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Study on User Equipment (UE) power saving in NR
(Release 16)

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Foreword

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1 Scope

The present document captures the findings of the study item, "Study on UE Power Saving in NR" [2]. The purpose of this TR is to study the UE power saving framework taking into consideration of latency and performance in NR as well as network impact. The study of UE power saving in NR includes the study of the power saving schemes and the associated procedures. The power saving schemes are to study the UE adaptation to the traffic and UE power consumption characteristics in frequency, time, antenna domains, DRX configuration, and UE processing timeline for UE power saving. The power saving signal/channel/procedure is used for triggering adaptation of UE power consumption characteristic. The power saving study also considers UE power consumption reduction in RRM measurements. The associated procedures for the power saving schemes include the enhancement of UE paging procedure based on the additional power saving signal/channel/procedure and the UE power saving procedure in supporting efficient transition from RRC_CONNECTED to RRC_IDLE/RRC_INACTIVE mode.

This document is a 'living' document, i.e. it is permanently updated and presented to TSG-RAN meetings.

2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905 Vocabulary for 3GPP Specifications

[2] 3GPP RP-181463 New SID: Study on UE Power Saving in NR

[3] 3GPP TR 38.913 Study on Scenarios and Requirements for Next Generation Access Technologies

[4] 3GPP TR 38.802 Study on New Radio Access Technology - Physical Layer Aspects

[5] 3GPP TS 38.814 Physical layer procedures for data

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3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

3.2 Symbols

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

<symbol> <Explanation>

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

PDCCH Physical Dedicated Control CHannel

4 Introduction

UE battery life is an important aspect of the user's experience, which will influence the adoption of 5G NR handsets and/or services. It is critical to study UE power consumption to ensure that UE power efficiency for 5G NR UEs can be better than that of LTE, and techniques and designs for improvements are identified and adopted.

ITU-R defines energy efficiency as one of the minimum technical performance requirements for IMT-2020. According to ITU-R report – Minimum requirements related to technical performance for IMT-2020 radio interface(s), "energy efficiency of the device can relate to the support for the following two aspects: a) Efficient data transmission in a loaded case; b) Low energy consumption when there is no data. Efficient data transmission in a loaded case is demonstrated by the average spectral efficiency. Low energy consumption when there is no data can be estimated by the sleep ratio".

Because NR system supports high speed data transport, the bursty user data would be served by network in very short durations. One efficient UE power saving mechanism is to trigger UE for network access from power efficient mode. UE would stay in the power efficient mode, such as micro sleep or OFF period in the long DRX cycle, unless it is informed of network access through UE power saving framework. Alternatively, network can assist the UE to switch from the "network access" mode to the "power efficient" mode when there is no traffic to deliver, e.g. dynamic UE transition to sleep with network assistance signal.

In addition to minimizing the power consumption with the new wake up/go-to-sleep mechanism, it is equally importance to reduce the power consumption during the network access in RRC_CONNECTED mode. More than half of the power consumption in LTE is UE in the access mode. The power saving scheme would focus on minimizing the dominate factor of power consumption during the network access, which includes the processing of aggregated bandwidth, number of active RF chains and active reception/transmission time, and dynamic transition to power efficient mode. From the field data collected in the LTE network, most of subframes contain no data or small data. The power saving scheme for the dynamic adaptation to the different data arrival should be studied in RRC_CONNECTED mode. Dynamic adaptation to traffic in different dimensions, such as carrier, antenna, beamforming, and bandwidth, would be studied in the studied. Furthermore, methods to enhance the transitions between "network access" mode and power efficient mode should be considered. Both network-assisted and UE-assisted approaches should be considered for UE power saving mechanism.

UE also consumes a lot of power for RRM measurements. In particular, UE would need to power up before the DRX ON period to track the channel in preparation for the RRM measurement. Some of the RRM measurements are not necessary but consumes a lot of UE power, for example, the low mobility UEs does not have to measure as frequent as high mobility UEs. Network would provide the signalling to assist UE to reduce the power consumption on unnecessary RRM measurements. Additional UE assistance, for example the UE status information, etc, is also useful for the network to enable the UE power consumption reduction on RRM measurements.

The study of UE power saving is to identify the feasibility and benefit of techniques to allow UE implementations which can operate with reduced power consumption. The study of the UE power saving framework would also take into consideration of latency and performance in NR as well as network impact.

5 UE power saving schemes

5.1 UE adaptation to the traffic and power consumption characteristic

5.1.1 Adaptation to the variation in frequency

The UE BWP adaptation is to dynamically switch the BWP by gNB based on, e.g., the traffic to support efficient operation of BWP switching in reducing the UE power consumption.

The UE adaptation to the CA/DC is to fast activation/deactivation of the SCell by gNB based on, e.g., the traffic to support efficient operation for fast SCell activation/deactivation in achieving UE power saving.

The UE power saving schemes for the UE adaptation in frequency domain in the study are as follows,

- BWP - UE adaptation to different BWP
  - RS to assist UE channel tracking and measurements to assist BWP switching
    - The assistance may also include CSI measurements (UE supports and processes one BWP at a time)
  - Enhancement of L1 signaling, e.g., power saving signal or DCI for power saving, in triggering the BWP switching
  - Association of BWP and DRX
  - UE assistance information could be considered

Table 1: Power saving schemes with UE adaptation to the BWP switching

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
MediaTek [18][40][59]	Rel-15 DCI and timer based BWP switching with A-CSI after switching to a larger-BW BWP	23.5% ~ 31.4%	FTP/Video: 23.54% IM: 24.79% VoIP: 31.42%	Latency Increase: FTP/Video: 3.98% IM: 1.91% VoIP: -0.07%	RU increase: FTP/Video: -0.55% IM: 1.29% VoIP: 0%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	A large-BW BWP of 100 MHz, a small-BW BWP of 20 MHz and a 20-ms BWP timer are assumed for IM and FTP/Video. For VoIP, small-BW BWP of 20 MHz is always applied.
vivo [58]	Adaptation in frequency domain (UE reports its preferred BWP), evaluated for gaming application	9% ~ 45%	30% for CDRX	Average packet latency: 16.83ms; Latency increase: 0%	Marginal	Numerical simulation Baseline assumption: The BWP is always 100MHz; Traffic model: gaming CDRX config: (40, 10,4)	
			45% for Fixed PDCCH monitoring periodicity (0.5ms)	Average packet latency: 0.5ms; Latency increase: 0%			
			9% for Fixed PDCCH monitoring periodicity (40ms)	Average packet latency: 20.30ms; Latency increase: 0%			
CATT[21][60]	Power saving signal trigger BWP adaption with the additional RS (PS- RS)	25.2% ~ 55.0% (8.5% ~ 26% for Rel-15 narrow vs	ftp3 with 160ms DRX-cycle: 25.2% IM with 320ms DRX-cycle:55.0%	Avg. UPT loss 17.1% (FTP3 λ=3.2)	7.14%, 14.29%, 21.4%. .	SLS with 10UE per TRP for DU scenario to get transmission rate, and observed one single UE for power consumption.	

		full BW switching)	ftp3 with 160ms DRX-cycle (Rel-15 narrow vs full BW BWP switching): 8.5% IM with 320ms DRX-cycle (Rel-15 narrow vs full BW BWP switching): 26%			Baseline: PDCCH monitoring, CSI and PDSCH reception on wider BW, FTP3 with 0.5Mbytes packet size and 200ms inter-arrival time, IM with 0.1Mbytes packet size and 2s inter-arrival time	
Apple [68][84]	1) When UE knows total size of file to download / upload, it can estimate power efficient BWP sizes. 2) UE can indicate its preferred BWP configuration to gNB. 3) gNB configure UE with the BWPs which was determined based on UE's recommendation. 4) File transfer occurs with the configured BWPs.	33 ~ 45%	0dBm case 0.1MB : 68% 0.5MB : 64% 2M : 46% 4M : 34% 23dBm case 0.1MB : 51% 0.5MB : 33% 2MB : 61% 4MB : 53%			Evaluation Method = Numerical Simulation, UE continuously monitors PDCCH, No CDRX assumed. No GTS assumed. 4Mbps for 0.1MB file 20Mbps for 0.5MB file	Power saving gain in each file size is computed against the bandwidth consuming highest power in each file size.
Apple [68][84]	1) When UE knows the total size of file to download / upload, it can estimate power efficient BWP sizes. 2) UE can indicate its preferred BWP configuration to gNB. 3) gNB configure UE with the BWPs which was determined based on UE's recommendation. 4) File transfer occurs with the configured BWPs. 5) BWP switching and DRX operation are enabled.	16 %	16%			Evaluation Method = Numerical Simulation UE continuously monitors PDCCH, CDRX (160, 100, 8) ms assumed. No GTS assumed FTP3(0.5MB, 0.2s) 20Mbps	Power saving gain in each file size is computed against the bandwidth consuming highest power.

Observation:

Rel-15 DCI and timer based BWP adaptation between full bandwidth and a narrow bandwidth can achieve power saving gain in the range 8.5% - 31%. The power saving schemes with UE adaptation to BWP bandwidth show 16% - 45% power saving gain if suitable BWP bandwidth is applied. The power saving schemes with UE adaptation to BWP switching show the power saving gains ranged from 8.5% - 45% from the Rel-15 BWP operation without adaptation. The higher power saving gain of 45% comes from suitable BWP adaptation, e.g., selection of BWP based on UE assistance information. Smaller power saving of 8.5% is provided from one source, assuming 15-ms CSI acquisition delay for the DCI triggering BWP adaptation. The average latency increase of the power saving schemes is up to 4%. One source showed that the power saving signal triggering BWP switching with additional RS for CSI measurements shows 17%-29% power saving gains in relation to Rel-15 BWP adaptation with UPT improvement of 17% and 7-21% overhead.

- CA/DC –
    - Quick activation/de-activation (e.g.,L1 signaling, MAC CE enhancement)
    - Adaptation of PDCCH monitoring/search space on activated SCell
        - Including cross carrier scheduling
    - Adaptation based on the operation in a group of cells in power efficient way
        - Including group of cells in bundle operation
    - CSI/RRM measurements and beam management at non-active SCell
    - UE assistance information could be considered

- Including the combined operation with the BWP switching

Table 2: Power saving schemes for SCell operation

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
MediaTek [18][40][59]	BWP-based SCell power saving and bundled BWP switching	Total Saving: 21.1% ~ 27.7% SCell saving: 51.18% ~ 67.33%	Total saving: FTP/Video: 21.1% IM: 27.7% SCell saving: FTP/Video: 51.18% IM: 67.33%	Latency increase: FTP/Video: -0.675% IM: 1.60%	RU increase: FTP/Video: -1.23% IM: 0%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10)	1. Background traffic of packet size 256 bits and mean arrival time 200 ms is added to the traffic models. 2. The SCell BWP transition follows the BWP transition of PCell.
Huawei [57]	Triggering SCell(s) PDCCH monitoring by starting of InactivityTimer on PCell	3.91% ~ 24.16%	3.91% ~ 13.76% for (Packet size / arrival rate) =(0.5/200) 19.13% ~ 24.16% for (Packet size / arrival rate) =(0.1/2000)	0.71~2.5%	none	SLS CDRX config: (160, 100, 8), (160, 40, 8), (40, 25, 4), (40, 10, 4) Packet size / arrival rate (Mbytes / ms): 0.5/200, 0.1/2000	Single UE in a cell. 4 activated CCs. A scaling factor of 0.2 is assumed for each activated SCell without PDCCH monitoring. Latency increasing results are obtained by system analysis.
		1.82% ~ 12.23%	1.82% ~ 5.40% for (Packet size / arrival rate) =(0.5/200) 7.67% ~ 12.23% for (Packet size / arrival rate) =(0.1/2000)	0.86~2.89 %	none	Same as first case	2 activated CCs. Other assumptions are same as first case
		2.73% ~ 16.11%	2.73% ~ 9.79% for (Packet size / arrival rate) =(0.5/200) 12.36% ~ 16.11% for (Packet size / arrival rate) =(0.1/2000)	0.09%~2.62%	none	Same as first case	10 UEs in a cell. Other assumptions are same as first case
Samsung [34][64]	(De)activation of SCell	57.75% 38.7%	Activated CCs adapted from 4 to 1. Activated CCs adapted from 4 to 2.	838.6Mbps /1.04ms, 867Mbps/1.0ms	DCI based power saving signal with monitoring, T = 1024ms	Numerical simulation No C-DRX, FTP3 traffic model with mean of inter packet arrivals = 4ms	Single UE. One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits. Cross-carrier scheduling Minimum scheduling delay = 0.5ms. (also assumed for activation/deactivation)
Apple [68][84]	1) In cases UE is aware of total size of file (e.g., video, app) to upload or download, UE can advise gNB how many Scells it needs or when to activate / deactivate SCells. 2) UE sends SCell deactivation request to network when file downloading is finished. 3a) Without DRX, following the deactivation, gNB can immediately move to RRC INACTIVE or IDLE state. 3b) With CDRX case, UE enters CDRX mode.	5% ~ 43%	43% for 1MB file with No CDRX 7% for 5MB file with No CDRX 17% for 1MB file with CDRX 5% for 5MB file with CDRX			Evaluation Method = Numerical Simulation Baseline configuration with 2 CC, 1 HARQ process, gNB deactivates SCells after SCell deactivation timer value of 320ms expires. CDRX = (320, 200, 10) ms	Note that both baseline and proposed schemes have no impact on user throughput since the SCell deactivation kicks in after file downloading is finished.

Qualcomm [48][70]	SCell Dormancy (e.g. based on dormant BWP, or semi-persistent search space config)	32%	#1) 33.6% #2) 32.7% 1-slot PDCCH periodicity results shown. Other settings available in tdoc.	Average latency increase #1) 0.38% #2) 0.73%	Signalling overhead due to transition commands	Method: SLS FR2. DL-only, No CDRX Traffic model: FTP3 Max 4CC Transition delay assumptions: #1) Transition Delay=1 slot (ideal assumption) #2) Transition Delay=6 slots (realistic assumption)	- Gain in average power consumption. - Baseline latency: 20.3ms - Additional latency is due to transition delay - Traffic scales with number of carriers - 10 UEs in system

Observation:

The power saving schemes for SCell operation show 12% - 57.75% power saving gain if the baseline settings exhibit a large amount of PDCCH monitoring without data scheduling due to sporadic traffic or long data inactivity in SCell(s). Smaller power saving gain in the range of 2%-7% is observed for the case of less PDCCH monitoring without data scheduling in SCell(s). The average latency increase is in the range of 0.1% - 2.6%. One source reports that the corresponding additional overhead in terms of DL resource usage is negligible.

5.1.2 Adaptation to the variation in time

The UE power saving schemes with UE adaptation to the traffic arrival in the time domain includes cross slot scheduling, single slot scheduling with a gap between PDCCH and PDSCH reception, and multi-slot scheduling. For both cross-slot scheduling and single slot scheduling, the UE may achieve power consumption by switching to micro sleep after PDCCH reception. For multi-slot scheduling, the UE may achieve power consumption by skipping the PDCCH monitoring at subsequent slots of PDSCH/PUSCH transmission.

- Cross-slot scheduling
  - Minimum K0 > 0 and aperiodic CSI-RS triggering offset is not within the duration - UE could switch to micro sleep after PDCCH reception – no addition PDSCH and CSI-RS signals reception within the given duration (e.g. the same slot)
    - It is known to the UE at PDCCH decoding
    - Extended micro sleep time and reduce the PDCCH processing in reducing UE power consumption
    - Minimum K2 > 0 is essential to avoid the requirements of fast PDCCH processing
    - UE assistance information can be considered
  - The general procedure for the study of the power saving scheme when cross-slot scheduling is used
    - gNB semi-statically configures TDRA to the UE, subject to UE capability (if any)
    - All schedulable TDRA values have K0 > = x and K2 >= x where x > 0
      - Determination of value x is FFS (which may also be done in the WI phase), e.g., may also be impacted by BWP switching triggered by DCI (jointly with cross-slot scheduling, if supported), etc.
    - All aperiodic CSI-RS triggering offsets are not smaller than the value x
    - UE decodes PDCCH and retrieves the index of schedulable TDRA values
    - UE could go to micro sleep after reception of last PDCCH symbol
    - UE processes PDSCH at the indicated starting time from TDRA values
    - Note: DRX cycle assumed in the evaluation results summarized in the table below is not necessary long DRX cycle; detailed DRX cycle assumption can be found in each reference
    - The following table is subject to further update, particularly regarding evaluation results/assumptions

Table 3: Power saving scheme with cross-slot scheduling

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Huawei [16][57]	Cross-slot scheduling	13.7% ~ 25.4%	Average power (28.1/24.3)~(40.9/30.6)	UPT loss: 13.4%~18.4% Latency increase: 0.84~3.2%	none	SLS CDRX config: (160, 100, 8), (160, 40, 8), (40, 25, 4), (40, 10, 4)	Single UE in a cell
		6.5% ~ 11.3%	(64.4/60.2)~(87.4/77.6)	UPT loss: 2.9%~5.2% Latency increase: 0.29%~0.46%	none	Same as first case	Multi-UE in a cell (10 UEs in average)
Vivo [58]	cross-slot scheduling	18%-29%	18%-25% for UE of 5 percentile SINR	Average packet Latency: 13.94- 58.36 ms; Latency increase: 1%-4%	Marginal	Numerical simulation Baseline assumption: non-UE preferred CDRX configuration; Traffic: ftp model 3	
			24%-28% for UE of 50 percentile SINR	Average packet Latency: 4.03- 47.80 ms; Latency increase: 1%-14%			
			25%-29% for UE of 95 percentile SINR	Average packet Latency: 3.01- 46.74 ms; Latency increase: 1%-20%			
Mediatek [59]	Cross-slot scheduling With positive values in K0, K2 and A-CSI offset	13.54% ~ 18.99%	FTP/Video: 18.99% IM: 17.26% VoIP: 13.54%	Latency Increase: FTP/Video: 0.84% IM: 0.34% VoIP: 3.72%	RU increase: FTP/Video: 0% IM: 0% VoIP: 0%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	K0, K2 and A-CSI offset > 0
CATT[21][60]	Cross-slot scheduling with K0 > 0 indicated to the UE in advance	1.1%~11.3%	ftp3 with 160ms DRX-cycle: 11.3% IM with 320ms DRX-cycle: 1.1%	--	0%	SLS with 10UE per TRP to get transmission rate, and observed one single UE for power consumption. Baseline: Cross-slot scheduling wo. micro-sleep, FTP3 with 0.5Mbytes and 200ms inter-arrival time, IM with 0.1Mbytes and 2s inter-arrival time	
ZTE [19][41][61]	Cross-slot scheduling with K0 =1 indicated to the UE in advance	24%~25%				Numerical simulation; DRX configuration (160-100-8) FTP3 traffic model with 0.1Mbytes and mean of inter packet arrivals = 200ms;	Peak throughput: 10-symbol PDSCH in one slot, 100MHz BWP. No UL. Single UE.
Samsung [34][64]	Cross-slot scheduling	21%	#1: 21% #2: 21% #3: 21%. #4: 21%	#1: 837Mbps/1.03ms #2: 565Mbps/1.53ms #3: 426.38Mbps/2.03ms #4: 342.36Mbps/2.53ms	DCI based power saving signal for triggering adaptation with monitoring, T = 1024ms	Numerical simulation No C-DRX, FTP3 traffic model with mean of inter packet arrivals = 4ms Minimum K0: Case #1: 0.5ms, Case #2: 1ms, Case #3: 1.5ms, Case #4: 2ms	Single UE, One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits.
Intel [65]	Cross-slot scheduling with K0=1	16.3% ~ 20.8%	16.34%	65.53 MBps / 85.42 ms		5% / FTP model 3 160, 100, 8	System level simulations 1%-4% UPT loss for FTP model 3 1.2-1.8% UPT loss for Instant Messaging 2.4% UPT loss for VoIP
			19.36%	84.6 MBps / 60.76 ms		50%	
			20.48%	88.11 MBps / 56.73 ms		95%	
			20.25%	5.65 MBps / 149.13 ms		5% / Instant Messaging 320, 80, 10	
			20.77%	5.73 MBps / 148.72 ms		50%	
			20.66%	5.73 MBps / 148.69 ms		95%	

			17.76%	0.0282 MBps	11.01 ms		5%	VoIP 40, 10, 4	
			17.72%	0.0279 MBps	11.03 ms		50%		
			17.44%	0.0282 MBps	11.02 ms		95%		
Interdigital [66]	Cross-slot scheduling with k0 = 1	13.1% ~ 22.4%	FTP: 20.1%, 16.2%, 13.1% IM: 18.5%, 18.0%, 22.4%				SLS Case 1(160, 100, 8), Case 2 (40, 25, 4), Case 3(40, 10, 4) Case 4(320, 80, 10) FTP (Case 1, 2, 3) IM (Case 2, 3, 4)		10 UEs per cell Average gain Higher gain observed for longer DRX cycle.
Apple [68][84]	1) UE can indicate its preferred K0, K1, K2 values to gNB before data transfer starts. 2) gNB can use those preferred K0, K1, K2 values for data scheduling.	5~41 %	5% for (K0,K1)=(8,8) 41% for (K0,K1)=(0,1)				Evaluation Method = Mathematical Analysis		
Apple [68][84]	1) gNB can configure UE's TDRA table with entries with enough gap between PDCCH and associated PDSCH. The gap (**in slot**) is long enough such that PDSCH transmission starts after the gap ends.	0~30%	0% for high load (grant is scheduled every slot). ~30% for very low load (grant is scheduled with very low probability)				Evaluation Method = Mathematical Analysis, It is assumed that arrived packet could be served with a single PDSCH.		TDRA based gap scheduling (cross slot scheduling only)
Ericsson [69]	Cross-slot scheduling comparing with minimum K0 > 0 K0 = 1 K0= 4 K0= 16	See next column	K0 = 1: 13%-21% K0 = 4: 9%-19% K0 = 16: 2%-15%	UPT loss: K0 = 1: 3%-5% K0 = 4: 10%-13% K0 = 16: 25%-30%			System-level simulation CDRX = (160, 100, 8) ms Traffic model is FTP3 with 180 kB packet size and 200 ms inter-arrival time is used. **48% RU**		
		See next column	K0 = 1: 16%-20% K0 = 4: 15%-17% K0 = 16: 6%-11%	UPT loss: K0 = 1: 0.3%-4% K0 = 4: 7%-12% K0 = 16: 20%-32%			System-level simulation CDRX = (160, 100, 8) ms Traffic model is FTP3 with 180 kB packet size and 200 ms inter-arrival time is used. **3% RU**		
Qualcomm [30][48][70]	Configuration of minimum DL scheduling offset that applies to K0 and A-CSI triggering offset	25.8% (for 1-slot PDCCH period)	For PDCCH period 1 slot: 25.8% 2 slots: 17.5% 4 slots: 11.0% 8 slots: 6.9%	Latency increase for PDCCH period 1 slot: 0.57% 2 slot: 0.80% 4 slot: 1.37% 8 slot: 2.50%		none	SLS **FR1** FTP3, no DRX		- Gain in average power consumption - Baseline latency: 87.6ms (PDCCH period 1 slot)
		27% (for 1-slot PDCCH period)	For PDCCH period 1 slot: 27.0% 2 slots: 20.9% 4 slots: 14.7% 8 slots: 9.6%	Latency increase for PDCCH period 1 slot: 0.46% 2 slot: 0.91% 4 slot: 1.37% 8 slot: 2.74%		none	SLS **FR2** FTP3, no DRX, $k0 > 0$		- Gain in average power consumption - Baseline latency: 21.9ms (PDCCH period 1 slot)
		21.7% (for 1-slot PDCCH period)	For PDCCH period 1 slot: 21.0% 2 slots: 16.0% 4 slots: 11.1% 8 slots: 07.8%	Latency increase for PDCCH period 1 slot: 0.14% 2 slot: 0.28% 4 slot: 0.42% 8 slot: 0.84%		none	SLS **FR2** FTP3, $k0 > 0$, CDRX config = (160, 100, 4)		- Gain in average power consumption - Baseline latency: 71.85ms (PDCCH period 1 slot)
Nokia, NSB [37][51]	Cross-slot scheduling k0 = {2, 4, 8, 16, 32} compared with DRX for k0=0	25.9%	k0=2: +25.9 % k0=4: +25.9 % k0=8: +25.9 % k0=16: +25.9 % k0=32: +25.9 %	Latency increase k0=2: +1.9 % k0=4: +3.7 % k0=8: +7.2 % k0=16: +14.2 % k0=32: +28.1 %		none	Numerical simulation FTP3 CDRX config (160, 40, 8) k0 = {2, 4, 8, 16, 32}. Baseline is k0 = 0. Other assumptions same as calibration		Cross-slot scheduling PDCCH-only power is applied in every relevant slot in all cases, because the k0 value is provided semi-statically through RRC messaging (PDSCH-TimeDomainResourceAllocationList)

Observation:

The power saving schemes with cross slot scheduling show 13% - 28 % power saving gain and UPT degradation 0.3 %-5% for minimum K0= 1, 13% - 25% power saving gain and UPT degradation 7 % -13 % for 1< minimum K0 < 4 and 2% - 25% power saving gain for minimum K0 >= 4 and UPT degradation up to 32%. When minimum K0>1, the power saving gain decreases and UPT degrades as the K0 increases. Smaller power saving gain in the range 1.1% - 6.5% is observed when the amount of PDCCH monitoring without data scheduling is limited because of high scheduling activity or going to DRX OFF by MAC-CE. The average latency increase is up to 4% if minimum K0 value is less than 4 and C-DRX is assumed. Larger latency increases up to 15% is observed for larger minimum K0 values or C-DRX is not applied.

- Same slot scheduling
  - Adaptation of TDRA configurations to achieve UE power saving – ensure the gap between PDCCH reception and PDSCH transmission known to the UE
  - Adjustment of TDRA configuration
    - Selection of TDRA entry in the TDRA table [5].
    - Note: cross-slot scheduling could be incorporated in the TDRA configuration
  - Power model for TDRA power saving scheme is the slot-averaged power for a slot with N-symbol PDSCH aligned to the end of the slot and PDCCH at the beginning of the slot reported by the proposed scheme.
  - UE assistance information can be considered
- The general procedure for the study of the power saving scheme when same slot scheduling is used
  - gNB semi-statically configures TDRA to the UE, subject to UE capability (if any).
  - All schedulable TDRA values with K0=0 include at least Y symbols between the last PDCCH symbol and the first PDSCH symbol
    - Y is FFS
      - Note: the value of Y is necessary for power modelling in evaluation, although the specification (if specified) of Y value may also be done in the WI phase
    - Note: in case there is a TDRA entry with K0>0, it is assumed that the gap between the last PDCCH symbol in a first slot and the first PDSCH symbol in a second slot is no less than Y
  - All aperiodic CSI-RS triggering offsets are greater than Y symbols
  - UE decodes PDCCH and retrieves the index of schedulable TDRA values
  - UE could go to micro sleep after reception of last PDCCH symbol
  - UE processes PDSCH at the indicated starting time from TDRA values

Table 4: Power saving scheme with same slot scheduling

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Mediatek [59]	Same-slot Scheduling with a specified time gap between PDCCH and PDSCH	-5.94% ~ 17.17%	FTP/Video: -5.94% IM: 17.17% VoIP: 15.50%	Latency Increase: FTP/Video: 55.60% IM: 0.47% VoIP: 0.45%	RU increase: FTP/Video : 100.27% IM: 93.51% VoIP: 0%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	# of symbols between PDCCH and PDSCH = 6 # of PDSCH symbols per slot = 7
Apple [68][84]	1) gNB can configure UE's TDRA table with entries with enough gap between PDCCH and associated PDSCH. The gap **(in symbols/ slots)** is long enough such that PDSCH transmission starts after the gap ends.	16~30%	16% for high load (grant is scheduled every slot) ~30% for low load (grant is			Evaluation Method = Mathematical Analysis, It is assumed that arrived packet could be served with a single PDSCH.	TDRA based gap scheduling (same slot scheduling only)

			scheduled very low probability)				

Observation:

The power saving schemes with same slot scheduling show by one source 15%-17% power saving gain for small data using evaluations, and by another source 16%-30% power saving gain for small data using numerical analysis, such as the instant message or VoIP traffic. 93% overhead increase is observed for the instant message. For large data, such as FTP traffic, one source shows power saving gain of negative 5.9% and 55% latency increase and 100% overhead increase due to the longer PDSCH transmission and reception time that is used to compensate the reduced PDSCH symbol number in a slot. It is noted that there is no consensus on the power model of same slot scheduling.

- Multi-slot scheduling – PDCCH decoding in one slot (e.g., one DCI, multiple DCI) supports scheduled PDSCH/PUSCH transmission over multiple slots.
  - Achieving UE power consumption reduction by potentially skipping PDCCH monitoring at subsequent slots of PDSCH/PUSCH transmission.

Table 5: Power saving scheme with multi-slot scheduling

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Samsung [34][64]	Multi-slot scheduling: one PDCCH schedules at most N TBs across N consecutive slots.	21.6% ~ 38.1%	#1: 21.64%, #2: 32.28%, #3: 35.65%, #4: 37.25%, #5: 38.1%	#1: 1Gbps/0.81 ms #2: 0.62Gbps/1.37ms #3: 0.45Gbps/1.54ms #4: 0.35Gbps/2.5ms #5: 0.28Gbps/3.06ms	no	Numerical simulation No C-DRX, FTP3 traffic model with mean of inter packet arrivals = 4ms Maximum schedulable slots, F, and PDCCH monitoring periodicity T, (F,T): Case #1: (2, 1ms) Case #2: (4, 2ms) Case #3: (6, 3ms) Case #4: (8, 4ms) Case #5: (10, 5ms)	The results shown also reflect combination with reduced PDCCH monitoring to balance the throughput. Single UE. One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits.
ZTE[76]	Multi-slot scheduling: One PDCCH schedules 2\3\4 TBs across 2\3\4 consecutive slots, monitor PDCCH at each slot except the slots with PDSCH transmission.	0.65%-1.9%				Numerical simulation; C-DRX config (160,100,8);	Monitor PDCCH at each slot except the slots with PDSCH transmission. Peak throughput: 10-symbol PDSCH in one slot, 100MHz BWP. No UL. Single UE.

Observation:

For the power saving schemes with multi-slot scheduling, 21.6% - 38.1% power saving gain and 30-70% UPT degradation are shown in combination of PDCCH monitoring reduction. The other source shows 0.65% - 1.9% power saving gain.

5.1.3 Adaptation to number of antenna

The UE power saving schemes with UE adaptation to the traffic is to reduce the maximum number of antenna/panels or MIMO layers indicated by the network semi-statically or dynamically to achieve the UE power saving. This may be done with potential UE assistance information. The dynamic approach may also be associated with a transition time, a timer, etc.

Table 6: Power saving scheme with UE adaptation to the number of antenna/MIMO layer

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Huawei [16][57]	Dynamic Adaptation to number of antennas, 2Rx for PDCCH only until a PDSCH is scheduled and 4Rx reception for PDCCH and PDSCH;	18.19%~22.43%	CDRX config of (160, 40, 8): 18.19%, average power: (18.46/15.10); CDRX config of (160, 100, 8): 22.43%, average power: (30.86/23.94)	Almost similar to the baseline	$5.94*10^{-6}$~$5.99*10^{-6}$	SLS CDRX config: (160, 100, 8), (160, 40, 8) Packet size / arrival rate (Mbytes / ms): 0.5/200 Scheme 2: 2Rx for PDCCH-only slot until a PDSCH is scheduled; Once a PDCCH with grant is detected, a timer starts and the UE starts to use 4 Rx before the timer expires; The timer shall be restarted when a grant DCI is detected; When the timer expires, UE operates with 2Rx; Baseline: 4Rx is always used in different states and cross-slot scheduling is used;	Single UE in a cell Cross-slot scheduling is assumed for all schemes and the baseline;
	2Rx is always used for reception and cross-slot scheduling is used	-2.31% ~ 19.40%	-2.31%~ -1.13% for 5%-tile UE for the FTP model-3 traffic	UPT loss: 2.55%~58.66% Latency increment: 1.3%~345%	$9.50*10^{-4}$~0.0069	SLS CDRX config: (160, 100, 8), (160, 40, 8) Packet size / arrival rate (Mbytes / ms): 0.5/200, 0.1/2000 Scheme 1: 2Rx is always used; Baseline: 4Rx is always used in different states and cross-slot scheduling is used;	10 UEs in a cell; for each configuration, 5%-tile UE and 95%-tile UE are evaluated respectively
	Dynamic Adaptation to number of antennas, 2Rx for PDCCH only until a PDSCH is scheduled and 4Rx reception for PDCCH and PDSCH;	2.96% ~18.49%	For the traffic of 0.1Mbyte with 2000 ms mean interval, the gain of 16%~17.8% for 5%-tile UE and 16.28%~18.49% for 95%-tile UE.	Almost similar to the baseline	$1.58*10^{-5}$ ~ $1.58*10^{-4}$	Same as above except this is for Scheme 2 Baseline: 4Rx is always used in different states and cross-slot scheduling is used;	10 UEs in a cell; Same as above
Vivo [58]	Adaptation to number of antenna (UE reports its preferred Rx antenna number), evaluated for gaming application	6% ~ 30%	20% for CDRX	Average packet latency: 16.83ms; Latency increase: 0%	Marginal	Numerical simulation Baseline assumption: The Rx number is always 4Rx; Traffic model: gaming CDRX config: (40,10,4)	
			30% for Fixed PDCCH monitoring periodicity (0.5ms)	Average packet latency: 0.5ms; Latency increase: 0%			
			6% for Fixed PDCCH monitoring periodicity (40ms)	Average packet latency: 20.30ms; Latency increase: 0%			
Mediatek [18][40][59]	BWP-based adaptation on the maximum MIMO layer number	14.37% ~ 19.53%	FTP/Video: 14.37% IM: 15.70% VoIP: 19.53%	Latency Increase FTP/Video: 3.36% IM: 1.79% VoIP: -1.78%	RU increase: FTP/Video: -0.43% IM: 1.95% VoIP: -4.08%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	One 4-layer BWP and one 2-layer BWP. DCI and timer based dynamic switching for FTP/Video and IM; Static 2-layer BWP for VoIP
Intel [65]	Number of UE antennas adaptation. Comparison of 2Rx and 4Rx chains with maximum rank 2	25.1 ~ 30.2%	26.06%	68.42 MBps; 80.49 ms		5%; FTP model 3 160, 100, 8	System level simulations 6%-8% UPT loss for FTP model 3 <1% UPT loss for Instant Messaging and VoIP
			26.89%	85.68 MBps; 60.33 ms		50%	
			25.11%	89.3 MBps; 56.13 ms		95%	
			29.66%	5.78 MBps; 149.13 ms		5%; Instant Messaging 320, 80, 10	
			29.4%	5.87 MBps; 148.72 ms		50%	
			29.87%	5.82 MBps; 148.69 ms		95%	
			30.03%	0.0287 MBps; 10.15 ms		5%; VoIP 40, 10, 4	
			29.32%	0.0284 MBps; 10.2 ms		50%	

			30.24%	0.0288 MBps 10.09 ms		95%	
Interdigital [66]	Dynamic receive antenna adaptation between 4x and 2x	10.2% ~ 19.9%	FTP: 10.2% IM: 19.9%	No impact on latency		SLS Case 1(160, 100, 8), Case 4(320, 80, 10) FTP (Case 1) IM (Case 4)	10 UEs per cell Average gain Higher gain observed for IM traffic.
Apple [68][84]	1) There are certain cases where gNB does not have to use large number of layers, e.g., low load traffic (traffic/control) transmission in good channel condition. 2) gNB can RRC configure UE with the maximum number of MIMO layers L_max. 3) gNB can dynamically indicate the mimo layer in DCI within L_max. 4) UE can buffer only up to L_max to avoid unnecessary buffering of layers which is not used.	0 % ~ 30 %	0 % for very low traffic load (when traffic load is low, no need to buffer PDSCH). 30% for high traffic load (when load is high, reducing to 2Rx from 4Rx could save up to 30% power).			Evaluation Method = Mathematical Analysis, Basic assumption is that SNR is high enough so that the BLER with 2Rx is very low enough.	
Ericsson [69]	Comparison of 2-Rx chains vs 4-Rx chains with maximum 2-layers	Negligible to negative power saving gains since UE with 2Rx operation (vs 4Rx) has to stay awake longer to receive data.		Latency (mean user serving time) increase by 1.4x-7.6x based on traffic load	Overhead (resources utilization) increase of 1.3x-2.7x Based on traffic load	System-level simulation	Increased PDCCH resource overhead due to 2Rx vs 4Rx is not modelled.
ZTE[19][76]	Adaptive configuration with 2 or 4 antennas	13% ~ 14%	10M:13.37% 20M: 13.26% 40M: 13.37% 80M: 13.85% 100M: 14.01%			Numerical simulation; FTP 3 with 0.1Mbytes and mean arrival time=200ms CDRX config: (160,100,8) Bandwidth=10M,20M,40M,80M,100M	Peak throughput: 10-symbol PDSCH in one slot. No UL. Single UE

Observation:

The power saving schemes with UE adaptation to the number of MIMO layers or number of Tx/Rx antenna (panels) provides up to 3%-30% power saving gain for the dynamic antenna adaptation and 6%- 30% for the semi-static antenna adaptation with some impact to the system performance, such as 4% latency increase for dynamic antenna adaptation, when reduced antenna operation is used mainly during periods of low scheduling activity and additional network resources are used for the compensation of the loss of multi-antenna processing gain. It was shown by one source that there is corresponding 10%-58% UPT degradation for the RRC configured antenna reduction without adaptation for FTP traffic. It is noted that with a set of simulation assumptions (such as traffic model and SCS) not aligned with the agreed ones for evaluation, it was observed by one source that the negative power saving gain and latency up to 760 % over Rel-15 4Rx antenna for the RRC configured antenna reduction without adaptation for FTP traffic was observed. It was observed by one source that the resulting additional overhead in terms of DL resource usage for the dynamic antenna adaptation is up to 2%.

5.1.4 Adaptation to DRX operation

The power saving scheme of power saving signal/channel triggering UE adaptation to DRX operation is to configure the power saving signal/channel before or at the beginning of the DRX ON duration to trigger UE waking up only when there is DL data arrival. UE is not required to wake up at the DRX ON at least for PDCCH monitoring, if the power saving signal is not detected. The go-to-sleep signaling is used as the indication allowing UE going back to sleep state after completion of PDSCH reception during the DRX ON period to further reduce the UE power consumption.

For power saving scheme with UE adaptation to the DRX operation for further study

- UE adaptation of its behavior to the DRX operation for UE power consumption reduction

- When is configured with power saving signal/channel, power saving signal/channel as the indication whether to wakeup or not before or at the beginning of DRX ON duration
    - At least for the indication of PDCCH monitoring
- Preparation period is used for (e.g., to perform channel tracking, CSI measurements, beam tracking).
    - Preparation period can be used in preparation for the PDCCH decoding
    - Preparation period could be before or during the DRX ON duration
    - Network can indicate UE to report CSI before or after the power saving signal/channel (if configured) during the preparation period
    - Network can indicate additional RS transmission (e.g., CSI-RS, TRS, SSB and power saving signal) at the preparation period
- Go-to-sleep signaling as the indication allowing UE going back to sleep state
    - MAC-CE
    - DCI
    - Power saving signal/channel
- Constraints on scheduling DCI during DRX_ON

The following table is subject to further update, particularly regarding evaluation results/assumptions

Table 7: Power saving scheme with UE adaptation to the DRX operation

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Huawei [52][53][54][57]	Wake-up signaling	0.2% ~ 17.79%	Average power: (97.75/97.55) ~ (65.75/54.05)	UPT: 0.49%~16.09% Latency: 2.22%~9.88%	$1.96*10^{-6}$ ~ $1.92*10^{-5}$	SLS DRX config: (320, 200, 10), (320, 80, 10), (160, 100, 8), (160, 40, 8), (40, 25, 4), (40, 10, 4)	10 UEs in a cell WUS transmitted 3ms before first slot of DRX on duration. WUS power value is 30 Included periodic background activity for time/frequency tracking, etc
Huawei [16][57]	DCI explicitly indicating restarting inactivity timer	6.7% ~ 37.5%	Average power: (23.0 / 21.5) ~ (55.6 / 34.7)	UPT: 10.9%~40.5% Latency: 2.7%~49.1%	none	Eval. method: SLS DRX config: (160, 100, 8), (160, 40, 8)	Single UE in a cell, and with different traffic model for packet size and data arrival rate are corresponding to 0.1/200, 0.1/100, 0.5/200, 0.5/100(Mbytes / ms) respectively.
Mediatek [40][59]	Wake-up signalling before DRX on-duration and aggregated with periodic/background activities around SS burst	9.40% ~ 30.39%	FTP/Video: 9.40% IM: 30.39% VoIP: 24.55%	Latency Increase: FTP/Video: 12.14% IM: 8.80% VoIP: 11.92%	RU increase: FTP/Video: -1.40% IM: 0% VoIP: -5.10%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	Constant wake-up and 8-slot PDCCH monitoring period for VoIP WUS power value is the same as that of cross-slot PDCCH-only monitoring
Mediatek [59]	Wake-up signalling right before DRX on-duration	5.03% ~ 20.47%	FTP/Video: 5.02% IM: 20.47% VoIP: 7.94%	Latency Increase: FTP/Video: 6.41% IM: 5.56% VoIP: 7.22%	RU increase: FTP/Video: -0.70% IM: 0% VoIP: -1.02%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	WUS power value is the same as that of cross-slot PDCCH-only monitoring

CATT[21][60]	Power saving signal trigger DRX adaptation and power saving reference signal for channel tracking, CSI measurement.	54.0% ~ 76.4%	ftp3 with 160ms DRX-cycle: 54.0% IM with 320ms DRX-cycle:76.4%	--	The overhead for additional is similar to CSI-RS.	SLS with 10UE per TRP to get transmission rate, and observed one single UE for power consumption. Baseline: R15 DRX scheme, considering procedure of channel tracking, CSI measurement. FTP3 with 0.5Mbytes and 200ms inter-arrival time, IM with 0.1Mbytes and 2s inter-arrival time	
ZTE [19][41][61]	two level structure of power saving signal triggering UE wake up	8.89% ~ 39.9%	FTP traffic:8.89% Instant Message:39.9 %			Numerical simulation; CDRX config: FTP traffic (160,100,8) Instant Message (320,80,10) Baseline: No WUS	Peak throughput: 10-symbol PDSCH in one slot; 100 MHz BWP No UL. Single UE
ZTE [19][41][61]	Association of BWP, two level structure of PS signal and DRX operation	44% ~ 54%	FTP traffic:44% Instant Message:54%			Numerical simulation; CDRX config: FTP traffic (160,100,8) Instant Message (320,80,10) Baseline: No WUS, BWP=100MHz	Peak throughput: 10-symbol PDSCH in one slot; 100 MHz BWP No UL. Single UE
LG[46][62]	PDCCH-based WUS signal triggering UE wake up	(1) 11.45%~ 14.24% (2) 12.41%~ 27.33% (3) 0.82%~ 6.81%		UPT loss: (1) 13.11%~ 16.59% (2) 38.59%~ 54.49% (3) 1.27%~ 4.07%		Traffic model: FTP3 with file size 0.5Mbps, CDRX config (160,100,8) Cases: (WUS occasions : DRX cycles) (1) 1:1 (2) 1:4 (3) 4:1	Reference schemes: PDCCH monitoring periodicity: 1 slot, K0=0
Samsung [34][64]	1-bit Power Saving signal triggering UE wakeup at DRX ON	4% ~ 11.4%	#1: 4% #2:8.4% #3:11.4%	23.8Mbps/36.5ms 16.75Mbps/51.8 ms 15.0Mbps/57.8ms	RS based power saving signal with monitoring periodicity equals to DRX cycle	Numerical simulation C-DRX = (160, 100, 8) FTP3 traffic model Cases: Mean of inter packet arrivals = #1:100ms, #2:200m, #:3300ms	Single UE. One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits.
Samsung[64]	Two levels CSI-RS based power saving signal prior to DRX ON duration for dynamic wake-up indication and scaling on CDRX configuration parameters	89.4% ~ 91.6%	#1:89.4% #2:91.2% #3:91.6%	13.4Mbps/64.7ms 6.12Mbps/141.8 ms 4.62Mbps/187.8 ms	RS based power saving signal with monitoring periodicity equals to DRX cycle	Numerical simulation C-DRX = (160, 100, 8) FTP3 traffic model Cases: Mean of inter packet arrivals = #1:100ms, #2:200m, #:3300ms	Single UE. One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits.
Intel [45][65]	Power saving signal triggering UE wake up for DRX on duration	1.6 ~ 67.5%	9.89%	64.3/62.6 MBps (2.6%) / 85.8/88.0 ms (2.5%)		5% — FTP model 3 160, 100, 8	System level simulation WUS detection power is assumed to
			11.86%	87.0/82.6 MBps (5.1%) / 59.8/63.2 ms (5.5%)		50%	

			12.65%	91.4/85.1 MBps (6.8%) / 55.7/60.4 ms (8.5%)		95%		be 100 units, i.e. PDCCH-based, and no transition energy reduction compared to the deep sleep reference is assumed.
			40.37%	5.79/5.54 MBps (4.4%) / 145.9/152.0 ms (4.2%)		5%		
			42.83%	6.07/5.74 MBps (5.4%) / 142.2/149.4 ms (5.1%)		50%	Instant Messaging 320, 80, 10	
			42.42%	5.90/5.51 MBps (6.6%) / 144.2/154.3 ms (7.0%)		95%		
			18.59%	0.0286/0.0232 MBps (18.9%) / 10.2/12.6 ms (24.4%)		5%		
			19.27%	0.0279/0.0229 MBps (17.8%) / 10.2/12.6 ms (22.9%)		50%	VoIP 40, 10, 4	
			17.71%	0.0289/0.0241 MBps (16.8%) / 10.1/12.3 ms (21.9%)		95%		
			2.52%	0.0568/0.0285 MBps (49.8%) / 16.8/18.4 ms (9.4%)		5%		
			1.68%	0.0531/0.0282 MBps (46.9%) / 17.2/18.5 ms (7.3%)		50%	Gaming 40, 10, 4	
			2.03%	0.0491/0.0303 MBps (38.3%) / 16.0/17.1 ms (6.7%)		95%		
			67.49%	2.26/2.16 MBps (4.4%) / 132.9/139.9 ms (5.2%)		5%		
			67.57%	2.33/2.25 MBps (3.7%) / 130.9/136.7 ms (4.4%)		50%	Web browsing 320, 80, 10	
			67.47%	2.27/2.16 MBps (4.7%) / 130.3/137.5 ms (5.5%)		95%		
			15.86%	0.1152/0.1066 MBps (7.4%) / 8.58/10.14 ms (18.2%)		5%		
			15.13%	0.1192/0.1113 MBps (6.6%) / 8.44/9.80 ms (16.1%)		50%	Video streaming 40, 10, 4	
			14.89%	0.1155/0.1084 MBps (6.2%) / 8.74/10.01 ms (14.6%)		95%		
Interdigital[66]	Wake-up signal triggering UE wake-up for DRX ON duration	11.5% ~ 88.1%	FTP: 11.5%, 24.2%, 27.9% IM: 84.6%, 88.1%, 36.6%	No impact		SLS Case 1(160, 100, 8), Case 2 (40, 25, 4), Case 3(40, 10, 4) Case 4(320, 80, 10) FTP (Case 1, 2, 3) IM (Case 2, 3, 4)		10 UEs per cell Average gain Assumes advanced knowledge of scheduling status for the upcoming DRX ON duration Higher gain observed from shorter DRX cycle. IM gain is higher.
Ericsson[69]	WUS +Shorter DRX cycle compared to no WUS + Longer DRX	8%~14%	8%-14% power saving gain for the same UPT	10% gain for same power consumption	One WUS sent in one symbol before each traffic burst	System-level simulation CDRX Traffic model is FTP3 with 180 kB packet size and 200 ms inter-arrival time is used. RU < 10%.		Several DRX Cycles from 20 to 160 ms are evaluated with On duration of 8ms and 100ms IAT
Qualcomm [70]	Pre-wake-up window	5.8 to 9.4%	C-DRX config (cycle, on dur.) (160ms, 8ms): 9.4% (320ms, 10ms): 5.8%		Additional CSI-RS/TRS transmission in PWU window before DRX ON duration	Method: Numerical analysis Baseline: SSB-based scheme Traffic model: PDCCH-monitoring only		
Qualcomm [30][48] [70]	PDCCH-based WUS triggering UE wakeup	5% ~ 50%	Highlights:	Latency increase: Web browsing /w DRX (160, 100)	Percentage of DRX cycles requiring one additional	Method: Numerical simulation FR1. DL-only.		CSI measurements in pre-processing before the 1st PDSCH reception

			Web browsing /w DRX (160, 100) (#1) 35% (#2) 25% FTP /w DRX (160, 100) (#1) 10% (#2) 5% FTP /w DRX (40, 10) (#1) 50% (#2) 31% IM /w DRX (320, 80) (#1) 21% (#2) 11%	4% FTP /w DRX (160, 100) 3% FTP /w DRX (40, 10) 13% IM /w DRX (320, 80) 2%	PDCCH as WUS: Web browsing /w DRX (160, 100) 5% FTP /w DRX (160, 100) 28% FTP /w DRX (40, 10) 11% IM /w DRX (320, 80) 14%	Sync every 160 msec. Traffic model: Web browsing, FTP, IM DRX configuration (40,10) (160,100) (320, 80) DRX ON duration assumption for baseline: (#1) Reference config (#2) 1-slot UE SINR assumption: Peak MCS, throughput	WUS power model: ~1/3 of baseline (See Section 2.1.1)
Nokia, NSB [71]	Wake-up signal with short DRX	DRX: 8% Short DRX 16% ~ 20%	DRX: 10 unit: +8.6 % 50 unit: +8.5 % 100 unit: +7.8 % Short DRX 10 unit: +20.3 % 50 unit: +19.5 % 100 unit: +18.6 % Short DRX ii: 10 unit: +19.7 % 50 unit: +18.5 % 100 unit: +17.0 % Short DRX iii: 10 unit: +18.6 % 50 unit: +17.4 % 100 unit: +15.8 %	DRX: +12.2 % Short DRX i: +11.3 % Short DRX ii: 16.7 % Short DRX iii: 51.6 %	WUS is PDCCH based i.e. few additional symbols for PDCCH before On Duration	Numerical simulation 3 slot delay between WUS and On Duration. Sleep transitions according to UE power model. WUS power level 10 units, 50 units, 100 units. No transition energy reduction is assumed and the reference deep sleep transition is assumed. Long DRX cycle incl. short DRX (as per MAC specification 38.321). Made for FTP3 Results are compared to each DRX configuration without WUS. Cases: DRX: 160 ms DRX cycle, 100 ms inactivity timer, 8 ms On Duration. Short DRX i: 80 ms DRX cycle, 5 ms inactivity timer, 8 ms On Duration, 40 ms short DRX cycle, 3 short cycles Short DRX ii: 40 ms DRX cycle, 5 ms inactivity timer, 4 ms On Duration, 20 ms short DRX cycle, 5 short cycles Short DRX iii: 20 ms DRX cycle, 5 ms inactivity timer, 4 ms On Duration, 10 ms short DRX cycle, 10 short cycles	DRX: No WUS 151682387 units, 10 units WUS 138601719 units, 50 units WUS 138716190 units, 100 units WUS 139860887 units Short DRX i: No WUS 78073432 units, 10 units WUS 62208308 units, 50 units WUS 62819068 units, 100 units WUS 63582502 units Short DRX ii No WUS 103096777 units, 10 units WUS 82757455 units, 50 units WUS 84021095 units, 100 units WUS 85600613 units Short DRX iii No WUS 201668275 units, 10 units WUS 164144242 units, 50 units WUS 166636202 units, 100 units WUS 169751089 DRX: No WUS 44.2 ms, WUS 49.6 ms Short DRX i: No WUS 31.1 ms, WUS 34.6 ms Short DRX ii: No WUS 14.4 ms, WUS 16.8 ms Short DRX iii No WUS 5.06 ms, WUS 7.67 ms
OPPO[20][42][83]	Wake-up scheme for DRX	4.3% and 26.75%	FTP: 4.3% IM: 26.75%		FTP: 0.01% IM: 0.005%	SLS Traffic model: FTP3, IM CDRX config: FTP: (160, 100, 8) IM: (320, 80, 10)	
CMCC [80]	Both power saving signal and CSI measurements in advance of DRX ON compared with only power	6.7%				SLS FTP3: 0.5Mbytes, 200ms CDRX=(160, 100, 10)	Power saving triggering UE wake up and CSI

	saving signal in advance of DRX ON						measurement before DRX ON. UE measures CSI-RS resources and reports CSI on PUCCH resource if power saving signal is detected.
Spreadtrum [67]	WUS with optimization (low power WUS + low transition power + short gap to WU) before DRX-ON	29% ~ 49%	FTP: 45%~49% IM: 42%~45% VoIP: 29%~35%			Numerical simulation CDRX config (cycle, on-dur.): FTP/Video (160, 8), IM (320, 10), VoIP (40, 4) Baseline: WUS is not used	

Observation:

The powers saving schemes with UE adaptation to the DRX operation include UE adaptation of its behavior to the DRX operation, and dynamic DRX configuration. Based on the evaluation, the schemes of power saving signal/channel triggering wake-up for CDRX show power saving gain in a range of 8% - 50% comparing to the baseline with the agreed C-DRX reference configuration. The latency increase/UPT degradation is in the range of (2% - 13%)/(0.5%-16%). It is shown the power saving gain tends to be higher when the C-DRX cycle is shorter, but it is smaller when C-DRX ON duration is shortened, For longer C-DRX cycle and/or high traffic load, smaller gain in the range of 5% - 10% is observed. The power saving gain shown by the power saving signal/channel triggering UE adaptation to the DRX operation has very little dependency on the assumed power consumption level of the power saving signal/channel.

Additional gain 4% -10% of the power saving scheme with UE adaptation to the DRX operation with the help of the preparation period is observed on top of the power saving gain from UE wake-up by power saving signal/channel. The corresponding additional overhead was not reported and summarized. The corresponding system impact (if any) was not analysed and summarized.

- Dynamic DRX configuration including at least the following
  - UE is configured with multiple DRX configurations
  - Dynamic selection of DRX configuration by gNB from multiple DRX configurations (e.g., traffic, mobility)
    - UE assistance information may be considered
  - Adaptive parameters setting of one DRX configuration
    - UE assistance information may be considered
    - DRX parameters are indicated by gNB
    - Adaptive UE behavior in the DRX operation (e.g, restart the inactivity timer)

The following table is subject to further update, particularly regarding evaluation results/assumptions

Table 8: Power saving scheme with multi-DRX configurations

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Vivo [58]	UE report preferred CDRX configuration	4%~80%	4%-57% for UE of 5 percentile SINR	Average packet Latency: 87.61 ms; Latency increase: 2%-74%	Marginal	Numerical simulation Baseline assumption: non-UE preferred CDRX configuration; Traffic model: ftp model 3	
			8%-77% for UE of 50 percentile SINR	Average packet Latency: 81.19 ms; Latency increase: 2%-94%			
			11%-80% for UE of 95 percentile SINR	Average packet Latency: 80.43 ms; Latency increase: 2%-95%			

Mediatek [18][40][59]	DRX parameters adaptation with UE assistance	42.09 ~ 70.06%	FTP/Video: 42.09% IM: 70.06%	Latency Increase: FTP/Video: 30.04% IM: 323.14%	RU increase: FTP/Video: -0.61% IM: 4.54%	SLS CDRX config: FTP/Video (160, 8, 20) IM (1280, 10, 20)	
Sony[22][56][63]	Dynamic DRX indication DDI). PDCCH triggering signal during DRX_ON duration indicates whether UE can go to sleep for remainder of DRX_ON	7~9%	Baseline{IT=100,slots=16}: 41.0 units {IT=100,slots=2}: 38.2 units = 7% saving Baseline{IT=40,slots=16}: 23.4 units {IT=40,slots=2}: 20.9 units = 9% saving	Baseline{IT=100,slots=16}: 47ms {IT=100,slots=2}: 50.9ms = 8.3% increase Baseline{IT=40,slots=16}: 59.5ms {IT=40,slots=2}: 63.2ms = 6.3% increase	None (spare resource used)	Numerical simulation. FTP3 0.5Mbyte Mean inter-arrival = 0.2sec C-DRX config: (160,100,8), (160,40,8) FR1, UL not modelled High SNR	'slots' is the number of slots after which the UE can go to sleep during the DRX_ON duration. Note that without 'DDI', UE goes to sleep 8ms = 16 slots after start of DRX_ON
Sony[22][56][63]	Dynamic DRX Configuration Adaptation of inactivity timer (IT) depending on whether the buffer is empty or NOT when the UE wakes up. IT is set to 0 or 100 depending on buffer status	48%	-	marginal	none	Analytical Evaluation. FTP3 0.1Mbytes, Mean inter-arrival time 2 sec. Baseline: 320/80	
Apple [68][84]	1) UE knows the current running application in device and its traffic pattern (delay, throughput, periodicity, etc). 2) UE can determine a DRX configuration which works best with the current application. 3) UE can send DRX configuration recommendation to gNB. 4) If the application is terminated or done with file transfer, then UE can recommend different DRX configuration (e.g., with relaxed DRX cycles).	33~52%	52% for DRX2 48% for DRX3 46% for DRX4 33% for DRX5 All w.r.t DRX1	for all DRX configurations Mean delay=16.46, 30.3, 29.75, 60.28, 84.15 ms for DRX1/2/3/4/5 Mean delay increase in % for DRX1/2/3/4/5 w.r.t DRX1= 100.00%, 184.08 %, 180.74%, 366. 22%, 511.23%		Evaluation Method = Numerical Simulation, Baseline configuration = DRX1, Traffic type = FTP 41.3Mbps	DRX1=(10,10,4) DRX2=(40,10,4) DRX3=(40,25,4) DRX4=(160,100,8) DRX5=(320,200,10)
		13~56%	13% for DRX1 56% for DRX2 25% for DRX3 15% for DRX4 All w.r.t DRX5			Evaluation Method = Numerical Simulation Baseline configuration = DRX5, Traffic type = VoIP	
Nokia, NSB [71]	DRX incl. short DRX (as per MAC specification 38.321). Evaluated for FTP3 and web browsing (4 s reading time)	-280 % to 47 %	FTP3: Short DRX i -36.9 %; Short DRX ii +29.6 % Short DRX iii +46.7 % Web: Short DRX i -279.7 %; Short DRX ii -167.3 % Short DRX iii -37.4 %	FTP3: Short DRX i -88.9 %; Short DRX ii -69.0 % Short DRX iii -33.4 % Web: Short DRX i -90.6 %; Short DRX ii -71.5 % Short DRX iii -41.2 %	Limited overhead during RRC configuration of short DRX	Numerical simulation Short DRX schemes compared to baseline: 160 ms DRX cycle, 100 ms inactivity timer, 8 ms On Duration. Short DRX i: 20 ms DRX cycle, 5 ms inactivity timer, 4 ms On Duration, 10 ms short DRX cycle, 10 short cycles Short DRX ii: 40 ms DRX cycle, 5 ms inactivity timer, 4 ms On Duration, 20 ms short DRX cycle, 5 short cycles Short DRX iii: 80 ms DRX cycle, 5 ms inactivity timer, 8 ms On Duration, 40 ms short DRX cycle, 3 short cycles	FTP3: Baseline: 145342876 units, short DRX i: 198960000 units, short DRX ii: 102274284 units, short DRX iii: 77486778 units, Baseline 46.7 ms, short DRX i 5.2 ms, short DRX ii 14.5 ms, short DRX iii 31.1 ms Web: Baseline: 45016524 units, short DRX i 170939164 units, short DRX ii 75298707 units, short DRX iii 61838460 units, Baseline 49.5 ms, short DRX I 4.66 ms, short DRX ii 14.1 ms, short DRX iii 29.1 ms
OPPO[20][42][74]	Adaptation of Inactivity timer	42.5% and 44.28%	FTP: 44.28%		FTP: About 0.0025%	SLS	

			IM: 42.5%		IM: About 0.0025%	Traffic model: FTP3, IM CDRX config: FTP: (160, 100, 8) IM: (320, 80, 10)	
Intel [81]	Dynamic DRX operation: inactivity timer adaptation by WUS	33.83% to 58% w.r.t C-DRX	58% for Case 1 42.97% for Case 2 33.83% for Case 3	71.5527ms Case 1 63.770ms for Case2 60.067ms for Case 3	0.0021% for Case1 0.0019% for Case 2 0.0018% for Case 3	CDRX config: Case 1(160, 20 or 40,4), Case 2(160,40 or 60,4), Case 3(160,50 or 100,4) Numerical evaluation for single UE case, assuming a 0.5Mbytes packet takes 5 slots to complete for the considered 50% geometry. No HARQ retransmission is assumed. AL = 8 is assumed for PDCCH based WUS. Inactivity timer value is set by WUS and during DRX ON, inactivity timer restarts anytime PDCCH is received.	Numerical simulation High power saving gain can be achieved by dynamically indicating inactivity timer in WUS based on traffic arrival Baseline values: Average Power/ms: 31.1651 Latency (ms): 48.6247

Observation:

Dynamic DRX configuration schemes show power saving gain in the range of 8% - 70% with latency increase at 2%-323%. When the DRX configuration and/or parameters are closely adapted to the traffic type, high power saving gain is observed. One source shows the power saving gain -37% to +47% over the agreed baseline with Rel-15 DRX configuration selection adapted to the traffic with suitable short DRX.

5.1.5 Adaptation to achieve reducing PDCCH monitoring/decoding

The UE power consumption can be reduced when the number of UE PDCCH monitoring occasions and/or the number of PDCCH blind decoding is reduced.

The power saving schemes to reduce PDCCH monitoring and blind decoding for further studies are as follows,

- Triggering of PDCCH monitoring – dynamic trigger through L1 signal/signaling
  - Power saving signal triggering PDCCH monitoring
  - Go-to-sleep signaling to skip PDCCH monitoring
- PDCCH skipping -
  - DCI based indication for PDCCH skipping (e.g., indication in DCI content, new SFI state).
  - L1 signal/signaling (other than DCI) based triggering -
- Multiple CORESET/search space configurations
  - Configuration of different PDCCH periodicities with dynamic signaling
  - Adaptation of CORESET/search space configuration – DCI/timer/HARQ-ACK based indication
  - Dynamic/semi-persistent CORESET/search space ON/OFF
  - Adaptation between DRX ON duration timer and inactivitytimer
  - Separated PDCCH monitoring of DL and UL
- L1 signaling triggering to assist UE in reducing the number of PDCCH blind decoding
- Reduced PDCCH monitoring on SCell (including cross carrier scheduling)
- Network assistance – RS is dynamically transmitted based on the need to assist UE performing synchronization, channel tracking, measurements and channel estimations before PDCCH decoding

Observation:

The power saving schemes for reducing PDCCH monitoring shows 5%-85% power saving gains with different detailed schemes comparing to the assumed baseline scheme of Rel-15 PDCCH monitoring for the purpose of evaluation, although each of the different detailed schemes offers various power saving gains. Lower power saving gains 5%-15% were observed for the continuous traffic. High power saving gains 50%-85% was observed for sporadic traffic arrival. This comes at the expense of reduced UPT throughput in the range of 5%-43%, and increased latency in the range of 0%-115% (which does not necessarily result in exceeding the corresponding delay budget). This also comes at the expense of additional overhead in the range of 0%-26.53% in terms of DL resource usage.

Table 9: Power saving scheme with UE adaptation to reduce PDCCH monitoring (Adaptation of PDCCH monitoring periodicity)

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Vivo [39][58]	Dynamic switching of PDCCH monitoring periodicities by DCI	0% ~ 83%	0%-74% (for gaming, and for all UE)	Average packet Latency: 20.30~0.40 ms; Latency increase: 0%~140%	No overhead (use the additional bits in scheduling DCI)	Numerical simulation; Baseline assumption: 1)Fixed PDCCH monitoring periodicity without CDRX; 2)CDRX; Traffic: gaming and ftp model 3	
			6%-59% (for FTP3, and for UE of 5 percentile SINR)	Average packet Latency: 37.41~106.62 ms; Latency increase: -90% ~84%			
			3%-80% (for FTP3, and for UE of 50 percentile SINR)	Average packet Latency: 28.13~101.53 ms; Latency increase: -92% ~115%			
			2%-83% (for FTP3, and for UE of 95 percentile SINR)	Average packet Latency: 27.26~100.88 ms; Latency increase: -92% ~118%			
Vivo [39][58]	Adaptation of CORSET/search space configuration – HARQ-ACK based indication (UE monitoring of PDCCH search space for retransmission is triggered by decoding failure of SPS PDSCH)	20%	20%	Average packet Latency: 1 ms; Latency increase: 0%	No overhead	Numerical simulation; Baseline assumption: UE monitoring of PDCCH search space for retransmission is configured by RRC; Traffic: VoIP	
Vivo [58]	UE report preferred PDCCH monitoring parameters, evaluated for gaming application	85%	85%	Average packet latency: 20.30ms; Latency increase: The delay requirement of gaming (60ms) can be fulfilled.	Marginal	Numerical simulation; Baseline assumption: Fixed PDCCH monitoring periodicity of 0.5ms; Traffic model: gaming	
Vivo [58]	PDCCH monitoring adaptation between DRX ONduration timer and inactivity timer	5%-50%	5%-32% for UE of 5 percentile SINR	Average packet Latency: 32-88 ms; Latency increase: 5%-24%	Marginal	Numerical simulation Baseline assumption: same PDCCH monitoring configurations between DRX ONduration timer and inactivitytimer; Traffic model: ftp model 3	
			7%-47% for UE of 50 percentile SINR	Average packet Latency: 23-82 ms; Latency increase: 6%-38%			
			7%-50% for UE of 95 percentile SINR	Average packet Latency: 22-81 ms; Latency increase: 7%-42%			
Mediatek [18][40][59]	PDCCH period adaptation via DCI	22.42% ~ 33.33%	FTP/Video: 33.33% IM: 30.76% VoIP: 22.42%	Latency Increase: FTP/Video: 15.27% IM: 1.25% VoIP: 7.90%	RU Increase: FTP/Video: -1.25% IM: 0% VoIP: -1.02%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10)	PDCCH period is adapted to 8 slot after DCI indication during data inactivity

					DCI Overhead (w.r.t. data DCI): FTP/Video: 6.03% IM: 43.78% VoIP: 95.30%	VoIP (40, 10, 4)	
Mediatek [59]	PDCCH period adaptation via time-out	6.48% ~ 29.94%	FTP/Video: 29.94% IM: 28.47% VoIP: 6.48%	Latency Increase: FTP/Video: 14.94% IM: 1.26% VoIP: 0.75%	RU Increase: FTP/Video: -0.95% IM: 0% VoIP: 0% DCI Overhead (w.r.t. data DCI): FTP/Video: 0% IM: 0% VoIP: 0%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	PDCCH period is adapted to 8 slot after time-out during data inactivity
Mediatek [59]	Joint Power Saving Adaptation by extended BWP framework	35.14% ~ 45.09%	FTP/Video: 32.85% IM: 45.09% VoIP: 35.53%	Latency Increase: FTP/Video: 20.57% IM: 11.06% VoIP: 11.92%	RU Increase: FTP/Video: -1.04% IM: 1.30% VoIP: -5.10%	SLS CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	WUS power value is the same as that of cross-slot PDCCH-only monitoring
ZTE [19][41][61]	PDCCH monitoring periodicity adaptation during the DRX active time	25%	FTP traffic:25.43% Instant Message:25.89%			Numerical simulation; CDRX config: FTP traffic (160,100,8) Instant Message (320,80,10) Baseline: PDCCH monitoring at each slot during DRX active time	Peak throughput: 10-symbol PDSCH in one slot; 100 MHz BWP No UL. Single UE
LG[46][62]	PDCCH monitoring periodicity adaptation during the DRX active time based on actual transmission	22.01% ~ 36.17%		UPT loss: 1.60%-4.33%		Traffic model: FTP3 with file size 0.5Mbps, DRX configuration (160,100,8)	Reference schemes: PDCCH monitoring periodicity: 1 slot, K0=0
Sony[22][63]	Reduced PDCCH monitoring while the inactivity timer is running	20-34%	Baseline: 41 units N=2: 32.8 unit = 20% saving N=4: 28.9 units = 30% saving N=8: 27.1 units = 34% saving	Baseline: 47ms N=2:47.6ms = 1.5% increase N=4:49.1ms = 4.5% increase N=8:52.4ms = 11.5% increase	0	Numerical simulation. FTP3 0.5Mbyte. Arrival rate = 0.2 sec Baseline: C-DRX config = 160/100/8 FR1. No UL modelled High SNR	"N" is number of slots between which PDCCH is monitored in inactivity period. PDCCH monitored for 1 slot Latency is increase relative to baseline (full monitoring baseline latency is 47ms)
Samsung [34][64]	Dynamic scaling of PDCCH monitoring periodicity/duration based on implicit adaptation criteria based on real-time detection results of DCI formats for scheduling PDSCH/PUSCH.	63.8%	Implicit adaptation criteria with parameters, (X1/X2/alpha/beta) = (1/1/0.5/0.5)	1.66Gbps/0.52ms	no	Numerical simulation No C-DRX, FTP3 traffic model w/ mean of inter-packet arrivals = 4ms	Single UE. Power model for RS based power saving signal detection: 55 power units One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits.

Interdigital [66]	Reduced PDCCH monitoring by increasing PDCCH monitoring periodicity	32% ~ 50%	49.6%, 33.5%, 32.0%	Latency increases by 116%, 50%, 56%		SLS Case 1(160, 100, 8), Case 2 (40, 25, 4), Case 3(40, 10, 4) Case 4(320, 80, 10) IM (Case 2, 3, 4)	10 UEs per cell Average gain Latency increase due to fixed monitoring periodicity.

Observation:

PDCCH monitoring periodicity configurations can be dynamically adapted based on explicit/implicit signaling, and works with or without C-DRX. The power saving gain over the agreed baseline in the range of 5% ~ 63.8% is observed, with latency increase in the range of 1.25% ~ 38% and overhead 0% -1.3 %. One source shows 85% power saving gain with latency 118%. The high latency is due to the not-fully-flexible PDCCH monitoring. If non-adaptive PDCCH periodicity is applied, one source shows 32% - 50% power saving gain subject to 56% - 116% latency increase. Generally, the larger the PDCCH monitoring periodicity, the larger the power saving gain but the associated latency increase would be higher.

Table 10: Power saving scheme with triggering UE adaptation to reduce PDCCH monitoring (PDCCH skipping, "go-to-sleep" signal)

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Mediatek [59]	Rel-15 MAC-CE-based Go-To-Sleep signalling	42.21% ~ 56.05%	FTP/Video: 56.05% IM: 48.30% VoIP: 42.21%	Latency Increase: FTP/Video: 77.54% IM: 9.84% VoIP: 59.39%	RU increase: FTP/Video: -1.25% IM: 0.65% VoIP: -26.53%	CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	
Huawei [57]	Go-to-sleep (GTS) signaling	9.22% ~ 27.31%	Average power: (76.45/69.40)~(97.75/71.05)	UPT: 5.58%~39.15% Latency: 0.04%~18.69%	$1.45*10^{-6}$ ~ $1.24*10^{-4}$	SLS DRX config: (320, 200, 10), (320, 80, 10), (160, 100, 8), (160, 40, 8), (40, 25, 4), (40, 10, 4)	10 UEs in a cell
Vivo [39][58]	DCI explicit indication of PDCCH monitoring occasions within a periodicity	0%-83%	0%-57% (for gaming and for all UE)	Average packet Latency: 20.81 ms; Latency increase: 3%-24%	One PDCCH per 40 ms	Numerical simulation; Baseline assumption: 1)Fixed PDCCH monitoring periodicity without CDRX; 2)CDRX; Traffic: gaming and ftp model 3	
			6%-59% (for FTP3, and for UE of 5 percentile SINR)	Average packet Latency: 40.11-119.45 ms; Latency increase: -89%-106%	One PDCCH per 50, 160 and 200 ms		
			3%-80% (for FTP3, and for UE of 50 percentile SINR)	Average packet Latency: 29.37-105.25 ms; Latency increase: -92% -122%	One PDCCH per 50, 160 and 200 ms		
			2%-83% (for FTP3, and for UE of 95 percentile SINR)	Average packet Latency: 28.23-103.65 ms; Latency increase: -92% -124%	One PDCCH per 50, 160 and 200 ms		
Mediatek [59]	Skipping PDCCH for a specified time via DCI	22.44% ~ 33.17%	FTP/Video: 33.17% IM: 30.76% VoIP: 22.44%	Latency Increase: FTP/Video: 14.62% IM: 1.28% VoIP: 7.82%	RU Increase: FTP/Video: -1.34% IM: 0% VoIP: -1.02% DCI Overhead (w.r.t. data DCI): FTP/Video: 93.91%	CDRX config: FTP/Video (160, 100, 8) IM (320, 80, 10) VoIP (40, 10, 4)	Repeatedly skipping 7 slots of PDCCH monitoring after DCI indication during data inactivity

					IM: 1250.81% VoIP: 286.02%		
CATT[21][60]	Power saving signal trigger PDCCH reduction and power saving reference signal for channel tracking, CSI measurement.	50.3% ~ 65.9%	ftp3 with 320ms DRX-cycle:50.3% IM with 160ms DRX-cycle:65.9%	--	Power saving signal is smaller PDCCH overhead.	SLS with 10UE per TRP to get transmission rate, and observed one single UE for power consumption. Baseline: R15DRX scheme, considering procedure of channel tracking, CSI measurement. FTP3 with 0.5Mbytes and 200ms inter-arrival time, IM with 0.1Mbytes and 2s inter-arrival time	
ZTE [19][41][61]	Power saving signal triggering UE go to sleep by indicating a sleep duration	21%-54%	Sleep duration=2ms: 22%-28% Sleep duration=4ms: 21%-33% Sleep duration=8ms: 29%-54% Sleep duration=16ms: 32%-54%			Numerical simulation; FTP3 model: file size=0.1Mbps,mean inter-arrival time 200msec CDRX config: 40-10-4 40-25-4 160-40-8 160-100-8 320-80-10 320-200-10 Baseline: No GTS	Peak throughput: 10-symbol PDSCH in one slot; 100 MHz BWP No UL. Single UE
LG[46][62]	GTS triggering sleep (1) Via MAC message (2) Via L1 signaling	(1) 44.12%-75.72% (2) 45.56%-78.43%		UPT loss: (1) 27.30%-41.57% (2) 30.60%-43.02%		Traffic model: FTP3 with file size 0.5Mbps, DRX configuration (160,100,8)	Reference schemes: PDCCH monitoring periodicity: 1 slot, K0=0
Samsung [34][64]	Dynamic PDSCH reception without PDCCH	38.7%	RS based power saving signal for PDSCH reception indication with monitoring periodicity of 1slot/0.5ms	1.68Gbps/0.52ms	PDCCH DMRS like power saving signal is considered for PDSCH reception indication.	Numerical simulation No C-DRX, FTP3 traffic model w/ mean of inter-packet arrivals = 8ms	Single UE. One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits.
Interdigital [66]	Reduced PDCCH monitoring by informing UE of scheduling pattern in advance	24% - 51%	FTP: 28.1%, 27.1%, 24.2% IM: 50.1%, 50.7%, 33.8%	No impact		SLS Case 1(160, 100, 8), Case 2 (40, 25, 4), Case 3(40, 10, 4) Case 4(320, 80, 10) FTP (Case 1, 2, 3) IM (Case 2, 3, 4)	10 UEs per cell Average gain Higher gain observed for IM traffic with shorter DRX cycle.
Apple [68][84]	1) gNB can send sleep indication to UE to make UE enter sleep state (e.g., skipping PDCCH) for specified amount of time. 2) UE enters sleep state (e.g., skipping PDCCH monitoring) for the specified amount of time once it receives sleep indication from gNB.	37%~71%	71% for low load when mean inter-grant arrival T is 20 slots. 55% for medium load (T=10) 37% for high load (T=5)			Evaluation Method = Numerical Simulation Baseline has no DRX considered.	DRX1=(10,10,4) DRX2=(40,10,4) DRX3=(40,25,4) DRX4=(160,100,8) DRX5=(320,200,10)
	1) gNB can send sleep indication (e.g., when DL queue is empty) to make UE enter sleep state until next ON duration. 2) If UE receives sleep indication, UE sleeps (e.g., skip PDCCH monitoring) until the next ON duration.	57~69%	69% for DRX5 57% for DRX4	20Mbps		Evaluation Method = Numerical Simulation, DRX5=(320,200,10) DRX4=(160,100,8) Baseline has no GTS signal	
	PDCCH skipping	Ideal indication: 11.4 ~ 47.3%	For PDCCH period 1 slot: 47.3% 2 slots: 31.5%	Latency increase for PDCCH period 1 slot: 0.57%		SLS	- Gain in average power consumption

Qualcomm [30][48][70]			4 slots: 19.3% 8 slots: 11.4%	2 slot: 0.80% 4 slot: 1.37% 8 slot: 2.50%		**FR1, no DRX** FTP3, $k0 > 0$, genie-aided PDCCH skipping indication	- Baseline latency: 87.6ms (PDCCH period 1 slot)
		SFI-based indication: 7.8% ~ 44.6%	For PDCCH period 1 slot: 44.6% 2 slots: 28.5% 4 slots: 16.0% 8 slots: 7.8%	Latency increase for PDCCH period 1 slot: 0.57% 2 slot: 0.80% 4 slot: 1.37% 8 slot: 2.50%	Signaling overhead: skipping indication (SFI) transmitted at rate of 20.75%	SLS **FR1, no DRX** FTP3, $k0 > 0$, SFI-based PDCCH skipping indication with periodicity of 8 slots	
		Ideal indication: 21.4 ~ 67%	For PDCCH period 1 slot: 67.0% 2 slots: 50.7% 4 slots: 34.4% 8 slots: 21.4%	Latency increase for PDCCH period 1 slot: 0.46% 2 slot: 0.91% 4 slot: 1.37% 8 slot: 2.74%		SLS **FR2, no DRX** FTP3, $k0 > 0$, genie-aided PDCCH skipping indication	- Gain in average power consumption - Baseline latency: 21.9ms (PDCCH period 1 slot)
		SFI-based indication: 11.9 ~ 62.3%	For PDCCH period 1 slot: 62.3% 2 slots: 44.4% 4 slots: 26.4% 8 slots: 11.9%	Latency increase latency for PDCCH period 1 slot: 0.46% 2 slot: 0.91% 4 slot: 1.37% 8 slot: 2.74%	Signaling overhead: skipping indication (SFI) transmitted at rate of 20.75%	SLS **FR2, no DRX** FTP3, $k0 > 0$, SFI-based PDCCH skipping indications with periodicity of 8 slots.	
		Ideal indication: 15.2 ~ 53.5%	For PDCCH period 1 slot: 53.5% 2 slots: 37.6% 4 slots: 24.3% 8 slots: 15.2%	Latency increase for PDCCH period 1 slot: 0.14% 2 slot: 0.28% 4 slot: 0.42% 8 slot: 0.84%		SLS **FR2, CDRX config = (160, 100, 4)** FTP3, $k0 > 0$, genie-aided PDCCH skipping indication	- Gain in average power consumption - Baseline latency: 71.85ms (PDCCH period 1 slot
		Ideal indication: 30.9 ~ 61.8%	For PDCCH period 1 slot: 61.8% 2 slots: 49.0% 4 slots: 38.2% 8 slots: 30.9%	Latency increase for PDCCH period 1 slot:0.13% 2 slot:0.25% 4 slot:0.37% 8 slot:0.75%		SLS **FR2, CDRX config = (160, 40, 4)** FTP3, $k0 > 0$, genie-aided PDCCH skipping indication	- Gain in average power consumption - Baseline latency: 80.25ms (PDCCH period 1 slot)
OPPO[20][42][74]	PDCCH skipping	45.77% and 60.82%	FTP: 45.77% IM: 60.82%		FTP: 0.3% IM: 0.3%	System level simulation. Traffic model: FTP3 and IM CDRX config: FTP: (160, 100, 8) IM: (320, 80, 10)	
Intel [45][65]	Power saving signal (go-to-sleep signal) triggering UE go to sleep for the specified amount of time	48.5-71.5%	48.52%	64.3/54.4 MBps (15.4%) / 85.8/100.1 ms (16.6%)		5% — System level simulation. FTP model 3 160, 100, 8	
			58.64%	87.0/71.4 MBps (17.9%) / 59.8/72.0 ms (20.3%)		50%	
			61.93%	91.4/73.2 MBps (19.8%) / 55.7/68.8 ms (23.6%)		95%	
			66.96%	5.79/5.36 MBps (7.4%) / 145.9/156.9 ms (7.6%)		5% — System level simulation Instant Messaging 320, 80, 10	
			67.74%	6.07/5.59 MBps (8.0%) / 142.2/153.7 ms (8.1%)		50%	
			68.35%	5.90/5.36 MBps (9.1%) / 144.2/158.2 ms (9.7%)		95%	
			58.93%	0.0286/0.0164 MBps (42.6%) / 10.2/23.8 ms (134.3%)		5% — System level simulation. VoIP 40, 10, 4	
			59.93%	0.0279/0.0148 MBps (47.0%) / 10.2/27.1 ms (165.2%)		50%	

			60.49%	0.0289/0.0154 MBps (46.6%) / 10.1/26.8 ms (165.3%)		95%		
			67.03%	0.0568/0.0252 MBps (55.7%) / 16.8/23.0 ms (36.6%)		5%	System level simulation. Gaming 40, 10, 4	
			68.82%	0.0531/0.0252 MBps (52.5%) / 17.2/22.7 ms (31.9%)		50%		
			68.28%	0.0491/0.0289 MBps (41.2%) / 16.0/21.9 ms (36.9%)		95%		
			59.57%	2.26/1.98 MBps (12.5%) / 132.9/148.8 ms (11.9%)		5%	System level simulation. Web browsing 320, 80, 10	
			59.6%	2.33/2.05 MBps (12.2%) / 130.9/145.8 ms (11.4%)		50%		
			59.67%	2.27/1.94 MBps (14.2%) / 130.3/148.2 ms (13.7%)		95%		
			70.16%	0.1152/0.0613 MBps (46.8%) / 8.58/19.79 ms (130.7%)		5%	System level simulation. Video streaming 40, 10, 4	
			71.55%	0.1192/0.0625 MBps (47.6%) / 8.44/19.79 ms (134.4%)		50%		
			71.42%	0.1155/0.0615 MBps (46.7%) / 8.74/19.88 ms (127.6%)		95%		
Nokia, NSB [71]	Go-to-sleep signal. DCI-based, indicating the UE can sleep until next On Duration. Based on a sliding window checking past x ms	DRX: 3-44 % Short DRX: 7-17 %	DRX: Version1 600 slots: +3.1 % 400 slots: +7.9 % 200 slots: +44.2 % Version2 600 slots: 0 % 400 slots: +3.0 % 200 slots: +36.1 % Short DRX: Version1 600 slots: +7.2 % 400 slots: +11.3 % 200 slots: +17.4 % Version2 600 slots: 0 % 400 slots: 0 % 200 slots: 0 %	DRX: Version1 600 slots: +1.0 % 400 slots: +3.7 % 200 slots: +21.9 % Version2 600 slots: 0 % 400 slots: +1.0 % 200 slots: +18.4 % Short DRX: Version1 600 slots: +2.8 % 400 slots: +4.2 % 200 slots: +2.8 % Version2 600 slots: 0 % 400 slots: 0 % 200 slots: 0 %	GTS is included in the PDCCH DCI so minor overhead	Numerical simulation Results are compared to each DRX configuration without GTS. Version1: send GTS if window is empty Version2: send GTS if window is empty and Inactivity Timer is running Long DRX cycle only (as per MAC specification 38.321). Made for FTP3 Cases: DRX: 160 ms DRX cycle, 100 ms inactivity timer, 8 ms On Duration. Short DRX: 40 ms DRX cycle, 5 ms inactivity timer, 4 ms On Duration, 20 ms short DRX cycle, 5 short cycles GTS windows are 600, 400, 200 slots		DRX: No GTS: 141272445 units, Version1: 600 slots 136919235 units, 400 slots 130127331 units, 200 slots 78768183 units, Version 2 600 slots 141272445 units, 400 slots 137092359 units, 200 slots 90270831 units, No GTS 51.1 ms Version 1: 600 slots 51.6 ms, 400 slots 53.0 ms, 200 slots 62.3 ms Version 2: 600 slots 51.1 ms, 400 slots 51.6 ms, 200 slots 60.5 ms Short DRX: No GTS: 100934244 units, Version1: 600 slots 93676773 units, 400 slots 89502438 units, 200 slots 83327871 units, Version 2 600 slots 100934244 units, 400 slots

							100934244 units, 200 slots 100934244 units, No GTS 14.3 ms Version 1: 600 slots 14.7 ms, 400 slots 14.9 ms, 200 slots 14.7 ms Version 2: 600 slots 14.3 ms, 400 slots 14.3 ms, 200 slots 14.3 ms

Table 10-1: Power saving scheme with PDCCH skipping or "go-to-sleep" signal comparing with short DRX

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)
Intel [101]	Long DRX operation with PDCCH skipping inactivity timer adaptation by WUS Long and short DRX	36% to 58% w.r.t C-DRX	Cast 1: Baseline 36% for Case 2 46% for Case 3 54% for Case 4 24.98 for Cast 5 20.73 for Case 6 18.9 for Case 7 19.07 for Case 8	41.22 and 21.93 ms for Case 1 47.03 and 26 ms for Case2 30.57 and 18.92 ms for Case 3 36.96 and 26.72 ms for Case 4 63.25 ms for Case5 66.25 ms for Case6 68.58 ms for Case7 90.37 ms for Case8		CDRX config: Case 1(80, 5,8 or 40,5, 4) , Case 2(80,5, 8 or 40,5, 4) + GTS Case 3(80,5, 8 or 40, 5, 4) + short DRX (40,-, 3) Case 3(80,5, 8 or 40, 5, 4) + short DRX (20,-,5) Case 5(160, 100,8) + GTS 10, Case 6(160,100, 8) + GTS 20 Case 7(160, 100,8) + GTS 40, Case 8(160,100, 8) + MAC CE	System Throughput 107.4 and 108.6 for Case1 95.2 and 161 for Case2 140.8 and 217.8 for Case3 118.8 and 191 for Case4 78.7 for Case5 75.6 for Case6 72.5 for Case7 56.3 for Case8
Xiaomi [102]	Long DRX operation: with PDCCH skipping Long and short inactivity timer adaptation w and w/o WUS Long and short DRX	7.69% to 84.62% w.r.t Long C-DRX	58.97% for Case 11 38.42% for Case 12 79.49% for Case 2 7.69% w/o WUS and 69.29% w WUS for Cast 21 33.33% w/o WUS and 79.49% w WUS for Cast 22 51.28% w/o WUS and 82.05% w WUS for Cast 23 69.29% w/o WUS and 84.62% w WUS for Cast 24	43 ms for cas 0 51 ms for Case 11 47 ms for Case12 83 ms for Case 2 44 ms w/o WUS and 51 ms w WUS for Case21 45 ms w/o WUS and 52 ms w WUS for Case22 47 ms w/o WUS and 53 ms w WUS for Case23 55 ms w/o WUS and 61 ms w WUS for Case24		CDRX config: Case 0(160, 100,8) , Case 11(160,100, 8) + PS 10 Case 12(160,100, 8) + PS 5 Case 2 (160,100, 8) + MAC CE Case 21(160, 100,8) +short DRX10, Case 22(160,100, 8) + short DRX 20 Case 23(160, 100,8) + short DRX 40, Case 24(160,100, 8) + short DRX 80	For inactivity timer = 5ms, big power saving loss for all cases without WUS were observed. The power saving scheme with PDCCH skipping, WUS or MAC shows comparable power consumption. The latency of all power saving scheme is reduced.

Observation:

Reduction of PDCCH monitoring can also be achieved with explicit/implicit information for UE to skip monitoring PDCCH. A related approach, such as power saving signal/channel triggering/enabling PDCCH monitoring or "go-to-sleep" signaling where the gNB can signal the UE to go to the DRX OFF state or skip the PDCCH monitoring, is considered. Power saving gain in the range of 9%~83% is observed, with latency increase in the range of 0.1%~75% and overhead of 0% - 1% with one source showing 124% latency increase. Generally, the gain is higher for scenarios with CDRX configuration with larger DRX inactivity timer duration and for lower traffic load, and higher latency increase is associated with higher gain.

Table 11: Power saving schemes with CORESET/Search Space/blind decoding reduction

Company	Power saving scheme	Power saving gain	Power saving gain for each configuration	UPT/Latency	Estimated Overhead	Evaluation methodology/baseline assumption	Note (include UE throughput)

Nokia, NSB [37][51]	Reduce PDCCH blind decoding from reference (36) to {32, 16, 8, 4, 2} candidates	3-24%	32: +2.8 % 16: +14.1 % 8: +19.7 % 4: +22.5 % 2: +23.9 %	No latency impact evaluated		Numerical simulation FTP3, DRX configuration (160, 40, 8) with # blind decoding candidates = [32, 16, 8, 4, 2]. The baseline reference has the same DRX configuration but 36 blind decoding candidates.	It is shown in [99] that assuming that ¼ or ½ of the UEs to be scheduled in a CORESET operate in energy saving mode with number of blind decoding candidates reduced by 50% will cause an increase in average blocking probability by 50% and 100%, correspondingly.
Samsung [34][64]	Reduction on PDCCH candidates in achieving PDCCH blind decoding reduction	/w CDRX 26.7% ~ 2.7% w/o CDRX 28.9% ~ 3.3%	w/ CDRX (26.7%/26%,24.5%,21.3%,15.1%,2.7%) w/o CDRX (28.9%/28.1%/26.5%/23.2%/16.5%/3.3%)	19Mbps / 45.6ms 1.7Gbps / 0.5ms	DCI based power saving signal for triggering adaptation with monitoring, T = 1024ms	Numerical simulation FTP3 traffic model w/ mean of inter-packet arrivals = 200ms Number of BDs equals to (1,2,4,8,16,32)	Single UE. One PDSCH over 10 symbols in one slot is capable of carrying 868584 information bits.

Observation:

PDCCH blind decoding reduction can also be used to potentially reduce the UE power consumption. Power saving gain of 1.4%-11% is shown when the number of blind decoding candidates is reduced by half, with system level impact in terms of higher DL control blocking probability (e.g. assuming that 1/4 of the UEs are to be scheduled in a CORESET with such reduced blind decoding limit, the average blocking probability would increase by 50%). One source shows power saving gain of 29% with single blind decoding candidate without showing the results of latency and expected high blocking probability.

Observation:

In relation to above power saving schemes aforementioned, some Rel-15 C-DRX schemes are also evaluated compared to the agreed baseline. In one source, Rel-15 MAC-CE based DRX command is evaluated, and the gain is observed to be 42%~56% with latency increase of 10%~77% across three traffic types. In another source, short DRX supported in Rel-15 is evaluated and power saving of 30%~280% is observed with latency increase of 31%~97%.

5.1.6 UE assistance Information

The UE assistance information for any UE power saving scheme is for UE to provide the assistance information to the network in configuration for UE adaptation to achieve power saving gain. UE assistance information reported by UE for power saving is a UE recommendation and the network shall make the final decision on whether and how to use that information.

The UE assistance information for the power saving schemes for further studies are as follows,

- UE assistance information/feedback to assist network in configurations for UE adaptation
  - UE preferred processing timeline parameters, e.g., K0, K1, K2 values
  - UE preferred BWP information/configuration
  - UE preferred antenna configuration, including MIMO layers, antenna panel awareness information
  - UE assistance/feedback on the DRX configurations/parameters
  - UE preferred BWP provided to assist network in BWP switching
  - UE request on SCell/SCG activation/de-activation/configuration
  - UE preferred PDCCH monitoring parameters/search space configuration/maximum number of blind decoding

Observation:

Some UE assistance information has been used by the power saving schemes to adapt to the traffic resulting in power saving gain. Power saving schemes including UE assistance information in the evaluation show power saving gain of 9%-45% for UE adaptation to BWP switching, 4%-80% for UE adaptation to DRX operation, and 5%-43% for SCell operation.

5.2 Power saving signal/channel/procedure for triggering adaptation to UE power consumption

5.2.1 Power saving signal/channel

The power saving signal/channel for UE adaptation includes the following signals/channels for further study

- Existing signal/channel based power saving signal/channel
    - PDCCH channel
    - TRS, CSI-RS type RS, SSS-like and DMRS
    - PDSCH channel carried MAC CE and/or RRC signaling
- New power saving signal/channel – sequence based

The aspects of the power saving signal/channel used for the UE adaptation to the traffic used for further evaluation of power saving signal design in addition to its triggering to the power saving gain.

- Network resource overhead
    - Resource and/or periodicity of power saving signal/channel
    - Multiplexing capability - include total number of UEs supported
    - Usage of resource
- Coexistence/multiplexing with existed signal/channel of Rel-15
- UE-specific, group-specific, cell-specific power saving signal/channel
- Detection performance
- Complexity
- Power consumption of the power saving signal/channel
- The behaviour when miss detection/false alarm happens
- Multiplexing with other signals/channels
- Number of information bits

The performance evaluation of the power saving signal/channel should target the miss detection at X% and the false alarm rate at Y% with the following aspects identified for the proposed power saving signal/channel

- The target of miss detection X% and the false alarm rate at Y% as baseline for evaluation
    - For power saving signal/channel for wake-up purpose, X=0.1 and Y=1
    - For power saving signal/channel for go-to-sleep purpose, X=1 and Y=0.1
    - Additional X and Y values are not precluded for the proposed power saving signal/channel based on the use cases and scenarios
    - For any other purpose(s) of power saving signal/channel, companies to report X & Y values

- The target of miss detection would be different depending on the behaviour of miss detection of power saving signal/channel.
    - If miss detection behaviour is defined as no subsequent PDCCH reception, low miss detection rate is required in order to avoid increased latency of missed chance of the scheduling.
    - If miss detection behaviour is defined as subsequent PDCCH reception, low miss detection rate is not required.
- The miss detection performance when multiple power saving signal/channel are multiplexed on the same resource, when applicable
- The performance of the power saving signal/channel should assume realistic implementation limitations, e.g., by using realistic channel estimation and time/frequency offset estimation, etc.

The UE miss detection performance results of UE power saving signal/channels, such as PDCCH based GC-PDCCH based, CSI-RS, TRS, SSS, and single-stage or multi-stage new sequences, are shown in Table 12.

Table 12: Miss detection performance of power saving signal/channel

Company	Power saving signal/channel	Required SNR at miss detection= 0.1%	False alarm rate	Multiplexing capacity	Trans. inform. Bits	Evaluation methodology/baseline assumption	Note
vivo *[73]*	PDCCH based	About [3, 6.1] dB for AL=[2, 4], inform. bits=12; About [2.3, 3.3] dB for AL=2, inform. bits=[1, 2]		1	1, 2, 12	TDL-C Low 100ns 10Hz; 1TX/2RX; SCS=30KHz; CSI-RS: 51 RBs, 1 OS SSS: 127 REs	
	CSI-RS	About 2.5 dB for density=3	1%	1	1		
	SSS	About [0.4, 1.2] dB for inform. bits=[1 2]	1%	1	1-2		
MTK[74]	PDCCH based	[5.7, 2.2, -2.4, -5.4, -9] dB for AL=[1, 2, 4, 8, 16] and delay spread 30 ns [6.5, -0.3, -3.6, -7.5, <-10] dB for AL=[1, 2, 4, 8, 16] and delay spread 100 ns [8.4, -0.4, -4.6, -8.7, <-10] dB for AL=[1, 2, 4, 8, 16] and delay spread 300 ns	1%	1	1	TDL-C 3km/hr with delay spread: 30 ns, 100 ns or 300 ns; 2TX/2RX; PDCCH/GC-PDCCH: 54/108/216/432/864 REs for AL1/2/4/8/16; Sequence detection for PDCCH, and Polar decoding for GC-PDCCH TRS: 312 REs in 52 RBs SSS: 127 REs in 12 RBs	
	TRS	-3.3 dB for delay spread 30 ns -5.3 dB for delay spread 100 ns -6 dB for delay spread 300 ns	1%	1	1		
	SSS (UE specific)	M = 1 UE: 1.2 dB for delay spread 30 ns 0.2 dB for delay spread 100 ns -0.3 dB for delay spread 300 ns M = 6 UEs: 8.9 dB for delay spread 30 ns 8.5 dB for delay spread 100 ns 7.9 dB for delay spread 300 ns	1%	M	1 per UE		
	GC-PDCCH based	M = 6 UEs; 2 bits per UE: [4.5, -5.7] dB for AL=[2, 16] and delay spread 30ns; [3.6, -7.7] dB for AL=[2, 16] and delay spread 100ns [4.4, -7.6] dB for AL=[2,	1%	M	2 per UE		

		16] and delay spread 300ns					
QC [86]	PDCCH based	FR1: About [3.5, -1.5, -5] dB for AL=[2, 4, 8], 2RX, TDL-A 30ns, inform. bits = 12; About [6, -1, -4] dB for AL=[2, 4, 8], 2RX, TDL-C 300ns, inform. bits = 12; About [5.5, 0, -3] dB for AL=[2, 4, 8], 2RX, TDL-A 30ns, inform. bits = 30; About [9, 1.5, -2.5] dB for AL=[2, 4, 8], 2RX, TDL-C 300ns, inform. bits = 30;		1	12, 30	Simulation parameters specified in Table A1.5-1 in TR38.802 For FR2: CDL-C 300ns; Carrier frequency: 30 GHz; 3 or more beams	
		FR2: 3dB for AL=8, 3 beams swept, for AL=4, 7 beams swept and up to 160ms C-DRX cycle.		1	24		
	CSI-RS-WUS	FR2: 3dB	1%	1			
Nokia, NSB [87]	PDCCH based	About [-2.5, -5.4] dB for AL=[8, 16], TDL-C 100ns, SCS=15KHz; About [-2, -5] dB for AL=[8, 16], TDL-C 300ns, SCS=15KHz; About [-3, -5] dB for AL=[8, 16], TDL-C 100ns, SCS=30KHz; About [-3, -4.5] dB for AL=[8, 16], TDL-C 300ns, SCS=30KHz;		1	10	TDL-C 100ns, 300ns; SCS=15KHz, 30KHz; 2TX/2RX ; SSS:127 REs	
	DMRS	About [-1, -4] dB for RBs=[48, 96], TDL-C 100ns, SCS=15KHz; About [-0.5, -4] dB for RBs=[48, 96], TDL-C 300ns, SCS=15KHz; About [-0.5, -4] dB for RBs=[48, 96], TDL-C 100ns, SCS=30KHz; About [1, -2] dB for RBs=[48, 96], TDL-C 300ns, SCS=30KHz;		1			
	SSS	>3dB	1%	1			
CATT*[75]*	PDCCH based	About [-9.15, -12.5, -15.2]dB for AL=[4，8, 16]		1	12	AWGN; 2TX/1RX; SCS=15KHz; CSI-RS: 150REs	
	CSI-RS	-13.3dB	1%	1			
	Multi-stage sequences	About [-15.1, -18, -20.97] dB for [256, 512, 1024] REs	1%	M, e.g., 16	$Log_2(N^2)$, N=256,512,1024		
	Single stage sequence	About [-15.1, -18, -20.97] dB for [256, 512, 1024] REs	1%	M, e.g., 16	$Log_2(N)$, N=256,512,1024		
Ericsson[85]	PDCCH based	About [-3, -6.5] dB for AL=[8, 16], inform. bits = 4; About [-2, -5] dB for AL=[8, 16], inform. bits = 30		1	4, 30	TDL-C 300ns; SCS=30KHz;	

	On-off keying sequence	3 dB				TDL-C SCS=15KHz;	
Intel[81]	PDCCH based	About [-1.4, -3.8, -6.2] dB for AL=[4, 8, 16]		1	12	TDL-C 30ns; 2TX/2RX; TRS: 288 REs (48 RBs, 2 OS; 96 RBs; 1 OS), 576 REs (96 RBs, 2 OS), RS density = 3	
	TRS	About [0, -1, -4] dB for [48 RBs, 2 OS; 96 RBs, 1 OS; 96 RBs, 2 OS], inform. bits=2; About -3 dB for 96 RBs, 2 OS, inform. bits=6	1%	1	2, 6		
OPPO[83]	CSI-RS	-6 dB	1%	1		Simulation parameters specified in Table A1.5-1 in TR38.802 2TX/2RX; CSI-RS: 24 RBs RS density = 3	
HW[72]	PDCCH based	About [3, 0, -2, -4, -6] dB for AL=[1, 2, 4, 8, 16]		1	4	CDL-C 100ns; 2TX/2RX; SCS = 30KHz	
Samsung[79]	DMRS	About [6, 0, -4.5] dB for [48 RBs, 1 OS; 24 RBs, 2 OS; 48 RBs, 2 OS] to reach 1% MDR	1%	1		TDL-A 30ns; 1TX/2RX CSI-RS config. [63]: config2: RS density=2, 2 OS config3: RS density=2, 4OS	
	CSI-RS	About [0, -3, -6] dB for [48 RBs, config2; 24 RBs, config3; 48 RBs, config3] to reach 1% MDR	1%	1			
	Second level DMRS	About [1, 0, -2, -3] dB for inform. bits=[4, 3, 2, 1] to reach 0.1% ER		1	1~4		
	Second level CSI-RS	About [6, 4.5, 2.5, 0] dB for inform. bits=[4, 3, 2, 1], config2 to reach 0.1% ER		1	1~4		
ZTE[61]	PDCCH based	About [2, -3] dB for AL=[2, 4]		1	12	TDL-C 300ns; 2TX/2RX	
	CRI-RS	About [1, -3.5] dB for CSI-RS sequence length=[108, 216]	1%	1			
Sony[78]	On-off keying sequence	[At BER = 0.15]	1%			AWGN; WUS length: 63 bits; SCS = 15KHz	

Observations:

- Power saving signal/channel used as the UE wakeup in triggering UE adaptation to the DRX operation shows the power saving gains 4%-97% with some overheads 0% -3.5%.
- Power saving signal/channel triggering to assist the BWP switching shows the power saving gain 25% - 55% with the overhead of 7%-21% from the additional RS.
- Power saving signal/channel triggering/enabling PDCCH monitoring reduction achieves the power saving gain 50%-66% with 1.7% overhead.
- The 0.1% miss detection performance of different power saving signal/channel, such as PDCCH-based, TRS, CSI-RS, DMRS, SSS-like, new sequence type, such as OOK, Gold sequence, had been shown with the required

SINR range -6 dB to 5.7 dB with false alarm probability at 1%. Fewer resource used by power saving signal/channel or beam degradation would require higher SINR operating point. The power saving signal/channel also has the multiplexing capability ranged 1-16 UEs in the evaluation depending on the power saving signal/channel type. The power saving signal/channel may carry additional information bits in addition to the triggering for UE adaptation. The power saving signal/channel detection performance shows that it is adequate for triggering the UE adaption to the power consumption.

5.2.2 Power saving procedure

The power saving signal/channel in triggering UE adaptation to DRX operation for further study is that the power saving signal/channel can be configured along the DRX configuration as the indication for UE to wake up from the sleep state. RS resources can be considered to assist UE in performing RRM/CSI measurement and channel time/frequency and/or beam tracking.

The power saving signal/channel candidate in triggering UE to achieve reducing PDCCH monitoring for further study is that the power saving signal/channel can be used to trigger UE to skip the PDCCH monitoring and/or to go to sleep for a period of time.

The power saving signal/channel in triggering UE frequency domain processing adaptation for further study is the power saving signal/channel can be used to trigger the indication of RS configuration for channel tracking, CSI measurements, and beam management for the additional assistance of dynamic switching of BWP or activation of SCell in achieving the power saving gain. The power saving signal/channel can be used for BWP switching, activation/deactivation of SCell or adaptation of PDCCH monitoring and/or CORESET/search space of PCell/SCell.

For further study, the power saving signal/channel in triggering adaption to the UE processing, such as MIMO configuration/layers, antenna configuration, UE processing time, and background processing can be used as the indication for UE adaptation. The power saving signal/channel in triggering UE adaptation to the processing is to allow UE in reducing the power consumption by indication of the processing time, such as PDCCH/PDSCH/PUSCH/PUCCH processing or the essential background processing, such as periodic CSI and RRM measurements.

5.2.3 Additional RS

Additional RS is the RS provided by gNB to assist UE in performing e.g., fine synchronization, channel/beam tracking, and/or CSI/RRM measurements in addition to the existing RS in Rel-15. The additional RS was proposed for study for power saving schemes for e.g,, UE adaptation to the DRX operation, BWP switching, fast SCell activation, reducing PDCCH monitoring, and/or RRM measurements. RS design is assumed to reuse Rel-15 waveform. Power saving signal could be used to meet the purpose of additional RS.

5.3 Power consumption reduction in RRM measurements

The RRM power saving study should consider RRC IDLE, INACTIVE and CONNECTED states. The deployment scenarios for further studies of RRM power saving focus on the stationary (e.g., 0km/h), pedestrian (e.g., 3km/h) and vehicular (e.g., 30km/h) scenarios when considering UE power saving techniques for RRM measurements,

- For IDLE/INACTIVE state, at least the following power components are recommended to be considered for RRM measurement power saving evaluation
    - Loop convergence (AGC, TTL & FTL) / time-frequency tracking
        - How many SSB bursts are used for Loop convergence, with consideration of being potentially confined in the same SSB burst or different SSB bursts for serving cells and neighboring cells measurement/ time-frequency tracing
        - FFS: The power value for loop convergence /time-frequency tracking is as the same as SSB processing.
    - Paging
    - SIB1 decoding (PDCCH+PDSCH)
    - Neighboring cell search (within SMTC), if any
    - SSB measurement (serving cell only / severing cell and neighboring cells, if any)
    - Sleep

- For CONNECTED state, at least the following power components are recommended to be considered for RRM measurement power saving evaluation,
  - Loop convergence (AGC, TTL & FTL) / time-frequency tracking
    - How many SSB bursts are used for Loop convergence, with consideration of being potentially confined in the same SSB burst or different SSB bursts for serving cells and neighboring cells measurement/ time-frequency tracing
    - Based on SSB and/or TRS(if configured)
  - PDCCH-only monitoring during active time
  - SSB measurement (serving cell only / severing cell and neighboring cells, if any)
  - Neighboring cell search (within SMTC), if any
  - Sleep

The following adaption mechanism of RRM measurement activities for UE power saving:

- gNB controlled RRM measurement operation with UE assistance information reported to gNB, e.g.,
  - mobility related information (e.g., mobility state, history of mobility state, UE's visited cells and cells not reselected due to the ping-pong effect, the number of handovers for certain period, etc.)
  - channel condition (e.g. change in serving RS/signal)
- gNB controlled RRM measurement operation without UE assistance information reported to gNB based on certain conditions, e.g.,
  - Doppler estimation for RRC CONNECTED states
  - cell type (e.g., small cell/macro cell)
- gNB controlled threshold to support UE autonomous RRM measurement adaptation based on e.g.,
  - signal measurements (e.g., RSRP)
  - UE mobility state (e.g., low/medium/high mobility)
  - UE location in the cell (e.g., cell-center/cell-edge)
  - S-measure enhancement (e.g. S-measure for SCell, CSI-RS)
- Other mechanisms/approaches are not precluded

5.3.1 Adapting/Relaxing RRM measurement in time domain

- It is observed that the following
  - For certain conditions (e.g., low mobility deployment/UE speed/favorable RSRP conditions), the number of RSRP measurement samples for a given duration (e.g., measurement period / evaluation period) can be relaxed with negligible impact on accuracy achieved by existing Rel-15 measurement.
  - For certain conditions (e.g., favorable RSRP conditions, etc.), reducing RRM measurement activities (e.g., measurement, reporting) for a given time period is beneficial from UE power saving perspective for RRC IDLE/INACTIVE/CONNECTED states.
- For intra frequency and/or inter frequency measurement, the following approaches are to be studied for UE power saving in time domain, including impact on mobility performance
  - Increasing measurement period
  - Reducing number of samples (e.g., OFDM symbols / slots) within a measurement period (e.g., SMTC window)

  - Confining RRM measurements within a measurement window and increasing the periodicity of the measurement window for intra frequency and/or inter frequency measurement
  - Other approaches are not precluded
  - Note: this does not necessarily mean that the techniques studied will have spec impact
- For UE autonomous RRM measurement adaptation in time domain with gNB controlled threshold, the following thresholds and corresponding adaptation schemes can be considered,
  - A RSRP threshold for UE adapting RRM measurement period,
  - A RSRP threshold for UE adapting RRM number of samples within a measurement period,
  - A RSRP threshold and a RSRP variation threshold within a period of time, and based on that, UE can adapt the measurement or report period
  - A RSRP variation threshold within a period of time, and based on that, UE can adapt the measurement or report period
  - A threshold for UE adapting RRM measurement period and the threshold can be at least one of the followings,
    - The amount of time during which the UE stays with a specific cell or beam (for RRM measurement)
    - UE's active TCI state for PDCCH does not change for specific time period.
    - The number of handovers/reselections for certain period.
  - A threshold which includes UE mobility status, serving cell quality, and based on that, UE can adapt the SMTC window, number of CSI-RS resources sets per target cell, periodicity of CSI-RS resources.

Table 13: Evaluation of relaxed RRM measurement in time-domain

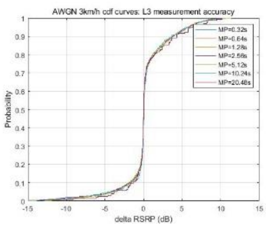
	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0) Power saving schemes description (1) Average power consumption (2) Power reduction compared to baseline [%]			(3) RRC Idle/RRC Inactive (i) or RRC Connected (c) (4)Measurement period [ms] (5)number of samples(e.g., SSB bursts) in each MP (6) UE speed and channel model (7) system impact, e.g., overhead (8) Performance impact (9)Additional assumption, e.g., PO and SSB offset,							Note
Source 1 Huawei [88]	If the RSRP of the serving cell is less than X, the MPs of serving cell and neighbour cells are according to RAN4's requirement; otherwise the MPs are N times of RAN4's requirement.	DRX cycle length = 0.32s 7.22(baseline) 5.21(N=4) *4.87(N=8)*	27.9% (N=4) 32.5% *(N=8)*	IDLE	-	1	3km/h and 30km/h NLOS	-	Little impact on RSRP accuracy, which can be seen in Fig. 1 in [88]. RSRP difference increases, which can be seen in Fig. 2 in [88].	The periodicity of SSB is 20ms, and the gap length between PO and SSB are randomly distributed	FR1 8 neighboring cells for intra-frequency measurement; 8 neighboring cells in each layer for inter-frequency measurement and totally 3 layers. Cell search is performed every three measurements. Group paging rate is 10%, and paging rate is 0%. 1 SSB burst set with 2 SSB is used for loop convergence, with periodicity of max (160ms, DRX cycle).
		DRX cycle length = 0.64s 4.11(baseline) 3.11(N=4) *2.94(N=8)*	24.75% (N=4) 28.6 *(N=8)*	IDLE	-	1		-			
		DRX cycle length = 1.28s 2.56(baseline) 2.05(N=4) *1.97(N=8)*	19.7% (N=4) 23.0% *(N=8)*	IDLE	-	1		-			
		DRX cycle length = 2.56s 1.78(baseline) 1.53(N=4) 1.48(N=8)	14.2% (N=4) 16.5% *(N=8)*	IDLE	-	1		-			
		DRX cycle length = 0.32s 3.35(baseline) 2.21(N=4) 2.02(N=8)	34.0% (N=4) 39.7 *(N=8)*	IDLE	-	1	3km/h and 30km/h LOS	-			
		DRX cycle length = 0.64s 2.17(baseline) 1.60(N=4)	26.2% (N=4) 30.6% *(N=8)*	IDLE	-	1		-			

		1.51(N=8)									
		DRX cycle length = 1.28s 1.59(baseline) 1.30(N=4) 1.25(N=8)	17.9% (N=4) 20.9% *(N=8)*	IDLE	-	1		-			
		DRX cycle length = 2.56s 1.29(baseline) 1.15(N=4) 1.13(N=8)	11.0% (N=4) 12.8% *(N=8)*	IDLE	-	1		-			
Source 2 Vivo [89]	Only SSB is used for RRM (2 samples per DRX cycle)	4.17	Baseline1	Idle	320	2	TDL-C 3km/h 30km/h	Low	RSRP accuracy impact are captured in Figure 2-3 in [89]	The power saving gain is average gain of [0-10] ms SSB/CSI-RS and PO offset. Additional assumptions: 1. The duration of SSB/CSI-RS measurement occasion per paging cycle is 2ms. 2. Periodicity of SSB is 20ms and SSB is transmitted in the 1st slot of each 20ms period. 3. Periodicity of CSI-RS is 10ms and CSI-RS is transmitted in the 6th slot of each radio frame. 4. Paging cycle (DRX cycle) is 320ms, and the paging is monitored in one slot in first 2 radio frames of each paging cycle by different UEs with equal probability (random paging occasion). 5. Assuming no cell reselection. Thus no SIB1 energy consumption is included. 6. Assuming no additional resource for AGC tuning. The slot duration is based on 30 kHz SCS for FR1 and 120kHz for FR2.	FR1
	The number of measurement samples is reduced to 1 per paging cycle in idle state. Measurement is still based on SSB	2.84	31.9%	Idle	320	1		Low			
	The measurement periodicity is extended to 2 paging cycle, 2 measurements sample per paging cycle.	3.02	27.6%	Idle	640	2		Low			
	Only SSB is used for RRM (2 samples per DRX cycle)	2.97	Baseline2	Idle	320	2		Low			FR2
	The number of measurement samples is reduced to 1 per paging cycle in idle state. Measurement is still based on SSB	2.173	26.8%	Idle	320	1		Low			
	The measurement periodicity is extended to 2 paging cycle, 2 measurements sample per paging cycle.	2.11	29%	Idle	640	2		Low			
	Reduce RRM measurement in RRC connected state. with short DRX InactivityTimer	40.45	Baseline1	Con	200	5		Low		Long DRXCycle = 160ms, onDurationTimer = 8ms, data_rate=300Mbps FTP Model 3, packet size =0.5MByte Periodic activities is not modeled, e.g., AGC	FR1, 200 ms measurement period is considered as the baseline. DRX InactivityTimer = 40ms
		35.80	11.5%	Con	400	5		Low			
		31.38	22.4%	Con	800	5		Low			
	Reduce RRM measurement in RRC connected state. With long DRX InactivityTimer	73.65	Baseline2	Con	200	5		Low			FR1, 200 ms measurement period is considered as the baseline. DRX InactivityTimer = 100ms
		69.98	5.2%	Con	400	5		Low			
		69.15	6.2%	Con	800	5		Low			
Source 3 MediaTek [90]	UE adapts the measurement period to be 2 times default measurement period when PCell RSRP is 2dB better than the best neighbor cell and 4 times default measurement period when PCell RSRP is 4dB better than the best neighbour cell	28.28 (baseline is 35.95 according to Table II)	21.34% (55.64 % RRM measurement is saved)	Con	200/400/800	5	30km/h, 3D UMa with 200m ISD	Near negligible, only simple comparison is needed	handover fail rate 2.08% → 2.81%	CDRX-cycle=40ms DRX-on=4ms SMTC window=2ms SMTC period=20ms, Light sleep time for Case 2=8ms FR1	Periodic activities, e.g. time/frequency, channel or beam tracking, and loop convergence, are performed every 160ms during the SMTC window. Periodic activities will align with RRM measurement if possible.
	UE adapts the measurement period to be 2 times default measurement period when PCell RSRP is 2dB better than the best neighbor cell and 4 times default measurement period when PCell RSRP is 4dB better than the best neighbour cell. UE keeps default measurement period when the variation between two serving cell RSRP measurements is larger than 0.3dB.	29.45 (baseline is 35.95 according to Table II)	18.08% (47.42 % RRM measurement is saved)	Con	200/400/800	5	30km/h, 3D UMa with 200m ISD	Near negligible, only simple comparison is needed	handover fail rate 2.08% → 2.43%	CDRX-cycle=40ms DRX-on=4ms SMTC window=2ms SMTC period=20ms, Light sleep time for Case 2=8ms FR1	Periodic activities, e.g. time/frequency, channel or beam tracking, and loop convergence, are performed every 160ms during the SMTC window. Periodic activities will align with RRM measurement if possible.
	UE adapts the measurement period to be 2 times default measurement period when PCell RSRP is 2dB better than the best	29.49 (baseline is 35.95 according to Table II)	17.97% (46.76 % RRM measurement	Con	200/400/800	2	120km/h, 3D UMa	Near negligible, only	handover fail rate 9.03% → 10.07%	CDRX-cycle=40ms DRX-on=4ms	Periodic activities, e.g. time/frequency, channel or beam tracking, and loop convergence, are performed every 160ms during the SMTC window.

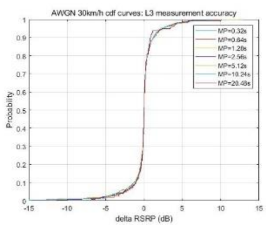
	neighbor cell and 4 times default measurement period when PCell RSRP is 4dB better than the best neighbour cell		is saved)				with 500 m ISD	simple comparison is needed		SMTC window=2ms SMTC period=20ms, Light sleep time for Case 2=8ms FR1	Periodic activities will align with RRM measurement if possible.
	UE adapts the measurement period to be 2 times default measurement period when PCell RSRP is 2dB better than the best neighbor cell and 4 times default measurement period when PCell RSRP is 4dB better than the best neighbour cell. UE keeps default measurement period when the variation between two serving cell RSRP measurements is larger than 1dB.	30.78 (baseline is 35.95 according to Table II)	14.38% (37.38 % RRM measurement is saved)	Con	200/400/800	2	120 km/h, 3D UMa with 500 m ISD	Near negligible, only simple comparison is needed	handover fail rate 9.03% → 9.59%	CDRX-cycle=40ms DRX-on=4ms SMTC window=2ms SMTC period=20ms, Light sleep time for Case 2=8ms FR1	Periodic activities, e.g. time/frequency, channel or beam tracking, and loop convergence, are performed every 160ms during the SMTC window. Periodic activities will align with RRM measurement if possible.
Source 4 CATT [91]	UE performs 5 measurement in one measurement period.	30.24	baseline	Con	200	5	3km/h	-	- Fulfilling the RSRP accuracy requirement in RAN4 RSRP accuracy impact are captured in [91]	DRX-cycle=40ms, DRX-on=4ms, SMTC period = 20ms	Relaxing samples in MP
	UE reduces the number of measurement samples in one measurement period from 5 to 3.	27	10.71%	Con	200	3	3km/h	-		DRX-cycle=40ms, DRX-on=4ms, SMTC period = 20ms	
	UE performs 5 measurement in one measurement period.	10.08	baseline	Con	800	5		-		DRX-cycle=160ms, DRX-on=8ms, SMTC period = 20ms	
	UE reduces the number of measurement samples in one measurement period from 5 to 3.	9.55	5.26%	Con	800	3		-		DRX-cycle=160ms, DRX-on=8ms, SMTC period = 20ms	
	UE performs 5 measurement in one measurement period.	5.88	baseline	Con	1600	5		-		DRX-cycle=320ms, DRX-on=10ms, SMTC period = 20ms	
	UE reduces the number of measurement samples in one measurement period from 5 to 3.	5.35	2.57%	Con	1600	3		-		DRX-cycle=320ms, DRX-on=10ms, SMTC period = 20ms	
	The measurement period is 800ms.	11.5	baseline	RRC Connected	800	5	-	-		DRX-cycle=160ms, DRX-on=8ms, SMTC period = 40ms	Relaxing measurement period
	The measurement period is extended from 800ms to 1600ms	10.13	11.91%	RRC Connected	1600	5	-	-		DRX-cycle=160ms, DRX-on=8ms, SMTC period = 40ms	
	The measurement period is extended from 800ms to 3200ms	9.45	17.83%	RRC Connected	3200	5		-		DRX-cycle=160ms, DRX-on=8ms, SMTC period = 40ms	
Source 5 Sony[93]	Reduced number of samples per measurement period	32.28	24%	Conn	80	2/slot	N/A	None	-		Baseline power is 42.4 units
	Reduced number of samples per measurement period	27.21	36%	Conn	160	2/slot	N/A	none	-		
Source 6 DoCoMo [94]	Normal case	31	baseline	Conn	320	5	3km/h			FR1	C-DRX cycle = 40ms, C-DRX on duration = 4ms 3km/h pedestrian, PDCCH-only monitoring during active time
	Relaxed RRM in time domain	26.63	14.1%	Conn	640	5				FR1	
		25.75	16.9%	Conn	800	5				FR1	
		24.44	21.2%	Conn	1280	5				FR1	
		24	22.6%	Conn	1600	5				FR1	
		23.34	24.7%	Conn	2560	5				FR1	
Source 7 Qualcomm [96]	L = 1, R = 1/2	2.06	baseline	Idle/Inactive	1280	2	stationary			FR1	The considered adaptation skips the measurement in one or more I-DRX cycles which is defined by variable R (e.g., R = 1/2 means RRM measurement
		2.04	0.71%		1280	2					
	L = 4, R = 1/2	2.11	baseline		1280	2				FR1	
		2.07	1.85%		1280	2					

	L = 8, R = 1/2	2.19	b		1280	2				FR1	is skipped once every 2 DRXs). L denotes the number of SSBs in a SSB set Notes: (3) I-DRX/paging cycle (4) The number of SSB burst sets are used for RRM and AGC/T-F tracking loops (5) UE speed (km/h) or stationary
		2.11	3.57%		1280	2					
	L = 1, R = 1/4	2.06	baseline		1280	2				FR1	
		2.04	1.07%		1280	2					
	L = 4, R = 1/4	2.11	baseline		1280	2				FR1	
		2.05	2.78%		1280	2					
	L = 8, R = 1/4	2.19	baseline		1280	2				FR1	
		2.07	5.36%		1280	2					
	L = 1, R = 1/2	2.48	baseline		1280	3				FR1	
		2.47	0.59%		1280	3					
	L = 4, R = 1/2	2.53	baseline		1280	3				FR1	
		2.49	1.54%		1280	3					
	L = 8, R = 1/2	2.61	baseline		1280	3				FR1	
		2.53	3.00%		1280	3					
	L = 1, R = 1/4	2.48	baseline		1280	3				FR1	
		2.46	0.89%		1280	3					
	L = 4, R = 1/4	2.53	baseline		1280	3				FR1	
		2.47	2.32%		1280	3					
	L = 8, R = 1/4	2.61	baseline		1280	3				FR1	
		2.49	4.49%		1280	3					
Source 8 ZTE [92][61]	The measurement period is 800ms.	20.28	baseline	Connect	800	5	N/A	N/A	N/A	DRX:160-40-10 (cycle-inactivity timer-ON duration) offset：U(0, measurement period)	Cell number to be measurement is 8.
	The measurement period is extended from 800ms to 1600ms	18.78	7.4%	Connect	1600	5	N/A	N/A	N/A		
	The measurement period is extended from 800ms to 3200ms	18.03	11.1%	C	3	5	N	N	N/ A		
	The measurement period is 200ms.	31.15	baseline	Connect	200	5	N/A	N/A	N/A	DRX:40-10-4 (cycle-inactivity timer-ON duration) offset：U(0, measurement period)	
	The measurement period is extended from 200ms to 400ms	25.61	17.8%	Connect	400	5	N/A	N/A	N/A		
	The measurement period is extended from 200ms to 800ms	22.85	26.6%	Connect	800	5	N/A	N/A	N/A		
	The offset between SMTC window and DRX ON duration is subject to uniform distribution U(0, measurement period).	6.53	baseline	Idle/Inactive	320	1	N/A	N/A	N/A	DRX cycle is 320ms , PO：10%	Cell number to be measurement is 8.
	The offset between SMTC window and DRX ON duration is 0	5.65	13.5%	Idle/Inactive	320	1	N/A	N/A	N/A	DRX cycle is 320ms , PO：10%	
	The offset between SMTC window and DRX ON duration is subject to uniform distribution U(0, measurement period).	2.42	baseline	Idle/Inactive	1280	1	N/A	N/A	N/A	DRX cycle is 1280ms , PO：10%	
	The offset between SMTC window and DRX ON duration is 0	2.19	9.5%	Idle/Inactive	1280	1	N/A	N/A	N/A	DRX cycle is 1280ms , PO：10%	
	The offset between SMTC window and DRX ON duration is subject to uniform distribution U(0, measurement period).	20.28	baseline	Connect	800	5	N/A	N/A	N/A	DRX:160-40-10 (cycle-inactivity timer-ON duration) Baseline offset：U(0, measurement period)	

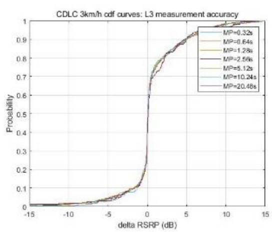
	The offset between SMTC window and DRX ON duration is 0	18.83	7.1%	Connect	800	5	N/A	N/A	N/A	DRX:160-40-10 (cycle-inactivity timer-ON duration) Baseline offset：U(0, measurement period)	
Source 9 Nokia [97]	System level evaluation of the impact of increasing measurement period. No power consumption analysis.	-	-	c	(a) 200ms (b) 400ms (c) 800ms (d) 1600 ms (e) 3200 ms	5 samples	3 km/h	N/A	Handover failure rate (%) (a) 0 (b) 0 (c) 0,26 (d) 0,14 (e) 0,49	System level assumptions given in[97]	
							30 km/h	N/A	Handover failure rate (%) (a) 0 (b) 0,08 (c) 0,41 (d) 1,57 (e) 11,33		
							60 km/h	N/A	Handover failure rate (%) (a) 0 (b) 0,33 (c) 1,00 (d) 3,68 (e) 25,89		
							120 km/h	N/A	Handover failure rate (%) (a) 0,17 (b) 0,86 (c) 3,14 (d) 15,59 (e) 56,74		



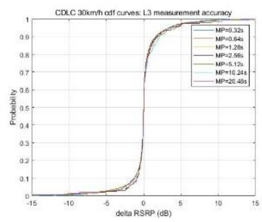
(1) AWGN RSRP accuracy at 3 km/hr [88]



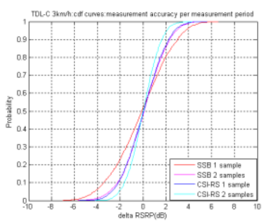
(2) AWGN RSRP accuracy at 30 km/hr [88]



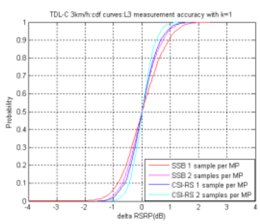
(3) CDL-C RSRP accuracy at 3 km/hr [88]



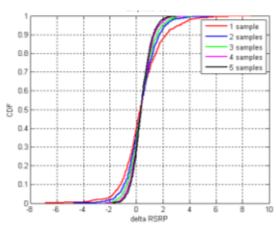
(4) CDL-C RSRP accuracy at 30 km/hr [88]



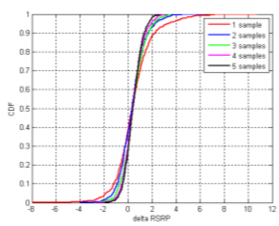
(1) L1 RSRP accuracy at 3 km/hr [89]



(2) L3 filtered RSRP accuracy at 3 km/hr[89]



(1) RSRP accuracy at 3 km/hr [91]



(2) RSRP accuracy at 30 km/hr[91]

For adapting/relaxing RRM measurement in time domain, the followings are observed from simulation results,

- For RRC CONNECTED state,
  - Among the results, 11.1% - 26.6% power saving gain is shown for extending measurement period 4 times, and 7.4% - 17.8% power saving gain is shown for extending measurement period 2 times, comparing with the baseline assumption.
- For RRC IDLE/INACTIVE state,

  - By increasing measurement period, the UE power saving gain at least depends on the number of I-DRX/paging cycles to be skipped for measurement and the number of SSB burst sets to be used for measurement and periodic activities. When measurement is performed once every 4 paging cycles, the gain is 17.9%-19.7% (one SSB burst set for measurement and periodic activities), 0.89%-5.36% (two or three SSB burst sets for measurement and periodic activities).

- While at the same time, for stationary or low mobility case, the mobility performance impact of increasing measurement period (e.g., handover failure rate, RSRP difference between two adjacent samples) is shown as follow,

  - The handover failure rate for RRC CONNECTED state is

    - with 4 times relaxing the measurement period, changed as follows:

      - 0% -> 0.26% for 3km/h, 0% ->0.41% and 2.08% ->2.81% for 30km/h, 0% ->1% for 60km/h, 0.17% ->3.14% and 9.03% -> 10.07% for 120km/h

    - with 16 times relaxing the measurement period, changed as follows:

    - 0% -> 0.5% for 3km/h, 0% -> 11.33% for 30km/h， 0% -> 25.89% for 60km/h, 0.17% -> 56.74% for 120km/h

    - the (5%-tile, 95%-tile) of the RSRP measurement error is within the range of (-4dB, 4dB) .

- It is shown that relaxing the number of samples within measurement period provides 2.57% - 36% power saving gain for RRC CONNECTED. For stationary or low mobility case, 1 source results show the (5%-tile, 95%-tile) of the RSRP measurement error is within the range of (-2dB, 3dB) for both 3km/h and 30km/h .

UE mobility/handover model and mobility performance metric follows TR36.839, where the handover is initiated based on an A3 RSRP measurement event (A3 event is also the major event for handover triggering from practical deployment) with detailed simulation model in [103].

For RRM measurement relaxation for all UEs in a cell, it is observed that:

- For 3km/h UE speed, relaxing the measurement period by 4 times, i.e. from 200ms to 800ms, impact on handover failure rate is negligible (i.e.,<=0.043% handover failure rate).

- For 30km/h or higher UE speed, relaxing the measurement period by 4 times, i.e. from 200ms to 800ms, impact on handover failure rate is non-negligible.

- For UE speed not higher than 30km/h, the impact of L1 measurement samples on handover failure rate is negligible (i.e., <=0.120% handover failure rate).

Table 13-1: Handover failure rate with different measurement periods (5 samples during one measurement period) for RRM measurement relaxation for all UEs in a cell

	UE speed 3km/h			UE speed 30km/h			UE speed 60km/h		
L3 Period(ms)	200	400	800	200	400	800	200	400	800
Timer-to-trigger: 0ms	0.000%	0.043%	0.043%	0.013%	0.135%	3.019%	0.052%	2.117%	15.840%
Timer-to-trigger: 320ms	0.000%	0.043%	0.043%	0.069%	0.334%	5.135%	0.375%	4.823%	21.461%
Timer-to-trigger: 640ms	0.043%	0.043%	0.043%	0.114%	0.755%	7.777%	1.519%	9.190%	27.117%

Table 13-2: Handover failure rate with different measurement L1 samples and same L3 period (measurement period is 200ms) for RRM measurement relaxation for all UEs in a cell

	UE speed 3km/h			UE speed 30km/h			UE speed 60km/h		
Samples in 200ms of L3 Period	5 (L1: 40ms)	2 (L1: 100ms)	1 (L1: 200ms)	5 (L1: 40ms)	2 (L1: 100ms)	1 (L1: 200ms)	5 (L1: 40ms)	2 (L1: 100ms)	1 (L1: 200ms)
Timer-to-trigger: 0ms	0.000%	0.000%	0.000%	0.013%	0.019%	0.019%	0.052%	0.057%	0.036%

Timer-to-trigger: 320ms	0.000%	0.000%	0.000%	0.069%	0.069%	0.050%	0.375%	0.318%	0.268%
Timer-to-trigger: 640ms	0.000%	0.000%	0.000%	0.114%	0.120%	0.120%	1.519%	1.413%	1.069%

For RRM measurement relaxation for partial UEs in a cell based on configurable relaxation conditions, e.g. RSRP threshold, it is observed that:

- For stationary or low speed UE, i.e. no more than 3km/h, relaxing the measurement period 4 times, i.e. from 200ms to 800ms, has no impact on mobility performance.
- For 30km/h UE speed, RRM measurement relaxation for partial UEs in a cell based on RSRP can achieve much lower handover failure rate (i.e., <=0.140% for 400ms measurement period, and <=0.654% for 800ms measurement period) than RRM measurement relaxation for all UEs in a cell, when the RSRP threshold is set to be 50% point of CDF curve for all UEs' serving cell RSRP.
- If the RSRP threshold is set to be an even higher value, e.g., 80% point of CDF curve for all UEs' serving cell RSRP, or set to be the threshold of S-measure, the handover failure rate is expected to be more negligible and even near to 0.

At least RRM measurement relaxation for partial UEs in a cell based on configurable relaxation conditions, e.g. RSRP threshold, needs to be further considered.

Table 13-3: Handover failure rate comparison between RRM measurement relaxation for all UEs in a cell and RRM measurement relaxation for partial UEs in a cell based on RSRP

	UE speed 30km/h					
	L3 period = 400ms			L3 period = 800ms		
	TTT=0ms	TTT=320ms	TTT=640ms	TTT=0ms	TTT=320ms	TTT=640ms
RRM relaxation for all UEs in a cell	0.135%	0.334%	0.755%	3.019%	5.135%	7.777%
RRM relaxation for partial UEs in a cell based on RSRP	0.019%	0.082%	0.140%	0.206%	0.387%	0.654%

For stationary or low speed UE, i.e. no more than 3km/h, relaxing the measurement period 4 times, i.e. from 200ms to 800ms for all UEs in a cell, should be supported. The RRM measurement relaxation criteria based on the measurment of serving cell quality can be further considered, e.g. when the measurement results is higher than a threshold, the RRM measurement relaxation can be appled.

5.3.2 Adapting/Relaxing intra-frequency measurements

It is observed that the following mechanisms can be beneficial in achieving the UE power saving,

- Reducing the number of cells for intra-frequency measurement can be beneficial for UE power saving,
  - Assuming that UE can limit the processing for measurement within a constrained time period and/or with reduced complexity.
  - Assuming number of neighbouring cells to be measured is reduced.
- For UE power saving perspective, reducing the need in neighbour cell intra-frequency measurement can be beneficial.

Table 14: Evaluation of adapting/relaxing intra-frequency measurements

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0) Power saving schemes description (1) Average power consumption (2) Power reduction compared to baseline [%]			(3) RRC Idle/RRC Inactive (i) or RRC Connected (c) (4)Measurement period [ms] (5)number of samples(e.g., SSB bursts) in each MP (6) UE speed and channel model (7) system impact, e.g., overhead (8) Performance impact (9)Additional assumption, e.g., PO and SSB offset,							Note

Source 1 Huawei [88]	Intra-cell measurement: With full cell search, the measured cell number can be reduced from 8 to 4. The power can be reduced from M to N. M is taken as baseline. The power in the bracket is power unit per millisecond. FR2	M=821860(1.64635) N(a)=763360(1.52917) N(b)= 604630(1.2112)	((	I	1	1	-	Additional signalling overhead from network	possible mobility impact	FR1 30kHz Sync	
		M= 860860(1.72448) N(a)= 802360(1.60729) N(b)= 620230(1.24245)	(a)6.80 % (b)27.9 5%	IDLE	1280	1	-		possible mobility impact	FR1 30kHz Async	DRX cycle length = 1.28s; Total considered time is 390 DRX cycle, i.e., 499.2s; the gap length between PO and SSB is assumed as 0; Cell search is performed every three measurements. Group paging rate is 10%, and paging rate is 0%. 1 SSB burst set with 2SSB is used for loop convergence, with periodicity of max (160ms, DRX cycle). (a) measurement duration = SMTC duration(5ms) (b) measurement duration = 2ms randomly located in SMTC window
		M=822055(1.64674) N(a)= 763555(1.52956) N(b)= 604825(1.21159)	(a)7.12 % (b)26.4 3%	IDLE	1280	1	-		possible mobility impact	FR1 60kHz Sync	
		M= 861055(1.72487) N(a)= 802555(1.60768) N(b)= 620425(1.24284)	(a)6.79 % (b)27.9 5%	IDLE	1280	1	-		possible mobility impact	FR1 60kHz Async	
		M=997555(1.99831) N(a)= 939055(1.88112) N(b)= 675025(1.35221)	(a)5.86 % (b)32.3 3%	IDLE	1280	1	-		possible mobility impact	FR2 60kHz Sync	
		M= 1114555(2.23268) N(a)= 1056055(2.11569) N(b)= 721825(1.44596)	(a)5.25 % (b)35.2 4%	IDLE	1280	1	-		possible mobility impact	FR2 60kHz	
		M=997652.5(1.9985) N(a)= 939152.5(1.88132) N(b)= 675122.5(1.35241)	(a)5.86 % (b)32.3 3%	IDLE	1280	1	-		possible mobility impact	FR2 120kHz Sync	
		M= 1114653(2.23288) N(a)= 1056153(2.11569) N(b)= 721922.5(1.44616)	(a)5.25 % (b)35.2 3%	IDLE	1280	1	-		possible mobility impact	FR2 120kHz	
	Intra-cell measurement: With full cell search, the measured cell number can be reduced from 16 to 4. The power can be reduced from M to N. M is taken as baseline. The power in the bracket is power unit per millisecond. FR1	M=938860(1.88073) N=763360(1.52917)	18.69%	IDLE	1280	1	-		possible mobility impact	FR1 30kHz Sync	DRX cycle length = 1.28s; Total considered time is 390 DRX cycle, i.e., 499.2s; measurement duration = SMTC duration(5ms) the gap length between PO and SSB is assumed as 0; Cell search is performed every three measurements. Group paging rate is 10%, and paging rate is 0%. 1 SSB burst set with 2SSB is used for loop convergence, with periodicity of max (160ms, DRX cycle).
		M= 977860(1.95885) N= 802360(1.60729)	17.95%	IDLE	1280	1	-		possible mobility impact	FR1 30kHz Async	
		M=939055(1.88112) N= 763555(1.52956)	18.69%	IDLE	1280	1	-		possible mobility impact	FR1 60kHz Sync	
		M= 978055(1.95924) N= 802555(1.60768)	17.94%	IDLE	1280	1	-		possible mobility impact	FR1 60kHz Async	
		M=1114555(2.23568) N= 939055(1.88112)	15.75%	IDLE	1280	1	-		possible mobility impact	FR2 60kHz Sync	
		M= 1231555(2.46706) N= 1056055(2.11569)	14.25%	IDLE	1280	1	-		possible mobility impact	FR2 60kHz Async	
		M=1114652.5(2.23288) N= 939152.5 (1.88132)	15.75%	IDLE	1280	1	-		possible mobility impact	FR2 120kHz Sync	

		M= 1231652.5(2.46725) N= 1056153(2.11569)	1	I	1	1	-		possible mobility impact	FR2 120kHz	
Source 2 Vivo [89]	Energy for full measurement (8 cells)	4.597	Baseline1	IDLE	320	2	--	No	Low	The measurement duration in SMTC is 2ms	FR1, Cell search is assumed to be performed in 1/3 of the SMTC measurement occasions.
	Reduce neighbour cell measurement(SCS is 30 kHz, Synchronous case, 4 cells)	4.229	8%	IDLE	320	2	--	No	Low	The measurement duration in SMTC is 2ms	
	Reduce neighbour cell measurement(SCS is 30 kHz, Asynchronous case, 4 cells)	4.474	37.54%	IDLE	320	2	--	No	Low	The measurement duration in SMTC duration is 2ms and 4ms for 4 cells and 8 cells.	
	Energy for full measurement (8 cells)	7.77	Baseline2	IDLE	320	2	--	No	Low	The measurement duration in SMTC is 2ms	FR2, Cell search is assumed to be performed in 1/3 of the SMTC measurement occasions.
	Reduce neighbour cell measurement(SCS is 30 kHz, Synchronous case, 4 cells)	7.02	9.6%	IDLE	320	2	--	No	Low	The measurement duration in SMTC is 4ms	
	Additional threshold is considered to reduce the number of intra-frequency measurements based on S-measures enhancement. Details in section 4.2 [89]	-	Baseline3	IDLE	320	2	--	No	Low		System level analysis. All the UEs in the cell is considered and there are 70% UEs which can actually reduce the number of cells from more than 8 cells to 4 cells, in dense urban single layer.
		-	18%	IDLE	320	2	--	No	Low	$S^{(2)}_{intraSearchP}$ is around -110 ~ -102dBm, when $S_{IntraSearchP}$ =-90.5dB.	
Source 3 ZTE [92][61]	The number to be measured is 8, and UE performs intra-frequency measurement for each DRX cycle.	6.53	baseline	Idle	320	1	N/A	N/A	N/A	DRX cycle is 320ms PO：10% Offset：U(0, measurement period)	The SMTC duration is 2ms
	The measured cell number is 8, but UE carries out intra frequency measurement every four DRX cycles, and only serving cell measurement is performed for the rest of the cycle.	6.22	4.7%	Idle	320	1	N/A	N/A	N/A	DRX cycle is 320ms PO：10% Offset：U(0, measurement period)	The SMTC duration is 2ms
	There are only serving cell to be measured.	5.66	13.3%	Idle	320	1	N/A	N/A	N/A	DRX cycle is 320ms PO：10% Offset：U(0, measurement period)	The SMTC duration is 0.5ms
	The number to be measured is 8	20.28	baseline	Connect	800	5	N/A	N/A	N/A	DRX:160-40-10 (cycle-inactivity timer-ON duration) offset：U(0, measurement period)	The SMTC duration is 2ms
	Reduce the measurement cell from 8 to 4	19.91	1.8%	Connect	800	5	N/A	N/A	N/A	DRX:160-40-10 (cycle-inactivity timer-ON duration) offset：U(0, measurement period)	The SMTC duration is 2ms
	Reduce the measurement cell from 8 to 1	18.59	8.3%	Connect	800	5	N/A	N/A	N/A	DRX:160-40-10 (cycle-inactivity timer-ON duration)	The SMTC duration is 0.5ms

										offset：U(0, measurement period)	
	The number to be measured is 8	31.15	baseline	Connect	200	5	N/A	N/A	N/A	DRX:40-10-4 (cycle-inactivity timer-ON duration) offset：U(0, measurement period)	The SMTC duration is 2ms
	Reduce the measurement cell from 8 to 4	29.68	4.7%	Connect	200	5	N/A	N/A	N/A	DRX:40-10-4 (cycle-inactivity timer-ON duration) offset：U(0, measurement period)	The SMTC duration is 2ms
	Reduce the measurement cell from 8 to 1	24.51	21.3%	Connect	200	5	N/A	N/A	N/A	DRX:40-10-4 (cycle-inactivity timer-ON duration) offset：U(0, measurement period)	The SMTC duration is 0.5ms

Observation:

- For adapting/relaxing RRM measurement for intra-frequency measurement by reducing the number of measured cells, the followings are observed from simulation results,
    - By assuming number of neighbouring cells to be measured is reduced, it is shown that about 4.7% - 7.1% power saving gain can be observed if reducing the number of measured cells for IDLE state. 1 source shows that about 1.8% - 21.3% power saving gain can be observed if reducing the number of measured cells for CONNECTED state.
    - In additional to that, by also assuming that UE can limit the processing for measurement within a constrained time period and/or with reduced complexity, 26.43% - 37.5% power saving gain is shown.
    - The corresponding performance impact was not reported and summarized

5.3.3 Power saving schemes for RRM measurements with additional resource

While it is observed under certain conditions and deployment scenarios, additional resource for RRM measurement can be beneficial for UE power saving, including at least the following aspects:

- Minimizing/reducing the timing gap between measurement (e.g., SSB) and DRX ON duration (e.g., paging monitoring occasion/reception, data reception, etc.)
- Additional resource around the measurement occasion, e.g., for AGC assistance
- Reducing measurement activities by providing additional resource may provide sufficient measurement/T-F accuracy.

The followings can be considered as the usage of additional resource for RRM measurement,

- CSI-RS, including TRS
- SSS only
- SSB
- PSS, SSS and wake-up signaling/paging
- E.g., including transmitted in SFN (single frequency network) manner
- DMRS for RMSI PDCCH/PDSCH for standalone
- Additional new RS/signal (e.g, configuring additional RS next to SSB) in addition to existing RS/signal in Rel-15

- Note: Existing structure/waveform of Rel-15 signals/channels is recommended to be studied for additional resource
- Note: companies report the purpose of additional resource for RRM measurement, e.g., measurement, cell search and etc.

RRC state(s) with the additional resource used for the RRM measurements,

- RRC IDLE
- RRC INACTIVE
- RRC CONNECTED

Table 15: Evaluation of additional resources for RRM power saving

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0) Power saving schemes description (1) Average power consumption (2) Power reduction compared to baseline [%]			(3) RRC Idle/RRC Inactive (i) or RRC Connected (c) (4)Measurement period [ms] (5)number of samples(e.g., SSB bursts) in each MP (6) UE speed and channel model (7) system impact, e.g., overhead (8) Performance impact (9)Additional assumption, e.g., PO and SSB offset,							Note
Source 1 vivo [89]	Only SSB is used for RRM (2 samples per DRX cycle)	4.17	Baseline1	RRC Idle	320	2	TDL-C 3km/h 30km/h	Low		The power saving gain is average gain of [0-10] ms SSB/CSI-RS and PO offset.	FR1
	The number of measurement samples is reduced to 1 per paging cycle in idle state. Measurement is still based on CSI-RS	2.84	31.9%	RRC Idle	320	1	TDL-C 3km/h 30km/h	Low	No impact for RSRP accuracy, RSRP accuracy analysis in [89]	The power saving gain is average gain of [0-10] ms SSB/CSI-RS and PO offset.	
	The number of measurement samples is reduced to 1 per paging cycle in idle state. Measurement is still based on either SSB or CSI-RS depending on which is closer to PO in time.	2.72	34.8%	RRC Idle	320	1	TDL-C 3km/h 30km/h	Low		The power saving gain is average gain of [0-10] ms SSB/CSI-RS and PO offset. The periodicity of CSI-RS is assumed to be 10ms.	
	Only SSB is used for RRM (2 samples per DRX cycle)	2.97	Baseline2	RRC Idle	320	2	TDL-C 3km/h 30km/h	Low		The power saving gain is average gain of [0-10] ms SSB/CSI-RS and PO offset.	FR2
	The number of measurement samples is reduced to 1 per paging cycle in idle state. Measurement is still based on CSI-RS	2.173	26.8%	RRC Idle	320	1	TDL-C 3km/h 30km/h	Low	No impact for RSRP accuracy, RSRP accuracy analysis in [89]	The power saving gain is average gain of [0-10] ms SSB/CSI-RS and PO offset.	
	The number of measurement samples is reduced to 1 per paging cycle in idle state. Measurement is still based on either SSB or CSI-RS depending on which is closer to PO in time.	2.07	30.3%	RRC Idle	320	1	TDL-C 3km/h 30km/h	Low		The power saving gain is average gain of [0-10] ms SSB/CSI-RS and PO offset. The periodicity of CSI-RS is assumed to be 10ms.	
Source 2 MediaTek [90]	Using SSS-only signal as additional RS before SSB for paging indication and RRM assistance.	1.634 (baseline is 2.089, values are calculated in Appendix in [90]	21.78 %	Idle	One IDRX cycle (1280 ms)	2	General	One symbol of SSS for SMTC window		IDRX-cycle=1280ms DRX on duration = 4ms SMTC window = 2ms SMTC period =20ms FR1	Periodic activities, e.g. time/frequency, channel or beam tracking, and loop convergence, are performed every IDRX cycle during the SMTC window. Periodic activities will align with RRM measurement if possible. *The SSS-only signal can be multiplexed in a CDMed way to accommodate more paging indications for different paging groups.* For 20/40 ms SMTC (SSB) periodicity, the additional SSS-only signal of 160ms periodicity introduces

											1.6%/3.3% overhead in terms of SSB unit.
Source 3 CATT [91]	Normal RRM measurement according to SMTC configuration	12.2	baseline	connected	800	5	-	-	-	DRX-cycle=160ms, DRX-on=8ms, SMTC= 80ms	on-demand RS for RRM measurement is that UE could perform multiple RRM measurements (e.g. 5 measurements in a consecutive period) when UE is triggered to wake up at a given DRX-ON period. Then UE can do L1 filtering for multiple RRM measurements at one DRX-ON period
	On-demand RS assistant RRM measurement during DRX-on duration	9.2	24.6%	connected	800	5	-	-	-	DRX-cycle=160ms, DRX-on=8ms, SMTC= 80ms	
	Normal RRM measurement according to SMTC configuration	66.34	0%	connected	800	5	-	-	-	DRX-cycle=160ms, DRX-on=8ms, Inactivity timer =100ms	on-demand RS is introduced to assist UE measurement during the data transmission, UE would go to sleep after data reception, which can reduce a part of UE power consumption.
	On-demand RS assistant RRM measurement during data transmission	12.42	81.28 %	connected	800	5	-	-	-	DRX-cycle=160ms, DRX-on=8ms, Inactivity timer =100ms	
Source 4 Qualcomm [96]	L=1	2.06		Idle/Inactive	1.28	2	stationary			FR1	Notes: - (3) I-DRX/paging cycle - (4) The number of SSB burst sets are used for RRM and AGC/T-F tracking loops - (5) UE speed (km/h) or stationary L denotes the number of SSBs in a SSB set
		1.67	18.86 %								
	L=4	2.11		Idle/Inactive	1.28	2	stationary			FR1	
		1.67	20.74 %								
	L=8	2.19		Idle/Inactive	1.28	2	stationary			FR1	
		1.67	23.58 %								
	L=1	2.17		Idle/Inactive	1	2	3			FR1	
		1.68	22.36 %								
	L=4	2.21		Idle/Inactive	1.28	2	3			FR1	
		1.68	24.08 %								
	L=8	2.29		Idle/Inactive	1.28	2	3			FR1	
		1.68	26.66 %								
	L=1	2.17		Idle/Inactive	1.28	2	30			FR1	
		1.68	22.67 %								
	L=4	2.22		Idle/Inactive	1.28	2	30			FR1	
		1.68	24.37 %								
	L=8	2.30		Idle/Inactive	1.28	2	30			FR1	
		1.68	26.94 %								
	L=1	2.48		Idle/Inactive	1.28	3	stationary			FR1	
		1.67	*32.66 %*								
	L=4	2.53		Idle/Inactive	1.28	3	stationary			FR1	
		1.67	33.96 %								
	L=8	2.61		Idle/Inactive	1.28	3	stationary			FR1	
		1.67	35.94 %								
	L=1	2.59		Idle/Inactive	1.28	3	3			FR1	
		1.68	35.02 %								
	L=4	2.64		Idle/Inactive	1.28	3	3			FR1	
		1.68	36.22 %								

	L=8	2.71		Idle/Inactive	1.28	3	3			FR1	
		1.68	38.06 %								
	L=1	2.60		Idle/Inactive	1.28	3	30			FR1	
		1.68	35.24 %								
	L=4	2.65		Idle/Inactive	1.28	3	30			FR1	
		1.68	36.43 %								
	L=8	2.72		Idle/Inactive	1.28	3	30			FR1	
		1.68	38.26 %								
	L=1	5.24		Idle/Inactive	0.32	2	stationary			FR1	
		3.68	29.67 %								
	L=4	5.43		Idle/Inactive	0.32	2	stationary			FR1	
		3.68	32.20 %								
	L=8	5.75		Idle/Inactive	0.32	2	stationary			FR1	
		3.68	35.89 %								
	L=1	5.66		Idle/Inactive	0.32	2	3			FR1	
		3.73	34.21 %								
	L=4	5.86		Idle/Inactive	0.32	2	3			FR1	
		3.73	36.40 %								
	L=8	6.17		Idle/Inactive	0.32	2	3			FR1	
		3.73	39.62 %								
	L=1	5.70		Idle/Inactive	0.32	2	30			FR1	
		3.73	34.61 %								
	L=4	5.89		Idle/Inactive	0.32	2	30			FR1	
		3.73	36.78 %								
	L=8	6.21		Idle/Inactive	0.32	2	30			FR1	
		3.73	39.96 %								
	L=1	6.93		Idle/Inactive	0.32	3	stationary			FR1	
		3.68	46.81 %								
	L=4	7.12		Idle/Inactive	0.32	3	stationary			FR1	
		3.68	48.27 %								
	L=8	7.43		Idle/Inactive	0.32	3	stationary			FR1	
		3.68	50.44 %								
	L=1	7.35		Idle/Inactive	0.32	3	3			FR1	
		3.73	49.31 %								
	L=4	7.55		Idle/Inactive	0.32	3	3			FR1	

		3.73	50.63 %								
	L=8	7.86		Idle/Inactive	0.32	3	3			FR1	
		3.73	52.59 %								
	L=1	7.39		Idle/Inactive	0.32	3	30			FR1	
		3.73	49.55 %								
	L=4	7.58		Idle/Inactive	0.32	3	30			FR1	
		3.73	50.85 %								
	L=8	7.89		Idle/Inactive	0.32	3	30			FR1	
		3.73	52.80 %								
	CSI-RS for mobility, w/o repetition (baseline)	36.9	baseline	Connected	40ms	16slots	Stationary			the power model for CSI-RS for mobility and the scaling rule with respect to the number of CSI-RS symbols in a slot are described in [96]	Repetition of CSI-RS for mobility in FR2
	CSI-RS for mobility, with 2 repetition	32.5	11.8%	Connected	80ms	16slots	Stationary		Refined Rx beam		
	CSI-RS for mobility, with 4 repetition	29.2	20.7%	Connected	160ms	16slots	Stationary		Refined Rx beam		
Source 5 Ericsson [95]	UE performs AGC on previous SSB, measures on next SSB	2826/1280 = 2.20	-	Idle	1280						
	One additional SSB sweep for AGC is provided 4 ms ahead of the measured SSB sweep	2522/1280 =1.97	11.8	Idle	1280						
	UE performs AGC on previous SSB, then monitors ON-duration	3032/1280 =2.36	-	Idle	1280						
	An additional on-demand RS for AGC purposes is provided 5 ms before the start of ON-duration	2918/1280 =2.28	3.8	Idle	1280						
	UE performs AGC on previous SSB, measures on next SSB, followed by monitoring ON-duration	3746/1280 =2.93	-	Idle	1280						
	One additional SSB sweep for AGC is provided 4 ms ahead of the measured SSB sweep, measures on next SSB, followed by monitoring ON-duration	3442/1280 =2.69	8.1	Idle	1280						

Observation:

- For RRC IDLE/INACTIVE, by using additional resources for RRM measurement, the UE power saving is 19%~38%. Analysis on network impact, higher-layer/PHY-layer signaling overhead and network energy consumption is not provided. Two sources report 1.6% of SSB overhead for 160ms additional reference signals periodicity assuming that SSB burst set periodicity is 20ms. If static UE specific signals (e.g., CSI-RS for connected mode UEs) can be reused as additional resource for RRM for RRC IDLE/INACTIVE, reference signal overhead may not increase.

- For RRC CONNECTED, one source showed that, by having CSI-RS repetition for CSI-RS based RRM in FR2, the UE power saving is 11.8%~20.7% assuming that CSI-RS overhead of baseline is identical to CSI-RS overhead with enhancement. The analysis on handover failure rate is not provided under the assumed overhead.

5.3.4 Adapting/Relaxing inter-frequency measurements

Table 16: Evaluation of adapting/relaxing inter-frequency measurements

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0) Power saving schemes description (1) Average power consumption (2) Power reduction compared to baseline [%]			(3) RRC Idle/RRC Inactive (i) or RRC Connected (c) (4) Measurement period [ms] (5) number of samples(e.g., SSB bursts) in each MP (6) UE speed and channel model (7) system impact, e.g., overhead (8) Performance impact (9) Additional assumption, e.g., PO and SSB offset,							Note
Source 1 Huawei [88]	Inter-frequency measurement: With full cell search in each layer, the measured frequency number can be reduced from 6 to 3. The power can be reduced from M to N. M is taken as baseline. The power in the bracket is power unit per millisecond. (a) totally indicated layer number= 6 and every layer has 8 neighbor cells. (b) totally indicated layer number= 6 and only 3 layers out of 6 layer have neighbour cells with 8 for each. Note: the assumptions of the number of layers may not be aligned with the baseline assumption	M(a)= 5.64948 M(b)= 4.25573 N= 3.65651	(a) 35.28% (b) 14.08%	IDLE	1280	1	-	Additional signalling overhead from network	possible mobility impact	FR1 30kHz Sync	DRX cycle length = 1.28s; Total considered time is 390 DRX cycle, i.e., 499.2s; measured duration in each layer equals to SMTC duration = 5ms; switching time for FR1 equals 0.5ms, for FR2 equals 0.25ms; the gap length between PO and SSB is assumed as 0; 8 neighbor cells for intra-frequency measurement; 8 neighbor cells in each layer for inter-frequency measurement. Cell search is performed every three measurements. Group paging rate is 10%, and paging rate is 0%. 1 SSB burst set with 2SSB is used for loop convergence, with periodicity of max (160ms, DRX cycle);
		M(a)= 6.19635 M(b)= 4.56823 N= (3.96901)	(a) 35.95% (b) 13.12%	IDLE	1280	1	-		possible mobility impact	FR1 30kHz Async	
		M(a)= 5.64987 M(b)= 4.25612 N= 3.6569	(a) 35.28% (b) 14.08%	IDLE	1280	1	-		possible mobility impact	FR1 60kHz Sync	
		M(a)= 6.19635 M(b)= 4.56862 N= 3.9694	(a) 35.94% (b) 13.12%	IDLE	1280	1	-		possible mobility impact	FR1 60kHz Async	
		M(a)= 8.05065 M(b)= 6.08815 N= 5.02878	(a) 37.54% (b) 17.40%	IDLE	1280	1	-		possible mobility impact	FR2 60kHz Sync	
		M(a)= 9.69128 M(b)= 7.02565 N= 5.96628	(a) 38.44% (b) 15.08%	IDLE	1280	1	-		possible mobility impact	FR2 60kHz Async	
		M(a)=8.05085 M(b)=6.08835 N=5.02897	(a) 37.54% (b) 17.4%	IDLE	1280	1	-		possible mobility impact	FR2 120kHz Sync	
		M(a)=9.69147 M(b)=7.02585 N=5.96647	(a) 38.44% (b) 15.08%	IDLE	1280	1	-		possible mobility impact	FR2 120kHz Async	
	CSI-RS resource in the same frequency layer are configured in a measurement window.	Number of configured CSI-RS resources = 4 5.03(baseline) 4.27(concentrated CSI-RS configuration)	15.10%	CONNECTED	200	5	3km/h NLOS	-		For baseline, all CSI-RS resource are randomly placed in the time domain (uniform distribution)	UE is assumed to retune its RF to target frequency to perform CSI-RS based inter-frequency measurement once there is a CSI-RS resource to measure, and it will immediately switch RF back to its serving frequency to continue Tx/Rx unless there is no enough time (i.e. time interval between two CSI-RS resources is shorter than 1ms). Number of configured CSI-RS resources are the allowed maximum number of CSI-RS resource for mobility
		Number of configured CSI-RS resources = 16 7.32(baseline) 4.54(concentrated CSI-RS configuration)	37.97%	CONNECTED	200	5	3km/h NLOS	-			
		Number of configured CSI-RS resources = 32 8.69(baseline) 4.90(concentrated CSI-RS configuration)	43.61%	CONNECTED	200	5	3km/h NLOS	-			
		Number of configured CSI-RS resources = 48 9.04(baseline) 5.25(concentrated CSI-RS configuration)	41.92%	CONNECTED	200	5	3km/h NLOS	-			
		Number of configured CSI-RS resources = 64 8.97(baseline) 5.61(concentrated CSI-RS configuration)	37.46%	CONNECTED	200	5	3km/h NLOS	-			
		Number of configured CSI-RS resources = 80 8.75(baseline) 5.97(concentrated CSI-RS configuration)	31.77%	CONNECTED	200	5	3km/h NLOS	-			
		Number of configured CSI-RS resources = 96 8.52(baseline) 6.32(concentrated CSI-RS configuration)	25.82%	CONNECTED	200	5	3km/h NLOS	-			
Source 2 Sony [93]	Reduced number of inter-freq layers measured (1 layer vs 2)	58.4: 1 layer 73.9: 2 layer	21%	Conn	40ms	2/slot	N/A	See note	-		Note: more non-gap resource is available to UE with fewer measurement gaps Power consumption averaged over DRX cycle and is also applicable to full measurement period
	Reduced number of inter-freq layers measured (2 layer vs 4)	73.9: 2 layer 99.6: 4 layer	26%	Conn	40 ms	2/slot	N/A	See note	-		

Table 17: Evaluation of relaxed the number of measured beams by considering spatial information aspects

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0) Power saving schemes description (1) Average power consumption (2) Power reduction compared to baseline [%]			(3) RRC Idle/RRC Inactive (i) or RRC Connected (c) (4)Measurement period [ms] (5)number of samples(e.g., SSB bursts) in each MP (6) UE speed and channel model (7) system impact, e.g., overhead (8) Performance impact (9)Additional assumption, e.g., PO and SSB offset,							Note
Source 1 Huawei [100]	Adjacent directional beams of each SSB can be provided by gNB to reduce SSB number of UE RRM measurement and loop convergence. A: UE measures all the beams B: all the adjacent beams and serving beam is used for RRM measurement and loop convergence.	A(baseline):7.86 B:4.03	48.7%	IDLE	DRX cycle length = 0.32s	1	-	Determined by signaling periodicity		The periodicity of SSB is 20ms, and the gap length between PO and SSB are randomly distributed	1 SSB burst set with 64 SSBs is used for loop convergence in baseline and with averaged adjacent SSBs for loop convergence in optimal schemes.
		A(baseline):4.43 B:2.51	43.2%	IDLE	DRX cycle length = 0.64s	1	-				
		A(baseline):2.72 B: 1.76	35.2%	IDLE	DRX cycle length = 1.28 s	1	-				
		A(baseline):1.86 B:1.38	25.8%	IDLE	DRX cycle length = 2.56 s	1	-				
		A(baseline):5.67 B:4.03	28.9%	IDLE	DRX cycle length = 0.32s	1	-	Determined by signaling periodicity		The periodicity of SSB is 20ms, and the gap length between PO and SSB are randomly distributed	1 SSB burst set with 32 SSBs is used for loop convergence in baseline and with averaged adjacent SSBs for loop convergence in optimal schemes.
		A(baseline):3.34 B:2.52	24.6%	IDLE	DRX cycle length = 0.64s	1	-				
		A(baseline):2.17 B:1.76	18.9%	IDLE	DRX cycle length = 1.28 s	1	-				
		A(baseline):1.58 B:1.38	12.9%	IDLE	DRX cycle length = 2.56 s	1	-				

Observation:

2 sources show that reducing the number of measured inter-frequency layers can provide 21~38% power saving gain for RRC CONNECTED states, and 1 source shows 4%-35% power saving gain for RRC IDLE states by assuming reducing inter-frequency layers from 6 to 3. The mobility performance impact is not provided.

6 Higher layer procedure for UE power saving

6.1 UE paging procedure based on power saving signal/channel/procedure

The power saving signal/channel related paging is down-prioritized in the study.

Extending the DRX cycle length to 10.24s in idle and inactive mode will be considered. Increasing it above 10.24s will not be studied.

A power saving specific rule will be defined for DRX cycle determination in idle and inactive mode, in the presence of different DRX cycle configurations (e.g. UE specific and default). It is FFS how it is enabled. The DRX cycles are decided by the network based on UE preference indications. All enhancements are aiming at reusing existing mechanism (e.g. eDRX).

More than one UE may monitor the same Paging Occasion (PO), which can cause false paging alarms in the UE, i.e. when the UE receives a paging message on PDSCH, which is not intended for that UE, causing unnecessary power consumption in the UE. False paging alarms also occur when the UE has changed cell since it was last paged, i.e. due to mobility, where the network has to page the UE in more than one cell. However, there was no consensus to prioritize this issue for RAN2.

6.2 UE power saving procedure in transition from RRC_CONNECTED to RRC_IDLE/RRC_INACTIVE state

A mechanism for a UE to indicate its preference of transitioning out of RRC_CONNECTED state to the network is beneficial to reduce UE's power consumption. And the corresponding signalling details and whether the UE provides release assistance and/or state preference are to be defined.

6.3 Higher layer procedures for the UE power saving schemes in RRC_CONNECTED

The higher layer procedure for the UE power saving schemes includes the required signalling and procedures (when needed) for the proposed power saving schemes in Section 5.

6.3.1 Higher Layer procedure related to PDCCH-based power saving signal/channel scheme for wake-up purpose (Section 5.1.4)

The PDCCH-based power saving signal/channel scheme for wake-up purpose is considered jointly with DRX i.e. it is only configured when DRX is configured. If the PDCCH-based power saving signal/channel for wake-up purpose is not configured, the legacy DRX operation applies. The higher layer procedure in support of the PDCCH-based power saving signal/channel scheme for wake-up purpose was studied for its adaptation to DRX operation (Section 5.1.4).

When configured, the PDCCH-based power saving signal/channel scheme for wake-up purpose is monitored at occasions located at a known offset before the start of the *drx-onDurationTimer*. The offset is part of physical layer design.

The PDCCH-based power saving signal/channel for wake-up purpose can indicate the UE to monitor or skip the PDCCH during the next occurrence of the *drx-onDurationTimer*. In the latter case, the UE does not start the *drx-onDurationTimer* at its next occasion. From higher layer perspective, in order to minimize the rate of such PDCCH-based power saving signal/channel transmission from the network, the preference is that the PDCCH-based power saving signal/channel for wake-up purpose is used to indicate to the UE to wake up to monitor the PDCCH during the next occurrence of the *drx-onDurationTimer.*

Except for the *drx-onDurationTimer,* the PDCCH-based power saving signal/channel for wake-up purpose has no impact on other DRX timers and does not impact the Active Time due to other triggers than the *drx-onDurationTimer*. The UE behaviour when the occasion of PDCCH-based power saving signal/channel for wake-up purpose collides with Active Time due to other triggers than the *drx-onDurationTimer* (e.g. *drx-InactivityTimer*) should be addressed in the WI phase.

UE behaviour in case of mis-detection of the PDCCH-based power saving signal/channel for wake-up purpose should also be addressed in the WI phase.

6.3.2 Higher Layer Procedure for DCI-based PDCCH monitoring reduction (Section 5.1.5)

The higher layer procedure in support of DCI-based PDCCH monitoring skipping (which can include DCI-based PDCCH monitoring periodicity adaptation) was studied to achieve PDCCH monitoring/decoding reduction (Section 5.1.5). If enabled, it is assumed that DCI-based PDCCH monitoring skipping could be configured with or without DRX.

DCI-based PDCCH monitoring skipping aims to operate on a short time scale (i.e. shorter time scale then the L2 DRX). Under this condition, it has not been identified that DCI-based PDCCH monitoring skipping duplicates the DRX functionality.

The DCI-based PDCCH monitoring skipping is a physical layer procedure with minimal impact, if any, on the MAC layer. The MAC timers are not affected by the DCI-based PDCCH monitoring skipping command, except for timers related to UL triggered activities (e.g. RA, SR and BFR), namely how/if the DCI-based PDCCH monitoring skipping command impacts L2 operation while a Random Access or scheduling request procedure is on-going.

Further simulation results involving more scenarios (short DRX, DRX MAC CE) are shown in Section 5.1.5 for comparison.

6.3.3 Power saving in CA/DC

UE's power consumption can be reduced in CA configuration by reducing PDCCH monitoring on activated SCells.

Methods for reducing power consumption in DC configuration (EN-DC in particular) should also be supported.

Enhancements to Rel-15 DRX procedure can be studied further if they do not violate the general principle of single DRX configuration per MAC entity.

6.3.4 UE assistance information (Section 5.1.6)

UE's power consumption may be reduced if the UE could provide following assistance information to the network: mobility history information (e.g. similarly as in LTE via *mobilityState*, and *MobilityHistoryReport* in TS 36.331), power preferred information (baseline LTE PPI in a well-defined manner) related to C-DRX, BWP and SCell configurations.

6.3.5 Adaptation to the number of antennas (Section 5.1.3)

The adaptation to the number of antennas was briefly studied. It is recommended to support the possibility to configure a different MIMO layer configuration for the initial/default BWP compared with other BWPs of a Serving Cell. It should be further considered if this can be extended to a per-BWP MIMO layer configuration.

6.4 Higher layer procedures for power consumption reduction in RRM measurements

Relaxing the serving and neighbour cell measurements for NR UE was studied, considering the mobility-related aspects. RRM measurement relaxation for serving cell is down-prioritized for UE in any RRC state. RRM measurements for neighbour cells in both intra and inter-frequencies can be relaxed for UEs in RRC_CONNECTED and RRC_IDLE/INACTIVE. Measurement relaxation for UEs in RRC_CONNECTED is under network control.

The relaxed monitoring criterion under which the UE may relax RRM measurements was studied. The relaxed monitoring criteria may include the following aspects, but are not limited to:

- UE mobility status (e.g. serving cell variation, speed, movement, direction, cell re-selection, UE type …)
- Link quality (e.g. serving cell threshold/quality, position in cell …)
- Serving cell beam status (e.g. beam change, direction, beam specific link condition…)

The exact relaxation criteria are to be defined, and the following two should be treated with higher priority:

1) UE is not at cell edge,
2) UE is stationary or with low mobility.

It is beneficial to perform RRM measurement relaxation by allowing measurements with longer intervals, and/or by reducing the number of cells/carriers/SSB to be measured.

Measurement relaxation rules can be discussed further,

Further simulation results addressing mobility performance evaluation for time domain RRM measurement relaxation are provided in section 5.3.1.

7 Conclusions

The UE power saving study completes the UE power consumption model for evaluation based on the inputs from many sources. Evaluation results have been shown based on the UE power consumption model through calibration and subsequent evaluations. The UE power model could be used as the reference model in evaluating the UE power consumption for any other features if applicable.

RAN1's study shows the following power saving gains over the agreed baseline in UE power saving schemes with UE adaptation in frequency domain, time domain, antenna domain, DRX operations, and reducing PDCCH monitoring with different traffic types, such as FTP, IM, web browsing, video streaming, gaming and VoIP, and network configurations,

- The power saving schemes with UE adaptation to BWP switching show the power saving gains ranged from 16% - 45% over the agreed baseline configuration. The power saving schemes with UE adaptation to SCell operation show12% - 57.75% power saving gain with average latency increase 0.1% - 2.6%.

- The power saving schemes with cross-slot scheduling shows up to 2%-28% power saving gains with UPT degradation 0.3%-25%. The power saving gain decreases and the UPT degradation increases as the K0 increase. The power saving gain 15%-17% and 0% -93% overhead increases is observed for same-slot scheduling only with small packet. The power saving gain less than 2% is observed for multi-slot scheduling.

- The power saving schemes with UE adaptation to the number of MIMO layers or number of Tx/Rx antenna (panels) provides up to 3%-30% power saving gain and 4% latency increase for dynamic antenna adaptation. The power saving gain 6%-30% is observed for semi-static antenna adaptation with expected latency and UPT degradation. Additional network resource is used for compensation of the loss of multi-antenna processing gain.

- The power saving schemes with UE adaptation to the DRX operation shows 8%~50% power saving gains with latency increase in the range of 2%~13%. The power saving gain for dynamic DRX configuration/adaptation is 8%-70% with latency increase 2% - 323%. Rel-15 enabled DRX operation shows negative 37% to 47 % power saving gain over the agreed baseline.

- The power saving schemes for dynamic adaption of UE PDCCH monitoring shows 5% - 85% power saving gains with the latency increase/UPT degradation in the range of (0% - 115%)/(5%- 43%).

It is noted that the combined power saving techniques (as listed above) may not necessarily provide linear addition of individual power saving gains. It is noted that the power saving gains shown in the specific context as cited above are relative numbers, while it is understood that the absolute percentage of power consumption for a specific context may vary depending on the actual usage.

The UE assistance information provides the gNB additional information in facilitating UE adaptation to the traffic and reducing the power consumption of some respective power saving schemes shown aforementioned. UE preferred configurations are fed back to the gNB to help the network optimizing the resource utilization and assisting UE in achieving power consumption reduction.

The power saving schemes with the power saving signal/channel triggering UE adaptation shows the power saving with adaptation in different domains, such as DRX operation, BWP switching, and reducing PDCCH monitoring aforementioned.

For adapting/relaxing RRM measurement in time domain

- 11.1% - 26.6% and 7.4% - 17.8% power saving gains are shown for increasing measurement period 4 times and 2 times respectively for RRC CONNECTED state, 17.9%-19.7% and 0.89%-5.36% power saving gains are shown RRC IDLE/INACTIVE state by increasing measurement period for 1 SSB burst set for measurement and periodic activities and 2 or 3 SSB burst set for measurement and periodic activities respectively.

- For stationary or low mobility (e.g., 3km/h) case, increasing measurement period has less impact (e.g., handover failure rate changes from 0% to 0.26% for 3km/h by extending 4 times measurement period) to the mobility performance compared to high mobility cases (e.g., handover failure rate changes from 0%-1% for 60km/h by extending 4 times measurement period).

For adapting/relaxing RRM measurement for intra-frequency measurement by reducing the number of measured cells,

  - By assuming number of neighbouring cells to be measured is reduced, it is shown that about 4.7% - 7.1% power saving gain can be observed if reducing the number of measured cells for IDLE state. 1 source shows that about 1.8% - 21.3% power saving gain can be observed if reducing the number of measured cells for CONNECTED state.
  - In additional to that, by also assuming that UE can limit the processing for measurement within a constrained time period and/or with reduced complexity, 26.43% - 37.5% power saving gain is shown.
  - The corresponding performance impact was not reported and summarized

For additional resource for RRM measurement

  - For RRC IDLE/INACTIVE, by using additional resources for RRM measurement, the UE power saving gain is 19%~38%. Analysis on network architecture impact, higher-layer/PHY-layer signaling overhead and network energy consumption is not provided. Two sources report 1.6% of SSB overhead for 160ms additional reference signals periodicity assuming that SSB burst set periodicity is 20ms. If static UE specific signals (e.g., CSI-RS) for connected mode UEs can be reused as additional resource for RRM, reference signal overhead may not increase.
  - For RRC CONNECTED, one source showed that, by having CSI-RS repetition for CSI-RS based RRM, the UE power saving gain is 11.8%~20.7% by assuming that CSI-RS overhead of baseline is identical to CSI-RS overhead with enhancement. The analysis on handover failure rate is not provided under the assumed overhead.

- For reducing the number of measured inter-frequency layers
  - 2 sources show that reducing the number of measured inter-frequency layers can provide 21%~38% power saving gain for RRC CONNECTED states, and 1 source shows 14%~35% power saving gain for RRC IDLE states by assuming reducing inter-frequency layers from 6 to 3. The mobility performance impact is not provided.

It is noted that for RRM evaluation, PDCCH-only monitoring without data is assumed for RRC CONNECTED state.

Further conclusions from the study of higher layer procedures are given below.

PDCCH-based power saving signal/channel scheme for wake-up purpose (Section 5.1.4)

It is recommended that the PDCCH-based power saving signal/channel for wake-up purpose is used to indicate to the UE to wake up to monitor the PDCCH during the next occurrence of the *drx-onDurationTimer*. At least the following should be addressed:

  - UE behaviour when the PDCCH-based power saving signal/channel for wake-up purpose collides with any event part of legacy Active Time (e.g. DRX Inactivity timer)
  - UE behaviour in case of mis-detection of the PDCCH-based power saving signal/channel for wake-up purpose

DCI-based PDCCH monitoring reduction (Section 5.1.5)

The DCI-based PDCCH monitoring skipping is studied, with or without DRX. For the power saving scheme to bring most value, it is recommended to consider skipping durations shorter than the L2 DRX cycles.

In general, the above feature could and should be designed to have minimal impact on the MAC layer.

MIMO layer adaptation (Section 5.1.3)

It is recommended to support the possibility to configure a different MIMO layer configuration for the initial/default BWP compared with other BWPs of a Serving Cell. It should be further considered if this can be extended to a per-BWP MIMO layer configuration.

Fast RRC state transition

It is recommended to support a mechanism for a UE to indicate its preference of transitioning out of RRC_CONNECTED state. The corresponding signalling details and whether the UE provides release assistance and/or state preference are to be addressed further.

Power saving in CA/DC

UE's power consumption can be reduced in CA configuration by reducing PDCCH monitoring on activated SCells.

Methods for reducing power consumption in DC configuration (EN-DC in particular) should also be supported.

Enhancements to Rel-15 DRX procedure can be studied further if they do not violate the general principle of single DRX configuration per MAC entity.

UE assistance information (Section 5.1.6)

It is also identified as helpful to further evaluate the following UE's assistance information: mobility history information (e.g. similarly as in LTE via *mobilityState*, and *MobilityHistoryReport* (TS 36.331), power preference indication (baseline LTE PPI in a well-defined manner), UE's preferred information related to C-DRX, BWP and SCell configurations. Other information that RAN1 considers as beneficial for UE power saving can be included in the UE assistance information.

RRM measurement relaxation (Section 5.3)

RRM measurement for neighbour cells for both intra and inter-freq can be relaxed for UE in RRC_CONNECTED and RRC_IDLE/INACTIVE. Measurement relaxation in RRC CONNECTED is under network control.

The exact relaxed monitoring criteria under which the UE may relax RRM measurements are to be defined, and the following two should be treated with higher priority: if UE is not at cell edge, or if UE is stationary or with low mobility.

It is beneficial to perform RRM measurement relaxation by allowing measurements with longer intervals, and/or by reducing the number of cells/carriers/SSB to be measured.

Measurement relaxation rules can be discussed further, involving RAN4, if this topic is addressed in the WI.

Power saving for paging procedure

The extending the DRX cycle length to 10.24s was studied in idle and inactive mode. A power saving specific rule will be defined for DRX cycle determination in idle and inactive mode, in the presence of different DRX cycle configurations (e.g. UE specific and default). The DRX cycles are decided by the network based on UE preference indications. All enhancements are aiming at reusing existing mechanism (e.g. eDRX).

The issue of false paging alarms in the UE caused by more than one UE monitoring the same Paging Occasion (PO) was studied but no consensus was reached.

8 Appendix – Evaluation methodology

8.1 UE power consumption model

The following power states and relative power consumption values for the reference configuration are adopted for the study of UE power saving.

8.1.1 UE power consumption model for FR1

Reference Configuration for FR1

- Downlink: TDD
  - Subcarrier spacing (SCS): 30 kHz
  - Number of carrier: 1CC,
  - System Bandwidth: 100 MHz
  - PDCCH region of 2 symbol at beginning of a slot,
    - k0 = 0,
    - maximum number of CCEs = 56,
    - 36 PDCCH blind decoding,

- PDSCH of max data rate
  - Modulation: 256QAM
  - MIMO configuration: 4x4 MIMO,
  - Number of RBs for TRS = 52,
  - 4RX UE Capability =1
- Uplink: TDD
  - Subcarrier spacing (SCS): 30 kHz SCS,
  - Number of carrier: 1CC,
  - System Bandwidth: 100MHz,
  - Tx antenna configuration: 1TX,
  - Power levels: 0dBm and 23dBm
- Power values are averaged over the operations within a slot.
- Different and/or additional parameter assumptions used for evaluation should be clearly stated.

Table 18: UE power consumption model for FR1

Power State	Characteristics	Relative Power
Deep Sleep	Time interval for the sleep should be larger than the total transition time entering and leaving this state. Accurate timing may not be maintained.	1 (Optional: 0.5)
Light Sleep	Time interval for the sleep should be larger than the total transition time entering and leaving this state.	20
Micro sleep	Immediate transition is assumed for power saving study purpose from or to a non-sleep state	45
PDCCH-only	No PDSCH and same-slot scheduling; this includes time for PDCCH decoding and any micro-sleep within the slot.	100
SSB or CSI-RS proc.	SSB can be used for fine time-frequency sync. and RSRP measurement of the serving/camping cell. TRS is the considered CSI-RS for sync. FFS the power scaling for processing other configurations of CSI-RS.	100
PDCCH + PDSCH	PDCCH + PDSCH. ACK/NACK in long PUCCH is modeled by UL power state.	300
UL	Long PUCCH or PUSCH.	250 (0 dBm) 700 (23 dBm)

- FFS: Power saving signal processing power and transition energy.

- The following additional transition energy and total transition time for the three sleep types are adopted as working assumption for power saving SI:
  - Both ramp down and ramp up transitions are included.
  - Additional processing time for acquiring synchronization is not included in total transition time.
  - There is always a non-sleep power state between adjacent sleeps.

Table 19: UE power consumption during the state transistion

Sleep type	Additional transition energy: (Relative power x ms)	Total transition time
Deep sleep	450	20 ms
Light sleep	100	6 ms
Micro sleep	0	0 ms*
* Immediate transition is assumed for power saving study purpose from or to a non-sleep state		

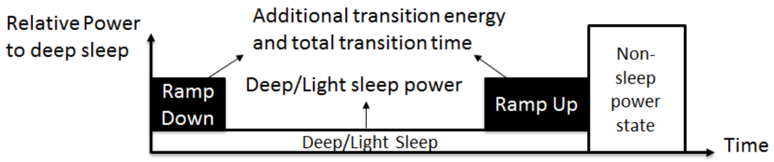


Figure 1: Illustration of UE power consumption at state transition

8.1.2 UE power consumption model for FR2

Reference configuration for FR2:

- Downlink: TDD, FR2
  - Subcarrier spacing (SCS): 120 kHz
  - Number of carriers: 1CC
  - System Bandwidth: 100 MHz
  - PDCCH region of 2 symbol at beginning of a slot
    - k0 = 0
    - maximum number of CCEs = 32
    - 20 PDCCH blind decoding
  - PDSCH of max data rate with
    - Modulation: 64QAM
    - MIMO configuration: 2x2
    - Number of RBs for TRS = TBD
    - 2RX UE Capability = 1
- Uplink: TDD, FR2
  - Subcarrier Spacing (SCS): 120 kHz
  - Number of carrier = 1CC
  - System Bandwidth = 100MHz
  - Tx antenna configuration: 1TX chain
  - Power levels: [FFS dBm]

- Power values are averaged over the operations within a slot
- Different and/or additional parameter assumptions used for evaluation should be clearly stated.

Table 20: UE power consumption model for FR2

Power State	Characteristics	Relative Power	
		FR1	FR2
PDCCH-only	No PDSCH and same-slot scheduling; this includes time for PDCCH decoding and any micro-sleep within the slot.	100	175
SSB or CSI-RS proc.	SSB can be used for fine time-frequency sync. and RSRP measurement of the serving/camping cell.. TRS is the considered CSI-RS for sync. FFS the power scaling for processing other configurations of CSI-RS. (Note 2 SSBs in a slot for the ref. config.)	100	175
PDCCH + PDSCH	PDCCH + PDSCH. ACK/NACK in long PUCCH is modeled by UL power state.	300	350
UL	Long PUCCH or PUSCH.	250 (0 dBm) 700 (23 dBm)	350 (FFS Tx power level)

- Sleep states power level, energy overhead, and transitions are same as FR1.

8.1.3 UE power consumption scaling for adaptation

The power scaling scheme for FR1 and FR2 power states are in Table 4.

Table 21: UE power consumption scaling for adaptation

Scaling for FR1	Proposal	Comment
BWP Bandwidth (DL)	Scaling of X MHz = 0.4 + 0.6 * (X - 20) / 80. Linear interpolation for intermediate bandwidths. Valid only for X = 10, 20, 40, 80, and 100. Above scaling is applicable for FR1 only. In case scaling is needed for FR2, companies can report the assumed scaling factor.	For 10MHz BW, only AL up to 8 can be used for PDCCH The transition time is the same as DCI-based BWP switching delay for Rel-15. If the power after scaling is smaller than the BWP transition power, assume the BWP transition power as the output of scaling unless otherwise justified.
BWP Bandwidth (UL)	No scaling at 0dBm or 23dBm Above scaling is applicable for FR1 only. In case scaling is needed for FR2, companies can report the assumed scaling factor.	
CA (DL)	2CC is 1.7x1CC 4CC is 3.4x1CC (i.e. 2x 2CC) Above refers to the worst case CA configuration in terms of power consumption.	Activation/deactivation delay follows RAN4 specification; FFS transition energy Applicable for FR1 and FR2
CA (UL)	Same as downlink at 0dBm. No scaling at 23dBm 2CC is 1.2x1CC at 23dBm Limit scaling up to 2CC.	Applicable for FR1 and FR2
Antenna scaling (DL)	2Rx power is 0.7x 4Rx power for FR1 1Rx power is 0.7x 2Rx power for FR2	Assume same number of antenna elements per Rx chain
Antenna scaling (UL)	2Tx power is 1.4x 1Tx power at 0dBm. 1.2x.at 23dBm FR1 only	2Tx support is not considered for FR2.
PDCCH-only	Power of cross-slot scheduling is 0.7x same-slot scheduling	Applicable for FR1 and FR2
SSB	One SSB power is 0.75 of two SSB power, i.e. 75 power units	
PDSCH-only slot	280 for FR1 325 for FR2	This assumes the same number of PDSCH symbols as in the PDCCH+PDSCH case.
CSI-RS	FFS for scaling w.r.t. # of symbols for CSI-RS	
Short PUCCH	Short PUCCH power = 0.3 x uplink power Reference config consists of 1-symbol PUCCH	Applicable for FR1 and FR2.
SRS	SRS power = 0.3 x uplink power	Applicable for FR1 and FR2.

- Note: Scaling applies only to non-sleep power states.
- Note: latency involved in antenna scaling is FFS
- For evaluation, when BWP transition duration is one slot or longer, the slot-average power level is 50 power units
  - In case when BWP transition duration is <one slot (if defined), up to each company to report the power level assumed
  - Companies to report the type of BWP transition time (type 1 and/or type 2) assumed in the evaluation

  - Note: When BWP adaptation power scaling is applied, the resultant power should not be smaller than the above power level. Justification should be provided if a different assumption is made (for example, UE is assumed to be in a state that is not fully active).
- The power scaling factors for BWP adaptation and number of antenna reduction are not intended to be applicable to the power states associated with RRM power modelling in section 8.1.4.
- For evaluation purpose, it is assumed that a periodicity of max(DRX cycle, 160 msec) is the baseline for periodic activities, e.g. time/frequency, channel or beam tracking (if applicable)
  - Other periodicity values are not precluded – companies to report if other values are assumed
  - Companies to report detailed assumptions, e.g. the resources used, the relative timing relationship between DRX cycle and periodic activity, whether and how UL reporting is done, etc.

Power scaling scheme for PDCCH candidates processing reduction:

- Scaling for the power reduction due to PDCCH candidates processing (e.g. AL/CCE/BD) reduction is modelled solely based on its effect on micro sleep portion of the PDCCH-only slot
- The UE power scheme should include the portion of PDCCH processing time reduction in accordance to PDCCH candidates (e.g. AL/CCE/BD) reduction
  - Note: In the reference configuration, the first two symbols are PDCCH symbols
- For power scaling for PDCCH candidate reduction (for same slot scheduling only):

$$P(\alpha) = \alpha \cdot Pt + (1 - \alpha) \cdot 0.7Pt$$

- where α is the ratio of PDCCH candidates to the max number of PDCCH candidates in the reference configuration (α>0). Pt is the PDCCH-only power for same-slot scheduling.

For UE power modelling, the following power scaling relationship is assumed:

- For simplicity,
  - The slot-averaged power for "PDCCH+PDSCH+PUCCH" is same as "PDCCH+PDSCH"
  - The slot-averaged power for "PDSCH+PUCCH" is same as "PDSCH-only"
  - The slot-averaged power for "PDCCH+PUCCH" is the sum of "PDCCH-only" power and "short PUCCH" power.
    - Note: PDCCH-only with cross-slot scheduling scaling is also applicable
  - Note: it is observed via evaluations (where 0dBm PUCCH Tx power is assumed) that the difference is not significant
- For non-RRM evaluation, for "PDCCH+PDSCH" concurrent in the same slot as "SSB or CSI-RS processing", assume "PDCCH+PDSCH" power
- For non-RRM evaluation, for "PDSCH only" concurrent in the same slot as "SSB or CSI-RS processing", assume "PDSCH only" power
- For "PDCCH-only" and "SSB or CSI-RS processing" concurrent in a slot, the slot-averaged power is 0.85x the sum of the respective power, at least for FR1
  - For FR1, 0.85*(100+100) = 170
  - For FR2, 0.85*(175+175) = 300
- For "SSB processing" and "CSI-RS processing" concurrent in a slot, the slot-averaged power is 0.85x the sum of the respective power, at least for FR1
  - For FR1, 0.85*(100+100) = 170
  - For FR2, 0.85*(175+175) = 300

- 2-SSB within a slot is assumed

8.1.4 UE power consumption model for RRM measurements

Reference configuration and assumptions for RRM measurements:

- SSB periodicity is 20msec
  - 2 SSBs per slot are measured
- SMTC periodicity is 20msec
- For inter-band
  - Up to 2 frequency layers and
  - Gap pattern ID = 0 defined in TS 38.133 (i.e., measurement gap length of 6msec and measurement gap periodicity of 40msec)

Use the following as a reference for RRM power evaluation:

- Assume SMTC window duration of 2ms (corresponding to 30kHz SCS) for synchronised FR1 scenario.
- Assume SMTC window duration of 5ms for all other cases
- Note: other values are not precluded

8.1.4.1 For intra-frequency measurements

Table 22: UE power consumption for the RRM measurements

N: Number of cells for intra-frequency measurement	Synchronous case		Asynchronous case	
	FR1	FR2	FR1	FR2
N=8	150	225-	170	285
N=4	120	195	140	255

- All above values are slot-averaged power (P_{fr1} or P_{fr2} for FR1 or FR2 respectively).
- Synchronous case means actual SSB transmissions from cells are time-aligned e.g., timing of SSB_i from $cell_i$ is aligned with timing of SSB_i from $cell_j$.
- Asynchronous case means actual SSB transmissions from cells are not time-aligned e.g., timing of SSB_i from $cell_i$ is not aligned with timing of SSB_i from $cell_j$
- The following maximum number of cells for intra-frequency measurement within a slot:

Table 23: Maximun numer of cells for intra-frequency measurements

FR1	FR2
Nmax = 19	Nmax = 9

<u>For combined measurement and search:</u>

To obtain combined neighboring cell measurement and search power, add the difference between full neighboring cell search state power and SSB/CSI-RS proc. state power to the neighboring cell measurement power, as shown below:

Table 24: UE power consumption of the combined neighbor cell measurements and cell search

N: Number of cells for intra-frequency measurement & search	Synchronous case		Asynchronous case	
	FR1	FR2	FR1	FR2
N=8	200	320	220	380
N=4	170	290	190	350

8.1.4.2 For inter-frequency measurement

The inter-frequency measurement is represented as function of the number of frequency layers:

UE needs to monitor *Nf* frequency layers within a measurement gap.

$$E3 = \left(\sum_{i=0}^{Nf-1} E_i\right) + Et \cdot (Nf + 1)$$

Where

- *Ei* is either P_{fr1}*Ns (for FR1) or P_{fr2}*Ns (for FR2) for each frequency layer *i*
  - *Ns* is the number of slot over which measurements (for each frequency layer *i*) are carried out
- *Nf* is the number of frequency layers measured
- *Et* = *Pt* * *Tt*, where
  - *Pt* is the switching power consumption
    - Assume micro sleep power for Pt
  - Tt is 0.5ms for FR1 and 0.25ms for FR2 (from RAN4)

It can be simplified to the following if Ei is same across frequency layers (i.e. *Ei* = *E* for all i).

E3 = E*Nf + Et*(Nf+1)

Note: RAN4 requirement assumes only one frequency layer per measurement gap.

For full neighboring cell search:

The baseline neighbor cell search power is independent of the number of cells on the first order and can be approximated as:

Table 8: UE power consumption of neighboring cell search

FR1	FR2
150	270

- It is expressed as the power averaged over a slot during which search is performed.

8.2 Simulation assumptions

Deployment scenarios

- Dense urban
- Single layer
- Additional deployment scenarios to be considered
  - Indoor hotspot
  - Rural macro
- Note: For RRM measurement evaluation, UE power consumption contributed by inter-frequency and/or inter-RAT measurement can be considered.

Performance metrics

- UE power saving gain - percentage of power consumption reduction of the proposed power saving scheme from the baseline scheme
  - FFS: For the case multiple applications are evaluated, whether power consumption is the overall DoU power across the applications
- System performance
  - Latency
  - Scheduling delay
  - User throughput
    - System throughput and/or resource utilization/overhead (if applicable) should be reported as the result of the evaluation, in addition to power saving gain.
- If a new signal/channel is introduced, the performance metrics include
  - Performance
  - Complexity
  - Overhead for reception of the signal/channel
- If the new signal is used for detection, the performance metrics include
  - False alarm rate
  - Miss-detection rate

Link level simulation assumptions:

- Simulation assumptions as specified in Table A1.5-1 in TR38.802 [4] should be the basis for link-level simulation evaluation.
  - Antenna configuration may use IMT-2020 as reference. The evaluation results should also include the antenna configuration if it is different from the reference antenna configuration,
- For LLS simulation on power saving signal detection performance, at least the following SINR values should be evaluated: -6dB, 3dB, 20dB.

System level simulation assumptions:

- Simulation assumptions as specified in Table A2.1-1 in TR38.802 [4] should be the basis for system-level simulation evaluation.
  - Antenna configuration may use IMT-2020 as reference. The evaluation results should also include the antenna configuration if it is different from the reference antenna configuration,
- It is clarified that user throughput measured from system level simulation does not preclude user perceived throughput taking into account TCP slow start if applicable
- For system level impact evaluation, IMT-2020 simulation assumptions can be adopted.
  - For system level simulation, whether to apply DRX depends on the particular power saving proposal being evaluated and the purpose of the simulation. Whether DRX is not applied in the simulation should be identified along with the evaluation results
- For reducing simulation time for system level simulation, scaling of the bandwidth and packet size of the traffic model can be considered (e.g. factor of 1/5). Companies to report the scale factor used, if any.
- For system level simulation, at least assume that the traffic model is FTP model 3 with 0.5Mbyte payload and mean inter-arrival time of 200 milliseconds

  - The mean inter-arrival time can be adjusted to achieve different cell loading scenarios.
  - Note: Other variations including different traffic models are not precluded
- The same traffic model settings should be used across all users.

System Configurations:

Reference DRX configurations:

- C-DRX cycle 320msec, inactivity timer {200, 80} msec
  - FR1 On duration: 10 msec
  - FR2 On duration: 5 msec
- C-DRX cycle 160msec, inactivity timer {100, 40} msec
  - FR1 On duration: 8 msec
  - FR2 On duration: 4 msec
- C-DRX cycle 40msec, inactivity timer {25, 10} msec
  - FR1 On duration: 4 msec
  - FR2 On duration: 2 msec
- I-DRX cycle 1.28 sec
  - Group paging rate (for a PO): 10%
    - P-RNTI is detected but PDSCH decoding results in no match
    - Note: Statistics for the matching case may be further considered based on use case
- Note: The selection and reporting of the settings for short DRX cycle, short DRX cycle timer, drx-RetransmissionTimerDL, drx-RetransmissionTimerUL, drx-HARQ-RTT-TimerDL, and/or drx-HARQ-RTT-TimerUL should be included in the results of the UE power saving scheme

Traffic model used for the UE power saving scheme evaluation

- Applications with the traffic model for the evaluation of the UE power saving scheme
  - FTP - FTP model 3
    - Other bursty traffic arrival models can be considered
  - Web-browsing
  - Video streaming
  - Instant messaging
  - VoIP
  - Gaming
  - Background app sync

For FTP, instant messaging, and VoIP application, the following traffic models and DRX configuration should be included for evaluation:

	FTP traffic	Instant messaging	VoIP
Model	FTP model 3	FTP model 3	As defined in R1-070674. Assume max two packets bundled.
Packet size	0.5 Mbytes	0.1 Mbytes	
Mean inter-arrival time	200 ms	2 sec	
DRX setting	Period = 160 ms Inactivity timer = 100 ms	Period = 320 ms Inactivity timer = 80 ms	Period = 40 ms Inactivity timer = 10 ms

Note: For ON duration setting, following reference DRX configurations as previously agreed.

- For web-browsing, video streaming, and gaming applications, the traffic models and the delay requirements defined in R1-070674 can be used in the evaluation. The parameters (e.g. packet size) may be updated to be in line with EMBB traffic requirements.
- For background app sync application, for power consumption evaluation purpose, it can be assumed that idle mode operations (inclusive of page detection, RRM, deep sleep and transition overhead) contributes to X% of the use case power. The remaining portion is contributed by intermittent RRC connections due to background activities (FFS: value of X)
- Companies should report the assumptions made in the evaluation

Evaluation methodology of the UE power saving schemes:

- Numerical analysis, system level simulation, and link level simulation are included as evaluation methods for power saving proposals. At least one of the methods should be selected and used for evaluation of a specific power saving proposal.
    - FFS: The criteria for selection of the methods

For power evaluation,

- For evaluation of DRX scenarios, the RRC release timer is set to infinity to ensure C-DRX and I-DRX cases are treated separately.
- Power consumption for channel/time/frequency and beam tracking operations should be taken into account.

Calibrations:

For the purpose of basic calibration of traffic modeling, FTP model 3 (use 0.1 Mbytes packet size, mean inter-arrival time 200msec) and VoIP model (as defined in R1-070674) should be used to generate time distribution for different power states, for the following scenarios

1) No C-DRX configured
    - For both VoIP and FTP
2) C-DRX cycle 40msec for VoIP
    - 10 msec inactivity timer
    - Assume max two packets bundled
3) C-DRX cycle 160msec for FTP
    - 100 msec inactivity timer

The time distribution for different power states shall be reported (e.g. x% in PDCCH-only, y% in PDCCH+PDSCH, z% in micro sleep, etc), as a result of the calibration exercise.

The following simplifying assumptions can be made:

- Power modelling reference configuration for FR1
- Peak throughput. 100MHz
- DL BWP. 10-symbol PDSCH (one symbol occupied by DMRS)
    - Capable of carrying 868584 information bits per slot (Note: a packet can fit within a PDSCH transmission)
- All packets can be successfully decoded on the first transmission
    - No HARQ retransmission
- No UL slot
- Single user
- Short DRX is not configured.

Calibration results

Traffic & configuration	Power States	HW [6] [98]	Vivo [7]	MTK [8]	ZTE [15]	Intel [14]	LGE [9]	CATT [10]	SS [11]	E/// [12] [50]	QCOM [13]	OPPO [42]	Sony[44]	Nokia [51]	Apple [68]
FTP, w/o C-DRX	PDCCH only	99.79%	99.75%	99.75%	99.73%	99.75%	99.75%	99.71%	99.75%	99.80%	99.75%	99.74%	99.75%	99.75%	99.75%
	PDCCH+PDSCH	0.21%	0.25%	0.25%	0.27%	0.25%	0.25%	0.29%	0.25%	0.20%	0.25%	0.26%	0.25%	0.25%	0.25%
	Micro sleep	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Light sleep	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Deep sleep	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FTP, w/ C-DRX	PDCCH only	34.96%	34.68%	34.62%	35%	34.96%	35.27%	37.92%	32.85%	38.20%	35.01%	35.65%	34.50%	34.95%	35.44%
	PDCCH+PDSCH	0.21%	0.25%	0.20%	0.27%	0.25%	0.26%	0.29%	0.20%	0.20%	0.25%	0.293%	0.25%	0.25%	0.21%
	Micro sleep	0.02%	0.01%	0.02%	0.03%	0.02%	0.02%	0.00%	0.01%	0%	0.01%	0.0248%	0.02%	0.02%	0.04%
	Light sleep	0.15%	0.13%	0.17%	0%	0.15%	0.17%	0.00%	0.14%	0%	0.15%	0.124%	0.15%	0.14%	0.07%
	Deep sleep	64.66%	64.94%	64.99%	65%	64.62%	64.28%	61.85%	66.80%	61.60%	64.58%	63.9%	65.09%	64.64%	64.57%
VoIP, w/o C-DRX	PDCCH only	98.92%	98.59%	98.56%	98.43%	98.75%		98.70%	98.46%	98.50%	98.60%		98.73%		98.7%
	PDCCH+PDSCH	1.08%	1.41%	1.44%	1.57%	1.25%		1.31%	1.54%	1.50%	1.40%		1.27%		1.3%
	Micro sleep	0.00%	0.00%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%		0.00%		0.00%
	Light sleep	0.00%	0.00%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%		0.00%		0.00%
	Deep sleep	0.00%	0.00%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%		0.00%		0.00%
VoIP, w/ C-DRX	PDCCH only	22.09%	22.40%	21.46%	19.31%	18.72%		14.43%	20.16%	32.40%	22.31%		20.20%		20.36%
	PDCCH+PDSCH	1.08%	1.09%	1.09%	0.78%	1.25%		0.40%	1.96%	1.50%	1.08%		0.96%		0.84%

	Micro sleep	0.00%	0.00%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%	0.00%		0.00%		0.00%
	Light sleep	1.37%	0.61%	0.41%	0.00%	0.00%		0.00%	0.34%	26.50%	0.54%		0.83%		0.00%
	Deep sleep	75.45%	75.90%	77.04%	79.92%	80.03%		85.16%	77.54%	39.60%	76.07%		78.02%		78.78%

Annex <X>: Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2018-10	RAN1#94bis	R1-1811896				TR Skeleton	0.0.0
2018-11	RAN1#95	R1-1812639				TR update after RAN1#94bis	0.0.1
2018-12	RAN1#95	R1-1814387				TR update after RAN1#95	0.1.0
2019-02	RAN1#96	R1-1902023				TR update after RAN1 AH#1901	0.1.1
2019-03	RAN1#96	R1-1903832				TR update after RAN1#96 and RAN2#105 - For information to plenary in RP-190574, inc. MCC clean-up	1.0.0
2019-05	RAN1#97	R1-1907967				TR update after RAN2#105bis and RAN2#106 – for presentation to plenary for final approval of TR	2.0.0
2019-06	RAN#84					Specification under change control (Release 16) further to RAN approval of RP-191083	16.0.0