Evaluations and Observations for R17 UE Power Saving Enhancements

RAN1 #101-e
May 2020

Overview

- Overview
- Evaluation Assumptions Updates for R17 and Observations
  - Idle-Mode Updates and Observations
  - Connected-Mode Updates and Observations
- Summary

Overview

WI Scope

- Two main directions, each of two sub-items:
  - **Specify enhancements for idle/inactive-mode UE power saving, considering system performance aspects [RAN2, RAN1]**
    - Study and specify **paging enhancement(s)** to reduce unnecessary UE paging receptions, subject to no impact to legacy UEs [RAN2, RAN1]
      - NOTE: RAN1 to check and update, if needed, evaluation methodology in RAN1 #100 meeting
    - Specify means to **provide potential TRS/CSI-RS occasion(s) available in connected mode to idle/inactive-mode UEs**, minimizing system overhead impact [RAN1]
      - NOTE: Always-on TRS/CSI-RS transmission by gNodeB is not required
  - **Study and specify, if agreed, enhancements on power saving techniques for connected-mode UE, subject to minimized system performance impact [RAN1, RAN4]**
    - Study and specify, if agreed, **extension(s) to Rel-16 DCI-based power saving adaptation during DRX Active Time for an active BWP**, including PDCCH monitoring reduction when C-DRX is configured [RAN1]
      - NOTE: Rel-15 and Rel-16 available power saving solutions should be supported by the UE and included in the evaluation. RAN1 will ask the confirmation from RAN2 that Rel-15 and Rel-16 available power saving solutions are properly utilized.
    - Study the feasibility and performance impact of **relaxing UE measurements for RLM and/or BFD**, particularly for low mobility UE with short DRX periodicity/cycle, and specify, if agreed, relaxation in the corresponding requirements [RAN4]
      - NOTE: Supplementary RAN2 work, if needed, can be triggered by RAN4 LS

Cross-WG Interactions

- Paging enhancement(s) for idle-mode UE power saving:

RAN2	• UE paging procedure and higher-layer enhancements • Specification of UE paging monitoring behavior and paging grouping design

RAN1	• Evaluation assumptions
	  • Common model and evaluation methodology to assist design consistency
	  • Target be provided in Aug meeting
	• Physical layer enhancement feasibility study and specification

- Connected-mode evaluation assumptions:
  - RAN1 to inform RAN2 the updates w.r.t. TR 38.840 (also targeted to be provided in Aug meeting)
  - RAN2 can request RAN1 to change specific assumption(s) if there is strong concern
- RLM and BFD relaxation:
  - RAN4 can request RAN2 to specify relaxation condition(s) according to RAN4 conclusions

Suggested WI Timeline

RAN WG — R1: 6 + 1, R2/4: 7 + 1

RAN Plenary

2020 — 2021

	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep
R17 timeline	SI start (R1)				WI start (R1/2/4)					Ad-hoc TBD				R1 freeze			R2 Ph3 & R4 core freeze	
R2 timeline Paging enh.								Study phase done									Work phase done	
R1 timeline Paging enh. L1 enh.					Eval. met -hod			Study phase done						Work phase done				
R1 timeline Idle RS info (no study phase)														Work phase done				
R4 timeline RLM/BFD relax					Eval. met -hod						Study phase done						Core part done	

Idle-Mode Evaluation Assumption Updates and Observations

Targets for Idle-Mode Update

- Enable quantitative analysis on idle-mode power consumption issue in SA network
  - Also for quantitative evaluation on potential enhancement(s)
- Include reduced capability UE in issue analysis and solution identification
  - Target unified solution(s) for both eMBB UE and reduced capability UE
- An common evaluation methodology across RAN1 and RAN2
  - Numerical calculation for few selected cases is preferred

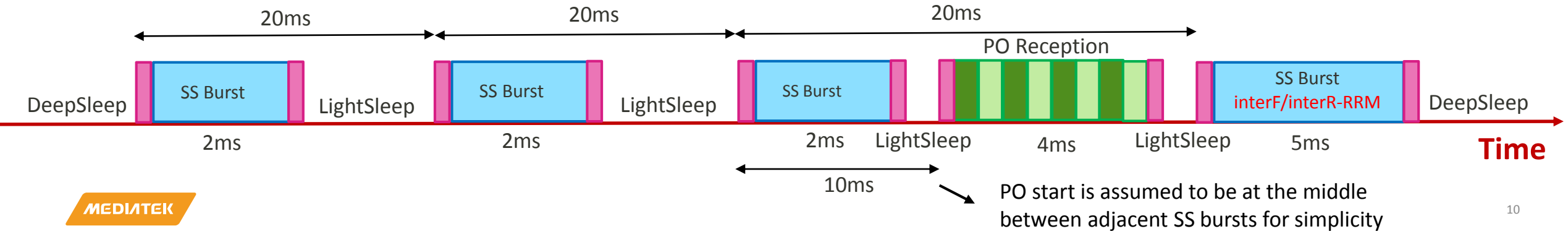
Reference Configuration

- Reference Configuration for idle-mode:
  - FR1, subcarrier spacing (SCS): 30 kHz
  - Reception Bandwidth <= 20 MHz
    - PDCCH & PDSCH of P-RNTI are within 20MHz BW
    - Include reduced capability UE
      - Note: Power consumption is similar for RX BW <= 20 MHz (lower bounded by 50 units)
    - Enable feasible comparison with LTE
  - I-DRX cycle: 1.28 sec
  - Group paging rate model:
    - per-UE paging rate (p) = 1%
    - #UE per group (N): 10 and 100
    - Group paging rate : 1 – (1 - p)^N ≈ 10% and 60%
  - SS burst periodicity: 20 ms
    - SMTC periodicity: 20 ms

Power State	Relative Power	Note
Deep Sleep	1	Not scaled with RX bandwidth
Light Sleep	20	
Micro sleep	45	
PDCCH-only	50 (X = 100)	Scaling to 20 MHz RX BW: $\max(X \cdot 0.4, 50)$, X: Power value @ 100MHz
PDCCH + PDSCH	120 (X = 300)	
Synchronization or serving cell measurement over SS burst	50 (X = 100)	
Infra/inter-freq. neighbor cell measurement over SS burst	[60 (X = 150)] or [150]	Suggested to also apply BW scaling for better consistency with other power states
No change to deep/light/mirco sleep power consumption model		

PO Processing Timeline Components

Requirement	Lower SINR	High SINR (e.g., >= 6 dB)	Note
#SS burst (inter-Freq/RAT RRM)	1	0 (S-meas. criterion)	5 ms SMTC window after PO
#SS burst (serving/intra-Freq RRM)	1 (incl. intra-band RRM)	1 (serving cell only)	2 ms SMTC window before PO
#SS burst (PDCCH)	1*	1*	• 2ms window for sync before PO # PDSCH more sensitive to sync error due to lower RS density (CHECK) # Average value as UE can may use 2/3/4 SS bursts for different SINR *Can reuse the same SS burst for serving-cell/intra-Freq RRM
#SS burst (PDSCH)	3#*	1*	
PDCCH processing within a PO	8 slots/4 ms per DRX cycle	2 slots/1 ms per DRX cycle	
PDSCH processing within a PO	8 slots/4 ms per DRX cycle¶	2 slots/1 ms per DRX cycle¶	¶ Subject to group paging rate

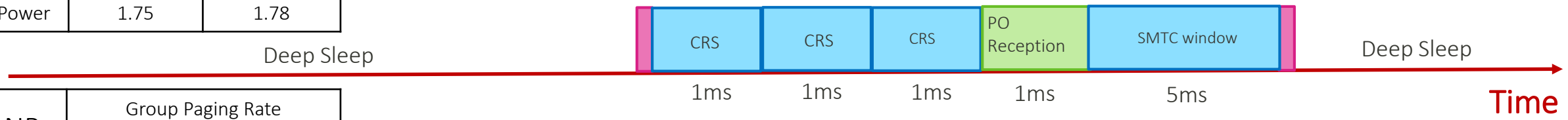


Detailed calculation

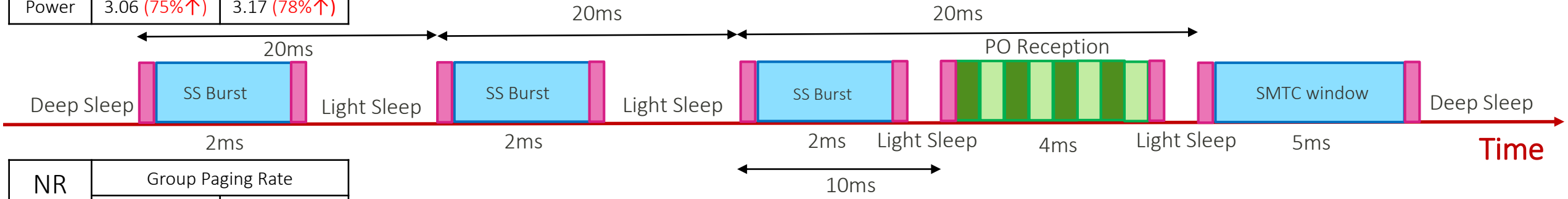
Idle-Mode Power Consumption Observations (1/3)

- Average power consumption for lower SINR case:

LTE	Group Paging Rate	
	10%	60%
Power	1.75	1.78

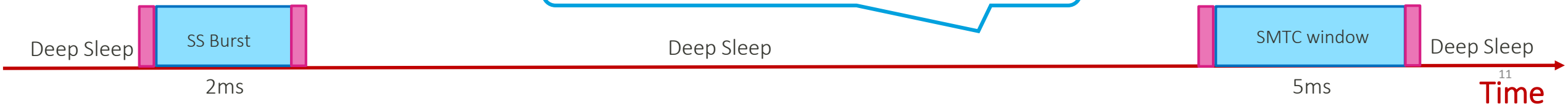


NR	Group Paging Rate	
	10%	60%
Power	3.06 (75%↑)	3.17 (78%↑)



NR Enh.	Group Paging Rate	
	10%	60%
Power	2.22 (27%↑)	2.79 (57%↑)

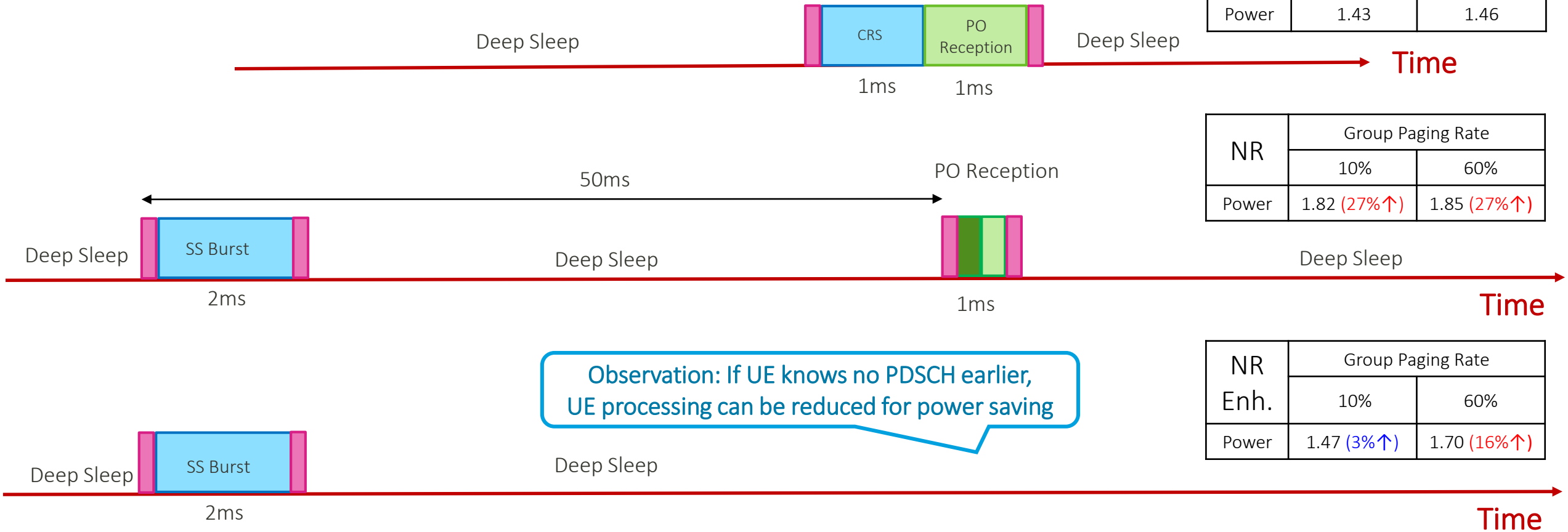
Observation: If UE knows no PDSCH earlier, UE processing can be reduced for power saving



Detailed calculation

Idle-Mode Power Consumption Observations (2/3)

- Average power consumption for High SINR case:



LTE	Group Paging Rate	
	10%	60%
Power	1.43	1.46

NR	Group Paging Rate	
	10%	60%
Power	1.82 (27%↑)	1.85 (27%↑)

NR Enh.	Group Paging Rate	
	10%	60%
Power	1.47 (3%↑)	1.70 (16%↑)

Idle-Mode Power Consumption Observations (3/3)

- Idle mode power consumption issue (@group paging rate 10%):

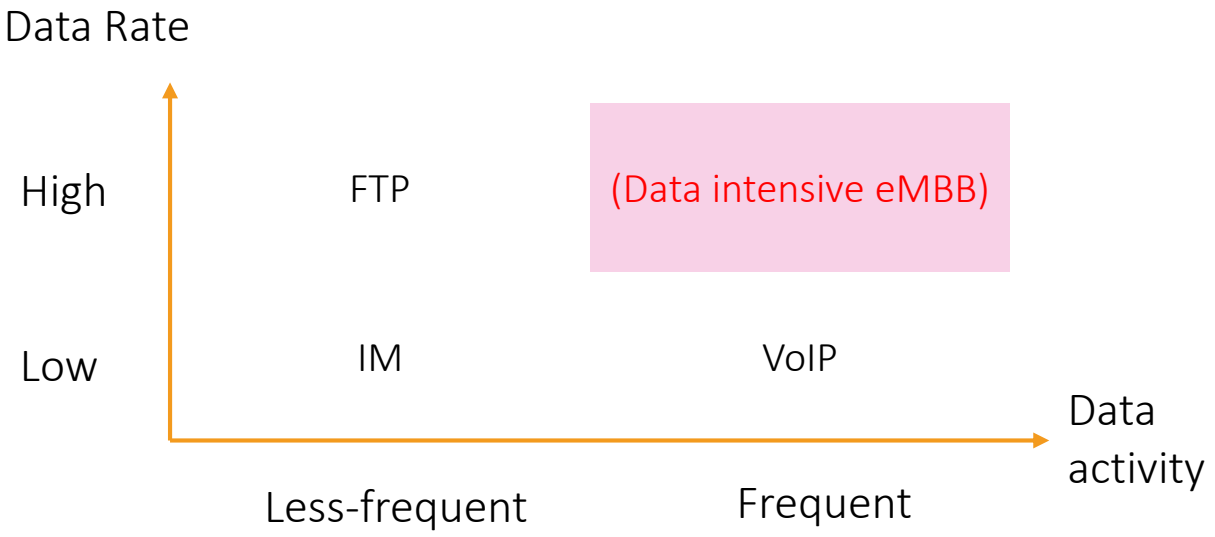
	High SINR (e.g. >= 6 dB)	Lower SINR	Average LTE idle-mode power	Average NR idle-mode power (increment w.r.t. LTE)	Potentially Improved NR idle-mode power (increment w.r.t. LTE)
Initial deployment	30%	70%	1.654	2.688 (62.5% ↑)	1.995 (20.6% ↑)
Matured deployment	70%	30%	1.526	2.192 (43.65% ↑)	1.695 (11% ↑)

- Idle-mode power saving enhancement is necessary for NR
  - UE idle-mode power consumption is dominated by PDSCH requirement even when UE is not paged
  - It is beneficial if UE can knows whether there is paging PDSCH earlier

Connected-Mode Evaluation Assumption Updates and Observations

Targets of Connected-Mode Updates

- Applicability to various NR traffic/service
  - R16: FTP, Instant Message (IM), VoIP
  - R17: Need to include data intensive eMBB



- Inclusion of R15 & R16 power saving features
  - R15: BW scaling, PDCCH monitoring configuration
  - R16: Power saving signal/DCP, cross-slot scheduling adaptation, MIMO layer number adaptation

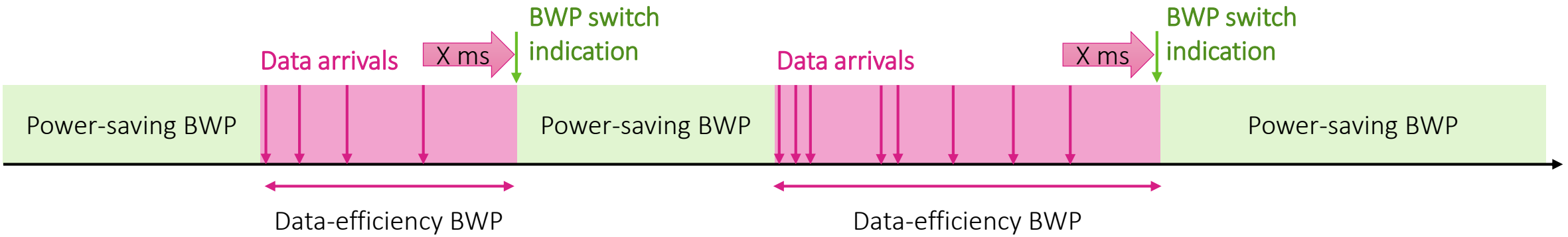
Connected-mode Evaluation Assumption Updates (1/4)

- Traffic Model Update:

	IM	FTP	VoIP	Data-Intensive eMBB
Traffic model	(TR 38.840) • FTP model 3 • Packet size: 0. 1 Mbytes • Mean packet inter-arrival time: **2000 ms** • Data rate: 400 kbps	(TR 38.840) • FTP model 3 • Packet size: 0. 5 Mbytes • Mean packet inter-arrival time: **200 ms** • Data rate: 20 Mbps	(TR 38.840) As defined in R1-070674. Up to two packets bundled • Mean inter-arrival time of voice payload: 20 ms • Date rate: <100 kbps	(Extended) • Model: FTP model 3 • Packet size: 0.05 Mbytes • Mean packet inter-arrival time: [20 ms or 16.67 ms] • Data rate: [20 Mbps]
cDRX setting	Long cycle*: 320 ms On-duration: 5 ms Inactivity timer: 80 ms	Long cycle*: 160 ms On-duration: 5 ms Inactivity timer: 100 ms	Long cycle*: 40 ms On-duration: 5 ms Inactivity timer: 10 ms	Long cycle*: 20 ms On-duration: 5 ms Inactivity timer: 10 ms
#CC	1CC of total 100 MHz FR1 or 1CC of total 100 MHz in FR2			2CCs of total 200 MHz FR1 or 4CCs of total 400 MHz in FR2
Note	*Long cycle only is suggested: • DRX short cycle can be used to replace a long inactivity timer. For the case of short inactivity timer, available short cycle sizes will, however, be limited since the on-duration timer size remains the same as long cycle. • For 10 ms inactivity timer and 5 ms on-duration timer, available short cycle sizes are 6 ms, 7 ms and 8 ms, and the corresponding OFF duration sizes are only 1 ms, 2 ms and 3 ms. • When R15 & R16 DCI-based power saving schemes are included, the power saving gain with short cycle becomes marginal (to be shown in later observation slide), and It is suggested to consider only long cycle for simulation simplicity.			

Connected-mode Evaluation Assumption Updates (2/4)

- DCI-based R15 & R16 power saving techniques:
  - Rel-16 power saving signal/DCP is applied to eliminate **DRX on-durations without data arrival**
  - **For on-durations with data arrival(s)**, BWP switch framework using DCI and/or timer indication is applied to combine multiple power saving schemes



Component	Characteristics
Data-efficiency BWP	Max RX BW, Max MIMO layers number, same-slot scheduling, per-slot PDCCH monitoring
Power-saving BWP	Reduced RX BW, reduced MIMO layer number, cross-slot scheduling, PDCCH monitoring periodicity > 1 slot
BWP switch indication	• X (ms) after last PDSCH of a packet/data burst • X (ms) >= UE proc. time + gNodeB proc. time + DRX on-duration timer size • Note: DRX on-duration timer size should consider all TDD patterns and beam-sweeping patterns

Connected-mode Evaluation Assumption Updates (3/4)

- Suggested settings:
  - Rel-16 power saving signal/DCP is applied with time gap of 1 slot and power value of [75]
  - BWP framework related settings:

Configuration	PCell	SCell (1 for FR1 and 3 for FR2, if available)
Data efficiency BWP	• FR1: 100 MHz BW, 4-layer MIMO, same-slot scheduling, per-slot PDCCH monitoring • FR2: 100 MHz BW, 2-layer MIMO, same-slot scheduling, per-slot PDCCH monitoring	
Power saving BWP	• FR1: 20 MHz BW, 2-layer MIMO, cross-slot scheduling (K0 = 1), PDCCH monitoring period of 1 ms • FR2: 100 MHz BW, [1]-layer MIMO, cross-slot scheduling (K0 = 4), PDCCH monitoring period of 1 ms	FR1 & FR2: SCell dormancy with 160 ms periodic CSI meas. and reporting

Simulation guideline	• Time duration of a packet transmission: The time duration starting from the slot with 1st TB transmission to X ms after the slot when all TBs are received.
	  • X = [8] or [50] (ms). Companies should report the applied X value for the evaluation results.
	• Power consumption value for each slot is based on the corresponding active BWP configuration
	  • Data efficiency BWP is active for each time duration of a packet transmission
	  • Power saving BWP is active only to the time gap between adjacent time durations of packet transmissions
	• Type-2 BWP switch delay, i.e., 5 slots for FR1 and 18 slots for FR2, is directly added to average page delay	

Connected-mode Evaluation Assumption Updates (4/4)

- CA simulation:
  - Simulation by either scaled packet size or increased simulation BW
  - If SCell dormancy is applied, power values are based on 1CC assumptions; otherwise, CA power scaling, i.e., 1.7x / 3.4x for 2 / 4 CCs, should be applied, including the power of micro sleep and BWP switch.
- Periodic Operation:
  - R16: Periodic operations for CSI (160 ms), including P1 over SSB and P-CSI over P-CSI-RS in on-duration
  - R17: Consider RLM and BFR operation (measuring part of the beams) per DRX cycle

	FR1	FR2
#measured beams/#total beams	2 (1 slot) /8	8 (4 slots) /64
Note: Assume micro sleep for the other slots within the measured SSB burst (FR1 average power example here)		

  - Suggest to merge an average SSB proc. power per DRX cycle so as to reuse R16 calculation rules
    - For overlapped operation with PDDCH, the same scaling rule applies 0.85 * (PDCCH power + average SSB proc. power)

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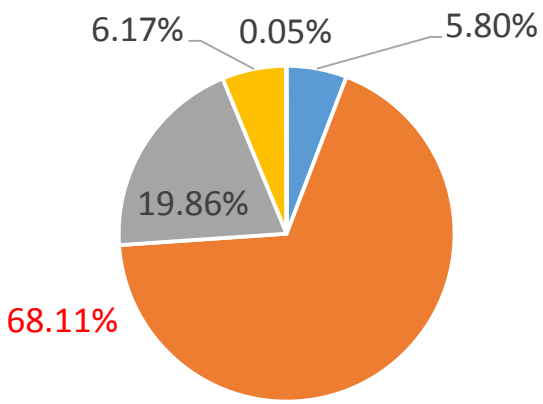
Power Consumption Observations (Less-Frequent Data; FR2)

FTP (1CC)

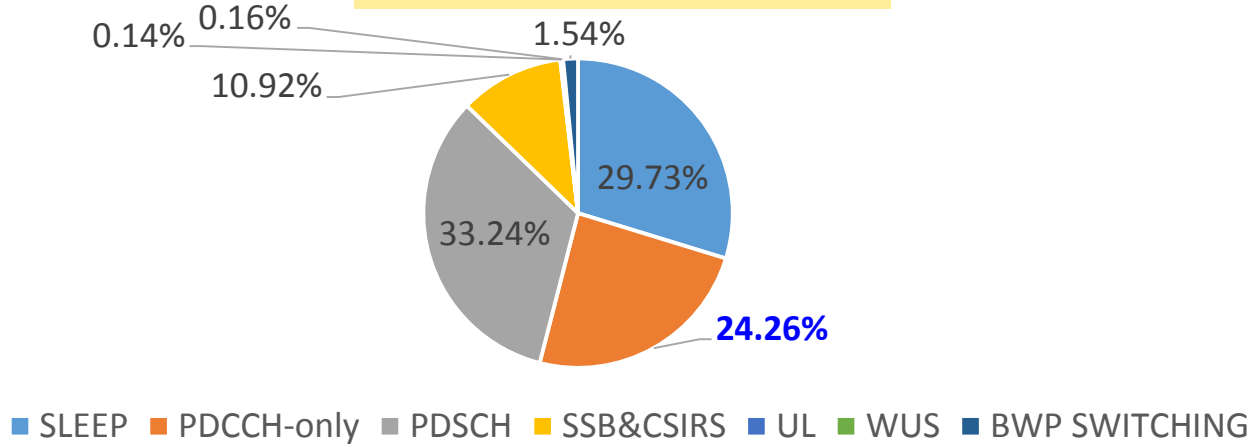
Power consumption: 84.19

R15 DRX only

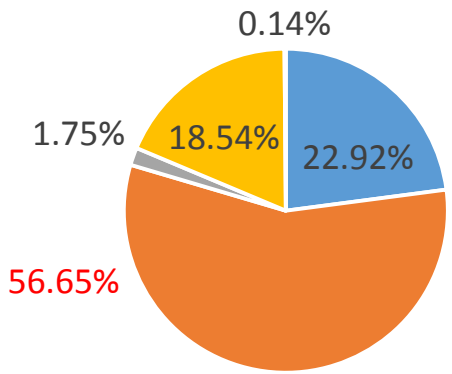


Power consumption: 47.86

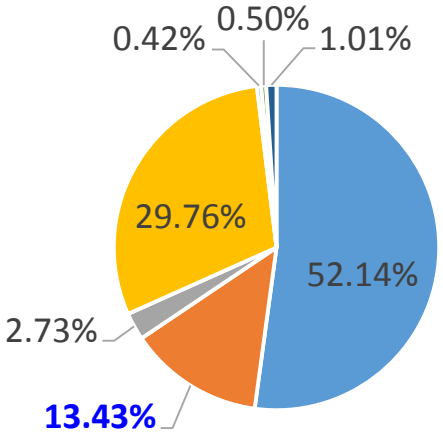
R15 & R16 PS features, X=8ms



IM (1CC)



Power consumption: 15.25



Power consumption: 9.28

- >40% power saving gain with R15 & R16 DCI-based power saving schemes
  - Additional gain with short cycle is 1.5% - 4% (CHECK)
- PDCCH-only power is no longer the most significant portion

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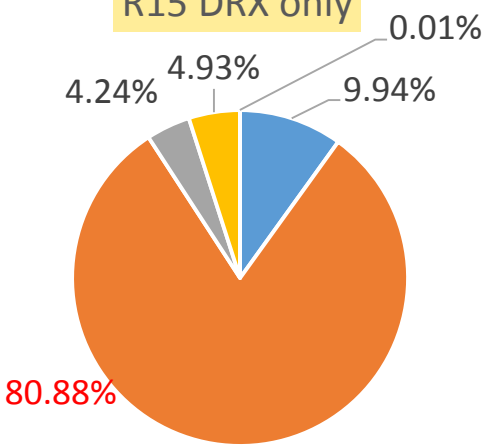
Power Consumption Observations (Frequent Data; FR2)

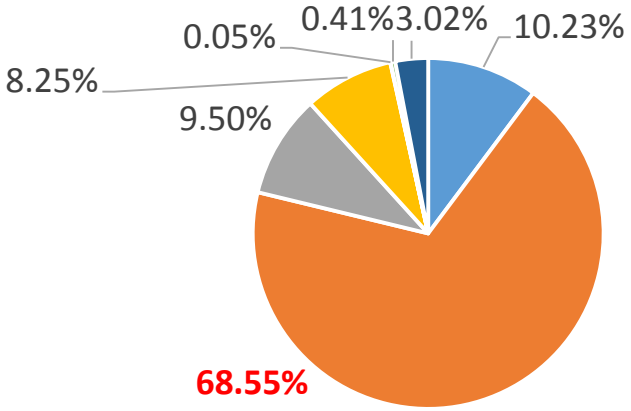
Power consumption: 325.68

R15 DRX only



Power consumption: 199.48

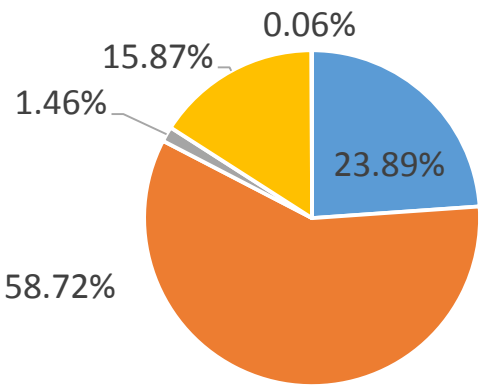
R15 & R16 PS features, X=8ms



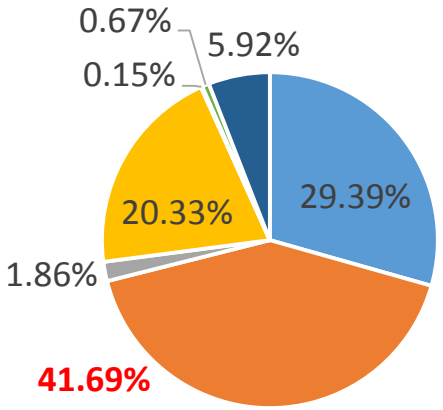
Data Intensive eMBB (4CC)

SLEEP PDCCH-only PDSCH SSB&CSIRS UL WUS BWP SWITCHING

VoIP (1CC)



Power consumption: 72.32



Power consumption: 57.37

- >20% power saving gain with R15 & R16 DCI-based power saving schemes
- PDCCH-only power remains the most significant portion

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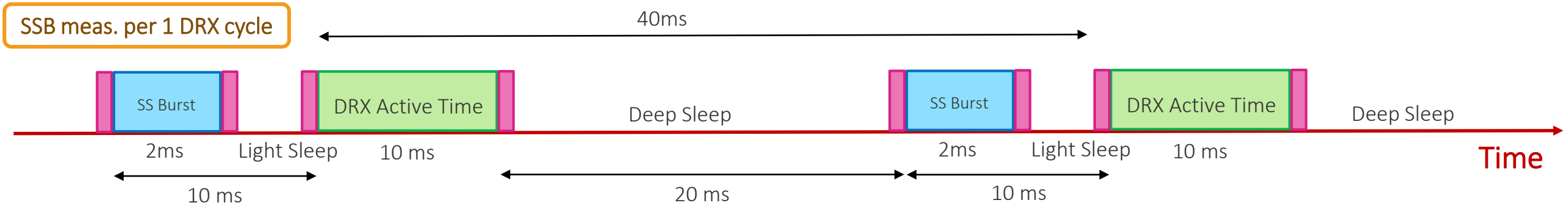
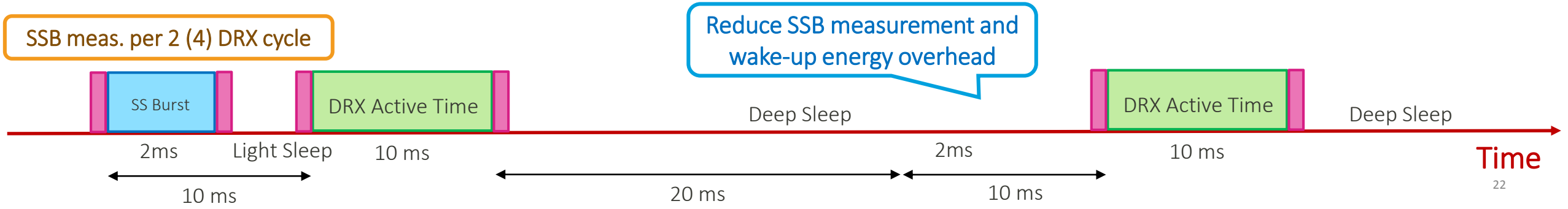
Power Consumption Observations (RLM/BFD Relaxation)

- VoIP with different SSB measurement periods:

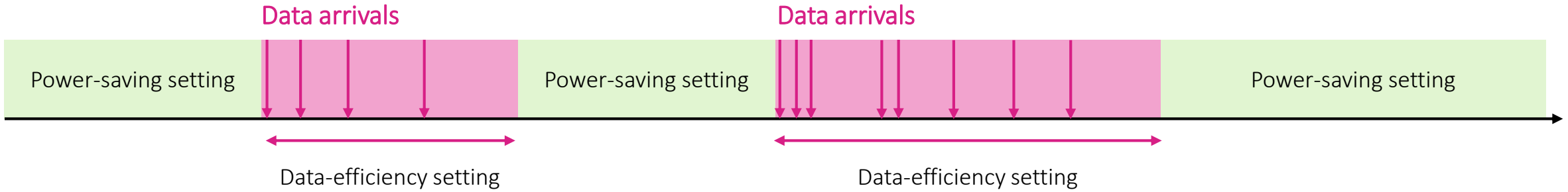


Link/beam measurement requirement	Power saving gain
SSB measurement per 1 DRX cycle	0%
SSB measurement per 2 (4) DRX cycles	>10% (>15%)



Discussion

- Connected-mode power consumption observations:
  - For the traffics of less-frequent data arrivals, e.g., FTP and IM, R15 & R16 DCI-based power saving schemes significantly reduce PDCCH-only power consumption → less room for further power saving
  - For the traffics of frequent data arrivals, e.g., data intensive eMBB and VoIP, the total power consumption with R15 & R16 DCI-based power saving schemes remains high.
    - PDCCH-only power consumption is still the most significant portion (>40% - 60%)
    - R17 can focus on further cutting down PDCCH-only power consumption for data intensive eMBB and VoIP traffics



  - For the traffic of smaller data amount and small DRX cycle size, e.g., VoIP, extending SS burst measurement period from one DRX cycle to multiple cycles can achieve >10% ~15% power saving gain
    - R17 to check the conditions that allow UE to relax its link/beam measurements subject to minimized system impact

Summary

Concluding Remarks

- Suggested evaluation assumption updates:

Idle-mode	Connected mode
Power scaling w.r.t. RX BW <= 20 MHz	Data intensive eMBB traffic
Group paging rate model	Inclusion of R15 & R16 DCI-based power saving schemes
PO processing operations and timeline	Inclusion of SSB processing power consumption per DRX cycle

- Power consumption observations:

Idle-mode	Connected mode
>40% - 60% average power consumption increment w.r.t. LTE in NR SA network	R15 & R16 DCI-based power saving schemes is less effective for data intensive eMBB and VoIP
Requirement on SS burst processing is dominated by the sensitivity to sync. error for PDSCH decoding → Power saving by reducing SS burst processing if UE can knows PDSCH presence earlier	PDCCH-only power consumption remains the significant portion (>40% - 60%) → Room for reducing PDCCH-only power consumption in R17
When group paging rate is high, PDSCH processing requirement dominates idle-mode power consumption → Small room for power saving with high group paging rate	SSB processing period contribute to >10% - 15% power consumption difference → Room for power saving by relaxing RLM/BFD requirement

Supplementary Slides

Performance Difference between Paging PDCCH and PDSCH

- Evaluation assumptions:

	PDCCH	PDSCH
Coding	Polar, DCI 60 bits, AL8	LDPC, MCS0
DMRS	Per-symbol	Per 7 symbols ~ Per 3 symbols
Synchronization	Based on SS burst(s)	
Paging cycle	1.28 sec	
BLER Target	1%	

- Performance difference in required SINR:
  - Observation: For the same BLER target, more SS bursts are required for paging PDSCH

#SS burst	Required SINR (PDSCH) – Required SINR (PDCCH) @ 1% BLER
1	> 2 dB
2	≤ 1 dB
4	≤ 0.5 dB

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Idle-Mode Power Consumption Analysis

Power Component	Relative Power	Component Description
P_{CRS}/P_{SSB}	50 / 50	CRS/SSB processing for LTE/NR
P_{intraF}	60	Intra-frequency neighbor cell measurement
P_{PO}	50 / 120	Paging occasion reception (without/with PDSCH)
P_{interF}	60	Intra-frequency neighbor cell measurement
P_{MS}	45	Micro sleep
P_{LS}	20	Light sleep
P_{DS}	1	Deep sleep

	Transition time threshold (ms)	Additional transition energy (relative power x ms)
Micro sleep	0	0
Light sleep	6	100 (E_{LS})
Deep sleep	20	450 (E_{DS})

Time Component	Duration (ms)	Component Description
T_{CRS}/T_{SSB}	1 / 2	LTE CRS/NR SSB proc. time for serv. meas. or sync
T_{intraF}	1 / 2	LTE CRS/NR SSB proc. time for intra-Freq. meas.
T_{PO}	1 or 4	Paging occasion reception 1 ms for LTE and NR high SINR case 4 ms for NR lower SINR case
T_{interF}	5	Inter-frequency neighbor cell measurement
T_{MS}	(*)	Micro sleep duration
T_{LS}	(*)	Light sleep duration
T_{DS}	(*)	Deep sleep duration
T_{IDRX}	1280	Idle mode DRX cycle length

(*): Depends on the position of PO

- LTE:

$$P_{LTE}(High_SINR) = \frac{P_{CRS} \times T_{CRS} + P_{PO} \times T_{PO} + P_{DS} \times (T_{IDRX} - T_{CRS} - T_{PO}) + E_{DS}}{T_{IDRX}}$$

$$= \frac{50 \times 1 + 50/120 \times 1 + 1 \times (1280 - 1 - 1) + 450}{1280} = 1.428/1.483$$

Without/With Paging

$$P_{LTE}(Lower_SINR) = \frac{P_{CRS} \times T_{CRS} \times 2 + P_{intraF} \times T_{intraF} + P_{PO} \times T_{PO} + P_{interF} \times T_{interF} + P_{DS} \times (T_{IDRX} - T_{CRS} \times 2 - T_{intraF} - T_{PO} - T_{interF}) + E_{DS}}{T_{IDRX}}$$

$$= \frac{50 \times 1 \times 2 + 60 \times 1 + 50/120 \times 1 + 60 \times 5 + 1 \times (1280 - 1 \times 2 - 1 - 1 - 5) + 450}{1280} = 1.743/1.798$$

- NR:

$$P_{NR}(High_SINR) = \frac{P_{SSB} \times T_{SSB} + P_{PO} \times T_{PO} + P_{DS} \times (T_{IDRX} - T_{SSB} - T_{PO} - T_{LS}) + E_{DS}}{T_{IDRX}}$$

$$= \frac{50 \times 2 + 50/120 \times 1 + 1 \times (1280 - 2 - 1) + 450 \times 2}{1280} = 1818/1.873$$

$$P_{NR}(Lower_SINR) = \frac{P_{SSB} \times T_{SSB} \times 2 + P_{intraF} \times T_{intraF} + P_{PO} \times T_{PO} + P_{interF} \times T_{interF} + P_{LS} \times T_{LS} + E_{LS} + P_{DS} \times (T_{IDRX} - T_{SSB} - T_{intraF} - T_{PO} - T_{interF} - T_{LS}) + E_{DS}}{T_{IDRX}}$$

$$= \frac{50 \times 2 \times 2 + 60 \times 2 + 50/120 \times 4 + 60 \times 5 + 20 \times (18 + 18 + 8 + 6) + 100 \times 4 + 1 \times \left(1280 - 2 \times 2 - 2 - 4 - 5 - (18 + 18 + 8 + 6)\right) + 450}{1280} = 3.035/3.254$$

Average SSB Processing Power (FR1)

- Assumption:
  - 8 beams/4 slots per SS burst
  - Periodic operations:
    - Periodic CSI related operation, e.g., P1, with periodicity 160 ms; all 8 beams/4 slots are utilized
    - RLM/BFD measurement: 2 beams/1 slot is utilized per DRX cycle

- Average SSB processing power with DRX cycle = 40 ms
  - Average over 160 ms (4 DRX cycles)
  - $\frac{1\text{ cycle}}{4\text{ cycles}} \times 100 + \frac{3\text{ cycles}}{4\text{ cycles}} \times \left(\frac{1\text{ slot}}{4\text{ slots}} \times 100 + \frac{3\text{ slots}}{4\text{ slots}} \times 45\right) \approx 70$

Additional Power Saving Gain with DRX Short Cycle

- Evaluation assumptions:
  - A long DRX inactivity timer, *Y* ms, is replaced by
    - A short DRX Inactivity timer of 8 ms
    - DRX short cycle(s) of cycle length 10 ms (50% duty cycle with on-duration timer of 5 ms)
    - #DRX short cycle = $\lfloor (Y - 8) / 10 \rfloor$; If #DRX short cycle = 0, DRX short cycle is not applied
    - Total length of the short DRX inactivity timer and DRX short cycle(s) is matched original long DRX inactivity timer to provide similar scheduling flexibility.
- Additional power saving gain with DRX short cycle:

	IM	FTP	VoIP/Data Intensive eMBB
Original inactivity timer (Y)	80 ms	100 ms	10 ms
Short inactivity timer	8 ms	8 ms	8 ms
#Short cycle: $\lfloor (Y - 8) / 10 \rfloor$	7	9	0 (not applied)
Additional power saving	1.56% (9.28 → 9.14)	4.06 % (47.86 → 45.92)	N/A

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