Qualcomm

2024

FR2 (Dual-Connectivity):

Device (UE) Power Saving Techniques & Potential Benefits

Contents

1. Introduction: 3GPP Power-Saving Techniques in FR2 (Dual-Connectivity Mode)

3GPP introduced various power-saving technologies for both FR1 and FR2, which can result in significant device (UE) power-saving. While many of those features had already been commercialized in FR1, FR2 so far witnessed only a very basic set of feature implementation. Given this and since many of these techniques have trade-offs between power-consumption and air-interface-latency and would therefore require optimal implementation, we will present in this paper the power saving potential and subsequently the air-interface-latency tradeoff of various 3GPP FR2 power saving features. In particular, we shall cover the following topics:

- Connected-DRX (C-DRX): Introduced in 3GPP Rel. 15.
- DCI-based PDCCH-skip / SSSG-Switching: Introduced in 3GPP Rel. 17.
- SCG Activation-Deactivation: Introduced in 3GPP Rel. 17.
- Sparse-PDCCH-Monitoring aka Time-Domain-Bandwidth-Part: Specific implementation within Rel. 15.

In the following sections, these power savings features are introduced along with power-latency tradeoff analysis, results, and recommendations.

2 Connected-DRX (C-DRX)

CDRX is a key power saving technique which allows UE to save power by allowing to monitor PDCCH only during a predefined monitoring interval, for e.g., for a CDRX cycle of 160 ms, first 10 ms can be ON duration where UE does PDCCH monitoring. Generally, CDRX configuration is represented as X-Y-Z ms, where X = Inactivity timer which gets reset every-time there is data transmission and UE keeps on monitoring PDCCH while inactivity timer is running; Y = ON duration where UE actively monitors PDCCH for any potential scheduling message; and Z = Long cycle duration. If there is no data during the ON period or after the expiration of inactivity timer, the UE sleeps (does not monitor PDCCH) for the rest of the long cycle duration to save power consumption.

3GPP allows the use of Long and Short CDRX cycle. Unlike long CDRX cycles, short CDRX cycle allows for multiple short CDRX cycles within the long CDRX cycle. The goal is to reduce any potential air-interface-latency impact while meeting the power-saving goal. Generally, in short CDRX cycles, the inactivity timer is kept smaller so that UE can go to sleep faster. It also makes sure that UE wakes up within the long CDRX cycle itself to serve any data arriving during this time-window. This helps improve the latency performance. Short-CDRX cycle is typically represented as X-Y-AxB-Z, where X, Y, and Z are the same as long CDRX cycle, A = Short cycle duration, and B = # of short cycles. The ON duration and inactivity timer for the short cycles are the same as those of long cycles.

The figure below depicts an example of typical C-DRX operation.

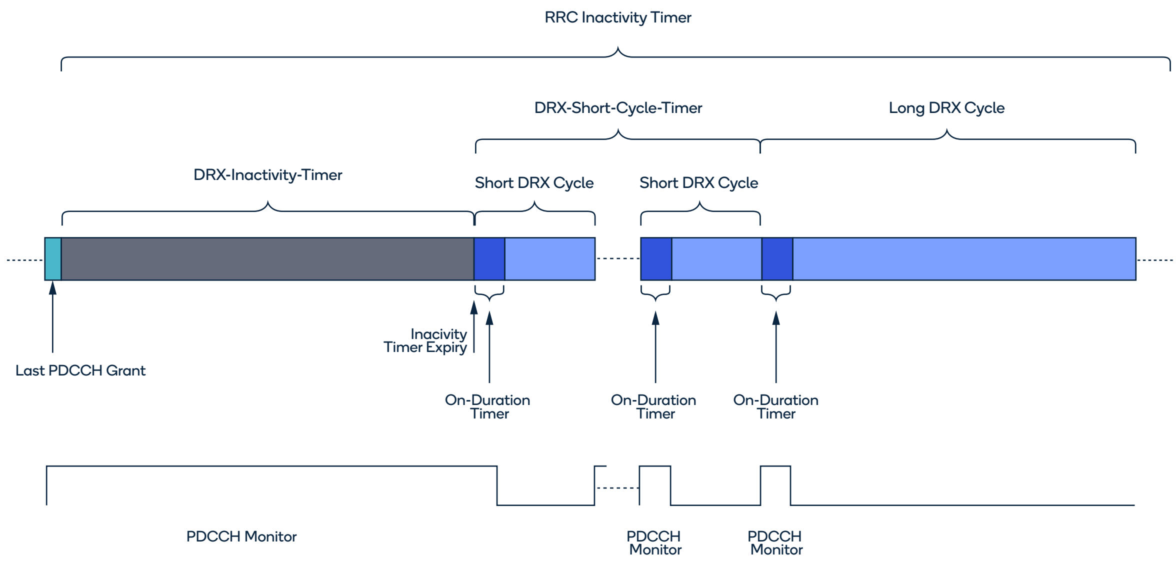

Figure 2-1 Connected-DRX (C-DRX) Operation

2.1 Simulation Assumption

The assumptions used for the simulations are as follows:

- Long CDRX used: 8-8-80, 8-8-160
- Short CDRX used: 8-8-40x2-160, 4-8-40x2-160, 4-4-40x2-160
- SCS → 120 KHz || TDD → DDDSU || #CC → 8 CCs: Pcell: 100 MHz, Scells = 7 x 100 MHz
- RF Condition → Mid and far-cell scenario
- Operating mode → EnDC (LTE Anchor) or NR-DC (FR1 Anchor)
- FR2 Scell activation happens if estimated DL latency exceeds a configurable threshold.
- FR2 Scell de-activation happens if Scell inactivity exceeds a configurable threshold.
- Note : CDRX numbers mentioned above are represented in ms.

2.2 Simulation Results

We simulated FR2 scenario for different CDRX configurations namely long and short CDRX cycles and compared their performance. Baseline CDRX scenario is assumed to be 8-8-80.

The table below shows that the short CDRX cycles give the best balance between the power saving and DL latency. Compared with the baseline, 8-8-160 provides maximum power savings for Chrome and DoU; however, it comes at the cost of higher DL latencies. Short CDRX cycles such as 8-8-40x2-160 and 4-8-40x2-160 also provides significant power saving with acceptable impact on air-interface-latency performance for most of the applications. It is also observed that for heavy apps like YouTube4K, short CDRX provides the maximum power saving with marginal impact to the latency performance.

APP Type	CDRX Config	mA Saving (%)	Avg DL Latency (ms)
Chrome	8-8-80	Ref	1.87
Chrome	8-8-160	18.8%	4.47
Chrome	8-8-40x2-160	-12.6%	1.59
Chrome	4-8-40x2-160	-6.8%	1.64
Chrome	4-4-40x2-160	5.3%	2.58
YouTube4K	8-8-80	Ref	1.49
YouTube4K	8-8-160	11.0%	1.76
YouTube4K	8-8-40x2-160	6.5%	0.92
YouTube4K	4-8-40x2-160	12.8%	1.01
YouTube4K	4-4-40x2-160	15.8%	1.02
DoU	8-8-80	Ref	1.55
DoU	8-8-160	20.4%	2.39
DoU	8-8-40x2-160	7.5%	1.14
DoU	4-8-40x2-160	12.4%	1.72
DoU	4-4-40x2-160	19.9%	1.84

Figure 2-2 Power-Latency Tradeoff of CDRX Configuration

Note-1 : mA saving refers to modem-RF only. Note-2 : Positive numbers (%) refer to power-saving (reduction) with respect to the baseline reference. Note-3 : Avg DL Latency refers to air-interface only. Note-4 : Numbers are representative in nature, and may vary depending on factors like network/device implementation and parametric configuration

From the table above, it can be concluded that, with respect to the current baseline (8-8-80) implementation, optimized CDRX config will allow for substantial saving of modem-RF power which would be possible to achieve without any significant degradation of latency.

In conclusion, a short-long DRX configuration of either 4-8-40x2-160 or 4-4-40x2-160 could be considered for field trial to realize such benefit.

Finally, it may be worth mentioning that, although the focus of this paper is EnDC/NRDC, this feature shall also apply to FR2-only-SA as well as FR1+FR2 CA scenarios.

3 DCI-based PDCCH Skip / Search-Space-Set-Group (SSSG) Switching

While 3GPP introduced various connected-mode power-saving measures in Rel. 15 and Rel. 16 to optimize UE battery consumption while operating at larger channel bandwidth, PDCCH-monitoring continues to be one of the primary contributors to modem-RF power consumption. Accordingly, 3GPP Rel. 17 introduced two new techniques to further reduce the duration of time that UE would need to monitor PDCCH during the active part of CDRX of the active bandwidth-part (BWP) of the serving cell.

3.1 DCI-based PDCCH Skip

PDCCH Skip allows a UE to reduce the amount of time it spends in monitoring PDCCH, which helps reduce connected mode power consumption. gNB sends a DCI to the UE indicating the length (time-duration) that UE should skip PDCCH monitoring.

Figure below represents the sequence of events taking place in course of DCI-based PDCCH Skip process, with an example of 16-slot skip duration (Note : Dummy-DCI below refers to a DCI to continue with PDCCH skip in absence of any payload).

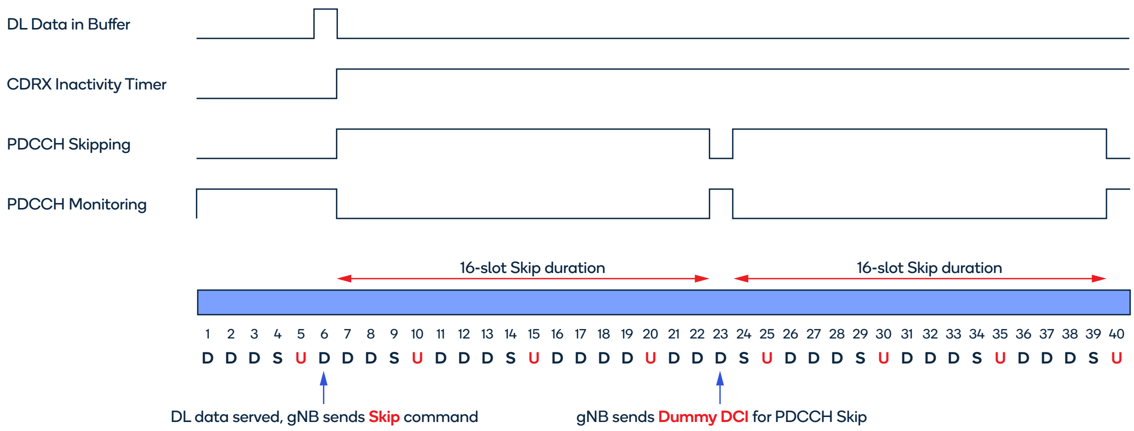

Figure 3-1 3GPP Rel. 17 DCI-based PDCCH-skip

At a high-level, PDCCH skipping involves the following steps:

- The gNB can configure up to 3 different PDCCH Skip durations via RRC messages.
- The gNB monitors the buffer occupancy and determines when to initiate PDCCH skipping
- The gNB transmits a DCI containing the PDCCH monitoring adaptation field (or simply, PDCCH Skip order). For this, new 1-bit or 2-bit structure had been introduced associated with a specific set of DCI formats.
- The UE stops monitoring PDCCH for the indicated number of slots after receiving a DCI containing the PDCCH Skip order.

To maximize UE power saving when no data is available, the gNB may need to send a new dummy-DCI containing another PDCCH Skip indication upon expiry of the current PDCCH Skip duration. In certain extreme scenarios, a gNB may not have enough PDCCH capacity to continuously send dummy-DCIs to multiple UEs simultaneously, in which case UEs might experience a loss of power saving efficiency.

3.2 SSSG (Search Space Set Group) Switching

The goal of SSSG switching is to allow a UE to dynamically switch between a set of SSSGs that is already configured on the active DL BWP of the serving cell.

While exact implementation may vary based on RAN-infra solution, at a high-level, SSSG switching involves the following steps:

- The gNB configures through RRC two SSSGs (SSSG0 and SSSG1) per BWP where SSSG switching is supported.
- The gNB may monitor traffic and buffer occupancy to determine when to initiate a SSSG switching.
- The gNB may transmit a DCI that causes the UE to switch SSSGs.
- The gNB may also configure the UE, with a timer for switching between SSSG0 and SSSG1. The timer may represent a fixed time duration or an inactivity timer in SSSG1.
- The UE stops monitoring the old SSSG and starts to monitor the new SSSG in the beginning of the first slot after the switch delay.

In DCI-based SSSG switching, it may be expected that SSSG0 configures discontinuous PDCCH monitoring to reduce UE power consumption, while SSSG1 configures PDCCH monitoring at every downlink slot. In such case, the gNB scheduler may switch the UE to SSSG1 for high throughput or low-latency data transmission, while switching the UE back to SSSG0 for low throughput, latency-tolerant traffic.

Figure below shows an example of UE monitoring PDCCH infrequently in SSSG0 during low data activity period, while also switching to SSSG1 during high data-burst and monitoring PDCCH at every slot.

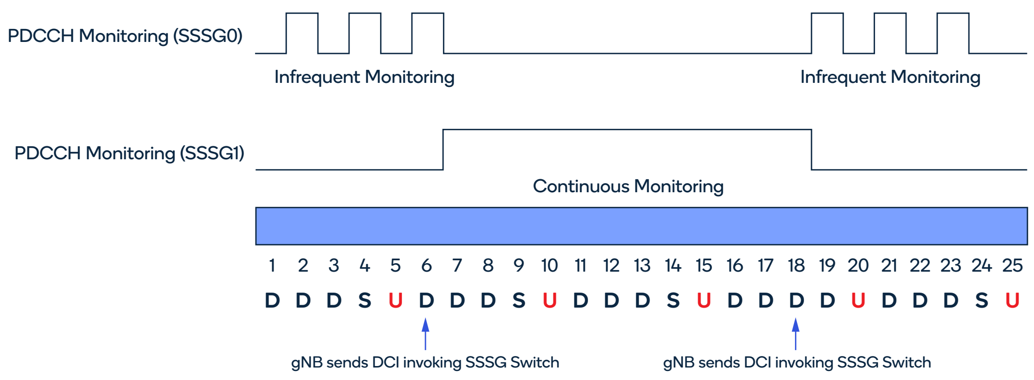

Figure 3-2 3GPP Rel. 17 SSSG Switching

3.3 Simulation Assumptions

The assumptions used for the simulations are as follows:

- Baseline Assumption
  - CDRX → 8ms (Inactivity)-8ms (On)-80 ms (Long-DRX)
  - SCS → 120 KHz || TDD → DDDSU || #CC → 8 CCs: Pcell = 100 MHz, Scells = 7 x 100 MHz
  - RF Condition → Near & mid-cell
  - Operating mode EnDC (LTE Anchor) or NR-DC (FR1 Anchor)
- FR2 Scell activation happens if estimated DL latency exceeds a configurable threshold.
- FR2 Scell de-activation happens if Scell inactivity exceeds a configurable threshold.
- DCI-based PDCCH-Skip → Skip duration: {2.5, 10, 40} ms.
- DCI-based SSSG-switching → Switching between SSSG0 and SSSG1 is latency-based.

3.4 Simulation Results

Tables below provides the results summary for PDCCH-skip vs baseline scenario. It shows that PDCCH-skip feature can provide significant power savings and acceptable impact to average DL air-interface-latencies. For a skip duration of 10 ms, we can see the power savings in the range of 40-50% for most of the apps while the increment in the average DL latencies below 5 ms.

Keeping in mind the tradeoff between power-saving and latency-impact, a PDCCH-Skip duration of up to 10ms could be a safe bet and may be considered for initial implementation.

	PDCCH-Skip w.r.to Baseline					
	Modem-RF Power Saving			Increase in Avg DL latency (ms)		
App	**2.5 ms**	**10 ms**	**40 ms**	**2.5 ms**	**10 ms**	**40 ms**
Chrome	29.5%	45.8%	47.6%	**<1**	**<1**	**<1**
TIKTOK	34.4%	48.3%	52.5%	<1	4	8
WeChat-Video	39.3%	42.2%	44.4%	**<1**	3	4
Sync & Idle	23.5%	41.5%	41.9%	<1	2	4

Figure 3-3 Power-Latency Tradeoff of PDCCH-Skip

The following table summarizes the results for SSSG-switching against the baseline scenario. The power saving percentages are even better, which however come with slightly higher but still acceptable air-interface-latency impact than PDCCH-skip results.

	SSSG-Switching w.r.to Baseline					
	Modem-RF Power Saving			Increase in Avg DL latency (ms)		
App	**2.5 ms**	**10 ms**	**40 ms**	**2.5 ms**	**10 ms**	**40 ms**
Chrome	35.3%	52.9%	60.3%	**1**	**6**	**21**
TIKTOK	37.4%	51.4%	63.4%	1	4	16
WeChat-Video	38.6%	53.6%	67.3%	**<1**	<1	6
Sync & Idle	23.7%	41.7%	42.4%	<1	4	15

Figure 3-4 Power-Latency Tradeoff of SSSG-Switching

Note-1: mA saving refers to modem-RF only. Note-2: Positive numbers (%) refer to power-saving (reduction) with respect to the baseline reference. Note-3: Avg DL Latency refers to air-interface only. Note-4: Numbers are representative in nature, and may vary depending on factors like network/device implementation and parametric configuration

Based on the simulation results above, we could conclude the following:

- Either feature shall offer measurable power-saving benefit and recommended for expedited commercialization.
- Considering the tradeoff between power-saving and latency-impact, an initial skip-duration of upto 10ms could be targeted, subject further optimization based on actual implementation and type of application.
- Both features may not be required simultaneously, as incremental benefit is not significant.

Considering the implementation-dependency of the features on factors like analog-beamforming vs digital-beamforming support at the gNB, and given that FR2-ecosystem so far evolved only around analog-beamforming which would make DCI-based PDCCH Skip implementation more challenging or probably even infeasible, SSSG-Switching is recommended as the preferred implementation technique for FR2, although FR1 ecosystem by virtue of the default digital-beamforming support capability is likely to evolve around DCI-based PDCCH Skip.

In future, as and when digital-beamforming becomes more ubiquitous in FR2 ecosystem, the need for DCI-based PDCCH Skip could be revisited appropriately with respect to the revised baseline, as needed.

Finally, it may be worth mentioning that, although the focus of this paper is EnDC/NRDC, this feature shall also apply to FR2-only-SA as well as FR1+FR2 CA scenarios.

4 SCG Activation / Deactivation

PsCell deactivation is a Rel. 17 power saving feature introduced for EnDC/NRDC scenarios. This is a UE initiated process which improves energy efficiency and resource utilization by deactivating the secondary (PsCell) when it is not needed for user data transmission. The gNB sends PsCell deactivation request message to UE to deactivate the PsCell. In response, UE can send a confirmation message to gNB confirming the deactivation of the PsCell.

Figure below depicts an example of typical SCG Activation/Deactivation process, when compared against legacy SCG Add/Release.

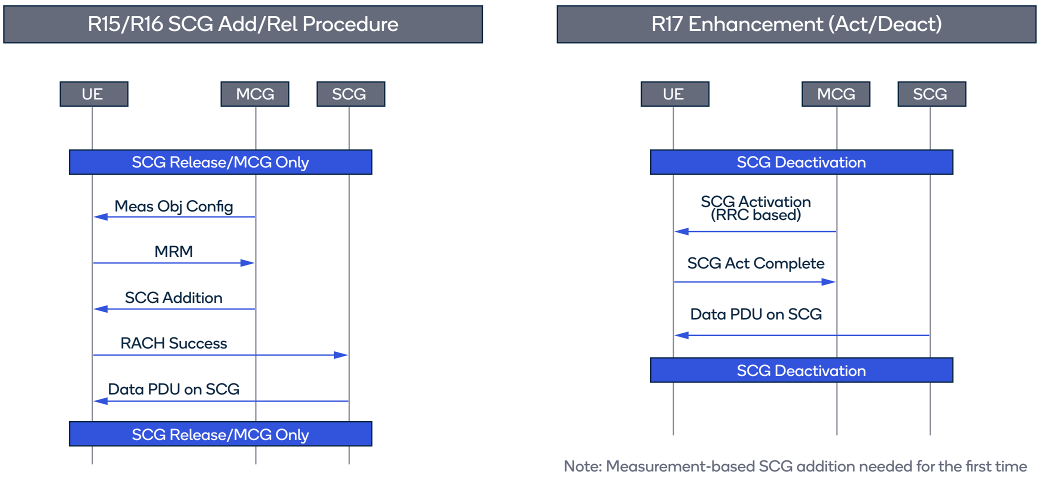

Figure 4-1 SCG Activation/Deactivation Process

4.1 Simulation Assumption

The assumptions used for the simulations are as follows:

- CDRX → FR2: 8ms (Inactivity)-8ms (On)-80 ms (Long-DRX), FR1/LTE: 100ms-10ms-160ms
- SCS → FR2: 120 KHz, FR1: 15 KHz || FR2 TDD → DDDSU || #CC → 8 CCs: PsCell = 100 MHz, Scells = 7 x 100 MHz, FR1 is FDD 20 MHz
- RF Condition → Mid-cell scenario
- Operating mode EnDC (LTE Anchor) or NR-DC (FR1 Anchor)
- PsCell De-activation occurs if PsCell inactivation exceeds a configurable threshold (1 sec in this sim)
- PsCell activation occurs if estimated DL latency exceeds a configurable threshold.
- Scell (7x100 MHz) activation happens if estimated DL latency exceeds a configurable threshold.
- Scell (7x100 MHz) de-activation happens if Scell inactivity exceeds a configurable threshold.
- Network loading of 50% for FR1 and 20% for FR2 is considered.
- PsCell activation can be RACH-less or RACH-based.

4.2 Simulation Results

We simulated and compared three different scenarios.

Baseline → FR1 20 MHz and FR2 100 MHz PsCell are always activated. The remaining FR2 7CCs are activated/deactivated as needed.

FR1 + 1CC PsCell (Rel. 17 Deact) + 7CC FR2 FR1 20 MHz is always activated. As needed FR2 Scells are activated/deactivated sequentially, i.e., at first FR2 PsCell 100 MHz is activated and then, as needed, the remaining FR2 7CCs (700 MHz) are activated together.

The results for different types of applications are presented the tables below:

The first table below is for the heavier applications like Twitch, YouTube, etc. It shows that Rel. 17 PsCell deactivation feature provides substantial power savings against the baseline with acceptable increment in the latencies.

APP Type	SCG Act/Deact Config	mA Saving (%)	Avg DL Latency (ms)
Twitch_DL_HD_streaming	**Baseline**	Ref	14.9
Twitch_DL_HD_streaming	FR1 + 1CC PsCell (Rel. 17 Deact) + 7CC FR2	58.3%	51.2
Youtube_DL_4K_streaming	**Baseline**	Ref	5.7
Youtube_DL_4K_streaming	FR1 + 1CC PsCell (Rel. 17 Deact) + 7CC FR2	44.2%	19.7
YouTube_DL_Live_streaming_Live_channels	**Baseline**	Ref	2.4
YouTube_DL_Live_streaming_Live_channels	FR1 + 1CC PsCell (Rel. 17 Deact) + 7CC FR2	56.2%	12.8

Figure 4-2 Power-Latency Tradeoff of SCG Activation/Deactivation (Heavy Apps)

The second table below is for lighter applications like Discord video call, Teams video calling, etc. This table also shows that Rel. 17 PsCell deactivation feature provides substantial power savings against the baseline without any impact in latency performance. In fact, we observed that FDD 20 MHz was enough for these applications. Hence, Rel. 17 PsCell deactivation feature helped them to deactivate PsCell entirely and save the power without compromising any latency performance.

APP Type	SCG Act/Deact Config	mA Saving (%)	Avg DL Latency (ms)
Discord_video_call	**Baseline**	Ref	0.5
Discord_video_call	FR1 + 8CC FR2 (Rel. 17 Deact)	43.3%	0.6
Facebook_DL_streaming_scrolling_mode	**Baseline**	Ref	1.0
Facebook_DL_streaming_scrolling_mode	FR1 + 8CC FR2 (Rel. 17 Deact)	50.6%	1.6
Instagram_DL_streaming_scrolling_mode	**Baseline**	Ref	0.7
Instagram_DL_streaming_scrolling_mode	FR1 + 8CC FR2 (Rel. 17 Deact)	54.1%	1.1
Teams_video_call	**Baseline**	Ref	0.5
Teams_video_call	FR1 + 8CC FR2 (Rel. 17 Deact)	44.3%	0.7

Figure 4-3 Power-Latency Tradeoff of SCG Activation/Deactivation (Light Apps)

Note-1: mA saving refers to modem-RF only. Note-2: Positive numbers (%) refer to power-saving (reduction) with respect to the baseline reference. Note-3: Avg DL Latency refers to air-interface only. Note-4: Numbers are representative in nature, and may vary depending on factors like network/device implementation and parametric configuration.

Based on these simulation results, we can conclude that the Rel 17 PsCell Act/De-act feature shall provide substantial power saving opportunity across all popular applications.

It may also be noted that, as the feature pertains to SCG activation/deactivation, which is independent of CDRX or SSSG, this will apply to any pre-existing CDRX/SSSG config and shall help save substantial power. It is also worth mentioning that, unlike the other features described in the paper which apply to EnDC, NRDC, FR2-only-SA, FR1+FR2 CA scenarios, SCG Activation/Deactivation shall apply to only EnDC and NRDC.

5 Sparse-PDCCH-Monitoring / Time-Domain-Bandwidth-Part

Bandwidth-Part (BWP) allows dividing the whole channel band into multiple segments and switch among the BWP allows for dividing the whole channel band into multiple segments and switch among those segments based on switching criteria like latency, throughput, loading etc. Usually, gNB uses DCI-based approach to send a command to UE to switch between BWPs. Such switching can be based on a timer as well.

The classical definition of Bandwidth-Part in 3GPP Rel. 15 pertains to frequency-domain bandwidth adaptation and switching between, based on a set of pre-defined condition, say for example 20MHz and 100MHz bandwidth-parts to optimize device power-saving.

Figure below depicts an example of such frequency-domain bandwidth-part operation.

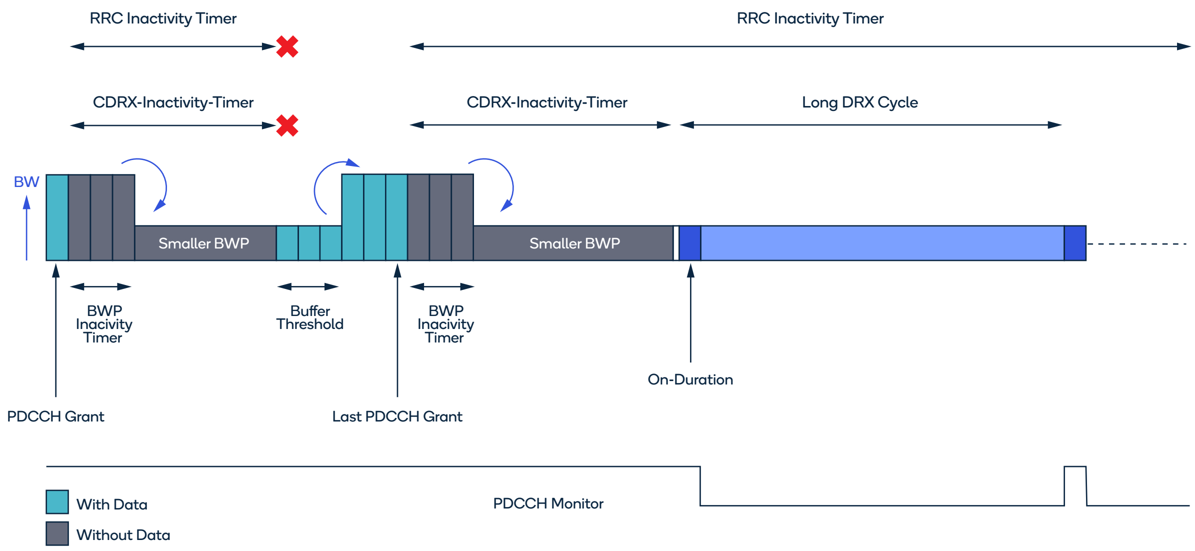

Figure 5-1 Frequency-Domain Bandwidth-Part Configuration

5.1 Sparse-PDCCH-Monitoring / Time-Domain BWP

Although not explicitly defined in 3GPP, an alternate technique that assumed ecosystem enablement, implemented such adaptation in time-domain. As for example, a gNB could configure two bandwidth-parts, each with 100MHz bandwidth i.e. no frequency-domain adaptation, but with different PDCCH-monitoring-periodicity, i.e. say BWP1 (100MHz) with PDCCH-Monitoring-periodicity of every slot, vs BWP2 (100MHz) with PDCCH-Monitoring-periodicity of every 4th slot. While either technique (freq-domain or time-domain) has their pros and cons, detailed discussion of which is outside the purview of this paper, as the situation stands today, both techniques have been commercialized on infra-specific basis, offering device power-saving.

In FR2, while either technique is feasible to implement, the simulation studies outlined below focused on assessing the power-saving opportunity of Sparse-PDCCH-Monitoring scheme.

Regarding the time-domain BWP, BWP0 is assumed to be the one where UE monitors PDCCH periodically (i.e., every X slot, where X = 0, 1, …., n) while BWP1 is the one where UE monitors every PDCCH during the active part of the CDRX.

5.2 Simulation Assumption

The assumptions used for the simulations are as follows:

- Short CDRX used: 4-8-40x2-160 || 4-4-40x2-160
- SCS → 120 KHz || TDD → DDDSU || #CC → 8 CCs: Pcell = 100 MHz, Scells = 7 x 100 MHz
- RF Condition → Mid and far-cell scenario
- Operating mode EnDC (LTE Anchor) or NR-DC (FR1 Anchor)
- Sparse PDCCH monitoring → Varies according to the configuration.
- Sparse to Dense PDCCH monitoring happens if estimated DL or UL latency exceeds a respective configurable threshold.
- Dense to Sparse PDCCH monitoring happens if estimated DL and UL latencies falls below respective configurable threshold.
- Scell activation happens if estimated DL latency exceeds a configurable threshold.
- Scell de-activation happens if Scell inactivity exceeds a configurable threshold.
- Note: CDRX numbers mentioned above are represented in ms.

5.3 Simulation Results

In each scenario, in BWP0 (sparse BWP), PDCCH monitoring happens periodically while in BWP1 (dense BWP) PDCCH is always monitored. The interest of these simulations was to analyze the sensitivity of ON duration together with sparse PDCCH monitoring. Sparse PDCCH monitoring periodicity was chosen in such a way that each configuration results in 3 monitored PDCCH slots per ON duration in the sparse BWP.

The results (DL avg latency vs mA curves below) show that the power-optimal configuration for YouTube is ON-duration=8ms and sPDCCH 1:20 (i.e., sparse PDCCH monitoring periodicity of 20 slots). Similarly, the optimal configuration for other apps is ON-duration=4ms and sPDCCH 1:10 (i.e., sparse PDCCH monitoring periodicity of 10 slots).

APP Type	CDRX Config	PDCCH Monitoring	mA Saving (%)	Avg DL Latency (ms)
Chrome	4-8-40x2-160	1:1	Ref	1.64
Chrome	4-8-40x2-160	1:20	21.7%	3.10
Chrome	4-4-40x2-160	1:1	11.3%	2.58
Chrome	4-4-40x2-160	1:10	25.0%	3.50
YouTube4K	4-8-40x2-160	1:1	Ref	1.01
YouTube4K	4-8-40x2-160	1:20	18.3%	2.60
YouTube4K	4-4-40x2-160	1:1	3.4%	1.02
YouTube4K	4-4-40x2-160	1:10	17.6%	1.50
DoU	4-8-40x2-160	1:1	Ref	1.72
DoU	4-8-40x2-160	1:20	18.0%	2.70
DoU	4-4-40x2-160	1:1	8.5%	1.84
DoU	4-4-40x2-160	1:10	22.8%	2.50

Figure 5-2 Power-Latency Tradeoff of Time-Domain Bandwidth-Part Configuration

Note-1: mA saving refers to modem-RF only. Note-2: Positive numbers (%) refer to power-saving (reduction) with respect to the baseline reference Note-3: Avg DL Latency refers to air-interface only. Note-4: Numbers are representative in nature, and may vary depending on factors like network/device implementation and parametric configuration

From the table above, it can be concluded that, with respect to the baseline of optimized CDRX config, time-domain bandwidth-part shall allow for substantial additional saving of modem-RF power which would be possible to achieve without any significant degradation of latency.

In particular, depending on the preferred short-long DRX configuration of either 4-8-40x2-160 or 4-4-40x2-160, a monitoring periodicity of either 20-slot or 10-slot could be chosen respectively for optimal power-latency tradeoff.

It is worth mentioning here and as might already be evident by now that Sparse-PDCCH-Monitoring technique has a lot of similarity with DCI-Based PDCCH Skip / SSSG. Therefore, we believe both techniques may not be needed simultaneously. In case of preference, given 3GPP-compliance as well as much higher device power-saving opportunity, our preference would be to implement Search-Space-Set-Group (SSSG) Switching, although it would lead to slightly higher air-interface latency. In scenarios however where SSSG implementation is deemed infeasible, either due to infra-support or other reasons, Sparse-PDCCH-Monitoring aka Time-Domain Bandwidth-Part could be considered as a fallback option to save device power.

6 Device and Infrastructure Requirement

6.1 UE Capability Requirement

Being 3GPP features, explicit UE-support indications are used as part of the capability message to inform gNB of its capability to support these features:

- UE must be able to handle different CDRX configuration (Rel. 15).
- UE must be able to handle Rel. 15/Rel. 16 time-domain BWP adaptation.
- UE must be able to handle Rel. 17 SCG Activation/Deactivation DCI command.
- UE must have appropriate capabilities to support Rel. 17 PDCCH Skip and Rel. 17 SSSG Switching.
- UE must be able to monitor the PDCCH and decode DCI messages.
- UE must be able to switch between different SSSGs.

6.2 gNB Infrastructure Requirement

Similar to the UE-capability and being 3GPP features, gNB is required to support these features although no explicit indication is sent out to the UE indicating its ability to support. However, upon receipt of UE-capability-message, gNB may decide to configure the UE appropriately, which could be treated as an indirect indication of its capability to support such features:

- gNB shall be configured to support different CDRX configurations.
- gNB shall be able to send DCI command for BWP switching.
- gNB shall be able to send DCI command for SCG activation or deactivation, as triggered.

- gNB shall be configured to support Rel. 17 PDCCH Skip and/or Rel. 17 SSSG Switching power saving features.
- gNB shall be able to send PDCCH commands (DCI with specific format) that are compatible with PDCCH skipping and SSSSG Switching.
- For PDCCH-skip, in addition to opportunistically sending DCI message with the last grant, gNB shall also be able to send dummy-DCIs after encountering DL empty buffers.
- For SSSG Switching, gNB shall be able to send DCI message indicating which SSSG shall be used and how the PDCCH monitoring shall happen within a particular SSSG.
- gNB shall be able to track the UE's state and ensure that it is not skipped over when a new DCI message is sent.

7 Deployment Recommendation

Based on the results above, it is imperative that ecosystem should focus on expedited commercialization of either of the features discussed above.

Following will be the recommended sequence of implementation:

- **Step-1:** Optimize CDRX setting, by implementing short-long-DRX, to extend benefit of this Rel.15 feature to all UEs.
- **Step-2:** Sequentially, implement Search-Space-Set-Group (SSSG) switching technique which will require Rel.17 support but is more suitable when gNB supports on analog-beamforming (current FR2 ecosystem).
- **Step-2a:** Implement Sparse-PDCCH as a fallback power-saving option if SSSG is not feasible to implement.
- **Step-3:** Either in parallel or sequentially, implement SCG Activation/Deactivation feature, where both UE and network shall need to support this Rel.17 feature.

Once deployed, it is important to monitor the performance of the network to identify any potential issues and subsequent parametric optimization.

8 Conclusion

Unlike FR1 where many 3GPP power-saving features have already been commercialized, FR2 had so far witnessed only basic implementation of C-DRX. Considering this and keeping in mind much higher device power-consumption in FR2 which is also dependent on coverage footprint, we envision significant modem-RF power-reduction opportunity by implementing 3GPP Rel. 15/Rel. 16/Rel. 17 features.

Owing to their definition in various 3GPP releases and hence being dependent on both gNB and UE capability, one key goal of commercialization will be to maximize the benefit to the largest number of UEs. Accordingly, a sequential implementation is recommended as per the steps mentioned below.

Figure 8-1 Recommended Feature Implementation Sequence

* SSSG preferred; Sparse-PDCCH is a fallback option

It may also be noted that the features discussed here shall in general be able to co-exist and depending on the application-type, network-configuration, and device-capacity, shall be able offer, although not additive, a cumulative modem-RF power-saving opportunity.

References

3GPP TS 38.211 NR; Physical channels and modulation

3GPP TS 38.213 NR; Physical layer procedures for control

3GPP TS 38.214 NR; Physical layer procedures for data

3GPP TS 38.306 NR; User Equipment (UE) radio access capabilities

3GPP TS 38.311 NR; NR; Radio Resource Control (RRC); Protocol specification

Abbreviations

3GPP	3rd Generation Project Partnership (www.3gpp.org)
BW	Bandwidth
BWP	Bandwidth Part
CC	Component Carrier
C-DRX	Connected-DRX
DL	Downlink
DOU	Days of Use
gNB	5G NR NodeB (the 5G NR base station)
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PRB	Physical Resource Block
PUSCH	Physical Uplink Shared Channel
RRC	Radio Resource Control
SCS	Sub Carrier Spacing
SCG	Secondary Cell Group
SPEF	Spectral Efficiency
SSSG	Search Space Set Group
TDD	Time Division Duplexing
UE	User Equipment
UL	Uplink

Follow us on:

For more information, visit us at:

qualcomm.com/snapdragon