**3GPP TSG RAN WG1 e-Meeting #102 R1-200XXXX**

**August 17th – 28th, 2020**

Agenda Item: 8.7.1.1

Source: Moderator (MediaTek)

Title: Summary for Potential Power Saving Enhancements

Document for: Discussion and Decision

# Introduction

For Rel-17 paging enhancement, the summary is for discussing the following two aspects:

* Evaluation Assumption
* Potential Page Enhancements

To facilitate the decision, the following phases are to be suggested:

* **Phase I (due 20th Aug 3 am PST)**: Collection of companies views
* **Phase II (20th Aug 6 am PST – 21th Aug 6 am PST)**: Convergence on high priority proposals related to evaluation assumptions (marked with red colored “Proposal”)
* **Phase III (24th Aug 3 am PST – 26th Aug 11 pm PST)**: Convergence on remaining proposals

# Evaluation Assumptions

In Rel-16, there establishes fundamental evaluation methodology in [1]. For Rel-17 UE power saving enhancements, the evaluation methodology can be reused with few updates for better characterizing idle/inactive mode UEs. It is also noticed that Reduced Capability NR Devices should also be taken into account in Rel-17 UE power saving enhancements [2].

From companies’ contributions [3] - [24], the following updates will be discussed further:

1. Power consumption model
2. UE Processing Timeline
3. Group Paging Rate
4. Performance Metric

## Power Consumption Model

For calculating UE power consumption, there require definition of power consumption value for each UE operation called “power state”. In [1], the power consumption values for the power states are defined with 100 MHz reference BW. On the other hand, for paging monitoring in idle/inactivity mode, it suffices for UE to receive and process a narrow frequency span covering CORESET 0 and SSB, and the typical frequency span is no larger than 20 MHz. For the same power consumption model to be applied to reduced capability UEs, scaling to 20MHz bandwidth is also necessary.

In Table 1, there summarize companies’ proposals, and 9 out of 11 companies propose to scale the reference power consumption values of 100 MHz bandwidth to 20 MHz:

Table 1: Companies’ proposals on power consumption model

|  |  |
| --- | --- |
| **Company** | **Proposals** |
| Huawei, HiSilicon [3]  | **Proposal 2: For evaluation, the power model in the following table is used, which follows the scaling rule and power model in TR38.840.**

|  |  |
| --- | --- |
| **Power state** | **Relative power units** |
| **Deep sleep** | **1** |
| **Light sleep** | **20** |
| **Micro sleep** | **45** |
| **PDCCH-only** | **50** |
| **PDCCH+PDSCH** | **120** |
| **SSB or CSI-RS proc.** | **50** |

 |
| Vivo [4] | Proposal 1: Adopt power model in Table 1 (except the power of PDCCH-only of cross-slot scheduling) for power saving evaluation in idle/inactive mode.Table 1: UE power consumption model for FR1

|  |  |  |
| --- | --- | --- |
| Power State | Relative Power (system bandwidth is 100 MHz) | Relative Power(initial bandwidth is 20 MHz) |
| Deep Sleep | 1 (Optional: 0.5) | 1 (Optional: 0.5) |
| Light Sleep | 20 | 20 |
| Micro sleep | 45 | 45 |
| PDCCH-only for same-slot scheduling | 100 | max {100\*0.4, 50} = 50 |
| PDCCH-only for cross-slot scheduling | 70 | max {70\*0.4, 50} = 50 |
| PDCCH + PDSCH | 300 | max {300\*0.4, 50} =120 |
| PDSCH-only | 280 | max {280\*0.4, 50} =112 |
| SSB or CSI-RS proc. | 100 | max {100\*0.4, 50} = 50 |
| Intra-frequency RRM measurement | 150 (synchronous case, N=8) | max {150\*0.4, 50} = 60 |
| Inter-frequency RRM measurement | 150 | max {150\*0.4, 50} = 60 |
| **Note 1**: 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 transition power is assumed as 50.**Note 2**: Power of cross-slot scheduling is 0.7x same-slot scheduling.**Note 3**: N is the number of cells for intra-frequency measurement. |

 |
| ZTE [5] | **Proposal 5: For RRC Idle/Inactive state, the power model (including the relative power for RRM measurement) can be derived by scaling down the relative power of RRC connected state. The power model in Table 1 can be considered as a starting point.**Table 1. UE power consumption model for FR1 in idle/inactive state

|  |  |  |
| --- | --- | --- |
| Power state | Relative power | Note |
| PDCCH-only | 50 | 0.4 times of the power consumption in RRC\_CONNECTED state is 40, which is less than the BWP transition power. Therefore, the BWP transition power is used. |
| SSB | 50 |
| Additional RS proc.（if any） | 50 |
| PDCCH + PDSCH | 120 | 0.4 times the power consumption in connected state. |
| RRM measurement | 60 | In RRC\_CONNECTED state, the UE power consumption for the RRM measurements is 150 when the number of cells for intra-frequency measurement equals to 8. The UE power consumption for inter-frequency measurements is also 150. Therefore, 0.4 times the power consumption in connected state is 60. |
| Micro sleep | 45 | Scaling is only applied to non-sleep power states. |
| Light sleep | 20 |
| Deep sleep | 1 |

 |
| Sony [6] | Table 1 - UE power consumption for FR1 in IDLE/INACTIVE mode

|  |  |  |
| --- | --- | --- |
| Power state | Relative power  | Comment |
| PDCCH only (P\_RNTI) | 50  | Scaling of X MHz: α = 0.4 + 0.6 \* (X - 20) / 80 Relative power = *max*(50, α.Pstate), where Pstate is power level at 100 MHz BW and BWP transition power is 50 power units. Substituting the following values in the above expression we find relative power corresponding to the power state in 20 MHz initial BWP. PPDCCH-pnly= PSSB-itra=100 PPDSCH=280PPDCCH-PDSCH=300PSSB-iter=150 |
| PDSCH (TMSI) | 112 |
| PDCCH+PDSCH (SIB1) | 120 |
| SSB burst (synchronization and serving/intra-freq RRM) | 50 |
| SSB burst (inter-freq/RAT RRM) | 60 |

No change to deep, light, and macro sleep relative power and transition times.Above scaling is applicable for FR1 only. In case scaling is needed for FR2, companies can report the assumed scaling factor. |
| MediaTek [7] | Proposal 5: For idle/inactive mode power consumption analysis, the power consumption values in Table 1 are utilized, which covers both normal capability and reduced capability UEs.Table 1: Scaled power consumption values for idle/inactive mode power analysis |
| CATT [8] | **Table 1 UE power saving modelling for FR1**

|  |  |
| --- | --- |
| Power State | Relative Power  |
| Deep Sleep | 1  |
| Light Sleep | 20 |
| PDCCH-only | 100 |
| SSB | 100(2 SSB per slot) |
| TRS/CSI-RS | 100(Number of RBs for TRS = 52) |
| Additional transition power | Deep sleep:450;Light sleep:100 |
| PDCCH + PDSCH (if CRC is true) | 300  |
| PDCCH-based paging indication | 100 |
| Sequence-based paging indication | 100(Assumption: Sequence-based paging indication and SSB concurrent in a same slot, the slot-averaged power is 0.85x the sum of the respective power) |
| PDCCH + PDSCH (if CRC is false) | 200 |
| RRM intra-frequency | 150 |

 |
| Samsung [14] | **Table 3: Assumption of power model with UE operation bandwidth of 20MHz**

|  |  |  |
| --- | --- | --- |
| **Power state** | **Relative power** | **Duration /ms** |
| Serving cell RRM measurement, Pmes | 150 | $$D\_{SMTC}$$ |
| Intra-frequency measurement, Pintra | 200 | $$D\_{SMTC}$$ |
| Inter-frequency measurement, Piner | 150 | $$D\_{MG}$$ |
| SSB processing, PSSB | 50 | $$D\_{SSBs}∙N\_{SSBs}$$ |
| PDCCH only, $P\_{PDCCH}$ | 50 | $$D'\_{PO}$$ |
| PDCCH + PDSCH, $P\_{PDCCH+PDSCH}$ | 120 | $$D'\_{PO}$$ |
| Sequence based I-WUS, PI-WUS,seq  | 45-50 | 0.5-2 |
| PDCCH based I-WUS, PI-WUS,DCI | 50 | $$D'\_{PO}$$ |
| Micro-sleep, PMS | 45 |  |
| Light sleep, PLS | 20 | >=6 |
| Deep sleep, PDS | 1 | >=30 |

 |
| CMCC [15] | **Proposal 1. The following updated parameters can be considered in the evaluation methodology in IDLE/INACTIVE state for FR1:*** **20MHz BWP bandwidth**
* **0.4 scaling factor for 20MHz**
 |
| Spreadtrum [16] | **Table 1: The power model for evaluation of paging in idle mode**

|  |  |  |
| --- | --- | --- |
| **Power state** | **Power consumption** | **Note** |
| Deep sleep | 1 | Not scaled with RX BW |
| Light sleep | 20 |
| Micro sleep | 45 |
| PDCCH-only | 50 | Scaling to 20MHz RX BW:Max(X∙0.4, 50), where X is power value at 100MHz |
| PDCCH + PDSCH | 120 |
| SSB or CSI-RS processing | 50 |
| Deep sleep transition energy | 450 | Transition time 20ms |
| Light sleep transition energy | 100 | Transition time 6ms |
| Micro sleep transition energy | 0 | Transition time 0ms |

 |
| Qualcomm [23] | Table 1: Power states and their agreed power values for I-DRX

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Power state** | **Power** | **Duration (ms)** | **Energy** | **Energy Notation** |
| Loop (AGC, TTL & FTL)  | 100 | 0.5$N\_{SSBS}$ | 50$N\_{SSBS}$ | $$E\_{loop}$$ |
| Paging (PDCCH-only)  | 100 | 0.5 | 50 | $$E\_{page}$$ |
| SIB1 decoding (PDCCH+PDSCH) | 300 | 1 | 300 | $$E\_{SIB1}$$ |
| Neighbor cell search (within SMTC) | 150 | 2 | 300 | $$E\_{srch}$$ |
| L-SSB measurement  | Depending on the # of SSBs to be measured and whether UE is stationary or not | $$E\_{meas}$$ |
| Serving cell SSB/CSI-RS processing | 100 | 0.5 | 50 | $$E\_{ssb}$$ |
| Light sleep 1 (between consecutive SSBs for the loops and RRM measurement) | 20 | 19.5 | 390 | $$E\_{L1}$$ |
| Light sleep 2 (gap between PO and the closest SSB) | 20 | 10 | 200 | $$E\_{L2}$$ |
| Light sleep transition |  |  | 100 | $$E\_{LT}$$ |
| Deep sleep transition |  |  | 450 | $$E\_{DT}$$ |
| Deep sleep | 1 | $$1280-T\_{active,I}$$ | $$1280-T\_{active,I}$$ | $$E\_{D}$$ |
| Note: * $N\_{SSBS}$ is the number of SSBs (one SSB in each SSB set) needed to run AGC/FTL/TTL loops (assuming $N\_{SSBS}=1$ in the model)
* $T\_{active,I}$ is the whole duration other than the deep sleep within an I-DRX
* For paging, 10% false alarm is assumed (i.e., 10% both PDCCH and PDSCH are decoded)
 |

 |
| Nokia [24] | In TR38.840, a UE power consumption model was defined. The values were provided for a 100 MHz bandwidth reference configuration, but paging may be confined to 20 MHz or less. Therefore, relevant power consumption states must be scaled according to the bandwidth scaling model:$$P\left(x MHz\right)=max\left(50,P\left(100 MHz\right)∙\left(0.4+0.6∙\frac{x-20}{80}\right)\right)$$$$P\left(20 MHz\right)=max\left(50,P\left(100 MHz\right)∙0.4\right)$$Table 1 provides the scaled power consumption states. Note that sleep state powers do not scale with bandwidth, i.e. they remain 1, 20, and 45 for deep, light, and micro sleep, respectively. Furthermore, the related transition times are not expected to change.Table 1 Power consumption for 20 MHz bandwidth, FR1.

|  |  |
| --- | --- |
| Power state | Relative power |
| PDCCH-only (same-slot scheduling) | 50 |
| PDCCH+PDSCH | 120 |
| SSB processing (serving cell) | 50 |

The power model also defines RRM states, e.g. intra- and inter-frequency cell measurements and search. However, it is explicitly stated that the bandwidth scaling model does not apply.**Proposal: RAN1 to define power consumption values for intra- and inter-frequency neighbor cell measurements and cell search for 20 MHz bandwidth for evaluation of objective 1a.** |

Regarding the majority view, the following proposal is first suggested:

Proposal 1: For Rel-17 paging enhancement or for reduced capability UEs, the power consumption values for the power states in TR 38.840 are scaled from 100 MHz reference bandwidth to 20 MHz bandwidth. Specifically, the following power consumption model is utilized:

|  |  |  |
| --- | --- | --- |
| Power State | Relative Power(TR 84.840; reception bandwidth 100 MHz) | Relative Power(Scaled to reception bandwidth of 20 MHz by the rule in TR38.840) |
| Deep Sleep | 1 | 1 |
| Light Sleep | 20 | 20 |
| Micro sleep | 45 | [35]Note1 |
| PDCCH-only  | 100 | max {100\*0.4, 50} = 50 for same-slot scheduling;[40] Note2 for cross-slot scheduling |
| PDCCH + PDSCH | 300 | max {300\*0.4, 50} =120 |
| PDSCH-only | 280 | max {280\*0.4, 50} =112 |
| SSB/CSI-RS proc.  | 100 (sync or serving cell measurement) | max {100\*0.4, 50} = 50 |
| Intra-frequency RRM measurement | 150 (synchronous case, N=8) | max {150\*0.4, 50} = 60Note3 |
| Inter-frequency RRM measurement | 150 | max {150\*0.4, 50} = 60Note3 |
| Note 1: Micro-sleep power consumption is scaled down to be no larger than scaled PDCCH-only power consumption with reduced PDCCH candidates. But, other sleep power consumption values and wake-up energy overheads are not scaled. Note 2: Cross-slot scheduling scaling is increased to avoid scaled PDCCH-only power consumption value is the same as micro-sleep (no UE processing) Note 3: RRM measurement power consumption values are scaled for consistent power consumption characteristics with other power states |

For achieving consensus, companies are welcomed to provide comments for Proposal 1 in Table 2:

Table 2: Companies’ comments for Proposal 1

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Apple | We are generally fine with the proposal.The note says “Cross-slot scheduling scaling is increased to avoid scaled PDCCH-only power consumption value is the same as micro-sleep”. But this does not seem to be the case. If we reduce the number of BDs to be 40% of the original, the scaling factor for the reduced BDs is 0.4+(1-0.4)\*0.7=0.82. Then the power consumption for PDCCH-only with cross-slot scheduling is 40\*0.82=32.8 < 35.  |
| Samsung | For RRM measurement, we suggest to consider the following changes to distinguish the power states for measurement only (high SINR) and perform both measurement and cell search (low SINR).

|  |  |  |
| --- | --- | --- |
| Power State | Relative Power(TR 38.840; reception bandwidth 100 MHz) | Relative Power(Scaled to reception bandwidth of 20 MHz by the rule in TR38.840) |
| Intra-frequency RRM measurement | * 150 (synchronous case, N=8, measurement only)
* 200 (combined measurement and search)
 | * max {150\*0.4, 50} = 60Note3(synchronous case, N=8, measurement only)
* max {200\*0.4, 50} = 80Note3 (combined measurement and search)
 |
| Inter-frequency RRM measurement | 150 (neighbor cell search power per frequency layer) | max {150\*0.4, 50} = 60Note3  |

For PDCCH-only state, we don’t see the need to model PDCCH-only power for cross-slot scheduling. Although NW may schedule paging message in different slot than the slot for paging PDCCH, UE can’t assume cross-slot scheduling by default. Also, we don’t see the need to consider PDSCH-only for idle mode. |
| Ericsson | The scaling models seems generally fine to us. However, given this model would be applicable generically (even existing UEs), in the preceding paragraph before the table, “For Rel-17 paging enhancements or reduced capability UEs” should be deleted.  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

## UE Processing Timeline

With the power consumption model in Section 2.2, it remains to specify UE processing timeline for a paging cycle so as to compute the average power consumption. In Table 3, there summarize companies proposals:

Table 3: Companies proposals of UE processing timeline for paging monitoring/reception

|  |  |
| --- | --- |
| **Company** | **Proposals** |
| Huawei, HiSilicon [3]  | **Proposal 4: Take the following as evaluation assumption for IDLE/INACTIVE mode UE**

|  |  |  |
| --- | --- | --- |
| **Parameter**  | **Good coverage** | **Bad coverage** |
| **#SSB burst****(Number of SSB burst to be received before the PO)** | 1 | 2 (eMBB UE) or 3(RedCap UE) |
| **SSB burst set periodicity** | 20ms | 20ms |
| **SCS** | 30kHz | 30kHz |
| **Neighbor cell measurement** | Not modeled for good coverage UE (considering S-criterion and RRM relaxation in Rel-16) | Only monitor one frequency layer in one DRX cycle (considering RRM relaxation in Rel-16)SMTC = 5ms |

 |
| Vivo [4] | Proposal 2: The evaluation should assume the number of SSBs for IDLE mode loop convergence / time-frequency tracking can be 1 or 3.Proposal 3: Paging assumptions in Table 2 in R1-2005388 should be adopted.Table 2: Paging assumptions for FR1

|  |  |
| --- | --- |
| Parameter | value |
| I-DRX cycle | 1.28 sec |
| SSB periodicity | 20 ms |
| paging rate for a PO**4** | 10% or 20% |
| SMTC window duration, i.e. intra-frequency measurement* 2 SSBs per slot are measured, total SSB number is 8.
 | 2 ms |
| SMTC window duration for all other cases, i.e. inter-frequency measurement | 5 ms |
| Total number of SSB burst | 4 in Low SINR case;1 in High SINR case. |
| PO reception duration | 8 slots/4 ms per DRX cycle in Low SINR case;2 slots/1 ms per DRX cycle in High SINR case. |
| **Note 4**: paging rate for a PO (per PO paging rate) means the overall paging rate for all UEs of one PO. It depends on the number of UEs for one PO and the average paging rate for one UE. |

Figure 1: The baseline paging assumption model |
| ZTE [5] | **Proposal 1: The paging cycle and the duration of PO should be clarified in evaluation assumption. The default paging cycle of 1280ms can be considered.****Proposal 2: Classify two scenarios such as high SINR scenario and low SINR scenario and differentiate the number of SSB and the SMTC duration in different scenarios.**Figure 1 UE operation in a paging cycleFigure 2 UE behavior in high SINR operation**Proposal 3: The time offset between SSB and PO should be clarified. Furthermore, the time offset can be assumed to be randomly distributed or fixed.** |
| MediaTek [7] | Proposal 9: When SINR is not high, or for reduced capability UE, the processing timeline in Figure 1 is assumed, where* **Three SS bursts before PO are utilized for synchronization; one is also used for serving cell and intra-band neighbour cell measurement**
* **4-ms PO processing is assumed for paging monitoring/reception across multiple beams**
* **One 5-ms SMTC window after PO is utilized for inter-band neighbour cell measurement**

Figure 1: UE processing timeline for paging monitoring/reception when SINR is not highProposal 10: For high SINR condition, the processing timeline in Figure 2 Figure 1is assumed, where* **One SS burst before PO is sufficient for synchronization and serving cell measurement.**
* **1-ms PO processing is assumed for paging monitoring/reception only over the best beam(s)**
* **No neighbour cell measurement after PO**
* **Note that, due to potential SINR change for each paging DRX cycle, an early SS burst is assumed so that UE can process the following SS bursts if identifying lower SINR condition from the first SS burst**

Figure 2: UE processing timeline for paging monitoring/reception in high SINR |
| CATT [8] | The general procedure of paging reception in RRC\_IDLE/Inactive is shown as follow. Before UE is at a Paging Occasion (PO) as shown in Figure 1, UE needs to perform following steps: 1) Waking up at the predetermined time before PO and turning all components in preparation of data reception (warm up); 2) Measuring SSB(s) to estimate the timing and frequency offset information for time and frequency tracking. The estimation could be done after one measurement or combination of multiple measurements. 3) Performing front end process in time and frequency compensation of receiving signals 4) Demodulating/decoding the DCI from PDCCH for paging indication.5) Demodulating/decoding PDSCH and retrieve the paging information. 6) If UE ID is included in the paging message, UE performs the subsequent processing, such as contention-based PRACH etc.. Otherwise, UE continues to go to sleep. **Figure 1: Illustration of paging reception procedure in Rel-16** |
| Samsung [14] | ***Proposal #3: For power saving evaluation of paging enhancement, support configuration of idle/inactive mode UE activities as defined in Table 2.*****Table 2: Assumption on the configuration of UE activities in idle/inactive mode**

|  |  |  |
| --- | --- | --- |
| **UE activities** | **Configuration parameters** | **Values** |
| Synchronization | SSB burst periodicity, $T\_{SSBs}$ | 20ms |
| # of SSBs per burst, or burst duration,$ D\_{SSBs}$ | 2ms |
| # of SSB bursts for synchronization, $N\_{SSBs}$ | 1-3 |
| Paging Monitoring | I-DRX cycle, $T\_{DRX}$ | 1.28s |
| PO duration, $D\_{PO}$ | 4 ms |
| Effective PO duration, $D'\_{PO}$ | 1 ms |
| Group paging rate, $γ\_{p}$ | 10% |
| RRM measurement | Measurement period (MP) | I-DRX cycle |
| Number of L1 samples per MP for serving cell RRM measurement, *L* | 1 |
| SMTC window duration, $D\_{SMTC}$ | 2ms |
| SMTC periodicity, $T\_{SMTC}$ | 20ms |
| Cell search rate, $γ\_{a}$ | 1/4 |
| Measurement gap (MG), $D\_{MG}$ | 6ms |
| # of frequency layers for neighboring cell measurement  | (2 inter, one intra) |
| # of cells per frequency layer | 8 |
| Cell reselection | Cell reselection rate, $γ\_{b}$ | [1/6] for mobility scenario, 0 for stationary scenario |

Figure 2: Illustration of the processing timeline for baseline in stationary scenario. |
| CMCC [15] | **Proposal 1. The following updated parameters can be considered in the evaluation methodology in IDLE/INACTIVE state for FR1:*** **20MHz BWP bandwidth**
* **0.4 scaling factor for 20MHz**
* **1280ms I-DRX cycle**
* **20ms SSB periodicity**
* **10ms offset between the nearest SSB and PO**
 |
| Apple [19] | From UE power consumption point of view, as shown in Figure 1, for each paging occasion, 1. The UE needs to wake up in advance to achieve the require level of synchronization accuracy. How much time in advance and the exact procedures a UE follows before PO reception heavily depends on UE implementation and most likely also depends on UE RF condition. That is, a UE in a poor RF condition may need to wake up earlier than a UE in a good RF condition, in order to achieve sufficient synchronization. In case the UE needs to wake up before-hand to monitor multiple SSBs, the UE may go into light sleep between SSB monitoring.
2. The UE does PDCCH blind decoding, and determines whether there is a paging DCI.
3. If a paging DCI is successfully decoded and it indicates that there is paging message carried in PDSCH, the UE decodes the PDSCH accordingly.

Figure 1 UE power consumption for monitoring a paging occasion |
| Ericsson [21] | *Figure 2: UE PO monitoring related activities per Idle/Inactive DRX occasion. UEs are assumed to be in* deep sleep *in-between the DRX occasions, acquiring 2 SSBs before the PO. Top subfigure depicts the case where the UE receives both PDCCH and PDSCH, whereas the lower subfigure depicts the case with PDCCH only (i.e. UE is not paged)* |
| Qualcomm [23] | The baseline UE power consumption in I-DRX is given by$$P\_{base, IDRX}=α\_{b}E\_{SIB1}+\frac{β\_{b}E\_{srch}+E\_{meas}+E\_{page}+E\_{loop}+E\_{sleep}}{T\_{IDRX}} $$where * $α\_{b}=\left(\frac{v}{ISD}\right)$ where $v $is UE speed (m/s) and $ISD$ is inter-site distance, and $β\_{b}=1/6$ assuming UE performs cell search one every 6 I-DRX cycles.
* For stationary scenarios, $E\_{meas}=P\_{ssb}T\_{s,L}$ with $P\_{ssb}=100$ (i.e., serving cell SSB processing). $T\_{s,L}$ is duration of $L$ SSBs during which the UE performs RRM measurement.
* For mobility scenarios, $E\_{meas}=P\_{ssb}T\_{s,L}+γ\_{b}P\_{m}T\_{SMTC}$ where $P\_{m}$ is intra-frequency measurement and $γ\_{b}$ depends on UE location/channel condition (e.g., cell edge or cell center). In particular, $γ\_{b}$ should account for the facts that neighbor cell measurement might not need performing every I-DRX and SSBs from neighbor and serving cells might be time-aligned. In the model, we assume $γ\_{b}=1/4$.
* $T\_{IDRX}$ is I-DRX cycle and $T\_{SMTC}$ is SMTC duration.
* $E\_{sleep}=\left(E\_{D}+E\_{DT}\right)+N\_{SSBS}\left(E\_{L1}+E\_{LT}\right)+\left(E\_{L2}+E\_{LT}\right)$
* The number of SSBs for tracking loop update per I-DRX cycle is $N\_{SSBS}=1$.
 |
| Nokia [24] | **Proposal: RAN1 to define the idle-mode DRX cycle to 1.28 s for evaluation of objective 1a.****Proposal: RAN1 to define the SSBs periodicity to 20 ms for evaluation of objective 1a.****Proposal: In terms of PO time locations, consider two configurations; where PO starts in the next half-frame after the SSBs and where PO is in between the SSBs.****Proposal: RAN1 to define the number of SSB samples required for synchronization prior to PO for evaluation of objective 1a.****Proposal: RAN1 to define the number of intra- and inter-frequency cells for measurements and cell search.** |

From companies’ proposals, there are three major types of operations:

1. SS burst processing before PO for synchronization as well as measurement of serving cell and, if needed, intra-band neighbor cell(s)
2. PO processing, including Paging PDCCH monitoring, and paging PDSCH processing (subject to group paging rate)
3. SS burst processing after PO for inter-band neighbor cell measurement

For operation 1), the number of required SS bursts ranges from 1 to 3, relating to the channel/coverage condition. It is also noticed that, for reduced capability UEs, the observed channel/coverage condition can be worse than a normal capability UE due to antenna reduction. For operation 3), network can allow UE not to measure neighbor cell when channel condition is good. Consequently, two UE processing timelines, one for SINR is not high or reduced capability UEs and the other for SINR is high can be considered. The following proposals are suggested:

Proposal 2: For Rel-17 paging enhancement, the following are assumed:

* **1.28 second paging cycle**
* **20 ms SS burst periodicity**
* **20 ms SMTC periodicity**
* **2 ms SMTC window for intra-frequency RRM measurement and 5 ms SMTC window for inter-frequency RRM measurement**

Proposal 3: When SINR is not high or for reduced capability UEs, the following reference UE processing timeline for a paging cycle and the corresponding evaluation are utilized:

|  |  |  |  |
| --- | --- | --- | --- |
| **Operation in sequence** | **Purpose** | **Time duration (ms)** | **Energy contribution(power \* time + energy overhead)** |
| SSB proc. | AGC, coarse synchronization, serving-cell/intra-freq. RRM measurement | 2 | 60 \* 2 |
| Light sleep | Power saving | 18 | 20 \* 18 + 100 |
| SSB proc. | Coarse/fine synchronization, (additional serving-cell/intra-freq. RRM measurement) | 2 | 50 \* 2 |
| Light sleep | Power saving | 18 | 20 \* 18 + 100 |
| SSB proc. | Fine synchronization, (additional serv.-cell/intra-freq. RRM measurement) | 2 | 50 \* 2 |
| Light sleep | Power saving | 8 | 20 \* 8 + 100 |
| PDCCH or PDCCH+PDSCH | Paging control proc. and data proc. (if paged); 8 slots for diversity reception | 4 | Not paged: 50 \* 4Paged: 120 \* 4 (subject to group paging rate, *P*) |
| Light sleep | Power saving | 6 | 20 \* 6 + 100 |
| Inter-freq. RRM measurement | Inter-frequency/inter-RAT neighbor cell measurement | 5 | 60 \* 5 |
| Deep sleep | Power saving | 1215 | 1 \* 1215 + 450 |
| **Total** | 1280 | 200 \* (1-*P*) + 480 \* *P* + 3685 |
| **Average Power Consumption = Total energy / page cycle (1280)** |

Proposal 4: When SINR is high, the following reference UE processing timeline for a paging cycle and the corresponding evaluation are utilized:

|  |  |  |  |
| --- | --- | --- | --- |
| **Operation in sequence** | **Purpose** | **Time duration (ms)** | **Energy contribution(power \* time + energy overhead)** |
| SSB proc. | AGC, Coarse/fine synchronization, serving-cell/intra-freq. RRM measurement.Note: Due to no a prior of SINR change, assume the same 1st SSB timing w.r.t. PO as the case where SINR is not high | 2 | 60 \* 2 |
| Light sleep | Power saving | 48 | 20 \* 48 + 100 |
| PDCCH or PDCCH+PDSCH | Paging control proc. and data proc. (if paged); 2 slots for more efficient reception | 1 | Not paged: 50 \* 1Paged: 120 \* 1 (subject to group paging rate, *P*) |
| Deep sleep | Power saving | 1229 | 1 \* 1229 + 450 |
| **Total** | 1280 | 50 \* (1-*P*) + 120 \* *P* + 2859 |
| **Average Power Consumption = Total energy / page cycle (1280)** |

For achieving consensus, companies are welcomed to provide comments for the above proposals in Table 4:

Table 4: Companies' comments for Proposals 2-4

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Xiaomi | Agree that two separate cases, in low and high SINR power scenarios, should be taken into consideration for power consumption calculation |
| Apple | We are generally fine with the proposals.But we would like to understand if it is reasonable to assume the UE always wakes up 3 SSBs in advance even for high SINR case. It may be sufficient for such a UE to wake up just 1 SSB in advance, and having tracking based on the latest SSB also provides better tracking performance. |
| Samsung | For proposal 3, we have the following concerns: * Although it is ok to consider the overlapped SSB occasion for synchronization and serving/intra-frequency RRM measurement, it is better to consider UE performs synchronization first and does serving cell RRM measurement based on the last SSB burst for synchronization.
* The power consumption for synchronization and RRM measurement should be computed separately although the measurement occasions may overlap.
* The power for serving/intra-frequency measurement should consider combined measurement and cell search, i.e. 80 instead of 60.

According to above comments, we suggest to consider the following changes:

|  |  |  |  |
| --- | --- | --- | --- |
| **Operation in sequence** | **Purpose** | **Time duration (ms)** | **Energy contribution(power \* time + energy overhead)** |
| SSB proc. | AGC, coarse synchronization, ~~serving-cell/intra-freq. RRM measurement~~ | 2 | ~~60 \* 2~~50\*2 |
| Light sleep | Power saving | 18 | 20 \* 18 + 100 |
| SSB proc. | Coarse/fine synchronization, ~~(additional serving-cell/intra-freq. RRM measurement)~~ | 2 | 50 \* 2 |
| Light sleep | Power saving | 18 | 20 \* 18 + 100 |
| SSB proc. | Fine synchronization, and ~~(additional~~ serv.-cell/intra-freq. RRM measurement~~)~~ | 2 | ~~50 \* 2~~50\*2+80\*2 |
| Light sleep | Power saving | 8 | 20 \* 8 + 100 |
| PDCCH or PDCCH+PDSCH | Paging control proc. and data proc. (if paged); 8 slots for diversity reception | 4 | Not paged: 50 \* 4Paged: 120 \* 4 (subject to group paging rate, *P*) |
| Light sleep | Power saving  | 6 | 20 \* 6 + 100 |
| Inter-freq. RRM measurement | Inter-frequency/inter-RAT neighbor cell measurement | 5 | 60 \* 5 |
| Deep sleep | Power saving | 1215  | 1 \* 1215 + 450  |
| **Total** | 1280 | ~~200 \* (1-P) + 480 \* P + 3685~~3825 + 200 \* (1-P) + 480 \* P |
| **Average Power Consumption = Total energy / page cycle (1280)** |

For proposal 4, we have the following concerns:* The power consumption for synchronization and RRM measurement should be computed separately although the measurement occasions may overlap.
* The sleep duration between SSB processing and PO is too long, UE is able to select the closest SSB for synchronization or RRM measurement by implementation.
* We think it makes sense to consider partial duration out from configured PO for paging processing at high SINR. But the location of selected effective duration varies depending on preferred beam directions. Instead of assuming UE always processes the first 1ms, we suggest to consider that the UE processes partial POs for efficient reception and the UE stays in micro-sleep for remaining duration.

According to above comments, we suggest to consider the following changes:

|  |  |  |  |
| --- | --- | --- | --- |
| **Operation in sequence** | **Purpose** | **Time duration (ms)** | **Energy contribution(power \* time + energy overhead)** |
| SSB proc. | AGC, Coarse/fine synchronization, serving-cell/intra-freq. RRM measurement.Note: Due to no a prior of SINR change, assume the same 1st SSB timing w.r.t. PO as the case where SINR is not high | 2 | 50\*2 + 60 \* 2  |
| Light sleep | Power saving | ~~48~~ 18 | 20 \* ~~48~~18 + 100 |
| PDCCH or PDCCH+PDSCH | 1msnote1 out of 4ms configured POs for effective Paging control proc. and data proc. (if paged); 2 slots for more efficient receptionNote1: UE processes partial POs for efficient reception and UE stays micro-sleep for remaining duration.  | ~~1~~ 4 | Not paged: ~~50 \* 1~~50\*1 + 35\*3 = 155Paged: ~~120 \* 1~~ (subject to group paging rate, *P*)120\*1 + 35\*3 = 225 |
| Deep sleep | Power saving | ~~1229~~1246 | 1 \* ~~1229~~1246 + 450 |
| **Total** | 1280 | ~~50 \* (1-~~*~~P~~*~~) + 120 \*~~ *~~P~~* ~~+ 2859~~155\*(1-P) + 225\*P + 2375 |
| **Average Power Consumption = Total energy / page cycle (1280)** |

 |
| Ericsson | P2 : * The proposal should be updated to reflect that these are evaluation assumptions for study of paging enhancements to reduce unnecessary paging receptions. A sub-bullet should be added to ask RAN2 feedback on any other I-DRX cycle length, e.g. such as extended DRX for RRC Inactive and/or Idle for reduced capability UE.

P3 and P4: * The SNR range vs number of SSBs that need to be processed by the UE should also be studied as part of the evaluations, i.e. for PDCCH reception and PDCCH + PDSCH reception, for typical oscillator frequency drift values.
* “When SNR is not high or for reduced capability UEs” - terminology should be clarified, especially it is unclear what is meant by “SNR is not high”. Also, for reduced capability UE, which aspect (e.g. complexity or power saving) of reduced capability UE is assumed for the evaluation ?
* The evaluation should also consider the provision of potential TRS/CSI-RS occasion(s) available in connected mode to idle/inactive-mode UEs.
* We will also need more time to check the numbers/purposes mentioned in the table.
 |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

## Group Paging Rate

To accomplish the evaluation, there requires specification on the group paging rate. In Table 5, there summarize companies’ proposals:

Table 5: Companies’ proposals on group paging rate

|  |  |
| --- | --- |
| **Company** | **Proposals** |
| Huawei, HiSilicon [3]  | **Proposal 3: For evaluation, the paging traffic in IDLE/INACTIVE mode is modeled by the paging rate of a UE and the number of UEs sharing a PO(N), which are defined by the following table.**

|  |  |  |
| --- | --- | --- |
| **Parameter**  | **Low load** | **High load** |
| **Paging rate of a UE(p)** | **1%** | **1%** |
| **N (the number of UEs sharing a PO)** | **10** | **[50]** |
| **P(paging rate of a PO, P=1-(1-p)^N)** | **9.56%** | **[39.50%]** |

 |
| Vivo [4] | Proposal 3: Paging assumptions in Table 2 in R1-2005388 should be adopted.Table 2: Paging assumptions for FR1 (paging rate related part)

|  |  |
| --- | --- |
| Parameter | value |
| paging rate for a PO**4** | 10% or 20% |
| **Note 4**: paging rate for a PO (per PO paging rate) means the overall paging rate for all UEs of one PO. It depends on the number of UEs for one PO and the average paging rate for one UE. |

 |
| ZTE [5] | **Proposal 4: The per-UE paging probability and the number of UE within the group which impact the group paging probability should be clarified in the simulation assumption.** |
| MediaTek [7] | Proposal 6: For paging related settings, consider* **1.28 second idle-mode paging DRX cycle**
* **Group paging rates of 10% and 60%, corresponding to around 10 and 100 UEs sharing the same PO**
 |
| CATT [8] | Table 2 system parameters assumptions for FR1

|  |  |
| --- | --- |
| Parameter | Assumption |
| Numerology | 30KHz, FR1 |
| SSB | 2SSB per slot.20ms period |
| Paging cycle | 32rf, 64rf, 128rf, 256rf |
| **Paging rate**  | **0.2, 0.01** |
| RRM measurement cycle | 4(32rf), 2(64rf),1(128rf,256rf);Ideal RRM measurement cycle: infinite |
| SMTC | 20ms |
| MGRP | 6 ms |

 |
| Samsung [14] | **Table 2: Assumption on the configuration of UE activities in idle/inactive mode (paging rate related part)**

|  |  |  |
| --- | --- | --- |
| **UE activities** | **Configuration parameters** | **Values** |
| Paging Monitoring | I-DRX cycle, $T\_{DRX}$ | 1.28s |
| PO duration, $D\_{PO}$ | 4 ms |
| Effective PO duration, $D'\_{PO}$ | 1 ms |
| **Group paging rate,** $γ\_{p}$ | **10%** |

 |
| Spreadtrum [16] | **Table 2: The evaluation assumptions**

|  |  |  |
| --- | --- | --- |
| **Item** | **Value** | **Note** |
| Subcarrier spacing (kHz) | 30 |  |
| Paging cycle (slot) | 640  | 320ms |
| Per-UE paging rate (p) | 1% |  |
| #UE per group (N) | 10 or 100 |  |
| Group paging rate | 10% or 60% | 1-(1-p)^N |
| Paging cycle number | 100 |  |

 |
| Ericsson [21] | Proposal 1: RAN1 should study simulation assumptions to get realistic estimates of false paging. * Paging rates in the range 0.4%...2% (10…50 pages/h) are proposed for the deriving false paging rates.
 |
| Qualcomm [23] | For paging, 10% false alarm is assumed (i.e., 10% both PDCCH and PDSCH are decoded) |
| Nokia [24] | In TR 38.840 [2] the group paging rate was set to 10 %. Paging outcome is a binomial random variable$$P\left\{X=i\right\}=\left(\begin{matrix}n\\i\end{matrix}\right)p^{i}\left(1-p\right)^{n-i}$$Where $\left(\begin{matrix}n\\i\end{matrix}\right)=\frac{n!}{i!\left(n-1\right)}$ and *i* is the number of objects from the set *n*.Paging occurs when at least 1 UE is paged$$P\left\{X>0\right\}=1-P\left\{X=0\right\}=1-\left(\begin{matrix}n\\0\end{matrix}\right)p^{0}\left(1-p\right)^{n-0}=1-\left(1-p\right)^{n}$$For a paging propability p=1% the group paging rate of 10 % can be achieved for UEs n=10. If a higher number of UEs are assigned to the same paging occasion the group paging rate increases, which likewise will increase the unnecessary paging of the UEs that are not scheduled with a paging message. **Proposal: RAN1 to define the paging probability p=1 % and number of UEs per PO n=10 for evaluation of objective 1a**. |

From the summary, 10% group paging rate is proposed by 7 out of 10 companies. Consequently, the following proposal is suggested:

Proposal 5: Group paging rate of 10% is assumed for Rel-17 paging enhancement

* FFS: Whether and what is another group paging rate assumed

Proposal 6: Send LS to RAN2 for informing the evaluation methodology based on Proposals 1 – 5 and TR 38.840 for Rel-17 paging enhancement

For achieving consensus, companies are welcomed to provide comments for Proposal 5 in Table 6:

Table 6: Companies' comments for Proposals 5 and 6

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Xiaomi  | The setting of Paging rate in a PO would heavily impact the power saving gain of paging grouping in simulation. So practical paging rates should be selected to reflect a real network paging load. We propose to select 3 values to reflect the low/medium/high paging load from 10%-40% |
| Apple | For proposal 5, it would be good to add at least one value for high group paging rate for sensitivity study.For proposal 6, the performance metrics should be also be included. |
| Samsung | For proposal 5, group paging rate of 10% can be assumed for legacy UEs, and we suggest to consider a higher group paging rate for RedCap use cases with larger connectivity.  |
| Ericsson | As mentioned in our comment above, we should also ask RAN2 for their feedback on any other I-DRX cycle length of interest.  |
| CMCC | For proposal 5, higher group paging rate should be supported both considering legacy UEs and RedCap UEs. |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

## Feasibility and Performance Metric

For paging enhancement, if UE processing is reduced, it is necessary to justify the feasibility. For example, if the number of UE synchronization operations in Proposal 3 is reduced by an enhancement proposal, proponent(s) should justify whether paging indication can still be correctly received by the UE. In [11], there suggest the evaluation assumptions for justifying the feasibility of reduced synchronization, which motivates the following proposal:

Proposal 7: If the reference UE processing timeline is changed/reduced by a paging enhancement scheme, technical justification should be provided for the feasibility that UE can correctly receive the paging indication subject to less than [1 dB] SINR requirement subject to

* **MDR [0.1%], FAR [1%]**
* **[0.5] ppm frequency error**
* **[TDL-C] channel with speed [60 km/hr]**

Finally, the following proposal is to collect the performance metric for studying potential paging enhancements:

Proposal 8: For Rel-17 paging enhancement, the following performance metrics are considered:

* **UE power saving gain**
* **System impact, including additional system overhead**
* **Applicability to reduced capability UEs**

For achieving consensus, companies are welcomed to provide comments for above proposals in Table 7:

Table 7: Companies' comments for Proposals 7 and 8

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Apple | In Proposal 7, what does the assumed frequency error correspond to? Is it the frequency error when the UE just wakes up from deep sleep?For Proposal 8, what does “Applicability to reduced capability UEs” mean exactly. I would assume the schemes we talk about are generally applicable to RedCap UEs. |
| Samsung | For proposal 7, we suggest to clarify the carrier frequency associated with frequency error, i.e. [0.5] ppm frequency error at carrier frequency of [2.6] GHz. |
| Ericsson | P8 * NW energy consumption should also be considered. Also, the last bullet should not be included here as it is not a “performance metric”.
* For UE power savings gain, both idle mode power savings gain, and overall UE power savings gain should be evaluated.
* Update the first sentence to “For the study on paging enhancements to reduce unnecessary paging reception, the following ….”
 |
| CMCC | For proposal 8, coexistence with Rel-15/Rel-16 legacy UE should also be considered. For example the cross-slot scheduling for paging PDSCH enhancement technique, the current default TDRA table cannot support it.  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

# Potential Paging Enhancements

According to companies’ contributions, the high power consumption for idle/inactive mode UE is caused by two main reasons. One is unnecessary pre-wakeup for AGC and/or time/frequency tracking to prepare paging PDCCH/PDSCH decoding, the other is unnecessary PDSCH processing due to paging false alarm. To effectively save UE power, the paging enhancement for power saving can consider two directions: (1) reduce UE wake-up energy overhead, and (2) reduce PDSCH processing. More details are provided in Section 3.1 and 3.2.

## Reduce wake-up energy overhead

There are 16 out of 22 companies proposing early indication before a paging occasion (PO) to indicate UE whether to receive paging data in the upcoming PO. Without early indication, in order to decode PDSCH successfully, UE needs to receive multiple SS burst for AGC and time/frequency tracking before PO. And due to the distributive SS bursts, UE needs to wake up multiple times before PO. The high wake-up energy overhead results in UE power consumption waste if the UE is not paged. This method can effectively save UE power by allowing UE to save unnecessary SSB processing if there is no need to receive paging data.

From the summary, we can further identify proponents and the sub-categories for the enhancement:

* New indication before PO: Huawei/HiSilicon, vivo, ZTE, MediaTek, CATT, TCL communication, Intel, Motorola, OPPO, Samsung, CMCC, Spreadtrum, LG, Apple, InterDigital, NTT DOCOMO
	+ DCI-based indication: Huawei/HiSilicon, CATT, LG
		- Reuse DCI format 1\_0 or 2\_6
		- New DCI format
	+ RS-based indication, e.g., based on TRS/CSI-RS or SSS: vivo, CATT, TCL communication, Samsung, Spreadtrum, InterDigital

Table 8: Contribution summary and proposals

|  |  |
| --- | --- |
| **Company**  | **Proposals** |
| Huawei, HiSilicon  | Observation 3: Early transmitted paging information before PO provides the benefit to reduce state transition from/to additional light sleep and extend the time in deep sleep.Proposal 5: Introduce early transmitted paging DCI to resolve the issue of unnecessary pre-wake-up and state transitions from/to light sleep causing power consumption waste.Proposal 6: Further discuss which information in paging DCI needs to be informed in an early transmitted paging DCI before the PO. |
| vivo | Observation 4: By configuring WUS before PO reception, up to 21.6%~29.2% power saving gain in Low SINR case and 1.2%~11.2% gain in High SINR case can be achieved. Observation 5: For Low SINR UEs, sequence based WUS has more benefits than PDCCH based WUS from power consumption perspective.Observation 6: There is no power saving benefit by PDCCH based WUS for High SINR UEs. Observation 7: Sequence based WUS scheme has the most power saving gain compared with other paging enhancement schemes.Proposal 5: Sequence based WUS before PO reception should be supported for paging enhancement. |
| ZTE  | Observation 1: To improve UE power efficiency in RRC idle/inactive state, if the number of processed SSB is decreased in addition to reduction of paging reception, the proportion of deep sleep will be increased and large power saving gain will be achieved.Observation 2: The unnecessary reception of paging DCI and message contributes to UE power consumption.Observation 3: A signal/channel-based paging indication before PO can reduce the unnecessary paging reception.Observation 4: A paging indication carried by a paging DCI can be used to reduce the unnecessary paging reception.Observation 6: In the scenario of high SINR, the paging indication before PO can derive about 3.2% power saving gain, and the paging indication within a paging DCI can derive about 3.9% power saving gain. Further, combination of paging indication and UE grouping can derive about 3.9%-4.5% power saving gain.Observation 7: In the scenario of low SINR, the paging indication before PO can derive about 21.4% power saving gain, and the paging indication within a paging DCI can derive about 29.0% power saving gain. Further, the combination of paging indication and UE grouping can derive about 23.4% - 31.7% power saving gain.Proposal 6: The techniques that can reduce paging reception and number of SSB processing can be considered in power saving enhancement for RRC idle/inactive state UE. Proposal 7: The paging enhancement schemes such as paging indication and UE sub-grouping can be considered for RRC Idle/Inactive state UEs. |
| MediaTek | Observation 4: Compared to UE subgrouping-only, PEI can allow UE to skip unnecessary SSB processing and PDCCH decoding if there is no UEs monitoring the same PO to be paged. Therefore, it can bring more significant power saving gains than UE subgrouping-only. Proposal 12: Introduce paging early indication (PEI) before PO for idle/inactive mode power saving.* PEI indicates UE whether to decode paging PDCCH/PDSCH in the PO
* PEI should be located near SS bursts to reduce UE wakeup overhead
* FFS PEI with UE subgrouping

Proposal 13: Due to the limited time of WI and large specification efforts, new signal/channel design for paging early indication(s) is not supported in Rel-17.Proposal 14: FFS the following existing signal/channel for paging early indication.* PDCCH channel
* Existing RS, e.g., SSS and TRS/CSI-RS
 |
| CATT | Observation 1: Power saving gain is very limited for the paging indication carried within paging DCI. Observation 2: TRS/CSI-RS assisted PDCCH-based paging indication can obtain 11.87%~38.44% power saving gain compared with Rel-16 paging procedure.Observation 3: Sequence-based paging indication can obtain 12.44%~40.36% power saving gain compared with Rel-16 paging procedure.Proposal 1: Power saving signal as the paging indication should be applied to indicate paging reception for IDLE/Inactive mode UE.Proposal 2: If PDCCH-based power saving signal/channel is considered for paging enhancement for UE in IDLE/Inactive mode, DCI format 2\_6 with CRC scrambled by PS-RNTI could be reused for paging reception. Proposal 3: The sequence-based paging indication should be supported in Rel-17 for UE in IDLE/Inactive mode for UE power saving. |
| TCL  | Proposal 1: Consider a sequence-based wake-up signal (WUS)Proposal 2: Consider reusing/adapting the design of group-WUS for LTE-MTC/NB-IoT.Observation 1: In beam-based transmission, the paging occasion must be repeated in all beams to ensure reception at the UE.Proposal 3: WUS must be transmitted in a burst-like fashion like SS/PBCH bursts. |
| Intel | Observation 1: For idle/inactive mode operation, sensitivity to CFO and timing error are critical factors for consideration while evaluating signal detection.Observation 2: PDCCH detection works well at 0.1ppm but deteriorates beyond 0.1ppm. At 1ppm, PDCCH MDR is close to 1. Observation 3: CFO compensation based on PDCCH detection may not always be feasible.Observation 4: One potential way to save power would be to reduce the number of SSBs necessary, if possible, that need to be processed before detecting the paging DCI, i.e., shorten the preparation time.Observation 5: TRS and SSS-based sequence detection performance seems to degrade as CFO is increased from 0.1ppm, but sensitivity to higher CFO seem to be less compared to PDCCH at least up to 1ppm.Observations 6: Sequence based WUS can be designed with multiple non-contiguous symbols in a slot so that CFO can be compensated. If WUS can also aid in tracking, preparation time can be reduced so that paging DCI can still be detected with low CFO sensitivity and consequently, it may lead to increased power saving gain.Proposal 1: At least CFO sensitivity should be taken into account for evaluating different candidates for WUS* FFS: timing error

Proposal 2: RAN1 to consider CFO compensation as part of evaluation of signal detection, wherever applicable.Proposal 3: Power consumption analysis should take into account the preparation time prior to detecting the paging DCI, in addition to duration of WUS, if introduced, and PO* This includes but not limited to number of SSBs monitored during the preparation time.
* RAN1 discusses # suitable length of preparation time for evaluation purpose.

Proposal 4: Further study whether WUS can be used for tracking purpose as well, so that preparation time for fine tracking before PO can be shorter |
| Lenovo, Motorola  | Observation 1: For an idle or inactive UE, before monitoring paging DCI, the UE may have to perform measurements on at least one SSB of a camped cell in order to select a suitable SSB and determine a paging DCI monitoring occasion corresponding to the selected SSB.Observation 2: An indication from gNB to skip monitoring of paging DCI and/or decoding of a paging message not intended to a UE may be beneficial for UE power saving.Observation 3: For a UE with delay-tolerant application, a network can delay paging the UE and accordingly, the UE can skip monitoring paging DCI over a certain number of DRX cycles based on gNB’s indication for power saving. Proposal 1: RAN1 further study Paging Power Saving (PPS)-PDCCH indicating whether UE should monitor paging DCI in a given paging cycle. |
| OPPO  | Observation 1: If DCI based power saving signal is considered for idle/inactive-mode UE, only PDCCH CSS set can be used. Observation 2: DCI based power saving signal for idle/inactive-mode UE has no backward compatibility issue. Observation 3: The performance of sequence is good enough to be used as power saving signal. Observation 4: Backward compatibility is main issue to define the resource for sequence based power saving signal.Observation 5: Power saving gain is an important issue to be considered when designing power saving signal.Observation 6: Paging procedure enhancements are mainly RAN2 issues. The power saving signal design may have impacts on the paging procedure enhancements. |
| Samsung | Observation #1: There is trade-off between detection performance (reliability) and additional power consumption on monitoring/reception for sequence based I-WUS and PDCCH based I-WUS.Observation #4: Paging enhancement of sequence based I-WUS achieves remarkable power saving gain for both cell-center and cell-edge UEs.Observation #5: Paging enhancement of DCI based I-WUS achieves less power saving gain for cell-edge UEs due to synchronization overhead.Observation #6: Paging enhancement of DCI based I-WUS achieves less power saving gain than sequence based I-WUS due to synchronization overhead. Proposal #1: Support power saving signal/channel for indication of paging reception in idle/inactive mode. |
| CMCC | Proposal 2. The UE group paging mechanism should be supported in NR to reduce unnecessary paging reception, which gNB transmitting signalling to indicate which UE groups in one PO should receive paging.Proposal 3. UE-ID based grouping and paging probability based grouping can all be supported in NR UE group paging mechanism.Proposal 4. The signalling design of paging group indication to indicate which UE group(s) to monitor PO or receive paging PDSCH can be further studied as the following, and Alt 3 can be as high priory:* Alt 1. Sequence based;
* Alt 2. New PDCCH based;
* Alt 3. Enhanced current paging DCI.
 |
| Spreadtrum | Proposal 2: Consider to study the paging indication.Proposal 3: Consider to study the sequence-based wakeup signal with low transition energy in idle mode. |
| LG | Proposal 1: To reduce unnecessary UE paging receptions, method for indicating UE group before PDSCH containing paging message should be considered. Proposal 2: Consider DCI based UE group indication for idle/inactive mode UE.Proposal 3: Consider introducing DCI based wake up channel which conveys UE group indication. |
| Apple | Proposal: Consider the following options for paging enhancements for idle/inactive-mode UEs:* Option 1: UE grouping within a PO
* Option 2: cross-slot scheduling for paging PDSCH
* Option 3: wake-up signal for a PO
 |
| InterDigital  | Proposal 1: Sequence based paging indication is considered for idle/inactive mode UEs. |
| NTT DOCOMO | Observation 1: Strive to introduce the power saving schemes used widely considering the trade-off between power saving gain and system impact/implementation cost. Observation 2: The trade-off between power saving gain and system impact/implementation cost should be considered for the signal design if WUS-like scheme is introduced.Proposal 1: For reduction of unnecessary paging reception, following options can be considered.* Option1: WUS-like scheme
	+ FFS: sequence-based WUS or PDCCH-based WUS
* Option2: Reduce the number of UEs per a paging occasion
	+ FFS: how to avoid impact on legacy UEs
 |

By the above, the following proposal is suggested:

Proposal 9: For Rel-17 paging enhancement, study new indication before PO to indicate UE whether to receive paging data in the upcoming PO. Potential candidate include

* **DCI-based indication, e.g., based on**
	+ **Extending existing DCI format 1\_0 or 2\_6**
	+ **New DCI format**
* **RS-based or sequence-based indication, e.g., based on TRS/CSI-RS or SSS**

Companies are encouraged to provide views for Proposal 9 in Table 9:

Table 9: Companies’ comments for Proposal 9

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Xiaomi | First,we would like to show our support for new indication before PO, which is basically like WUS in idle mode.TRS/CSI-RS can be a potential solution for idle WUS, since we have already decided to introduce TRS/CSI-RS in idle mode。 |
| Apple | Support the proposal |
| Samsung | As there seems to be sufficient support for introducing the indication, it may be worth considering to somewhat expedite progress. If there are concerns, we can fall back to “study”. A wording change as follows is suggested: Proposal 9: For Rel-17 paging enhancement, ~~study~~ support a new indication before PO to indicate UE whether to receive paging data ~~in~~ associated with the upcoming PO. Potential candidate indication methods include* **DCI-based indication, e.g., based on**
	+ **Extending existing DCI format 1\_0 or 2\_6**
	+ **New DCI format**
* **RS-based or sequence-based indication, e.g., based on TRS/CSI-RS or SSS**
 |
| Ericsson | First sentence should be rephrased to “For the study on paging enhancements to reduce unnecessary paging reception, evaluate new indication……” |
| CMCC | Support the proposal. |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

## Reduce PDSCH processing

There are 14 out of 22 companies propose to consider UE subgrouping for power saving. Since paging PDCCH is for a group of UEs, it is possible that a UE decodes paging PDCCH/PDSCH but finds itself is not paged, i.e., paging false alarm. Further dividing UEs monitoring the same PO into subgroups can reduce the paging false alarm rate and avoid unnecessary PDSCH decoding. On the other hand, 3 companies also propose to consider cross-slot scheduling for PDCCH with CRC scrambled by P-RNTI to further relax the PDSCH processing time.

The candidate schemes for reduce PDSCH processing and the corresponding proponents are listed below:

* UE subgrouping: Huawei/HiSilicon, vivo, ZTE, Sony, MediaTek, Xiaomi, Samsung, CMCC, Spreadtrum, LG, Apple, InterDigital, NTT DOCOMO, Qualcomm
	+ Legacy paging indication
		- Multiple P-RNTI: Qualcomm
		- Bits in paging DCI to indicate subgrouping: Huawei/HiSilicon, Qualcomm
	+ New indication
		- Dedicated information: Huawei/HiSilicon, vivo, MediaTek
		- Frequency-domain subgrouping, e.g. different CORESETs for PO monitoring: Samsung, Spreadtrum
* Option 2: Cross-slot scheduling for paging: Panasonic, Apple, Qualcomm

Table 10: Contribution summary and proposals

|  |  |
| --- | --- |
| **Company**  | **Proposals** |
| Huawei, HiSilicon  | Proposal 7: Support UE sub-grouping to increase the power saving gain, which can be indicated in early transmitted paging information and/or paging DCI. |
| vivo | Observation 3: The power saving gain is marginal by configuring the group paging indication in legacy paging PDCCH.Proposal 4: UE grouping indication for sequence based WUS and PDCCH based WUS should be studied and evaluated. |
| ZTE | Observation 5: UE sub-grouping may reduce unnecessary paging reception for UE.Observation 6: In the scenario of high SINR, the paging indication before PO can derive about 3.2% power saving gain, and the paging indication within a paging DCI can derive about 3.9% power saving gain. Further, combination of paging indication and UE grouping can derive about 3.9%-4.5% power saving gain.Observation 7: In the scenario of low SINR, the paging indication before PO can derive about 21.4% power saving gain, and the paging indication within a paging DCI can derive about 29.0% power saving gain. Further, the combination of paging indication and UE grouping can derive about 23.4% - 31.7% power saving gain.Proposal 6: The techniques that can reduce paging reception and number of SSB processing can be considered in power saving enhancement for RRC idle/inactive state UE. Proposal 7: The paging enhancement schemes such as paging indication and UE sub-grouping can be considered for RRC Idle/Inactive state UEs. |
| Sony | Proposal 1 – The design of paging enhancements shall consider UE energy consumption reduction, network overhead, and design complexity. Proposal 2 – Support paging enhancement with UE grouping mechanism. Proposal 3 – RAN1 studies solutions to mitigate overhearing cost due to missed paging by UEs.  |
| MediaTek | Observation 4: Compared to UE subgrouping-only, PEI can allow UE to skip unnecessary SSB processing and PDCCH decoding if there is no UEs monitoring the same PO to be paged. Therefore, it can bring more significant power saving gains than UE subgrouping-only. Proposal 12: Introduce paging early indication (PEI) before PO for idle/inactive mode power saving.* PEI indicates UE whether to decode paging PDCCH/PDSCH in the PO
* PEI should be located near SS bursts to reduce UE wakeup overhead
* FFS PEI with UE subgrouping
 |
| Xiaomi | Proposal 1: Any enhancements for paging should not impact legacy UEsProposal 2: Maximum numbers of PO can be increased to reduce false alarm rate for paging.Proposal 3: UE grouping methods within a PO should be studied further.Proposal 4: Methods to solve paging capacity problem should be further studied if longer paging DRX cycles will be implemented.Proposal 5: Search space reducing should be studied to reduce power consumption for paging. |
| Samsung | Observation #3: NR Rel-16 supports UE grouping or distribution for paging monitoring in the time domain, but not in the frequency domain.Observation #7: Paging enhancement of UE sub-grouping achieve about 1% power saving gain.Proposal #2: Support UE sub-grouping for paging monitoring in frequency domain. |
| CMCC | Proposal 2. The UE group paging mechanism should be supported in NR to reduce unnecessary paging reception, which gNB transmitting signalling to indicate which UE groups in one PO should receive paging.Proposal 3. UE-ID based grouping and paging probability based grouping can all be supported in NR UE group paging mechanism. |
| Spreadtrum  | Proposal 1: Consider to study the resource based paging group refining. |
| LG | Proposal 1: To reduce unnecessary UE paging receptions, method for indicating UE group before PDSCH containing paging message should be considered. Proposal 2: Consider DCI based UE group indication for idle/inactive mode UE.Proposal 3: Consider introducing DCI based wake up channel which conveys UE group indication. |
| Panasonic | Proposal 1: Cross-slot scheduling for paging should be studied for Rel.17 power saving enhancement. The compatibility with lower release UE should also be studied. |
| Apple | Proposal: Consider the following options for paging enhancements for idle/inactive-mode UEs:* Option 1: UE grouping within a PO
* Option 2: cross-slot scheduling for paging PDSCH
* Option 3: wake-up signal for a PO
 |
| InterDigital  | Proposal 2: Methods to reduce false alarm rate should be studied. |
| NTT DOCOMO | Proposal 1: For reduction of unnecessary paging reception, following options can be considered.* Option1: WUS-like scheme
	+ FFS: sequence-based WUS or PDCCH-based WUS
* Option2: Reduce the number of UEs per a paging occasion
	+ FFS: how to avoid impact on legacy UEs
 |
| Ericsson  | Proposal 1 RAN1 should evaluate the additional power savings achieved by skipping PDSCH decoding and receiving only PDCCH for paging reception.Proposal 2 RAN1 should evaluate the power savings gain vs. system impact of potential paging enhancements. |
| Qualcomm  | Proposal 2: To alleviate unnecessary paging reception, associate UEs that share the same paging occasion with multiple UE groups based on* Option 1 - Multiple P-RNTIs
* Option 2 - Additional grouping information included in the content (i.e., reserved bits, Short Message field) of paging DCI

Proposal 3: The reserved bits field and Short Message field of the paging PDCCH can be used to indicate the paged UE groups* If Short Message Indicator is not 00 or 01, use reserved bits to indicate the paged UE groups in the PO
* If Short Message Indicator is 00 or 01, use additional bits to further indicate which sub-groups within a UE group indicated by the reserved bits field are paged in the PO.

Proposal 4: The set of P-RNTIs can be provided in a SIB or defined in specifications. The UE is associated with a group and the corresponding P-RNTI based on the UE’s ID.Proposal 5: Network adopts cross-slot scheduling for the PDCCH CRC scrambled by P-RNTI for the scheduling of paging PDSCH. |
| Nokia  | Observation: Applying extended DRX for RRC Inactive and/or Idle could be considered to reduce the paging monitoring power consumption.Observation: Possible merits of paging monitoring triggering channel/signal to reduce paging monitoring power consumption through reduced wake-up’s could be evaluated.Observation: Method to reduce the unnecessary paging message reception could be evaluated for power saving. |

Based on the summary, the following proposal is suggested:

Proposal 10: For Rel-17 paging enhancement, study the following the candidate schemes for reduced PDSCH processing:

* **UE subgrouping based on, e.g.,**
	+ **Legacy paging indication**
		- **Multiple P-RNTI**
		- **Bits in paging DCI to indicate subgrouping**
	+ **New indication**
		- **Dedicated information**
		- **Frequency-domain subgrouping, e.g. different CORESETs for PO monitoring**
* **Cross-slot scheduling for paging**

Proposal 11: Send LS to RAN2 for informing the potential paging enhancements in Proposal 9 and Proposal 10 to be studied in RAN1

Companies are encouraged to provide views for Proposals 10 and 11 in Table 11:

Table 11: Companies’ comments for Proposals 10 ad 11

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Xiaomi | Besides reducing PDSCH processing, reducing paging DCI search space so as to reduce blind decoding can also be a possible way to save power. For example, when search space #0 for paging crosses PDCCH monitoring occasions on multiple slots, we can restrict paging DCI in certain slots among them to reduce blind decoding. We propose to add reducing paging DCI search space as a subbullet in Proposal 10. |
| Apple | We support the proposals.We would like to clarify one point: is the intention of Proposal 9/10 to be the complete list for the enhancement schemes to be studied, or companies may still be allowed to bring new proposals? |
| Samsung  | Since there is a clear majority of companies supporting UE subgrouping, we should prioritize it over cross-slot scheduling. We suggest to have a proposal for UE subgrouping first, and capture only the high level ideas for the candidate schemes. The description of “legacy” or “new” may not be accurate, since in some sense they are all “new”. We suggest the following updates for proposal 10:Proposal 10: For Rel-17 paging enhancement, ~~study~~ support UE subgrouping for paging monitoring and reception, including the following candidate schemes:* **Multiple P-RNTI**
* **Bits in paging DCI to indicate subgrouping**
* **Dedicated information**
* **Multiple POs in frequency-domain**

In our view, cross-slot scheduling for paging is not related to reduced PDSCH processing.We are OK with Proposal 11.  |
| Ericsson | P10 - Should be rephrased to “For the study on paging enhancements to reduce unnecessary paging, study the following ……” Given cross-slot scheduling is also possible for paging already (through TDRA table configuration), why would it be considered an enhancement? Perhaps some clarification would be helpful on what is intended. |
| CMCC | We support UE subgrouping has high priority than cross-slot scheduling.It is noted that only same-slot scheduling is supported in default TDRA table, the introduction of cross-slot scheduling for paging PDSCH may cause coexistence issue with legacy UE. |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

# Summary of Email Discussion

# References

1. TR 38.840, “Study on User Equipment (UE) power saving in NR”, online available @ <https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3502>
2. RP-200938, “Revised WID: UE Power Saving Enhancements for NR”, MediaTek Inc., RAN#88-e
3. R1-2005262, “Paging enhancement(s) for UE power saving in IDLE/inactive mode”, Huawei, HiSilicon
4. R1-2005388, “Discussion on paging enhancements for idle/inactive mode UE power saving”, vivo
5. R1-2005520, “Discussion on power saving enhancements for paging”, ZTE
6. R1-2005582, “Considerations on paging enhancements”, Sony
7. R1-2005615, “Evaluation methodology and paging enhancement for idle/inactive mode UE power saving”, MediaTek Inc.
8. R1-2005719, “Paging enhancement for UE power saving”, CATT
9. R1-2005738, “Paging enhancement for power saving”, Beijing Xiaomi Software Tech
10. R1-2005773, “Potential paging enhancements”, TCL Communication Ltd.
11. R1-2005884, “On paging enhancements for UE power saving”, Intel Corporation
12. R1-2005935, “Power efficient paging”, Lenovo, Motorola Mobility
13. R1-2006041, “Paging enhancements for power saving”, OPPO
14. R1-2006157, “On potential paging enhancements ”, Samsung
15. R1-2006221, “Discussion on paging enhancement”, CMCC
16. R1-2006291, “Discussion on potential paging enhancements”, Spreadtrum Communications
17. R1-2006311, “Discussion on potential paging enhancements”, LG Electronics
18. R1-2006385, “Potential paging enhancements for idle/inactive-mode UE power saving”, Panasonic
19. R1-2006527, “Potential paging enhancements for idle/inactive-mode UE power saving”, Apple
20. R1-2006544, “Paging enhancements for UE power saving”, InterDigital, Inc.
21. R1-2006665, “Discussion on potential paging enhancements for UE power savings”, Ericsson
22. R1-2006736, “Discussion on paging enhancements”, NTT DOCOMO, INC.
23. R1-2006815, “Paging enhancements and evaluation methodology”, Qualcomm Incorporated
24. R1-2006896, “On paging enhancements for UE power saving”, Nokia, Nokia Shanghai Bell