POWER SAVING TECHNIQUES FOR USER EQUIPMENT IN 5G RELEASE 16/17

Lothar Walther
3GPP RAN2/SA2 Delegate

ROHDE&SCHWARZ

Make ideas real

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16/17

Introduction - History of UE Power Saving Techniques

UE Power Saving Techniques in 5G Release 16

UE Power Saving Techniques in 5G Release 17

Battery Lifetime Measurements

Rohde & Schwarz   Lothar Walther

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16/17

Introduction - History of UE Power Saving Techniques
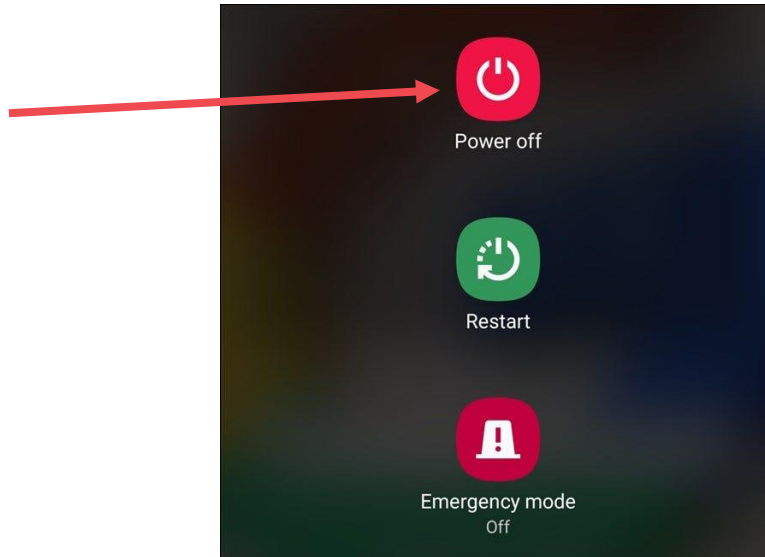
UE Power Saving Techniques in 5G Release 16

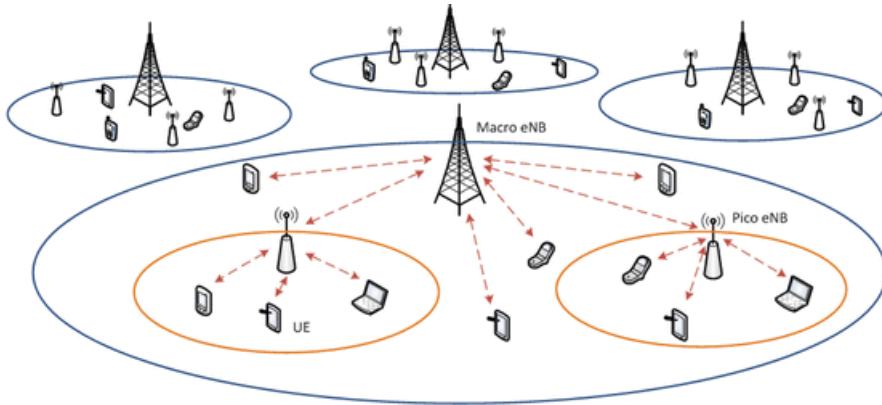UE Power Saving Techniques in 5G Release 17

Battery Lifetime Measurements

Rohde & Schwarz   Lothar Walther

HISTORY OF UE POWER SAVING TECHNIQUES

► The easiest way to save power: turn off the phone!!!

► Even the most cutting-edge phones allow you to switch off the phone 🙂

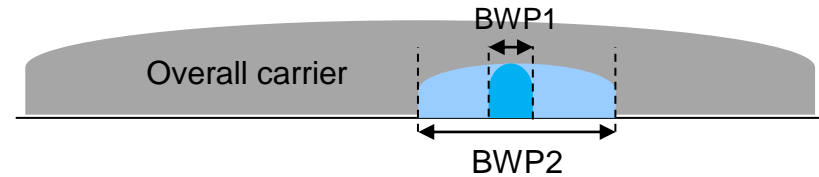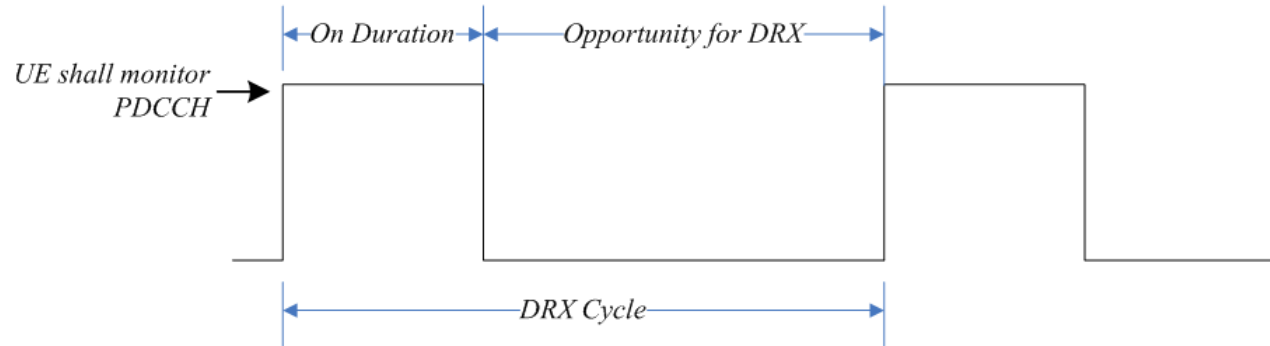# HISTORY OF UE POWER SAVING TECHNIQUES

use small cells

use low bandwidth

- use idle/inactive mode
- reduce paging
- reduce tracking area updates
- ……..

HISTORY OF UE POWER SAVING TECHNIQUES

► turn off receiver → DRX in idle mode and in connected mode (e.g. voice over IP)

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UE POWER SAVING TECHNIQUES IN 5G RELEASE 16/17

Introduction - History of UE Power Saving Techniques

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UE Power Saving Techniques in 5G Release 17

Battery Lifetime Measurements

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UE POWER SAVING TECHNIQUES IN 5G RELEASE 16

Wake-up signal - WUS

Per-BWP Max DL MIMO layers

SCell dormancy-like behavior

Cross-slot scheduling

UE assistance based power saving

RRM measurement relaxation

RRC-connected

RRC-idle/ inactive

2-step RACH

Rohde & Schwarz   Lothar Walther

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16

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Per-BWP Max DL MIMO layers

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Cross-slot scheduling
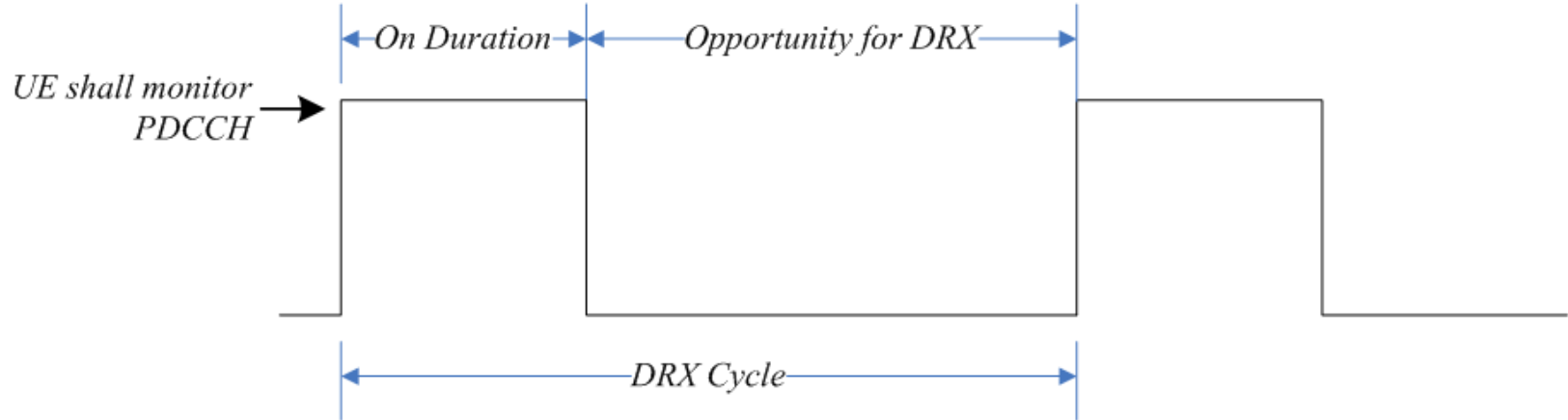
UE assistance based power saving

RRM measurement relaxation

RRC-connected

RRC-idle/inactive

Rohde & Schwarz   Lothar Walther
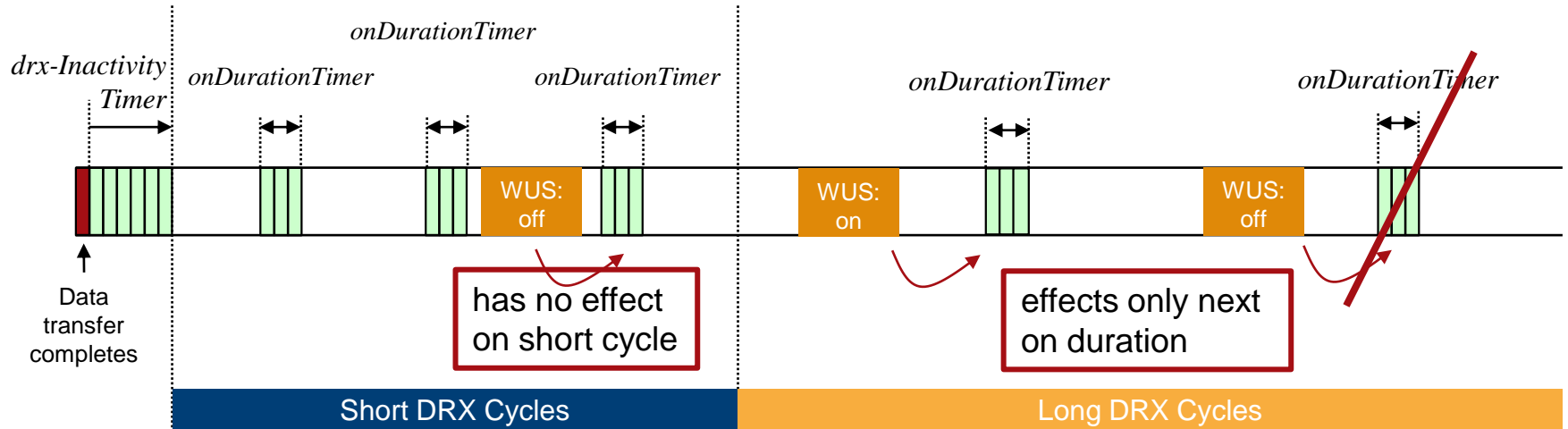
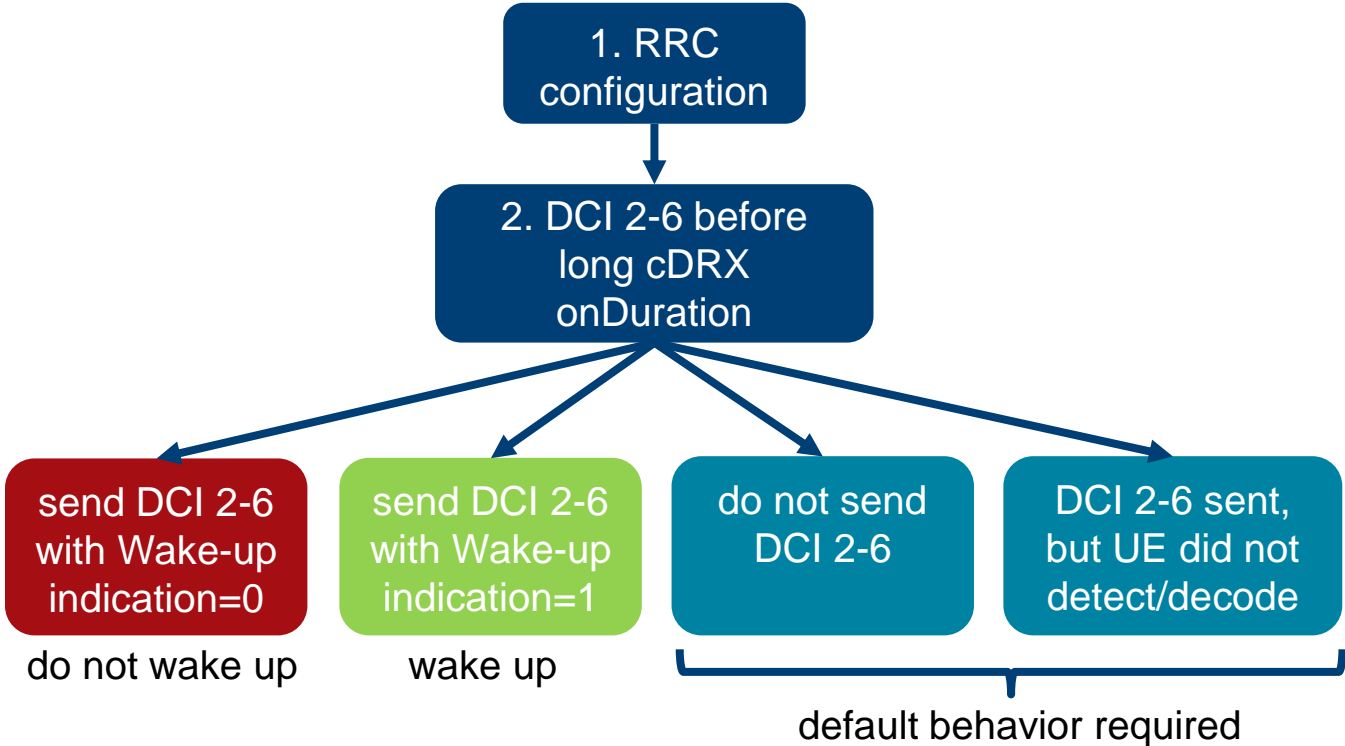# R16 WUS MODIFIES LONG DRX OF RRC CONNECTED UE

cDRX (LONG) + WUS

WUS = **DCI 2-6 with Wake-up indication**

0 = do not wake up (do not start next onDuration timer)

1 = wake up (start next onDuration timer)

WAKE-UP SIGNAL (WUS) FOR RRC-CONNECTED UEs

```
┌─────────────────┐
│  1. RRC         │
│  configuration  │
└─────────────────┘
         │
         ▼
┌─────────────────┐
│  2. DCI 2-6     │
│  before         │
│  long cDRX      │
│  onDuration     │
└─────────────────┘
```

send DCI 2-6 with Wake-up indication=0	send DCI 2-6 with Wake-up indication=1	do not send DCI 2-6	DCI 2-6 sent, but UE did not detect/decode

do not wake up   wake up

default behavior required

PDCCH WUS

DCI 2-6 before long cDRX onDuration

0.125 – 15 ms

onDuration

ps-Offset

onDuration

DCI2-6: WUS: on

UE has to monitor PDCCH

time

SS-duration

MinTimeGap

UE capability

long DRX cycle

= *duration* and *monitoringSymbolsWithinSlot* of *SearchSpace* IE

SCS (kHz)	Minimum Time Gap X (slots)	
	Value 1	Value 2
15	1	3
30	1	6
60	1	12
120	2	24

PDCCH WUS

DCI 2-6 before long cDRX onDuration

| onDuration | ps-Offset | "onDuration" |

| DCI2-6: WUS: off | UE does not have to monitor |

time

| SS-duration | MinTimeGap |

| long DRX cycle |

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PDCCH WUS

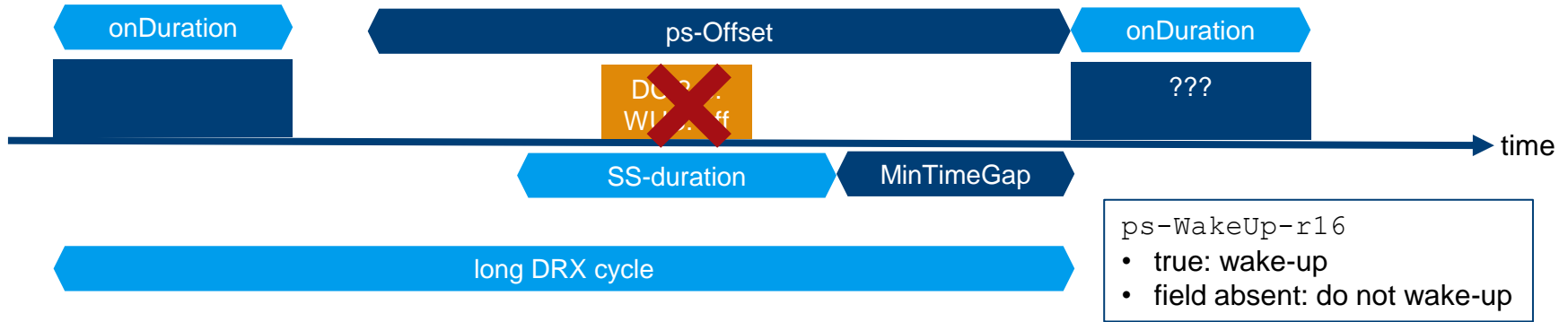DCI 2-6 before long cDRX onDuration

More than one monitoring occasion can be configured within a slot or multiple slots before DRX onDuration

DCI2-6 parameter values have to be identical in this case (repetition)

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PDCCH WUS

DCI 2-6 before long cDRX onDuration

onDuration

ps-Offset

onDuration

???

DCI 2-6
WUS off

time

SS-duration

MinTimeGap

long DRX cycle

```
ps-WakeUp-r16
```
- true: wake-up
- field absent: do not wake-up

default behavior if WUS is RRC configured, but
DCI 2-6 was not sent or could not be decoded

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16

Wake-up signal - WUS

Per-BWP Max DL MIMO layers

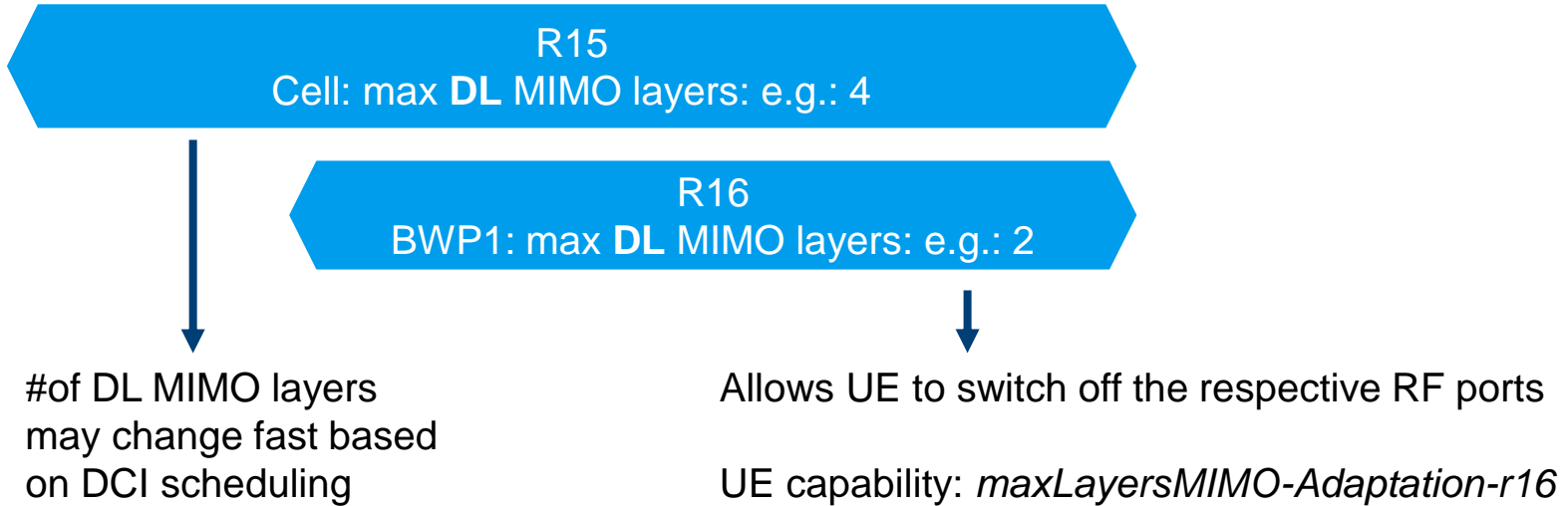SCell dormancy-like behavior

Cross-slot scheduling

UE assistance based power saving

RRM measurement relaxation

RRC-connected

RRC-idle/inactive

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UE ADAPTATION TO MAXIMUM NUMBER OF MIMO LAYERS

R15
Cell: max **DL** MIMO layers: e.g.: 4

R16
BWP1: max **DL** MIMO layers: e.g.: 2

#of DL MIMO layers
may change fast based
on DCI scheduling

Allows UE to switch off the respective RF ports

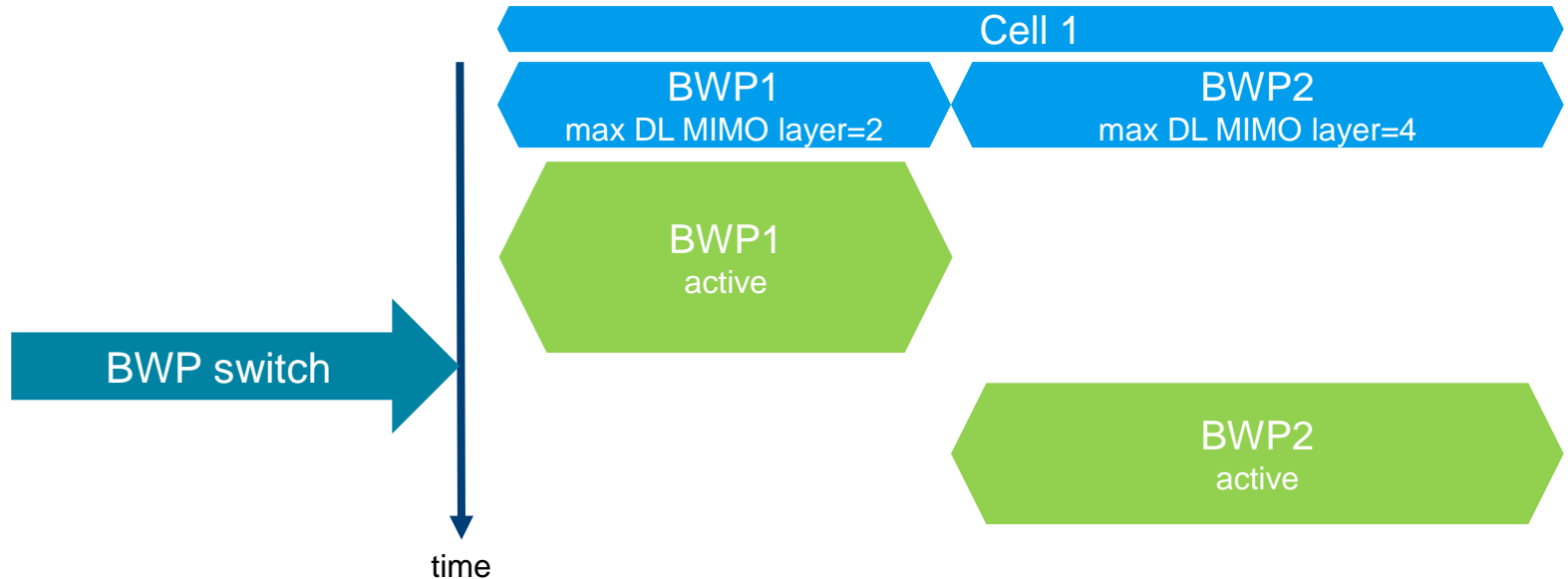UE capability: *maxLayersMIMO-Adaptation-r16*

UE ADAPTATION TO MAXIMUM NUMBER OF DL MIMO LAYERS

```
PDSCH-Config
→ BWP-DownlinkDedicated
    → maxMIMO-Layers-r16    SetupRelease { MaxMIMO-LayersDL-r16 }  OPTIONAL
```

Cell 1

BWP1
max DL MIMO layer=2

BWP2
max DL MIMO layer=4

BWP1
active

BWP switch

BWP2
active

time

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16

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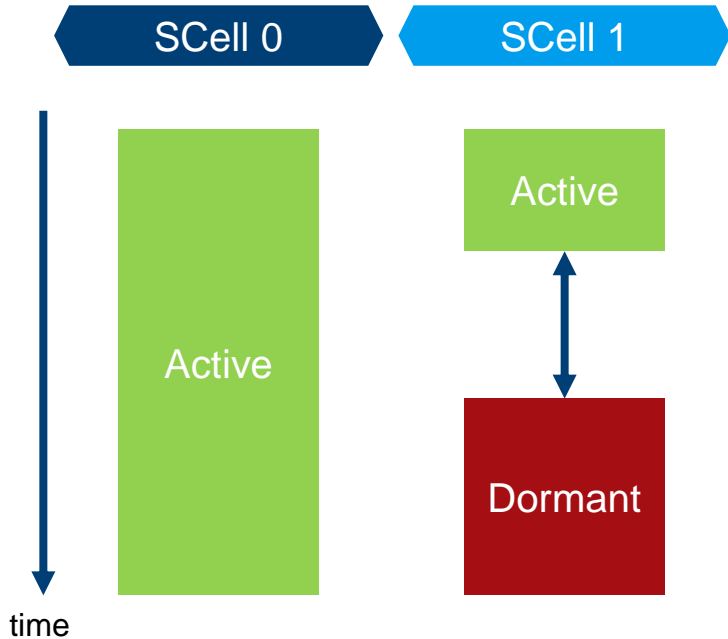
UE assistance based power saving

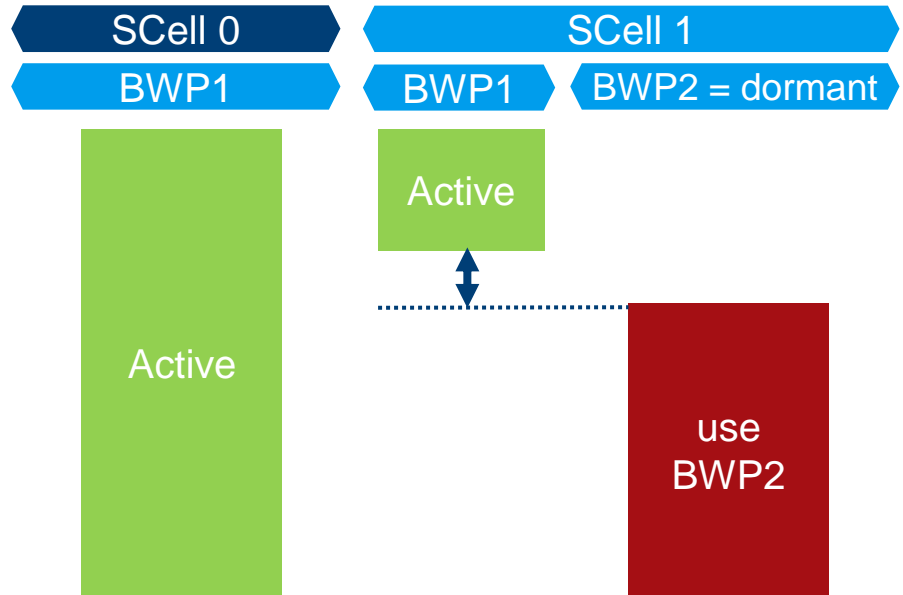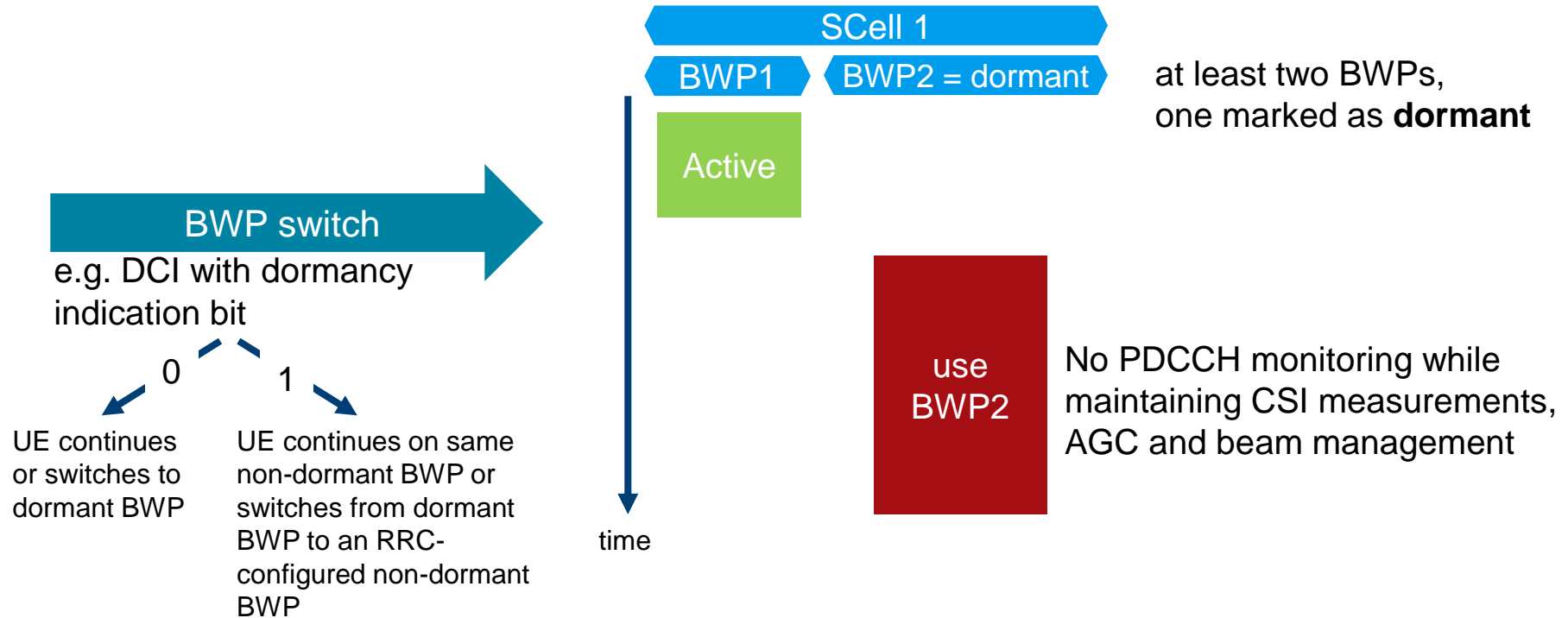RRM measurement relaxation

RRC-connected

RRC-idle/ inactive

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SCell DORMANCY-LIKE BEHAVIOR

LTE R15: SCell dormancy

NR R16: BWP dormancy
("SCell dormancy-like behavior")

| SCell 0 | SCell 1 |

Active (SCell 0)

Active (SCell 1)

Dormant (SCell 1)

| SCell 0 | SCell 1 |
| BWP1 | BWP1 | BWP2 = dormant |

Active (SCell 0)

Active (SCell 1 BWP1)

use BWP2

time

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SCell DORMANCY-LIKE BEHAVIOR

SCell 1

BWP1 | **BWP2 = dormant**

at least two BWPs, one marked as **dormant**

Active

BWP switch

e.g. DCI with dormancy indication bit

0 → UE continues or switches to dormant BWP

1 → UE continues on same non-dormant BWP or switches from dormant BWP to an RRC-configured non-dormant BWP

time

use BWP2

No PDCCH monitoring while maintaining CSI measurements, AGC and beam management

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16

Wake-up signal - WUS

Per-BWP Max DL MIMO layers
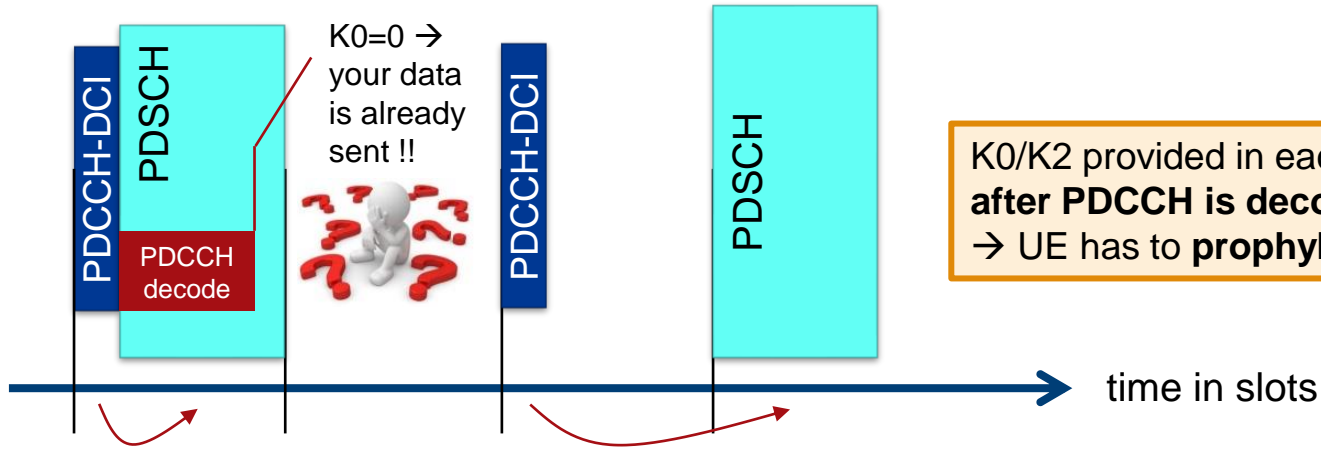
SCell dormancy-like behavior

Cross-slot scheduling

UE assistance based power saving

RRM measurement relaxation

RRC-connected

RRC-idle/ inactive

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CROSS-SLOT SCHEDULING

K0=0 → your data is already sent !!

K0/K2 provided in each DCI, but only known to UE **after PDCCH is decoded**
→ UE has to **prophylactically** read RE into buffer

time in slots

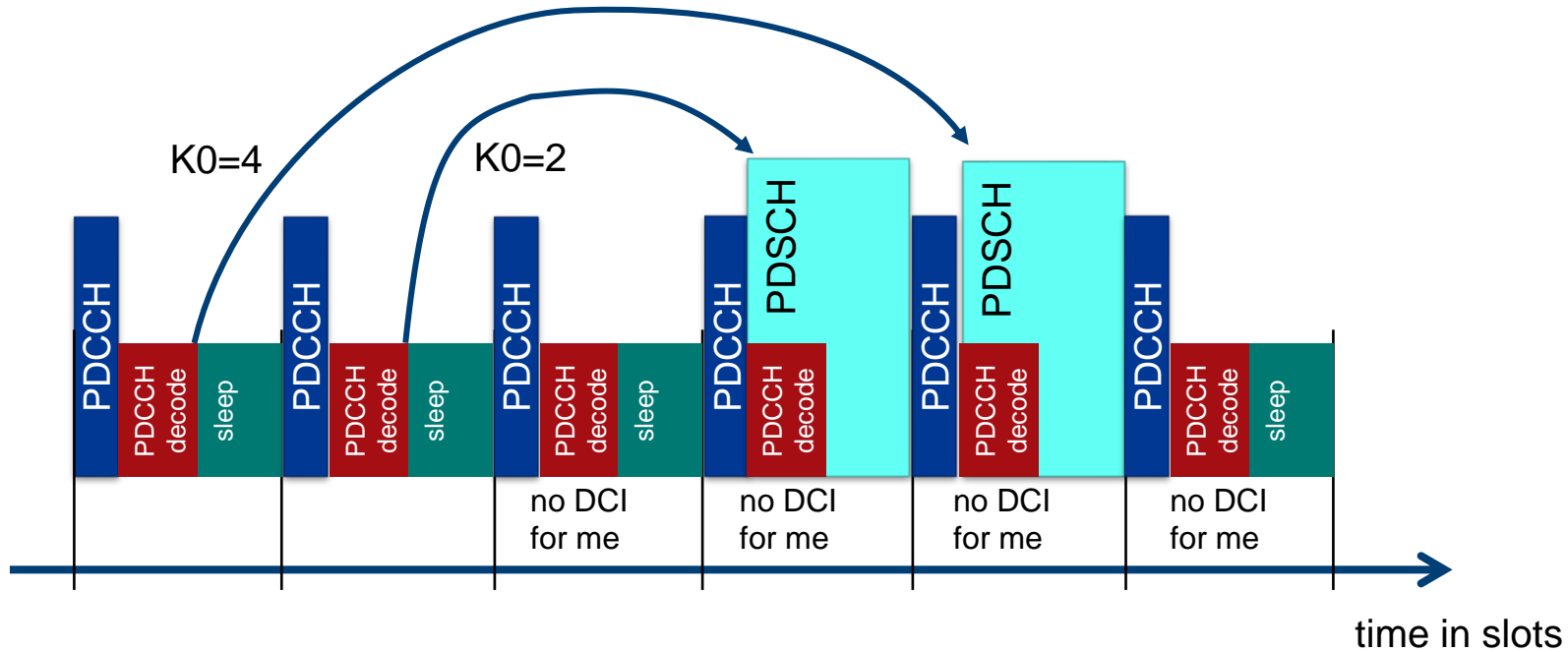same slot scheduling:
DL: K0=0

cross-slot scheduling:
DL: K0=1

Better for power consumption:
- guarantee a minimum scheduling delay K0/K2
- avoid using K0/K2 = 0

trade-off: latency

- scheduling delay for UL: K2
- K0/K2 can range from 0…32 slots

CROSS-SLOT SCHEDULING

Example: K0min=2 slots

Lothar Walther

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16

Wake-up signal - WUS

Per-BWP Max DL MIMO layers
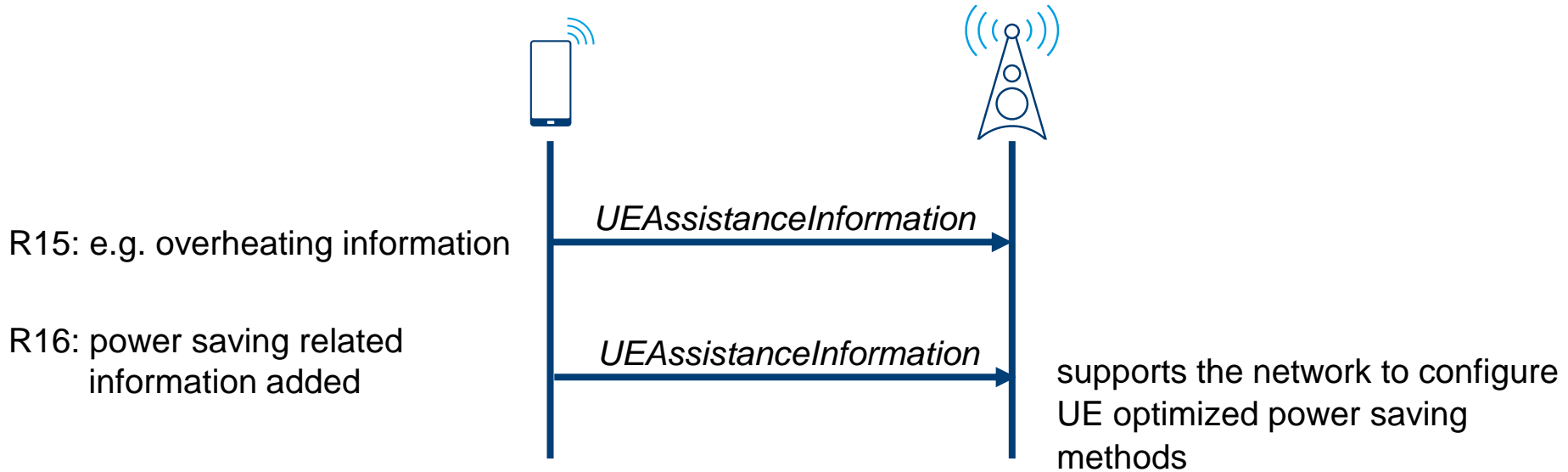
SCell dormancy-like behavior

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UE assistance based power saving
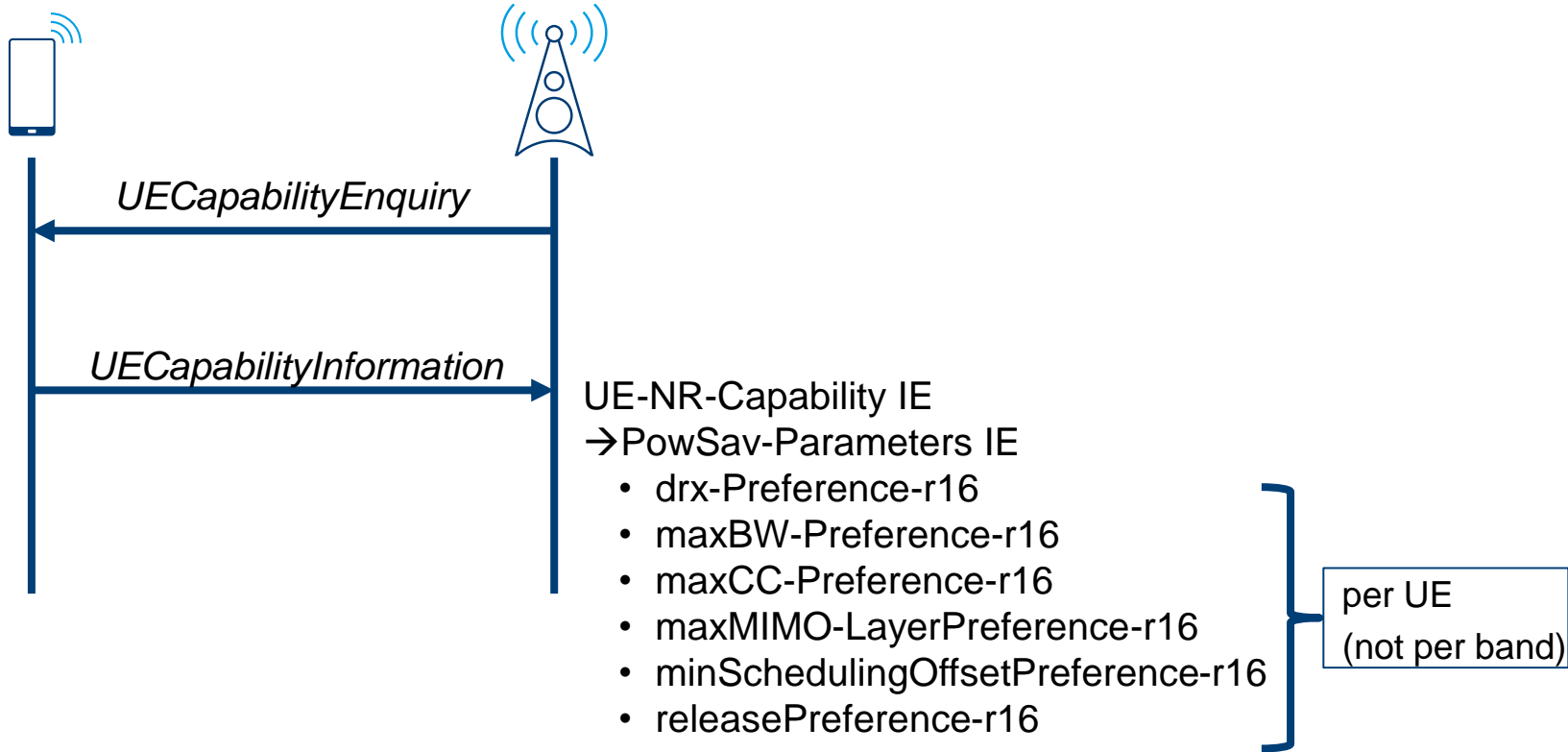
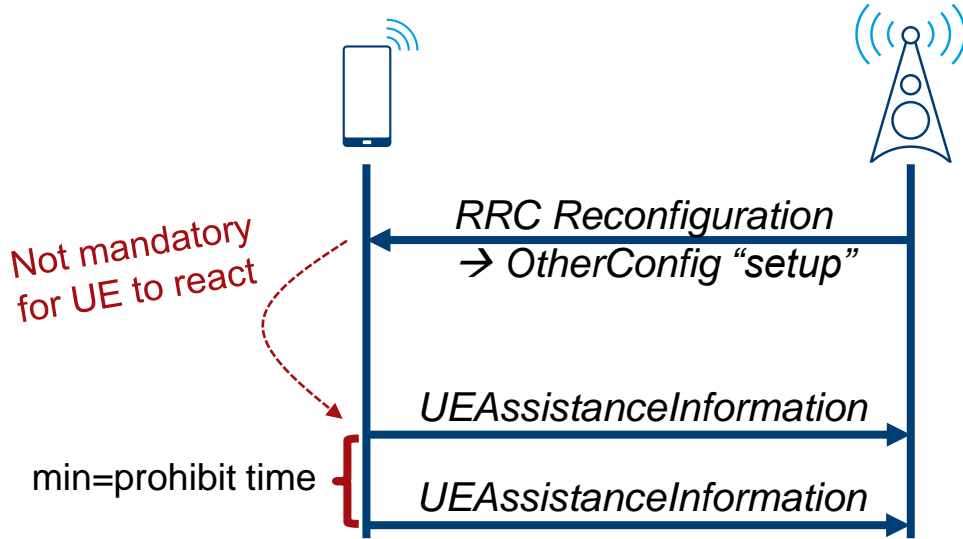RRM measurement relaxation

RRC-connected

RRC-idle/ inactive

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UE ASSISTANCE INFORMATION

R15: e.g. overheating information

R16: power saving related
     information added

UEAssistanceInformation

UEAssistanceInformation

supports the network to configure
UE optimized power saving
methods

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UE ASSISTANCE INFORMATION

UECapabilityEnquiry

UECapabilityInformation

UE-NR-Capability IE
→PowSav-Parameters IE
- drx-Preference-r16
- maxBW-Preference-r16
- maxCC-Preference-r16
- maxMIMO-LayerPreference-r16
- minSchedulingOffsetPreference-r16
- releasePreference-r16

per UE
(not per band)

UE ASSISTANCE INFORMATION

Not mandatory for UE to react

RRC Reconfiguration
→ *OtherConfig "setup"*

UEAssistanceInformation

min=prohibit time

UEAssistanceInformation

UE **may** initiate the procedure and add values for allowed parameters
- including upon having a preference
- upon change of its preference

- drx-PreferenceConfig-r16
- maxBW-PreferenceConfig-r16
- maxCC-PreferenceConfig-r16
- maxMIMO-LayerPreferenceConfig-r16
- minSchedulingOffsetPreferenceConfig-r16
- releasePreferenceConfig-r16
- → including individual prohibit timers

- drx-Preference-r16
- maxBW-Preference-r16
- maxCC-Preference-r16
- maxMIMO-LayerPreference-r16
- minSchedulingOffsetPreference-r16
- releasePreference-r16

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16

Wake-up signal - WUS

Per-BWP Max DL MIMO layers
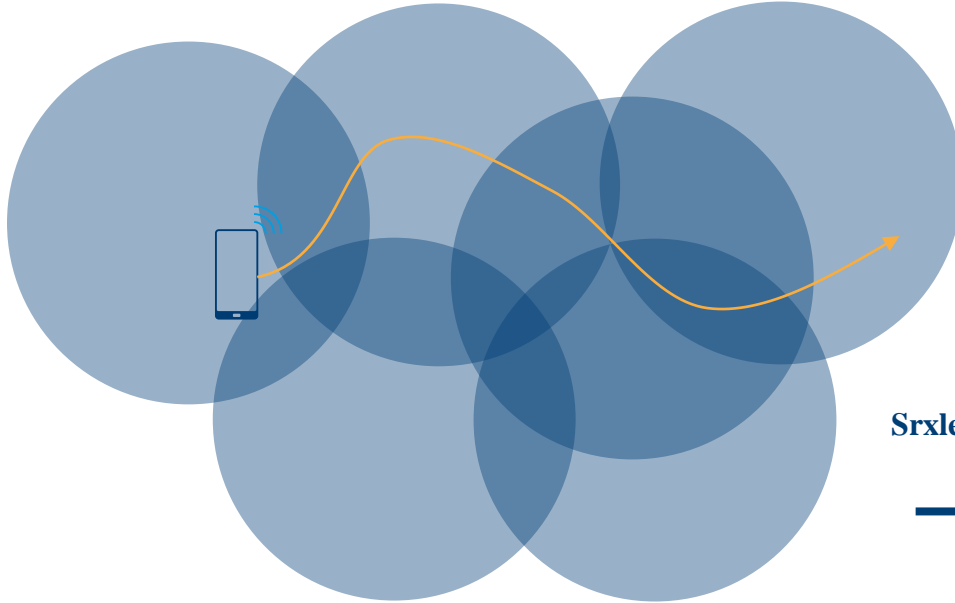
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RRC-connected

RRM measurement relaxation

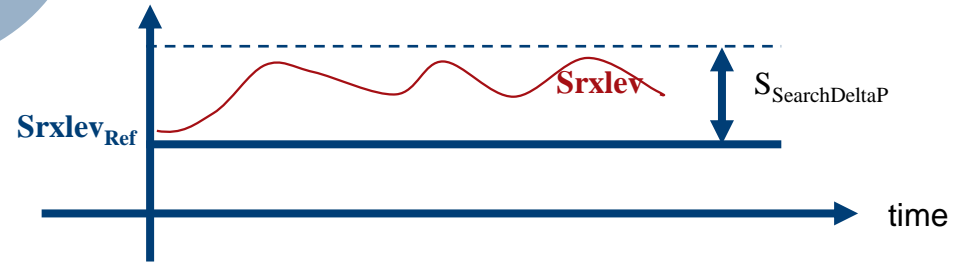RRC-idle/ inactive

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RRM MEASUREMENT RELAXATION IN RRC-IDLE/-INACTIVE

Low mobility:

If UE moves slow (or does not move at all), less frequent neighbor cell measurements would be sufficient

$\text{Srxlev}_{\text{Ref}}$

Srxlev

$S_{\text{SearchDeltaP}}$

time

(re)select
to this cell

"low mobility if received power doesn't change a lot"

RRM MEASUREMENT RELAXATION IN RRC-IDLE/-INACTIVE
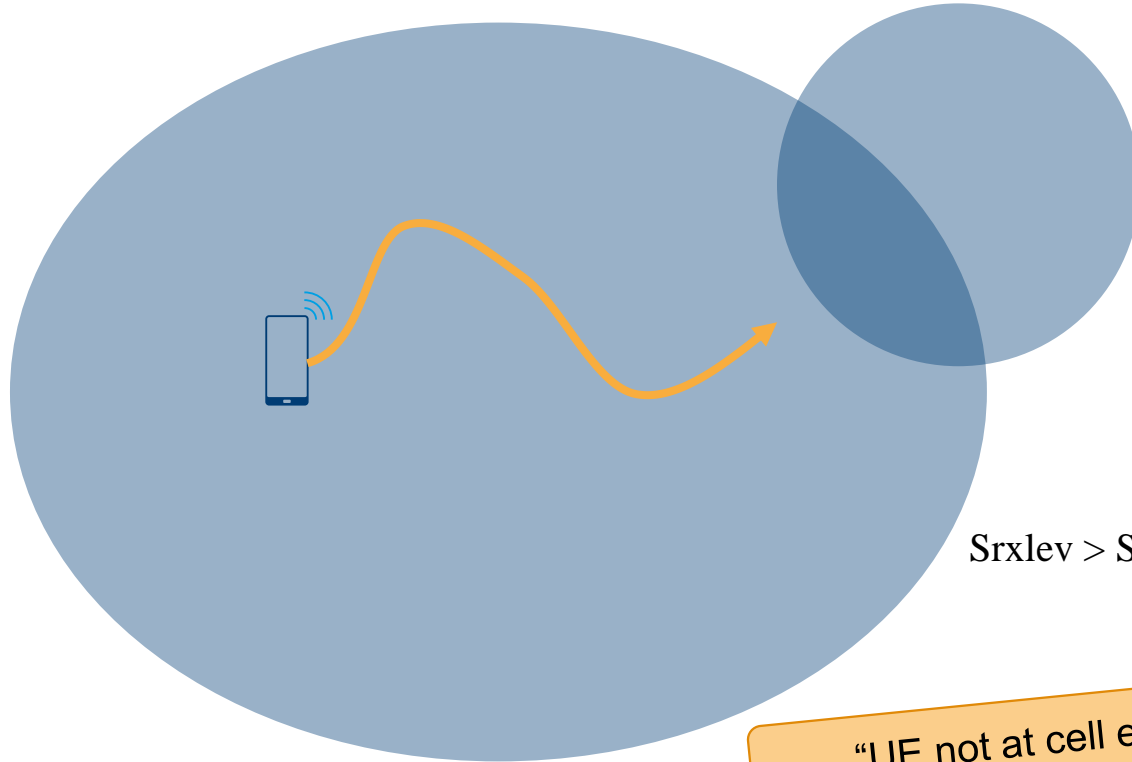
Not at cell edge:
If UE is not at the cell edge, less frequent neighbor cell measurements would be sufficient

$$\text{Srxlev} > S_{\text{SearchThresholdP}} \text{ and } \text{Squal} > S_{\text{SearchThresholdQ}}$$

"UE not at cell edge if power is high enough"

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UE POWER SAVING TECHNIQUES IN 5G RELEASE 16/17

Introduction - History of UE Power Saving Techniques

UE Power Saving Techniques in 5G Release 16

UE Power Saving Techniques in 5G Release 17

Battery Lifetime Measurements

UE POWER SAVING TECHNIQUES IN 5G RELEASE 17

| RedCap devices | Small Data Transmission (SDT) in RRC-inactive state | UE Power saving enhancements |

just to send small data
I can stay inactive ☺

this is covered next

UE POWER SAVING TECHNIQUES IN 5G RELEASE 17

Paging Enhancements
→ PEI (paging early indication)

TRS occasion(s) for idle/inactive UEs

RRC-idle/inactive (NR SA)

Further PDCCH monitoring reduction (enhanced search space set group (SSSG) switching and PDCCH skipping)

Relaxation of UE measurements for RLM and/or BFD in connected mode

RRC-connected

UE POWER SAVING TECHNIQUES IN 5G RELEASE 17

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and/or BFD in connected mode

RRC-connected

UE POWER SAVING ENHANCEMENTS - R17

► **idle/inactive-mode power consumption**

 – **paging enhancements** → PDCCH based paging early indication (PEI)

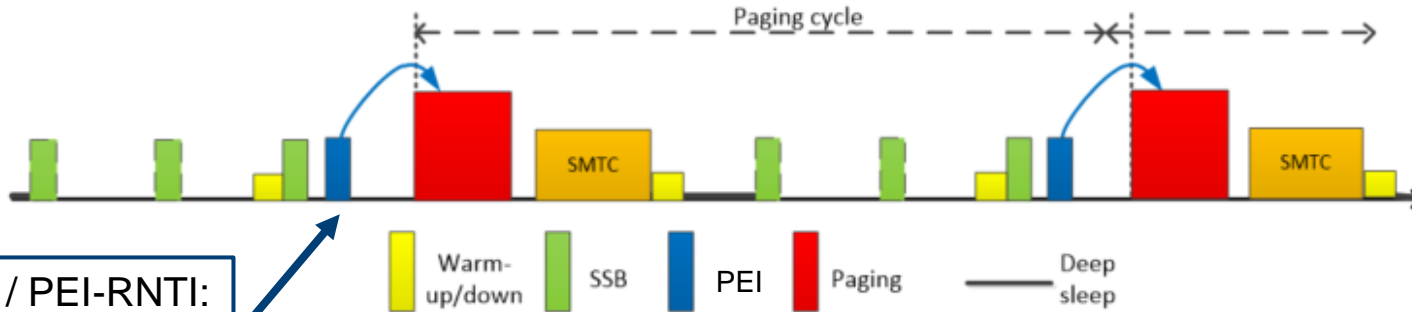 – **TRS occasion(s) for idle/inactive UEs** → to make detection of only **one SSB** sufficient

In order to ensure the decoding performance of PDCCH and paging message when channel condition is not good enough, UE usually needs to detect **multiple SSBs** before PO to adjust automatic gain control (AGC), acquire synchronization in time and frequency domain and perform RRM measurements, etc.
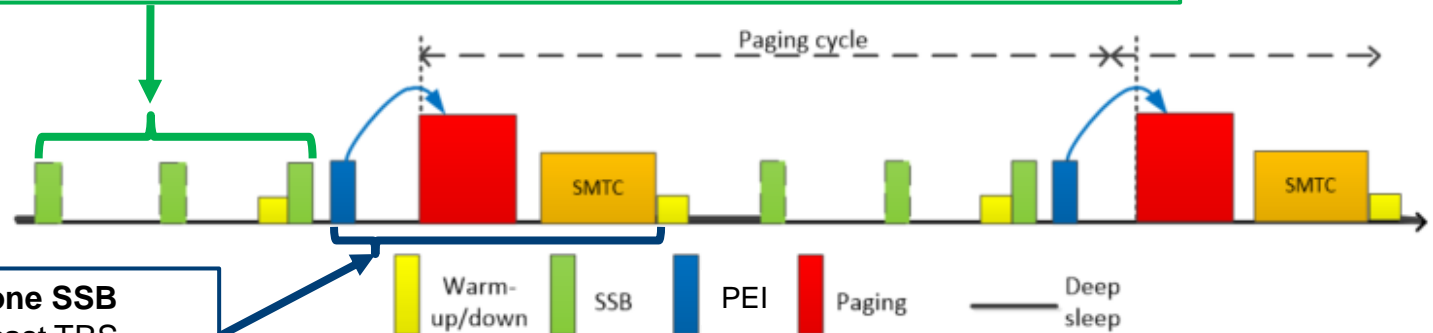
to make detection of only **one SSB** sufficient, gNB may broadcast TRS occasions configured for connected UEs

Paging cycle

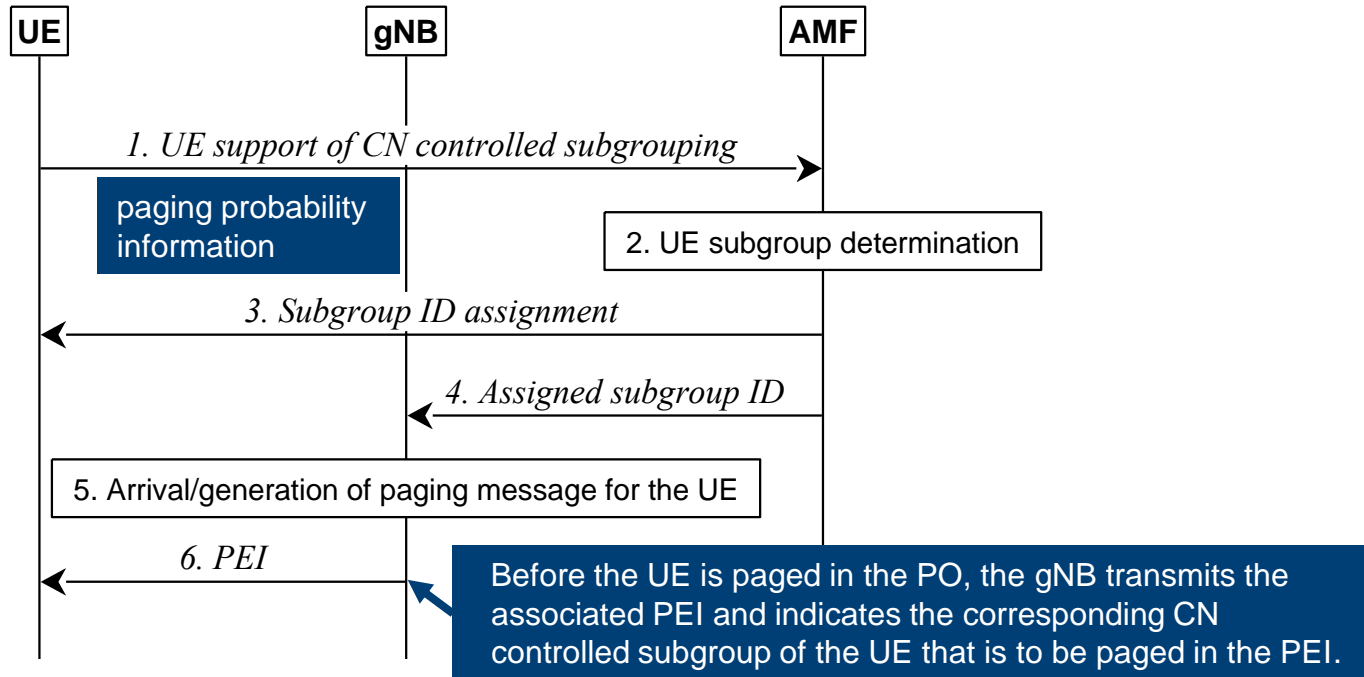| Warm-up/down | SSB | PEI | Paging | Deep sleep |

PAGING EARLY INDICATION (PEI) FOR IDLE/INACTIVE UE

► PEI based on DCI 2_7 before a PO to indicate whether to monitor PDCCH / P-RNTI

► UE subgroups (max 8 per PO), indicated in PEI

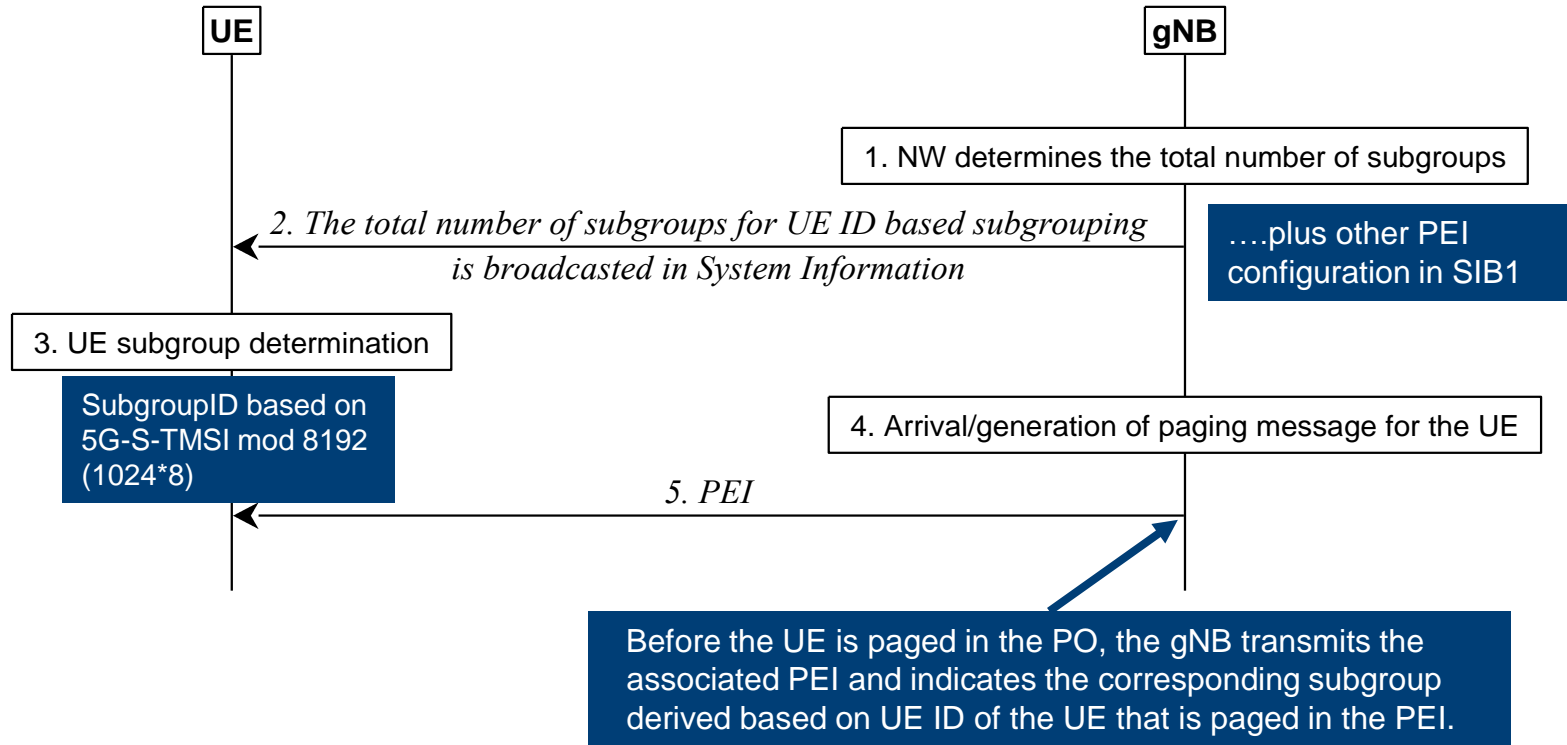► PEI only in architectures where paging happens in NR
(e.g. NE-DC, NR-SA, NR-DC)

DCI 2_7 / PEI-RNTI:
- PEI
- TRS availability

CN CONTROLLED SUBGROUPING

38.300

UE-ID BASED SUBGROUPING

UE   **gNB**

1. NW determines the total number of subgroups

2. The total number of subgroups for UE ID based subgrouping is broadcasted in System Information

….plus other PEI configuration in SIB1

3. UE subgroup determination

SubgroupID based on 5G-S-TMSI mod 8192 (1024*8)

4. Arrival/generation of paging message for the UE

5. PEI

Before the UE is paged in the PO, the gNB transmits the associated PEI and indicates the corresponding subgroup derived based on UE ID of the UE that is paged in the PEI.
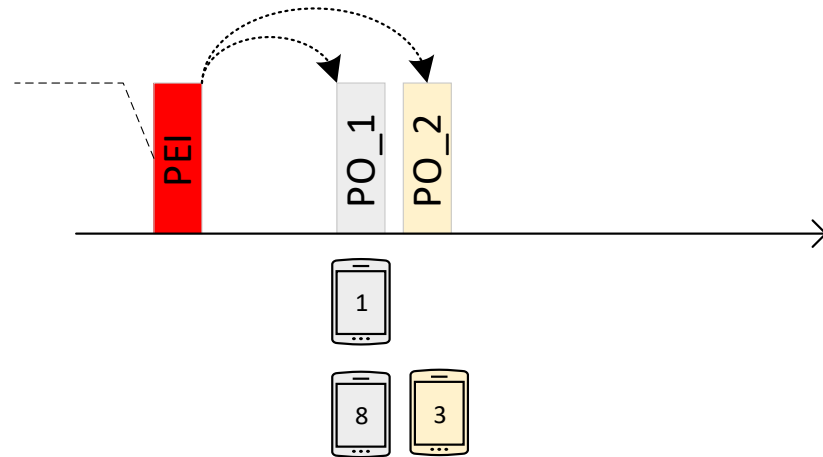
38.300

PEI RECEPTION

► PEI occasion (PEI-O) configuration example: 1 PEI for 2 PO in 1 PF

PEI config example (one-to-two):
- 8 bits for individual subgroups of PO_1
- 8 bits for individual subgroups of PO_2

PEI contents example:
- PO_1: 10000001 → (Subgroups 1, and 8)
- PO_2: 00000100 → (Subgroup 3)

R1-2112149

UE POWER SAVING TECHNIQUES IN 5G RELEASE 17

Paging Enhancements
→ PEI (paging early indication)

TRS occasion(s) for idle/inactive UEs

RRC-idle/
inactive (NR SA)

Further PDCCH monitoring reduction
(enhanced search space set group (SSSG)
switching and PDCCH skipping)

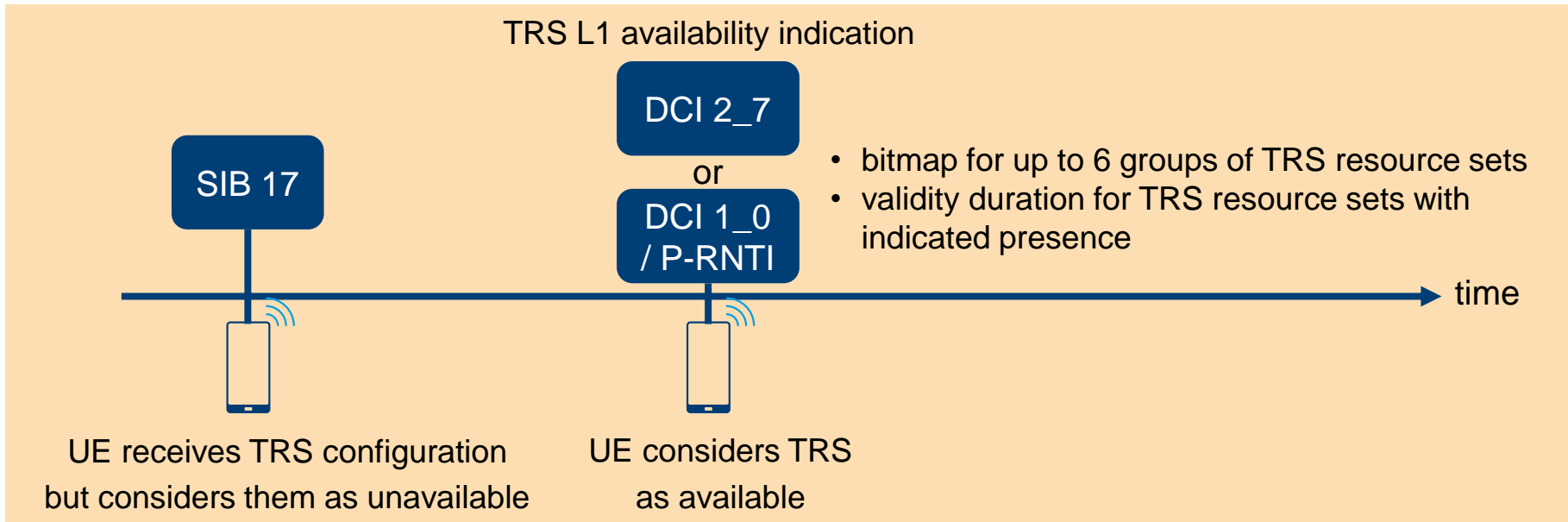Relaxation of UE measurements for RLM
and/or BFD in connected mode

RRC-connected

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TRS OCCASION(S) FOR IDLE/INACTIVE UEs

► Provision of potential TRS/CSI-RS occasion(s) available in connected mode to idle/inactive-mode UEs

► Always-on TRS/CSI-RS transmission by gNodeB is not required

TRS L1 availability indication

DCI 2_7

or

DCI 1_0 / P-RNTI

- bitmap for up to 6 groups of TRS resource sets
- validity duration for TRS resource sets with indicated presence

SIB 17

time

UE receives TRS configuration but considers them as unavailable

UE considers TRS as available

UE POWER SAVING TECHNIQUES IN 5G RELEASE 17

Paging Enhancements
→ PEI (paging early indication)

TRS occasion(s) for idle/inactive UEs

RRC-idle/inactive (NR SA)

Further PDCCH monitoring reduction (enhanced search space set group (SSSG) switching and PDCCH skipping)

Relaxation of UE measurements for RLM and/or BFD in connected mode

RRC-connected

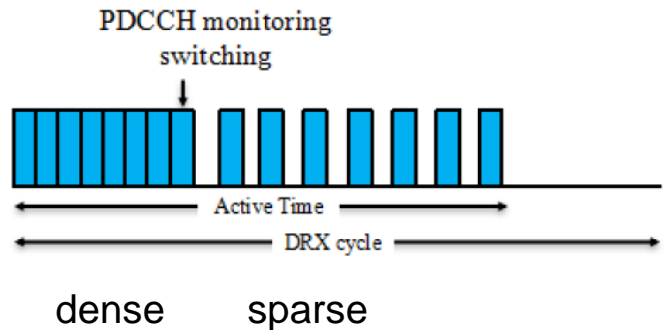# UE POWER SAVING ENHANCEMENTS: CONNECTED-MODE
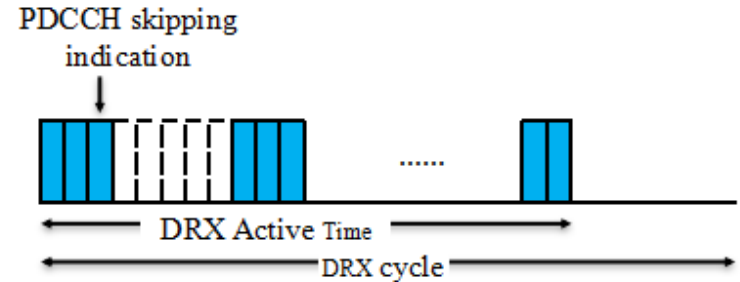
► Further PDCCH monitoring reduction

PDCCH Monitoring Adaptation:
gNB can switch UE to sparser PDCCH monitoring occasions within one BWP when data arrives sparsely.
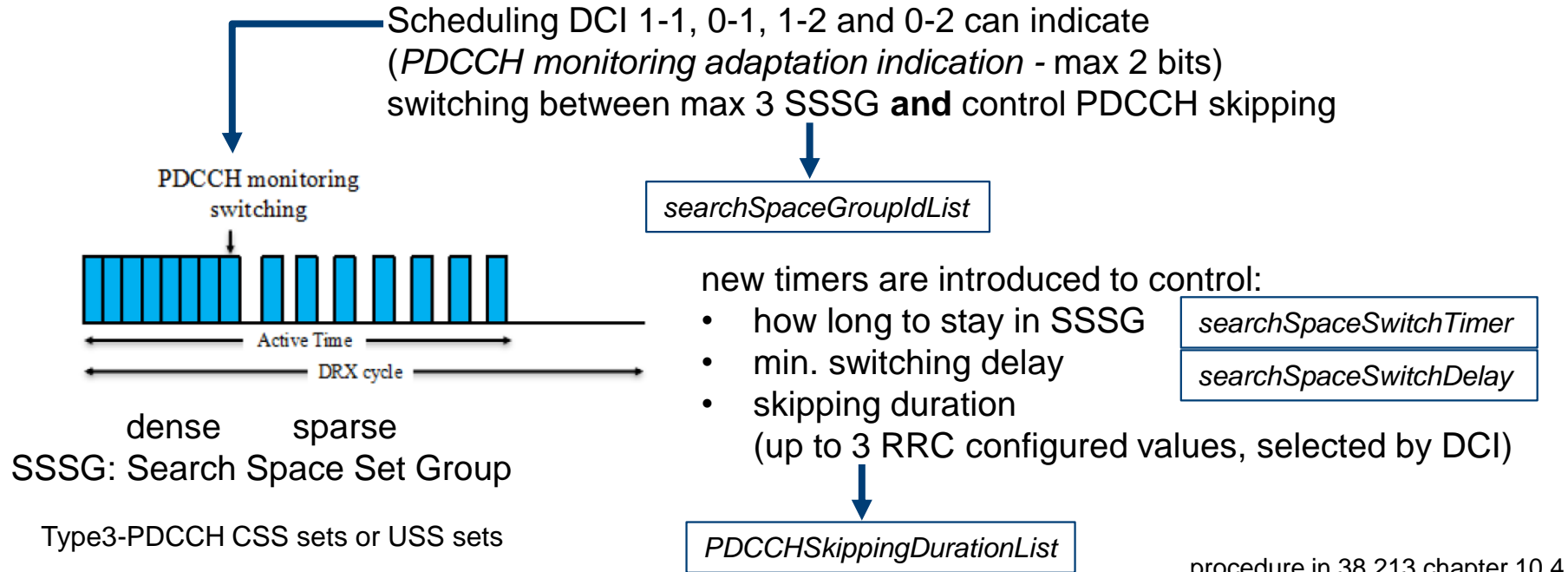
PDCCH Skipping:
gNB can indicate UE to perform PDCCH skipping if there is no data to be transmitted to UE. After UE receives the indication, UE can stop monitoring PDCCH to save power.

dense   sparse

SSSG: Search Space Set Group

UE POWER SAVING ENHANCEMENTS: CONNECTED-MODE

► Further PDCCH monitoring reduction

Scheduling DCI 1-1, 0-1, 1-2 and 0-2 can indicate
(*PDCCH monitoring adaptation indication* - max 2 bits)
switching between max 3 SSSG **and** control PDCCH skipping

PDCCH monitoring switching

Active Time

DRX cycle

dense   sparse
SSSG: Search Space Set Group

Type3-PDCCH CSS sets or USS sets

searchSpaceGroupIdList

new timers are introduced to control:
- how long to stay in SSSG
- min. switching delay
- skipping duration
  (up to 3 RRC configured values, selected by DCI)

searchSpaceSwitchTimer

searchSpaceSwitchDelay

PDCCHSkippingDurationList

procedure in 38.213 chapter 10.4

UE POWER SAVING TECHNIQUES IN 5G RELEASE 17

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→ PEI (paging early indication)

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RRC-idle/
inactive (NR SA)

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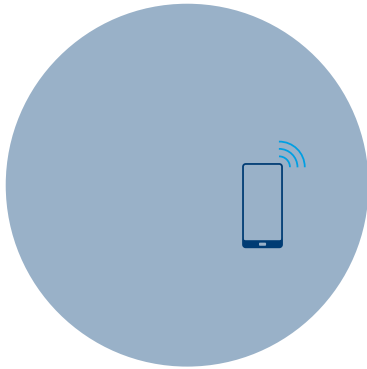(enhanced search space set group (SSSG)
switching and PDCCH skipping)

Relaxation of UE measurements for RLM
and/or BFD in connected mode

RRC-connected

RLM AND BFD MEASUREMENT RELAXATION

If serving cell radio link quality is better than a
threshold, RLM and BFD measurements can be
relaxed

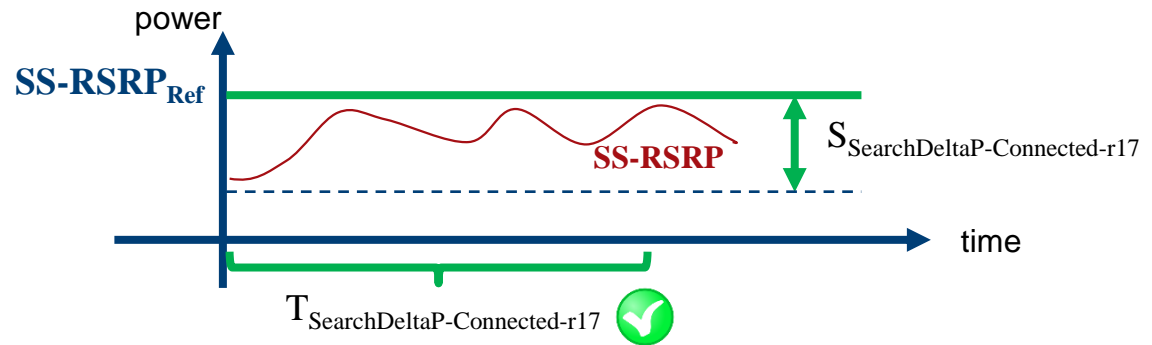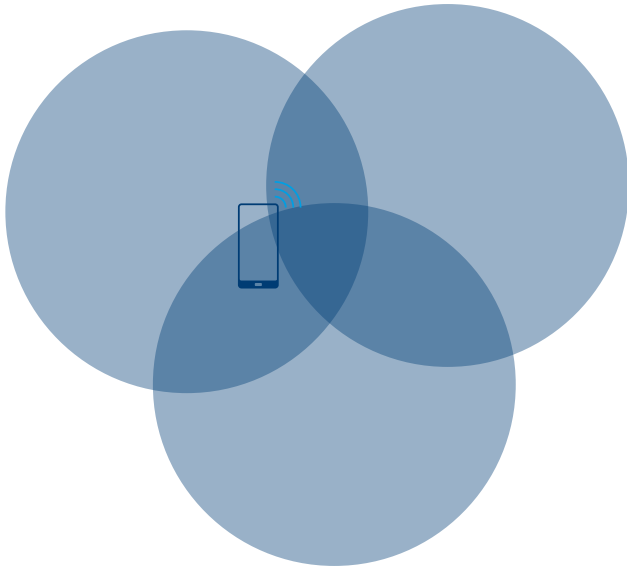DL radio link quality of RLM-RS / BFD-RS resource > Q_{in}+XdB

38.133 8.1

"good serving cell quality" if
RLM-RS / BFD-RS power
higher than threshold

offset in
goodServingCellEvaluationRLM
goodServingCellEvaluationBFD

RLM AND BFD MEASUREMENT RELAXATION

And (optionally) if mobility state is low,
RLM and BFD measurements can be relaxed

$\text{SS-RSRP}_{\text{Ref}}$

power

SS-RSRP

$S_{\text{SearchDeltaP-Connected-r17}}$

time

$T_{\text{SearchDeltaP-Connected-r17}}$

"low mobility fulfilled if received (SSB) power doesn't change a lot"

UE ASSISTANCE INFORMATION

R15: e.g. overheating information

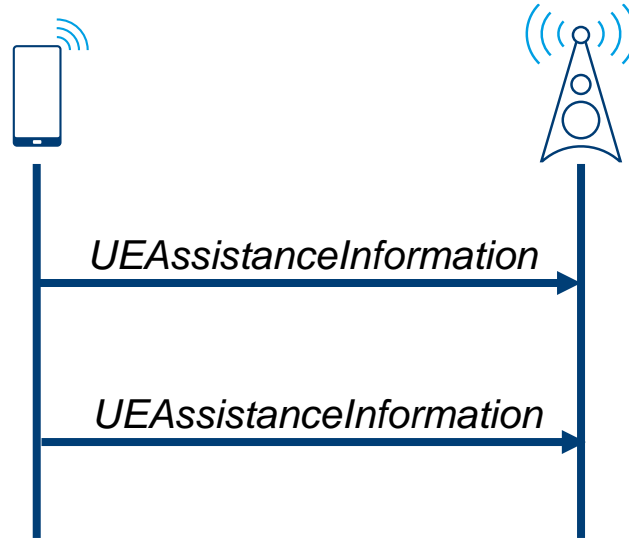R16: power saving related
     information added

R17:…………………..
RedCap:
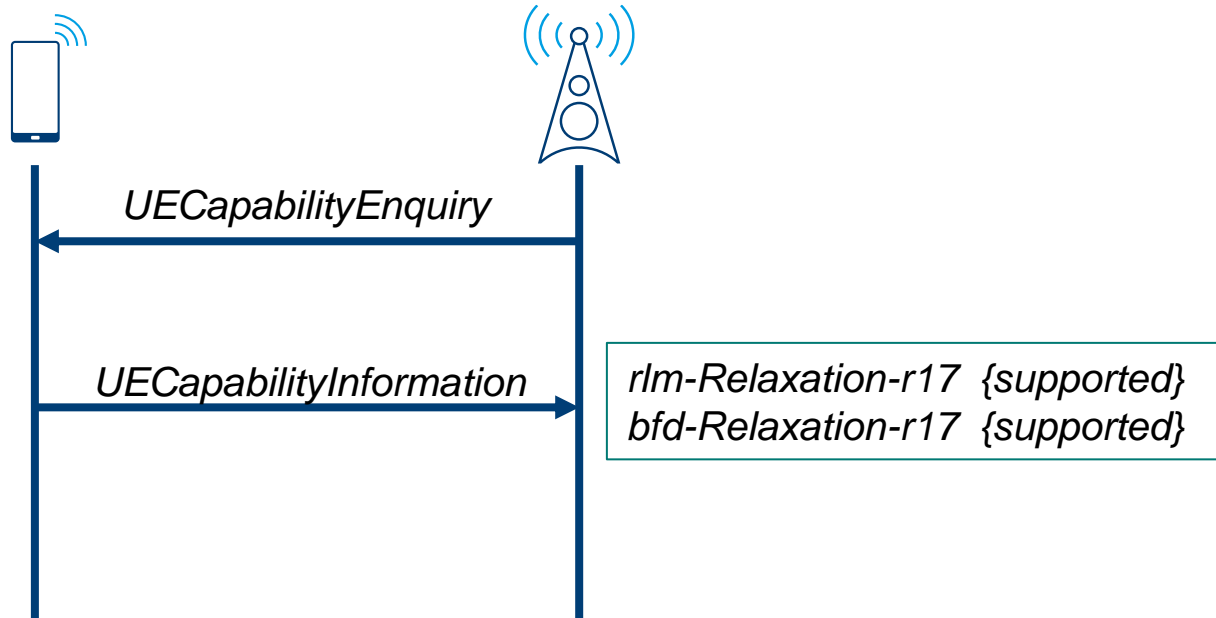*rrm-MeasRelaxationFulfilment-r17*
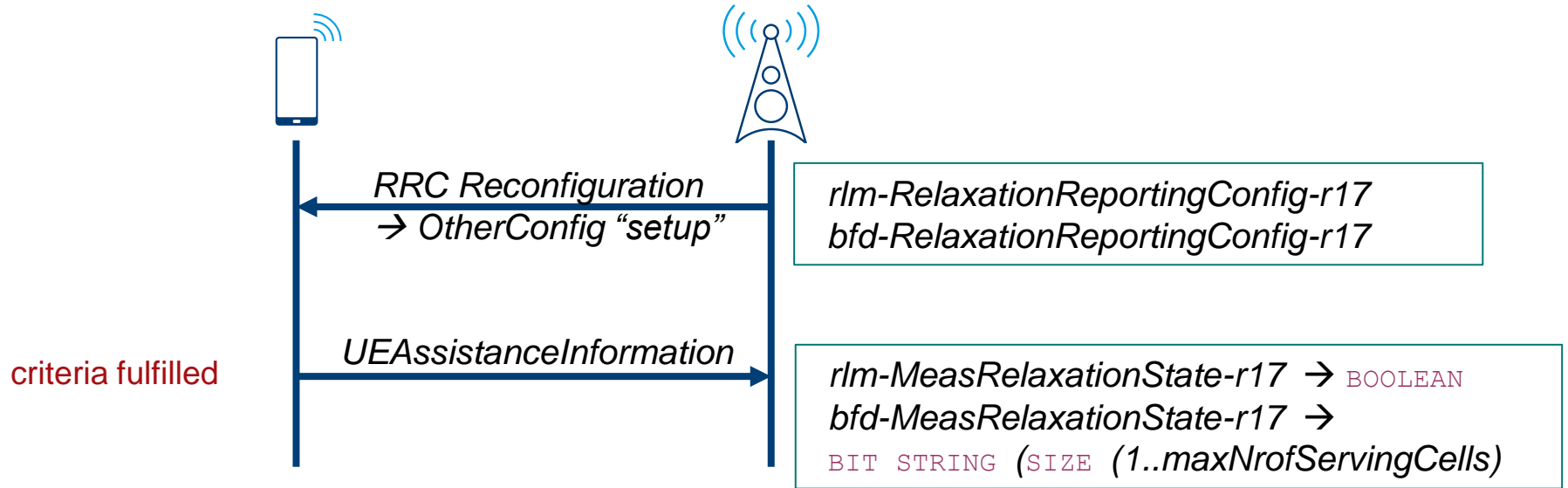
General:
rlm-Relaxation-r17
bfd-Relaxation-r17

UEAssistanceInformation

UEAssistanceInformation

supports the network to configure UE optimized settings

UE ASSISTANCE INFORMATION

UECapabilityEnquiry

UECapabilityInformation

rlm-Relaxation-r17 {supported}
bfd-Relaxation-r17 {supported}

UE ASSISTANCE INFORMATION

RRC Reconfiguration
→ *OtherConfig "setup"*

rlm-RelaxationReportingConfig-r17
bfd-RelaxationReportingConfig-r17

criteria fulfilled

UEAssistanceInformation

rlm-MeasRelaxationState-r17 → `BOOLEAN`
bfd-MeasRelaxationState-r17 →
`BIT STRING` (`SIZE` *(1..maxNrofServingCells)*

UE reports to network when it no longer meets relaxation criteria.

UE POWER SAVING TECHNIQUES IN 5G RELEASE 16/17

Introduction - History of UE Power Saving Techniques

UE Power Saving Techniques in 5G Release 16
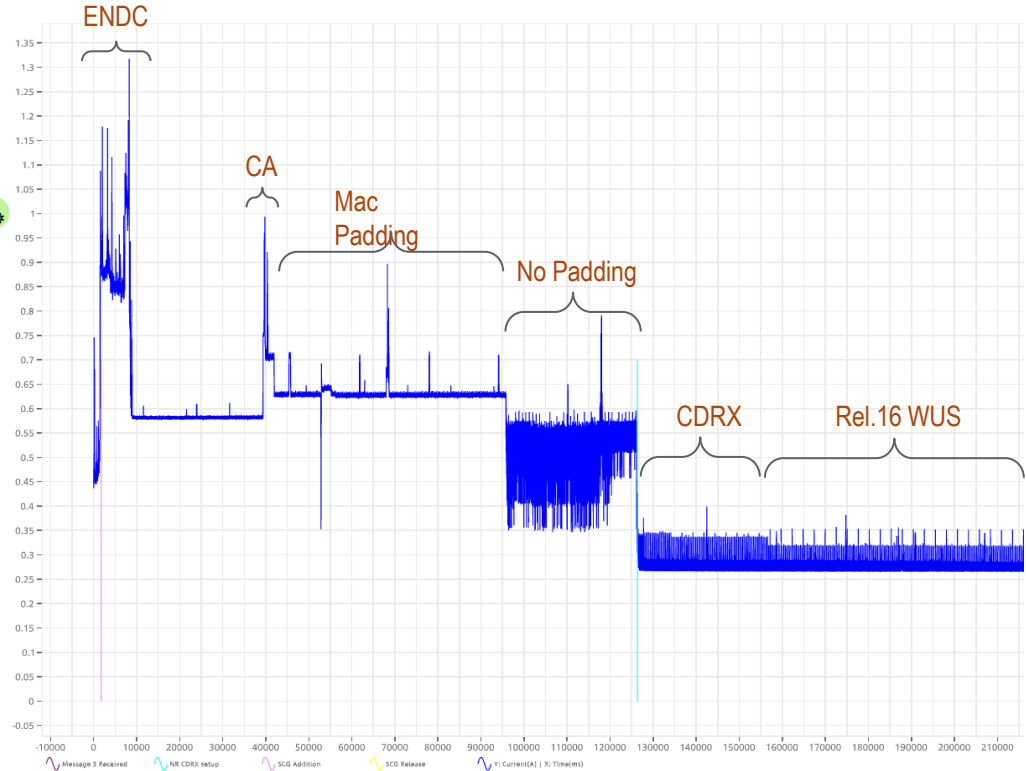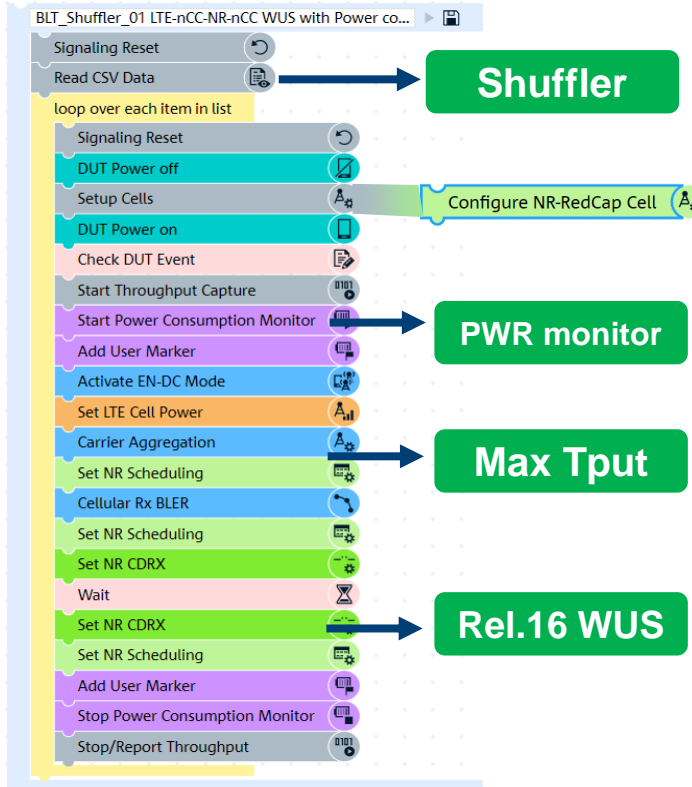
UE Power Saving Techniques in 5G Release 17

Battery Lifetime Measurements

Rohde & Schwarz   Lothar Walther

POWER CONSUMPTION MEASUREMENTS

► DUT Power consumption measurements with CMX500 and NGM Power supply

► CMsequencer for automated testing

CMsquares & CMsequencer

NGM Power Supply

LAN

DUT

RF COM

CMX500 Radio Com Tester
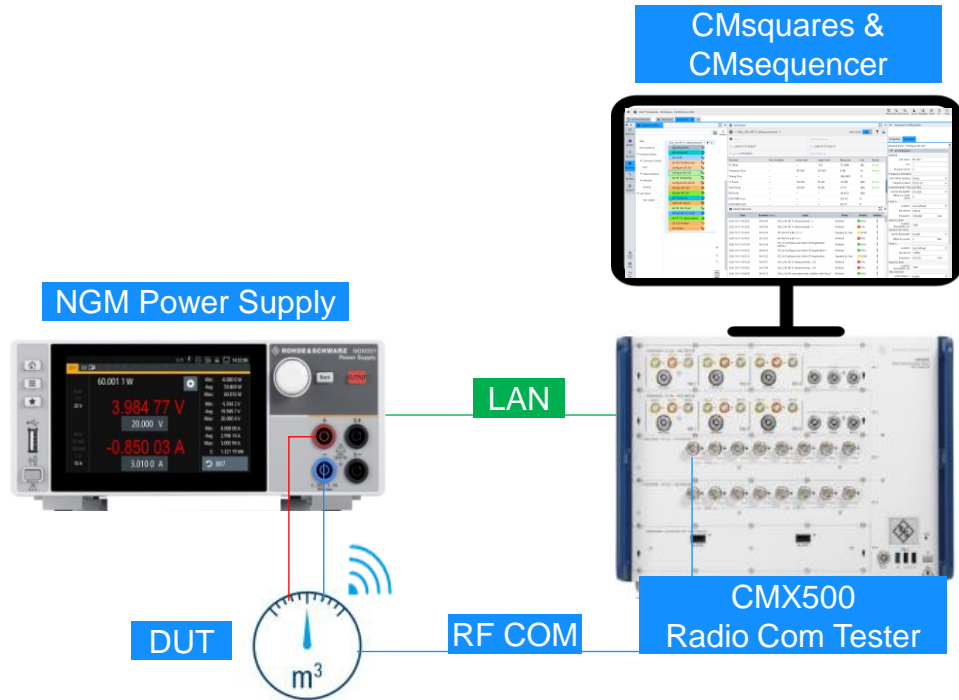
MANY USE CASES, ONE SCRIPT

Find out more

www.rohde-schwarz.com/5G

THANK YOU

ROHDE&SCHWARZ

Make ideas real