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Title: Discussion on power saving signal triggering UE adaptation
Agenda item: 7.2.9.1
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1. Introduction

At RAN #84 meeting, the WID of UE power saving was approved as the following [1],

- 1) Specify power saving techniques with UE adaptation with focus in RRC_CONNECTED mode [RAN1, RAN4]
 - a) Specify the power saving techniques with power saving signal/channel
 - i) Specify the PDCCH-based power saving signal/channel triggering UE adaptation in RRC_CONNECTED
 - ii) Note: this objective shall not duplicate DRX operation and impact to DRX is studied at RAN2
 - iii) Note: Any change of PDCCH channel coding and payload interleaver is not in the scope
 - b) Specify the procedure of cross-slot scheduling power saving techniques
 - i) Note: The procedure is in addition to Rel-15 cross-slot scheduling procedure
- 2) Evaluate the required switching and interruption times for UE dynamic adaptation to the maximum number of MIMO layers [RAN4]
 - a) Note: Switching on/off the RF is part of the evaluation

Note:

- These objectives are RAN1/RAN4 focus and do not consider RAN2 impact.
- The objectives are subject to further update in RAN#84. The update will be based on recommendations from the completion of RAN2 study and remaining RAN1 recommendations based on the conclusion of RAN1 study.

In this contribution, the general PDCCH-based power saving signal design and possible triggering UE adaptations in both DRX and non-DRX scenarios will be discussed.

2. Power saving signal design and triggering UE adaptation

In this section, design of power saving signal in both DRX operation and non-DRX operation and triggering UE adaptation in several power saving schemes are discussed.

2.1. Power saving signal design principle

At the study in SI stage, several power saving schemes have been evaluated and shown potential power saving gains, such as adaptation in DRX, adaptation in BWP/Scell, adaption in PDCCH monitoring, cross-slot scheduling, adaptation in antenna domain. From our point of view, PDCCH-based power saving signal should be designed to take these power saving schemes into account as much as possible. For example, during DRX off time, power saving signal can be used to indicate UE wake up or not, while during DRX active time and in non-DRX operation, power saving signal can be used to indicate UE to adaptation to PDCCH monitoring, cross-slot scheduling, maximum MIMO layer or other schemes.

To achieve this purpose, two PDCCH-based power saving signal design framework can be considered.

- Option 1: Only one unified power saving signal to be designed which could be used to indicate all possible UE power saving schemes in different UE operation states, e.g., during DRX off time, during DRX active time, in non-DRX operation. The power saving signal design and configuration is simple in this design framework but the payload size will be large due to all possible fields need to be carried in power saving signal.
- Option 2: Different power saving signals are to be designed for different UE operation states, e.g., during DRX off time, during DRX active time, in non-DRX operation. In this method, the payload of each power saving signal payload will be reduced to have better demodulation performance.

From our point of view, we prefer option 2, and we think two different power saving signals considering different UE operation states:

- Power saving signal # 1: used in DRX cycle off time, it can indicate UE to wake up in the associated DRX cycle, trigger an on demand CSI preparation as in section 2.2.2 to realize timely CSI acquisition, or other potential power saving schemes such as adaptation in BWP/Scell operation. The power saving signal #1 is transmitted before DRX ON with the same periodicity of one DRX cycle.
- Power saving signal # 2: used in DRX Active time and non-DRX operation, it can indicate UE to adaptation to PDCCH monitoring, cross-slot scheduling, maximum MIMO layer or other schemes. Some of these are further explained in section 2.3.1, i.e., skipping PDCCH monitoring to avoid PDCCH-only detection, and some are explained in section 2.3.2, e.g., UE adaptation in time domain or antenna domain. The power saving signal # 2 is transmitted with a configured periodicity similar to R15 search space configuration.

Proposal 1: Two different PDCCH-based power saving signals could be designed for different UE operation states, e.g., during DRX off time, during DRX active time, in non-DRX operation.

- Power saving signal #1 could be designed to be transmitted in DRX off time in order to wake up UE, trigger CSI report before DRX ON, or other potential power saving schemes such as adaptation in BWP/Scell operation.
- Power saving signal #2 could be designed to be transmitted in DRX active time and non-DRX operation in order to trigger UE adaptation to PDCCH monitoring, cross-slot scheduling, maximum MIMO layer or other schemes.

2.2. Power saving signal design for DRX off state

2.2.1. Triggering UE wake up before DRX ON

Even though PDCCH monitoring occasions are reduced when DRX is configured to UE, there will be also no scheduling in some DRX cycle, which causes useless UE power consumption. In NB-IoT and MTC, wake up signal/DTX scheme is designed to indicate UE to monitor paging or not.

Similarly, power saving signal in NR can be used to indicate UE whether to monitor PDCCH in a DRX on duration or not. As discussion in section 2.1, a power saving signal #1 used before DRX cycle can realize this function. Besides, the power saving signal and DTX transmission scheme can be used in NR to reduce power saving detection complexity. When UE detects power saving signal successfully, it will wake up in the associated DRX cycle or continue to sleep if not detect it.

Although only one bit carried in “wake up” power saving signal is able to indicate UE to monitor PDCCH in associated DRX cycle or not, other power saving schemes can also be introduced in DRX operation to further get more power saving gains such as triggering CSI before DRX ON as in section 2.2.2 or other potential power saving schemes such as adaptation in BWP/Scell operation which may be determined in RAN#84.

Proposal 2. PDCCH-based power saving signal used in DRX off time could be transmitted at least to wake up before DRX on duration, and some other fields for triggering CSI before DRX ON or other potential power saving schemes such as adaptation in BWP/Scell operation should also be considered when designing this PDCCH-based power saving signal.

2.2.2. Triggering CSI measurement and report before DRX ON

In current DRX operation procedure, UE can only report CSI in DRX Active time and the CSI measurement for this time report occurs in DRX Active time as well. This restriction causes that gNB can not acquire timely and efficient CSI at the beginning of DRX cycle. In order to make an efficient scheduling with timely and effective CSI information at the beginning of DRX cycle, PDCCH-based power saving signal can trigger an on demand CSI report before DRX ON if there is data to be conveyed. That is the power saving signal used before DRX cycle have two functions, one is to wake up UE in current DRX cycle to receive or transmit data, and another is to trigger a CSI report before the beginning of drx-onDurationTimer.

Considering less impact to RAN2 DRX operation and the timing relationship with detecting power saving signal and reporting CSI, the procedure of CSI measurement and report before DRX ON triggered by power saving signal is as the Figure 1. Power saving signal is transmitted before DRX cycle, if UE successfully detects power saving signal, UE measures and reports CSI before drx-onDurationTimer and monitors PDCCH when drx-onDurationTimer is running as R15 DRX operation. If UE cannot detect power saving signal, UE will not monitor PDCCH in this DRX cycle. In this

procedure, DRX configuration parameters and UE behaviour including all the timers in DRX operation will not change compared to R15. The only change of UE behaviour is detecting power saving signal and CSI reporting before the DRX ON operation.

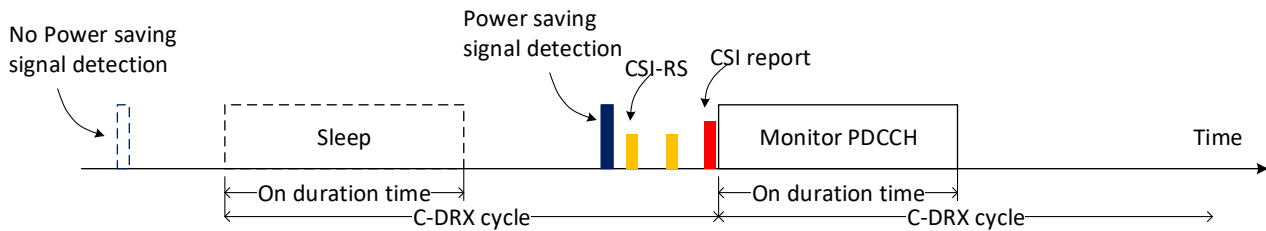


Figure 1. Procedure of CSI measurement before DRX ON triggered by power saving signal

In the on demand CSI report procedure triggered by power saving signal before DRX ON, the CSI measurement resource and CSI report resource can be designed as following schemes considering the network overhead and payload size of PDCCH-based power saving signal.

2.2.2.1. CSI measurement resource

In power saving signal triggering CSI report before DRX ON, both aperiodic CSI-RS and periodic CSI-RS can be studied as the CSI measurement resource:

1) Aperiodic CSI-RS as the measurement resource:

In this case, power saving signal triggers aperiodic CSI-RS and CSI report similar to scheduling DCI triggering aperiodic CSI report procedure. gNB can configure one or more configurations of CSI-RS resource and the time offset from power saving signal and power saving signal can indicate the CSI-RS resource similarly to the “CSI request” field in scheduling DCI. Furthermore, the number of CSI-RS resource configurations can be limited and even only one configuration to restrict the payload size of PDCCH-based power saving signal. That is power saving signal is used to indicating the on demand CSI-RS configuration index similar to “CSI request” in DCI format 0_1.

2) Periodic CSI-RS as the measurement resource:

The periodic configuration of CSI report setting can not always ensure that the CSI report appears at the DRX cycle starting position, although the periodic CSI-RS reporting has been configured for UE. To fully utilize the existing configurations, such as CSI resource configuration, CSI report PUCCH setting, power saving signal can trigger a shift of nearest CSI resource and report. An example is shown in Figure 2, since the CSI report occasion is not happened before gNB can schedule data, a CSI report occasion shift is triggered by the power saving signal which indicates wake up information for the following DRX on duration. Then the UE can use the configured periodic CSI-RS resource/CSI report but a different occasion from the periodically configured occasion to measure and report the CSI, all the parameters such as the PUCCH resource, frequency allocation can be reused. That is power saving signal is used to indicate UE the periodic CSI-RS resource index and the associated shifted duration. The shifted duration can be number of slots or the fraction of CSI-RS periodicity.

If the CSI measurement resource happens to be just before the DRX ON, then the power saving signal can trigger a CSI measurement using the periodic CSI-RS resource outside the active time.

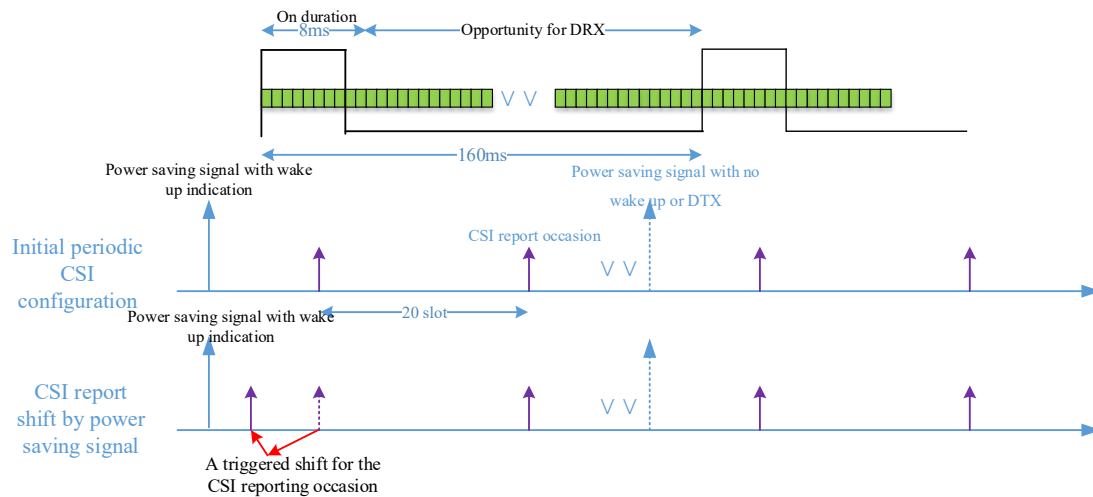


Figure 2. CSI report occasion shift triggered by power saving signal

In addition, the overhead of CSI-RS is not a problem. For aperiodic CSI-RS, the CSI-RS will only be transmitted when UE need to wake up in one DRX cycle. Besides, the CSI-RS resource can also be shared by a group of UEs. GNB can configure the time offsets among power saving signal and CSI-RS resource and DRX cycle to make the CSI-RS resource position align in time domain although the beginnings of UEs' DRX cycle are different. For periodic CSI-RS, it will be always transmitted during DRX active time, and the power saving signal only triggers a shift to make the CSI report align with the begin of DRX ON.

2.2.2.2. CSI report resource

Another issue for power saving signal triggering CSI report is the CSI report resource. In traditional CSI report, PUCCH configured by RRC signalling is used as the periodic CSI report resource and PUSCH indicated by UL grant is used as the aperiodic CSI report resource.

In the scenario of power saving signal triggering CSI measurement and report before DRX ON, in order to reduce the payload size of PDCCH-based power saving signal to satisfy signal detection requirement, pre-configured PUCCH resource by higher layer signalling can be used as the CSI report resource without the resource allocation indication field in power saving signal.

As the discussion above, both aperiodic CSI-RS and periodic CSI-RS can be used as the CSI measurement resource, the PUCCH as CSI report resource can be applied to two CSI-RS measurement resources but has a little difference. For aperiodic CSI-RS, gNB can configure the resource allocation of PUCCH and the relationship between CSI-RS resource by RRC signalling, UE reports on corresponding PUCCH resource after measures CSI-RS. For periodic CSI-RS, the CSI-RS resource and PUCCH resource are simultaneously configured in a CSI report configuration by RRC signalling, the power saving signal can trigger the shift for both the CSI-RS resource and PUCCH resource.

Proposal 3. Power saving signal used in DRX off time could trigger an on demand CSI report before DRX ON. Aperiodic CSI-RS or periodic CSI-RS could be used as the CSI measurement resource and PUCCH could be used as the CSI report resource for the on demand CSI report before DRX ON. The aperiodic CSI-RS configuration index or the periodic CSI-RS configuration index and associated shifted duration could be indicated in the power saving signal used in DRX off time.

2.3. Power saving signal design for DRX active state and non-DRX operation state

2.3.1. Triggering UE skipping PDCCH monitoring

As the discussion in SI stage, one of the problem of UE power consumption is the PDCCH-only detection, power saving signal is useful for triggering UE skipping some PDCCH monitoring in DRX active time or when no DRX is applied to save UE power.

Two solutions can be considered for skipping PDCCH monitoring. One is "wake up", which means that power saving signal is used to indicate the time duration UE would keep awake to monitor PDCCH after UE detect it. Another is "go to sleep", which means that power saving signal is used to indicate the time duration UE would go to sleep and not monitor PDCCH. The objective of both "wake up" and "go to sleep" is to skip PDCCH-only monitoring occasions.

These two solutions can achieve the same power saving effect with different signalling, i.e., “wake up” or “go to sleep”. However, the performance requirements of “wake up” and “go to sleep” are different as described in TR 38.840 [2]. For power saving signal/channel for wake-up purpose, the target of miss detection 0.1% and the false alarm rate at 1%. For power saving signal/channel for go-to-sleep purpose, the target of miss detection 1% and the false alarm rate at 0.1%. We can see that the miss detection requirement of “wake up” is more stringent than “go to sleep”, since if “wake up” power saving signal is miss detected, UE will not wake up to monitor PDCCH and miss data transmission, which will cause severe performance degradation. While if “go to sleep” power saving signal is miss detected, UE will not go to sleep and continue to monitor PDCCH although there are no data scheduling which only cause more UE power consumption but no performance degradation. For PDCCH-based power saving signal, the 0.1% miss detection can only be met when the payload is less or the CCE is large enough such as 16, while the false alarm rate can easily fulfil 0.1% since CRC is used. Therefore, “go to sleep” is more suitable for PDCCH-based power saving signal than “wake up” to trigger UE adaptation in skipping PDCCH monitoring.

Proposal 4. PDCCH-based power saving signal could be used to indicate UE to go to sleep for a duration in DRX active time or non-DRX operation for triggering UE skipping PDCCH monitoring.

2.3.2. Triggering power saving states adaptation

In addition to skipping PDCCH monitoring, other power saving schemes can also be indicated in power saving signal such as cross-slot scheduling, MIMO layers adaptation. One solution is that power saving signal indicates the parameters for other potential power saving schemes respectively, e.g., minimum k_0/k_2 , maximum MIMO layers. However, the payload size in this case will increase with the introduction of more power saving related parameters and power saving signal performance may not be guaranteed. Another solution is to configure several different power saving states by RRC signalling, as the discussion in our companion contribution [3], and each power saving state is associated with a combination of different values for the parameters of potential power saving schemes, and then PDCCH-based power saving signal can be used to further dynamically indicate UE which power saving state to use. For example, two power saving states are configured, for power saving state index 0, minimum $k_0 = 0$ and maximum MIMO layers = 4 for one codeword and PDCCH monitoring periodicity = 1 slot, while for power saving state index 1, minimum $k_0 = 1$ and maximum MIMO layers = 2 for one codeword and PDCCH monitoring periodicity = 5 slots. PDCCH-based Power saving signal can dynamically indicate UE which power saving state to use with 1 bit. This method can achieve a good trade off between the PDCCH overhead and indication flexibility. Therefore, we propose to introduce the concept of power saving states when designing the PDCCH-based power saving signal to trigger UE adaptation in DRX active time and non-DRX operation.

Proposal 5. Introduce the concept of power saving states when designing the PDCCH-based power saving signal to trigger UE adaptation in DRX active time and non-DRX operation. Several different power saving states could be configured with RRC signalling, and then PDCCH-based power saving signal could be used to further dynamically indicate UE which power saving state to use.

3. Other issues in power saving signal based DRX procedure

In this section, the association of BWP switching operation and power saving signal based DRX procedure is discussed.

In R15, active BWP can be changed by RRC signalling, DCI or `bwp-InactivityTimer` and the BWP change procedure does not have relationship with DRX operation. For example, the `bwp-InactivityTimer` can be used for DL BWP switching from a wideband active DL BWP to a narrow band default BWP or initial BWP. Once UE receives a dynamic DL or UL grant or the MAC PDU is transmitted in a configured uplink grant or received in a configured downlink assignment, the `bwp-InactivityTimer` will start or restart, and if `bwp-InactivityTimer` expires, UE will switch to default BWP or initial BWP. This procedure can save UE power because the `bwp-InactivityTimer` expires means UE has not been scheduled in a long time and can work in a narrow band default BWP or initial BWP.

However, if power saving signal is used to indicate UE wake up in a DRX cycle, the time relationship between DRX operation and BWP operation should be designed together to save UE power better. For example in Figure 3, UE first detects power saving signal indicating wake up in next DRX cycle and then the `bwp-InactivityTimer` expires before next DRX cycle. If UE follows R15 procedure, UE should switch to default BWP or initial BWP. However, since gNB transmit power saving signal to wake up UE in next DRX cycle that means there are much data to be transmitted to this UE. As the power model in TR 38.840 [2], if the data packet size is fixed, faster transmitting in a large BWP will save more UE power than slower transmitting in a narrow BWP. Thus, gNB is likely to transmit a PDCCH for BWP switch to this UE in DRX active time to change UE active BWP to a larger one.

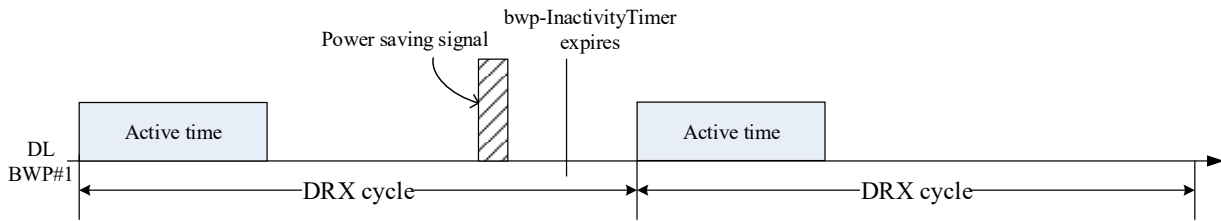


Figure 3. Bwp-InactivityTimer expires after power saving signal triggering DRX wake up

That is, UE switch to the default BWP and then to the large BWP again, which will cause more power consumption. Therefore, in this case, UE should not switch to default BWP or initial BWP according to bwp-InactivityTimer but should wake up in current active BWP in next DRX cycle.

There are several schemes to solve this problem as the following:

- 1) If UE detects the power saving signal, UE stops or restarts bwp-InactivityTimer to avoid BWP switching.
- 2) If UE receives the power saving signal configuration in one DL BWP, UE will ignore the configuration of bwp-InactivityTimer that means the function of BWP switch by timer is disabled in this case.

Proposal 6. To avoid BWP switch in power saving signal based DRX operation before UE waking up in next DRX cycle, the following schemes can be further studied:

- 1) UE stops or restarts bwp-InactivityTimer after detecting the power saving signal.
- 2) UE ignores the configuration of bwp-InactivityTimer after receiving the power saving signal configuration in one DL BWP.

4. Conclusions

In this contribution, the power saving signal design and power saving triggering UE adaptation in both DRX operation and non-DRX operation are discussed, and the following observations and proposals are made.

Proposal 1: Two different PDCCH-based power saving signals could be designed for different UE operation states, e.g., during DRX off time during DRX active time, in non-DRX operation.

- Power saving signal #1 could be designed to be transmitted in DRX off time in order to wake up UE, trigger CSI report before DRX ON, or other potential power saving schemes such as adaptation in BWP/Scell operation.
- Power saving signal #2 could be designed to be transmitted in DRX active time and non-DRX operation in order to trigger UE adaptation to PDCCH monitoring, cross-slot scheduling, maximum MIMO layer or other schemes.

Proposal 2. PDCCH-based Power saving signal used in DRX off time could be transmitted at least to trigger UE wake up in the next DRX cycle or not, and some other fields for triggering CSI before DRX ON or other potential power saving schemes such as adaptation in BWP/Scell operation should also be considered when designing this PDCCH-based power saving signal.

Proposal 3. Power saving signal used in DRX off time could trigger an on demand CSI report before DRX ON. Aperiodic CSI-RS or periodic CSI-RS could be used as the CSI measurement resource and PUCCH could be used as the CSI report resource for the on demand CSI report before DRX ON. The aperiodic CSI-RS configuration index or the periodic CSI-RS configuration index and associated shifted duration could be indicated in the power saving signal used in DRX off time.

Proposal 4. PDCCH-based power saving signal could be used to indicate UE to go to sleep for a duration in DRX active time or non-DRX operation for triggering UE skipping PDCCH monitoring.

Proposal 5. Introduce the concept of power saving states when designing the PDCCH-based power saving signal to trigger UE adaptation in DRX active time and non-DRX operation. Several different power saving states could be configured with RRC signalling, and then PDCCH-based power saving signal could be used to further dynamically indicate UE which power saving state to use.

Proposal 6. To avoid BWP switch in power saving signal based DRX operation before UE waking up in next DRX cycle, the following schemes can be further studied:

- 1) UE stops or restarts bwp-InactivityTimer after detecting the power saving signal.**
 - 2) UE ignores the configuration of bwp-InactivityTimer after receiving the power saving signal configuration in one DL BWP.**
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5. References

- [1] RP-190727, New WID: UE Power Saving in NR, CATT, CAICT
- [2] 3GPP TR 38.840, NR; Study on UE Power Saving (Release 16).
- [3] R1-1904739, Discussion on dynamic adaption of power saving states, CMCC