, 5.1%, 5.4%, 5.6%, 5.7% |
| Low load: 7.5 % RU | 4.4%, 6.7%, 7.8%, 8.3%, 8.6%, 8.8% |
| Low load: 2 % RU | 5.4%, 8.1%, 9.4%, 10.1%, 10.4%, 10.6% |
| Medium load: 42 % RU | 0.6%, 1.1%, 1.4% | Cat 1  Set 1  8 SSBs for FR1 and ssb-periodicity = 80 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 1.0%, 2.3%, 3.0% |
| Low load: 7.5 % RU | 2.5%, 5.9%, 7.6% |
| Low load: 2 % RU | 4.5%, 10.7%, 13.8% |
| Medium load: 42 % RU | 0.5%, 0.8%, 0.9% | Cat 2  Set 1  8 SSBs for FR1 and ssb-periodicity = 80 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 0.7%, 1.1%, 1.3% |
| Low load: 7.5 % RU | 1.2%, 1.8%, 2.1% |
| Low load: 2 % RU | 1.4%, 2.1%, 2.5% |
| Medium load: 42 % RU | 1.0%, 1.8%, 2.3%, 2.5%, 2.6%, 2.6% | Cat 1  Set 3  64 SSBs for FR2 and ssb-periodicity = 80 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 1.3%, 2.6%, 3.2%, 3.5%, 3.7%, 3.7% |
| Low load: 7.5 % RU | 2.1%, 4.1%, 5.0%, 5.5%, 5.8%, 5.9% |
| Low load: 2 % RU | 2.6%, 5.0%, 6.2%, 6.8%, 7.1%, 7.2% |
| Medium load: 42 % RU | 1.1%, 1.6%, 1.8%, 2.0%, 2.0%, 2.1% | Cat 2  Set 3  64 SSBs for FR2 and ssb-periodicity = 80 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 1.5%, 2.2%, 2.6%, 2.8%, 2.9%, 2.9% |
| Low load: 7.5 % RU | 2.3%, 3.5%, 4.1%, 4.4%, 4.5%, 4.6% |
| Low load: 2 % RU | 2.9%, 4.3%, 5.0%, 5.4%, 5.5%, 5.6% |
| Medium load: 42 % RU | 0.3%, 0.6%, 0.7% | Cat 1  Set 1  8 SSBs for FR1 and ssb-periodicity = 160 | | FTP3 Model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 0.5%, 1.3%, 1.6% |
| Low load: 7.5 % RU | 1.5%, 3.5%, 4.5% |
| Low load: 2 % RU | 3.3%, 7.8%, 10.1% |
| Medium load: 42 % RU | 0.3%, 0.4%, 0.5% | Cat 2  Set 1  8 SSBs for FR1 and ssb-periodicity = 160 | | FTP3 model. For each load, reduced the number of SSB transmissions: 4, 2, 1 |
| Light load: 24 % RU | 0.4%, 0.6%, 0.7% |
| Low load: 7.5 % RU | 0.6%, 0.9%, 1.0% |
| Low load: 2 % RU | 0.7%, 1.1%, 1.3% |
| Medium load: 42 % RU | 0.5%, 0.9%, 1.1%, 1.3%, 1.3%, 1.3% | Cat 1  Set 3  64 SSBs for FR2 and ssb-periodicity = 160 | | FTP3 model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 0.7%, 1.3%, 1.6%, 1.8%, 1.9%, 1.9% |
| Low load: 7.5 % RU | 2.6%, 7.1%, 9.3%, 10.4%, 11.0%, 11.2% |
| Low load: 2 % RU | 6.0%, 16.0%, 21.0%, 23.5%, 24.8%, 25.4% |
| Medium load: 42 % RU | 0.5%, 0.8%, 0.9%, 1.0%, 1.0%, 1.1% | Cat 2  Set 3  64 SSBs for FR2 and ssb-periodicity = 160 | | FTP3 model. For each load, reduced the number of SSB transmissions: 32, 16, 8, 4, 2, 1 |
| Light load: 24 % RU | 0.8%, 1.1%, 1.3%, 1.4%, 1.5%, 1.5% |
| Low load: 7.5 % RU | 1.2%, 1.8%, 2.1%, 2.2%, 2.3%, 2.3% |
| Low load: 2 % RU | 1.5%, 2.2%, 2.6%, 2.8%, 2.8%, 2.9% |

The following show the BS energy savings by technique A-1-3, i.e. configuration/adaptation of longer periodicity of common signals and/or uplink random access opportunities.

Based on the results with static configurations from 9 sources, it can be observed that longer SSB/SIB1 periodicity can bring BS with significant energy savings in most cases (with gains up to 84.8%), compared to a selected baseline, for both BS Categories, under all reference configurations. When other configurations/settings are the same, the saving gain generally increase as the periodicity becomes larger, and decrease as the traffic load increases or the number of SSBs increases. Particularly, there are two sources providing results with SSB periodicity larger than 160ms which is the maximum value that is currently supported, i.e., being 640ms and 1280ms, and observed that together with longer SIB1/RACH/RO monitoring periodicities, then depending on the traffic load, the BS energy saving gain can be 53.6%~7.1% and 83.6%~3.4%, respectively, compared to a baseline with 20ms SSB periodicity.

The scheme does not affect the UPT for empty load case. When traffic occurs and load increases, the UPT also significantly decreases. The latency/access delay/UE power consumption increases proportionally as the periodicity of SSB/SIB increases compared to a corresponding baseline.

Performance of dynamic SSB/SIB1 periodicity adaptation is not provided.

Table 6.1.1.2-3: BS energy savings by adapting SSB/SIB1 periodicities

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT/Access delay/latency/UE power consumption, etc. (loss w.r.t. baseline)** | **Baseline configuration/assumption/Other notable setting** |
| **CMCC  [23]** | SSB periodicity 20ms, SIB repetition period 40ms. | cat.2 | Zero | 13.7% |  | Baseline: normal SSB/SIB1 transmission, with 20ms repetition period for both. |
| SSB and SIB1 repetition period 40ms. | 17.6% |  |
| SSB periodicity 20ms, SIB repetition period 40ms. | cat.1 | Zero | 25.7% |  |
| SSB and SIB1 repetition period 40ms. | 28.7% |  |
| **vivo [10] [20]** | Period adaptation of common signals and channels (ES scheme: 160ms SSB and SIB1, 160ms RACH listening) | Cat1 | Zero | 78.8% | UE power consumption: 0% | Baseline scheme: 20ms SSB and SIB1, 20ms RACH listening |
| Cat2 | 16.6% | UE power consumption: 0% |
| **NOKIA/NSB [12]** | SSB/SIB1/RO monitoring period= 160ms | Cat 2 | Zero, Low, Light, Medium | 48.4%, 44.3%, 43.7%, 39.9% | UPT: 0 Mbps, 83 Mbps, 70 Mbps, 55 Mbps | SSB/SIB1/random-access occasion (RO) monitoring periodicity @ 20ms UEs are initially in RRC\_idle state |
| SSB/SIB1/RO monitoring period= 640ms | Zero, Low, Light, Medium | 53.6%, 49.0%, 48.8%, 46.1% | UPT: 0 Mbps, 29 Mbps, 27 Mbps, 25 Mbps |
| SSB/SIB1/RO monitoring period= 1280ms | Zero, Low, Light, Medium | 83.6%, 51.3%, 51.7%, 50.6% | UPT: 0 Mbps, 11.2 Mbps, 11 Mbps, 10.5 Mbps |
| **Spreadtrum [13]** | Prolonging the periodicity of SSB/SIB1/paging: 1) SSB burst periodicity is 160ms, and SIB1 repetition periodicity is 160ms.  2) PF periodicity at gNB side is 160ms (T=1280ms, N=8).  3) gNB can enter light sleep for Cat 1, but can only enter micro sleep for Cat 2. | Cat 1 | Zero | Set 1- Set 3: 23.8%, 19.6%, 16.3% |  | 1) SSB burst periodicity is 20ms, and SIB1 repetition periodicity is 20ms.  2) PF periodicity at gNB side is 20ms (T=1280ms, N=64).  3) gNB can enter light sleep for Cat 1, but can only enter micro sleep for Cat 2. |
| Cat 2 | Set 1- Set 3: 9.3%, 8.3%, 9.4% |  |
| Transmission window of SSB/SIB1/paging: 1) SSB burst periodicity is 20ms, and SIB1 repetition periodicity is 20ms. 2) PF periodicity at gNB side is 20ms (T=1280ms, N=64). 3) gNB can enter light sleep for Cat 1, but can only enter micro sleep for Cat 2. | Cat 1 | Set 1- Set 3: 23.8%, 19.6%, 16.3% |  | 1) The transmission window periodicity is 1280ms, and the transmission window duration is 160ms. 2) SSB burst periodicity is 20ms within the transmission window, and SIB1 repetition periodicity is 20ms within the transmission window. 3) PF periodicity at gNB side is 160ms (T=1280ms, N=8) within the transmission window. 4) gNB can enter light sleep for Cat 1, and can enter both light sleep and micro sleep for Cat 2 (at the tail of the transmission window). |
| Cat 2 | Set 1- Set 3: 51.5%, 47.3%, 20.6% |  |
| **Intel [22]** | Increasing the common channel/signal periodicity | Cat 1 | Low | 40.1% | UPT: 819.66 Mbps  Avg EE\* (baseline): 5.10 Avg EE (ES scheme): 9.17 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 160 msec periodicity.  EE\* is defined as cell throughput (in Mbps) / average power consumption (in relative power), and averaged from all BS. |
| 45.0% | UPT: 819.66 Mbps  Avg EE (baseline): 5.10  Avg. EE (ES scheme): 10.60 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 640 msec periodicity |
| Light | 14.6% | UPT: 611.45Mbps  Avg EE (baseline): 2.66 Avg. EE (ES scheme): 3.31 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 160 msec periodicity |
| 16.8% | UPT: 611.45Mbps  Avg EE (baseline): 2.66 Avg. EE (ES scheme): 3.46 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 640 msec periodicity |
| Medium | 6.2% | UPT: 457.92Mbps  Avg EE (baseline): 1.50 Avg. EE (ES scheme): 1.63 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 160 msec periodicity |
| 7.1% | UPT: 457.92Mbps  Avg EE (baseline): 1.50 Avg. EE (ES scheme): 1.65 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 640 msec periodicity |
| Cat2 | Low | 8.2% | UPT: 819.66Mbps  Avg EE (baseline): 35.82 Avg. EE (ES scheme): 39.23 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 160 msec periodicity |
| 10.9% | UPT: 819.66Mbps  Avg EE (baseline): 35.82 Avg. EE (ES scheme): 40.09 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 1280 msec periodicity |
| Light | 5.1% | UPT: 611.45Mbps  Avg EE (baseline): 20.75 Avg. EE (ES scheme): 22.00 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 160 msec periodicity |
| 5.8% | UPT: 611.45Mbps  Avg EE (baseline): 20.75 Avg. EE (ES scheme): 22.19 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 1280 msec periodicity |
| Medium | 3.0% | UPT: 457.92Mbps  Avg EE (baseline): 12.44 Avg. EE (ES scheme): 12.89 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms ES scheme: SSB/SIB1/PRACH: 160 msec periodicity |
| 3.4% | UPT: 457.92Mbps  Avg EE (baseline): 12.44 Avg. EE (ES scheme): 12.96 | Baseline: SSB/PRACH: 20 msec periodicity; SIB periodicity 40ms. ES scheme: SSB/SIB1/PRACH: 1280 msec periodicity |
| **CATT [25]** | Adaptation of common signals and channels | Cat 1 | Zero load | 10.2%, 72.7%, 84.8% |  | Baseline: 20ms SSB;  ES scheme: SSB: 40ms, 80ms, 160ms for each load |
| Low load | 3.4%, 18.8%, 19.7% |  | Baseline: SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms; CSI-RS/TRS 10ms;  ES scheme: SSB: 40ms, 80ms, 160ms for each load |
| Light load | 1.9%, 5.2%, 5.6% |  | Baseline: SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms; CSI-RS/TRS 10ms;  ES scheme: SSB: 40ms, 80ms, 160ms for each load |
| Medium load | 1.3%, 2.2%, 2.6% |  | Baseline: SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms; CSI-RS/TRS 10ms;  ES scheme: SSB: 40ms, 80ms, 160ms for each load |
| **Fujitsu [11]** | SSB/SIB1 period= 40ms | Cat2 | Zero, low, light, medium | 17.9%, 13.7%, 11.1%, 8.6% |  | Baseline scheme: 20 ms SSB/SIB1 period |
| SSB/SIB1 period= 80ms | Zero, low, light, medium | 26.8%, 20.6%, 16.7%, 12.8% |  |
| SSB/SIB1 period= 160ms | Zero, low, light, medium | 31.4%, 24.1%, 19.4%, 15.0% |  |
| SSB/SIB1 period= 40ms | Zero, low, light, medium | 18.3%, 12.6%, 9.4%, 6.9% |  |
| SSB/SIB1 period= 80ms | Zero, low, light, medium | 27.4%, 18.8%, 14.1%, 10.4% |  |
| SSB/SIB1 period= 160ms | Zero, low, light, medium | 32.0%, 22.0%, 16.5%, 12.1% |  |
| **Ericsson [18]** | 40ms SSB+SIB1 | Cat1 | Zero | 0.9% |  | Baseline scheme: 20ms SSB + 160ms SIB1  ES: one SSB. Energy calculation: per symbol energy consumption is modeled. |
| 80ms SSB+SIB1 | 48.5% |  |
| 160ms SSB+SIB1 | 72.6% |  |
| 40ms SSB+SIB1 | -6.2% |  | Baseline scheme: 20ms SSB + 160ms SIB1  ES: Four SSBs. Energy calculation: per symbol energy consumption is modeled. |
| 80ms SSB+SIB1 | 43.8% |  |
| 160ms SSB+SIB1 | 70.5% |  |
| **Qualcomm [17]** | Adaptation of Common Signals and Channels | Category 1 | No Load | 13.9% | Access delay/latency: additional 20 ms;  UE power consumption increment: 99% | Note: "SSB period of 40 ms" without any network traffic either in DL or UL. Therefore, there are no statistics for UPT, latency, etc.. |

The following show the BS energy savings by technique A-1-4, configuration/adaptation of transmission patterns of common signals, i.e. Paging or SSB based on the submitted results.

Based on the results,

* One source observed that for BS category 1 and at empty load case, statically adapting paging configuration could provide BS energy savings by 0.2%~6.7% when paging load (resource used for paging) is 0.2%~0.5%, and the gain can be up to 42.3% when paging load is increased up to 3.6%. The gain could also increase as the number of SSB increases. Performance of dynamically adapting paging configurations is not provided. The above energy saving gains were achieved with SSB periodicity of 80ms or 160ms.
* One source observed that having compact SSB (i.e., no time gap between consecutive SSBs) could provide 10.3% network energy saving for BS category 1 and at empty load case in FR2 when SSB periodicity is 20ms. Furthermore, UE power saving can be improved by 4%.

Table 6.1.1.2-4: BS energy savings by adapting Paging/SSB transmission patterns

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT/access delay/latency/UE power consumption (%: loss w.r.t. baseline)** | **Reference configuration** | **Baseline configuration/assumption** | **Other evaluation methodology/assumption details/notable settings** |
| **Intel [22]** | Enhanced Paging by increasing the number of consecutive POs within a PF by factor of M while reducing PF density by a factor of M. This keeps the total number of POs same within the DRX cycle. | Cat1 | Zero, Paging load 2% | 21.2% |  | Set 1 | Paging Parameters: N = T/4; Ns = 4; Enh. Paging†: N = T/4;  Ns = 4; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 80 msec periodicity; Number of SSB: 1  Paging load is the average load per simulation run time.  Paging events were randomly generated.  Same as below results. The value of T is larger than 160ms. |
| Zero, Paging load 0.2% | 4.0% |  | Paging Parameters: N = T/16; Ns = 2; Enh. Paging†: N = T/16; Ns = 2; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 80 msec periodicity; Number of SSB: 1 |
| Zero, Paging load 2% | 42.3% |  | Paging Parameters: N = T/4; Ns = 4; Enh. Paging†: N = T/4;  Ns = 4; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 160 msec periodicity; Number of SSB: 1; |
| Zero, Paging load 0.2% | 6.7% |  | Paging Parameters: N = T/16; Ns = 2; Enh. Paging†: N = T/16; Ns = 2; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 160 msec periodicity; Number of SSB: 1; |
| Zero, Paging load 3.6% | 18.9% |  | Paging Parameters: N = T/4; Ns = 4; Enh. Paging†: N = T/4;  Ns = 4; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 80 msec periodicity; Number of SSB: 4; SSB and SIB1 contained in same slot. 1 SSB per slot along with SIB1 to maximize SSB/SIB1 packing; |
| Zero, Paging load 0.5% | 0.2% |  | Paging Parameters: N = T/16; Ns = 2; Enh. Paging†: N = T/16; Ns = 2; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 80 msec periodicity; Number of SSB: 4; SSB and SIB1 contained in same slot. 1 SSB per slot along with SIB1 to maximize SSB/SIB1 packing; |
| Zero, Paging load 3.6% | 26.4% |  | Paging Parameters: N = T/4; Ns = 4; Enh. Paging†: N = T/4;  Ns = 4; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 160 msec periodicity; Number of SSB: 4; SSB and SIB1 contained in same slot. 1 SSB per slot along with SIB1 to maximize SSB/SIB1 packing; |
| Zero, Paging load 0.5% | 0.3% |  | Paging Parameters: N = T/16; Ns = 2; Enh. Paging†: N = T/16; Ns = 2; M = 4 | No C-DRX used for UEs; CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 160 msec periodicity; Number of SSB: 4; SSB and SIB1 contained in same slot. 1 SSB per slot along with SIB1 to maximize SSB/SIB1 packing; |
| **Qualcomm [17]** | Adaptation of Common Signals and Channels | Category 1 | No Load | 10.3% | UE power consumption: -4% | FR2 Set 3 |  | "Compact SSB" without any network traffic either in DL or UL. Therefore, there are no statistics for UPT, latency, etc.. |

The following show the BS energy savings by the technique A-1-5, adapting common signals, i.e. RACH based on the submitted results.

Based on the results with multiple static RACH occasion configurations, one source observed that adaptation of RACH occasions can achieve BS energy savings by 14.4%~24.9% for BS Category 1 at empty load case under FR1 TDD compared to 10ms RACH periodicity without adaptation. The gain generally increases as PRACH periodicity increases for the same number of SSBs. Performance of dynamic RACH configuration is not provided.

On UPT/access delay/latency, this scheme increases access delay/latency from 10ms to 70ms, proportional to the increased PRACH periodicity.

Table 6.1.1.2-5: BS energy savings by adapting RACH periodicity/occasions

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT/access delay/latency/UE power consumption (w.r.t. baseline)** | **Reference configuration** | **Baseline configuration/assumption/notable settings** | **Other evaluation methodology/assumption details** |
| **Ericsson**  **[18]** | PRACH periodicity= 20ms | Cat1 | Zero | 14.4% | Access delay/latency: 10ms increase | Set 1 | Baseline scheme: 20 ms SSB, 40ms SIB1 period, 10ms PRACH periodicity.  Per symbol energy consumption is modeled.  ES scheme: adapting PRACH periodicity for energy efficiency via dynamic PRACH occasions adaptation. Note separate evaluation performed for different PRACH periodicities (i.e. no switching between these settings). | 1 SSB |
| PRACH periodicity= 40ms | 20.9% | Access delay/latency: 30ms increase |
| PRACH periodicity= 80ms | 22.2% | Access delay/latency: 70ms increase |
| PRACH periodicity= 20ms | 17.3% | Access delay/latency: 10ms increase | four SSBs |
| PRACH periodicity= 40ms | 23.9% | Access delay/latency: 30ms increase |
| PRACH periodicity= 80ms | 24.9% | Access delay/latency: 70ms increase |

The following show the BS energy savings by technique A-1-6, scheduling of SIB1 by SSB, without PDCCH for SIB1, with repetition period 20ms.

It is observed by one source that using SSB to schedule SIB1 can obtain 4.8%~14.8% BS energy savings for Set 1 reference configuration for BS Category 1, compared to SSB/SIB1 periodicity of 20ms for both.

Table 6.1.1.2-6: BS energy savings by scheduling of SIB1 by SSB

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT/access delay/latency/UE power consumption/Other KPI(s), if any** | **Reference configuration** | **Baseline configuration/assumption** | **Traffic model** | **Other evaluation methodology/assumption details - Part 1 (other than power modeling aspects)** | **Other evaluation methodology/assumption details - Part 2 (power modeling aspects)** |
| **CEWiT**  **[24] [27]** | Scheduling of SIB1 by SSB, without PDCCH for SIB1, with repetition period 20ms | Cat.1 | Zero | 4.8% |  | Set 1 | Baseline: normal SSB/SIB1 transmission, with 20ms repetition period for both. |  | numerical analysis | •SIB1: PDCCH: 3 symbols; PDSCH: 12 OFDM symbols including DMRS. •ղ=1, A=0.4. •Time unit for power model is ms. power consumption is calculated in a 20ms long period |
| Scheduling of SIB1 by SSB, without PDCCH for SIB1, 4 beams, with repetition period 20ms | Cat.1 | Zero | 11.4% |  | Set 1 | Baseline: normal SSB/SIB1 transmission, with 20ms repetition period for both. |  | numerical analysis | •SIB1: PDCCH: 3 symbols; PDSCH: 12 OFDM symbols including DMRS.  •ղ=1, A=0.4. •Time unit for power model is ms. power consumption is calculated in a 20ms long period |
| Scheduling of SIB1 by SSB, without PDCCH for SIB1, 8 beams, with repetition period 20ms | Cat.1 | Zero | 14.8% |  | Set 1 | Baseline: normal SSB/SIB1 transmission, with 20ms repetition period for both. |  | numerical analysis | •SIB1: PDCCH: 3 symbols; PDSCH: 12 OFDM symbols including DMRS.  •ղ=1, A=0.4. •Time unit for power model is ms. power consumption is calculated in a 20ms long period |

#### 6.1.1.3 Legacy UE and RAN1 specification impacts

The access latency of legacy UEs may be impacted.

Specification impact of the technique(s) may include the following.

For (technique A-1-1) simplified version of SSB, such as only PSS, only PSS and SSS without PBCH, or PSS and SSS with partial PBCH:

* signaling mechanism to inform the UE about the use of simplified version of SSB, if needed,
* changes to SSB may have impact on SI acquisition, initial access, RRM/RLM measurements, and mobility for legacy UEs and UEs that may not support the technique,
* technique may be enabled for a carrier only when legacy UEs are not using the carrier.

For (technique A-1-2) skipping of SSB/SIB1 transmission occasion:

* signaling mechanism to inform the UE about the skipping of SSB/SIB transmission occasions, if needed,
* skipping of common signals and channels, such as SSB and SIB1, may have impact on initial access, RRM/RLM/BM measurements, and performance for legacy UEs and UEs that may not support the technique,
* technique may be enabled for a carrier only when legacy UEs are not using the carrier.

For (technique A-1-3) configuration/adaptation of longer periodicity of SSB/SIB1 and/or uplink random access opportunities:

* signaling mechanism to inform the UE about the configuration/adaptation,
* adaption of common signals and channels may have impact on SI acquisition, initial access, RRM/RLM/BM measurements, and performance for legacy UEs and UEs that may not support the technique.

For (technique A-1-4) the paging enhancement where paging resources are grouped in a compact manner, potential specification impact of the enhancements from paging transmission includes the following:

* paging reception procedure (RAN2), i.e., identification of POs and PFs for Rel-18 UEs,
* UEs that do not support the technique are expected to follow legacy paging reception procedure in the cell.

For (technique A-1-5) dynamically adapting PRACH periodicity and occasions:

* signaling mechanism to inform the UE about the RACH enhancement resources,
* preparation procedure time for dynamic PRACH adaptation,
* UEs that do not support the technique are expected to use legacy RACH resources in the cell.

For (technique A-1-6) scheduling of SIB1 without PDCCH:

* signaling mechanism to inform the UE about the use of SIB1 without PDCCH, if needed,
* changes to PDCCH of SIB1 may have impact on initial access, and system information acquisition for legacy UEs and UEs that may not support the technique,
* the specification impacts may include signalling mechanism to inform the UE about SIB1 transmissions, details of SI acquisition,
* technique may be enabled for a carrier only when legacy UEs are not using the carrier.

### 6.1.2 Technique A-2 Adaptation of UE specific signals and channels

#### 6.1.2.1 Description of technique

The semi-static configured UE specific channels/signals may require the gNB to perform periodic transmission or reception if they are activated. Except for positioning RS (PRS), the configurations for the listed UE-specific signals/channels are BWP-specific. Current specification allows gNB to dynamically activate/deactivate CG-PUSCH/SPS/CSI-RS/CSI report/SRS using DCI (i.e., PDCCH transmission) in UE specific manner.

Technique A-2 aims to reduce or omit time occasions for the UE specific resources during low activity/non-active periods of the cell. The potential list of UE specific resources includes periodic/semi-static CSI-RS, group-common/UE-specific PDCCH, SPS PDSCH, PUCCH carrying SR, PUCCH/PUSCH carrying CSI reports, PUCCH carrying HARQ-ACK for SPS, CG-PUSCH, SRS, positioning RS (PRS).

UEs may assist the network with information related to the traffic (e.g., about which resources are necessary or unnecessary) so that the network can optimize its scheduling and achieve more sleep opportunities.

#### 6.1.2.2 Analysis of NW energy saving and performance impact

No evaluations of this technique are available.

#### 6.1.2.3 Legacy UE and RAN1 specification impacts

Reducing or omitting time occasions for the UE specific resources during low activity/non-active periods of the cell are not expected to impact UEs that do not support the technique.

Specification impact of the technique may include at least:

* mechanisms to configure and/or inform UEs about the resource availability,
* UE behavior and procedures when configuration and/or information of the resource availability of cell is provided.

### 6.1.3 Technique A-3 UE wake up signal (WUS) for gNB

#### 6.1.3.1 Description of technique

Technique A-3 enables the UE to send an uplink wake-up signal to request transitioning of a cell from no or reduced transmission/reception activity to active transmission or reception of a channel/signal. The technique can be applied to UEs in one or more RRC states. The UE wake up signal (WUS) by technique A-3-1 may be used to trigger the SSB/SIB transmission. It can be used to trigger SSB/SIB1 transmissions with technique A-5. It can also be used to trigger gNB to wake up with technique A-4.

With the support of WUS, the gNB might be inactive (e.g., where it does not transmit nor receive signal/channel or where it only transmits and receives limited signals). A gNB can transit to become active for transmitting or receiving a channel/signal upon reception of an uplink signal from the UE, referred to as technique A-3-2.

#### 6.1.3.2 Analysis of NW energy saving and performance impact

The following capture the results for waking up gNB triggered by UE WUS.

Table 6.1.3.2-1: BS energy savings by UE wake up signal (WUS)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT (%: loss)** | **Access delay/latency (%: increase)** | **UE power consumption (%: increase)** | **Reference configuration** | **Baseline configuration/assumption** | **Traffic model** | **Other evaluation methodology/assumption details/notable settings** |
| **MTK [19]** | UE\_can\_wake\_up\_gNB | Cat 1 | Low | 49.3% | 0.00% | 0.00% | 0.07% | Set 1 | All 21 cells active | VoIP | SLS; DRX (40, 4, 10); 9 out of 21 cells remain active. BS power consumption value is sum of 21 cells. |
| Cat 2 | 51.9% | 0.00% | 0.00% | 0.07% |
| **ZTE, Sanechips [15]** | UE WUS is used to wake up a gNB in an energy saving state without DL transmission including SSB/SIB1 | 1 | low | 7.4%  19.6%  23.8% | 0.66%  2.59%  5.04% |  |  | Set 1 | no WUS, cell is in a normal state with {20ms/40ms} SSB/SIB periodicity | FTP3 | UE mobility. slot-level; Pstatic=P3, η(s\_f,s\_p )=1; time-domain scaling for SSB; time and frequency domain scaling for SIB.  WUS period=20ms/80ms/160ms for each load. |
| light | 4.9%  12.7%  15.5% | 0.11%  0.43%  0.86% |  |  |
| 2 | low | 6.2%  6.4%  6.5% | 0.66%  2.59%  5.04% |  |  | no WUS, cell is in a normal state with {20ms/40ms} SSB/SIB periodicity |
| light | 4.5%  4.6%  4.7% | 0.11%  0.43%  0.86% |  |  |
| **vivo [10] [20]** | UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | Cat 1 | 0% | 29.7%  66.6%  80.7% |  |  | 0.00%  0.00%  0.00% | Set 1 | legacy BS, where all cells are always in the normal mode. Normal mode: 20ms SSB and SIB1, 20ms RACH listening | NaN  NaN  NaN | SLS No UE DRX 100% detection reliability |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | 0.002% | 27.3%  60.4%  72.8% | 0.8%  15.5%  21.7% | 5.68%  38.73%  39.53% | 0.00%  0.00%  0.00% | FTP3, mean packet interval of 10s, packet size of 100bytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | 20.55%  20.81%  20.49% | 0.8%  4.3%  6.0% | 3.4%  4.5%  8.6% | 9.70%  20.72%  32.51% | 0.98%  1.46%  1.66% | FTP3, mean packet interval of 200ms, packet size of 0.5Mbytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | 41.79%  41.17%  41.35% | -2.4%  0.3%  0.1% | 2.7%  6.0%  7.2% | 8.95%  14.55%  20.53% | 1.13%  1.51%  1.97% |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 0% | 32.1%  69.6%  83.7% |  |  | 0.00%  0.00%  0.00% | NaN  NaN  NaN |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 0.002% | 29.4%  63.3%  75.6% | 0.8%  16.5%  24.2% | 4.17%  38.05%  39.53% | 0.00%  0.00%  0.00% | FTP3, mean packet interval of 10s, packet size of 100bytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 20.71%  20.51%  20.66% | -0.1%  6.4%  6.6% | 3.9%  7.0%  8.7% | 11.04%  20.31%  29.07% | 1.08%  1.33%  1.65% | FTP3, mean packet interval of 200ms, packet size of 0.5Mbytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 41.74%  41.91%  42.07% | -2.2%  -0.7%  -0.6% | 1.3%  6.6%  7.5% | 10.32%  16.58%  18.21% | 1.13%  1.63%  1.84% |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | Cat 2 | 0% | 19.1%  19.4%  19.4% |  |  | 0.00%  0.00%  0.00% | NaN  NaN  NaN |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | 0.002% | 18.1%  18.3%  18.3% | 0.76%  5.40%  11.79% | 0.58%  8.98%  20.16% | 0.00%  0.00%  0.00% | FTP3, mean packet interval of 10s, packet size of 100bytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | 20.58%  20.28%  20.76% | 0.5%  1.0%  -0.4% | 0.69%  1.02%  2.88% | 7.93%  9.93%  17.27% | 0.64%  0.56%  0.99% | FTP3, mean packet interval of 200ms, packet size of 0.5Mbytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: 160ms SSB, 20ms/80ms/160ms UEWUS) | 41.46%  41.22%  41.04% | -2.4%  -2.1%  -1.8% | 0.05%  0.30%  0.45% | 5.94%  10.07%  11.62% | 0.99%  1.10%  0.96% |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 0% | 20.3%  20.6%  20.6% |  |  | 0.00%  0.00%  0.00% | NaN  NaN  NaN |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 0.002% | 19.2%  19.4%  19.5% | 0.85%  4.17%  10.53% | 2.63%  9.83%  20.86% | 0.00%  0.00%  0.00% | FTP3, mean packet interval of 10s, packet size of 100bytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 20.55%  20.61%  21.26% | 0.5%  0.3%  -1.0% | 0.36%  0.61%  2.21% | 8.30%  10.14%  17.32% | 0.71%  0.73%  1.11% | FTP3, mean packet interval of 200ms, packet size of 0.5Mbytes |
| UE WUS to wake up a ES gNB without or with sparse SSB/SIB1 and RACH monitoring  (the cells without traffic are switching to ES mode ES mode: no SSB, 20ms/80ms/160ms UEWUS) | 42.05%  41.38%  41.74% | -3.1%  -2.3%  -2.9% | 0.10%  0.21%  0.36% | 7.48%  9.16%  10.22% | 1.26%  0.98%  1.04% |
| **NOKIA/NSB [12]** | Wake up of gNB triggered by UE wake up signal (WUS) @ 20ms | Cat 2 | Low | 45.6% | 13,01 Mbps |  |  | Set 1 | SSBs/SIB1s/RO monitoring @ 20ms default periodicity UEs are initially in RRC\_idle state | UL - IM | SLS+Post-processing |
| Wake up of gNB triggered by UE wake up signal (WUS) @ 160ms | 51.9% | 6,08 Mbps |  |  |
| Wake up of gNB triggered by UE wake up signal (WUS) @ 640ms | 52.5% | 2,15 Mbps |  |  |
| Wake up of gNB triggered by UE wake up signal (WUS) @ 1280ms | 66.7% | 1,16 Mbps |  |  |
| **Samsung [21]** | Wake up of gNB triggered by UE wake up signal (WUS), @10 ms WUS periodicy | Cat 1 | Low | 70.3%  64.0%  57.2% |  | 0.00%  0.00%  0.00% |  | Set 2 | SR periodicity = 10ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE | SLS No UE DRX 100% detection reliability (one shot transmission). slot level, WUS detection power is 90. |
| Wake up of gNB triggered by UE wake up signal (WUS), @15 ms WUS periodicy | 76.4%  69.4%  61.8% |  | 0.00%  0.00%  0.00% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @10 ms WUS periodicy | 80.1%  73.7%  66.7% |  | 0.00%  0.00%  0.00% |  | SR periodicity = 10ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE | SLS No UE DRX 100% detection reliability (one shot transmission). slot level, WUS detection power is 55. |
| Wake up of gNB triggered by UE wake up signal (WUS), @15 ms WUS periodicy | 83.7%  76.5%  68.8% |  | 0.00%  0.00%  0.00% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @10 ms WUS periodicy | 92.8%  86.2%  79.0% |  | 0.00%  0.00%  0.00% |  | SR periodicity = 10ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE | SLS No UE DRX 100% detection reliability (one shot transmission). slot level, WUS detection power is 10. |
| Wake up of gNB triggered by UE wake up signal (WUS), @15 ms WUS periodicy | 93.0%  85.7%  77.8% |  | 0.00%  0.00%  0.00% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @5 ms WUS periodicy | 45.0%  39.2%  32.8% |  | -29.56%  -28.9%  -29.41% |  | SR periodicity = 10ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE | SLS No UE DRX 100% detection reliability (one shot transmission). slot level, WUS detection power is 90. |
| Wake up of gNB triggered by UE wake up signal (WUS), @5 ms WUS periodicy | 39.1%  32.6%  25.7% |  | -45.37%  -45.15%  -45.51% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @10 ms WUS periodicy | 67.1%  60.2%  52.7% |  | -22.44%  -22.85%  -22.79% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @5 ms WUS periodicy | 64.7%  58.5%  51.8% |  | -29.56%  -28.9%  -29.41% |  | SR periodicity = 10ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE | SLS No UE DRX 100% detection reliability (one shot transmission). slot level, WUS detection power is 55. |
| Wake up of gNB triggered by UE wake up signal (WUS), @5 ms WUS periodicy | 60.8%  54.1%  46.7% |  | -45.37%  -45.15%  -45.51% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @10 ms WUS periodicy | 78.0%  70.9%  63.2% |  | -22.44%  -22.85%  -22.79% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @5 ms WUS periodicy | 90.0%  83.4%  76.3% |  | -29.56%  -28.9%  -29.41% |  | SR periodicity = 10ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE | SLS No UE DRX 100% detection reliability (one shot transmission). slot level, WUS detection power is 10. |
| Wake up of gNB triggered by UE wake up signal (WUS), @5 ms WUS periodicy | 88.9%  81.6%  73.8% |  | -45.37%  -45.15%  -45.51% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| Wake up of gNB triggered by UE wake up signal (WUS), @10 ms WUS periodicy | 92.0%  84.7%  76.8% |  | -22.44%  -22.85%  -22.79% |  | SR periodicity = 15ms | FTP3, mean packet interval of 2s, UL traffic only, 1/5/10 UE |
| **Qualcomm**  **[17]** | Wake up of gNB triggered by UE two symbol wake up signal (WUS) | Category 1 | No Load | 18.7% |  | | | FR2 Set 3 | "light SSB" combined with UL WUS and on demand SIB 1 | | |

For UE WUS triggering SSB/SIB1/RACH for RRC IDLE/INACTIVE/CONNECTED mode by technique A-3-1, based on results from 4 sources, it is observed that, with UE WUS signal triggering a BS of 100% detection assumption,

* With C-DRX, at low load, one source observed about 50% network energy savings with marginal UE power increment, without UPT loss observed. The scheduling delay when switching to a new gNB is not modelled.
* For the evaluations with assumption of RRC\_IDLE/INACTIVE mode without C-DRX,
  + without DL transmission including DL common signals before gNB reception of WUS, with WUS period of 20ms, 80ms and 160ms, at zero or low load, the network energy savings could be 7.4%~32.1% (6.2%~45.6%), 19.6%~69.6% (6.4%~51.9%), 23.8%~ 83.7% (6.5%~52.5%) respectively by using Category 1 (Category 2) BS power model. The savings can increase as the WUS period increases, and decrease as the traffic load increases. When WUS period is 20ms, marginal UPT loss, access delay/latency increment and UE power consumption increment are observed. The UPT loss and access delay/latency increases as WUS periodicity increases, while there is marginal UE power consumption increment.
  + With sparse SSB of 160ms periodicity transmitted before gNB reception of WUS, at zero or low load, 27.3%~29.7% (18.1%~19.1%), 60.4%~66.6% (18.3%~19.4%), 72.8%~80.7% (18.3%~19.4%) network energy savings can be achieved with WUS period of 20ms, 80ms and 160ms respectively by using Category 1 (Category 2) BS power model. When WUS period is 20ms, marginal UPT loss, access delay/latency increment and UE power consumption increment are observed. The UPT loss and access delay/latency increases as WUS periodicity increases, while there is marginal UE power consumption increment.
* Note: gNB coordination for WUS reception is assumed. Resource configuration for WUS is not specifically modelled, while one source assumes the configuration of WUS can be obtained from a camping cell. For the case of no DL transmission, gNB synchronization is further assumed.
* Note: For evaluation results from 2 sources, it is assumed that UE achieves timing for the UL WUS transmission from the other cell. For evaluation results from 2 sources, it is assumed that UE achieves synchronization with the gNB targeting for energy saving by utilizing discovery signal from the same cell, and one source assumed the discovery signal contains PSS only and its use is to help the UE to get synchronized and to be able to transmit an uplink triggering signal. The differentiation of multiple gNBs which have detected the WUS is not modelled.
  + The detection of WUS is assumed to be ideal. False triggering for detection of targeting gNB is not considered.

For UE WUS triggering gNB to wake up in case of uplink traffic arrival by technique A-3-2, for RRC\_CONNECTED without C-DRX, and without DL common signals/DL transmission other than PDCCH carrying UL grant, with the assumption of a separate receiver used and 100% detection assumption, at low load, 1 source observed that,

* With WUS detection power of 10, 55 or, with 90 which has the same active UL power,
  + When the WUS periodicity is same as the baseline of SR periodicity, 77.8%~93%, 66.7%~92.8% or 57.2%~76.4% network energy savings could be achieved respectively;
  + When the WUS periodicity is smaller than the SR periodicity of the baseline, 76.3%~92%, 46.7%~78% or 25.7%~67.1% network energy savings could be achieved respectively;
  + For each case, the gain generally increases as the WUS periodicity increases and decreases as the traffic load increases. The gain could also increase as the gNB detection power decreases.
  + There is latency reduction observed, which could increase as the periodicity of WUS decreases. The gain can be up to 45%.
* The assumption is that gNB needs to wake up to detect SR but can detect WUS during sleep state. gNB is assumed to be in a state such that the main UL receiver is still in deep sleep when detecting wake-up signal and gNB is able to wake up from deep sleep to active in one slot after WUS detection. The WUS receiver is assumed to be active only when detection of WUS signal and becomes 0 power in other time.

When technique A-3-1 is combined with a light version of SSB and on demand SIB1, one source observed 18.7% network energy savings at low load for FR2, assuming the light version of SSB contains PSS only and its use is to help the UE to get synchronized and to be able to transmit an uplink trigger signal.

#### 6.1.3.3 Legacy UE and RAN1 specification impacts

Legacy UEs and UEs that do not support this technique cannot wake up a cell that is inactive. Legacy UEs and UEs that do not support this technique are not provided with expected transmission from the cell, therefore they cannot operate in the cell.

Specification impact of the technique may include:

* design of uplink wake-up signal/channel,
* signaling details of wake-up signal/channel and if needed, downlink signal/channel design/procedure for carrying information regarding the wake-up configuration,
* conditions for triggering WUS,
* mechanisms for DL synchronization and UE measurements needed prior to WUS transmission,
* UE’s assistance information to aid wake up operations by gNB,
* UE behavior/procedure after transmitting WUS,
* mechanism on how the UE can be informed about cell activity or lack of activity.

### 6.1.4 Technique A-4 Adaptation of DTX/DRX

#### 6.1.4.1 Description of technique

Currently, the gNB can use reduced downlink transmission/uplink reception activity without an explicit cell DTX/DRX pattern with restrictions due to UE DRX configurations and any configured transmission/reception, e.g., common channels/signals. Currently C-DRX is configured per UE. The alignment of the DRX cycles or offsets for different UEs can be done only via RRC. During UE DRX off period, the UE does not expect to monitor PDCCH, but it is allowed to initiate UL transmission according to the configured resources (e.g. using PUCCH, RACH, SR, or CG-PUSCH). Aligning/Omitting of DRX patterns across multiple UE’s can be achieved via gNB implementation.

Technique A-4 aims at providing mechanisms informing UE whether the cell stays inactive. This may include enhancements to UE DRX configuration, e.g. to align/omit DRX cycles or start offsets of DRX, for UEs in connected mode or idle/inactive mode, potentially allowing longer opportunities for cell inactivity. During a cell DTX/DRX, the cell may have no transmission/reception or only keep limited transmission/reception. For example, the cell does not need to transmit or receive some periodic signals/channels, such as common channels/signals or UE specific signals/channels.

#### 6.1.4.2 Analysis of NW energy saving and performance impact

The following captures the results for adaptation of UE DTX/DRX.

Table 6.1.4.2-1: BS energy savings by adaptation of UE DTX/DRX

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT (%: loss)** | **Access delay/latency/UE power consumption/Other KPI(s), if any; (%: increase)** | **a) Reference configuration**  **b) Baseline configuration/assumption**  **c) Traffic model**  **d) Other evaluation methodology/assumption details/notable settings** | | | |
| **MTK [19]** | DRX\_offset\_alignment | Cat 1 | Low | 29.8% | 0.91% | Access delay/latency: 0.92%  UE power consumption: 2.17% | Set 1  Random DRX offset (granularity = 5 ms)  VoIP  SLS; DRX (40, 4, 10); DRX offset aligned to 0 | | | |
| Cat 2 | 13.7% | 0.91% |
| **OPPO [14]** | DRX align | Cat 1 | low load(RU-9.3%) | 4.7% | 361.08Mbps (15.5%) | Access delay/latency: 78.03ms(+50%) | Set 1  UE-specific DRX, SSB with 20 RBs for 20 ms periodicity | | FTP (0.5MB as packet size, 200ms as mean inter-arrival time) | SLS, C-DRX config: FTP (160,100,8), DRX align |
| low load(RU-0.15%) | 6.7% | 85.91Mbps (8.7%) | Access delay/latency: 143.55ms(+3.83%) | IM (0.1MB as packet size, 2s as mean inter-arrival time) | SLS, C-DRX config: IM (320,80,10), DRX align |
| DRX align and dropping SSB outside UE active time | low load(RU-9.3%) | 14.4% | 361.08Mbps (15.5%) | Access delay/latency: 78.03ms(+50%) | FTP (0.5MB as packet size, 200ms as mean inter-arrival time) | SLS, C-DRX config: FTP (160,100,8), DRX align and dropping SSB outside UE active time |
| low load(RU-0.15%) | 70.1% | 85.91Mbps (8.7%) | Access delay/latency: 143.55ms(+3.83%) | IM (0.1MB as packet size, 2s as mean inter-arrival time) | SLS, C-DRX config: IM (320,80,10), DRX align and dropping SSB outside UE active time |
| **ZTE, Sanechips [15]** | DRX alignment | 1 | low | 0.3%  0.9% | 5%  1.30% | unfinished packet ratio=(total number of unfinished packet for baseline-total number of unfinished packet for enhanced)/total number of unfinished packet for baseline: 50%, 54.5% for each BS category | Set 1  UE-specific CDRX  FTP3  CDRX pattern for FTP3  CDRX alignment in a cell | | | |
| 2 | 0.2%  0.4% | 5%  1.30% |
| **Spreadtrum [13]** | traffic concentration (in a transmission window | Cat 1 | Low | 37.8%  34.9%  30.9% |  |  | a) For each BS Category: Set 1, Set 2, Set 3  b)- 1) There are 5% load (UE specific data) in 40 slots every 20ms. The load is frequency multiplexed with SSB burst and SIB1 in 2 slots every 20ms. 2) Scaling: Sf≈0.21 in 2 slots every 20ms, and Sf≈0.05 in 38 slots every 20ms  c)-1) The load is concentrated in first 10ms. There are 10% load (UE specific data) in the first 20 slots every 20ms, zero load in the last 20 slots every 20ms. The load is frequency multiplexed with SSB burst and SIB1 in 2 slots every 20ms. 2) gNB can enter light sleep for Cat 1, but can only enter micro sleep for Cat 2. 3) Scaling: Sf≈0.26 in 2 slots every 20ms, and Sf≈0.1 in 18 slots every 20ms  d)- 1) 160ms duration in total. 2) SSB burst periodicity is 20ms, and SIB1 repetition periodicity is 20ms. Two SSBs and the corresponding SIB1 share a slot. SSB burst and SIB1 take 40 PRBs. 3) PF periodicity at gNB side is 20ms (T=1280ms, N=64). Paging is transmitted in another slot every PF assuming one PO is effective in each PF. Paging takes 40 PRBs. 4) Scaling: Sa=1, Sp=1, P\_static=P3. Numerical evaluation results. | | | |
| Cat 2 | 31.1%  27.7%  29.2% |  |  |
| Offload between cells (the offloaded cell is turned off) | Cat 1 | Low | 57.7%  53.5%  47.9% |  |  | a) For each BS Category: Set 1, Set 2, Set 3  b)-1) Cell #1 and cell #2: There are 5% load (UE specific data) in 40 slots every 20ms. The load is frequency multiplexed with SSB burst and SIB1 in 2 slots every 20ms. 2) Scaling: Sf≈0.21 in 2 slots every 20ms, and Sf≈0.05 in 38 slots every 20ms  c)-1) The load in cell #1 is shifted to cell #2.  1.1) Cell #1: There are zero load. There are only SSB burst and SIB1 in 2 slots every 20ms. gNB can enter light sleep for Cat 1, but can only enter micro sleep for Cat 2. 1.2) Cell #2: There are 10% load (UE specific data) every 20ms. The load is frequency multiplexed with SSB burst and SIB1 in 2 slots every 20ms. 2) Scaling: 2.1) Cell #1: Sf≈0.16; 2.2) Cell #2: Sf≈0.26 in 2 slots every 20ms, and Sf≈0.1 in 38 slots every 20ms  d)-1) 160ms duration in total. 2) SSB burst periodicity is 20ms, and SIB1 repetition periodicity is 20ms. Two SSBs and the corresponding SIB1 share a slot. SSB burst and SIB1 take 40 PRBs. 3) PF periodicity at gNB side is 20ms (T=1280ms, N=64). Paging is transmitted in another slot every PF assuming one PO is effective in each PF. Paging takes 40 PRBs. 4) Scaling: Sa=1, Sp=1, P\_static=P3. Numerical evaluation results. | | | |
| Cat 2 | 46.5%  44.3%  46.6% |  |  |
| **Intel [22]** | Enhanced C-DRX | Cat1 | Light | 2.8% | Baseline: 122.3 Mbps ES: 86.4 Mbps | Avg EE (baseline): 5.20 Avg EE (ES): 4.82 | a)Set1  c) FTP3  d) SLS CSI feedback based on SRS; SIB1 BW: 48 PRB; SSB/PRACH/SIB1: 160 msec periodicity; Number of SSB: 1; Slot-level model For scaling: A = 0.4; η(s\_f,s\_p )=1 for any sf, sp; | Baseline DRX Parameters: DRX Cycle: 80 msec; ON duration 4ms, Inactivity Timer: 40msec For Enh C-DRX, cycle is 80ms and gNB is active for 20ms. | | |
| Medium | 29.7% | Baseline: 93.2 Mbps ES: 29.6 Mbps | Avg EE (baseline): 1.87 Avg EE (ES): 2.33 |
| Low | 2.3% | Baseline: 111.2 Mbps ES: 186.5 Mbps | Avg EE (baseline): 8.81 Avg EE (ES): 9.37 | Baseline DRX Parameters: DRX Cycle: 160 msec;ON duration 8ms, Inactivity Timer: 100msec For Enh C-DRX, cycle is 160ms and gNB is active for 80ms | | |
| Light | 2.3% | Baseline: 98.1 Mbps ES: 66.6 Mbps | Avg EE (baseline): 5.31 Avg EE (ES): 4.66 | Baseline DRX Parameters: DRX Cycle: 160 msec;ON duration 8ms, Inactivity Timer: 100msec For Enh C-DRX, cycle is 160ms and gNB is active for 40ms | | |
| Light | 2.6% | Baseline: 98.1 Mbps ES: 164.3 Mbps | Avg EE (baseline): 5.31 Avg EE (ES): 5.31 | Baseline DRX Parameters: DRX Cycle: 160 msec;ON duration 8ms, Inactivity Timer: 100msec For Enh C-DRX, cycle is 160ms and gNB is active for 80ms | | |
| Medium | 30.9% | Baseline: 75.0 Mbps ES: 28.2 Mbps | Avg EE (baseline):1.97 Avg EE (ES): 2.54 | Baseline DRX Parameters: DRX Cycle: 160 msec; Inactivity Timer: 100msec For Enh C-DRX, cycle is 160ms and gNB is active for 40ms | | |
| Medium | 4.8% | Baseline: 75.0 Mbps ES: 116.6 Mbps | Avg EE (baseline):1.97 Avg EE (ES): 2.04 | Baseline DRX Parameters: DRX Cycle: 160 msec; Inactivity Timer: 100msec For Enh C-DRX, cycle is 160ms and gNB is active for 80ms | | |
| **CATT [25]** | Adaptation of DTX/DRX | Cat 1 | Low load | 71.4% |  |  | Set1 | SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms; CSI-RS/TRS 10ms; | FTP3, inter-arrival time = 200ms, packet size = 0.5Mbytes | SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); DTX configuration: gNB starting offset of DTX on locate before UE DRX on duration in order to support UE wakeup; SSB periodicity: 20ms; CSI-RS/TRS periodicity: 10ms. |
| Light load | 62.6% |  |  | FTP3, inter-arrival time = 200ms, packet size = 0.5Mbytes |
| Medium load | 47.8% |  |  | FTP3, inter-arrival time = 200ms, packet size = 0.5Mbytes |

Based on 6 sources results, semi-static UE C-DRX alignment achieves BS energy savings gain by 0.2%~71.4% depending on the traffic, UE DRX configurations, and the assumed baseline, e.g. random DRX offset per UE, or gNB is always ON to provide service to the UE. At low or light traffic load cases, 4 sources show that the gain can be 14.4%~71.4%, while 3 sources show less than 6.7% gain, depending on whether BS and UE active duration are aligned or not; at medium load case, 2 sources show network energy saving gain can be 4.8%~47.8%. According to one source, dropping SSB outside UE active time can achieve the energy savings by 14.4%~70.1% and it is assumed that the UE active durations are aligned and the potential impact on synchronization and UE measurement outside the UE duration is not considered.

On UPT, one source shows there is marginal negative impact while one source shows it can be up to 15.5%. Also, one source shows that the impact on UPT varies: when the UE DRX cycle is 160ms and gNB active time is 80ms, the UPT is increased while in other configurations, there can be large UPT loss.

On access delay/latency, one source shows marginal increment while one source shows the increment can be up to 50%. Also, about 50% unfinished packet ratio is observed from one source compared to the baseline without UE C-DRX alignment during the evaluation period. The increments are related to the DRX configuration.

Additionally, one source shows that at low and medium load, the average EE is increased by up to 28.93% when UE DRX alignment is assumed, whereas for light load case, average EE decreases by up to 12.24% when UE DRX alignment is assumed.

#### 6.1.4.3 Legacy UE and RAN1 specification impacts

For the cell DTX/DRX cases, depending on DTX/DRX occasions, legacy UEs and UEs that do not support the technique may not have impact to idle/inactive/connected mode operations. For example, if DTX/DRX are not applied to common signals and channel required for idle/inactive/connected modes or applied in UE specific manner, legacy UEs and UEs that do not support the technique may not be impacted.

Specification impact of the technique may include:

* design of cell DTX/DRX pattern/timers/parameters/procedure, if needed,
* configuration and indication of cell DTX/DRX information to UE, if needed and applicable,
* UE behavior and procedures when cell DTX/DRX is in operation and/or when UE DRX is configured, if needed,
* potential channel/signal design and mechanism and uplink procedure (e.g., UE request or assistance feedback) related to cell DTX/DRX,
* enhancements to UE DRX configuration
* enhancements to UE DRX parameter adaptation.

#### 6.1.4.4 Higher layer procedures

Cell DTX/DRX is applied to at least UEs in RRC\_CONNECTED state. A periodic Cell DTX/DRX (i.e., active and non-active periods) can be configured by gNB via UE-specific RRC signalling per serving cell. Below examples on Cell DTX/DRX behaviour during non-active periods are assumed to be possible options, and the UE behaviour/impact will be studied:

* Example 1: gNB is expected to turn off all transmission and reception for data traffic and reference signal during Cell DTX/DRX non-active periods.
* Example 2: gNB is expected to turn off its transmission/reception only for data traffic during Cell DTX/DRX non-active periods (i.e., gNB will still transmit/receive reference signals)
* Example 3: gNB is expected to turn off its dynamic data transmission/reception during Cell DTX/DRX non-active periods (i.e., gNB is expected to still perform transmission/reception in periodic resources, including SPS, CG-PUSCH, SR, RACH, and SRS).
* Example 4: gNB is expected to only transmit reference signals (e.g., CSI-RS for measurement).

The study focus on UE behavior when at any point in time the cell activates a single DTX/DRX configuration. It is up to NW whether legacy UEs can access cells with Cell DTX/DRX.

The Cell DTX/DRX mode can be activated/de-activated via dynamic L1/L2 signalling and UE-specific RRC signaling. Both UE specific and common L1/L2 signalling can be considered for activating/deactivating the Cell DTX/DRX mode.

Cell DTX and Cell DRX modes can be configured and operated separately (e.g., one RRC configuration set for DL and another for UL). Cell DTX/DRX can also be configured and operated together. At least the following parameters can be configured per Cell DTX/DRX configuration: periodicity, start slot/offset, on duration. Details related to UE behaviour can be discussed during WI phase. Whether to support multiple Cell DTX/DRX configurations can be discussed later in the WI phase.

It is beneficial to align UE DRX with Cell DTX and DRX alignment among multiple UEs. The alignment mechanism can be discussed during the WI phase.

From RAN2 perspective, Cell DTX/DRX is feasible.

6.1.4.5 Impacts on network interfaces

The cell DTX/DRX information is considered necessary to be exchanged and coordinated between neighbour gNBs. The gNB can use the received cell DTX/DTX information to determine its own cell DTX/DRX configuration for network energy saving purpose.

Note: The details of cell DTX/DRX is finally up to RAN1 and RAN2.

### 6.1.5 Technique A-5 adaptation of SSB/SIB1 including on-demand SSB/SIB1

#### 6.1.5.1 Description of technique

Current specification supports SSB/SIB1-less operation for intra-band CA, where UE retrieves system information from and can perform synchronization based on another intra-band cell that transmits SSB and SIB1. Current specification supports SSB periodicity configuration up to 160 msec.

For technique A-5-1 for non-CA, the UE may obtain system information from other associated carriers/cells and synchronize from other associated carriers/cells and/or synchronize from signal(s) transmitted on the cell.

Technique A-5-2 also supports on-demand SSB/SIB1 transmissions and enable longer periods of cell inactivity to achieve network energy saving. SSB/SIB1 transmission at the serving cell can be triggered on-demand, e.g. by the UE.

#### 6.1.5.2 Analysis of NW energy saving and performance impact

The following capture the results for adaptation of SSB and/or SIB1, with focus on on-demand operation.

Table 6.1.5.2-1: BS energy savings by on-demand SSB and/or SIB1

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT** | **Access delay/latency/UE power consumption/Other KPI(s), if any** | **Reference configuration** | **Baseline configuration/assumption** | **Traffic model/Other evaluation methodology/assumption details/notable settings** |
| **CATT [25]** | Adaptation of SSB/SIB1 | Cat 1 | Low load | 22.0% |  |  | set1 | SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms; CSI-RS/TRS 10ms; | FTP3, inter-arrival time = 200ms, packet size = 0.5Mbytes. SLS;Cell OFF: Without normal SSB/SIB/CSI-RS transmission within Cell off duration; On demand SSB transmission is trigger by neighbour cell with 300ms transmission duration and 20ms SSB. For the case with DRX, DTX configuration: gNB starting offset of DTX on locate before UE DRX on duration in order to support UE wakeup; A=0.4; η(s\_f, s\_p)=1. |
| 43.4% |  |  | SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms; CSI-RS/TRS 10ms; DTX configuration: gNB starting offset of DTX on locate before UE DRX on duration in order to support UE wakeup; |
| **Ericsson [18]** | 20ms Discovery signal (4 symbols) + no SIB1 | Cat1 | Zero | 2.6% / 5.9% |  |  | Set 1 | Baseline scheme: 20ms SSB + 160ms SIB1 | one SSB/ four SSBs  Energy calculation: per symbol energy consumption is modeled.  According to Rel-15 specification, SIB1 can be transmitted with variable transmission repetition periodicity within a 160 ms period, including one SIB1 PDSCH transmission every 160ms or even sparser. |
| **Qualcomm [17]** | on-demand SIB1 | Cat 1 | Empty load | 5.8% / 7.7% / 8.6% |  |  | Set 1 | **Baseline**: 20ms periodicity for SSB/SIB1/RO, one beam **Enhanced**: 20%/10%/5% SIB1 Tx rate, C-WUS with 20ms periodicity |  |
| 32.1% / 36.6% / 38.8% |  |  | **Baseline**: 20ms periodicity for SSB/SIB1/RO, 8 beams **Enhanced**: 20%/10%/5% SIB1 Tx rate, C-WUS with 20ms periodicity |  |

One source shows that with a 4-symbol Discover signal (DRS), and without SIB1 transmission and for on-demand SIB1, 2.6% and 5.9% energy savings can be achieved for one SSB and four SSB respectively, at empty load with baseline of 20ms SSB/160ms SIB1 periodicity.

One source shows on-demand SSB can achieve BS energy savings by 22.0% or 43.4% at low load compared to a baseline of 20ms SSB/SIB1 periodicity, for without or with gNB DTX configuration respectively.

One source is provided with on-demand SIB1 at empty load with baseline of 20ms SSB/SIB1 periodicity, 5.8%~8.6% BS energy savings can be achieved at SIB1 transmission rate of 20%~5% for one SSB beam, and the gains can increase to 32.1%~38.8% for 8 beams case for a same SIB1 transmission rate range.

Performance impact of on demand SSB/SIB was not provided.

#### 6.1.5.3 Legacy UE and RAN1 specification impacts

For on-demand SSB, if no SSB or simplified SSB is transmitted and normal SSB transmission is triggered upon reception of UE WUS, legacy UEs and UEs that do not support this technique may not be able to operate in this cell.

* Technique may be enabled for a carrier only when legacy UEs are not using the carrier.

For on-demand SIB1, if no SIB1 is transmitted and normal SIB1 transmission is triggered upon reception of UE WUS, legacy UEs and UEs that do not support this technique may not be able to operate in this cell.

* Technique may be enabled for a carrier only when legacy UEs are not using the carrier.

For technique where UE may obtain system information from other associated carriers/cells, cell without a SSB cannot be used as PCell/PSCell/inter-band SCell for legacy UEs and UEs that do not support this technique.

For technique where UE may obtain system information from other associated carriers/cells, cell without a SIB1 cannot be used as PCell for legacy UEs and UEs that do not support this technique.

Specification impact of the technique may include:

* channel/signal design and behavior and procedures of on-demand SSBs/SIB1 and any related signaling,
* random access related enhancement including procedures and configuration for UEs to access the SSB/SIB1-less carrier/cell,
* mobility support or paging for the cell that does not transmit SSB and/or SIB1,
* design for new signal/channel (if any) and related procedures.

6.1.6 SCell without SSB in inter-band CA (RAN2)

From RAN2 perspective, the technique is studied from time domain. The description of this technique, analysis of network energy saving and performance impact as well as impact on legacy UE and RAN1 specification, can be found in section 6.1.5 for Technique A-5-1 and in section 6.2.1 for Technique B-1-1.

#### 6.1.6.1 Description of technique

Refer to section 6.1.5 for Technique A-5-1 and section 6.2.1 for Technique B-1-1.

#### 6.1.6.2 Analysis of NW energy saving and performance impact

Refer to section 6.1.5 for Technique A-5-1 and section 6.2.1 for Technique B-1-1.

#### 6.1.6.3 Legacy UE and RAN1 specification impacts

Refer to section 6.1.5 for Technique A-5-1 and section 6.2.1 for Technique B-1-1.

6.1.6.4 Higher layer procedures

The SCell without SSB in intra-band CA is considered as baseline, i.e., for a serving cell without transmission of SS/PBCH blocks, a UE acquires time and frequency synchronization with the serving cell based on receptions of SS/PBCH blocks on the SpCell or the SCell, of the cell group.

More detailed discussion on higher layer procedures for RAN2 may be needed in WI phase according to the other WGs input.

Feasibility of this solution is in RAN1 scope.

6.1.7 NES Cell without SIB/SSB (RAN2)

From RAN2 perspective, the technique is studied from time domain. The description of this technique, analysis of network energy saving and performance impact as well as impact on legacy UE and RAN1 specification, can be found in section 6.1.5 for Technique A-5-1 and in section 6.2.1 for Technique B-1-1.

#### 6.1.7.1 Description of technique

Refer to section 6.1.5 for Technique A-5-1 and section 6.2.1 for Technique B-1-1.

#### 6.1.7.2 Analysis of NW energy saving and performance impact

Refer to section 6.1.5 for Technique A-5-1 and section 6.2.1 for Technique B-1-1.

#### 6.1.7.3 Legacy UE and RAN1 specification impacts

Refer to section 6.1.5 for Technique A-5-1 and section 6.2.1 for Technique B-1-1.

6.1.7.4 Higher layer procedures

The concept of non-anchor NES cell without SIB is only applicable in multi-carrier scenario, where the UE is in coverage of an anchor cell and one or multiple non-anchor NES cell(s).

Anchor cell is a cell where a UE is capable of receiving SSB, system information and paging.

A non-anchor NES cell without SIB is a cell where the UE cannot receive SIB.

A non-anchor NES cell without SSB and SIB is a cell where a UE can receive neither SSB nor SIB.

Depending on the design, the access may occur only via anchor cell or also directly in the non-anchor NES cell. If access directly to a non-anchor NES cell is supported, the SIB transmitted by anchor cell may also include the necessary information to access the non-anchor NES cell.

How and whether the timing, synchronization and QCL relationship of the non-anchor NES cell without SSB and SIB can be determined via another cell is decided within WI.

UE camps on an anchor cell, not on a non-anchor NES cell without SIB (or without SSB and SIB).

Paging on a non-anchor NES cell without SIB or a non-anchor NES cell without SSB and SIB is not supported.

Feasibility of this solution is in RAN1 scope.

## 6.2 Techniques in frequency domain

### 6.2.1 Technique B-1 Multi-carrier energy savings enhancements

#### 6.2.1.1 Description of technique

Intra-band SSB-less SCell operation is supported by the current specification. PCell switching is supported by handover command according to current specification.

Technique B-1-1 for CA supports inter-band CA with SSB-less SCell. No SSB transmission in some inter-band SCell(s). The synchronization is acquired from other cell with SSB transmission or same cell with simplified signal transmission, also in order for fast activation and deactivation of SCell. Enabling of inter-band SSB-less SCell operation that may include mechanism for UE/gNB to trigger normal SSB transmission and/or reference signals, if needed, on a SCell for fast access, where the on-demand uplink triggering signal can be received either at inter-band SSB-less cell or another carrier/cell. RACH transmission opportunity may be supported in SSB-less SCell.

Technique B-1-2 supports dynamic PCell switching in which a common primary cell may be dynamically indicated for a group of UEs.

#### 6.2.1.2 Analysis of NW energy saving and performance impact

The following capture the results by multi-carrier energy savings enhancements.

Table 6.2.1.2-1: (a) BS energy savings by multi-carrier enhancements for results submitted to Technique B-1-1 [8]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **KPI** | **Baseline configuration/assumption** |
| **Huawei, HiSilicon**  **[9]** | Inter-band SSB-less on SCell | Cat 2 | 0% load(zero) | 14.4% |  | 4 SSB beams with 20ms period, 20RB  2 SSB per slot, and 4 symbols for each SSB, when the SSB is transmitted on a carrier |
| 10% load(low) | 9.3% |
| 20% load(light) | 7.4% |
| 30% load(medium) | 5.7% |
| **ZTE, Sanechips**  **[15]** | SSB-less SCell | 1 | zero load | 97.4% |  | SSB20ms for baseline; set 1; |
| 93.9% | SSB80ms for baseline; set 1; |
| 88.4% | SSB160ms for baseline; set 1; |
| 2 | 83.8% | SSB20ms for baseline; set 1; |
| 82.4% | SSB80ms for baseline; set 1; |
| 82.1% | SSB160ms for baseline; set 1; |
| 1 | 97.3% | SSB20ms for baseline; set 2; |
| 93.8% | SSB80ms for baseline; set 2; |
| 88.3% | SSB160ms for baseline; set 2; |
| 2 | 82.1% | SSB20ms for baseline; set 2; |
| 80.7% | SSB80ms for baseline; set 2; |
| 80.4% | SSB160ms for baseline; set 2; |
| SSB-less SCell with DL traffic | 1 | low | 58.4% | UPT:801.79, SSB-less UPT：812.57  UPT gain: 1.3%;  SCell activation delay reduced by 6ms | SSB20ms for baseline; set 1; with DL traffic;  SCell activation delay =12 ms |
| 35.2% | UPT:804.41, SSB-less UPT：812.57  UPT gain: 1.0%;  SCell activation delay reduced by 6ms | SSB80ms for baseline; set 1; with DL traffic;  SCell activation delay =12 ms |
| 21.2% | UPT:804.54, SSB-less UPT：812.57  UPT gain: 1.0%  SCell activation delay reduced by 6ms | SSB160ms for baseline; set 1; with DL traffic;  SCell activation delay =12 ms |
| 2 | 15.2% | UPT:801.79, SSB-less UPT：812.57  UPT gain: 1.3%;  SCell activation delay reduced by 6ms | SSB20ms for baseline; set 1; with DL traffic;  SCell activation delay =12 ms |
| 7.4% | UPT:804.41, SSB-less UPT：812.57  UPT gain: 1.0%;  SCell activation delay reduced by 6ms | SSB80ms for baseline; set 1; with DL traffic;  SCell activation delay =12 ms |
| 6.1% | UPT:804.54, SSB-less UPT：812.57  UPT gain: 1.0%;  SCell activation delay reduced by 6ms | SSB160ms for baseline; set 1; with DL traffic;  SCell activation delay =12 ms |
| 1 | 72.7% | UPT:115.80, SSB-less UPT：119.41  UPT gain: 3.1%;  SCell activation delay reduced by 6ms | SSB20ms for baseline; set 2; with DL traffic;  SCell activation delay =12 ms |
| 51.7% | UPT:118.20, SSB-less UPT：119.41  UPT gain: 1.0%;  SCell activation delay reduced by 6ms | SSB80ms for baseline; set 2; with DL traffic;  SCell activation delay =12 ms |
| 34.9% | UPT:118.70, SSB-less UPT：119.41  UPT gain: 0.6%;  SCell activation delay reduced by 6ms | SSB160ms for baseline; set 2; with DL traffic;  SCell activation delay =12 ms |
| 2 | 24.9% | UPT:115.80, SSB-less UPT：119.41  UPT gain: 3.1%;  SCell activation delay reduced by 6ms | SSB20ms for baseline; set 2; with DL traffic;  SCell activation delay =12 ms |
| 16.9% | UPT:118.20, SSB-less UPT：119.41  UPT gain: 1.0%;  SCell activation delay reduced by 6ms | SSB80ms for baseline; set 2; with DL traffic;  SCell activation delay =12 ms |
| 15.5% | UPT:118.70, SSB-less UPT：119.41  UPT gain: 0.6%  SCell activation delay reduced by 6ms | SSB160ms for baseline; set 2; with DL traffic;  SCell activation delay =12 ms |
| SSB-less SCell with UL traffic | 2 | low | 39.4% | SCell activation delay reduced by 6ms | SSB20ms for baseline; set1; with UL traffic;  SCell activation delay =12 ms |
| 22.4% | SSB80ms for baseline; set1; with UL traffic;  SCell activation delay =12 ms |
| 18.7% | SSB160ms for baseline; set1; with UL traffic;  SCell activation delay =12 ms |
| **Vivo**  **[10] [20]** | Inter-band CA with SSB-less carriers/SCell (ES scheme: CC 1: 20ms SSB and SIB1(with 48 PRB), 20ms RACH listening;  CC 2: neither transmission nor reception) | Cat 1 | 0% | 14.7% | UE power consumption increase: 0% | Baseline scheme: CC 1: 20ms SSB and SIB1(with 48 PRB), 20ms RACH listening;  CC 2: only 20ms SSB |
| Cat 2 | 0% | 5.1% |
| **Intel**  **[22]** | inter-band SSB-less SCell | Cat1 | Low | 3.0% | UPT: 1639.3 Mbps;Avg EE (baseline): 6.56; Avg EE (ES): 6.81 | Baseline: CC# 2 (SCell): 160 msec SSB, no SIB1/PRACH, ES: CC# 2 (SCell): no SSB/SIB1/PRACH, |
| Cat1 | Light | 1.0% | UPT:1222.9 Mbps;Avg EE (baseline): 2.96; Avg EE (ES): 3.00 |
| Cat1 | Medium | 0.3% | UPT: 915.8Mbps;Avg EE (baseline): 1.57; Avg EE (ES): 1.57 |
| **MTK**  **[19]** | SCell\_w/o\_SIB1 | Cat 1 | Light | 2.3% | UPT loss: 0.00%; Access delay/latency increase: 0%; UE power consumption increase: 0% | SCell has SSB and SIB1 |
| Cat 2 | 1.1% |
| SCell\_w/o\_SSB\_SIB1 | Cat 1 | 7.9% |
| Cat 2 | 1.3% |
| **CMCC**  **[23]** | SCell with simplified SSB: SCell with only PSS/SSS, with 20ms periodicity. PCell with normal SSB, SIB1 and also SIB information for SCell. | Cat.2 | Zero | 5.7% | N/A | Baseline: normal SSB on SCell. PCell with normal SSB, SIB1 and also SIB1 information for SCell. |
| Cat.1 | 10.5% |  |
| **Vivo**  **[10] [20]** | SSB/SIB-less carrier operation with assistance of anchor carrier (ES scheme: CC 1: 20ms SSB and SIB1(with 72 PRB), 20ms RACH listening;  CC 2: only 20ms RACH listening) | Cat 1 | 0% | 14.8% |  | Baseline scheme: CC 1: 20ms SSB and SIB1(with 48 PRB), 20ms RACH listening;  CC 2: 20ms SSB and SIB1(with 48 PRB), 20ms RACH listening |
| Cat 2 | 0% | 9.1% |  |
| **CATT**  **[25]** | Multi-carrier energy savings enhancements | Cat 1 | Low load | 25.7% |  | SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms;CSI-RS/TRS 10ms;Rel-17 SCell activation/deactivation; |
| Light load | 24.1% |  |
| Medium load | 15.5% |  |
| Low load | 30.3% |  |
| Light load | 29.1% |  |
| Medium load | 20.3% |  |
| **Qualcomm**  **[17]** | Dynamic UE-group PCell  switching | Cat 1 | Medium  (39% RU for 1 CC; 22% RU across 2 CCs) | 37.5% | UPT loss: 14% | **Assumption**: Number of Ues changes from 25 to 20 **Baseline**: Keep 2 CCs activated **Enhancement**: deactivate 1 CC and keep 1CC activated |

(b) BS energy savings by multi-carrier enhancements for results submitted to Technique A-5-1 [8]

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT** | **Access delay/latency/UE power consumption/Other KPI(s), if any** | **Reference configuration** | **Baseline configuration/assumption** | **Traffic model/Other evaluation methodology/assumption details/notable settings** |
| **CMCC [23]** | SSB/SIB1-less scheme: gNB has 2 co-deployed CCs, both of them are available for UE with single carrier operation to access, but only CC1 has normal SSB and SIB1 with default 20ms transmission period. CC2 only has PSS/SSS for synchronization. | cat.2 | Zero | 31.4% | / | CC1 carries SIB1 of CC2, the power consumption of CC1 increases 1.73% for FDM SIB of both CC. | set 1 | Baseline scheme: gNB has 2 co-deployed CCs, both of them are available for UE with single carrier operation to access, so both CC1 and CC2 has SSB and SIB1 with default 20ms transmission period. As shown in Figure.5 (a). | numerical analysis.  •SIB1:  -Baseline: for both CC1 and CC2, PDCCH: 2 symbols, 48RB; PDSCH: 12RBs, 12 OFDM symbols including DMRS. -SSB/SIB1-less scheme: no SIB1 on CC2, but CC1 carries SIB1 for CC2, so the TBS will be doubled. The number of PDSCH PRBs is 24 RBs, 12OFDM symbols. PDCCH still occupies 2 OFDM symbols, 48 PRBs. •SSB1 and SSB are transmitted in different slots, e.g. value in Table 13-11 is assumed to be 5ms. •ղ=1, A=0.4. •Time unit for power model is slot. power consumption is calculated in a 40ms long period |
| cat.1 | 56.5% | / | CC1 carries SIB1 of CC2, the power consumption of CC1 increases 1.41% for FDM SIB of both CC. |
| **Huawei, HiSilicon [9]** | SIB-less on ES CC | Cat 2 | 0% load(zero) | 33.6% | N/A | N/A | Set 2 | 4 SIB1 with 20ms period,20RB | FTP3 IM.  NO C-DRX; Subband based CSI-feedback in every 5 slots.  slot level with time-domain scaling; A=0.4; η=1, 0.76(s\_f\*s\_p<0.5) |
| 10% load(low) | 26.2% | N/A | N/A |
| 20% load(light) | 19.0% | N/A | N/A |
| 30% load(medium) | 16.0% | N/A | N/A |
| dual SIB on Anchor CC | 0% load(zero) | -7.5% | N/A | N/A |
| 10% load(low) | -6.7% | N/A | N/A |
| 20% load(light) | -6.1% | N/A | N/A |
| 30% load(medium) | -5.5% | N/A | N/A |
| SIB-less on ES CC | 0% load(zero) | 20.2% | N/A | N/A | 4 SIB1 with 40ms period,20RB |
| 11.2% | N/A | N/A | 4 SIB1 with 80ms period,20RB |
| 5.9% | N/A | N/A | 4 SIB1 with 160ms period,20RB |
| 10% load(low) | 15.7% | N/A | N/A | 4 SIB1 with 40ms period,20RB |
| 9.3% | N/A | N/A | 4 SIB1 with 80ms period,20RB |
| 4.0% | N/A | N/A | 4 SIB1 with 160ms period,20RB |
| **ZTE, Sanechips [15]** | (SSB and SIB)-less cell | 1 | zero | 97.9%  95.4%  91.1% |  |  | Set 1 | Baseline: SSB+SIB: {20ms+40ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell | FTP3 for Set 1. IM for Set 2.  slot-level; Pstatic=P3, η(s\_f,s\_p )=1;  time-domain scaling for SSB;  time and frequency domain scaling for SIB.  For the multiplexing pattern of two SIBs in the anchor cell (when applicable), TDM is considered in the evaluations. |
| low | 64.3%  43.6%  28.0% |  |  |
| SIB-less cell | zero | 19.3%  24.6%  23.5% |  |  | Baseline: SSB+SIB: {20ms+40ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: SIB1-less for non-anchor cell |
| low | 15.5%  13.6%  8.8% |  |  |
| anchor cell with dual SIB transmission | zero | -14.1%  -18.9%  -18.1% |  | energy increase for anchor cell with SIB1 transmission for SIB1-less cell | Baseline: SSB+SIB: {20ms+40ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell, anchor cell with SIB1 transmission for SIB1-less cell |
| low | -11.6%  -10.5%  -6.8% |  |
| (SSB and SIB)-less cell | zero | 98.4%  96.2%  92.6% |  |  | Set 2 | Baseline: SSB+SIB: {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell |
| low | 80.3%  59.4%  42.4% |  |  |
| SIB-less cell | zero | 40.7%  38.4%  37.0% |  |  | Baseline: SSB+SIB: {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: SIB1-less for non-anchor cell |
| low | 28.0%  16.0%  11.5% |  |  |
| anchor cell with dual SIB transmission | zero | -17.6%  -12.4%  -12.0% |  | energy increase for anchor cell with SIB1 transmission for SIB1-less cell | Baseline: SSB+SIB: {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell, anchor cell with SIB1 transmission for SIB1-less cell |
| low | -17.8%  -10.8%  -7.7% |  |
| (SSB and SIB)-less cell | 2 | zero | 85.8%  83.6%  82.8% |  |  | Set 1 | Baseline: SSB+SIB: {20ms+40ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell |
| low | 24.5%  13.4%  9.4% |  |  |
| SIB-less cell | zero | 12.1%  7.0%  3.7% |  |  | Baseline: SSB+SIB: {20ms+40ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: SIB1-less for non-anchor cell |
| low | 10.8%  6.2%  3.3% |  |  |
| anchor cell with dual SIB transmission | zero | -8.0%  -4.6%  -2.4% |  | energy increase for anchor cell with SIB1 transmission for SIB1-less cell | Baseline: SSB+SIB: {20ms+40ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell, anchor cell with SIB1 transmission for SIB1-less cell |
| low | -7.5%  -4.3%  -2.3% |  |
| (SSB and SIB)-less cell | zero | 87.5%  82.6%  81.4% |  |  | Set 2 | Baseline: SSB+SIB: {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell |
| low | 42.9%  23.6%  19.1% |  |  |
| SIB-less cell | zero | 28.2%  9.8%  5.3% |  |  | Baseline: SSB+SIB: {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: SIB1-less for non-anchor cell |
| low | 23.9%  8.0%  4.3% |  |  |
| anchor cell with dual SIB transmission | zero | -14.1%  -4.9%  -2.6% |  | energy increase for anchor cell with SIB1 transmission for SIB1-less cell | Baseline: SSB+SIB: {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; Enhanced: (SSB+SIB1)-less for non-anchor cell, anchor cell with SIB1 transmission for SIB1-less cell |
| low | -13.8%  -4.6%  -2.5% |  |
| **NOKIA/NSB [12]** | SSB-less at 20 ms period of RO | CAT2 | Unloaded/low/light/Medium | 27.5%  26.1%  26.0%  22.7% | /  135 Mbps  105 Mbps  74 Mbps |  | SET 1 | Intra-band/collocated cells with non-CA case, consisting of:  \* Coverage cell with 20 ms periodicity of SSB/SIB1 Tx and RO monitoring \* Capacity cell with 20 ms periodicity of SSB/SIB1 Tx and RO monitoring UEs initially in RRC Idle state. | DL-FTP3. SLS+Post-processing |
| SSB-less at 160 ms period of RO | Unloaded/low/light/Medium | 51.8%  48.2%  47.3%  43.2% | /  85 Mbps  72 Mbps  56 Mbps |  |
| SIB1-less at 20 ms period of RO | Unloaded/low/light/Medium | 43.1%  40.5%  40.1%  36.5% | /  132 Mbps  104 Mbps  73 Mbps |  |
| SIB1-less at 160 ms period of RO | Unloaded/low/light/Medium | 53.8%  51.2%  47.3%  43.2% | /  84 Mbps  72 Mbps  56 Mbps |  |
| SSB&SIB1-less at 20 ms period of RO | Unloaded/low/light/Medium | 52.7%  50.6%  52.7%  44.4% | /  135 Mbps  105 Mbps  74 Mbps |  |
| SSB&SIB1-less at 160 ms period of RO | Unloaded/low/light/Medium | 55.1%  53.1%  54.9%  46.8% | /  85 Mbps  72 Mbps  56 Mbps |  |
| **Fujitsu [11]** | SSB&SIB-less | Cat2 | Zero  low  light  medium | 34.5%  27.0%  21.7%  16.7% |  |  | Set 1 | Baseline scheme: 20 ms SSB/SIB1 period | BS goes into mico-sleep on symbolc w/o TX/RX  simplified SSB which contains SSS and PSS is transmitted with periodicity of 160 ms No UE DRX. A=0.4, η=1 |
| Zero  low  light  medium | 36.0%  24.7%  18.4%  13.5% |  |  | Set 2 |

Observation includes the results for techniques that are also evaluated under technique A-5 for non-CA. The following is observed.

In general, for SSB and/or SIB saved from one carrier of two carriers, 8 resources observed BS energy savings gain, by 5.1%~98.4% for empty load, 3.0%~58.4% for low load, and 1.0%~7.9% for light load, 0.3%~5.7% for medium load. When traffic load is low, network may turn off SCell for energy saving. The results are for FR1 only.

With one of two carriers having simplified SSB and no SIB1, one source shows BS energy saving gain can be achieved by 31.4%~56.5% compared with a baseline of both carriers having SSB and SIB1 periodicity of 20ms; the same source also shows that with CA configured where SIB1 is already carried by PCell, compared with normal SSB on SCell, the gain of simplified SSB on SCell can be 5.7%~10.5%.

With SIB-less only from one of two carriers and SSB is still transmitted,

* one source shows that 33.6%~16.0% BS energy saving gain can be achieved compared with a carrier has 20ms SIB1 periodicity and both SSB and SIB1 are transmitted, and the gain decreases as the traffic load increases. Meanwhile, the SIB1 carried on another carrier increase the energy of that carrier by 7.5%~5.5%, resulting a total saving across two carries by 26.1%~10.5%. The gain decreases to 4.0% when the baseline SIB1 periodicity increases to 160ms;
* one source shows BS energy saving gain can be 3.3%~40.7% compared with baseline of SSB+SIB periodicity of {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell; meanwhile, the SIB1 carried on another carrier increase the energy of that carrier by 2.3%~17.8%, resulting a total saving across two carries by 1%~22.9%;
* one source shows at different loads, compared to baseline of 20ms SSB/SIB1 periodicity, that BS energy savings can be achieved by 53.8%~36.5% with RO periodicity of 20ms and 160ms;
* also one source shows less than 2.3% BS energy savings when compared with a baseline of SCell having SIB1.

With SSB-less only from one of two carriers, in which case the SIB is already saved from SCell, with assumption that UE is able to acquire sync from a carrier of another band,

* for non-CA at different loads, compared to a baseline of 20ms SSB/SIB1 periodicity, one source shows BS energy savings by 27.5%~22.7% and 51.8%~43.2% when the RO periodicity is 20ms and 160ms respectively;
* for CA, two sources show that BS energy savings can be 5.1%~14.7% at different loads, compared to a baseline of 20ms SSB periodicity;
* for CA, one source shows, BS energy saving gain can be 80.4%~97.4% at empty load, 6.1%~72.7% at low load for DL traffic, or 18.7%~39.4% at low load for UL traffic compared with baseline of SSB periodicity of {20ms, 80ms, 160ms}. The BS energy saving gain from SSB-less cell with UL traffic is 12.6%~24.2% larger than SSB-less cell with DL traffic for BS category 2.
* for CA, one source also shows that when the baseline SCell SSB periodicity is 160ms, only 0.3%~3% BS energy savings can be achieved, and one another shows BS energy savings by less than 7.9% if compared with SCell having SIB1;
* UE measurement is based on SSB(s) transmitted in the other carrier of the two carriers.

With both SSB-less and SIB1-less from one of two carriers for non-CA operation, with assumption that UE is able to acquire sync from a carrier from another band,

* compared to baseline of 20ms SSB/SIB1 periodicity on both carriers, one source shows BS energy savings by 55.1%~44.4% with RO periodicity of 20ms~160ms at different loads, and one source shows 9.1%~14.8% energy savings at empty load if an anchor carrier carries additional SIB1 for another carrier;
* at different loads, compared to baseline of 20ms SSB/SIB1 periodicity, one source shows BS energy savings by 36.0%~13.5% when combined with simplified SSB (i.e. PSS and SSS only);
* one source shows that with baseline of SSB+SIB periodicity of {20ms+20ms, 80ms+80ms, 160ms+160ms} for anchor cell and non-anchor cell, BS energy savings can be 9.4%~98.4% if an anchor carrier carries the SSB and SIB1 for another carrier depending on the traffic load. Meanwhile, the SIB1 carried on another carrier increase the energy of that carrier by 2.3%~17.8%, resulting a total saving across two carries by 7.1%~80.6%.
* Comparison with CA is not provided.
* UE measurement is not considered.

For results where SSB is not transmitted in SCell, performance impact(s) due to lack of AGC and cell measurement results before SCell access and activation is not provided.

For results where SSB is not transmitted in neighbour cell, mobility performance impact(s) due to SSB-less operation in neighbour cell(s) is not provided.

In results for SSB and/or SIB saved from one carrier of two carriers, the UPT is not negatively impacted while one source shows slightly increased UPT. One source shows that the SCell activation delay can also be reduced to 6ms from the baseline.

No negative impact observed on UE power consumption for the above schemes.

Additionally, SSB-less SCell for CA can slightly improve the average EE, as observed by one source.

One source showed that UE-group PCell switching together with SCell dormancy could provide network energy saving by up to 37.5% for two-CC CA scenario with FR1 Set 1. However, UPT degrades by 14% if one SCell goes to dormant state.

#### 6.2.1.3 Legacy UE and RAN1 specification impacts

Legacy UEs or UEs that do not support this feature may not be able to operate inter-band CA with SSB-less SCells. A carrier without SSB cannot be operated as a PCell/PSCell for legacy UEs. The carrier cannot be operated as an SCell for legacy UEs if another intra-band carrier with SSB is not present. At least the feasibility and/or potential requirements of acquiring synchronization/measurements (including AGC aspects) from other cell with SSB transmission in inter-band CA needs study.

For SSB-less inter-band CA, specification impact of the technique may include:

* RACH procedures in SSB-less SCell for inter-band CA,
* enhancement on SCell activation procedure,
* enhancements on SCell dormancy operation,
* design for new simplified signal/channel (if supported) and related procedures.

For UE-group PCell switching, specification impact may include:

* mechanism to signal PCell switching,
* UE behavior based on indicated signalling.

### 6.2.2 Technique B-2 Adaptation of bandwidth part of UE(s) within a carrier

#### 6.2.2.1 Description of technique

In Rel-17, UE-specific BWP configuration and switching is supported. For SPS PDSCH reception, type-2 CG PUSCH transmission, and SP-CSI reporting on PUSCH, once BWP is switched, they should be reactivated by activation DCI.

Technique B-2 supports enhancements to enable UE group-common or cell-specific BWP configuration and/or switching. Also supports enhancements to enable SPS PDSCH reception/Type-2 CG PUSCH transmission/SP-CSI reporting on PUSCH without reactivation after the BWP switching.

#### 6.2.2.2 Analysis of NW energy saving and performance impact

The following capture the results for semi-statically configured bandwidth part of UEs within a carrier. The evaluation is performed with different traffic, e.g. medium traffic to light traffic for Set 1, and low traffic to very low traffic for Set 3, and the reduced BW of 80 MHz is applied as NES mode compared with baseline BW of 100 MHz.

Table 6.2.2.2-1: BS energy savings by BWP adaptation within carrier

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Company** | **BS Category** | **Load scenario** | **ES gain (%)** | **KPI (%: loss w.r.t. baseline)** | **Reference configuration** | **Baseline configuration/assumption** |
| **Samsung**  **[21]** | Cat 1 | Baseline traffic: 42.8 % RU Reduced traffic: 28.47 % RU | 38.2% | UPT: 6.05%; Packet latency: 6.44%; Scheduling latency: No increase | Set1 | Baseline: full 100MHz with 55 dBm  NES mode: 80 MHz with 54 dBm |
| Cat 2 | 27.8% |
| Cat 1 | Baseline traffic: 7.5 % RU Reduced traffic: 2.75 % RU | 52.2% | UPT: 14.67%; Packet latency: 17.2%; Scheduling latency: No increase |
| Cat 2 | 17.6% |
| Cat 1 | Baseline traffic: 32.1 % Reduced traffic: 25.7 % | 17.4% | UPT: 28.24%; Packet latency: 39.4%; Scheduling latency: No increase | Set3 | Baseline: full 100MHz with 49 dBm  NES mode: 80 MHz with 48 dBm |
| Cat 2 | 17.8% |

One source observed BS energy savings by 17.4%~52.2% at the expense of UPT loss by 28.4%~14.47%, and packet latency increases by 6.44%~39.4% when traffic is reduced compared to corresponding baseline. BWP switching delay is not modelled.

On scheduling latency, no negative impact is observed from the same source.

#### 6.2.2.3 Legacy UE and RAN1 specification impacts

Legacy UEs and UEs that do not support the technique are not able to change the BWP using the enhanced signaling mechanisms.

Specification impact of the technique may include signaling and procedure to support UE group-common or cell-specific BWP configuration and/or switching of BWP.

### 6.2.3 Technique B-3 Adaptation of bandwidth of UE(s) within a BWP

#### 6.2.3.1 Description of technique

Currently, a bandwidth of a BWP is semi-statically configured, and the bandwidth of the given BWP cannot be dynamically changed. The current BWP framework allows the UEs to be configured with a default BWP and switching to a default BWP based on timer. Reduction of the frequency resources within a BWP can be achieved via configuration and scheduling a the gNB.

Technique B-3 supports enhancements to enable group-common signaling to adapt the bandwidth of active BWP and continue operating in same BWP. Some frequency resources within the active BWP may be deactivated.

#### 6.2.3.2 Analysis of NW energy saving and performance impact

The following captures the results for dynamic /(semi)-static adaptation of bandwidth of active BWP.

Table 6.2.3.2-1: BS energy savings by BW adaptation within BWP

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **KPI** | **Baseline configuration/assumption** |
| **OPPO [14]** | adaptation of bandwidth of active BWP of UEs | Cat 1 | low load(RU-10%) | 1.4% | UPT: 554.74Mbps(-46.8%); Access delay/latency: 9.35ms(+86.3%) | system BW of 100MHz, 64T: (M, N, P, Mg, Ng, MP, NP,) = (8, 8, 2, 1, 1, 4, 8) |
| low load(RU-0.2%) | 1.3% | UPT: 513.43Mbps(-52%); Access delay/latency: 1.78ms(+48.3%) |
| **Intel [22]** | intra-carrier BWP adaptation | Low | -20.6% | UPT: Baseline (819.7Mbps), ES (346.8 Mbps); Avg EE (baseline): 5.10; Avg EE (ES): 1.87 | Baseline: Full BW ES: 50% BW |
| -75.4% | UPT: Baseline (819.7Mbps), ES (99.4 Mbps); Avg EE (baseline): 5.10; Avg EE (ES): 0.54 | Baseline: Full BW ES: 25% BW |
| Light | -45.9% | UPT: Baseline (611.5Mbps), ES (155.2Mbps); Avg EE (baseline): 2.66; Avg EE (ES): 0.69 | Baseline: Full BW ES: 50% BW |
| -61.8% | UPT: Baseline (611.5Mbps), ES (25.7Mbps); Avg EE (baseline): 2.66 Avg EE (ES): 0.26 | Baseline: Full BW ES: 25% BW |
| Medium | -27.6% | UPT: Baseline (457.9Mbps), ES (50.5Mbps); Avg EE (baseline): 1.50 Avg EE (ES): 0.44 | Baseline: Full BW ES: 50% BW |
| -13.5% | UPT: Baseline (457.9Mbps), ES (12.3Mbps); Avg EE (baseline): 1.50; Avg EE (ES): 0.44 | Baseline: Full BW ES: 25% BW |
| **CEWiT**  **[31]** | Dynamic adaptation of bandwidth of active BWP of UEs with dynamic indication | Cat 1 | Medium | 1.75% |  | Baseline: Full BW of 100MHz, 32 ports ES: 50% BW |

3 sources show different observations.

One source shows small BW energy saving gain by 1.3%/1.4% at the expense of about 50% UPT loss and increased access delay/latency by 48.3%/86.3%. One source shows BW energy saving gain of 1.75%. One source shows BS power consumption increases with BWP size reduction in a carrier and negative energy saving gain in the range of -13.5%~ -75.4% is observed, together with significantly reduced UPT, and additionally reduced average EE.

#### 6.2.3.3 Legacy UE and RAN1 specification impacts

Specification impact of the technique may include behaviour, procedure, and signalling related to enabling group-common adaptation of the bandwidth of active BWP.

## 6.3 Techniques in spatial domain

### 6.3.1 Technique C-1 Adaptation of spatial elements

#### 6.3.1.1 Description of technique

According to legacy MIMO procedures, the adaptation of spatial elements can be achieved by RRC (re-)configurations updating, such as CSI-RS (re-)configurations, in a semi-static manner. Moreover, the current framework allows UE to be configured with multiple CSI-RS resources, where these CSI-RS configurations may be with respect to different numbers of spatial antenna ports or antenna elements. With CSI reports respect to different number of spatial elements available, gNB is able to dynamically adjust the number of spatial elements for PDSCH transmission in current specification. CSI-RS and CSI reporting configurations are BWP-specific, and BWP adaptation framework can be utilized for the adaptation for a UE capable of multiple BWPs and dynamic BWP switching.

Indication for potential enhancements related to spatial element adaptation may help the UEs to adapt the already configured CSI-RS configuration such as dynamic/semi-persistent ON-OFF of CSI-RS or to reconfigure the CSI-RS configuration, with respect to adapted number of spatial elements/ports.

Technique C-1 aims to enhance dynamically adaptation of spatial elements such as the number of active transceiver chains or the number of active antenna panels at gNB in transmitting and/or receiving channels and signals.

#### 6.3.1.2 Analysis of NW energy saving and performance impact

The following captures the results for (dynamic) adaptation of spatial elements.

Table 6.3.1.2-1: BS energy savings by adaptation of spatial elements

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Company | ES scheme | BS Category &Reference configuration | Load scenario | ES gain (%) | UPT/latency/UE power/ Other KPIs | Baseline configuration/assumption | Evaluation methodology/assumption details/traffic model |
| MTK  [19] | #TxRU\_32 | Cat 1, Set 1 | Light | 15.8% | UPT loss:4.54%;  latency increase:4.76%;  UE power increase:3.48% | BS #TxRU 64 | SLS; DRX (160, 8, 100); FTP3 traffic |
| Cat 2, Set 1 | 15.8% | UPT loss:4.54%;  latency increase:4.76%;  UE power increase:3.48% |
| #TxRU\_16 | Cat 1, Set 1 | 19.2% | UPT loss:16.92%;  latency increase:20.36%;  UE power increase:14.70% |
| Cat 2, Set 1 | 22.1% | UPT loss:16.92%;  latency increase:20.36%;  UE power increase:14.70% |
| #TxRU\_8 | Cat 1, Set 1 | 22.1% | UPT loss:47.48%;  latency increase:90.42%;  UE power increase:47.94% |
| Cat 2, Set 1 | 24.9% | UPT loss:47.48%;  latency increase:90.42%;  UE power increase:47.94% |
| #TxRU\_32 | Cat 1, Set 1 | Medium | 25.3% | UPT loss:6.39%;  latency increase:6.83%;  UE power increase:4.20% |
| Cat 2, Set 1 | 26.6% | UPT loss:6.39%;  latency increase:6.83%;  UE power increase:4.20% |
| #TxRU\_16 | Cat 1, Set 1 | 31.4% | UPT loss:44.78%;  latency increase:81.08%;  UE power increase:32.85% |
| Cat 2, Set 1 | 36.7% | UPT loss:44.78%;  latency increase:81.08%;  UE power increase:32.85% |
| #TxRU\_8 | Cat 1, Set 1 | 36.0% | UPT loss:87.08%;  latency increase:647.07%;  UE power increase:79.99% |
| Cat 2, Set 1 | 45.2% | UPT loss:87.08%;  latency increase:647.07%;  UE power increase:79.99% |
| #TxRU\_32\_PDSCH\_PowOffset\_-3dB | Cat 1, Set 1 | Light | 18.8% | UPT loss:9.06%;  latency increase:9.96%;  UE power increase:7.62% | BS #TxRU 64; PDSCH power offset 0 dB | SLS; DRX (160, 8, 100);  FTP3 traffic model;  Single value η (=1) |
| Cat 2, Set 1 | 19.7% | UPT loss:9.06%;  latency increase:9.96%;  UE power increase:7.62% |
| OPPO  [14] | Dynamic adaptation of spatial elements. | Cat 1, Set 1 | low load(RU-10%) | 22.1% | UPT: 550Mbps (47.2% loss);  latency: 12.41ms (+147%) | system BW of 100MHz, 64T: (M, N, P, Mg, Ng, MP, NP,) = (8, 8, 2, 1, 1, 4, 8) | SLS, 8T: (M, N, P, Mg, Ng, MP, NP,) = (4, 2, 2, 1, 1, 2, 2) is used for evaluation;  FTP3 traffic model;  A = 0.4 and η=1 |
| low load(RU-0.2%) | 13.7% | UPT: 782.56Mbps (21.2% loss);  latency:1.79ms(+49.1%) | SLS, 8T: (M, N, P, Mg, Ng, MP, NP,) = (4, 2, 2, 1, 1, 2, 2) is used for ES evaluation,;  FTP3 IM traffic model;  A = 0.4 and η=1 |
| Huawei,HiSilicon  [9] | Dynamic TRX adaption with Multiple CSIs | Cat 2, Set 1 | 10% load(low) | 7.7% | 0% UPT loss | Dynamic TRX adaption with Single 64T CSI; | NO C-DRX;  Subband based CSI-feedback in every 5 slots;  FTP3 IM traffic model;  A=0.4; η=1, 0.76 |
| 4.0% | 5% UPT loss |
| 3.4% | 10% UPT loss |
| 30% load(medium) | 13.0% | 0% UPT loss |
| 11.3% | 5% UPT loss |
| 9.6% | 10% UPT loss |
| 10% load(low) | 7.5% | 0% UPT loss | C-DRX with (cycle, on-duration, inactivity timer) = (320, 10, 80) ms;  Subband based CSI-feedback in every 5 slots;  FTP3 IM traffic model;  A=0.4; η=1, 0.76 |
| 30% load(medium) | 10.9% | 0% UPT loss |
| Cat 2, Set 2 | 10% load(low) | 7.5% | 0% UPT loss | NO C-DRX;  Subband based CSI-feedback in every 5 slots;  FTP3 IM traffic model;  A=0.4; η=1, 0.76) |
| 13.2% | 5% UPT loss |
| 10.2% | 10% UPT loss |
| 30% load(medium) | 10.3% | 0% UPT loss |
| 19.2% | 5% UPT loss |
| 14.8% | 10% UPT loss |
| ZTE,Sanechips  [15] | TxRU reduction 48TxRU | Cat 2, Set 1 | Low load(RU=8.8%) | 7.8% | 1.5% UPT loss | Baseline: 64TxRU | FTP3: 20K packet size;η=1 |
| TxRU reduction 32TxRU | Low load(RU=8.8%) | 15.5% | 4.47% UPT loss |
| TxRU reduction 16TxRU | Low load(RU=8.8%) | 23.5% | 11.06% UPT loss |
| TxRU reduction 48TxRU | light load(RU=20%) | 10.8% | 1.5% UPT loss |
| TxRU reduction 32TxRU | light load(RU=20%) | 21.7% | 7.06% UPT loss |
| TxRU reduction 16TxRU | light load(RU=20%) | 33.7% | 15.31% UPT loss |
| TxRU reduction 48TxRU | medium load(RU=32%) | 12.5% | 3.34% UPT loss |
| TxRU reduction 32TxRU | medium load(RU=32%) | 24.6% | 10.44% UPT loss |
| Dynamic TxRUs adaptation via multi-CSI | Low load(RU=8.8%) | 27.1% | 0.9% UPT loss |
| light load(RU=20%) | 28.7% | 1.5% UPT loss |
| light load(RU=20%) | 31.3% | 7% UPT loss |
| medium load(RU=32%) | 23.8% | 1.17% UPT loss |
| TxRU reduction 48TxRU | Low load(RU=10%) | 5.6% | 6.89% UPT loss | FTP3: 0.1M packet size,η=1 |
| TxRU reduction 32TxRU | Low load(RU=10%) | 11.0% | 18.39% UPT loss |
| TxRU reduction 48TxRU | light load(RU=20%) | 9.1% | 6.32% UPT loss |
| TxRU reduction 32TxRU | light load(RU=20%) | 18.6% | 14.88% UPT loss |
| TxRU reduction 48TxRU | Medium load(RU=40%) | 11.8% | 8.01% UPT loss |
| TxRU reduction 32TxRU | Medium load(RU=40%) | 25.0% | 20.88% UPT loss |
| Dynamic TxRUs adaptation via multi-CSI | Low load(RU=10%) | 7.6% | 3.1% UPT loss |
| Low load(RU=10%) | 11.1% | 5.04% UPT loss |
| Low load(RU=10%) | 12.7% | 6.03% UPT loss |
| light load(RU=20%) | 13.8% | 2.52% UPT loss |
| light load(RU=20%) | 16.3% | 4.13% UPT loss |
| light load(RU=20%) | 18.7% | 5.15% UPT loss |
| light load(RU=20%) | 21.1% | 6.96% UPT loss |
| Medium load(RU=40%) | 15.7% | 2.89% UPT loss |
| Medium load(RU=40%) | 17.1% | 4.16% UPT loss |
| TxRU reduction 24TxRU | Cat 2, Set 2 | Low load(RU=5%) | 4.8% | 2.03% UPT loss | Baseline: 32TxRU | FTP3: 20K packet size,η=1 |
| TxRU reduction 16TxRU | Low load(RU=5%) | 9.6% | 5.61% UPT loss |
| TxRU reduction 8TxRU | Low load(RU=5%) | 14.8% | 12.5% UPT loss |
| TxRU reduction 24TxRU | Low load(RU=11%) | 8.0% | 3.07% UPT loss |
| TxRU reduction 16TxRU | Low load(RU=11%) | 15.9% | 9.75% UPT loss |
| TxRU reduction 8TxRU | Low load(RU=11%) | 25.3% | 19.36% UPT loss |
| TxRU reduction 24TxRU | light load(RU=20%) | 9.6% | 5.19% UPT loss |
| TxRU reduction 16TxRU | light load(RU=20%) | 19.7% | 12.87% UPT loss |
| TxRU reduction 8TxRU | light load(RU=20%) | 32.1% | 23.931% UPT loss |
| TxRU reduction 24TxRU | Low load(RU=5%) | 7.9% | 0.42% UPT loss | FTP3: 4K packet size, η=1 |
| TxRU reduction 16TxRU | Low load(RU=5%) | 15.8% | 1.72% UPT loss |
| TxRU reduction 8TxRU | Low load(RU=5%) | 24.3% | 3.54% UPT loss |
| TxRU reduction 24TxRU | Low load(RU=13%) | 11.2% | 0.67% UPT loss |
| TxRU reduction 16TxRU | Low load(RU=13%) | 22.7% | 1.5% UPT loss |
| TxRU reduction 8TxRU | Low load(RU=13%) | 35.0% | 3.84% UPT loss |
| TxRU reduction 24TxRU | light load(RU=28%) | 14.0% | 1.86% UPT loss |
| TxRU reduction 16TxRU | light load(RU=28%) | 27.8% | 6.16% UPT loss |
| TxRU reduction 8TxRU | light load(RU=28%) | 43.4% | 14.15% UPT loss |
| TxRU reduction 24TxRU | Medium load(RU=48%) | 14.3% | 5.07% UPT loss |
| TxRU reduction 16TxRU | Medium load(RU=48%) | 29.4% | 14.63% UPT loss |
| Dynamic TxRUs adaptation via multi-CSI | Low load(RU=5%) | 18.1% | 0.62% UPT loss |
| Low load(RU=13%) | 23.7% | 0.16% UPT loss |
| light load(RU=28%) | 19.4% | 0.74% UPT loss |
| Medium load(RU=48%) | 13.7% | 1.01% UPT loss |
| Vivo  [10] [20] | Dynamic antenna port adaptation (antenna ports are dynamically adapted (between 64 ports and 8 ports) according to the cell traffic load, in every slot) | Cat 1, Set 1 | 12.38% | 9.4% | UPT loss:0.36%;  latency increase: 0.08%;  UE power increase: 0.02% | Baseline: antenna ports are always 64 | SLS; No UE DRX; FTP3 traffic model,A=0.4, η=1 |
| 12.57% | 9.4% | UPT loss:1.98%;  latency increase: 2.20%;  UE power increase: 0.04% |
| 15.31% | 6.8% | UPT loss:12.26%;  latency increase: 14.20%;  UE power increase: 1.35% |
| Cat 2, Set 1 | 12.52% | 8.1% | UPT loss:2.12%;  latency increase: 2.35%;  UE power increase: 0.17% |
| 13.16% | 8.1% | UPT loss:6.48%;  latency increase:8.25%;  UE power increase:0.45% |
| 16.42% | 6.7% | UPT loss:18.50%;  latency increase:38.22%;  UE power increase:1.96% |
| Dynamic antenna port adaptation (between 64 ports and 8 ports) with multi-CSI | Cat 1, Set 1 | 15.33% | 12.8% | UPT loss:0.02%;  latency increase: 0.05%;  UE power increase: 0.01% | Baseline: antenna ports are always 64 | SLS; No UE DRX; FTP3 traffic model,A=0.4, η=1 |
| NOKIA/NSB  [12] | Reduced number of TX to 32 | Cat 2, Set 1 | Low | 27.6% | UPT: 163,26 Mbps | Single cell operation as per SET1 (64 TRX). UEs are initially in RRC\_CONNECTED state | SLS+Post-processing; FTP3 traffic model; A=0,4; Single value η (=1) |
| Light | 28.5% | UPT: 117,64 Mbps |
| Medium | 29.5% | UPT: 75,47 Mbps |
| Intel  [22] | Antenna port adaptation | Cat 1, Set 1 | Low | 19.1% | UPT Baseline: 819.7Mbps UPT ES: 731.1Mbps;  Avg EE (baseline): 5.11 Avg EE (ES): 5.46 | Baseline: 64Tx (fixed) ES: 32Tx (fixed) | SLS No C-DRX used for UEs; CSI feedback based on SRS; FTP3 traffic model; A = 0.4; η(s\_f,s\_p )=1 for any sf, sp; |
| 27.3% | UPT Baseline: 819.7Mbps UPT ES: 585.5Mbps;  Avg EE (baseline): 5.11 Avg EE (ES): 4.81 | Baseline: 64Tx (fixed) ES: 16Tx (fixed) |
| 4.5% | UPT Baseline: 819.7Mbps UPT ES: 801.8Mbps;  Avg EE (baseline): 5.11 Avg EE (ES): 5.07 | Baseline: 64Tx (fixed) ES: variable |
| Light | 25.7% | UPT Baseline: 611.5Mbps UPT ES: 539.8Mbps;  Avg EE (baseline): 2.67 Avg EE (ES): 3.11 | Baseline: 64Tx (fixed) ES: 32Tx (fixed) |
| 35.7% | UPT Baseline: 611.5Mbps UPT ES: 400.3Mbps;  Avg EE (baseline): 2.67 Avg EE (ES): 2.73 | Baseline: 64Tx (fixed) ES: 16Tx (fixed) |
| 1.9% | UPT Baseline: 611.5Mbps UPT ES: 606.7Mbps;  Avg EE (baseline): 2.67 Avg EE (ES): 2.71 | Baseline: 64Tx (fixed) ES: variable |
| Medium | 29.6% | UPT Baseline: 457.9Mbps UPT ES: 389.3Mbps;  Avg EE (baseline): 1.5 Avg EE (ES): 1.84 | Baseline: 64Tx (fixed) ES: 32Tx (fixed) |
| 41.8% | UPT Baseline: 457.9Mbps UPT ES: 243.9Mbps;  Avg EE (baseline): 1.5 Avg EE (ES): 1.67 | Baseline: 64Tx (fixed) ES: 16Tx (fixed) |
| 0.0% | UPT Baseline: 457.9Mbps UPT ES: 457.8Mbps;  Avg EE (baseline): 1.5 Avg EE (ES): 1.50 | Baseline: 64Tx (fixed) ES: variable |
| CATT  [25] | Dynamic adaptation of spatial elements | Cat 1, Set 1 | Low load | 6.8% | UPT loss:0.32% | SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms); SSB periodicity 20ms;CSI-RS/TRS 10ms;TxRU= 64. | SLS; (cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms);  SSB periodicity 20ms; CSI-RS/TRS 10ms; dynamic spatial antenna adaptation:  gNB dynamic adaptation of the number of TxRU from 64TxRU to 32 TxRU;  FTP3 traffic model; A=0.4; η(s\_f, s\_p)=1. |
| Light load | 12.2% | UPT loss:0.62% |
| Medium load | 18.0% | UPT loss:3.8% |
| Low load | 6.9% | UPT loss:1.5% | SLS; SSB periodicity 20ms; CSI-RS/TRS 10ms; TxRU= 64. | SLS; No DRX;  SSB periodicity 20ms; CSI-RS/TRS 10ms; dynamic spatial antenna adaptation:  gNB dynamic adaptation of the number of TxRU from 64TxRU to 32 TxRU;  A=0.4; η(s\_f, s\_p)=1. |
| Light load | 12.3% | UPT loss:1.6% |
| Medium load | 19.6% | UPT loss:1.8% |
| Fujitsu  [11] | Dynamic TxRU adaptation | Cat 2, Set 1 | low | 24.1% | 5.7% average UPT loss | BS #TxRU=64 | CSI feedback period = 20ms, feedback delay = 4ms,  immediate antenna adaptation delay gNB dynamically turns out half of the TxRUs if the DL data in the buffer is expected to be transmitted in the next slot;  FTP3 traffic model; A=0.4; Single value η (=1) |
| light | 18.6% | 4.1% average UPT loss |
| medium | 12.0% | 2.3% average UPT loss |
| Cat 2, Set 2 | low | 26.5% | 0.6% average UPT loss | BS #TxRU=32 |
| light | 20.0% | 0.5% average UPT loss |
| medium | 12.8% | 0.3% average UPT loss |
| Ericsson  [18] | BS #TxRU 32 | Cat1, Set 1 | Low | 15.0% | UPT loss of 1% for 95-%,  UPT loss of 2% for 50-% UPT loss of 8% for 5-% | BS #TxRU 64 | 1 SSB Single value η (=1)  FTP3 traffic model  Dynamic switching applied, i.e. adapting number of antennas for energy efficiency in durations when only users in good channel condition are scheduled. Note separate evaluation performed for different number of antennas (i.e. no switching between these settings). |
| Light | 21.2% | UPT loss of 3% for 95-%,  UPT loss of 6% for 50-% UPT loss of 12% for 5-% |
| Medium | 22.4% | UPT loss of 3% for 95-%,  UPT loss of 14% for 50-% UPT loss of 22% for 5-% |
| BS #TxRU 16 | Low | 21.4% | UPT loss of 3% for 95-%,  UPT loss of 5% for 50-% UPT loss of 14% for 5-% |
| Light | 31.6% | UPT loss of 6% for 95-%,  UPT loss of 15% for 50-% UPT loss of 44% for 5-% |
| Medium | 36.6% | UPT loss of 8% for 95-%,  UPT loss of 25% for 50-% UPT loss of 33% for 5-% |
| Qualcomm  [17] | #TxRU reduction (64 to 32) | Cat 1, Set 1 | Low | 29.4% | UPT loss at 50%tile: 31%; DL SINR loss at 5% tile: 4.5dB | BS #TxRU 64 | FTP3 traffic model |
| Light | 28.6% | UPT loss at 50%tile: 30%; DL SINR loss at 5% tile: 6.5dB |
| Samsung  [21] | #TxRU reduction (64 to 32) | Cat 1, Set 1 | Medium | 28.82% | UPT loss: 12.97%; latency increase: 16.69%  Baseline traffic: 27.87 % RU Changed traffic: 32.28 % RU | BS #TxRU 64 | FR1, Port adaptation from 64 to 32 TxRU  FTP3 traffic model |
| Light | 25.3% | UPT loss: 14.70%; latency increase: 16.84%;  Baseline traffic: 14.21 % RU Changed traffic: 16.94 % RU |
| Low | 19.47% | UPT loss: 19.19%; latency increase: 17.46%  Baseline traffic: 3.48 % RU Changed traffic: 4.05 % RU |
| Low | 10.93% | UPT loss: 25.12%; latency increase: 16.66%  Baseline traffic: 1.29 % RU Changed traffic: 1.56 % RU |
| #TxRU reduction (32 to 16) | Cat 1, Set 3 | Medium | 31.9% | UPT loss: 10.37%; latency increase: 4.58%  Baseline traffic: 21.69 % RU Changed traffic: 22.56 % RU | BS #TxRU 32 | FR2, Port adaptation from 32 to 16 TxRU  FTP3 traffic model |
| Low | 26.8% | UPT loss: 13.42%; latency increase: 15.54%  Baseline traffic: 7.23 % RU Changed traffic: 7.5 % RU |
| #TxRU reduction (32 to 8) | Cat 1, Set 3 | Medium | 48.2% | UPT loss: 7.6%; latency increase: 12.47%  Baseline traffic: 21.69 % RU Changed traffic: 23.31 % RU | BS #TxRU 32 | FR2, Port adaptation from 32 to 8 TxRU  FTP3 traffic model |
| Low | 40.5% | UPT loss: 13.7%; latency increase: 26.4%  Baseline traffic: 7.23 % RU Changed traffic: 7.76 % RU |

12 sources observed that BS energy savings can be achieved, at all loads for different sets of reference configurations with FTP3 for FTP3 IM traffic models, with or without UE C-DRX configuration. The gain depends on whether there is multiple CSI report assistance, the number of antenna ports that can be adapted, the load scenarios, and UPT loss. No performance analysis was provided for broadcast and common channels with dynamic antenna adaptation.

With dynamic/semi-static adaptation of spatial elements,

* One source shows that BS energy saving for UE specific PDSCH for FR1 can be achieved by 3.4%~19.6% with dynamic adaptation and multi-CSI, compared to dynamic adaptation of spatial elements with single CSI report. The UPT loss was observed by less than 10%;
* 3 sources show that the gain for UE specific PDSCH for FR1 can be 6.8%~31.3% with dynamic adaptation and multi-CSI, compared with no adaptation, with UPT loss of 0.02%~7%;
* 2 sources show that the gain can be 6.7%~26.5% with dynamic adaptation without multi-CSI, compared to no adaptation, with UPT loss of 0.3%~18.5%;
* 9 sources show that the gain can be 4.8%~48.2% with static adaptation without multi-CSI, compared to no adaptation, with UPT loss of 0.02%~87.08%. One source observed that the downlink coverage is reduced by 4.5dB ~ 6.5dB when reducing the number of TxRUs from 64 to 32 in Set 1 FR1 configuration;
* One source shows that when dynamic antenna adaptation is variably changed, the gain is reduced to a range of 0~4.5% with 0.02%~2.18% UPT loss;
* One source shows BS energy saving can be 18.8%~19.7% that additional gain can be obtained when this scheme is combined with PDSCH power offset. The UPT loss is observed by 9.06%;
* More number of elements are reduced, more gain can be generally obtained.

On latency, there is negative impact observed in three sources and the increment becomes larger as the number of reduced antenna ports becomes larger.

On UE power consumption, 2 sources show that there is increase by up to 79.99% (when number of TX RU is reduced from 64 to 8).

Additionally, one source shows that the average EE can be generally increased except for the low load case where number of antennas is reduced from 64 to 16, and the case of antenna number variably changing.

#### 6.3.1.3 Legacy UE and RAN1 specification impacts

There is no impact for legacy UEs if the spatial element adaptation is used on a UE-specific basis, i.e., applied only for UEs supporting the technique.

Specification impact of the technique may include:

* mechanisms to indicate spatial element adaptation to the UE,
  + signaling to update the active CSI-RS configurations,
* enhancements on CSI-RS (re)configuration, CSI/RRM/RLM measurements, CSI reporting (e.g., multiple CSI reports), and beam management for gNB to switch between different spatial domain configurations,
* associated UE behavior in case of spatial element adaptation occurs, if needed, e.g., measurements, CSI feedback, power control, PUSCH/PDSCH repetition, SRS transmission, TCI configuration, beam management, beam failure recovery, radio link monitoring, cell (re)selection, handover, initial access, etc.

### 6.3.2 Technique C-2 Adaptation of TRPs in mTRP operation

#### 6.3.2.1 Description of technique

Technique C-2 aims to support TRP activation/deactivation that can be informed to the UE when a UE is configured with multiple TRPs. The technique aims to dynamically adapt the number of TRPs transmitting and/or receiving signals and channels.

#### 6.3.2.2 Analysis of NW energy saving and performance impact

The following capture the results for TRP muting in multi-TRP operation.

Table 6.3.2.2-1: BS energy savings by TRP muting in multi-TRP operation

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **UPT/latency/UE power consumption/ Other KPIs** | **Baseline configuration/assumption** | **Evaluation methodology/assumption details** |
| **NOKIA/NSB**  **[12]** | Semi-static reduced number of TRPs | Cat 2, Set 1 | Low | 38.8% | UPT loss: -14.49% | 2 TRPs are assumed. UEs are initially in RRC\_CONNECTED state. | SLS+Post-processing,  FTP3 traffic model; A=0,4; Single value η (=1).  70% of the P\_Static among TRPs |
| Light | 37.2% | UPT loss: -14.14% |
| Medium | 36.9% | UPT loss: -7.27% |
| **CATT**  **[25]** | Dynamic TRP muting/adaptation in multi-TRP operation | Cat 1, Set 1 | Low load | 28.4% | UE power: 50.6;  UE ESG:12.7% | M-TRP configuration:  One cell is configured with 2TRPs;  Both of TRP are activated. | SLS; (DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms);  SSB periodicity 20ms;  CSI-RS/TRS 10ms;  TRP OFF: 160ms SSB/CSI-RS transmission.  When TRP is activated, additional CSI-RS/TRS is transmitted before data scheduling. FTP3 traffic model; A=0.4; η(s\_f, s\_p)=1. |
| Light load | 28.7% | UE power: 50.6;  UE ESG:12.7% |
| Medium load | 19.7% | UE power: 51.6;  UE ESG:12.4% |
| **Qualcomm**  **[17]** | Semi-static TRP reduction (2 to 1) | Cat 1, Set 1 | Low | 41.6% | UPT loss at 50%-tile: 16% | 2 TRPs, each with 64 TxRUs | FTP3 traffic model |
| Light | 39.0% | UPT loss at 50%-tile: 22% |

For two TRP configuration case at different loads,

* (2 sources) with semi-static TRP reduction, BS energy saving gain can be achieved by 36.9%~41.6% compared to no TRP reduction, with UPT loss of 7.27%~22%;
* (one source) with dynamic TRP reduction, compared to no TRP reduction, BS energy saving gain can be achieved by 19.7%~28.7%, without reported UPT impact. It assumes two TRP are always transmitting CSI-RS.

For the BS energy saving gain around 19.7%~28.7%, it is also observed from one source that UE power savings can be achieved by about 12%.

#### 6.3.2.3 Legacy UE and RAN1 specification impacts

There is no impact for legacy UEs if the spatial element adaptation is used on a UE-specific basis, i.e., applied only for UEs supporting the technique.

Specification impact of the technique may include:

* UE-specific/group-level/cell common signaling for indicating adaptation of TRPs and TRP-related parameters (e.g. TRP index or CORESET pool index) in mTRP,
* enhancements to UE behaviours due to dynamic adaptation of TRPs, e.g., measurements, CSI feedback, power control, PDCCH/PUCCH/PUSCH/PDSCH repetition, single-DCI based scheduling, multi-DCI based scheduling, SRS transmission, TCI configuration, beam management, beam failure recovery, radio link monitoring, cell (re)selection, handover, initial access, etc.

## 6.4 Techniques in power domain

### 6.4.1 Technique D-1 Adaptation of transmission power of signals and channels

#### 6.4.1.1 Description of technique

As per current specification, the SSB reference power, *ss-PBCH-BlockPower* is defined in SIB1. The *powerControlOffsetSS* that is the power offset between (NZP)CSI-RS and SSB, and the *powerControlOffset* that is the power offset of PDSCH and (NZP) CSI-RS, are semi-statically configured via RRC signaling. The power offset configurations for PDSCH and CSI-RS are BWP-specific. Current specification allows gNB to adapt the PDSCH transmission power.

Technique D-1 aims at adapting the transmission power or PSD of downlink signals and channels dynamically, by enhancing the related configuration to the UE (e.g. considering power offsets that account for potential power adaptation) and/or enhancing the UE feedback (e.g. CSI report) to assist NW energy saving operation. The technique may be applicable to one or more of PDSCH, CSI-RS, DMRS, broadcast channels/signals (e.g., SSB/SI/paging). Enhancements for updating the power offset values between various signals and channels, e.g., CSI-RS to SSB, or PDSCH to CSI-RS include using lower layer signaling.

#### 6.4.1.2 Analysis of NW energy saving and performance impact

The following capture the results for adaptation of transmission power of signals and channels.

Table 6.4.1.2-1: BS energy savings by (dynamic) transmission power adaptation

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **Baseline configuration/assumption** | **Other KPI (%: loss w.r.t. baseline)** |
| **MTK**  **[19]** | PDSCH\_PowOffset\_-3dB | Cat 1 | Light | 8.7% | Baseline：PDSCH power offset 0 dB  ES scheme：PDSCH power offset -3/-6/-9 dB  reference configuration：Set1  FTP3，DRX (160, 8, 100)，Single value η (=1) | UPT:2.03%,UE power comsumption:1.80%,ltency:2.07% |
| PDSCH\_PowOffset\_-6dB | 11.1% | UPT:5.66%,UE power comsumption:4.47%,latency:6.00% |
| PDSCH\_PowOffset\_-9dB | 9.0% | UPT:10.80%,UE power comsumption:9.17%,latency:12.11% |
| PDSCH\_PowOffset\_-3dB | Medium | 13.9% | UPT:3.28%,UE power comsumption:2.46%,latency:3.39% |
| PDSCH\_PowOffset\_-6dB | 18.7% | UPT:8.97%,UE power comsumption:6.80%,latency:9.85% |
| PDSCH\_PowOffset\_-9dB | 17.7% | UPT:19.49%,UE power comsumption:14.78%,latency:24.21% |
| PDSCH\_PowOffset\_-3dB | Cat 2 | Light | 8.7% | UPT:2.03%,UE power comsumption:1.80%,latency:2.07% |
| PDSCH\_PowOffset\_-6dB | 11.8% | UPT:5.66%,UE power comsumption:4.47%,.latency:6.00% |
| PDSCH\_PowOffset\_-9dB | 11.2% | UPT:10.80%,UE power comsumption:9.17%,latency:12.11% |
| PDSCH\_PowOffset\_-3dB | Medium | 14.7% | UPT:3.28%,UE power comsumption:2.46%,latency:3.39% |
| PDSCH\_PowOffset\_-6dB | 20.6% | UPT:8.97%,UE power comsumption:6.80%,latency:9.85% |
| PDSCH\_PowOffset\_-9dB | 21.0% | UPT:19.49%,UE power comsumption:14.78%,latency:24.21% |
| #TxRU\_32\_PDSCH\_PowOffset\_-3dB | Cat 1 | Light | 18.8% | Baseline：PDSCH power offset 0 dB,BS #TxRU 64  ES scheme：PDSCH power offset -3 dB, BS #TxRU 32  reference configuration：Set1  FTP3，DRX (160, 8, 100)，Single value η (=1) | UPT:9.06%,UE power comsumption:7.62%,latency:9.96% |
| Cat 2 | 19.7% | UPT:9.06%,UE power comsumption:7.62%,latency:9.96% |
| **Huawei，HiSilicon**  **[9]** | Dynamic Power back-off with Multiple CSIs | Cat 2 | 30% load(medium) | 5.3% | baseline: Dynamic Power back-off with Single CSI  ES scheme: Dynamic Power back-off with Multiple CSIs  reference configuration: Set1  FTP3 IM, NO C-DRX; Subband based CSI-feedback in every 5 slots, slot level with time-domain scaling; A=0.4; η=1, 0.76(s\_f\*s\_p<0.5) | UPT: 0% loss |
| 7.3% | baseline: Dynamic Power back-off with Single CSI  ES scheme: Dynamic Power back-off with Multiple CSIs  reference configuration: Set1  VoIP, NO C-DRX; Subband based CSI-feedback in every 5 slots, slot level with time-domain scaling; A=0.4; η=1, 0.76(s\_f\*s\_p<0.5) |
| 6.9% | baseline: Dynamic Power back-off with Single CSI  ES scheme: Dynamic Power back-off with Multiple CSIs  reference configuration: Set2  VoIP, NO C-DRX; Subband based CSI-feedback in every 5 slots, slot level with time-domain scaling; A=0.4; η=1, 0.76(s\_f\*s\_p<0.5) |
| 11.5% | baseline: Dynamic Power back-off with Single CSI  ES scheme: Dynamic Power back-off with Multiple CSIs  reference configuration: Set2  VoIP, 4T for Set 2,NO C-DRX; Subband based CSI-feedback in every 5 slots, slot level with time-domain scaling; A=0.4; η=1, 0.76(s\_f\*s\_p<0.5) |
| 5.3% | baseline: Dynamic Power back-off with Single CSI  ES scheme: Dynamic Power back-off with Multiple CSIs  reference configuration: Set2  FTP3 IM, 4T for Set 2, NO C-DRX; Subband based CSI-feedback in every 5 slots, slot level with time-domain scaling; A=0.4; η=1, 0.76(s\_f\*s\_p<0.5) |
| **ZTE,Sanechips**  **[15]** | PDSCH PSD reduction 53.75dBm | Cat 2 | Low load(RU=10%) | 2.3% | Baseline: 55dBm  reference configuration:Set 1: FR1 TDD, FTP3: 20K packet size, slot-level,Pstatic=P3, η=1 | 0.56% UPT loss |
| light load(RU=20%) | 4.4% | 1.82% UPT loss |
| Medium load(RU=31%) | 6.0% | 3.8% UPT loss |
| PDSCH PSD reduction 52dBm | Low load(RU=10%) | 6.4% | 1.26% UPT loss |
| light load(RU=20%) | 10.1% | 1.83% UPT loss |
| Medium load(RU=31%) | 12.9% | 2.38% UPT loss |
| Low load(RU=4.7%) | 3.9% | Baseline: 55dBm  reference configuration:Set 1: FR1 TDD, FTP3: 0.5M packet size, slot-level,Pstatic=P3, η=1 | 5.74% UPT loss |
| Low load(RU=9.6%) | 7.0% | 4.32% UPT loss |
| light load(RU=23.5%) | 12.2% | 5.48% UPT loss |
| Medium load(RU=38.4%) | 16.6% | 9.81% UPT loss |
| PDSCH PSD reduction 47.75dBm | Low load(RU=13%) | 5.9% | Baseline: 49dBm  reference configuration:Set 2: FR1 FDD, FTP3: 0.1M packet size, slot-level,Pstatic=P3, η=1 | 0.64% UPT loss |
| light load(RU=29%) | 8.6% | 0.05% UPT loss |
| PDSCH PSD reduction 46dBm | Low load(RU=13%) | 11.8% | 1.56% UPT loss |
| light load(RU=29%) | 17.0% | 0.75% UPT loss |
| Dynamic PDSCH PSD adaptation via multi-CSI | Low load(RU=10%) | 12.1% | Baseline: 55dBm  reference configuration:Set 1: FR1 TDD, FTP3: 20K packet size, slot-level,Pstatic=P3, η=1 | 0.38% UPT loss |
| light load(RU=20%) | 16.6% | 0.35% UPT loss |
| Medium load(RU=31%) | 23.8% | 1.17% UPT loss |
| Medium load(RU=31%) | 16.4% | 0.27% UPT loss |
| **NOKIA/NSB**  **[12]** | Reduced DL transmit power by 3dB | Cat 2 | Low | 9.8% | Baseline: MaximumTx power of 49 dBm.UEs are initially in RRC\_CONNECTED state  reference configuration:Set 2, DL-FTP3, A=0,4; Single value η (=1)  SLS | UPT:144 Mbps |
| Reduced DL transmit power by 6dB | 12.2% | UPT:134 Mbps |
| Reduced DL transmit power by 9dB | 13.4% | UPT:119 Mbps |
| Reduced DL transmit power by 3dB | Light | 15.4% | UPT:104 Mbps |
| Reduced DL transmit power by 6dB | 19.7% | UPT:97 Mbps |
| Reduced DL transmit power by 9dB | 17.9% | UPT:88 Mbps |
| Reduced DL transmit power by 3dB | Medium | 16.2% | UPT:76 Mbps |
| Reduced DL transmit power by 6dB | 23.4% | UPT:70 Mbps |
| Reduced DL transmit power by 9dB | 24.7% | UPT:63 Mbps |
| **DCM**  **[16]** | PDSCH\_PowOffset\_-6dB | Cat 1 | Light | 6.6% | Baseline:PDSCH power offset 0 dB  reference configuration:Set 1,FTP3, A=0.4, Single value η (=1) | 1.00% UPT loss |
| PDSCH\_PowOffset\_-12dB | 8.3% | 2.60% UPT loss |
| PDSCH\_PowOffset\_-18dB | 8.7% | 5.70% UPT loss |
| PDSCH\_PowOffset\_-6dB | Medium | 15.5% | 2.50% UPT loss |
| PDSCH\_PowOffset\_-12dB | 19.5% | 2.00% UPT loss |
| PDSCH\_PowOffset\_-18dB | 20.4% | 5.80% UPT loss |
| PDSCH\_PowOffset\_-6dB | High | 24.1% | -3.10% UPT loss |
| PDSCH\_PowOffset\_-12dB | 29.9% | -0.70% UPT loss |
| PDSCH\_PowOffset\_-18dB | 31.4% | 0% UPT loss |
| **Intel**  **[22]** | Transmit Power Adaptation/ -12dB power | Cat1 | Low | 19.2% | Baseline: Full power  SLS; No C-DRX used for UEs;  CSI feedback based on SRS;  SIB1 BW: 48 PRB;  No paging overhead;  1 SSB beam;  SSB/PRACH periodicity: 20msec;  SIB1 periodicity: 40msec;  Slot level model  For scaling:  A = 0.4;  η(s\_f,s\_p )=1 for any sf, sp; | Baseline: 819.7 Mbps ES: 746 Mbps  Avg EE (Baseline): 5.10  Avg EE (ES) : 5.43 |
| Light | 28.2% | Baseline: 611.5 Mbps ES: 567.5 Mbps  Avg EE (Baseline): 2.66 Avg EE (ES) : 3.25 |
| Medium | 34.3% | Baseline: 457.9 Mbps ES: 415.1 Mbps  Avg EE (Baseline): 1.5 Avg EE (ES) : 2.03 |
| Transmit Power Adaptation/ -6dB power | Low | 17.6% | Baseline: 819.7 Mbps ES: 798.5 Mbps  Avg EE (Baseline): 5.10 Avg EE (ES) : 5.83 |
| Light | 25.4% | Baseline: 611.5 Mbps ES: 604.8 Mbps  Avg EE (Baseline): 2.66 Avg EE (ES) : 3.41 |
| Medium | 30.0% | Baseline: 457.9 Mbps ES: 450.7 Mbps  Avg EE (Baseline): 1.5 Avg EE (ES) : 2.06 |
| **CATT**  **[25]** | Adaptation of transmission power of signals and channels | Cat 1 | Low load | 3.9% | Baseline:SSB periodicity 20ms;CSI-RS/TRS 10ms;Transmission power:55dBm;  reference configuration:Set 1, FTP3, inter-arrival time = 200ms, packet size = 0.5Mbytes;  A=0.4; η(s\_f, s\_p)=1. | UPTloss:1.6% |
| Light load | 7.7% | UPTloss:1.8% |
| Medium load | 9.1% | UPTloss:2.8% |
| Low load | 4.1% | Baseline: SSB periodicity 20ms;CSI-RS/TRS 10ms;(DRX-cycle, on duration timer, inactivity timer) = (160ms, 8ms, 100ms);Power domain adaptation;  reference configuration:Set 1, FTP3, inter-arrival time = 200ms, packet size = 0.5Mbytes;  A=0.4; η(s\_f, s\_p)=1. | UPTloss:1.9% |
| Light load | 7.7% | UPTloss:3.9% |
| Medium load | 11.2% | UPTloss:3.1% |
| **Ericsson**  **[18]** | Tx power adaptation (reduction up to 12 dB) | Cat1 | Low | 20.9% | Baseline: BS Tx power 55 dBm  reference configuration:Set 1,FTP3  1 SSB  Single value η (=1).  For ES scheme: dynamic switching applied, i.e. adapting DL Tx power for energy efficiency in durations when only users in good channel condition are scheduled. Note separate evaluation performed for different power settings (i.e. no switching between these settings) | UPT loss of 1% for 95-% UE,  UPT loss of 3% for 50-% UE UPT loss of 22% for 5-% UE |
| Light | 40.5% | UPT loss of 1% for 95-% UE,  UPT loss of 8% for 50-% UE UPT loss of 36% for 5-% UE |
| Medium | 47.6% | UPT loss of 0% for 95-% UE,  UPT loss of 9% for 50-% UE UPT loss of 13% for 5-% UE |
| Tx power adaptation (reduction up to 6 dB) | Low | 17.7% | UPT loss of 1% for 95-% UE,  UPT loss of 1% for 50-% UE UPT loss of 2% for 5-% UE |
| Light | 33.0% | UPT loss of 0% for 95-% UE,  UPT loss of 4% for 50-% UE UPT loss of 7% for 5-% UE |
| Medium | 38.5% | UPT loss of 2% for 95-% UE,  UPT loss of 9% for 50-% UE UPT loss of 7% for 5-% UE |
| **Samsung**  **[21]** | Transmission power adaptation | Cat 1 | Reference traffic:  7.5 % RU  Reduced traffic:  4.4 % RU | 51.5% | Baseline: BS Tx power 55 dBm  reference configuration:Set 1,FTP3  a static part of power for BS: P\_3 A: 0.4 For eta, If two values of η(s\_f,s\_p ) are used for evaluation,η(s\_f,s\_p ) = 0.76 if s\_f\*s\_p <0.5; otherwise, η(s\_f,s\_p )=1. 46.5 and 5.2 relative power per a SSB for Cat 1 and Cat 2 | UPT:10.40%, Packet latency: 24.7%  Scheduling latency: No increase |
| Cat 2 | 17.5% | UPT:10.40%, Packet latency: 24.7%  Scheduling latency: No increase |
| **Qualcomm**  **[17]** | Tx power reduction (55dBm to 52dBm) | Cat 1 | Low | 13.1% | Baseline: BS BS #TxRU 64 with 55dBm Tx power  reference configuration:Set 1,FTP3 | UPT lsss at 50%-tile: 10%,  DL SINR loss at 5% tile: 4dB |
| Light | 6.6% | UPT loss at 50%-tile: 16%,  DL SINR loss at 5% tile: 3dB |

With transmission power reduction on PDSCH, 10 sources show that it can achieve BS energy savings gain at all load cases for both Set 1 FR1 TDD and Set 2 FR1 FDD including 4Tx BS antenna configuration, for both BS categories with FTP3 or FTP3 IM model, with or without UE C-DRX configuration.

With dynamic power reduction assisted by multi-CSI,

* For UE specific PDSCH in FR1, one source observed BS energy saving gain by 5.3%~11.5%, compared to dynamic power reduction without multi-CSI report; one source observed BS energy savings by 12.1%~23.8%, compared to no power reduction baseline;
* The gain generally increases when the traffic load increases;
* The UPT loss is less than 1.17%;
* No performance analysis was provided for broadcast and common channels with dynamic downlink transmission power adaptation.

With semi-static power reduction of 3~18dB in 6 sources and two other sources, compared to a baseline without power reduction, network energy saving can be achieved by 2.3%~51.5%,

* The gain can increase as the traffic load increases in most cases while one source observed a reduced gain, for BS category 1 with power reduction of 3 dB;
* The UPT loss is observed by 2.03%~19.49%.

One source observed that the latency can be increased by up to 24.21% when the power reduction level is up to 9 dB; one source observed that packet latency can be increased by 24.7% while scheduling delay is not increased.

On UE power consumption, one source shows that less than 10% increment is observed in most cases.

One source also observed that when combined with spatial element reduction, in the case of 3 dB power reduction, the network energy savings can be further increased by about 10%, while together with UPT loss/UE power consumption increase/latency increase of 9.06%/7.62%/9.96% respectively.

One source shows this scheme can increase the average EE. One source observed that the downlink SINR is reduced by 3dB~ 4dB when reducing the downlink transmission power from 55dBm to 52dBm in Set 1 FR1 configuration.

#### 6.4.1.3 Legacy UE and RAN1 specification impacts

There is no impact for legacy UEs and UEs that do not support the technique if the signaling of modified power ratio between CSI-RS and PDSCH/SSB or between SSB and CSI-RS, enhancements on CSI measurement and reporting are used on a UE-specific basis, i.e., applied only for UEs supporting the enhancement.

Specification impact of the technique may include:

* signaling of modified power of SSB or power ratio between CSI-RS and PDSCH/SSB to provide adaptation of power ratio values, e.g. by utilizing UE-specific, group-level or cell common signaling,
* enhancements on RRM measurements, beam management, beam failure recovery, radio link monitoring, cell (re)selection and handover procedure,
* enhancements to CSI measurements and reporting, e.g. multiple CSI reports in a single report.

### 6.4.2 Technique D-2 Over the air digital pre-distortion

#### 6.4.2.1 Description of technique

gNB may implement digital pre-distortion (DPD) to compensate for the non-linear impairments of the transmitter in standard transparent manner.

Technique D-2 supports over the air digital pre-distortion at the gNB. In gNB digital pre-distortion over the air, the UEs assist the gNB in reducing nonlinear impairments introduced by the PA, by processing on training signals, and reporting the information needed for gNB digital pre-distortion.

#### 6.4.2.2 Analysis of NW energy saving and performance impact

The following capture the results by over the air DPD.

Table 6.4.2.2-1: BS energy savings by over the air DPD

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **Baseline configuration/assumption** | **Other KPI** | **Note** |
| **Qualcomm**  **[28]** | Over the air DPD (DPD-OTA) | Cat 1 |  | 8.9% | Set 3 | UPT loss:0.00%  Latency increase: 0% | Evaluation showing utilization of PAPR reduction, where the PAPR reduction is used to reduce the backoff PA attribute (Pmax) while maintaining the TX power and signal EVM  Note: η was calculated corresponding to the backoff reduction as was provided by a formula [29]. |

One source observed that DPD-OTA can achieve BS energy saving by 8.9% for Set 3 reference configuration. Note PA scaling values used for this NW ES scheme are not covered by RAN1 power consumption scaling model. On UPT/latency, no negative impact is observed.

Additional UE power consumption is considered to be negligible due to the low report periodicity expected.

#### 6.4.2.3 Legacy UE and RAN1 specification impacts

Legacy UEs and UEs that do not support providing assistance information for gNB digital pre-distortion (DPD) may not be able to contribute to improvement of the DPD.

Specification impact of the technique may include:

* signaling/configuration for supporting gNB digital pre-distortion,
* introduction of training signals/CSI-RS enhancements,
* signaling for reporting assistance information for gNB digital pre-distortion,
* indication to the UE of whether it needs to apply non-linear equalization for a transmission.

### 6.4.3 Technique D-3 Tone reservation

#### 6.4.3.1 Description of technique

Technique D-3 supports tone reservation that decreases PAPR, potentially taking into account channel conditions and characteristics. Tone reservation (TR) exploits the channel nulls to carry TR tones, potentially taking into account channel conditions and characteristics. The UE is to be notified of the sub-carriers carrying the TR signal for rate matching purposes only if UE performs transmission or reception of the resource including sub-carriers carrying the TR signal.

gNB may be able to implement PAPR reduction including tone reservations via implementation with appropriate scheduling of signals and channels.

#### 6.4.3.2 Analysis of NW energy saving and performance impact

The following capture the results by channel aware tone reservation.

Table 6.4.3.2-1: BS energy savings by Channel Aware Tone reservation

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **Baseline configuration/assumption** | **Other KPI** | **Note** |
| **Qualcomm**  **[26]** | PA Backoff reduction of 1-3dB due to PAPR reduction from Channel Aware Tone reservation | Cat 1 |  | 9.5% | Set 3 | UPT loss:0.00%  latency increase: 0%  UE power consumption increase: 0% | Evaluation showing utilization of PAPR reduction, where the PAPR reduction is used to reduce the backoff PA attribute (Pmax) while maintaining the TX power and signal EVM  The Backoff also compensates for the tones used for the TR signal, thus no UPT loss occurs  Comparing Channel Aware Tone Reservation to Transparent Tone Reservation  Note: η was calculated corresponding to the backoff reduction as was provided by a formula [29]. |
|  | 2.1% |
|  | 4.4% | Set 1 |
|  | 2.1% |

One source observed that channel aware tone reservation can achieve PA back-off reduction of 1~3 dB which leads to 2.1%~9.5% BS energy saving gains depending on configurations, compared with transparent tone reservation. Note PA scaling values used for this NW ES scheme are not covered by RAN1 power consumption scaling model.

On UPT/latency, no negative impact is observed.

No impact on UE power consumption is observed.

#### 6.4.3.3 Legacy UE and RAN1 specification impacts

Legacy UEs and UEs that do not support the technique may not be aware of tone reservation positions.

Specification impact of the technique may include:

* assistance information from the UE to help gNB determine tone reservation positions,
* mechanism to convey information about tone reservation positions to the UE,
* behavior associated with handling of resources with tone reservation positions.

### 6.4.4 Technique D-4 PA power bias adaptation

#### 6.4.4.1 Description of technique

In case of low load, the PA can adapt/reduce its backoff thus reduce the PA power consumption. PA backoff impacts unwanted in-band and out-of-band emissions. gNB may be able to implement PA backoff adaptation in a specification transparent manner.

Technique D-4 supports modification and/or reduction of the power amplifier (PA) backoff in cases of no or low load. This technique enables PA backoff adaptation for few msec and coordinate PA backoff adaptation among neighbouring cells.

#### 6.4.4.2 Analysis of NW energy saving and performance impact

No evaluations of this technique are available.

#### 6.4.4.3 Legacy UE and RAN1 specification impacts

Specification impact of the technique may include enhancements to UE measurements for assessing the impact from the PA backoff adaptation of neighbour cells.

### 6.4.5 Technique D-5 UE post-distortion

#### 6.4.5.1 Description of technique

Technique D-5 supports the UE performing received signal post-distortion processing (e.g. non-linear equalization stage that will “invert” the non-linearity) to combat non-linear impairments from the transmitter. The technique also considers enhancements to transmission of reference signals or information to aid the UE to perform post-distortion processing.

#### 6.4.5.2 Analysis of NW energy saving and performance impact

The following capture the results for UE post-distortion.

Table 6.4.5.2-1: BS energy savings by UE post-distortion

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Company** | **ES scheme** | **BS Category** | **Load scenario** | **ES gain (%)** | **Baseline configuration/assumption** | **Other KPI** | **Note** |
| **Qualcomm**  **[26]** | UE post-distortion | Cat 1 |  | 16.1% | Set 3 | UPT loss:0.00%  latency increase: 0% | Evaluation showing utilization of PAPR reduction, where the PAPR reduction is used to reduce the backoff PA attribute (Pmax) while maintaining the TX power and signal EVM  The Backoff also compensates for the tones used for the TR signal, thus no UPT loss occurs  Processing and power consumption of the UE depends on the UE receiver’s design for DPoD.  Note: η was calculated corresponding to the backoff reduction as was provided by a formula [29]. |

One source observed that UE post-distortion can achieve BS energy saving by 16.1% for Set 3 reference configuration. Note PA scaling values used for this NW ES scheme are not covered by RAN1 power consumption scaling model.

On UPT or latency, there is no negative impact observed.

The impact on UE power consumption depends on UE receiver’s design for DPoD.

#### 6.4.5.3 Legacy UE and RAN1 specification impacts

Legacy UEs and UEs that do not support the technique are not able to compensate the received signal distortions based on this enhancement mechanism.

Specification impact of the technique may include:

* mechanism and signalling to enable operation of UE post distortion,
* enhancements to reference signals to aid UE post distortion,
* signaling/configuration for supporting UE digital post-distortion,
* introduction of activation of UE post distortion, notification of selected power amplifier model, and possibly configuration of training reference signals,
* signaling for indicating to the UE of whether it needs to apply non-linear equalization for a downlink transmission.

## 6.5 Higher layer aspects for network energy savings

From RAN3 perspective, the following candidate techniques (i.e., those described in section 6.5.3 and 6.5.4) should be evaluated in terms of energy saving gain at the normative phase. Other candidate techniques discussed are not excluded.

### 6.5.1 Cell selection/reselection

For backward compatibility, there is a need to allow NES cells to prevent legacy UEs from camping. NES cells should be able to configure whether to prevent legacy UEs, while allowing NES-capable UEs to camp on. Possible solutions may include but not limited to:

* Use *IntraFreqExcludedCellList*/*InterFreqExcludedCellList*
* Use the *cellBarred* or cell reservation fields in MIB/SIB

The definition of NES cell will be discussed in the WI phase.

The NW should be able to configure NES-capable UEs to prioritize/down-prioritize a specific NES cell or NES cells on a specific frequency. It is left to the WI phase whether the existing mechanism for cell (re)selection is sufficient according to the NES techniques specified.

From RAN2 perspective, legacy UEs and NES-capable UEs can be handled via cell selection/reselection techniques in the presence of NES cells.

### 6.5.2 Connected mode mobility

During the switching of NES modes, it is possible to handover the UEs faster by enhancing the CHO framework with:

1. Evaluation of conditional handover conditions depending on the NES mode of source/target cell,
2. How to indicate to UE the triggering of the CHO evaluation is up to the WI phase.

Whenever mobility from source cell is triggered, the NES mode of the target cell could also be considered, e.g., to avoid UEs selecting cells operating in NES mode if any other cell is available.

From RAN2 perspective, CHO enhancements are feasible.

Group HO (optimizing the Rel-15 HO procedure) and BWP adaptation with group signalling are not considered by RAN2.

### 6.5.3 Inter-node Beam Activation

This mechanism allows an NG-RAN node to request a neighbouring NG-RAN node to switch on certain SSB beams which have been deactivated e.g., in the capacity layer. With this mechanism, the NG-RAN node (e.g., in the coverage-layer) can request the re-activation of SSB beams that are deactivated before.

### 6.5.4 Paging Enhancements

This mechanism allows an NG-RAN node to page, e.g. the stationary UEs in a restricted area. For example, paging can be done in certain SSB(s) instead of all the SSBs within a cell.

# 7 Conclusions

Network energy savings for NR have been studied for both FDD and TDD, both FR1 and FR2. Power model comprised of different BS power states/modes for BS power consumption is defined in section 5 for evaluation purpose by using relative power, which includes different sleep and active states (including DL transmission and UL reception), and two types of BS categories. A scaling approach considering BS power split by a static part of power and a dynamic part of power is established for evaluation purpose, reflecting the relationship of BS power consumption with respect to transmission resources/configurations in time, frequency, spatial and power domain.

The potential techniques for enabling/improving network energy savings in various domains are evaluated and analysed, as documented in section 6.1- 6.4. Techniques description, performed evaluations and performance impact on selected KPIs including UPT, access delay, latency, UE power consumption, or on averaged energy efficiency etc., as well as legacy UE impact and specification impact are summarized therein. The relevant higher layer procedures and analysis for some techniques are also included in section 6.1. Other common aspects from higher layer are studied and the outcome is documented in section 6.5.

The study of time domain techniques can be summarized as follows.

Depending on factors such as selected baselines, BS categories, SLS configurations (including reference configurations, traffic models, number/periodicity of reference signals), scaling parameters, and UE profiles (including UE RRC\_IDLE/INACTIVE/CONNECTED mode, DRX configurations), as well as conditions (such as gNB detection, gNB coordination, UE ability of synchronization) etc.,

* 4 sources show technique A-1-1 of simplified SSB without PBCH or with partial PBCH could achieve BS energy savings by 0.7%~30.49% in range, with no observed impact on UPT due to empty load.
* 2 sources show technique A-1-2 of static skipping one or more of SSB/SIB1 transmission could achieve BS energy savings by 0.3%~25.4% in range, meanwhile the impact on access delay/latency is not provided in the simulation.
* 9 sources show technique A-1-3 of statically adapting the periodicity of SSB longer than 20ms up to 1280ms (with current maximum periodicity being 160ms) could achieve BS energy savings by 0.9%~84.8% in range, meanwhile when traffic occurs and load increases, the UPT significantly decreases and the latency/access delay/UE power consumption increases proportionally as the periodicity of SSB/SIB increases compared to a corresponding baseline.
* 2 sources show technique A-1-4 of statically adapting Paging (by 1 source) or SSB transmission patterns (by 1 source), could achieve BS energy savings by 0.2%~42.3% in range for Paging enhancement or 10.3% for SSB enhancement, meanwhile UPT/latency impact are not reported.
* 1 source shows technique A-1-5 of statically adapting RACH periodicity/occasions could achieve BS energy savings by 14.4%~24.9% in range, meanwhile access delay/latency is increased from 10ms to 70ms, proportional to the increased PRACH periodicity.
* 1 source shows technique A-1-6 of scheduling SIB1 by SSB could achieve BS energy savings by 4.8%~14.8% in range without report of impact on UPT/latency as irrelevant to the technique.
* 5 sources show technique A-3-1 of UE WUS triggering gNB for SSB/SIB/RACH, with the assumption of ideal detection of UE WUS, could achieve BS energy savings by 6.2%~80.7% in range with UPT loss by 0%~24.2%, while 1 source shows technique A-3-2 of UE WUS triggering gNB to wake up in case of uplink traffic arrival could achieve BS energy savings by 25.7%~93% in range, with latency reduction of 0%~45.5% depending on the SR periodicity assumed in the baseline,
  + Note technique A-3-2 of UE WUS triggering gNB to wake up in case of uplink traffic arrival assumes that gNB can detect WUS during sleep state.
* 6 sources show technique A-4 of semi-static UE C-DRX alignment could achieve BS energy savings by 0.2%~71.4% in range, meanwhile, 3 sources show that there is negative impact on UPT with loss from 0.91% to 15.5%, and 1 source shows that when the UE DRX cycle is 160ms and gNB active time is 80ms the UPT is increased while in other configurations there can be large UPT loss (up to 62.4%), 1 source shows marginal increment on latency while 1 source show up to 50% latency increase.
* 3 sources show technique A-5-2 of on-demand SSB/SIB1 could achieve BS energy savings by 2.6%~43.4% in range, meanwhile performance impact of on demand SSB/SIB was not provided.
* Technique A-1-4 of adapting Paging and technique A-1-5 of adapting RACH periodicity/occasions may be used in a cell where legacy UE can still use legacy Paging/RACH resources with negative impact on latency for legacy UEs, while other techniques except technique A-3 and A-4 may be enabled for a carrier only when legacy UEs are not using the carrier.
  + For technique A-3, legacy UEs cannot wake up a cell that is inactive, and cannot operate in the cell if not provided with expected transmission from the cell; for technique A-4, depending on DTX/DRX configuration, legacy UEs may not be impacted.
* Technique A-4 of adaptation of Cell DTX/DRX is also studied in higher layer. From RAN2 perspective, technique A-4 is considered feasible and it is also beneficial to align UE DRX durations with Cell DTX and DRX durations among multiple UEs.
* Technique A-3 of UE WUS is also discussed in higher layer and from RAN2 perspective, it is feasible if RAN1 agrees to support WUS, and details can be discussed in normative phase if supported.

For techniques in frequency domain, the study can be summarized as follows.

Under various conditions,

* 8 sources show technique A-5-1 (for non-CA) or B-1-1 (for CA) of SSB- and/or SIB1-less operation in two carriers deployment could achieve BS energy savings by 0.3%~98.4% in range on the energy saving cell/carrier and if more information, such as system information, needs to be transmitted at the anchor carrier then 2.3%~18.9% BS energy increases on the associated cell/carrier, meanwhile the UPT/UE power consumption is not negatively impacted while 1 source shows slightly increased UPT and 1 source shows reduced SCell activation delay, assuming UE sync is based on SSB from anchor carrier and UE measurement is not considered,
  + A cell without SSB (or SIB1) cannot be operated as PCell/PSCell/inter-band SCell (or PCell for SIB1-less) for legacy UEs. Mobility performance impact(s) (for techniques A-5-1 of SSB-less operation in non-CA), or performance impact(s) due to lack of AGC and cell measurement (for techniques B-1-1 of SSB-less operation in CA) is not provided. For non-CA operation with both SSB-less and SIB1-less, comparison to CA is not provided.
* 1 source shows technique B-1-2 of dynamic UE-group PCell switching could achieve BS energy savings by 5.8%~37.5% in range, meanwhile UPT degrades by 14% if one SCell goes to dormant state.
* 1 source shows technique B-2 of statically BWP adaptation of BW reduction for multiple UEs within a carrier could achieve BS energy savings by 17.4%~52.2% in range, while the reported UPT loss ranges from 6.1%~28.2%.
* 2 source show technique B-3 of BW adaptation of multiple UEs within a BWP could achieve BS energy savings by up to 1.75%, and 1 source shows negative energy saving gains (i.e. energy consumption increase) up to 75.4% with significant UPT loss (up to 88%).
* Evaluation of all techniques is based on the baseline BS power model in Section 5.
* From RAN2 perspective, technique A-5-1/B-1-1 of SCell without SSB in inter-band CA and NES cell without SSB/SIB may need more detailed study in normative phase (if supported) with feasibility up to RAN1. From RAN2 perspective, techniques B-2 is not considered.

Based on the study and summary, from time and frequency domain,

* For technique A-4 of adaptation of DTX/DRX, at least alignment of Cell DTX/DRX with UE DRX, is beneficial for network energy savings.
* Adaptation/reduction/elimination of common channels/signals (UE WUS can also be considered) in single or multi-carrier operation are beneficial for network energy savings.

For techniques in spatial domain, over baseline of 32/64 TxRU for a gNB/TRP, the study can be summarized as follows,

* 12 sources show technique C-1 of adaptation of spatial elements could achieve BS energy savings by 0~48.2% in range, with legacy UE co-existence, at the expense of small (less than 10% for dynamic adaptation with multi-CSI) to large (up to 87.08% for static adaptation) negative impact on UPT. 4 sources provide evaluation results for dynamic adaptation while 9 sources provide evaluation result for static adaptation.
* 3 sources show technique C-2 of TRP muting in multi-TRP operation could achieve BS energy savings by 19.7%~41.6% in range, at the expense of UPT loss of 7.27%~22% for static TRP muting. 1 source provides evaluation results for dynamic adaptation while 2 sources provide evaluation results for static adaptation.

Based on the study, at least a technique based on C-1 is beneficial for network energy savings, and can be recommended. Technique C-2 also has the potential to provide large network energy saving gain.

For techniques in power domain, the study can be summarized as follows,

* 10 source show technique D-1 of transmission power reduction on PDSCH could achieve BS energy savings by 2.3%~51.5% in range, with legacy UE co-existence, with UPT loss of 0~19.49%/latency increment of up to 24.21%/UE power consumption increment of up to 14.78%. 2 sources provide evaluation results for dynamic adaptation while 8 sources provide evaluation results for static adaptation.
* 1 source shows technique D-2 of over the air digital pre-distortion, technique D-3 of channel aware tone reservation, and technique D-5 of UE post-distortion, could achieve BS energy savings by 8.9%, by 2.1%~9.5%, and by 16.1% respectively, with no/negligible negative impact on UPT/UE power consumption, with PA scaling values not covered by the scaling of power model in section 5.

Based on the study, at least a technique based on D-1 is beneficial for network energy savings.

For other higher layer aspects for network energy savings, from their perspective, the study can be summarized as follows.

* It is feasible to handle legacy UEs and NES-capable UEs via cell (re-)selection techniques. It is also feasible and possible to enhance the CHO framework to handover UEs faster.
* Group HO is not considered.
* Inter-node beam activation and paging enhancement need more study in normative phase, if supported.
* A means that one can prevent legacy UEs from camping on NES cells (of which definition can be left to WI phase), and/or allow NES-capable UEs to (down-)prioritize specific NES cell(s) on specific frequency, is needed, which is left to the WI phase depending on whether the existing mechanism for cell (re)selection is sufficient according to the NES techniques specified.

It is recommended that the normative phase includes not only energy saving techniques (the necessary enhancements would need to be further identified during the normative phase) but also the mitigation of their impacts when network applies network energy savings technique(s).

Annex A: Evaluation scenarios, traffic models and loads

For FR1, at least urban macro is prioritized. Urban micro can be optionally considered. For FR2, urban micro is prioritized.

FTP3 (0.5MB as packet size, 200ms as mean inter-arrival time), FTP3 IM (0.1MB as packet size, 2s as mean inter-arrival time) and VOIP can be considered in the evaluation. It is up to company report which traffic model is used among the agreed three traffic models in their evaluations. Other models may be used as well, and parameter (e.g. packet size and arrival rate) adjustment can be optionally considered and reported.

In the evaluation,

* a load (L)% of a cell is a percentage of resources used for UE specific PDSCH/PUSCH.
* The following load scenarios are considered.

Table A-1

|  |  |
| --- | --- |
| Load scenario | Characteristics |
| Idle/empty load | * Include cell-specific signals and channels, and * L = 0 |
| low load | * Include cell-specific signals and channels, and * 0 < L≤15 |
| Light load | * Include cell-specific signals and channels, and * 15 < L≤30 |
| Medium load | * Include cell-specific signals and channels, and * 30 < L≤50 |
| For CA, the companies report whether the load is defined per CC or across all CCs. | |

It is up to company report the use of UE C-DRX.

* the baseline configuration (for alignment/calibration) for C-DRX, if reported, can be as below;
* Other inactivity timer values can be optionally reported.

Table A-2

|  |  |  |  |
| --- | --- | --- | --- |
| Traffic type | FTP | IM | VoIP |
| Model | FTP model 3 | FTP model 3 | As defined in R1-070674.  Assume max two packets bundled. |
| Packet size | 0.5 Mbytes | 0.1 Mbytes |
| Mean inter-arrival time | 200 ms | 2 sec |
| DRX Period | 160 ms | 320 ms | 40 ms |
| DRX Inactivity timer | 100 ms | 80 ms | 10 ms |
| On duration | FR1: 8 ms  FR2: 4 ms | FR1: 10 ms  FR2: 5 ms | FR1: 4 ms  FR2: 2 ms |

Annex B: Simulation assumptions

For FR1, the baseline SLS assumptions is provided as below. Other carrier frequencies can be optionally considered.

Table B-1: Baseline SLS assumptions for FR1 Set 1 and Set 2

|  |  |  |  |
| --- | --- | --- | --- |
|  | | **Parameters** | |
| **Set 2** | **Set 1** |
| **Basic parameters** | **Channel model** | 3D-Uma as in TR 38.901 (low-loss O2I penetration model) | 3D-Uma as in TR 38.901 (low-loss O2I penetration model) |
| **Percentage of high loss and low loss building type** | 100% low loss | 100% low loss |
| **Device deployment** | 80% indoor, 20% outdoor | 80% indoor, 20% outdoor |
| **Inter-site distance** | 500m | 500m |
| **Network Topology** | 7\*3 Sector | 7\*3 Sector |
| **Carrier Frequency** | 2.1GHz | 4.0GHz or 2.6GHz |
| **Multiple access** | OFDMA | OFDMA |
| **Duplexing** | FDD | TDD |
| **Numerology** | 15KHz,  14 OFDM symbol slot | 30kHz,  14 OFDM symbol slot |
| **Guard band ratio on simulation bandwidth** | FDD: 6.4% (104RB for 15kHz SCS and 20 MHz BW) | TDD: 2.08% (272 RB for 30kHz SCS and 100 MHz bandwidth) |
| **Simulation bandwidth** | Follow reference configuration, (equal split of 10 MHz for UL and DL) | Follow reference configuration |
| **Frame structure** | / | DDDSU (S slot is assumed as 10D:2G:2U) |
| **UT attachment** | Based on RSRP | Based on RSRP |
| **Wrapping around method** | Geographical distance based wrapping | Geographical distance based wrapping |
| **Traffic model** | Follow previous RAN1 agreements | Follow previous RAN1 agreements |
| **BS parameters** | **BS antenna height** | 25 m | 25 m |
| **BS noise figure** | 5 dB | 5 dB |
| **BS antenna element gain** | 8 dBi | 8 dBi |
| **Antenna configuration at TRxP** | For 32T: (M,N,P,Mg,Ng; Mp,Np) = (8,8,2,1,1;2,8) (dH, dV)=(0.5, 0.8)λ | For 64T:  (M, N, P, Mg, Ng, MP, NP,) = (8, 8, 2, 1, 1, 4, 8).  based on 38.802 |
| **UE parameters** | **UE power class** | 23dBm | 23dBm |
| **UE noise figure** | 9 dB | 9 dB |
| **UE antenna element gain** | 0 dBi | 0 dBi |
| **UE antenna height** | Outdoor UEs: 1.5 m; Indoor Uts: 1.5m or consider floor height | Outdoor UEs: 1.5 m; Indoor Uts: 1.5m or consider floor height |
| **Antenna configuration at UE** | For 4R: (M,N,P,Mg,Ng; Mp,Np)= (1,2,2,1,1; 1,2)  (dH, dV)=(0.5, N/A)λ | For 4R: (M,N,P,Mg,Ng; Mp,Np)= (1,2,2,1,1; 1,2)  (dH, dV)=(0.5, N/A)λ |
| **Transmission parameters** | **Modulation** | Up to 256 QAM | Up to 256 QAM |
| **Transmission scheme** | SU-MIMO | SU-MIMO |
| **SU dimension** | For 4Rx: Up to 4 layers | For 4Rx: Up to 4 layers |
| **DL CSI measurement** | Non-precoded CSI-RS based | Precoded CSI-RS based |
| **DL codebook** | Type I/II codebook | non-PMI transmission |
| **SRS transmission** | N/A | For UE 4 Tx ports: Non-precoded SRS |
| **CSI feedback** | Company to report the assumptions | Company to report the assumptions |
| **Interference measurement** | SU-CQI; CSI-IM for inter-cell interference measurement | SU-CQI; CSI-IM for inter-cell interference measurement |
| **Scheduling** | PF | PF |
| **Receiver** | MMSE-IRC | MMSE-IRC |
| **Channel estimation** | Non-ideal | Non-ideal |
| **HARQ scheme** | Ideal | Ideal |
| **Max HARQ retransmission** | 3 | 3 |
| **Target BLER** | 10% of first transmission | 10% of first transmission |
| **Power control parameters** | Open loop, P0=-80dBm, alpha=0.8 | Open loop, P0=-80dBm, alpha=0.8 |
| **Common RS** | **SSB period** | 20ms | 20ms |
| **SS blocks per SSB burst** | Up to 4 | Up to 8 |
| **SSB time resource** | 4 symbols for each SSB | 4 symbols for each SSB |
| **SSB frequency resource** | 20 RBs | 20 RBs |

For FR2, the baseline SLS assumptions is provided as below. Other carrier frequencies can be optionally considered.

Table B-2: Baseline SLS assumptions for FR2 Set 3

|  |  |  |  |
| --- | --- | --- | --- |
| **BS type** | Micro | **UE BWP** | 100 Mhz |
| **Network layout and inter-site distance** | 21 cells Wraparound (ISD=200m) | **UE height** | 1.5m |
| **Channel model** | UMi | **UE noise figure** | 13 dB |
| **Link direction** | Downlink | **UE antenna element gain** | 5 dBi |
| **Frequency range** | 30GHz | **UE receiver** | MMSE-IRC |
| **Duplex** | TDD | **UE deployment** | 20% Outdoor in cars: 30km/h,  80% Indoor in houses: 3km/h |
| **Frame structure** | DDDSU (S slot is assumed as 10D:2G:2U) | **Traffic model and C-DRx configuration** | follow previous RAN1 agreement |
| **Subcarrier spacing** | 120 kHz | **UE density/NW Load** | Follow previous RAN1 agreements |
| **Simulation bandwidth** | 100 MHz | **Maximum supported Modulation and coding scheme** | Up to 256QAM |
| **Number of carriers** | 1 CC | **Guard band ratio on simulation bandwidth** | 7.8% (64 RB for 120kHz SCS and 100 MHz bandwidth) |
| **Slot size** | 14 OFDM symbols | **Channel estimation** | Ideal |
| **BS antenna configuration** | 2 TxRU:  Baseline:  (M, N, P, Mg, Ng; Mp, Np) = (4,4,2,1,1;1,1); (dH, dV) = (0.5λ, 0.5λ) (dg,H, dg,V) = (2.5λ, 2.5λ)  Optional:  (M, N, P, Mg, Ng)=(8:16:2:2:2) | **HARQ scheme** | Ideal |
| **Total Tx power** | 33 dBm, EIRP limited to 63 dBm (as agreed in ref. conf. set 3) | **Max HARQ retransmission** | 3 |
| **BS height** | 10m | **Target BLER** | 10% of first transmission |
| **BS noise figure** | 7 dB | **Power control parameters** | Open loop, Alpha=1, P0=-106 dBm |
| **BS antenna element gain** | 8 dBi | **Scheduling algorithm** | PF |
| **UE antenna configuration** | 2T/4R, (M, N, P, Mg, Ng; Mp, Np) = (1,2,2,1,1;1,2),  (dH, dV) = (0.5λ, N/Aλ) | **Cell selection algorithm** | RSRP Slow Fading |
| **UE max transmit power** | 23 dBm | **SS blocks per SSB burst** | Up to 64 |

(M, N, P, Mg, Ng; Mp, Np)

- M: Number of vertical antenna elements within a panel, on one polarization

- N: Number of horizontal antenna elements within a panel, on one polarization

- P: Number of polarizations

- Mg: Number of panels in a column;

- Ng: Number of panels in a row;

- Mp: Number of vertical TXRUs within a panel, on one polarization

- Np: Number of horizontal TXRUs within a panel, on one polarization.

Other parameters can be optionally reported.

Company can also optionally report the actual total DL transmit power allocation for the baseline and the proposed technique, if different from the agreed reference configuration.

Additionally, for FR1, the following SLS assumptions can be optionally included:

* BS antenna configuration: 4T
* BS Total Tx power: derived based on the scaling in section 5.1
* SS blocks per SSB burst: reduced to 1
* Other assumptions are same as those corresponding to Set 2 reference configuration
* Additional transition energy is calculated taken into account the additional transition energy for Set 1/Set 2/Set 3 in section 5.1
* Company to report the details.

Annex C:  
Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2022-05 | RAN1#109-e | R1-2205307 |  |  |  | TR Skeleton | 0.0.1 |
| 2022-05 | RAN1#109-e | R1-2205694 |  |  |  | Endorsed TR Skeleton | 0.0.2 |
| 2022-08 | RAN1#110 | R1-2208315 |  |  |  | TR update per agreements in RAN1#109-e and RAN1#110, and skeleton of TR 38.864 for NR network energy savings approved in RAN3 per R1-2207999. | 0.1.0 |
| 2022-10 | RAN1#110bis-e | R1-2209679 |  |  |  | TR update per agreements in post RAN1#110 email discussion and some editorials. | 0.2.0 |
| 2022-10 | RAN1#110bis-e | R1-2210792 |  |  |  | TR update per agreements during RAN1#110bis-e. | 0.3.0 |
| 2022-11 | RAN1#111 | R1-2212483 |  |  |  | TR update for inclusion of agreements made in R2-2211067 in RAN2 #119bis-e and in R3-226001 in RAN3 #117bis-e. | 0.4.0 |
| 2022-11 | RAN1#111 | R1-2213007 |  |  |  | TR update for reflection of agreements made in RAN1#111, and post meeting email discussion of RAN1, RAN2#120 (R2-2213041) and RAN3#118 (R3-226898). | 0.5.0 |