**3GPP TSG RAN WG1 Meeting #110 R1-2207697**

**Toulouse, France, August 22 – 26, 2022**

**Source: Moderator (Intel Corporation)**

**Title: Discussion Summary for energy saving techniques of NW energy saving SI**

**Agenda item: 9.7.2**

**Document for: Discussion**

# Introduction

In this contribution, moderator summarizes discussions on remaining issues related to potential solutions for network energy saving SI from RAN1 #110. SI objectives agreed in RP-220297 is shown below for reference.

|  |
| --- |
| The objectives of the study are the following:1. Definition of a base station energy consumption model [RAN1]
* Adapt the framework of the power consumption modelling and evaluation methodology of TR38.840 to the base station side, including relative energy consumption for DL and UL (considering factors like PA efficiency, number of TxRU, base station load, etc), sleep states and the associated transition times, and one or more reference parameters/configurations.
1. Definition of an evaluation methodology and KPIs [RAN1]
* The evaluation methodology should target for evaluating system-level network energy consumption and energy savings gains, as well as assessing/balancing impact to network and user performance (e.g. spectral efficiency, capacity, UPT, latency, handover performance, call drop rate, initial access performance, SLA assurance related KPIs), energy efficiency, and UE power consumption, complexity. The evaluation methodology should not focus on a single KPI, and should reuse existing KPIs whenever applicable; where existing KPIs are found to be insufficient new KPIs may be developed as needed.

Note: WGs will decide KPIs to evaluate and how.1. Study and identify techniques on the gNB and UE side to improve network energy savings in terms of both BS transmission and reception, which may include:
* 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, and potential UE assistance information [RAN1, RAN2]
* Information exchange/coordination over network interfaces [RAN3]

Note: Other techniques are not precludedThe study should prioritize idle/empty and low/medium load scenarios (the exact definition of such loads is left to the study), and different loads among carriers and neighbor cells are allowed. The following example scenarios (mapping between scenarios and network loads is left to the study) including single-carrier and multi-carrier deployments are used as the starting point for discussion on prioritized scenarios for the study. The following example scenarios are listed in no particular order.* Urban micro in FR1, including TDD massive MIMO (note: this scenario can also model small cells)
* FR2 beam-based scenarios (note: this scenario can also model small cells)
* Urban/Rural macro in FR1 with/without DSS (no impact to LTE expected in case of DSS)
* EN-DC/NR-DC macro with FDD PCell and TDD/Massive MIMO on higher FR1/FR2 frequency

Note 1: legacy UEs should 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.Note 2: the study of energy savings specifically for IAB is not part of the scope.The study should coordinate with RAN4 as needed. |

# Summary of issues

## 2.1 General aspects of Network Energy Saving

* [5] Nokia/NSB
	+ Proposal-1: Prioritize the network energy saving techniques for evaluation as well as consolidate the proposed techniques to better align the understanding among companies.
* [18] Fraunhofer IIS/Fraunhofer HHI
	+ Observation 1: Network energy saving techniques can be realized in many different forms.
	+ Proposal 1: In the study phase, the different approaches for network energy saving should be investigated and compared.
	+ Observation 2: For the sake of network energy saving, the load should be understood as the relation between user activity and cell density.
	+ Proposal 2: The reduction of gNB active time where there is no user traffic should be investigated.
	+ Observation 3: The existing Xn mechanism does not include means to gather information needed to take decisions to switch on or off cells.

### Summary of Discussions

* There were some suggestions for prioritization of the discussion of the techniques for evaluation.
* There were some suggestions for aligning terminology and understanding of the evaluation metrics.

Given that the SI is planned to be completed by end of 2022, there is only 1 more RAN1 meeting left before completion. Moderator expects either some discussion to focus and prioritize the contents to be captured in the TR based on findings in RAN1, or some discussion to draft a conclusion to the SI as an input to the WI phase will need to take place. Moderator assumes this can be done as part of the discussions for each specific technique that may or may not be captured in the TR as RAN1 findings.

## 2.2 Time-domain based Energy saving Techniques

* [1] Futurewei
	+ Observation 1: Support of selective transmission/reception of SSB and SIB1 should be enhanced with group-common or cell-common signaling to the UE(s) on the changes in the SSB/SIBs transmissions.
	+ Observation 2: Group-common or cell-common signaling of CSI-RS would provide an efficient signaling that supports bandwidth adaptation for network energy savings.
	+ Observation 3: Resource adaptation at the multicell-level can provide an effective adaptation towards network energy savings.
	+ Observation 4: The UE should support being configured through RRC signaling the different conditions/triggers for the UE to send an UL Wake-Up signal.
	+ Proposal 1: UE grouping and group common signaling to support efficient network resource adaptation should be introduced and supported.
	+ Proposal 2: Multicell-level resource adaptation, cell-level resource adaptation, and sub-cell-level resource adaptation should be introduced and supported.
	+ Proposal 3: Assistance information in the form of an UL wake-up signal from the UE to the gNB should be introduced and supported. Support of an UL wake-up signal that can be specific to different use cases should be studied.
* [2] Huawei
	+ Proposal 1: Evaluate on-demand SSB/SIB1 transmission with light/relaxed common signal for sync with the following assumptions:
		- Two symbol DRS with the broadcast periodicity of 20ms
		- The interval between two neighbor WUS occasions can be 20ms, with certain detection probability e.g. 1%
		- Upon receiving WUS, BS could start to broadcast SSBs and SIB1 periodically from the next SSB-burst, e.g. 1 or twice for certain reliability.
	+ Proposal 2: Further study possible methods to adapt the time domain transmission of common signals, e.g. SSB and SIB1 for NR in consideration of common signals in neighboring LTE carrier. Note change is only expected for NR side as per SID.
* [3] Spreadtrum Communications
	+ Observation 1: The reduction of common signal/channel may not be standalone, and it can be realized by other techniques, e.g. dynamic cell on/off and DTX.
	+ Observation 2: When the macro cell is in light loading (e.g. 30% loading), the micro cell can enter micro sleep, and when the macro cell is in heavy loading (e.g. 50% loading), the micro cell can be woken up from micro sleep to keep the macro cell in low level of transmission power.
	+ Observation 3: The dynamic cell on/off and loading balance can provide the energy saving gain about 14% in average.
	+ Observation 4: The DTX and traffic concentration can provide the energy saving gain about 24%.
	+ Observation 5: The DTX can be combined with the dynamic cell on/off to provide the combined energy saving gain.
* [4] vivo
	+ Proposal 1: Study energy saving cell activation by UE wake up signal, at least including design on UE WUS signal, configuration, procedure and etc.
	+ Observation 1: The UE WUS scheme can achieve a good BS power gain without a significant reduction in UPT.
* [5] Nokia/NSB
	+ Observation-1: The HW components and circuits associated with BS transmission can be switched-off for improved network energy savings, while the ones associated with BS reception can be assumed to remain active to monitor for potential UE transmissions with marginal impact to network energy consumption in most scenarios.
	+ Proposal-2: For time-domain NW ES adaptations, enhancements for increasing BS (µ)DTX opportunities can be prioritized over BS (µ)DRX.
	+ Proposal-3: If BS (µ)DRX is shown to bring significant network energy savings, enhancements leveraging UE assistance / indication to increase (µ)DRX / network sleeping opportunities can be studied.
	+ Proposal-4: As part of study of time-domain NW ES techniques, further adaptation / reduction of SSB/SIB1 transmissions can be prioritized.
	+ Proposal-5: Study enhancements for extending network sleeping modes opportunities including (µ)DTX indication to UE e.g. for UE power saving.
	+ Observation-2: The existing paging design distributes the paging occasions evenly in time, which minimizes the possibility for a base station to sleep between paging occasions.
	+ Proposal-6: Study possibilities to save base station energy via time domain enhancements of the paging mechanism.
	+ Proposal-7: Study enhancements enabling faster cell deactivation / reactivation and faster offloading of UEs to neighboring cells.
* [6] Panasonic
	+ Proposal 1: Time domain adaptation should be considered with higher priority. The PDCCH monitoring controlled by DRX adaptation can be considered as starting point. It can be inclusive for other channel/signal related enhancement.
* [7] Fujitsu
	+ Proposal 1: When the cell is in off state, both stopping UL reception and maintaining UL reception can be considered.
	+ Observation 1. When a cell is turned off with short duration (e.g., symbol/slot/subframe-level), keeping UEs connected with the cell can avoid ping-pong handover and frequent activation/deactivation.
	+ Proposal 2. Study the following three options considering the power saving effect, initial access, cell discovery performance and impacts on RLM/RRM measurements jointly.
		- Option 1: Cell off is not performed for the symbols occupied by common signals and CSI-RS.
		- Option 2: Cell off is performed regardless of the symbols occupied by common signals and CSI-RS.
		- Option 3: Cell off is not performed at the symbols occupied by common signals while can be performed at the symbols occupied by CSI-RS.
	+ Proposal 3. Study the following methods regarding reducing/adapting common signal transmission and RAN2 work should be evolved.
		- On-demand SIB1 transmission
		- SSB-less SpCell
		- On-demand MIB/PBCH transmission
		- SS transmission on SSB-less cells
		- Discovering SSB-less cells via reference signal of an anchor cell
* [8] NEC
	+ Proposal 1: gNB DTX and DRX should be supported, and the impact on UE operation, e.g., the measurement, synchronization and C-DRX procedures, should be considered.
	+ Proposal 2: Support configurable periodicity and offset for fully flexible time domain energy saving pattern, and simultaneous multiple configurations should be considered.
	+ Proposal 3: Support SS/PBCH transmission with reduced density, on-demand SSB and dynamically adjustable SSB transmission periodicity.
* [9] OPPO
	+ Proposal 1: RAN1 considers to reduce the periodic DL transmission from the network to reduce the network energy consumption.
	+ Proposal 2: RAN1 considers semi-static/dynamic on-off method to reduce the network energy consumption.
	+ Proposal 3: RAN1 considers UE reporting assistance information to reduce the power consumption for UL periodic reception.
* [10] CATT
	+ Proposal 1: Time domain energy saving transition mechanism based on gNB state of system load should be supported for 5G network.
	+ Observation 1: To achieve obvious network energy saving gain, transmission periodicity of common channels/signals should be long enough to allow gNB to stay in deep sleep state.
	+ Proposal 2: With the increase of the transmission periodicity of common control channels/signals in a cell, the impacts on initial access procedure for legacy RRC Idle/Inactive mode UE should be considered and network energy saving gain should be further evaluated in case of providing service to RRC connected mode UEs.
	+ Proposal 3: For Rel-18, semi-static/dynamic cell ON/OFF should be supported for network energy saving.
	+ Observation 2: The slot/symbol granularity is not feasible for long transition time of Cell ON/OFF.
	+ Proposal 4: Network control mechanism in triggering the transmission of on-demand DRX from the turned-off cell (e.g., on-demand SSB) should be considered for the network energy saving.
	+ Proposal 5: For semi-static/dynamic cell ON/OFF, both periodic DRS and on-demand DRS should be studied for network energy saving.
	+ Observation 3: When system load is low and the less number of UEs access the system, the staggering C-DRX configuration for system load balancing becomes unnecessary.
	+ Observation 4: gNB could reduce the energy consumption with the DTX transmission in low system load state by allocating same set of C-DRX configuration for all UEs, which including DTX-ON and DTX-OFF.
	+ Proposal 6: The gNB DTX/DRX should be considered to reduce network energy consumption for low system load state.
	+ Proposal 7: DTX parameters should be configured to Rel-18 UEs through high layers and gNB DTX-ON duration should be associated with Active Time of UEs.
	+ Proposal 8: DTX/DRX coordination in Uu, Xn and NG should be supported for reduction of network energy consumption.
	+ Observation 5: gNB DTX transmission with centralized DRX-ON configuration can obtain 31.8%~53.3% energy saving gain. With the decrease of system loads, larger NES gain is achieved.
	+ Observation 6: Without achieving DL synchronization, the energy saving cell could not be directly woken up by the UE via the gNB WUS signal.
* [11] Lenovo
	+ Observation 1: SSB subset-specific periodicity can reduce SSB transmission time substantially (e.g. 20~50% reduction).
	+ Observation 2: Even though there is a mismatch between an actual SSB transmission periodicity and legacy UE’s assumption, legacy UEs would not select a SSB not being transmitted based on measurement. Thus, impact on the legacy UEs is expected to be minimal.
	+ Proposal 1: Support configuring multiple SSB periodicities for a SSB burst, each SSB periodicity applicable to a subset of SSBs of the SSB burst.
	+ Observation 3: Dynamic indication of transmitted SSBs in a SSB burst allows dynamic omission of SSBs and corresponding paging PDCCH/PDSCH and SI PDCCH/PDSCH for a certain duration.
	+ Proposal 2: Support dynamic indication of transmitted SSBs in a SSB burst to enable gNB to dynamically omit and add back SSBs that are semi-statically indicated as being transmitted, as frequently as in every 160ms, for network power savings.
	+ Proposal 3: Consider supporting multiple SSB burst configurations in a cell, where each SSB burst configuration corresponding to one network node within the cell includes separately configured SSB positions in burst and SSB transmit power.
	+ Proposal 4: Consider MAC CE based change of a default SSB burst configuration, where the default SSB burst configuration is used for PDSCH/PDCCH resource mapping and RACH resource mapping.
* [12] Intel
	+ Observation 1: For gNBs that support deeper power saving modes that require transition time between active and power saving state is between 10’s of msec to 100’s of msec, the ability to extend the periodicity of system critical channel transmission and reception, such as SSB, SIB1, PRACH, etc, are key for obtaining further improvements in power saving.
	+ Proposal 1:
		- Focus the study on potential methods of reducing/adapting transmission/reception of common channels/signals, such as SSB, SIB1, other SI, paging, PRACH, including techniques to constrain the transmission/reception to a relatively small time window.
		- Study further on the need to support SSB, SIB1, PRACH transmission/reception periodicity beyond 160 msec, and its potential specification impact.
	+ Proposal 2:
		- Study further on the need for supporting SSB-less cell operation with inter-band CA, and its potential specification impact.
		- Number of port changes to CSI-RS reference signals can be performed using RRC reconfiguration.
		- Dynamic switching between set of configured CSI-RS reference signals can be performed with BWP switching.
* [13] Xiaomi
	+ Proposal 1: For dynamic cell on-off, how to reduce the interruption duration for RRC-idle UE and avoid unnecessary handover or simplify the handover procedure for RRC-connected UE should be studied.
	+ Proposal 2: The measurement for RLM/ BFD/ beam selection and recovery/CSI /RRM should be enhanced considering dynamic beam on-off.
	+ Proposal 3: Reducing unnecessary DL reference signal transmission for dormant cell can be studied for energy saving.
	+ Proposal 4: Flexibly adjusting CSI-RS for RLM/BFD can be studied.
	+ Proposal 5: Enhancement for NCD-SSB to reduce or avoid PBCH transmission can be studied.
	+ Observation 1：Type #0 CSS transmission does not need to be as frequent as SSB.
	+ Proposal 6: Reduced Type #0 CSS transmission can be studied.
	+ Proposal 7: Reduced transmission for UE request SI can be studied.’
* [14] Interdigital
	+ 6.x.x Dynamic adaptation of resources in connected mode
		- Network energy saving opportunities may be restricted by resources that are semi-statically assigned to UEs in Connected mode such as periodic CSI-RS, PRS, periodic SRS, PDCCH, PUCCH carrying SR, CSI or SPS HARQ\_ACK, configured grants or semi-persistently scheduled PDSCH. Benefits from reducing the number of time occasions for these resources during periods of low activity are envisioned. Accordingly, the following enhancements enabling dynamic adaptation of periodic and semi-persistent resources in connected mode are considered.
			* Configuration of resources available in each network energy saving state;
			* Downlink dynamic indication of a network energy saving state;
			* Uplink request for activation of configured resources (wake-up request).
	+ 6.x.y Adaptation of DRX
		- The C-DRX cycle configured in connected mode can over dimensioned when the serving cell is in sleep mode. To enable network energy savings without affecting the UE power consumption, the UE can switch to an NES C-DRX cycle when the serving cell is in a NES state in order to also save UE power. Accordingly, the following enhancements are considered:
			* - Configuration of UE-group common NES alternative C-DRX cycle;
			* - Switching to NES C-DRX cycle upon reception of dynamic indication of a network energy saving state;
	+ 6.x.z Adaptation of DL common signals in idle and inactive modes
		- Network energy saving can be relaized by varying the periodicity of downlink common and broadcast signals in Idle and Inactive states, including SSBs and SI. SSBs can be transmitted with larger periods between SSB occasions compared to the legacy periodicities. Cells operating in a sleep mode can thus broadcast SSBs less frequently and possibly with a reduced number of SSBs compared to the legacy cycle. For example, simplified wider beam SSBs or PSS-only SSB can be transmitted with larger period between SSB occasions when the serving cell is in a NES state. Larger energy savings can be achieved by coupling the transmissions occasion of SI and SSBs for NES. The UE can assume that SSBs are transmitted at the NES periodicity upon reception of an indication of network energy saving state or reception of a simplified SSB for NES.
* [15] China Telecom
	+ Proposal 1: A hybrid mechanism of long/short transmission period of common signals can be considered for reducing the energy consumption and balancing the network performance at the same time.
	+ Proposal 2: Longer periodicity of SSB/SIB can be considered for BS energy saving.
	+ Proposal 2: The Msg4 can be considered omitted in the energy saving mode when there is no contention in the CBRA of initial access.
	+ Proposal 4: The 2-step semi-persistent symbol switch on-off can be supported in Rel-18.
* [16] Samsung
	+ Proposal 2: Support semi-static switching and dynamic switching for network states transition (cell ON/OFF) of a serving cell at least for single cell case.
		- Further study whether/how to reuse/reinterpret semi-static slot configuration and/or dynamic slot format indication.
		- Further study network states transition (cell ON/OFF) switching applies jointly or separately to DL and UL, for a TDD band.
	+ Observation 1: Current NR system requires large signaling overhead to adapt time domain resources for p/sp physical layer resources via RRC reconfiguration or semi-static (de)activation per UE.
	+ Proposal 3: Study cell-specific/UE group common dynamic adaptation on periodic/semi-persistent physical layer resources in DL or UL for NW energy savings.
	+ Proposal 4: Study introducing SSB periodicity larger than 160ms.
	+ Proposal 5: Further study SSB transmission reduction for Pcell or single cell case.
	+ Proposal 6: For DL reception adaptation in the energy saving state (cell OFF),
		- RRC configures whether to monitor the PDCCH in a search space;
		- RRC configures whether to receive the SPS PDSCH per SPS configuration.
	+ Proposal 7: For SR/CG PUSCH transmission adaptation for NWES during the energy saving state (cell OFF), study the following options:
		- Option 1) RRC configures whether to transmit the SR/CG PUSCH per configuration;
		- Option 2) UE does not transmit SR/CG PUSCH.
	+ Observation 2: Legacy C-DRX results in large transition energy when gNB wakes up multiples times to process noncontiguous ON durations.
	+ Observation 3: There is a tradeoff between NW energy savings and UE performance for C-DRX configuration. Current NR system requires large signaling overhead to adapt C-DRX configuration via RRC signaling per UE.
	+ Proposal 8: Study at least the following aspects of UG-specific dynamic adaptation of C-DRX for NW energy saving:
		- Align or concatenate the ON durations from the gNB perspective;
		- Save signaling overhead.
	+ Proposal 17: Support gNB wake up request under Pcell/PScell network energy saving state (cell OFF). The following options can be considered.
		- Option 1) UE transmits semi-static configured UL channels X symbols after transmitting gNB wake up request.
		- Option 2) UE monitors PDCCH carrying an ACK for gNB wake up request after transmitting gNB wake up request.
	+ Proposal 18: The following channels can be considered to carry the gNB wake up request.
		- PUCCH with SR.
		- PRACH
		- PUCCH with a new UCI type.
* [17] CMCC
	+ Observation 1: When gNB mutes some TxRUs for network energy saving, the corresponding PAs and antenna elements are also turned off, which may lead to power backoff of signal transmission, including SSB, CSI-RS, PDSCH, etc.
	+ Proposal 1: Enhancements on CSI-RS or PL RS measurements can be studied when measuring before and after TxRUs on/off.
	+ Proposal 2: Enhancements on threshold for beam failure recovery or radio link monitoring procedure can be studied together with TxRUs on/off.
	+ Proposal 3: The impacts on cell (re)selection or handover can be studied due to TxRUs on/off.
	+ Proposal 4: Enhancements can be considered to enable adaptation of CQI, RI, or PMI calculation with TxRUs on/off.
	+ Proposal 5: MAC CE or DCI can be used for dynamic CSI-RS port adaptation.
	+ Proposal 6: CSI reporting enhancement can be considered for assistance information feedback.
	+ Observation 2: Reducing SSB/SIB1 transmission for single carrier case will have impact on legacy UEs’ initial access performance, so it should be careful to apply such schemes to network with legacy UEs.
	+ Proposal 7: Reducing SSB/SIB1 transmission for single carrier case can be considered for new deployment with only new UEs.
	+ Proposal 8: To reduce initial access impact for legacy UEs, SSB transmission with lower power for some occasions can be considered.
	+ Proposal 9: When reduced SSB/SIB1 transmission is introduced, mechanisms for UE to trigger SSB/SIB1 transmission should be studied.
	+ Proposal 10: Schemes to realize dynamic alignment of C-DRX configuration can be studied for gNB power saving.
* [18] Fraunhofer IIS/Fraunhofer HHI
	+ Observation 5: When a gNB is not serving any user, it could be very useful to define larger intervals between SSBs so that the gNB can go into a deeper sleep mode thereby saving network energy.
	+ Proposal 4: Define larger SSB periods so that gNBs with no UEs to be served can go to deeper sleep modes to save network energy.
	+ Proposal 5: Enable UEs to send wake-up signals to request dormant gNBs to restore shorter SSB periods.
* [19] Mediatek
	+ SSB reduction from 8 to 4 in a half frame may save 43% BS power in the idle traffic. However, legacy UEs cannot support the dynamic adaption of SSB configurations.
	+ In NR, CONNECTED UEs monitor SI change indication at least once per modification period, and IDLE or INACTIVE UEs monitor SI change indication every DRX cycle on any paging occasion.
	+ Reducing SSB transmission can be used as a discovery signal when a cell is deactivated, i.e., no DL transmission except SSB.
	+ Monitoring RACH occasions per 20ms than 10ms saves 12.4% of BS power consumption in idle traffic. However, dynamic RACH occasion change will be difficult for legacy UEs.
	+ Long RACH occasion period can be configured for a sleeping cell, i.e., no DL transmission except (long period) SSB.
	+ DCI-based deactivation for period UL procedures saves 15.4% of BS power consumption than RRC-based deactivation. BS monitors UL reception every 5 ms after sending the deactivation.
	+ Dynamic adaptation of period UL is beneficial to BS power savings. However, NR supports type-2 CG PUSCH, AP/SP SRS, and AP/SP CSI reports providing sufficient flexibility.
	+ Dynamic adaptation for periodic UL can be up to gNB implementation.
	+ BS may not trigger cell reselection for an IDLE UE camping on a cell before BS turns off the cell (without cellBarred) because cell reselection is based on RSRP and RSRQ measurement.
	+ For dynamic BS on/off, enhancement on cell reselection for IDLE UE can be FFS.
	+ Monitoring PRACH preamble for a sleeping cell, e.g., a deactivated small cell, is beneficial for NW to determine whether to turn on/off a BS.
	+ For dynamic BS on/off, enhancement on PDCCH-order-based RA can be used as a BS wake-up request.
	+ DRX reconfiguration can align DL traffic, but the RRC processing delay will be up to 10ms.
	+ NW may provide preconfigured DRX offset values via RRC and activate one of them via UE-group common DCI.
* [20] LGE
	+ Proposal #4: It is beneficial to switch off gNB’s periodic/semi-persistent transmission (and/or reception) at least when gNB does not need to transmit data to the UE, in terms of network energy savings.
	+ Proposal #5: Study how to support efficient mechanisms to switch off gNB’s transmission (and/or reception) for a specific period of time.
	+ Proposal #6: Support of adjustment of SSB transmission and on-demand procedure for common channels/signals such as SIB1, paging, or PRACH, should be carefully studied at least considering impacts on initial access procedure and measurements, and how to enable on-demand procedure.
	+ Proposal #7: Study how to support a mechanism for waking gNB up from power save mode when new data arrives at UE.
	+ Proposal #8: Consider to support UE’s report of zero buffer status for UL transmission.
	+ Proposal #9: Study how to enhance UE’s DRX mechanism for the purpose of network energy saving.
* [21] ZTE/Sanechips
	+ Observation:
		- SSB-less SCell or SSB-limited SCell is beneficial to network energy saving.
		- The synchronization and TA issue of SSB-less SCell can be handled by NW implementation.
		- TRS is not needed for the SSB-less SCell at least in the case there is no DL traffic in the SCell.
		- The SSB-less SCell scheme can obtain 4.3%~22.6% energy saving gain in the cases RU=4.9%~37.5%.
		- The SSB-less SCell scheme can obtain 9.3% ~ 36.2% energy saving gain in the cases RU=4.9%~37.9%.
	+ Proposal:
		- SSB-less SCell should be supported for inter-band CA.
		- Aperiodic TRS is triggered only when it is needed in the SCell activation process.
		- A serving cell with DL common signal/channel (i.e., SSB, SIB) reduction can be considered for network energy saving.
		- UEs can obtain SIB via an assistant cell to get access to the SIB-less cell.
		- An uplink wake-up mechanism (WUS) can be considered for network energy saving.
* [22] CeWIT
	+ Observation 1: Mandatory set operations consume energy at the gNB irrespective of the load.
	+ Observation 2: Use of lighter version of SSB provides 31.32% savings in urban macro scenario and 29.08% saving in rural macro scenario.
	+ Proposal 1: For energy saving, use of light versions of SSB at the gNB is supported.
	+ Proposal 2: Adaptation of SSB periodicity at beam level is supported.
	+ Proposal 3: Avoiding CORESET 0 and optimizing the scheduling of SIB1 is supported.
	+ Observation 3: Sleep states in symbol level needs fast transition between different states, which is difficult to achieve and may not provide a significant energy saving gain.
	+ Proposal 4: Sleep states for gNB in frame, subframe and slot level is supported.
	+ Observation 4: The adaptation of sleep states at gNB will have an impact on the legacy operations at UE.
	+ Proposal 5: Signaling information about sleep state, in terms of starting time and duration, to connected UE is supported.
* [23] Rakuten Mobile
	+ Proposal 4:
	+ For further study of adaptive cell on/off based on signalling, necessary transient time for activation/deactivation from different sleep modes should be considered.
* [24] Qualcomm
	+ Observation 1: Network energy consumption in this scenario of “gNB in idle mode”, i.e., case of no or few PDSCH, PUSCH, CSI/RS, SRS transmissions, is mainly dependent on SSB transmission and associated downlink and uplink procedures for initial access and system information transmission.
	+ Proposal 1: Capture in TR the following description with regards to the reduction/adaptation of transmission/reception of common channels/signals:
		- RAN 1 to focus the work on network energy saving mechanisms for Rel. 17 SSB beam sweeping on the “gNB in idle mode” scenario, i.e., scenario of very low load and in which the gNB activity is largely due to SSB transmission and RACH reception. SSB beam sweeping and associated signaling, e.g., paging, RACH reception is the highest energy contributor in the case of very low load in the cell.
	+ Proposal 2: Capture in TR the following description with regards to the reduction/adaptation of transmission of common channels/signals:
		- Alternative “light SSB” mechanisms as a replacement to or along with traditional SSB transmission are mechanisms in which only the minimum SI and PSS/SSS is transmitted via SSBs,
		- SSB/RACH configuration in “compact bursts” is a scheme of “SSB burst composition” in which gaps between SSBs are avoided,
		- flexible (e.g., “non-uniform” or beam-specific) configuration of SSB, RMSI, and/or RACH, are the schemes allowing per-beam configuration of SSB transmission power and periodicity,
		- “on demand” support of SSB, RMSI, and/or RACH are the schemes in which SSB, RMSI and RACH are transmitted after UE request for SSB, RMSI and RACH.
	+ Observation 2: Coordination of UE C-DRX configurations across multiple UEs may facilitate BS DTX/DRX implementation for network energy savings.
	+ Proposal 3: Capture in TR the following description for semi-static and/or dynamic cell on/off:
		- Network initiated BS DTX/DRX is the mechanism allowing the BS to go to sleep mode for a defined period of time “BS Tx/Rx Inactive State” duration. Semi-static and/or dynamic BS DTX/DRX patterns are supported. UEs in the cell are notified about the “BS Tx/Rx Inactivity State” either via RRC or via a combination of RRC and L1 signaling.
	+ Proposal 4: Capture in TR the following description for dynamic C-DRX configuration adaptation
		- A UE may be configured with a C-DRX configuration for network energy savings in addition to a legacy C-DRX configuration. The C-DRX configuration for network energy savings can be common to a group of UEs. The UE may receive L1/L2 signalling to switch between the configured C-DRX configurations.
		- Specification impact at least includes L1/L2 signaling to switch between the configured C-DRX configurations.
	+ Observation 3: Cell wake-up mechanism could enable BS flexibly provision downlink channel transmission (e.g., broadcast channel) and uplink channel reception (e.g., RO, SR, and configured grant) to achieve network energy savings.
	+ Observation 4: Cell wake-up mechanism might be applicable to a cell without any connected mode UE (empty scenario) and with some connected mode UEs (low load scenario).
	+ Proposal 5: Capture in TR the following description for cell wake-up procedure
		- Cell wake-up procedure is a procedure in which a UE may send a cell wake-up request to help gNB transition from a sleep state to an active state. Furthermore, based on the received request, gNB may broadcast its active time to one or a group of UEs.
		- Specification impact may include cell wake-up request from UE, UE behaviour when base station is in sleep state, and indication of gNB active time.
* [25] Apple
	+ Proposal 1: Consider dynamic signaling of network off status as one of the techniques for network energy saving.
* [26] NTT Docomo
	+ Proposal 1: Study CDRX and WUS for gNB for network energy saving techniques.
	+ Proposal 2: Study SSB periodicity adaptation such as extended SSB periodicity for network energy saving techniques.
		- Trade-off between power saving gain and initial access and handover performance should be considered.
	+ Proposal 3: Study SSB-less SCell for inter-band CA for network energy saving techniques.
* [27] Ericsson
	+ Observations:
		- Frequent Rx/Tx activities (e.g., periodic TRS or PRACH occasions) at low-moderate loads increases the network energy consumption.
	+ Proposals:
		- Study and identify techniques minimizing periodic reference signal transmissions, e.g., enabling fully aperiodic TRS for FR1 and FR2 when needed.
		- Study and identify techniques which enable dynamic adaptation of PRACH and PUCCH occasions according to the need.
		- Study and identify techniques in which the UE can assist the network in optimizing its scheduling to maximize its sleep opportunities.
* [28] ITRI
	+ Proposal 2: The following aspects for increasing time domain energy saving opportunities by the gNB can be considered:
		- Dynamic adaptation of UE C-DRX configurations according to the energy saving state(s) or sleep mode(s)
		- Dynamic adaptation of transmission/reception of common signals according to the energy saving state(s) or sleep mode(s)

### Summary of Discussions

Given that RAN1 only has 2 meeting left for completion of the SI (including this meeting), moderator suggests trying to formulate texts that could be potentially captured into the TR.

Proposal #2-1 is a very rough draft that will likely need several updates. Moderator suggests focusing the initial discussion in high level outline of the techniques, including addition or removal of the time domain techniques. Once a high-level outline is available, work further on providing further details, which may include potential specification impact list, potential use case and deployment scenarios, and others.

#### Proposal #2-1

* The following text are used as baseline for further discussion, with the intent to be captured into the SI TR. Note, the technique numeration is only for identification of the techniques for discussion purposes.
* Technique #A-1 Adaptation of common signals and channels
	+ Network energy saving can be realized by varying the periodicity of downlink common and broadcast signals, such as SSB/SI/paging, and periodicity of uplink random access opportunities.
	+ Currently NR specification supports varying the SSB and SI transmission and PRACH reception periodicity up to 160 msec.
		- [Editor note: may want to reference sources that provide information about how much gain we can expect from longer SSB/SIB1/paging/PRACH periodicity]
	+ Support of burst transmission and reception of common signals and channels within a relatively small time-window along with longer periodicity between are expected to potentially provide longer inactivity periods for the gNB and potentially provide higher power saving gains.
	+ Support of on-demand SSBs/SIB1 transmissions or SSB-less operations may also enable long periods of inactivity at the gNB and potentially provide energy savings.
		- This may include leveraging SSB-less cell operations and potential enhancements for SSB-less cells, e.g. support SSB-less cell operation for inter-band CA.
		- This may include support of discovery reference signals (DRS) intended to aid discovery of cells in lieu of SSBs.
	+ [Editor note: may need to provide additional context and potential specification impact]
* Technique #A-2: Dynamic adaptation of UE specific signals and channels
	+ Network energy saving opportunities may be restricted by UE specific signals and channels that are semi-statically configured such as periodic CSI-RS, PRS, periodic SRS, PDCCH, PUCCH carrying SR, CSI or SPS HARQ\_ACK, configured grants or semi-persistently scheduled PDSCH/PUSCH.
	+ Reducing the number of time occasions for these resources during periods of low activity may potentially provide energy saving benefits.
	+ Potential enhancements to synchronize the UE specific signal and channel transmission reception such that they provide longer inactivity periods at the gNB can be considered.
	+ This may also include group level signaling of the UE specific signals and channel transmission and reception that allow gNB to minimize configuration overhead and potentially minimize overall gNB activity.
* Technique #A-3: wake up signal (WUS) for gNB
	+ To facilitate quick wake up of gNB that is in a dormant power state, support of wake up signal (WUS) transmitted by the UE to the gNB can be considered.
		- [Editor Note: reference for sources that provide potential gains, and list of potential specification impact might be needed]
* Technique #A-4: Adaptation of DRX
	+ Synchronization of the DRX cycle configured for UEs in connected mode or idle mode can potentially provide longer inactivity periods at the gNB.
	+ [Editor Note: further details are needed, including list of potential specification impact]

## 2.3 Frequency-domain based Energy Saving Techniques

* [2] Huawei/HiSilicon
	+ Observation 11: Use of SSB/SIB1 received from one carrier for other carriers in multi-carrier scenarios can bring considerable energy saving gain.
	+ Proposal 5: Evaluate SIB1-less operation in multi-carrier scenario, where the SIB1 for one carrier with/without SSB/DRS with low-load is broadcasted/obtained from another carrier.
	+ Observation 12: For SCell (de)activation, the UE can acquire time and frequency synchronization based on the reference signal, e.g. SSB, TRS and etc, on another CC for further BS energy saving and fast SCell (de)activation.
	+ Observation 13: The switch time produced by cell-specific BWP switch at network/gNB side cannot be used by any UE, and results in decreased spectrum efficiency.
	+ Observation 14: Compared with the adaptation of scheduled PRBs in the same BWP, it is not clear how much further network power saving gain/benefit can be achieved by dynamic BWP bandwidth/PRBs adaptation via BWP switching.
* [3] Spreadtrum Communications
	+ Observation 6: The dynamic cell on/off and the DTX can be realized by SCell operations, and the similar energy saving gain can be achieved.
	+ Observation 7: The loading balance by bandwidth adaptation may provide the energy saving gain.
* [4] vivo
	+ Proposal 5: Study anchor carrier concept for network energy saving in frequency domain, including design and procedure for initial access UEs, RRC idle UEs and RRC connected UEs.
* [5] Nokia/NSB
	+ Observation-3: From NW perspective, the BWP framework may not benefit to the network side energy saving. Practically, the NW / gNB could be running with FFT/iFFT of fixed size, where majority of the NW hardware components may not be scaled / switched-off despite the smaller bandwidth.
	+ Observation-4: Energy saving gain may be quite minor when adjusting the number of allocated PRBs.
	+ Observation-5: From network perspective, it is unclear for us what is the benefit when reducing the BWP switching delay or if frequent BWP switching could bring network side energy saving.
	+ Observation-6: From network saving perspective, the benefits of group-common signaling for BWP operation could be minor if there is a limited number of UEs in the cell in a low-load scenario, which is the target of the Rel18 NW ES study as stated in the SID.
	+ Observation-7: Joint adaptation of transmission bandwidth and power spectral density, practically, can be achieved via implementation schemes.
	+ Observation-8: For a network with multiple component carriers (CC), the network hardware components, i.e. baseband processing as well as radio unit part, may be shared or commonly applied to all CCs. These hardware components cannot be switched off for power saving as long as there is one active CC with serving UEs.
	+ Proposal-8: Inter-band CA with SSB-less or SIB1-less secondary carrier can be jointly considered with the corresponding time-domain technique discussion on SSB/SIB1 transmission adaptation.
* [6] Panasonic
	+ Proposal 2: For frequency domain adaptation for network energy saving, enhancement of BWP framework should be further considered for better efficiency. For multi-carrier adaptation enhancement, more careful study is needed for clearer benefit due to possible larger specification impact.
* [7] Fujitsu
	+ Proposal 4. The energy saving techniques (not only frequency technique but also time, spatial and power domain techniques) can be applied on a specific BWP.
	+ Proposal 5. The UE can be preconfigured with an energy saving BWP and BWP switching is activated when the serving cell entering energy saving state.
	+ Proposal 6. Group-common signaling for PCell switching, SCell activation/deactivation and SCell dormancy can be considered. Details on such signaling should be studied in RAN1 and RAN2.
* [8] NEC
	+ Proposal 4: enhancement on cell activation/deactivation and cell dormancy should be supported to better support gNB energy saving and minimize the impact on UE operation.
	+ Proposal 5: support cell wake-up signal transmitted by UE to wake-up a cell from deep sleeping mode, and UE assistant information carried by the cell wake-up signal can be considered.
	+ Proposal 6: Reduced CSI-RS density for frequency domain network energy saving should be considered.
	+ Proposal 7: Support reduced bandwidth and default UE BWP for network energy saving mode, as well as autonomous BWP switching.
	+ Proposal 8: jointly design of spatial domain and frequency domain techniques should be considered to get good balance among energy consumption, coverage and capacity, e.g., joint antenna on/off and BWP switching.
	+ Proposal 9: support SSB and CSI-RS updating mechanism due to the dynamic antenna switching on/off, and techniques to reduce the delay of UE beam measurement and TCI state update after SSB updating should be studied.
	+ Proposal 10: Consider using an associated TRX pool index to address the spatial domain configuration whenever the network enters into the energy saving mode.
	+ Proposal 11: Consider the activation of different network energy saving techniques (e.g., time, frequency, spatial, power) via semi-static network energy saving configuration.
* [9] OPPO
	+ Proposal 4: further study the potential gain from BW adaptation.
* [10] CATT
	+ Proposal 9: Dynamic bandwidth adaption for gNB energy saving could be considered in frequency domain.
	+ Observation 7: gNB dynamic BWP adaption scheme could obtain 5.7%~21.9% energy saving gain.
	+ Proposal 10: Dynamic and fast SCell activation/deactivation should be studied for network energy saving.
	+ Proposal 11: SSB-less transmission in PCell should not be supported.
	+ Proposal 12: If SSB enhancement for SCells in case of inter-band CA is considered, accurate DL synchronization should be ensured.
* [11] Lenovo
	+ Proposal 5: To support carrier bandwidth adaptation, study cell-specific resource grid adaptation and UE-specific bandwidth adaptation of an active BWP.
	+ Proposal 6: For efficient SCell activation/deactivation management, cell activation request from UE and/or L1-based SCell activation/deactivation can be considered.
* [14] Interdigital
	+ Dynamic adaptation of bandwidth part within a carrier
		- One considerable source of energy consumption within a single carrier comes from operating multiple bandwidth parts within a carrier, as each BWP can come with its own set of periodic and common signals (e.g. SSBs, CSI-RSs, PRS, etc). Although each UE can only have one BWP, the gNB can have multiple BWPs active simultaneously. At low cell load conditions, it can be beneficial to save energy by have all remaining connected UEs in the cell on the same active BWP. Such BWP can be a cell-specific BWP common to all UEs in the cell, e.g. the initial BWP or a separate BWP configured for NES. The following enhancements enabling dynamic adaptation of power offset are considered:
			* Configuration of a group common NES bandwidth part for a given carrier;
			* Bandwidth part switching upon reception of a group common L1 signalling indicating a BWP switch or an indication of a network energy savigns state.
	+ 6.n.y Multi-carrier energy savings enhancements
		- The gNB can achieve considerable energy savings from operating SCells without transmitting periodic signals such as SSBs or CSI-RS for inter-band CA. This enables a lean Scell operation without having to wake such cells periodically, especially when the load in the cell group is low, while keeping SCells active enables offloading high throughput bursts when needed. The following enhancements enabling dynamic adaptation of power offset are considered:
			* The UE can determine the downlink timing from another cell (e.g. a PCell or a PSCell) in certain conditions, including:
				+ whether the SCell is geolocated with the PCell or PSCell
				+ whether the beam management can be inferred from the PCell or PSCell.
		- Further network energy saving can be achieved by ensuring that remaining UEs have the same PCell, as it allows the gNB to operate other carriers as SCells without SSB or deactivate them when not needed. It is therefore desirable to have the same PCell for all UEs in the cell. This can be achieved by signalling common indication to switch the PCell designation to a cell-group common carrier that can be preconfigured.
* [15] China Telecom
	+ Proposal 8: The Scells without SSB in inter-band CA should be supported in Rel-18. Which bands are feasible and the related UE requirements should be further identified.
* [16] Samsung
	+ Proposal 9: Support a dedicated BWP for gNB’s transmission/reception in the energy saving state.
	+ Proposal 10: Support SPS PDSCH reception/Type-2 CG PUSCH transmission without reactivation after BWP switching.
	+ Observation 4: For a given data rate (low to medium), a combination of power and frequency domain adaptation would provide a balance between energy saving and system performance.
	+ Proposal 11: Support joint adaptation of gNB transmission bandwidth and power spectral density.
	+ Proposal 12: Support a cell-specific/UG-specific signaling for cell switching on/off in the energy-saving.
	+ Proposal 13: For supporting inter-band CA, RAN1 shall ask RAN4 to investigate at least the following requirements on the carriers to perform CA operation:
		- Synchronization requirement between carriers;
		- Frequency distance requirement between carriers;
		- Reception power difference between carriers;
		- QCL assumption requirement across carriers.
* [17] CMCC
	+ Observation 3: The power saving gain of dynamic cell specific or group common BWP adaption depends on implementation.
	+ Observation 4: The absolute power saving gain of intra-band SSB-less depends on gNB implementation, at least the transmit power for such symbols on Scell can be reduced.
	+ Observation 5: Fast activation/de-activation of Scell can be acheived along with intra-band SSB-less Scell.
	+ Proposal 11: DCI based Scell activation/de-activation can be introduced for intra-band SSB-less Scell scenario.
	+ Proposal 12: Inter-band Scell with reduced SSB/SIB1 can be studied to reduce power consumption of gNB.
	+ Proposal 13: Mechanisms to trigger normal SSB/SIB1 on demand should be studied for inter-band Scell with reduced SSB/SIB1 scenario.
	+ Proposal 14: To realize offloading before RRC connected mode for common Pcell, initial access by Scell can be studied.
	+ Proposal 15: Dynamic indicating of activated Scells can be studied to reduce gNB power consumption.
	+ Proposal 16: Dynamic Pcell change can be studied to support fast carriers on/off.
* [19] Mediatek
	+ NR has supported a fast BWP switch, e.g., 1ms for 15kHz SCS, based on UE capability.
	+ A study on reducing BWP switch delay may NOT be needed for Rel-18 NWES.
	+ Turning off one CC from two saves 14% BS power consumption with 15% RU per CC. However, the power saving gain depends on whether BS uses shared RF modules on these two CCs.
	+ Consider UE-group SCell activation/deactivation via L1 singling for multiple SCells.
	+ Turning off both SIB1 and SSB on a single SCell saves 5.7% of BS power consumption for video traffic with RU = 15% per cell with BW = 100 MHz.
	+ Cell-group SSB/SIB1 on/off via common L1 signaling for CONNECTED/IDLE UEs can be FFS.
* [20] LGE
	+ Observation: Legacy mechanisms such as SCell (de)activation, BWP switching, and SCell dormancy indication, can be reused for the purpose of network energy savings in frequency domain.
	+ Proposal #10: Consider to enhance indication methods for deactivating frequency domain resources (e.g., SCell (de)activation or BWP switching via group-common DCI or MAC CE) or for adjusting the bandwidth of a given BWP.
* [22] CeWIT
	+ Observation 5: Dynamic adaptation of bandwidth causes deactivation of certain frequency resources assigned to a UE that leads to conflicts, unnecessary transmissions and needless monitoring.
	+ Proposal 6: gNB signaling information about dynamic adaptation of BW to the active UEs is supported.
* [24] Qualcomm
	+ Proposal 6: Capture in TR the following description for dynamic UE group specific Pcell change.
		- In CA operation, the UE is configured with a set of secondary cells in addition to a primary cell. To reduce network power consumption, some secondary cells may be dynamically deactivated or put in a dormant state while a common primary cell may be dynamically configured for a group of connected mode UEs especially when the system load is not high.
		- Specification impact may include joint dynamic indication of primary cell change to a group of UEs.
	+ Observation 6: SSB/SI can be transmitted at a long periodicity in Scell to reduce broadcast overhead and network power consumption.
	+ Observation 7: A long SSB/SI periodicity together with R17 temporary RS should already provide reasonably low Scell activation latency.
	+ Proposal 7: Capture in TR the following description for inter-band CA with SSB-less carriers.
		- For inter-band CA with SSB-less carriers, the UE is configured with a primary cell and one or multiple secondary cells that do not transmit SSB. The secondary cells are associated with the primary cell. In particular, the UE may receive or transmit a signal/channel from the secondary cells based on time, frequency and QCL information from the associated primary cell.
		- Impact study may include
			* Reliability of the time/frequency/spatial information from one carrier with SSB to be used for SSB-less carrier
			* collocation requirements for secondary cells and associated primary cell,
			* band requirements for secondary cells and associated primary cell,
			* requirements on timing difference between secondary cells and associated primary cell,
			* QCL for receiving/transmitting signal/channel on secondary cells,
			* transmit power determination for receiving signal/channel on secondary cells,
			* Path loss and TA determination for transmitting signal/channel on secondary cells.
			* Mobility measurement for SSB-less carrier.
* [25] Apple
	+ Proposal 2: Consider dynamic signaling of network operating bandwidth as one of the techniques for network energy saving.
	+ Proposal 3: For SSB-less SCells for inter-band CA, send an LS to RAN4 on the feasibility study.
	+ Proposal 4: Consider SIB-less cells or cells with reduced SIB transmissions for network energy saving.
* [26] NTT Docomo
	+ Observation 1: The existing BWP switching can be used for dynamic TX/RX bandwidth adaptation for network energy saving, while it will lead to DL overhead and power consumption due to DCI indications required for each UE in a cell.
	+ Proposal 4: Study group-common based BWP switching and group-common BWP for network energy saving techniques.
* [27] Ericsson
	+ Observations:
		- BW adaptation at the network can potentially save energy at both network and UE side.
	+ Proposals:
		- Study potential of reducing the BW adaptation delays for Rel18 UEs.
		- Study group-common or cell-specific BWP switching.
		- Study techniques which optimize reference signal transmissions over SCells in terms of network energy savings.

### Summary of Discussions

Given that RAN1 only has 2 meeting left for completion of the SI (including this meeting), moderator suggests trying to formulate texts that could be potentially captured into the TR.

Proposal #3-1 is a very rough draft that will likely need several updates. Moderator suggests focusing the initial discussion in high level outline of the techniques, including addition or removal of the frequency domain techniques. Once a high-level outline is available, work further on providing further details, which may include potential specification impact list, potential use case and deployment scenarios, and others.

#### Proposal #3-1

* The following text are used as baseline for further discussion, with the intent to be captured into the SI TR. Note, the technique numeration is only for identification of the techniques for discussion purposes.
* Technique #B-1: Multi-carrier energy savings enhancements
	+ The gNB can achieve potential energy savings from operating SCells without transmission and reception of periodic signals and channels such as SSB, SI, CSI-RS for mobility measurements, PRACH, paging, etc.
	+ To facilitate leveraging of lean SCells, potential enhancements to provide time and frequency synchronization, and other measurement sources by another cell can be considered.
		- [Editor notes: further details of how to provide t/f sync and measurements sources is needed. Further discussion to handle the overlap with time domain technique needed]
	+ Additionally, ability to quickly activate and deactivate CC and put CCs in dormant states is expected to potentially provide energy savings at the network.
	+ [Editor notes: further details including potential list of specification impact needed]
* Technique #B-2: Dynamic adaptation of bandwidth part of UE(s) within a carrier
	+ Enhancements to enable group-common or cell-specific BWP configuration and/or switching may lower signaling overhead and operational cost for adaptation of BWPs of UE(s) and potentially improve gNB power consumption.
	+ [Editor notes: companies seem to have some different understanding of how potentially bandwidth part changes can be potentially utilized by the gNB to lower power consumption, some clarification and details are further needed]

## 2.4 Spatial-domain based Energy Saving Techniques

* [2] Huawei/HiSilicon
	+ Observation 7: Dynamic antenna adaptation applied to PDSCH has the potential of BS energy savings with room of performance improvement by CSI measurement enhancement, while that for reference signal has limited potential for energy saving with large specification/performance impact.
	+ Proposal 3: Evaluate dynamic antenna port shutdown with one CSI report with multiple CSI results (e.g. 4), corresponding to multiple shutdown pattern(s) prior to or after UE measurement/reports.
	+ Observation 8: The spatial domain impact on dynamic TRxP adaptation should be further justified.
* [3] Spreadtrum Communications
	+ Observation 8: The dynamic cell on/off and the DTX can be emulated by TRxP(s) on/off adaptation, and a fraction of energy saving gain can be achieved.
* [4] vivo
	+ Proposal 2: Study both dynamic port adaptation and dynamic TRP On/Off for network energy saving.
	+ Observation 3: Dynamic port adaptation can achieve more power saving gain than semi-static way.
	+ Proposal 3: Study Group-common L1 signaling to enable faster port adaptation and efficient TRP On/Off.
	+ Observation 4: Multi-CSI reporting can alleviate the negative impacts of inaccurate CSI tracking.
	+ Proposal 4: Study CSI measurement/report enhancement for network energy saving to facilitate fast port adaptation with good performance.
* [5] Nokia/NSB
	+ Observation-9: At least intuitively, spatial domain techniques such dynamic port adaptation and dynamic TRP adaption are expected to provide important network energy saving gains.
	+ Proposal-9: Support considering and evaluating dynamic port adaptation technique in terms of network energy saving gains.
	+ Proposal-10: Support considering and evaluating dynamic TRP adaptation technique in terms of network energy saving gains.
	+ Observation-10: Dynamic port adaptation would have implications on some CSI-RS configuration parameters. For instance, CBSR (codebook-subset restriction) may be different between the case where a port subset is enabled and the case where this subset is disabled.
	+ Proposal-11: For dynamic port adaptation, consider group-common signaling for CSI-RS port disabling/enabling indication.
	+ Proposal-12: Under dynamic port adaptation, consider defining UE behaviour regarding measurements and reporting.
	+ Proposal-13: For dynamic port adaptation, consider the impact of the transmission of aperiodic CSI-RS and periodic CSI-RS with different number of ports.
	+ Observation-11: For the state-of-art MIMO operation in 5G NR, the adaptation of spatial elements, i.e., adaptation of logical antenna port, is operated at a rather large time scale, due to the hardware limitations with large spatial element activation delays.
	+ Proposal-14: Discuss hardware limitations about the time required for gNB to perform spatial elements adaptation.
	+ Observation-12: For enabling dynamic TRP muting/unmuting (including for CA cases), similar approaches as for enabling legacy SCell deactivation/activation seem workable, i.e., approaches based on explicit indication and ‘activity-aware’ timer.
	+ Proposal-15: For dynamic TRP muting/unmuting, impact on UE measurement and reporting should be considered.
	+ Proposal-16: For dynamic TRP muting/unmuting, impact on the Rel-17 per-TRP beam failure and recovery operations should be considered.
	+ Proposal-17: For dynamic TRP muting/unmuting, consider how to identify/represent a TRP.
* [6] Panasonic
	+ Proposal 3: As of spatial/antenna domain adaptation for network energy saving, the SSB on/off can be discussed and potentially supported together with time domain adaptation. For the enhancement to the TCI frameworks and CSI feedback, it needs more investigation on whether additional mechanism is needed.
* [7] Fujitsu
	+ Observation 2. TxRU(s) reduction can be considered as the most effective technique in spatial domain for network energy saving.
	+ Proposal 7. TxRU(s) reduction can be performed for UL or DL transmission, respectively.
	+ Proposal 8. The following enhancements on CSI measurement/report should be considered to support dynamic TxRU adaptation
		- If the number of logical antenna port changes after TxRU adaptation, L1 signaling to update of CSI-RS configuration for periodic / semi-persistent CSI reporting can be considered.
		- If the number of logical antenna port remains unchanged after TxRU adaptation, L1 signaling to inform UE report based on the CSI-RS transmitted after TxRU adaptation can be considered.
		- Group-common signaling can be considered to avoid obvious increase of signaling overhead.
	+ Proposal 9. When applying TxRU adaptation and power adjustment, SSB transmission should not be affected.
	+ Proposal 10. Enhancements on RLM and RRM measurement can be considered regarding the transmission power fluctuate of CSI-RS caused by TxRU adaptation and power adjustment.
* [9] OPPO
	+ Proposal 5: RAN1 considers antenna port number/TRXU chains/antenna elements number adaptation to achieve network power saving.
* [10] CATT
	+ Proposal 13: Dynamic antenna adaptation at low/middle system load should be considered.
	+ Observation 8: Without change of the number/pattern of antenna ports, dynamic reduction of antenna elements has no obvious specification impact.
	+ Proposal 14: If dynamic antenna ports adaptation was supported, NZP CSI-RS ports adaptation information should be indicated to UE with group/cell common signaling.
	+ Proposal 15: If dynamic antenna ports adaptation was supported, enhanced CSI acquisition/reporting could be considered.
	+ Proposal 16: If dynamic antenna adaptation was supported, gNB should ensure no performance loss of cell coverage through implementation.
	+ Proposal 17: The dynamic antenna adaptation technique to support the coexistence with legacy UE should be further studied.
	+ Observation 9: Dynamic antenna adaptation scheme could obtain 13.2% ~ 18.4% energy saving gain with 3.6%~7.2% UPT loss and 2.5%~13.6% latency loss.
	+ Observation 10: When the TRP is dynamically turned off, sparse CSI-RS could be transmitted to achieve good trade-off between energy saving gain of gNB and CSI measurement performance of UE.
	+ Observation 11: If ON/OFF of multi-TRP is dynamically indicated to UE, energy saving gain can be provided for both Network and UE.
	+ Proposal 18: Triggering of dynamic ON/OFF of multi-TRP should be considered.
* [12] Intel
	+ Observation 2: Type of spatial domain adaptation, and the frequency in which the adaptation needs to occur plays an important factor in determination of potential specification impact.
	+ Proposal 3:
		- Classify spatial domain adaptation into two categories, type 1 and type 2.
		- Type 1 spatial domain adaptation is enabling or disabling specific reference signal resource(s) and/or antenna port(s) corresponding to a beam pattern.
		- Type 2 spatial domain adaptation is enabling or disabling some antenna element(s) that constituted a beam pattern. Disabling some antenna element(s) would result in potential changes to the transmission power, transmission/reception beam gain, and transmission/reception beam pattern for one or more reference signal(s) and channel(s).
		- Further study the frequency in which spatial domain adaptation (including changes to transmit power of reference signals) needs to occur and how fast the adaptation should be performed in order to benefit from lower power consumption.
		- Further study potential specification impact associated with frequent and dynamic spatial domain adaptation (including changes to transmit power of reference signals).
	+ Proposal 4: It is not preferred to couple the optional BWP switching functionality from Rel-15 with potentially antenna port adaptation that may be introduced for Rel-18. Newly considered features for Rel-18 should have a separate capability.
* [14] Interdigital
	+ Dynamic adaptation of spatial elements
		- Network energy savings could be obtained by reducing the number of active transceiver chains or spatial elements of the gNB during periods of low activity. Such change requires adaptation of corresponding semi-statically configured reference signals assigned to UEs for CSI reporting and other functionalities. The following enhancements enabling dynamic adaptation of reference signals are considered:
		- Indication of a group identity for each configured reference signal;
		- Indication of a subset of antenna ports for each configured reference signal and each possible energy saving state;
		- Dynamic indication of a group identity and applicable energy saving state.
* [15] China Telecom
	+ Proposal 5: The CSI reporting should be enhanced for better deciding the TRX switch on-off.
	+ Proposal 6: The network can consider self-adapted switch-off the TRX with the reference of PMI.
	+ Proposal 7: The CSI-RS should be reconfigured when the TRX switch off is adopted.
* [16] Samsung
	+ Proposal 14: Study mechanisms to dynamically mute CSI-RS (BM) ports for NW energy savings.
	+ Proposal 15: Study mechanisms of power adaptation on CSI-RS (BM) ports for NW energy savings.
	+ Proposal 16: Study mechanisms of beam adaptation on CSI-RS (BM) ports for NW energy savings.
* [19] Mediatek
	+ Turning off TxRU saves 35% of BS power consumption from 64 TxRU to 32 TxRU, and has a marginal UE performance impact.
	+ Consider UE-group BWP switch to support dynamic antenna port adaptation at least for CSI-RS, SPS-PDSCH, and CG-PUSCH.
* [20] LGE
	+ Proposal #1: It is beneficial to dynamically adjust the number of gNB’s activated antenna elements, in terms of network energy savings.
	+ Proposal #2: Study how to efficiently support changing the number of gNB’s transmit antenna elements (e.g., by deactivating a NZP CSI-RS with 32 antenna ports while activating another NZP CSI-RS with 16 antenna ports, or turning off 16 antenna ports out of 32 antenna ports configured for the NZP CSI-RS) and how to handle related issues such as indication methods, beam management, and TCI state/configuration control.
	+ Proposal #3: Discuss whether any enhancements for UL signal/channel (e.g., SRS) transmission are needed depending on the number of gNB’s receive spatial elements.
* [21] ZTE/Sanechips
	+ Observations:
		- RRC reconfiguration is needed to update the configuration of reference signals due to the TxRU de-activation, which will increase the signaling overhead and decrease the spectrum efficiency.
		- CSI measurement results may be out-of-state if partial TxRUs are de-activated.
		- When the antenna configuration is reduced from 64TxRUs to 32TxRUs, 8.4%~20.2% energy saving gain can be observed in the case RU=4.9%~37.8%.
	+ Proposals:
		- The following impacts need to be considered in spatial domain adaptation
			* The validity of the reference signal configurations, including CSI-RS
			* The accuracy of measurement/report results, including CSI measurement/report
		- Fast/efficient indication of antenna ports can be considered to minimize the impacts of NW energy saving technique in spatial domain.
* [22] CeWIT
	+ Proposal 7: gNB dynamically adapting the logical ports for NES is supported.
	+ Proposal 8: gNB dynamically signaling information about ports adaptation to the UE is supported.
* [23] Rakuten Mobile
	+ Proposal 1: For necessary CSI-RS enhancements for predetermined TRxP configuration, impact on L1-RSRP measurement should be studied further.
	+ Proposal 2: For dynamic antenna array reconfigurations, study solutions to resolve the challenges such as channel estimation and UE service degradation.
	+ Proposal 3: For dynamic antenna array reconfiguration, utilize UE assistant information.
	+ Observation 1: For assistance information from the UE, how the information can be utilized for network energy saving needs to be clarified in the SI
* [24] Qualcomm
	+ Observation 8: Dynamic antenna port adaptation could help gNB dynamically adapt antenna port configurations for reducing network power consumption.
	+ Observation 9: Dynamic antenna port adaptation could be implemented by the current NR specifications, but such implementation is not efficient.
	+ Observation 10: Some enhancements on physical layer procedures e.g., CSI framework and/or transmit power signaling might be introduced to make dynamic antenna port adaptation more efficient.
	+ Observation 11: Dynamic antenna port adaptation at gNB provides 42% or higher network energy savings and 33% or higher network energy efficiency depending on gNB antenna configuration for the simulated traffic model.
	+ Observation 12: However, dynamic antenna port adaptation at gNB reduces UPT by 13.2% or higher and reduce coverage by 1dB or higher depending on gNB antenna configuration for the simulated traffic model.
	+ Proposal 8: Capture in TR the following description for dynamic gNB antenna port adaptation
		- Dynamic gNB antenna port adaptation is a technique that allows the gNB to dynamically turn on/off some transmission/reception chains.
		- Specification impact may include enhancing physical layer procedures (e.g., CSI and/or downlink transmission power signaling framework) to efficiently support dynamic antenna port adaptation.
	+ Observation 11: Dynamic TRP dormancy might be implemented by the current NR specifications, but such implementation is not efficient.
	+ Observation 12: Some TRP dormancy enhancements e.g., UE group specific TRP dormancy indication to make dynamic TRP dormancy more efficient.
	+ Observation 13: Dynamic switching between multi-TRP and single TRP can provide up to 15% network energy savings at the expense of 4% UPT reduction.
	+ Proposal 9: Capture in TR the following description for dynamic TRP adaptation
		- Dynamic TRP adaptation is a technique that allows the gNB to dynamically turn on/off one of TRPs.
		- Specification impact may include dynamic TRP indication from gNB to one or a group of UEs.
* [25] Apple
	+ Proposal 5: For spatial domain adaptation, consider the following enhancements to support dynamic change in the number of beams and/or antenna ports
		- Indication signaling for changing the number of beams/antenna ports and the corresponding UE behavior
		- Multiple CSI report configurations corresponding to different number of antenna ports
* [26] NTT Docomo
	+ Proposal 5: For CSI measurement and reporting, two indication options can be considered for dynamic adaptation of gNB antenna port. Option 2 achieves smaller indication latency and payload size than Option 1.
		- Option 1: Indication of the RE/ports switch on/off status.
		- Option 2: RE/ports switch on/off status is transparent to UE. gNB just indicates the effective CSI reporting configuration.
* [27] Ericsson
	+ Observations:
		- A need for increasing number of transceiver chains is foreseen in gNBs in the future, especially at higher frequencies.
		- For efficient beam management, increased number of transceiver chains results in a higher number of energy consuming components and reference signal transmissions.
		- Higher number of antennas results in a high energy consumption even in low to medium load scenarios.
		- Using few antennas for data transmission, while maintaining some reference signals transmission in the background on more antennas still brings major energy savings.
		- Excessive CSI reporting/polling for turning on/off transceiver chains is quite energy consuming both for the UE and for the network.
		- Changes in gNB port to antenna mapping may require reference signal reconfiguration.
		- Reference signal reconfigurations via RRC is slow and leads to excessive energy consumption.
	+ Proposals:
		- Study and identify light-weight techniques, preferably DCI/MAC-CE-based, that allow fast CSI-RS reconfigurations.
		- Study and identify techniques including conditions/criteria for UE measurements and feedback to gNB for (de)activation of CSI-RS ports.
		- Study the techniques that can allow UE to feedback antenna muting pattern recommendations to the gNB.
* [28] ITRI
	+ Proposal 3: The following aspects for the adaptation of number of spatial elements of the gNB can be considered:
		- Dynamic adaptation of the number of antenna ports according to the energy saving state(s) or sleep mode(s)
		- Dynamic adaptation of the number of antenna elements according to the energy saving state(s) or sleep mode(s)

### Summary of Discussions

Given that RAN1 only has 2 meeting left for completion of the SI (including this meeting), moderator suggests trying to formulate texts that could be potentially captured into the TR.

Proposal #4-1 is a very rough draft that will likely need several updates. Moderator suggests focusing the initial discussion in high level outline of the techniques, including addition or removal of the spatial domain techniques. Once a high-level outline is available, work further on providing further details, which may include potential specification impact list, potential use case and deployment scenarios, and others.

#### Proposal #4-1

* The following text are used as baseline for further discussion, with the intent to be captured into the SI TR. Note, the technique numeration is only for identification of the techniques for discussion purposes.
* Technique #C-1: Dynamic adaptation of spatial elements
	+ gNB may conserve energy by reducing the number of active transceiver chains or spatial elements.
	+ Adaptation can be further categorized into two types:
		- Type 1: enable/disable all spatial elements associated to a logical antenna port, e.g. a subset of ports of a CSI-RS resource, specific SSB with a specific SSB index.
		- Type 2: enable/disable of part of spatial elements associated to a logical antenna port(s). This may result in changes to the antenna pattern, gains, and/or transmission power of the reference signal or channel that uses the antenna port(s).
	+ Reduction of usage of spatial elements in specific scenarios and situations may enable minimal network impact while facilitating lower energy consumption.
	+ [Editors note: further details of the technique, including potential enhancements, specification impact is needed]

## 2.5 Power-domain based Energy Saving Techniques

* [1] Huawei/HiSilicon
	+ Observation 9: Considerable power saving gain with small performance loss can be achieved by dynamic PSD back-off with multiple CSIs for different PSD back-off ratios.
	+ Observation 10: UE assisted power enhancement mechanisms, e.g. OTA DPD and DPoD, cause significant UE hardware impact, and require RAN4 expertise for further study.
	+ Proposal 4: Evaluate dynamic DL transmission power backoff from BS with one CSI report with multiple CSI results (e.g. 4), corresponding to multiple power offsets between PDSCH and CSI-RS
		- Power allocation configurations of SSB/CSI-RS is assumed to be unchanged.
* [4] vivo
	+ Observation 5: Dynamic or semi-static downlink power control for DL transmissions can be achieved by BS implementation without spec impact.
	+ Observation 6: PA efficiency enhancement at BS side (e.g., ET and DPD) can be achieved by BS implementation without spec impact.
	+ Proposal 6: Whether to study UE-assisted BS PA efficiency enhancement scheme should consider power saving gain compared to implementation-based scheme (ET and DPD) and the cost of UE complexity.
* [5] Nokia/NSB
	+ Proposal-18: Considering enhancing the configuration of the power offset between PDSCH and NZP CSI-RS to assist NW energy saving operation.
	+ Proposal-19: To minimize the impact on MIMO performance, the CSI report from UE can be extended to assist the network for adjustment of the transmission power and/or bandwidth assignment.
	+ Observation-13: The role of UE feedback and possible RAN1 relevance for the adaptation of digital pre-distortion by the gNB, use of digital post-distortion by the UE and adaptation of transceiver filtering operation requires further clarification.
	+ Observation-14: The use of tone reservation together with DFT-s-OFDM in uplink might enable lower PAPR, however the complexity of using tone reservation on top of CP-OFDM in downlink requires further study.
* [6] Panasonic
	+ Proposal 4: gNB power domain adaptation for energy saving can possible be controlled by the frequency domain adaptation. The adaptation of Tx power of different channels that impacts coverage may possibly work without specification impact so can be down prioritized. PA efficiency related discussion may involve RAN4 expertise, if necessary.
* [10] CATT
	+ Observation 12: In case of support of low transmission power, static power consumption of PA/RF and low PA efficiency could degrade network energy saving gain significantly.
	+ Observation 13: Compared with RF chains ON/OFF adaptation in spatial domain, dynamic adjustment of gNB’s transmission power has limited energy saving gain.
	+ Proposal 19: The power scaling of the DL Tx power variation in NES power model should be determined for identifying the NES technique in power domain.
	+ Observation 14: Digital pre-distortion technique could increase the PSD of DL link and the DL coverage but provide limited impact in gNB power consumption.
* [14] Interdigital
	+ Dynamic adaptation of transmission power
		- Network energy savings could be obtained by reducing the transmission power of the gNB for PDSCH during periods of low activity. Such change requires adaptation of corresponding semi-statically configured power offsets for NZP CSI-RS reference signals assigned to UEs for CSI reporting. The following enhancements enabling dynamic adaptation of power offset are considered:
		- Support for CSI reporting:
			* Indication of a group identity for each configured NZP CSI-RS reference signal;
			* Indication of a change of power offset for each configured NZP CSI-RS reference signal and each possible energy saving state;
			* Dynamic indication of a group identity and applicable energy saving state.
	+ 6.z.y Support for digital pre-distortion and post-distortion
		- Network energy savings could be obtained by increasing power amplifier efficiency of gNB while utilizing digital pre-distortion at the transmitter.
		- To assist the gNB in compensating for the increased non-linear response of the power amplifier as the power efficiency is improved, the following enhancements are considered:
			* Definition of a measurement for assessing non-linearity characteristics of transmitter;
			* Definition of reference signal or resource for non-linearity measurement;
			* Measurement configuration and reporting for non-linearity measurement.
		- To assist the UE in compensating for the increased distortion of the received signal, the following enhancements are considered:
			* Definition of a reference signal for assisting UE in calculating post-distortion settings applicable to a certain power efficiency state of the transmitter;
			* Indication of a power efficiency state associated to the transmission of the assisting reference signal;
			* Indication of a power efficiency state associated to other transmissions, enabling UE to apply post-distortion setting calculated based on the assisting reference signal with same power efficiency state.
* [17] CMCC
	+ Proposal 17: Adaptation of SSB transmission power should be carefully evaluated to maintain the cell coverage.
	+ Proposal 18: Dynamically indication the value of powerControlOffsetSS can be applied for the adaptation of CSI-RS transmission power.
	+ Observation 6: The EPRE of PDCCH and PDSCH depends on the gNB implementation algorithm.
	+ Proposal 19: Dynamically indication of PDCCH and PDSCH transmission power is not needed.
	+ Proposal 20: CSI reporting enhancement can be considered for gNB to adjust DL transmission power.
* [19] Mediatek
	+ Dynamic TX adaptation may impact open loop power control and CQI report, where the power of SSS, CSI-RS, and PDSCH are provided in a semi-static manner.
	+ Consider UE-group BWP switch to support dynamic TX power adaptation for open loop UL power control and CQI report.
	+ For PAPR enhancement, using 1024 QAM than 64 QAM can save 6.3% BS power for video traffic with RU = 30%. The gain comes from additional sleep opportunities due to shorter active time.
	+ Interested companies may contribute methodology to evaluate PAPR enhancement techniques rather than shortening BS transmission time.
* [20] LGE
	+ Proposal #11: Investigate impacts of power adaptation for SSB and/or NZP CSI-RS if transmit power for SSB and/or NZP CSI-RS can be dynamically changed.
* [21] ZTE/Sanechips
	+ Observation:
		- Fixed DL transmission power cannot adapt to requirements of NW power saving, UE power saving and interference management.
		- Dynamic power adjustment can help UE and gNB power saving and keeps performance impact under control.
		- Power reduction with 3dB can obtain 4.6%~13.6% power saving gain in the case of RU=4.9%~38%.
	+ Proposal:
		- More dynamic DL power allocation and information reported by UE can be considered for NW ES in power domain.
		- Dynamic DL power control for reference signal can be considered for NW ES in power domain.
* [22] CeWIT
	+ Proposal 9: Dynamically adapting the DL transmission power at gNB in specific set of frequency and time resources utilizing assistance information from the UE is supported.
* [24] Qualcomm
	+ Observation 14: Dynamic transmit power adaptation could help gNB dynamically adapt PA operation for achieving network energy savings.
	+ Observation 15: Dynamic transmit power adaptation at gNB provides 17% or higher network energy savings and 33% or higher network energy efficiency depending on maximum transmit power configuration for the simulated traffic model.
	+ Observation 16: Dynamic transmit power adaptation at gNB reduces UPT by 8.9% or higher depending on maximum transmit power configuration and could have smaller impact to coverage than antenna port adaptation for the simulated traffic model.
	+ Proposal 10: Capture in TR the following description for dynamic downlink transmission power adaptation
		- Dynamic downlink transmission power adaptation is a technique that allows the gNB to dynamically adjust the transmit power of one or multiple downlink signals/channels.
		- Specification impact may include enhancing physical layer procedures (e.g., CSI and/or downlink transmission power signalling framework) to efficiently support dynamic downlink transmission power adaptation.
	+ Observation 17: OTA DPD increases the EVM at the transmitter by 2.5dB to 6dB based on the PA transmission power, increasing bits/Joule (one of the KPIs reducing network power consumption as explained at the beginning of this section).
	+ Proposal 11: Study the over the air training digital pre distortions method (OTA DPD) for DPD at the gNB’s transmission chain.
	+ Observation 18: DPoD increases the EVM at the transmitter by between 3dB and 8dB based on the PA transmission power and received SNR, increasing bits/Joule (one of the KPIs reducing network power consumption as explained at the beginning of this section).
	+ Observation 19: DPoD increases the throughput between 10% and 25% in most received SNRs (using higher MCSs). This throughput increase is reflected in higher bits/Joule (one of the KPIs reducing network power consumption).
	+ Proposal 12: Study DPoD (Digital post distortion) for increasing efficiency at the gNB’s transmitter.
	+ Observation 20: Channel aware TR technique provides gain between 1dB and 3dB over no TR waveform in SNRs between -5 and 25 dBs, varying on the received SNR.
	+ Proposal 13: study Channel Aware Tone Reservation technique that allows reduction of PAPR of the DL, using dynamic selection of subcarriers and method to notify the UEs.
	+ Proposal 14: Capture in TR the following description for gNB transceiver algorithms and processes to improve PAPR and power efficiency:
		- Power back off relaxation in low loaded scenarios is the technique allowing the BS PA to increase its efficiency. Minimizing the impact of PA backoff adaptation onto UEs in the cell and in neighbor cells is achieved via BS coordination.
* [26] NTT Docomo
	+ Proposal 6: For dynamic power adaptation on RS (such as SSB and CSI-RS) and channels (such as PDSCH), it is better to take down-selection for further investigation. Several key KPIs should be considered for this down-selection work.
		- Specification impact
		- Power saving effect
		- Cell discovery performance
* [27] Ericsson
	+ Observations:
		- Lowering the gNB output power for UEs in good coverage may have very limited impact on throughput.
		- UEs need to be aware of PDSCH power offset changes in relation to reference signals, otherwise the CSI reports and UE internal receiver settings may become invalid.
		- PDSCH power offsets to reference signals (CSI-RS) is configured via RRC signalling.
	+ Proposals:
		- Study and identify techniques where power offset(s) between PDSCH and CSI-RS can be dynamically adapted for CSI-RS.
* [28] ITRI
	+ Proposal 4: The following aspects for adaptation of transmission power by the gNB can be considered:
		- Dynamic adaptation of transmission power according to the energy saving state(s) or sleep mode(s)
* [29] KT
	+ Observation 1: With the support of efficient dynamic adjustment of transmission power, some proper scheduler including power adjustment can achieve energy saving by lowering MCS indices and transmission power adopting higher bandwidth consumption.
	+ Proposal 1: Study the PDSCH to apply the dynamic adjustment of transmission power in aspect of MCS adjustments.
	+ Proposal 2: Study the evaluation of efficiency of power amplifier and/or total power consumption of RU module along the transmission power adjustment.
	+ Proposal 3: Study the necessity of notification to UEs about the information of transmission power adjustment.

### Summary of Discussions

Given that RAN1 only has 2 meeting left for completion of the SI (including this meeting), moderator suggests trying to formulate texts that could be potentially captured into the TR.

Proposal #5-1 is a very rough draft that will likely need several updates. Moderator suggests focusing the initial discussion in high level outline of the techniques, including addition or removal of the power domain techniques. Once a high-level outline is available, work further on providing further details, which may include potential specification impact list, potential use case and deployment scenarios, and others.

#### Proposal #5-1

* The following text are used as baseline for further discussion, with the intent to be captured into the SI TR. Note, the technique numeration is only for identification of the techniques for discussion purposes.
* Technique #D-1: Adaptation of transmission power of signals and channels
	+ Network energy savings could be potentially obtained by reducing the transmission power of various signals and channels, e.g CSI-RS, PDSCH, during specific scenarios or situations.
	+ [Editors Note: further details of potential enhancements, specification impact is needed]
* Technique #D-2: enhancements to gNB digital pre-distortion and UE post-distortion
	+ Transmission energy efficiency at the network can be potentially improved with use of enhanced digital pre-distortion at the gNB and/or post-distortion at the UE.
	+ [Editors Note: further details of potential enhancements, specification impact is needed]
* Technique #D-3: adaptation of transceiver processing algorithm
	+ gNB may opt to use different transceiver processing algorithms, including some that may favor lower power consumption at the expense of degraded system performance.
	+ Use of the different transceiver processing algorithms at the gNB may be transparent to the UE.
	+ [Editors Note: further details of potential enhancements, specification impact (if any) is needed]

## 2.6 Other Energy Saving Aspects/Techniques

* [12] Intel
	+ Proposal 5:
		- Capture adaptation of signal processing flow or algorithms to improve network power consumption at the potential sacrifice of RF and/or throughput performances as one of the potential solutions to network energy saving.
		- Further study on whether there is any associated specification impact with adaptation of signal processing flow or algorithms.
		- Further study the potential power consumption benefits from adaptation of signal processing flow or algorithms.
	+ Observation 3: Current 5G application protocol supports identification of various QoS parameters for a session flow which can be mapped to radio bearer. Some of the QoS parameters that can be potentially provided with the flow are Guaranteed Flow Bit Rate (GFBR), Maximum Flow Bit Rate (MFBR), maximum packet loss rate, delay critical resource type information, priority level, packet delay budget, packet error rate, maximum data burst volume, etc.
	+ Proposal 6: Further study QoS related parameters that could be useful for network to perform power saving, including existing 5G application protocol QoS parameters.
* [16] Samsung
	+ Proposal 1:
		- Support at least the following three network states for the study of network energy saving:
			* Non-energy-saving state: the gNB operates in a legacy way and no network energy saving technic is used;
			* Energy-saving state 1: the gNB doesn’t transmit/receive any signal/channel;
			* Energy-saving state 2: the gNB only transmits/receives a particular set of signal/channel and/or gNB applies bandwidth/PSD/TXRU adaptation for channel transmission/reception;
		- The study shall further investigate the UE behavior in each of the network states.
	+ Proposal 19: Study UE assistance information for SSB request during network energy saving state.
	+ Observation 5: UE assistance signaling for indicating an SR/CG PUSCH transmission is beneficial for network power consumption.
	+ Proposal 20: Study UE assistance information for indicating an SR/CG PUSCH transmission during network energy saving state.
	+ Proposal 21: MAC layer decides whether to trigger the transmission of gNB wake up request/UE assistance information.
* [18] Fraunhofer IIS/Fraunhofer HHI
	+ Observation 4: In order to achieve optimized network configuration in the desired finer granularity of adaptations, new mechanisms to gather traffic and mobility information may be needed.
	+ Proposal 3: UE Assistance information helping network energy saving should be studied and identified.
* [21] ZTE/Sanechips
	+ Observation: UE assistance information can help network to better acquire UE’s requirements, so that the energy saving techniques can be adjusted more accurately to reduce the impact on user experience and assist network energy saving.
	+ Proposal: The UE assistance information can be considered for network energy saving.
* [23] Rakuten Mobile
	+ Proposal 5: Energy saving state of the gNB should is indicated to the UE.
* [28] ITRI
	+ Proposal 1: The energy saving state(s) or sleep mode(s) may be defined for network energy saving.

### Summary of Discussions

Given that RAN1 only has 2 meeting left for completion of the SI (including this meeting), moderator suggests trying to formulate texts that could be potentially captured into the TR.

Proposal #6-1 is a very rough draft that will likely need several updates. Moderator suggests focusing the initial discussion in high level outline of the techniques, including addition or removal of the other techniques not explicitly covered by time/frequency/spatial/power domain techniques. Once a high-level outline is available, work further on providing further details, which may include potential specification impact list, potential use case and deployment scenarios, and others.

#### Proposal #6-1

* The following text are used as baseline for further discussion, with the intent to be captured into the SI TR. Note, the technique numeration is only for identification of the techniques for discussion purposes.
* Technique #E-1: UE assistance information to further facilitate gNB network energy saving
	+ TBD
	+ [Editor note: further details of UE assistance information needed]

# Reference

1. R1-2205756, “Enhancements for network energy saving,” FUTUREWEI
2. R1-2205861, “Discussion on network energy saving techniques,” Huawei, HiSilicon
3. R1-2206000, “Discussion on network energy saving techniques,” Spreadtrum Communications
4. R1-2206054, “Discussions on network energy saving techniques,” vivo
5. R1-2206075, “Network energy saving techniques,” Nokia, Nokia Shanghai Bell
6. R1-2206142, “Discussion on potential network energy saving techniques,” Panasonic
7. R1-2206173, “Discussion on Network energy saving techniques,” Fujitsu
8. R1-2206242, “Discussion on network energy saving techniques,” NEC
9. R1-2206309, “Discussion on network energy saving techniques,” OPPO
10. R1-2206412, “Network Energy Saving techniques in time, frequency, and spatial domain,” CATT
11. R1-2206517, “Network energy saving techniques,” Lenovo
12. R1-2206596, “Discussion on Network energy saving techniques,” Intel Corporation
13. R1-2206655, “Discussions on techniques for network energy saving,” Xiaomi
14. R1-2206666, “Potential techniques for network energy saving,” InterDigital, Inc.
15. R1-2206697, “Discussion on potential techniques for network energy saving,” China Telecom
16. R1-2206839, “Network energy saving techniques,” Samsung
17. R1-2206926, “Discussion on network energy saving techniques,” CMCC
18. R1-2206947, “On Network Energy Saving Techniques,” Fraunhofer IIS, Fraunhofer HHI
19. R1-2206980, “Network energy saving techniques,” MediaTek Inc.
20. R1-2207038, “Discussion on physical layer techniques for network energy savings,” LG Electronics
21. R1-2207060, “Discussion on NW energy saving techniques,” ZTE, Sanechips
22. R1-2207074, “Discussion on Network energy saving techniques,” CEWiT
23. R1-2207119, “Discussion on network energy saving techniques,” Rakuten Mobile, Inc
24. R1-2207246, “Network energy saving techniques,” Qualcomm Incorporated
25. R1-2207344, “Discussion on Network energy saving techniques,” Apple
26. R1-2207419, “Discussion on NW energy saving techniques,” NTT DOCOMO, INC.
27. R1-2207438, “Network energy savings techniques,” Ericsson
28. R1-2207446, “Discussion on potential L1 network energy saving techniques for NR,” ITRI
29. R1-2207481, “Discussion on network energy saving techniques,” KT Corp.