3GPP TSG RAN WG1 #120 **R1-2501160**
Athens, Greece, February 17th – 21st, 2025

Agenda item: 9.5.1

Source: Qualcomm Incorporated

Title: On-demand SSB operation for Scell

Document for: Discussion/Decision

1 Introduction

The contribution provides our views on supporting on-demand SSB operation in Scell for connected mode UEs configured with CA, which was one of the techniques to improve network energy savings for NR [1]:

> 1. Specify procedures and signaling method(s) to support on-demand SSB SCell operation for UEs in connected mode configured with CA, for both intra-/inter-band CA. [RAN1/2/3/4]
>
> - Specify triggering method(s) (select from UE uplink wake-up-signal using an existing signal/channel, cell on/off indication via backhaul, Scell activation/deactivation signaling)
> - Note1: On-demand SSB transmission can be used by UE for at least SCell time/frequency synchronization, L1/L3 measurements and SCell activation, and is supported for FR1 and FR2 in non-shared spectrum.

2 On-demand SSB Transmission

RAN1#118 agreed that on-demand SSB in a cell supporting on-demand SSB Scell operation is non-cell-defining SSB that is not located on synchronization raster:

> **Agreement**
> For a cell supporting on-demand SSB SCell operation, at least the following is supported
> - On-demand SSB on the cell is not located on synchronization raster.
> - On-demand SSB on the cell is non-cell-defining SSB
>
> FFS: Additional support of OD-SSB for CD-SSB located on sync-raster

It is FFS on whether on-demand SSB can be cell defining SSB located on synchronization raster. WID has a note that "On-demand SSB transmission can be used by UE for at least SCell time/frequency synchronization, L1/L3 measurements and SCell activation." Furthermore, on-demand SSB is expected to be transmitted in a bursty or semi-persistent manner over a short period. If the on-demand SSB is cell-defining SSB, it is not useful for idle/inactive UEs (including both legacy UEs and R19 UEs) whose idle mode operations rely on periodic cell-defining SSB. In fact, it may request UE's cell reselection more often due to short term availability of the on-demand SSB.

There was some discussion that cell defining SSB can be configured for on-demand SSB if the legacy UEs are barred from camping/accessing the cell supporting on-demand SSB Scell operation. However, our concern regarding impact of using cell-defining SSB for on-demand SSB on idle/inactive UE operation is applicable to both legacy UEs and R19 UEs. As a result, the barring should be applied to not only legacy idle/inactive UEs but also R19 idle/inactive UEs if the barring approach is pursued. In addition, for some types of legacy UEs (e.g., UEs supporting NTN, Redcap, NES), the barring is provided in SIB1, which is not preferable from UE implementation perspectives in supporting on-demand SSB Scell operation.

Observation 1: Having on-demand SSB configured as cell-defining SSB has negative impact to both legacy idle/inactive UEs and R19 idle/inactive UEs.

Proposal 1: On-demand SSB for cell defining SSB located on synchronization raster is not supported

On the indication of on-demand SSB transmission on the cell, RAN1#117 agreed to support both RRC and MAC-CE based signaling while whether to support DCI based signaling is FFS.

> **Agreement (RAN1#117)**
> - For a cell supporting on-demand SSB SCell operation,
>   - Support RRC based signaling to indicate on-demand SSB transmission on the cell.
>   - Support MAC CE based signaling to indicate on-demand SSB transmission on the cell.
>   - FFS: Whether to support DCI based signaling to indicate on-demand SSB transmission on the cell.
>   - This DCI signaling does not provide SCell activation/deactivation.

- If supported, details on DCI including UE-specific or group-common DCI, DCI contents, etc.
- FFS: Scenarios where the above signalings are applicable

From our perspectives, DCI based signaling to indicate on-demand SSB transmission on the cell should not be supported since on-demand SSB transmission typically does not need changing very frequently. There was also a discussion on possible benefit of having group command DCI to reduce signaling to the connected mode UEs. However, such benefit is unclear when the cell has a low load with a very limited number of connected UEs.

Proposal 2: DCI based signaling to indicate on-demand SSB transmission on the cell is not supported.

3 Timeline of On-demand SSB Transmission

3.1 MAC-CE based OD-SSB indication

RAN1#118b made the following agreement related to the determination of the time instance A when the signaling to indicate on-demand SSB transmission is based on MAC-CE, which is illustrated in Figure 1:

Agreement

The previous RAN1 agreement is partly confirmed and further revised as follows.

- For SSB burst(s) indicated by on-demand SSB SCell operation via a MAC CE, UE expects that on-demand SSB ~~burst(s)~~ is transmitted from time instance A which is determined as follows.
  - Alt 3-1: Time instance A is the beginning of the first slot containing ~~[candidate SSB index 0 or~~ the first actually transmitted SSB index~~]~~ ~~of~~within the first "possible" on-demand SSB burst which is at least T slots after the slot where UE receives a signalling from gNB to indicate on-demand SSB transmission
    - The SSB time domain positions of on-demand SSB burst are configured by gNB.
      - The location(s) (e.g., SFN offset, half frame index) in the time domain of "possible" on-demand SSB burst and SSB position within the burst should be configured by the gNB
  - Note: The value of T is not less than existing timeline required for UE's MAC CE processing for SCell activation
  - (Working assumption): T is not less than T_min=$m + 3N_{slot}^{subframe,\mu}$+1 where slot n+m is a slot indicated for PUCCH transmission with HARQ-QCK information when the UE receives MAC CE signaling to indicate on-demand SSB transmission ending in slot n, and $N_{slot}^{subframe,\mu}$ is as defined in current specification.
    - RAN4 to confirm that T_min can be equal to $m + 3N_{slot}^{subframe,\mu}$+1
  - (Working assumption) T=T_min
- Above applies at least for the case where SCell with on demand SSB transmission and cell with signalling transmission have the same numerology.

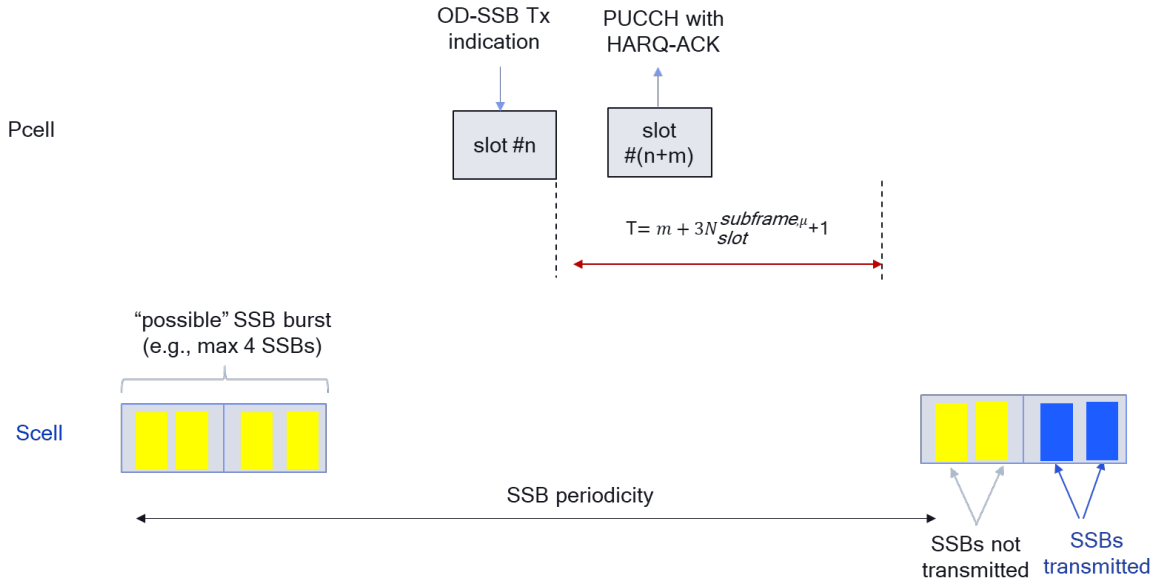


Figure 1: Illustration of MAC-CE based indication timeline

RAN4 provided reply to RAN1 LS (R1-2407565) as follows:

> RAN4 would like to thank RAN1 for the LS on timeline for On-demand SSB operation on SCell. After discussion in RAN4 meetings, following agreement have been achieved:
>
> - RAN4 to confirm that T_min equals to $m + 3N_{slot}^{subframe,\mu}+1$ from network transmission perspective.
> - Note 1: This does not imply UE shall be ready to process the OD-SSB from time instance A from RAN4 requirement perspective.
> - Meanwhile, RAN4 is discussing the additional UE processing/preparation time for OD-SSB reception for RAN4 requirement.

From our perspective, the working assumptions can be confirmed with understanding that T_min equals to $m + 3N_{slot}^{subframe,\mu}+1$ from network transmission perspective to be aligned with RAN4's understanding.

Proposal 3: Confirm the working assumptions in determining T with understanding that T_min equals to $m + 3N_{slot}^{subframe,\mu}+1$ from network transmission perspective.

The current agreement is applicable at least for the case where SCell with on demand SSB transmission and cell with signalling transmission have the same numerology. It is beneficial to extend the agreement to the case where SCell with on demand SSB transmission and cell with signalling transmission have the different numerologies. In particular, the SCS for determining the value of T is the SCS of the active DL BWP that UE receives the OD-SSB transmission indication signaling.

Proposal 4: The SCS for determining the value of T is the SCS of the active DL BWP that UE receives the OD-SSB transmission indication signaling.

3.2 RRC based OD-SSB transmission indication

The processing delay for RRC procedure is defined in TS 38.331 while the latency from UL grant to RRC UL response is up to UE implementation. From our perspective, the UE should expect OD-SSB transmission from the first on-demand SSB burst after receiving RRC carrying indication of OD-SSB transmission.

Proposal 5: For SSB burst(s) indicated by on-demand SSB SCell operation via RRC, UE expects on-demand SSB is transmitted from the first on-demand SSB burst after receiving RRC carrying indication of OD-SSB transmission.

4 Relationship between always-on SSB and OD-SSB in Case #2

Relation in frequency domain

It was agreed that the frequency location of on-demand SSB is the same as the frequency location of always-on SSB at least for the case where always-on SSB is not CD-SSB. RAN1 is discussing the frequency location of OD-SSB for the case where always-on SSB is CD-SSB which may or may not be on a synchronization raster.

> **Agreement**
> Response to Q3 (What is the relation in terms of frequency location between the always-on SSB and OD-SSB?) of Obj.1:
> - The frequency location of on-demand SSB is the same as the frequency location of always-on SSB at least for the case where always-on SSB is not CD-SSB. RAN1 is discussing the frequency location of OD-SSB for the case where always-on SSB is CD-SSB.
>
> **Agreement**
> Down-select at least one of the following alternatives.
> - Alt 1: If always-on SSB is CD-SSB on a synchronization raster, the frequency location of on-demand SSB is different from the frequency location of always-on SSB.
> - Alt 2: If always-on SSB is CD-SSB on a synchronization raster, the frequency location of on-demand SSB is the same as the frequency location of always-on SSB
> - Alt 3: Do not support the case where always-on SSB is CD-SSB on a synchronization raster.

Down-select at least one of the following alternatives.

- Alt A: If always-on SSB is CD-SSB and not on a synchronization raster, the frequency location of on-demand SSB can be same or different from the frequency location of always-on SSB, subject to its configuration.
- Alt B: If always-on SSB is CD-SSB and not on a synchronization raster, the frequency location of on-demand SSB is the same as the frequency location of always-on SSB
- Alt C: Do not support the case where always-on SSB is CD-SSB and not on a synchronization raster.

The scenarios of having always-on SSB as CD-SSB on a synchronization raster are reasonable since OD-SSB can be additional SSBs to enhance various PHY procedures e.g., time/frequency tracking loop and beam management. Furthermore, OD-SSB should be located in a frequency different from the frequency location of always-on SSB to avoid impact to the idle UEs operating the idle mode operations based on the always-on SSB. On the other hand, the benefit of having scenarios with OD-SSB and always-on SSB as CD-SSB that is not on a synchronization raster is unclear.

Proposal 6: When always-on SSB is CD-SSB, support

- ***Alt 1 (If always-on SSB is CD-SSB on a synchronization raster, the frequency location of on-demand SSB is different from the frequency location of always-on SSB.)***
  - ***Note: This is subject to a UE capability that is different from the UE capability on the support of the same frequency location for on-demand SSB and always-on SSB***
- ***Alt C (Do not support the case where always-on SSB is CD-SSB and not on a synchronization raster.)***

Relation in spatial and power domain

The spatial relation between the always-on SSB and OD-SSB was agreed as follows:

Agreement

Response to Q4 (What is the spatial relation between the always-on SSB and OD-SSB?) of Obj.1:

- SS/PBCH blocks with the same SSB indexes for always-on SSB and on-demand SSB are quasi co-located with respect to Doppler spread, Doppler shift, average gain, average delay, delay spread, and when applicable, spatial RX parameters.
  - Applies at least for the case when the centre frequency locations of always-on SSB and OD-SSB is same
- When a signal/channel is configured to be QCLed with a SSB index, the signal/channel is QCLed with the same SSB index of always-on SSB and on-demand SSB (if transmitted) with the same QCL parameters according to existing specifications
  - Applies at least for the case when the centre frequency locations of always-on SSB and OD-SSB is same
- At least the case where SSB indices within on-demand SSB burst are identical to SSB indices within always-on SSB burst is supported. RAN1 is discussing whether to support the case where SSB indices within on-demand SSB burst can be subset of SSB indices within always-on SSB burst.

For case when the frequency location of on-demand SSB is different from the frequency location of always-on SSB if being supported, if both always-on SSB and on-demand SSB are configured for measurement, the following requirements should be supported:

- SSB indices within on-demand SSB burst are identical to SSB indices within always-on SSB burst
- The on-demand SSB transmit power is identical to the always-on SSB transmit power.

Proposal 7: For the case when the frequency location of on-demand SSB is different from the frequency location of always-on SSB, if both always-on SSB and on-demand SSB are configured for measurement,

- ***SSB indices within on-demand SSB burst are identical to SSB indices within always-on SSB burst***
- ***The on-demand SSB transmit power is identical to the always-on SSB transmit power.***

Relation in time domain

The relation of always-on SSB and OD-SSB for Case #2 is under discussion as being agreed below:

Agreement

- For a cell supporting on-demand SSB SCell operation, support to configure time domain location of on-demand SSB per on-demand SSB periodicity by RRC for both Case #1 and Case #2.
  - For Case #1 (i.e., No always-on SSB on the cell),
    - Based on two parameters, where one is to indicate SFN offset from a reference point and the other is to indicate half frame index

- The reference point is SFN which satisfies (SFN index *10) modulo (OD-SSB periodicity) = 0
- If SFN offset parameter is NOT configured, UE assumes SFN offset set to 0.
- If half frame index parameter is NOT configured, UE assumes half frame index set to 0.
- The value range of SFN offset is 0 to 15 unless longer periodicity for on-demand SSB than 160 ms is introduced.
- The value range of half frame index is 0 or 1.

- For Case #2 (i.e., Always-on SSB is periodically transmitted on the cell), down-select one of the following alternatives.
  - Alt A: Same as for Case #1
  - Alt B: Based on a single parameter which is to indicate the time offset between always-on SSB and on-demand SSB (e.g., similar to *ssb-TimeOffset*)

For Case #2, the time-domain configuration of on-demand SSB should be similar to the configuration defined for Case #1. Furthermore, at least for the deployment in which the frequency locations of the always-on SSB and the on-demand SSB are identical, the time domain locations of always-on SSB burst is a subset of the time domain locations of on-demand SSB burst as illustrated in Figure 2.

Proposal 8: At least for Case #2 in which the frequency locations of always-on SSB and on-demand SSB are identical, the time domain configuration of on-demand SSB is identical to the time domain configuration of on-demand SSB in Case #1. Furthermore, the time-domain locations of always-on SSB burst is a subset of the time-domain locations of on-demand SSB bursts.

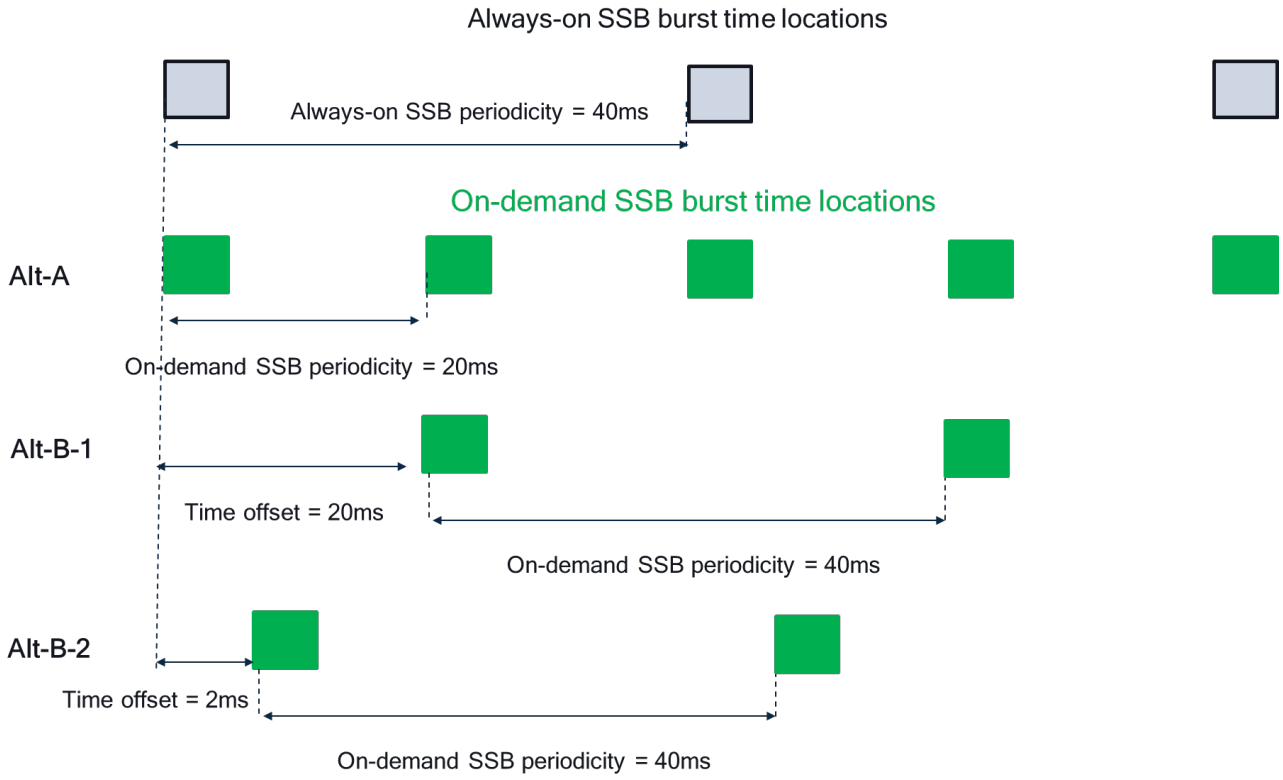


Figure 2: Examples for on-demand SSB time-domain configuration in Case #2

5 Deactivation of on-demand SSB transmission

It was agreed in RAN1#118b and RAN1#119 that deactivation of on-demand SSB transmission is supported for a cell supporting on-demand SSB Scell operation:

Agreement
For a cell supporting on-demand SSB SCell operation, deactivation of on-demand SSB transmission is supported. In order to deactivate on-demand SSB transmission from a UE perspective, support at least one of the following options.

- Option 1: Explicit indication of deactivation for on-demand SSB via MAC-CE for on-demand SSB transmission indication
- Option 1A: Explicit indication of deactivation for on-demand SSB via RRC for on-demand SSB transmission indication
- Option 2: Configuration/indication of the number N of on-demand SSB bursts to be transmitted after on-demand SSB is indicated
- Option 3: Configuration/indication of the duration of on-demand SSB transmission window
- Option 4: On-demand SSB transmission, if any, is deactivated when UE receives SCell deactivation MAC-CE for the activated SCell
- Option 4A: On-demand SSB transmission, if any, is deactivated when the timer for SCell deactivation is expired
- Option 5: On-demand SSB transmission, if any, is deactivated when SCell activation is completed
- Option 6: Explicit indication of deactivation for on-demand SSB via [group-common] DCI
- FFS: Each option is applicable to which Cases or Scenarios
- FFS: Details related to each of the above options

Agreement

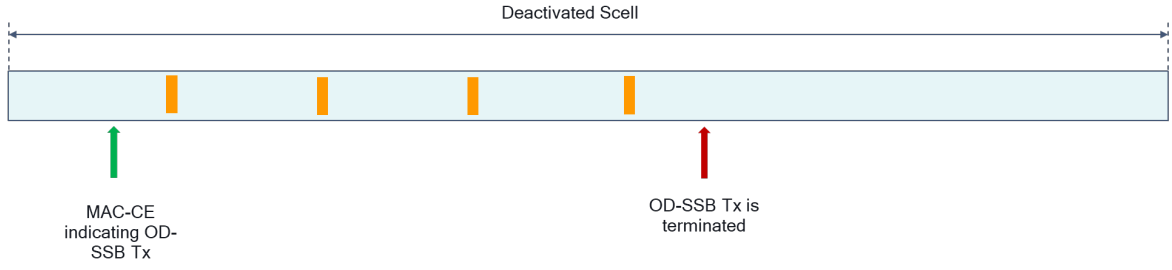
For a cell supporting on-demand SSB SCell operation, support at least the following options to deactivate on-demand SSB transmission from a UE perspective.

- Option 1: Explicit indication of deactivation for on-demand SSB via MAC-CE for on-demand SSB transmission indication
  - Deactivation by RRC is up to RAN2
  - FFS: Which scenario Option 1 is used
- Option 2: Configuration/indication of the number N of on-demand SSB bursts to be transmitted after on-demand SSB is indicated
  - FFS: Whether Option 4, 4a is needed in addition to Option 2
  - FFS: Whether the value of N can be implicitly determined using a timer

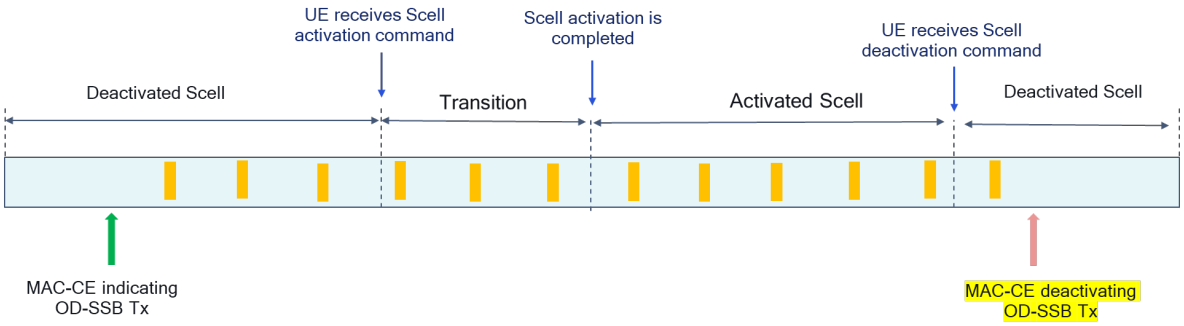
On Option 1 (Explicit indication of deactivation for on-demand SSB via MAC-CE for on-demand SSB transmission indication)

For Case #1 (without always-on SSB transmission), we can have the following combinations when considering the times UE receives the indication of OD-SSB transmission and the deactivation of OD-SSB transmission, which are illustrated in Figure 6 - Figure 8.

Combination	Indication in	Deactivation in	Note
1	Scenario 2	Scenario 2	• Support • OD-SSB in Scenario 2 is for L3 measurement only
2	Scenario 2A	Scenario 2	• Support
3	Scenario 2 or Scenario 2A	Scenario 2A or Scenario 3A or Scenario 3B	• Not support (since there would be period without SSB for UE to perform SSB based operations)



(a)



(b)

Figure 3: Example for combination 1

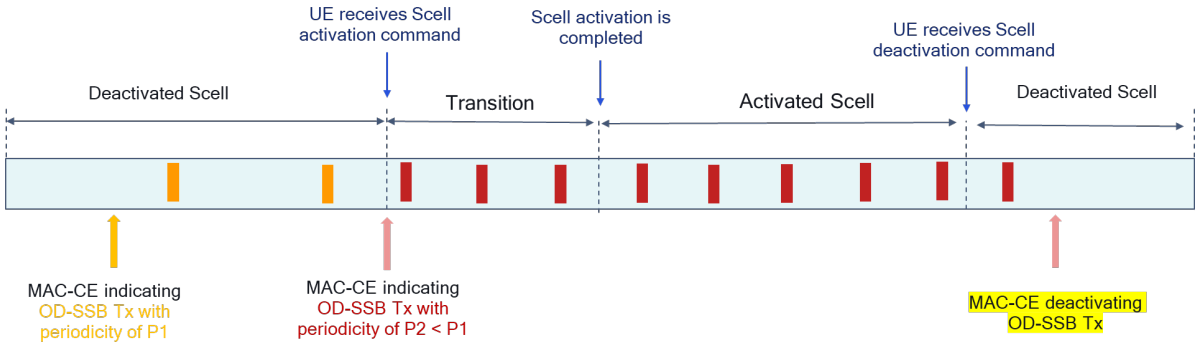


Figure 4: Example for combination 2

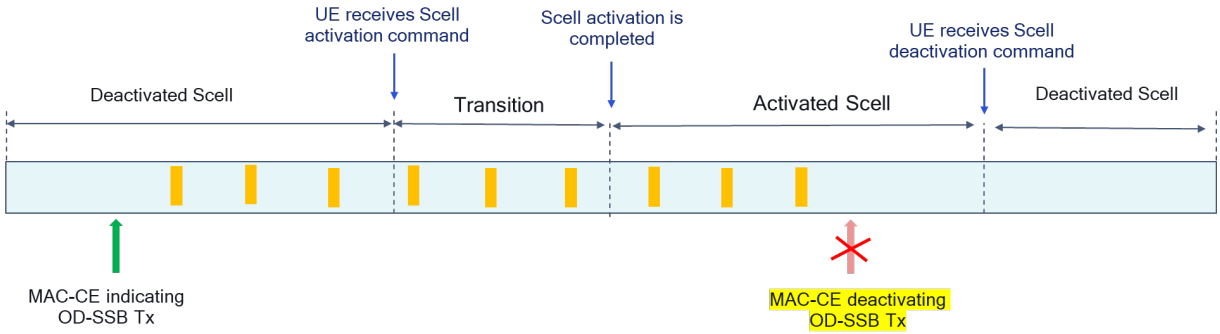


Figure 5: Example for combination 3

Based on the above analysis, we make the following proposal:

Proposal 9: For MAC-CE based deactivation of OD-SSB transmission in Case #1, the deactivation is only signaled in Scenario 2. The timing of the deactivation is

- ***Before the time UE receives the Scell activation signaling, or***
- ***At the same time or later than the time that UE receives the Scell deactivation signaling or timer for SCell deactivation is expired.***

For Case #2 (with always-on SSB transmission), similar considerations in Case #1 are applied. In addition, the deactivation can be signaled in Scenario 3B (motivated by the fact that denser SSB may be already transmitted for another UE and can be leveraged for this UE as long as the SSB is still needed for the other UE). When combining both Scenario 2 and Scenario 3B together, we can have the timing of the deactivation before the time UE receives the Scell activation signaling or after the Scell activation is completed (e.g., after the UE successfully sends the first CSI report).

Proposal 10: For the MAC-CE based deactivation of OD-SSB transmission in Case #2, the deactivation can be signaled in Scenario 2 or Scenario 3B. In particular, the timing of the deactivation is before the time UE receives the Scell activation signaling or after the Scell activation is completed (e.g., after the UE successfully sends the first CSI report).

<u>On Option 2 (Configuration/indication of the number N of on-demand SSB bursts to be transmitted after on-demand SSB is indicated)</u>

It was agreed that the OD-SSB can be transmitted before gNB transmits the Scell activation. However, it is still open on how the OD-SSB is transmitted. In particular, two following deployments should be discussed:

- OD-SSB transmission for L3 measurement in deactivated Scell (illustrated in Figure 5): This may be beneficial for gNB in evaluating whether the cell can be activated or not. For this use case, an explicit MAC-CE for indicating the termination of OD-SSB transmission is not necessary. Instead, transmission duration-based deactivation (e.g., a transmission window or a number of transmitted SSB bursts) such as Option 2 should be sufficient.

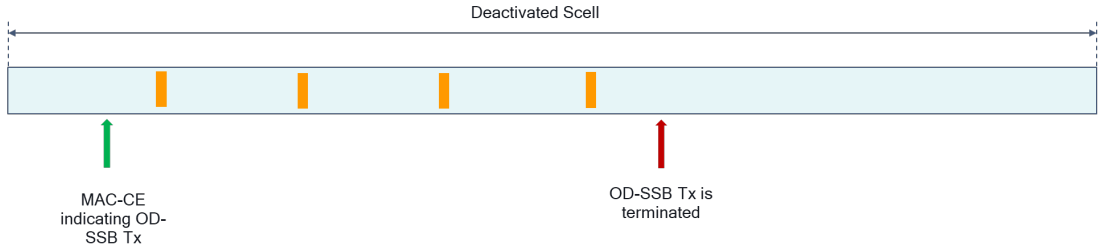


Figure 6: OD-SSB transmission for L3 measurement in deactivated Scell

- OD-SSB transmission for L3 measurement in deactivated Scell and L3/L1 measurement in activated Scell: If window of the OD-SSB transmission for L3 measurement in deactivated Scell overlaps with the time UE receives Scell activation command, the UE can assume that the OD-SSB is transmitted until the activated cell is deactivated (as in Option 4 and Option 4A) as being illustrated in Figure 6.

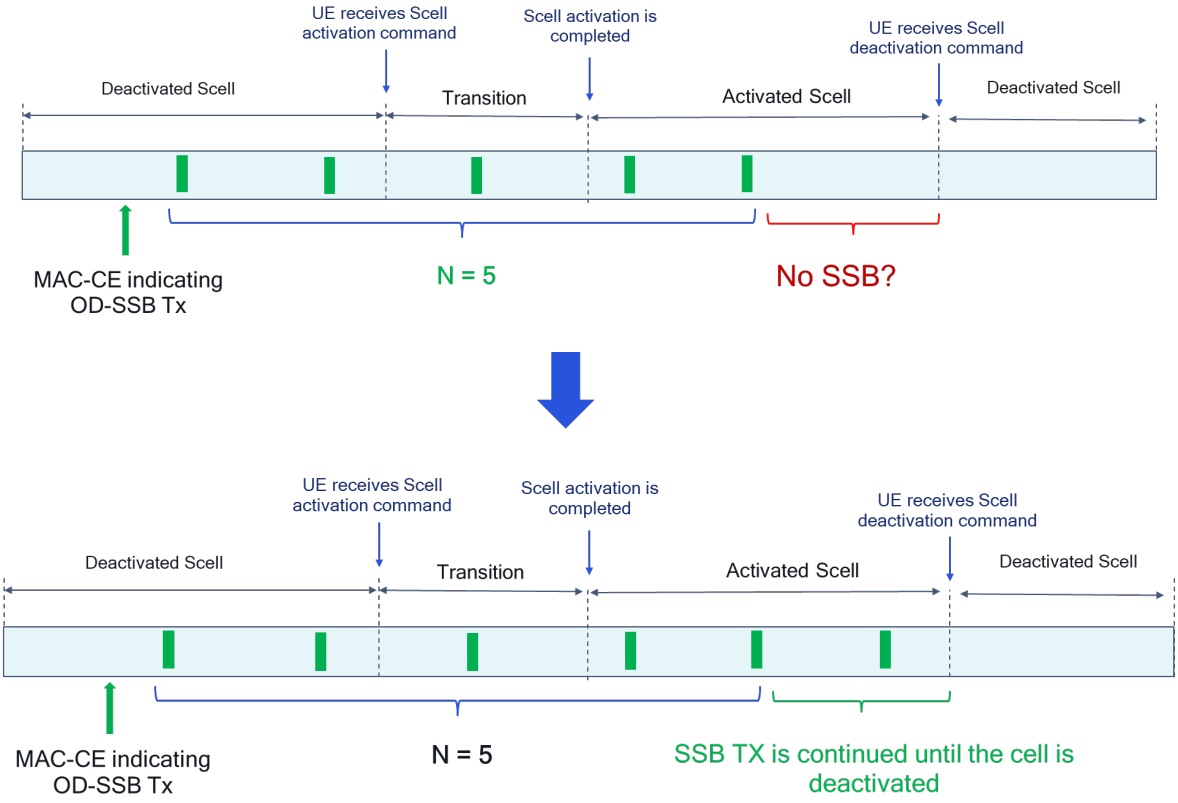


Figure 7: OD-SSB transmission for L3/L1 measurement in activated Scell

Observation 2: For Option 2 in Case #1, gNB may not be able to configure the value of N properly to ensure sufficient SSB transmission in activated cell. Therefore, Option 4 or Option 4A should be used in addition to Option 2.

Proposal 11: For Option 2 in Case #1, UE assumes OD-SSB transmission is deactivated when UE receives SCell deactivation MAC-CE for the activated SCell (Option 4) or the timer for SCell deactivation is expired (Option 4A) if the Nth SSB transmission is after Scell activation completion and before the time UE receives Scell deactivation command or the timer for SCell deactivation is expired.

6 CSI measurement configuration in Case #2

RAN1#118b made the following agreement related to CSI report configuration in which the reference signal for CSI measurement can be always-on SSB and/or OD-SSB for Case #2:

Agreement
For a cell supporting on-demand SSB SCell operation and for Case #2 (i.e., Always-on SSB is periodically transmitted on the cell), consider only one or both of the following options for UE to perform L1 measurement based on on-demand SSB.
- Option 1: A CSI report configuration is associated with both of on-demand SSB and always-on SSB
- Option 2: A CSI report configuration is associated with one of always-on SSB and on-demand SSB
- FFS: Whether OD-SSB and always on SSB have same beam or not

The discussion depends on the outcome of related discussion in Section 4. In particular, if it is agreed that Case 2 only supports both always-on SSB and OD-SSB as NCD-SSB on the same frequency location, using both types of SSB in the same CSI report configuration is reasonable. On the other hand, if Case 2 also supports always-on SSB as CD-SSB on sync raster and OD-SSB as NCD-SSB not on sync raster, only one of the SSB type that is associated with the frequency location configured for the CSI reference signal should be used. It should be noted that in the current spec, the reference signals configured for CSI measurements are all in the same frequency locations.

Observation 3: Whether a CSI report configuration is associated with one or both of on-demand SSB and always-on SSB depends on whether on-demand SSB and always-on SSB are located in the same frequency or not.

7 Conclusion

The contribution has discussed our views on on-demand SSB operation for Scell. In particular, we make the following observations and proposals:

Observation 1: Having on-demand SSB configured as cell-defining SSB has negative impact to both legacy idle/inactive UEs and R19 idle/inactive UEs.

Observation 2: For Option 2 in Case #1, gNB may not be able to configure the value of N properly to ensure sufficient SSB transmission in activated cell. Therefore, Option 4 or Option 4A should be used in addition to Option 2.

Observation 3: Whether a CSI report configuration is associated with one or both of on-demand SSB and always-on SSB depends on whether on-demand SSB and always-on SSB are located in the same frequency or not.

Proposal 1: On-demand SSB for cell defining SSB located on synchronization raster is not supported

Proposal 2: DCI based signaling to indicate on-demand SSB transmission on the cell is not supported.

Proposal 3: Confirm the working assumptions in determining T with understanding that T_min equals to $m + 3N_{slot}^{subframe,\mu}+1$ from network transmission perspective.

Proposal 4: The SCS for determining the value of T is the SCS of the active DL BWP that UE receives the OD-SSB transmission indication signaling.

Proposal 5: For SSB burst(s) indicated by on-demand SSB SCell operation via RRC, UE expects on-demand SSB is transmitted from the first on-demand SSB burst after receiving RRC carrying indication of OD-SSB transmission.

Proposal 6: When always-on SSB is CD-SSB, support
- Alt 1 (If always-on SSB is CD-SSB on a synchronization raster, the frequency location of on-demand SSB is different from the frequency location of always-on SSB.)
    - Note: This is subject to a UE capability that is different from the UE capability on the support of the same frequency location for on-demand SSB and always-on SSB
- Alt C (Do not support the case where always-on SSB is CD-SSB and not on a synchronization raster.)

Proposal 7: For the case when the frequency location of on-demand SSB is different from the frequency location of always-on SSB, if both always-on SSB and on-demand SSB are configured for measurement,
- SSB indices within on-demand SSB burst are identical to SSB indices within always-on SSB burst
- The on-demand SSB transmit power is identical to the always-on SSB transmit power.

Proposal 8: At least for Case #2 in which the frequency locations of always-on SSB and on-demand SSB are identical, the time domain configuration of on-demand SSB is identical to the time domain configuration of on-demand SSB in Case #1. Furthermore, the time-domain locations of always-on SSB burst is a subset of the time-domain locations of on-demand SSB bursts.

Proposal 9: For MAC-CE based deactivation of OD-SSB transmission in Case #1, the deactivation is only signaled in Scenario 2. The timing of the deactivation is
- Before the time UE receives the Scell activation signaling, or

- At the same time or later than the time that UE receives the Scell deactivation signaling or timer for SCell deactivation is expired.

Proposal 10: For the MAC-CE based deactivation of OD-SSB transmission in Case #2, the deactivation can be signaled in Scenario 2 or Scenario 3B. In particular, the timing of the deactivation is before the time UE receives the Scell activation signaling or after the Scell activation is completed (e.g., after the UE successfully sends the first CSI report).

Proposal 11: For Option 2 in Case #1, UE assumes OD-SSB transmission is deactivated when UE receives SCell deactivation MAC-CE for the activated SCell (Option 4) or the timer for SCell deactivation is expired (Option 4A) if the Nth SSB transmission is after Scell activation completion and before the time UE receives Scell deactivation command or the timer for SCell deactivation is expired.

8 Reference

[1] RP-242354, Enhancements of network energy savings for NR