LTE Scheduler

Basic scheduler (DL/UL)
DL scheduler
UL Interference Aware scheduler
UL Channel Aware scheduler

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LTE scheduler
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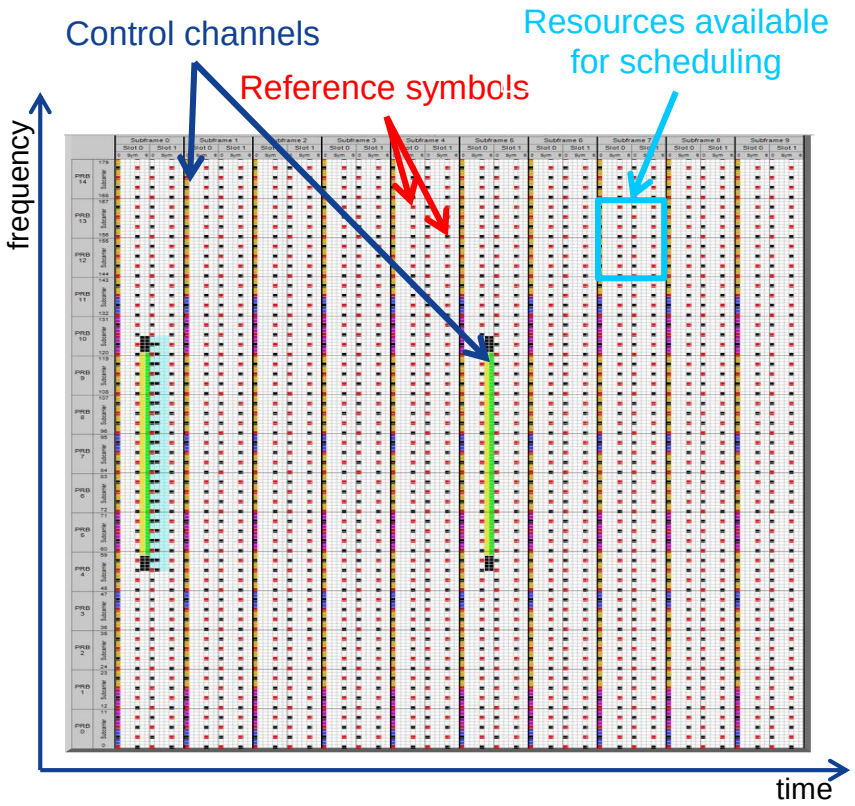
Scheduler in LTE

- Packet scheduler is one of a core functionalities in LTE
- The scheduler is responsible for allocating physical resources to the UEs
  - Separate allocation in **downlink** and **uplink**
  - Scheduler takes new set of decisions every TTI (1ms)

- Scheduling decisions have to be integrated with other LTE functionalities (HARQ process, DRX, ATB)
- The scheduler has to distribute resources to **all requesting users** to provide appropriate **QoS** to every user (priority, delay)



Introduction to scheduling

Main Menu

Questions to be answered during each round of scheduling process:

- How many resources are available for scheduling?
- Which UEs to select ?
- How many resources to allocate to each UE?
- Which resources to allocate to each UE?

The decision process need also to fit into overall scheduling strategy:

- Which users should be treated in preferred way?
- How to maintain minimal and maximal values of traffic volume?
- How to handle delay-sensitive traffic?

The scheduling process shall take into account:

- Channel state (in uplink and in downlink)
- Buffer state (for each user, in uplink and in downlink)
- Own previous decisions

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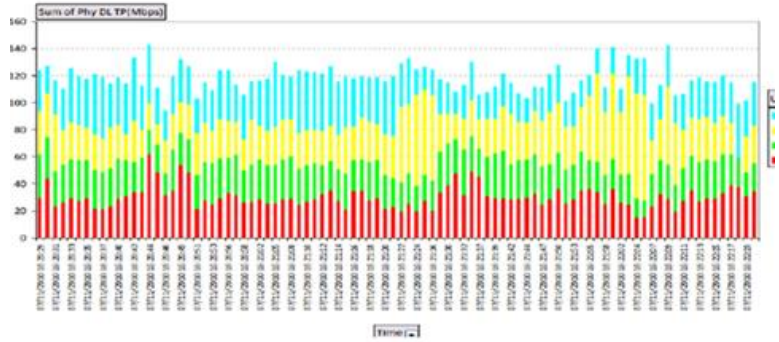
Basic scheduler principles

Main Menu

- LTE **downlink** scheduler is **channel aware**, basic uplink scheduler is channel unaware
- Resource allocation is done in **time domain** as well as in **frequency domain**
- Explicit priority is granted to HARQ retransmissions and Signaling Radio Bearers (SRB)
- Many UEs may be scheduled per **single TTI**

- Scope of packet scheduler is **cell level**
  - Decisions made in uplink and downlink are **independent**
- Duration of each allocation is one TTI (1ms)
  - Note that long term variables (spanning over several PRBs) have to also be controlled by scheduler



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LTE scheduler in RL40

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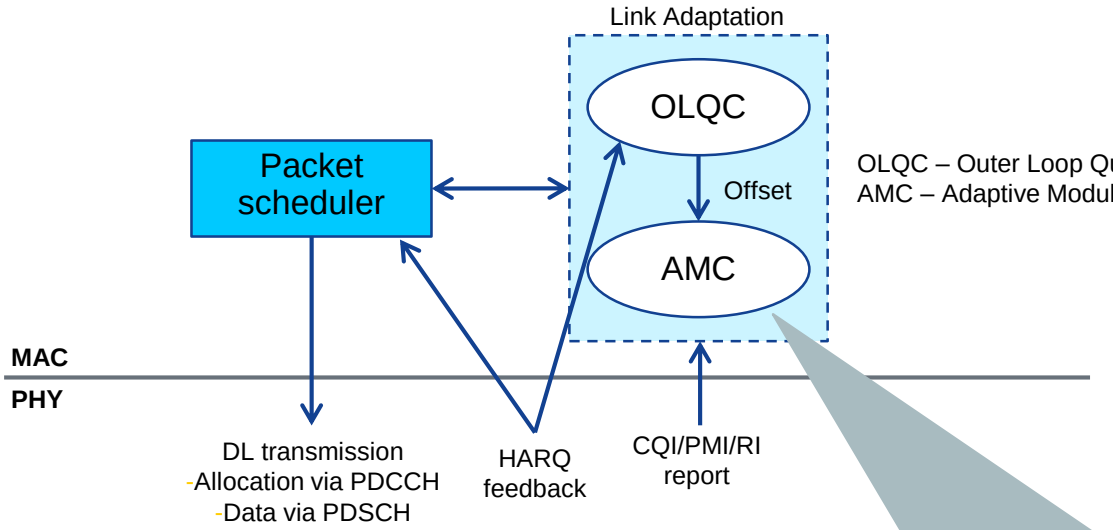
Downlink scheduler – General Framework

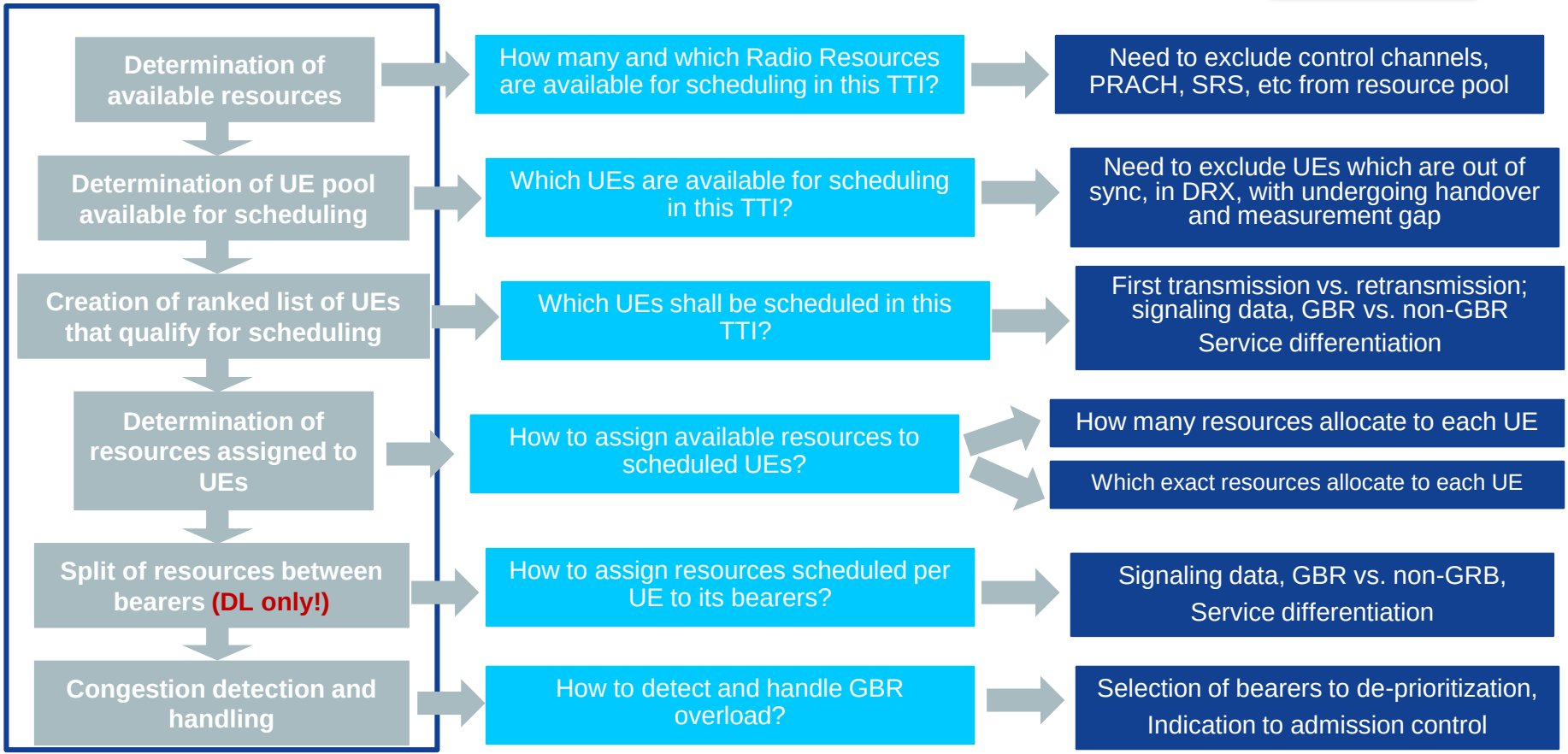


Scheduler interacts with **Link Adaptation** entity:

AMC and **OLQC** provide estimate of achievable throughput on any subband based on latest CQI and ACK/NACK reports

Generic scheduling process - DL and UL

Main Menu



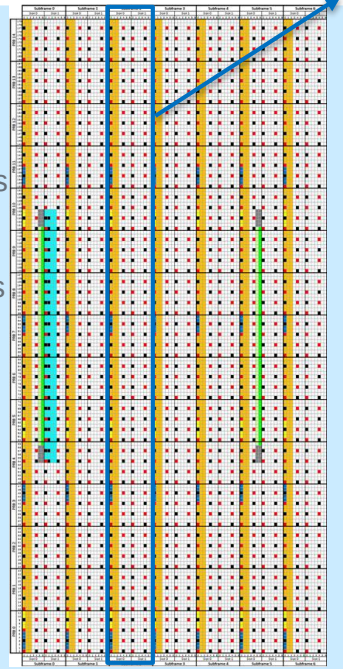
Determination of available resources

LTExxx – Feature Name / Other Data / Complex Name

Main Menu

Downlink

- Disregard resources needed for:
  - Synchronization signals (**PSS/SSS**)
  - **PBCCH**
  - Cell specific **RS** signals
  - L1/L2 control signaling (**PDCCH, PHICH, PCFICH**)

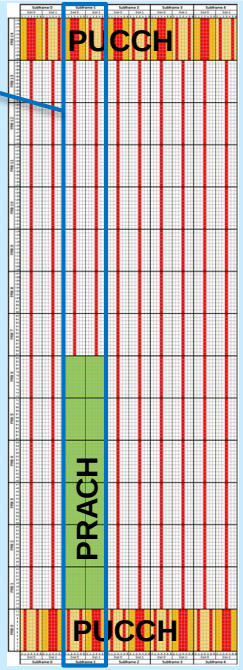


Final result: **List of available RBGs**

Timeframe = 1TTI

Uplink

- Disregard PRBs permanently allocated to:
  - **PUCCH**
  - **PRACH**
- Evaluation and virtual reservation of resources needed for RA message 3



Final result: **List of available PRBs**

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Determination of UE pool available for scheduling

Main Menu

Downlink	Uplink
UE is in ‘out of sync’ or ‘drifting’ state	UE has pending Random Access Procedure
UE is in ‘DRX Sleep’ state	UE is in ‘out of sync’ or ‘drifting’ state
UE is in measurement gap or has pending handover	UE is in ‘DRX Sleep’ state
UE’s Channel Quality Feedback (CQI) is not available and parameter *LNCEL:dlamcCqiDef* = 0	UE is in measurement gap or has pending handover
	UE has pending HARQ retransmission
UE has data in buffer for DRB or SRB	UE has pending Scheduling Request
	UE has data in buffer for DRB or SRB

Legend:

UE is **available** for scheduling (added to Candidate Set 1)

UE is **not available** for scheduling (not added to Candidate Set 1)

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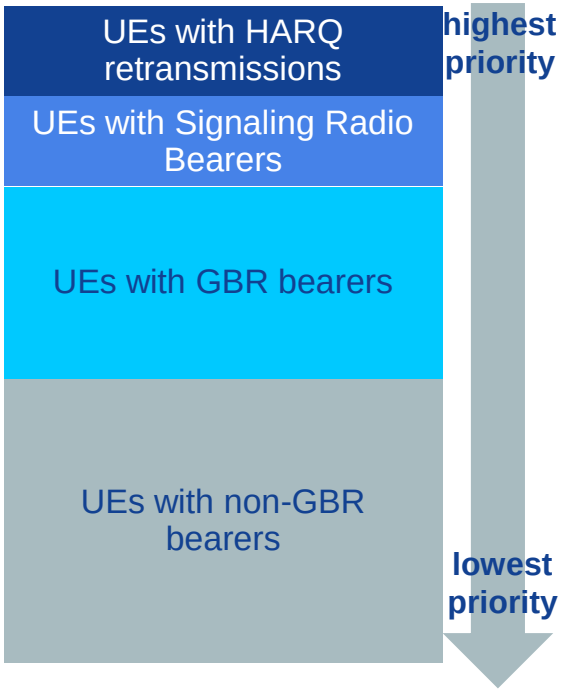
Time domain scheduling – DL/UL

Main Menu

- Creation of ranked list of UEs to be scheduled is very similar in downlink and uplink (little differences in criterion calculations)
- First on the list are UEs which are retransmitting and those with Signaling Radio Bearer
- Then UEs with GBR bearers according to calculated criterion (channel conditions + packet delay)
- And at the end UEs with non-GBR bearers according to calculated criterion (throughput + service differentiation)
- Number of UEs on the list is limited by ***maxNumUeDl*** and ***maxNumUeUl*** parameters



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TD Criterion calculation for GBR bearers

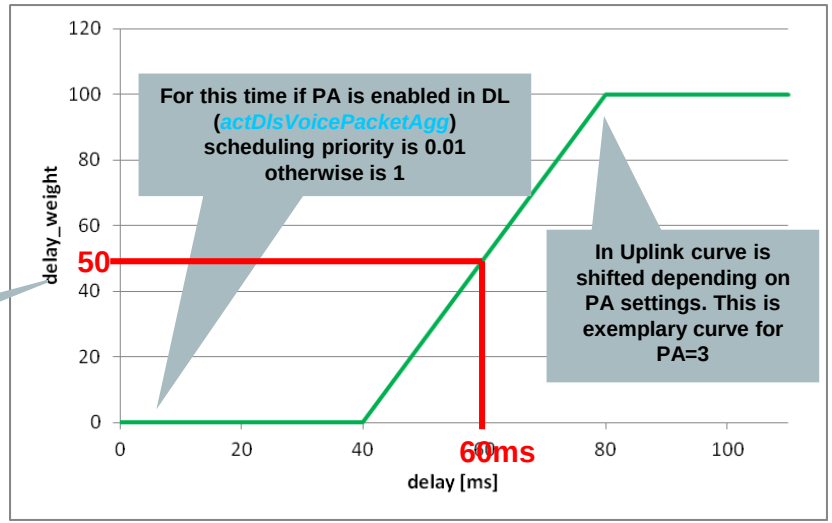
Main Menu

- For UEs with VoIP bearers (QCI 1) criterion is calculated according to channel conditions and packet delay dependent weight

$$C = channel\_conditions * delay\_weight$$

In downlink based on WB-CQI, in uplink based on MCS

- Delay weight factor is read out from delay curve
- For VoIP bearers there is Packet aggregation mechanism. In downlink can be activated using ***actDlsVoicePacketAgg*** parameter, while in uplink by ***ulsMaxPacketAgg***
- Shape of delay curve depends on QCI, ***delayTarget*** parameter and Packet aggregation settings



Example:

If packet delay is 60ms – corresponding delay_weight = 50

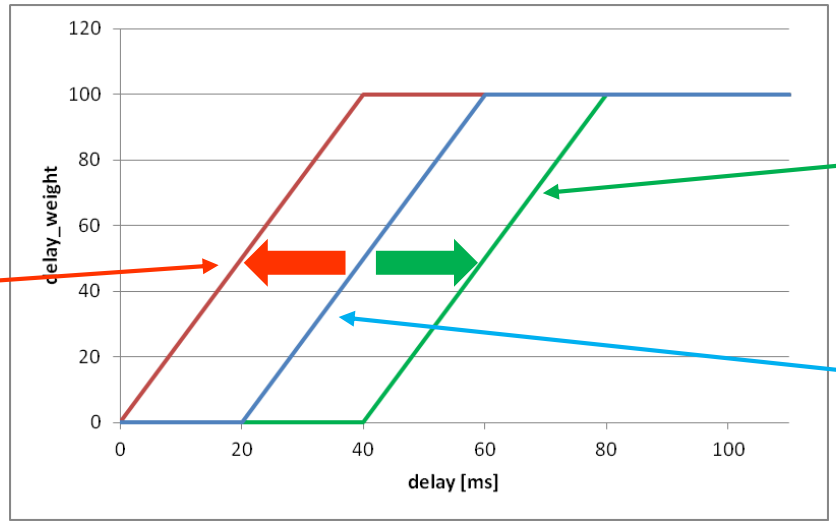
Outer Loop Delay Target Control - downlink

Main Menu

- Additional mechanism to control delay and packet aggregation is used in downlink for QCI 1 bearer.
  - The Outer Loop Delay Target is set for controlling timely reception of the packets in both good and poor radio conditions
  - Scheduler evaluates the actual scheduling delay of voice bearers and compares it with current delay target:

Measured delay > **delayTarget** -> **UE priority is increased** (curve is shifted to the left)

Measured delay < **delayTarget** -> **UE priority is decreased** (curve is shifted to the right)



Poor channel conditions, priority need to be boosted earlier

Good channel conditions, More relaxed priority increase

Relatively fair channel conditions

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TD Criterion calculation for GBR bearers

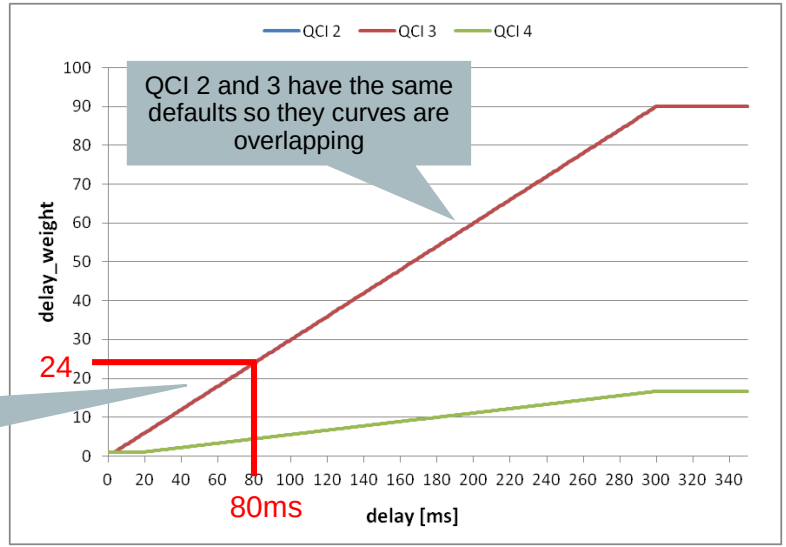
Main Menu

- For UEs with GBR bearers (QCIs 2-4) criterion is also calculated according to channel conditions and packet delay dependent weight (different shape of curve than for QCI 1 bearer)

$$C = channel\_conditions * delay\_weight$$

In downlink based on WB-CQI, in uplink based on MCS

- Delay weight factor is read out from delay curve
- Shape of delay curve depends on QCI and ***delayTarget*** parameter. Presented curves are generated using default values of delay target for each QCI.



Example:

If packet delay is 80ms – corresponding delay_weight = 24

TD criterion calculation for non-GBR bearers

Main Menu

- For UEs with non-GBR bearers criterion is calculated according to throughput and QCI specific scheduling weight

$$C = \frac{\text{immediate\_throughput}}{\text{past\_averaged\_throughput}} * \text{QCI\_weight}$$

- QCI_weight depends on the QCI and can be configured using ***schedulWeight*** or ***schedulweightDl*** and ***schedulweightUl*** (in case different weights needs to be configured for DL and UL) parameter
- Default values of ***schedulWeight, schedulWeightDl*** and ***schedulWeightUl*** parameters for each non-GBR QCI are presented in table on the right
- The higher QCI value, the lower priority

QCI	Default QCI_weight
QCI5	40
QCI6	20
QCI7	10
QCI8	5
QCI9	1

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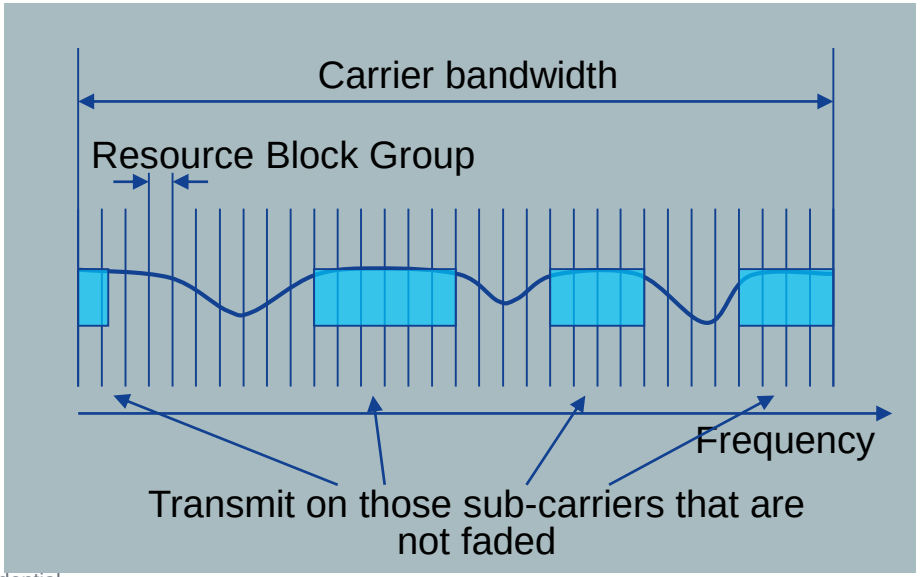
Frequency domain scheduling in downlink

Main Menu

- Allocating resources to the UEs is done according to channel state:
  - Allocation of Resource Block Groups (RBG) which consist of 1-4 PRBs (depending on channel bandwidth)
  - The channel quality is evaluated for all UEs for all potential RGBs before assignment (subband CQI required)



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Frequency domain scheduling in downlink

Main Menu

- With QCI2,3 and 4 feature switched off allocation of resources to selected UEs is done in one step (number of PRBs + which exact PRBs using proportional fair algorithm

Proportional Fair (PF)

- Scheduling history is considered through average scheduling rate
- Has proportional fair allocation of the resources, in function of the UE channel condition
- Supports different QCI weights
- Improves overall cell capacity

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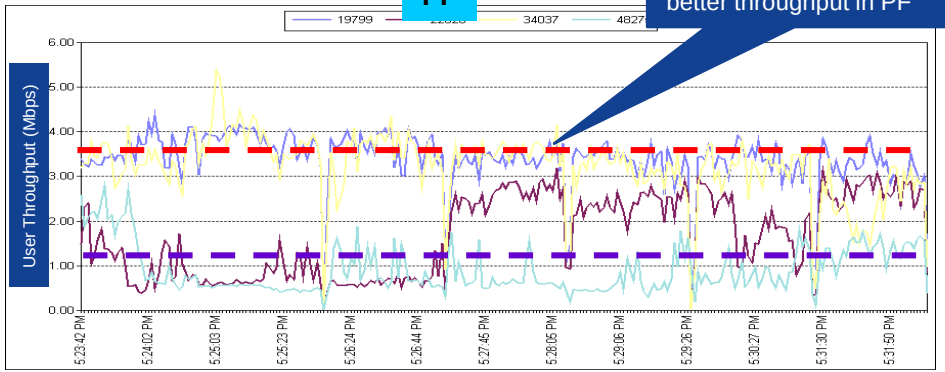
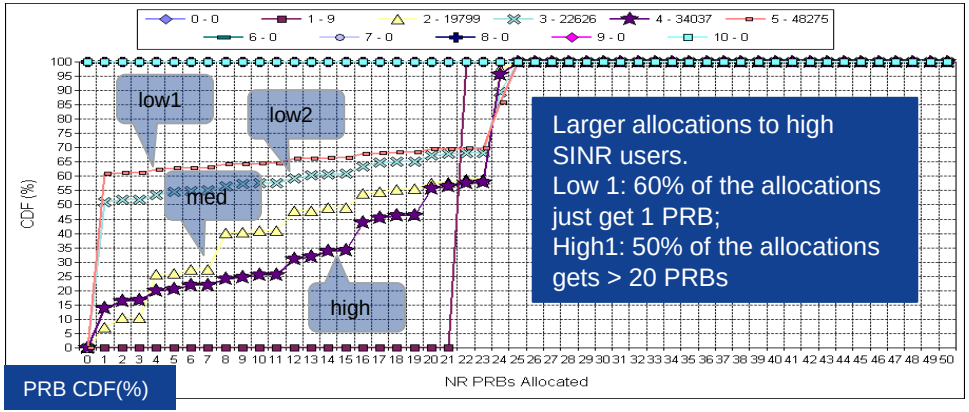
Proportional Fair – lab results

Main Menu

PF

High/med SINR UEs have better throughput in PF





Larger allocations to high SINR users.
Low 1: 60% of the allocations just get 1 PRB;
High1: 50% of the allocations gets > 20 PRBs

PRB CDF(%)

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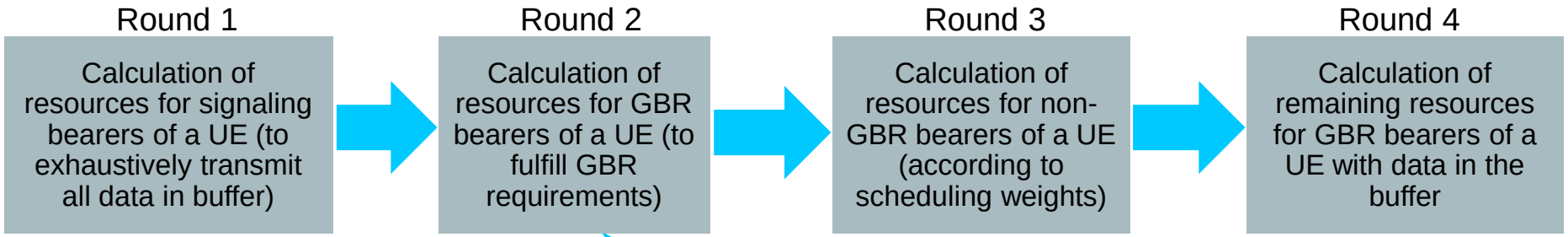
RL40 – Frequency domain scheduling

Main Menu

- Starting with RL40 when support of QCI 2, 3 and 4 was introduced, allocation of resources to chosen UEs is done in two steps:
  - In first step number of PRB which will be allocated to every UE is calculated. Calculation is done in rounds: in each round bearers of different types are considered



  - In second step exact PRBs for every UE are chosen (with the limitation coming from previous step). It is done using existing algorithm (PF)

In case of **Multiple GBR** feature enabled in Round 2 resources are calculated only for GBR bearer with highest criterion

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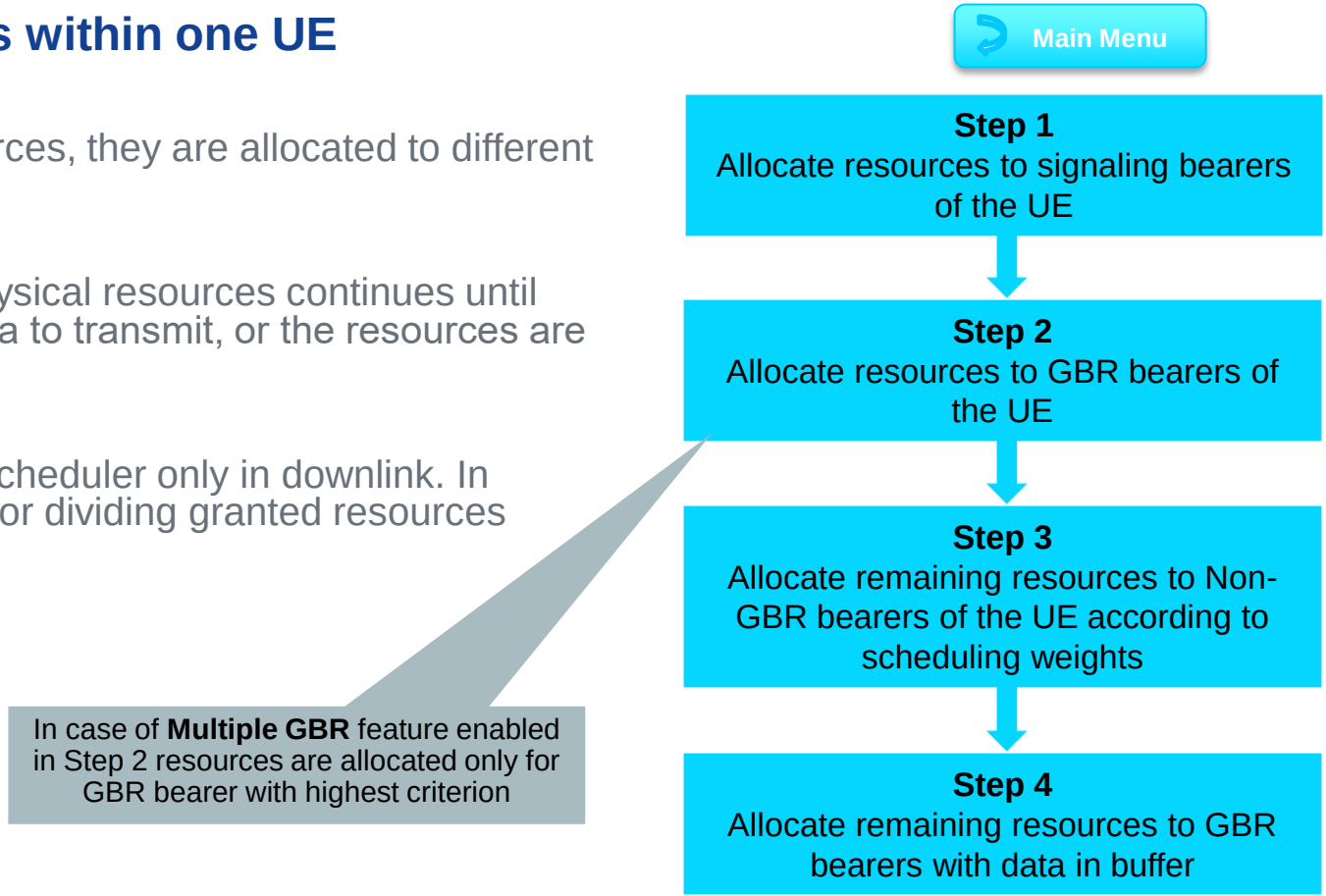
Handling of bearers within one UE

- After UE is granted resources, they are allocated to different bearers of a UE
- Allocation user data to physical resources continues until either there's no more data to transmit, or the resources are exhausted for this TTI
- This step is done by the scheduler only in downlink. In Uplink UE is responsible for dividing granted resources between its bearers



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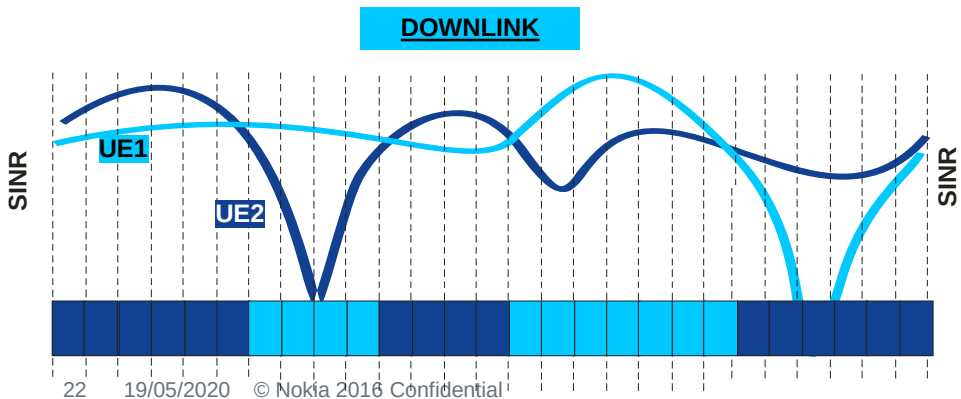
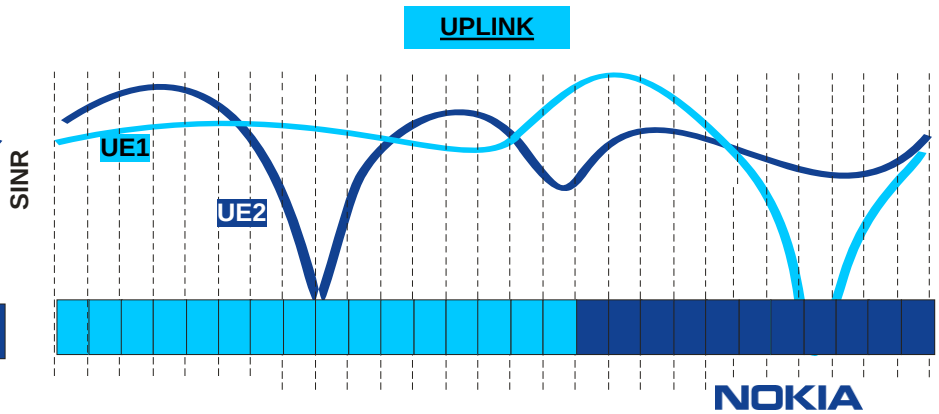
Uplink Scheduler

Main Menu

- Uplink Packet Scheduler has a role of allocating PUSCH resources (PRBs) to UEs
- Like in downlink it also do both: chooses UEs which will be scheduled in given TTI and select resources which will be allocated to those UEs
- In Uplink only contiguous allocation of PRBs to single UE is possible
- Allocations are done per Logical Channel Groups (LCG), not bearers like in downlink
- Basic scheduler is channel unaware:
  - Random allocation of PRBs to UEs (blind frequency hopping)
  - Does not require channel sounding





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LCGs to bearers mapping

Main Menu

- In RL40 when Multiple GBR feature is activated following mapping of bearers to LCGs is introduced:

LCG	QCI which can be mapped	Remarks
LCG0 (signaling LCG)	SRBs QCI5 (if it is configured as signaling bearer)	LCG reserved for signaling bearers
LCG1 (GBR LCG)	QCI1 QCI2 QCI3	LCG reserved for GBR bearers QCI1 is always mapped in LCG1
LCG2 (GBR or non-GBR LCG or mixed GBR/non-GBR)	QCI2 QCI3 QCI4 QCI5(if it is configured as non-GBR bearer) QCI6-9	It is recommended to map either GBR or non-GBR bearers only It is possible to map GBR and non-GBR bearers together
LCG3 (non-GBR LCG or mixed GBR/non-GBR)	QCI4 QCI5(if it is configured as non-GBR bearer) QCI6-9	It is recommended to map non-GBR bearers only It is possible to map GBR and non-GBR bearers together

Without Multiple GBR feature LCG0 was for SRBs, LCG1 for GBR and LCG2,3 for non-GBR bearers

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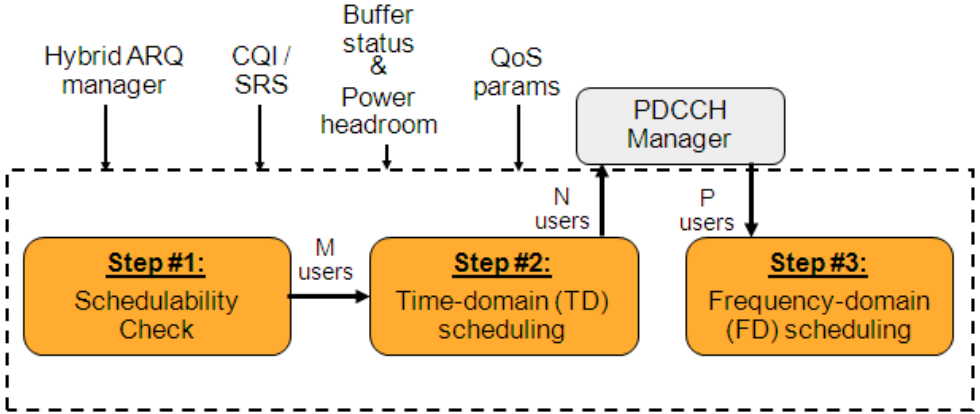
Uplink scheduler – General Framework

Main Menu



- The scheduling decision requires inputs from:
  - **Buffer status report** - UEs should be scheduled depending on the amount of data in their buffer
  - **Power Headroom report** – may indicate that it is necessary to limit the number of PRBs that can be allocated
- Note that - Due to synchronous HARQ operation in uplink, users with pending HARQ retransmissions shall always be scheduled

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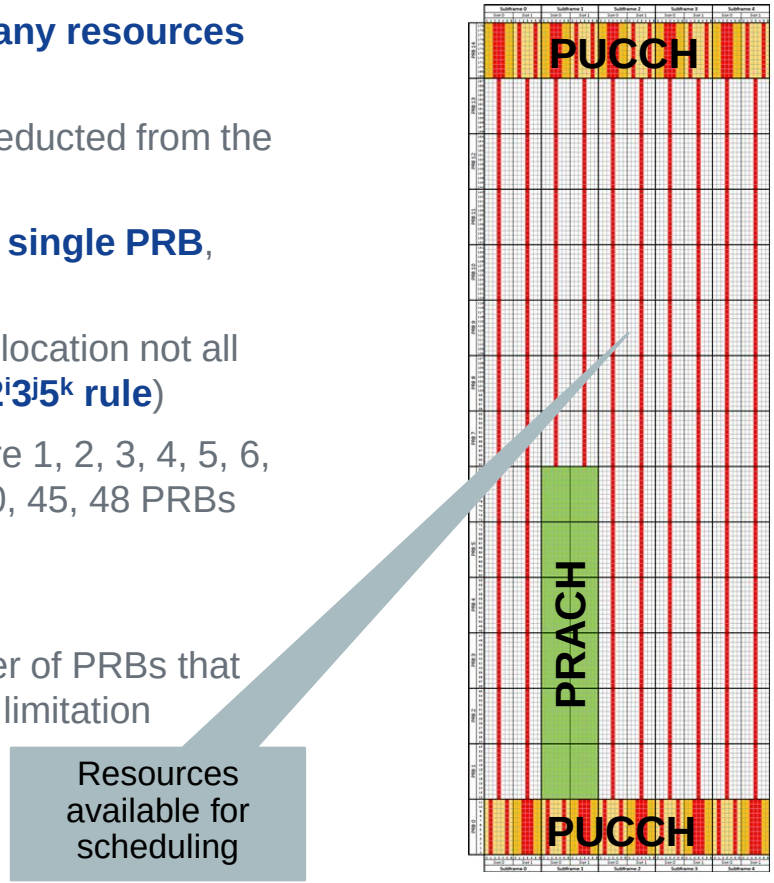
Evaluation of available resources

Main Menu

- The first step of UL scheduling consists of evaluating **how many resources** can be put in the scheduling pool.
  - The resources required for PUCCH, PRACH shall be deducted from the pool
  - The uplink allocations can be done with granularity of a **single PRB**, (unlike in downlink where RBGs are used)
  - Due to 3GPP originated limitations in uplink resource allocation not all quantities of PRBs can be allocated to any single UE (**$2^i 3^j 5^k$ rule**)
    - e.g. for 10MHz bandwidth the possible allocations are 1, 2, 3, 4, 5, 6, 8, 9, 10, 12, 15, 16, 18, 20, 24, 25, 27, 30, 32, 36, 40, 45, 48 PRBs (disregarding PUCCH bandwidth)

- There is also a mechanism (**ATB**) that reduces the number of PRBs that can be allocated to a single UE in case of its uplink power limitation



Frequency domain scheduling in uplink

Main Menu

- In Uplink allocation of available resources to UEs is done in two steps. In first step number of PRBs which will be allocated to each UE is calculated using following algorithms:

Weighted Round Robin (WRR)

➢Assigns physical resources equally fair to the UEs selected by TD scheduler until the PRBs are sufficient for the service or physical resources of the cell are used up
➢Not every bearer waiting for the transmission may be scheduled in every TTI
➢Weights are associated with each bearer (according to QCIs) to increase occurrence of selecting given bearer

Exhaustive (Ex)

➢Assigns in the priority sequence defined by TD scheduler as many physical resources as possible to the UE until the number of PRBs are sufficient for the service or resources of the cell are used up
➢The algorithm is unfair because not all UEs selected by TD scheduler may have some resources allocated
➢Algorithm is recommended for VoIP

Mixed Mode

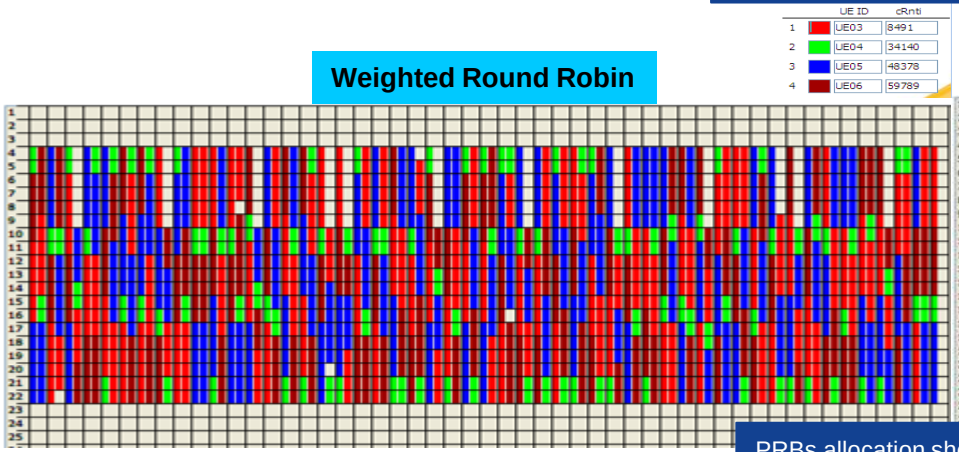
➢Mixed mode was introduced in RL30 and it is a combination of two above algorithms and it works in such a way that GBR bearers are handled by Ehxaustive and non-GBR bearers by Weighted Round Robin algorithms

RR vs Exh

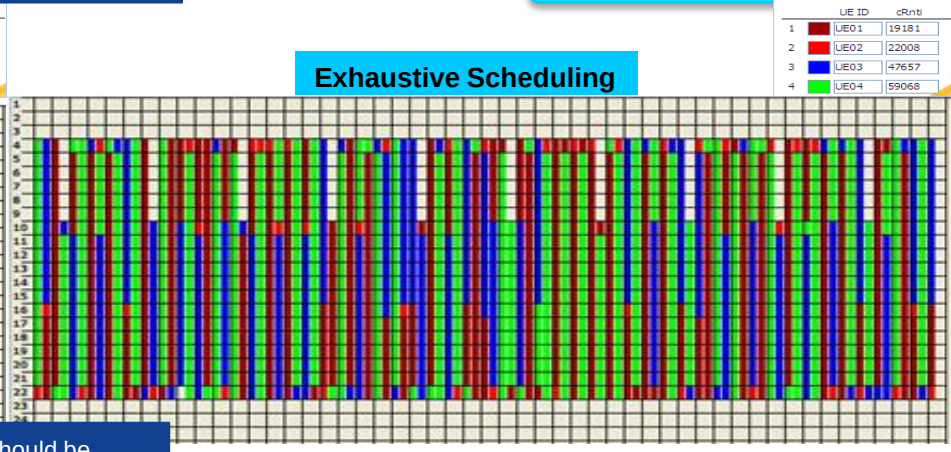
6PRBs used for PUCCH. Only 19 PRBs available for PUSCH

Main Menu

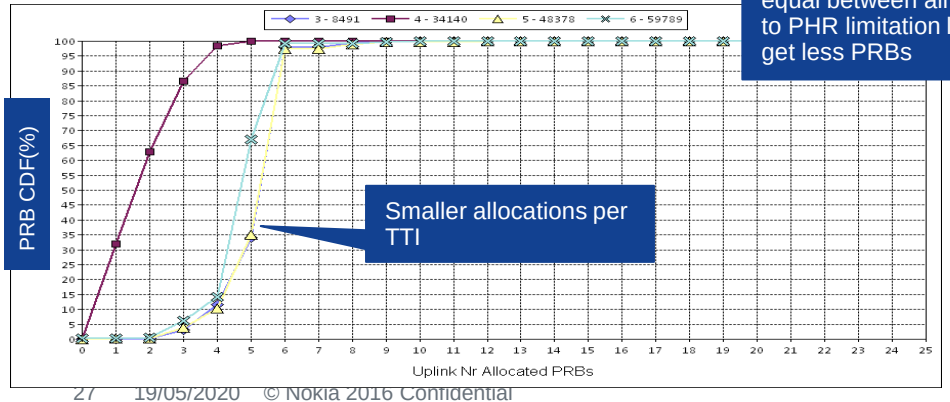
Weighted Round Robin



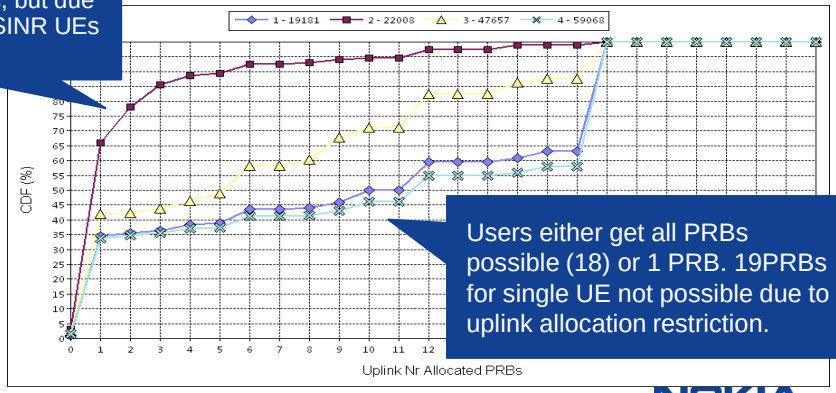
Exhaustive Scheduling



PRBs allocation should be equal between all UEs, but due to PHR limitation low SINR UEs get less PRBs



Smaller allocations per TTI



Users either get all PRBs possible (18) or 1 PRB. 19PRBs for single UE not possible due to uplink allocation restriction.

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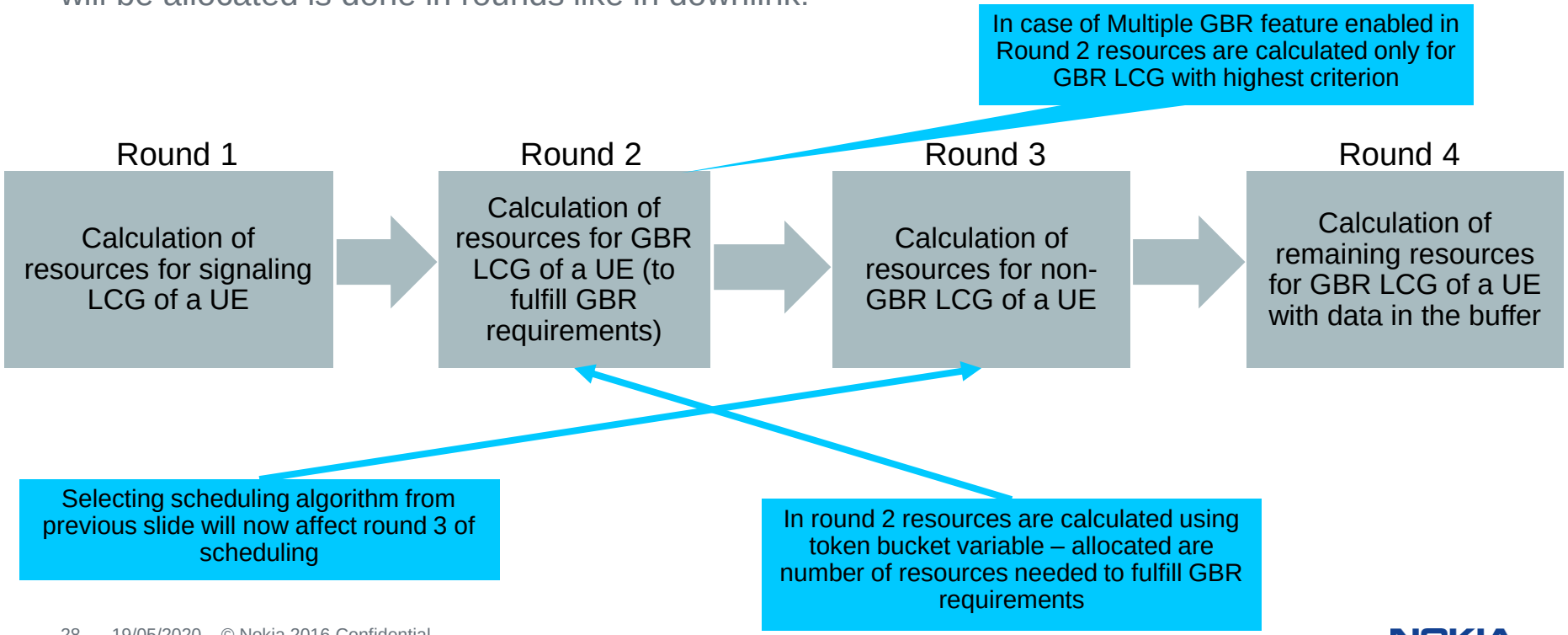
RL40 Frequency domain scheduling

Main Menu

- Starting with RL40 when support of QCI 2, 3 and 4 was introduced, calculation of resources which will be allocated is done in rounds like in downlink:



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LTE scheduler in RL40
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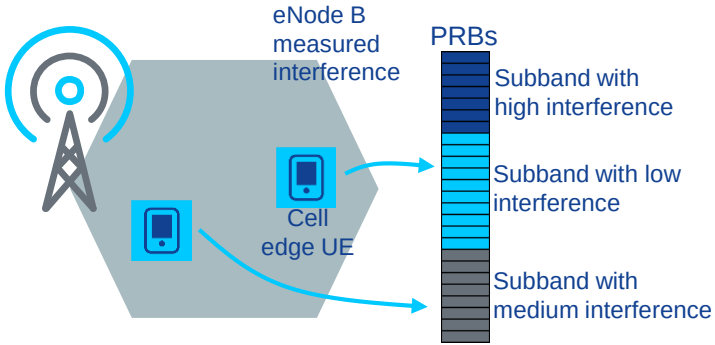
Uplink Interference aware scheduler (LTE619)

Main Menu

- The motivation for the improvement of the scheduler in the uplink is to make this scheduler interference aware
- The primary aim is to reduce the interference level as perceived by the neighboring cells
- The main focus is put on the performance of the cell edge users
  - Cell edge users have typically high TX power density
    - increased pathloss is compensated by increased TX power (UL open loop/closed loop Power Control algorithm)
    - Adaptive Transmission Bandwidth (ATB) mechanism allocates less PRBs for power-limited users

- The UEs with high TX power density will heavily interfere neighboring cells



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Uplink Interference Aware Scheduler (LTE 619) – details

Main Menu

- The scheduling criterion in the frequency domain (i.e. which users will have which PRBs) is based on Tx power density (Tx power per PRB)

1. The PUSCH spectrum is divided into several segments (can have different size)
2. For each segment the interference and noise power is measured
3. Segments are ranked according to measured noise+interference
4. Users with high TX power density are assigned to preferred segment (the one having lowest interference)

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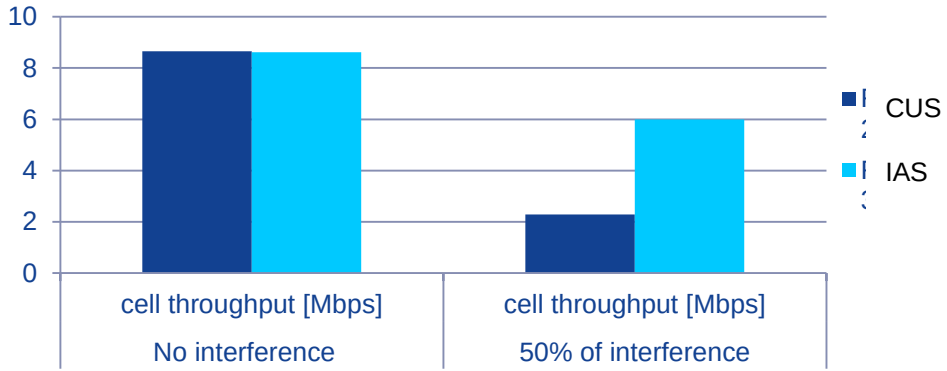
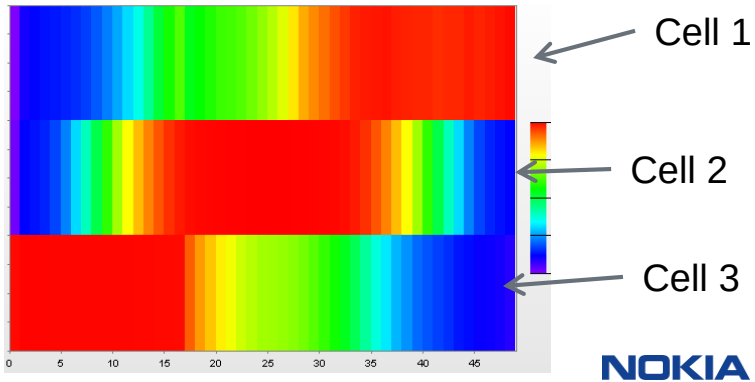
Uplink Interference Aware Scheduler (LTE 619) – gains

Main Menu

- ✓ The functionality brings most benefits if implemented in a cluster of neighboring cells
  - ✓ Each cell tends to assign own cell-edge users to different segment
- ✓ This type of functionality:
  - ✓ does not require full-blown channel aware scheduler (no need for SRS),
  - ✓ does not require ICIC solutions,
  - ✓ does not require presence of X2 interface
- ✓ The gains over Channel Unaware Scheduler will be most prominently visible in the clusters where the level of UL interferences is high





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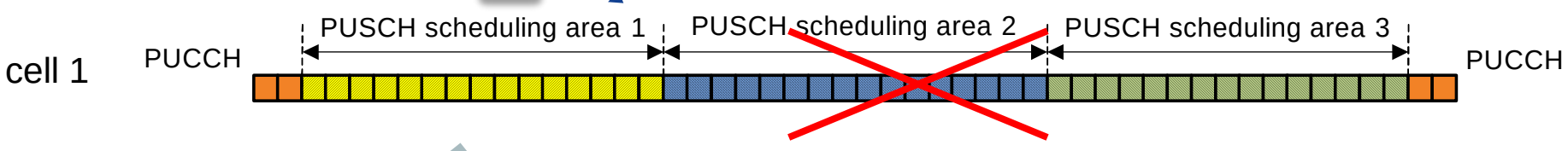
Interfernce Aware Scheduler - example

Main Menu

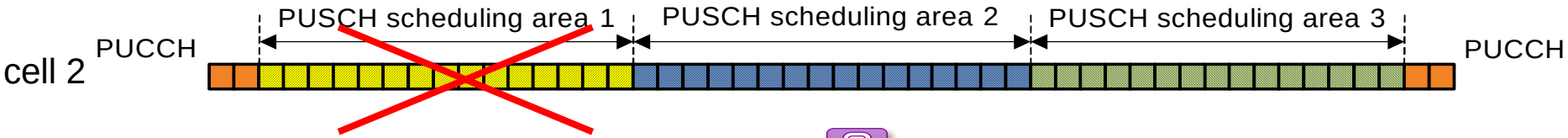
1. cell edge users assigned to “preferred” segment 1

5. cell edge users of cell 1 not assigned to segment 2



2. high interference measured in segment 1 of cell 2

4. high interference measured in segment 2 of cell 1



3. cell edge users not assigned to segment 1 of cell 2 but rather to segment 2

neighbor cells assign cell edge users to different segments

LTE scheduler in RL40

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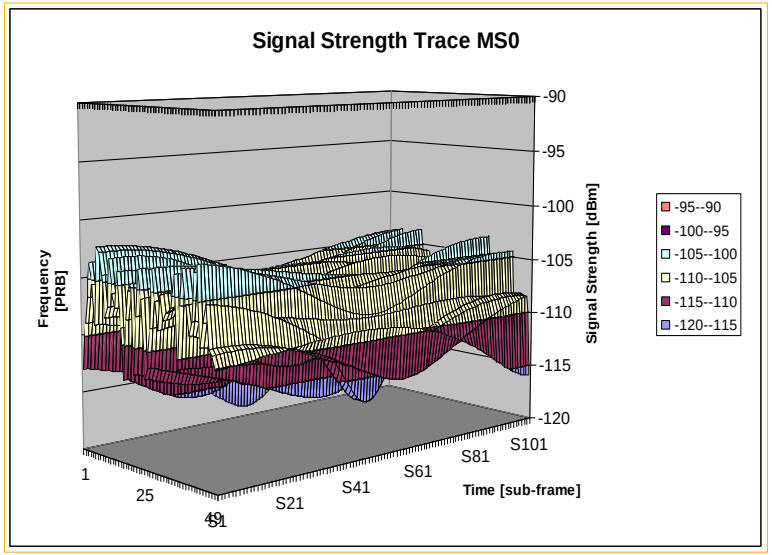
Channel Aware scheduler in uplink - principles

Main Menu

- The principle of channel aware scheduler is to further optimize assignments of the PRBs to the particular user in frequency domain
- The target of the algorithm is to **optimally assign the uplink resources** (UL PRBs) depending on the actual quality of air link between given UE and eNB
- The scheduler uses both **channel awareness and interference awareness** for the optimum PRB allocation
  - PUSCH area divided into segments and UE allocation is focusing on “preffered segment” with lower measured interference level
  - The most important gain coming from this feature is **boosted overall system capacity**
  - Gains are visible especially in clusters with high UL interference level



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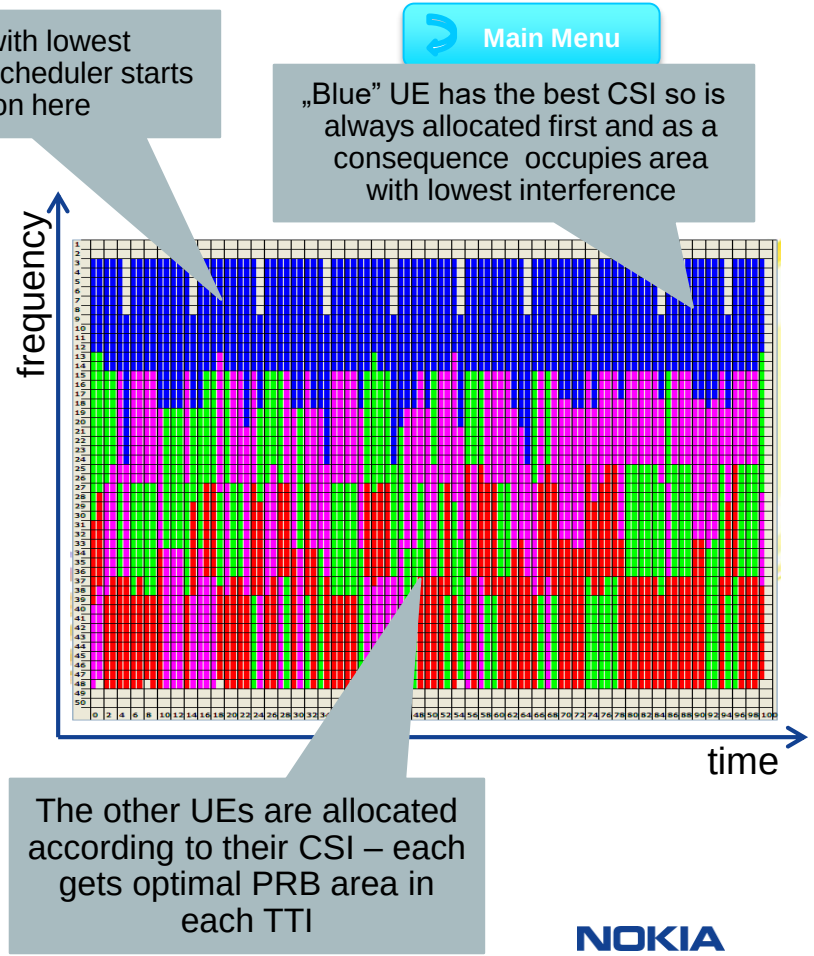
Channel Aware Scheduler – details

- Channel Aware Scheduler decisions covers two dimensions:
  - Uplink interference level
    - Done by splitting PUSCH area into contiguous zones and zone with lowest interference is selected (separate evaluation for each TTI)
  - Signal strength of each UE
    - The scheduler tries to find optimum allocation for each UE, in function of Channel State Information. Allocation starts with zone which has the lowest interference.
- Scheduler tries to find optimum allocation for each UE
  - Uplink allocations need to be continuous, therefore scheduler can't allocate best individual PRBs for each UE, rather it focuses on optimal averaged area for given number of PRBs



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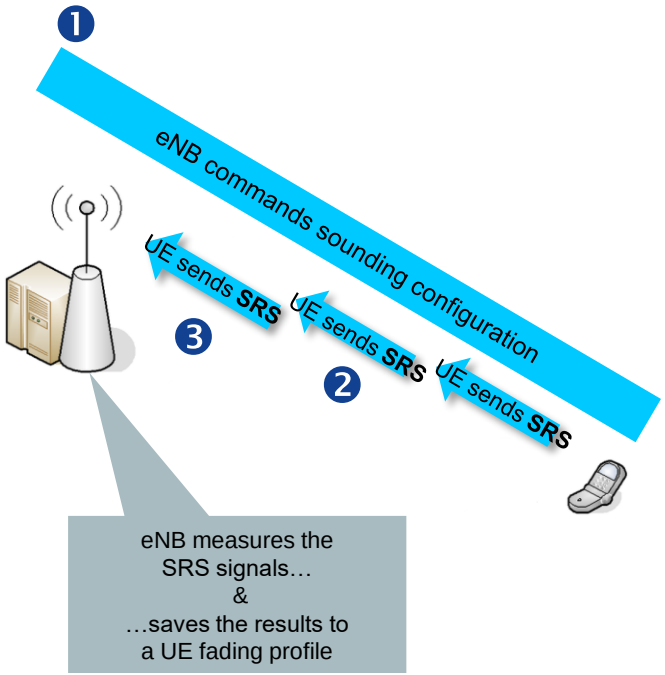
Channel Aware Scheduler – details

Main Menu

- The feature requires the UEs to include the Sounding Reference Signals (SRS) in their transmission
  - SRS is UL equivalent to CQI reporting for the DL scheduling
  - UL Tx power for SRS may vary from the one used for PUSCH
- The channel state information is derived from SRS and PUSCH – per UE, per PRB.
  - Bandwidth relevant for SRS is higher than the one used for PUSCH
- Not all UEs served by a given cell may have SRS configured:
  - for high number of active UEs some UEs may be scheduled without SRS (scheduling is still channel aware but the CSI of such UEs is only based on PUSCH)



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Sounding Reference Signals – introduction

Main Menu

- The Channel State Information is derived from the **Sounding Reference Signals**
  - Sounding Reference Signals (SRS) are special signals defined in uplink
  - Their transmission by UEs is independent from PUSCH and PUCCH transmission
    - **SRS use different bandwidth** than this for PUCCH (several PRBs at the edge of uplink band) and for PUSCH (decided and assigned by uplink scheduler)
  - The SRS can occupy 4 PRBs at minimum, the maximum range depends on the system bandwidth
  - The SRS are always transmitted at **the last OFDM symbol** of the subframe
    - The resource blocks (PRBs) at the SRS subframes will have reduced capacity
  - The available configurations contain each 2 classes of SRS – one wideband configuration and one narrowband
    - The Nokia system first allocates UEs with wideband SRS transmission (Class 1), if there is no more Class 1 capacity left, the next UEs are assigned with Class 2 SRS configuration (narrowband)
    - UEs with insufficient power resources will have their SRS class downgraded (Class 1=>Class 2)
  - SRS Hopping is always enabled
  - Supported periodicities: 5 ms and 10 ms

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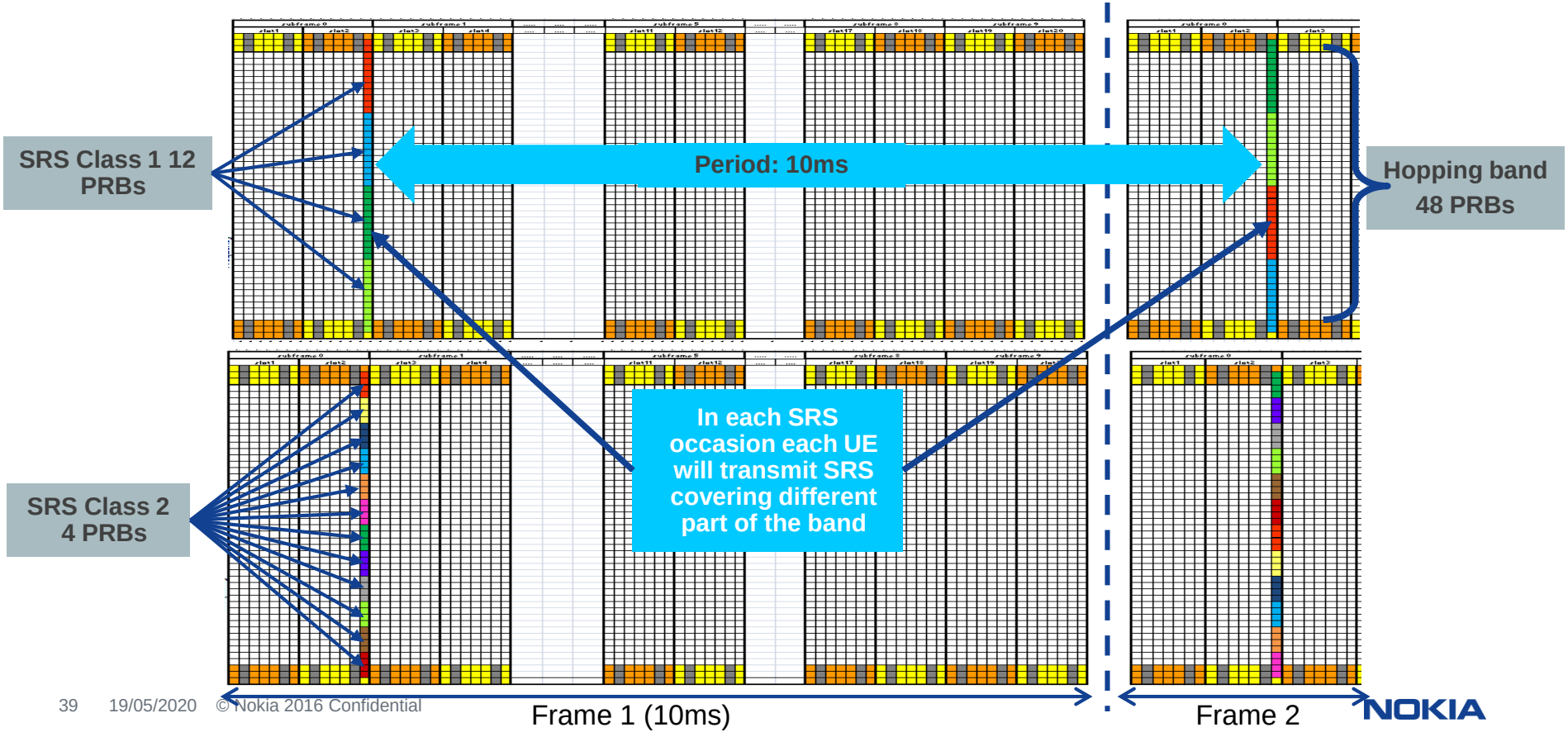
SRS configuration example (10MHz, 10ms SRS periodicity)

Main Menu



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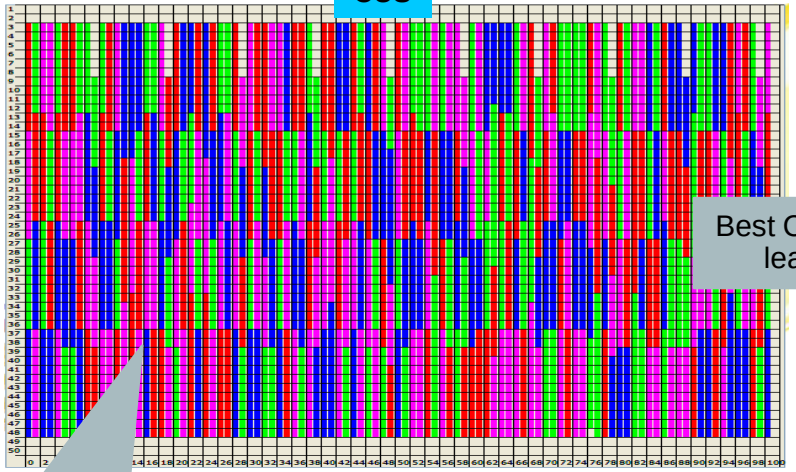
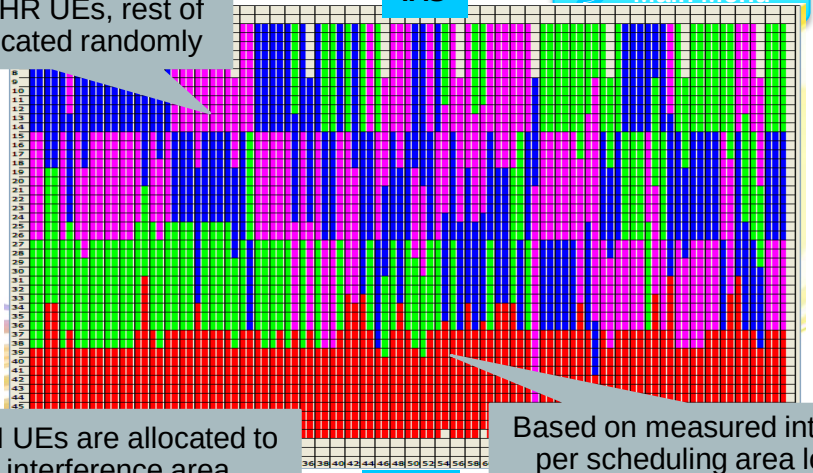
CUS vs. CAS vs. IAS

Plots show PRBs allocation per TTI

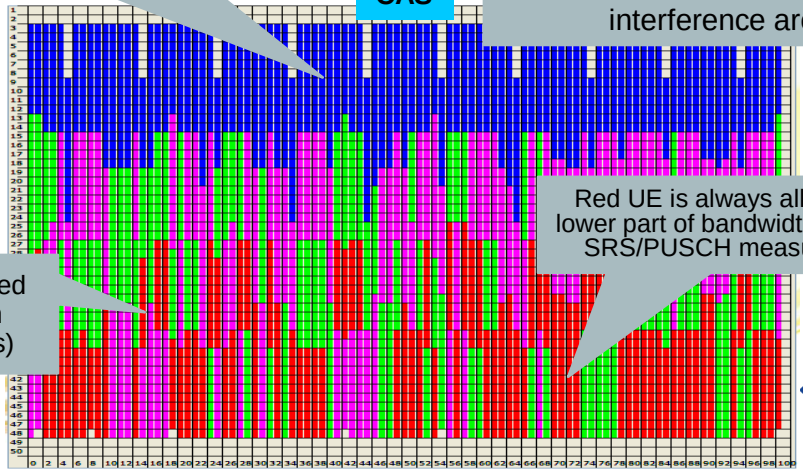
CUS



IAS



CAS



Except low PHR UEs, rest of them are allocated randomly

Best CSI UEs are allocated to least interference area

Based on measured interference per scheduling area low PHR UEs are allocated to least interference area

PRB allocation is random. All PRBs are used all the time for all UEs

Rest of UEs are allocated based on channel state information (SRS/PUSCH measurements)

Red UE is always allocated on lower part of bandwidth, based on SRS/PUSCH measurements

Main Menu

CUS vs. CAS vs. IAS

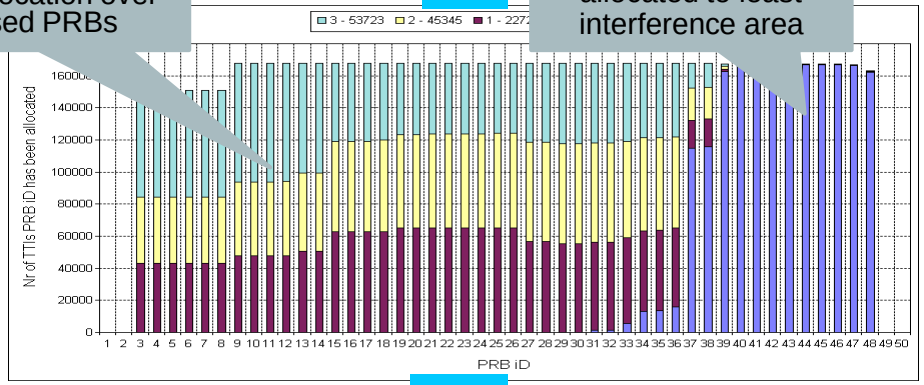
Main Menu

Plots show how often each PRB has been allocated to specific UE

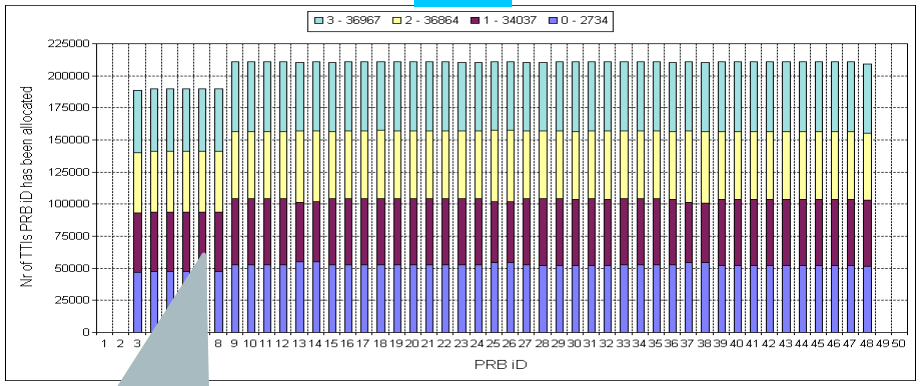
Rest of UEs have random allocation over all unused PRBs

Low PHR UE always allocated to least interference area

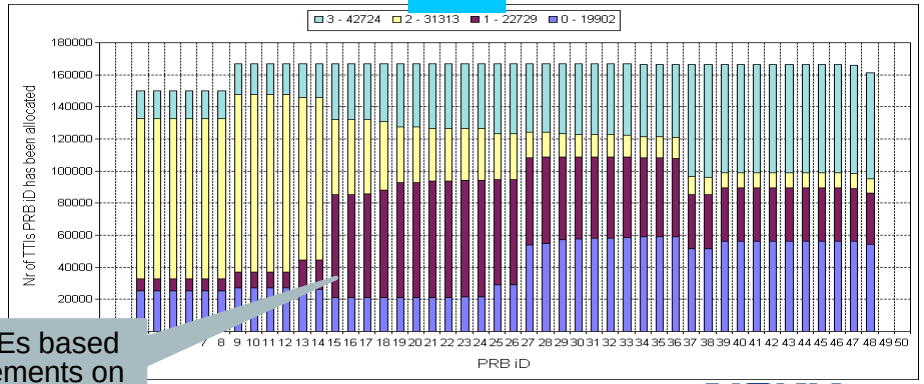
IAS



CUS



CAS



All PRBs are used over time by all UEs – equally distributed

PRBs allocated to UEs based on absolute measurements on SRS/PUSCH

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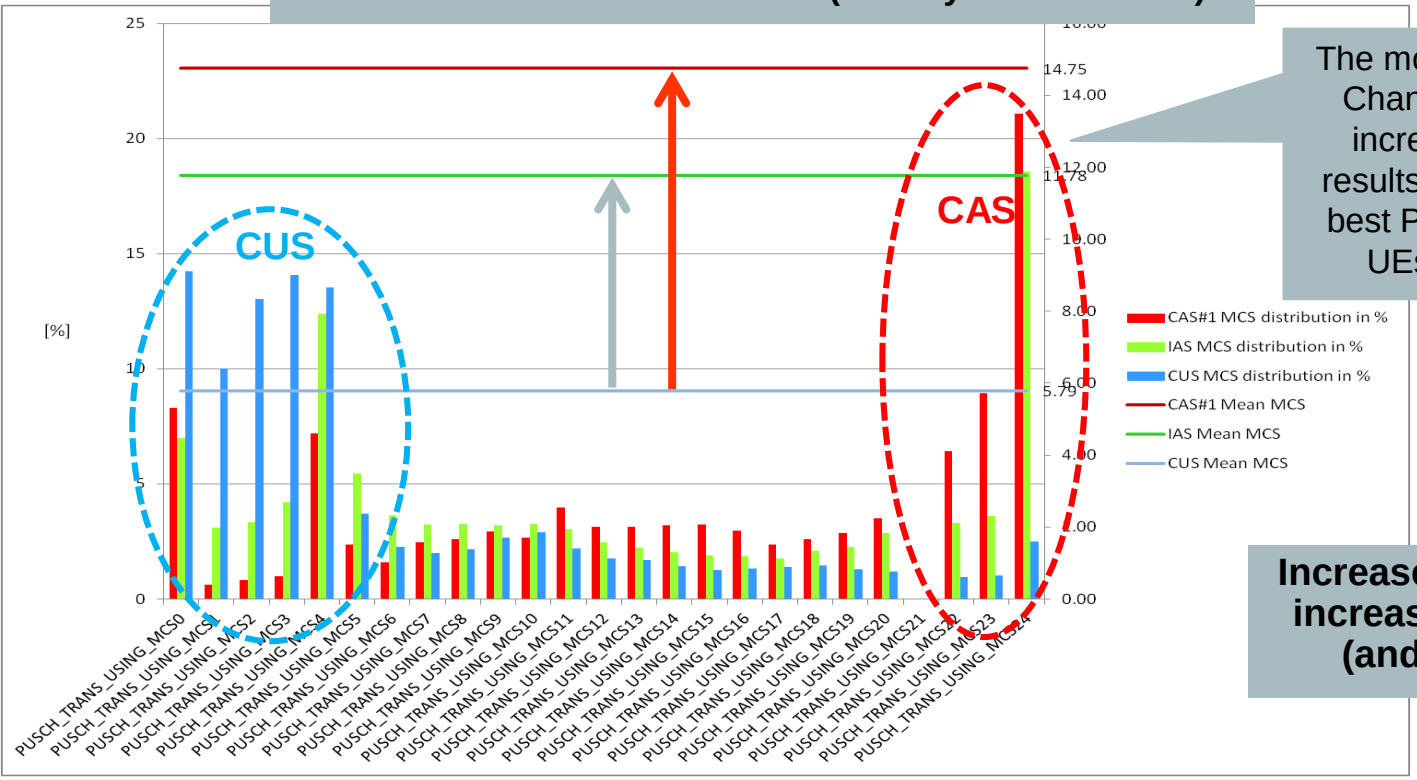
CUS vs. CAS vs. IAS

Main Menu

Distribution of individual MCSs (from system counters)



The most significant outcome of the Channel Aware Scheduler is the increase in average MCS. This results from intentional selection of best PRB allocations for individual UEs, based on reported CSI.

Increased MCS translates into increased uplink throughput (and also cell capacity)

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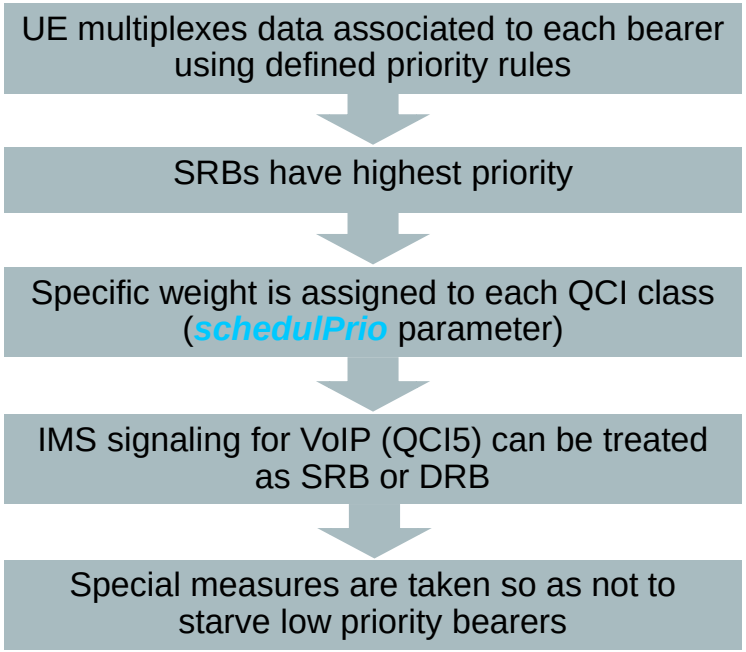
Handling of bearers within one UE – UL

Main Menu

- UE is responsible for handling the priorities of its bearers in uplink
- It is not done by the uplink scheduler because only UE knows the state of buffer for each of its bearers. Separate scheduling of individual bearers would generate too much signaling traffic. Moreover, the Scheduling Grant is issued per UE, not per specific radio bearer



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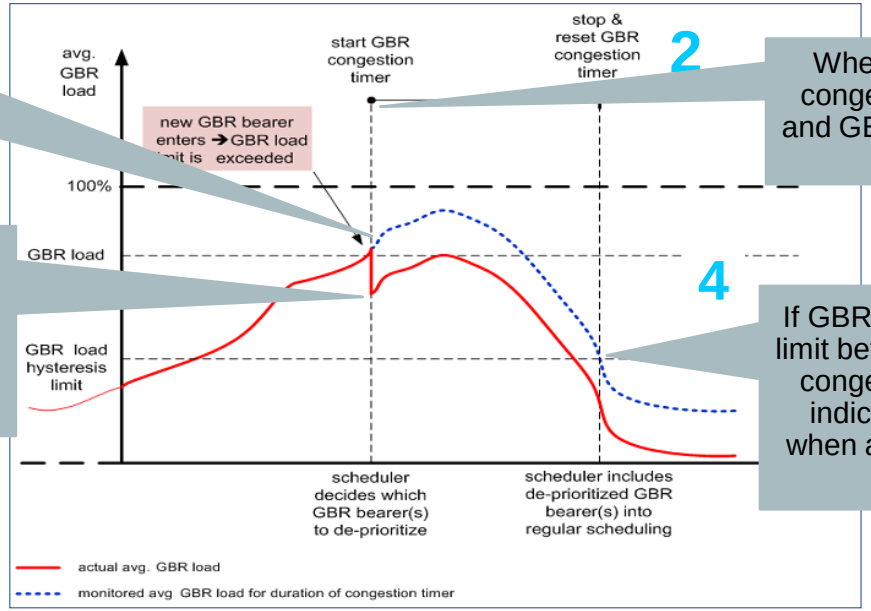
Congestion detection and handling

Main Menu

- Starting with RL40 when support of QCI 2,3 and 4 was introduced to fulfill QoS requirements for new GBR bearers, congestion detection and handling mechanism had to be created

1 Congestion is detected when average PDSCH cell level resource utilization from GBR bearers exceeds GBR load limit - ***maxGbrTrafficLimit*** parameter



2 When congestion is detected congestion timer starts running and GBR bearers are selected for de-prioritization

3 Bearers are de-prioritized in order of QCI priority or ARP priority depending on chosen algorithm (in uplink power bearers of power limited UEs are de-prioritized first)

4 If GBR load will fall below hysteresis limit before congestion timer expires, congestion is resolved. Otherwise indication is send to higher layer when admission control can release de-prioritized bearers

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DL scheduler configuration parameters

Main Menu

- Scheduler works in a certain way – there are not many parameters to configure it.
- To activate RL40 scheduler parameter ***actEnhAcAndGbrServices*** have to be set to true.
  - With support of QCI 2,3,4 ***gbrCongHandling*** parameter should be set to enable congestion handling
  - Congestion weight calculation algorithm should be chosen using ***congWeightAlg*** parameter
- To differentiate priority between non-GBR bearers ***schedulWeight*** parameter for each QCI should be set accordingly
- For GBR bearers ***delayTarget*** and ***schedulBSD*** parameter should be chosen to assure required QoS
- ***maxNumUeDl*** parameter must also be set to allow multiple UEs to be scheduled within 1TTI

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UL Configuration parameters

Main Menu

- There are also not many parameters in Uplink scheduler that need to be set/tuned
- The main parameter is ***ulsSchedMethod*** which can be set to **CUS IAS** or **CAS**
- Second most important parameter is ***ulsFdPrbAssignAlg*** which can be set to **RoundRobinFD**, **ExhaustiveFD** or **MixedFD**, but if previous parameter is set to IAS or CAS this must be set to MixedFD.

- If Channel Aware Scheduler is chosen following parameters also need to be configured:
  - Sounding Reference Signals must be activated and configured with ***srsConfiguration*** *(starting with FL15A its* ***srsActivation****)* parameter
  - Number of PUSCH scheduling areas must be configured with ***ulsNumSchedAreaUl*** parameter (starting from FL16)

- ***maxNumUeUl*** parameter must also be set to allow multiple UEs to be scheduled within 1TTI

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SRS capacity and scanning time: 20 MHz

Table of Contents

Available configurations for 20 MHz bandwidth

Time needed for a single UE to report SRS from entire hopping bandwidth

20 MHz	Hopping SRS bandwidth	SRS periodicity [ms]	SRS bandwidth wide	Full report time [ms]	Capacity (number of UEs)	SRS bandwidth narrow	Full report time [ms]	Capacity (number of UEs)
Configuration 1	96	10	16 PRBs	60	48	4 PRBs	240	192
Configuration 2	96	5	16 PRBs	30	24	4 PRBs	120	96
Configuration 3	80	10	20 PRBs	40	32	4 PRBs	200	160
Configuration 4	80	5	20 PRBs	20	16	4 PRBs	100	80

Configurations recommended for LTE786

Quantity of UEs than can transmit SRSs in a given configuration

In most cases these are the only configurations allowing for practical deployment of PUCCH blanking (i.e. allowing for blanking more than just single border PRBs)

The configurations with 10 ms periodicity allow for doubling the capacity (two sets of SRS can be configured because SRS occasions occur every 5ms)

SRS capacity and scanning time: 10 MHz

Table of Contents

Available configurations for 10 MHz bandwidth

Time needed for a single UE to report SRS from entire hopping bandwidth

10 MHz	Hopping SRS bandwidth	SRS periodicity [ms]	SRS bandwidth wide	Full report time [ms]	Capacity (number of UEs)	SRS bandwidth narrow	Full report time [ms]	Capacity (number of UEs)
Configuration 1	48	10	12 PRBs	40	32	4 PRBs	120	96
Configuration 2	48	5	12 PRBs	30	16	4 PRBs	60	48
Configuration 3	48	10	8 PRBs	60	48	4 PRBs	120	96
Configuration 4	48	5	8 PRBs	30	24	4 PRBs	60	48
Configuration 5	40	10	20 PRBs	20	16	4 PRBs	100	80
Configuration 6	40	5	20 PRBs	10	8	4 PRBs	50	40
Configuration 7	32	10	8 PRBs	40	32	4 PRBs	80	64
Configuration 8	32	5	8 PRBs	20	16	4 PRBs	40	32

Quantity of UEs than can transmit SRSs in a given configuration

Configurations recommended for LTE786

NOKIA

SRS capacity and scanning time: 5 MHz

Table of Contents

Available configurations for 5 MHz bandwidth

Time needed for a single UE to report SRS from entire hopping bandwidth

5 MHz	Hopping SRS bandwidth	SRS periodicity [ms]	SRS bandwidth wide	Full report time [ms]	Capacity (number of UEs)	SRS bandwidth narrow	Full report time [ms]	Capacity (number of UEs)
Configuration 1	24	10	24 PRBs	10	8	4 PRBs	60	48
Configuration 2	24	5	24 PRBs	5	4	4 PRBs	30	24
Configuration 3	20	10	20 PRBs	10	8	4 PRBs	50	40
Configuration 4	20	5	20 PRBs	5	4	4 PRBs	25	20

Configurations recommended for LTE786

Quantity of UEs than can transmit SRSs in a given configuration

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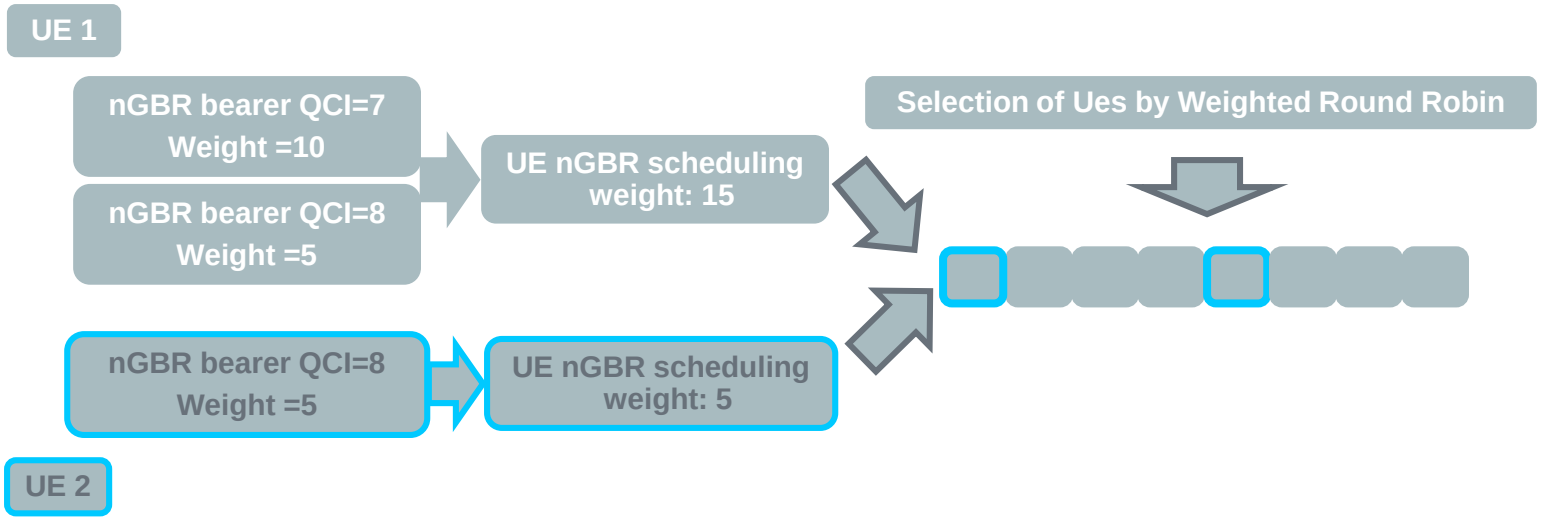
UE weights - example

Main Menu



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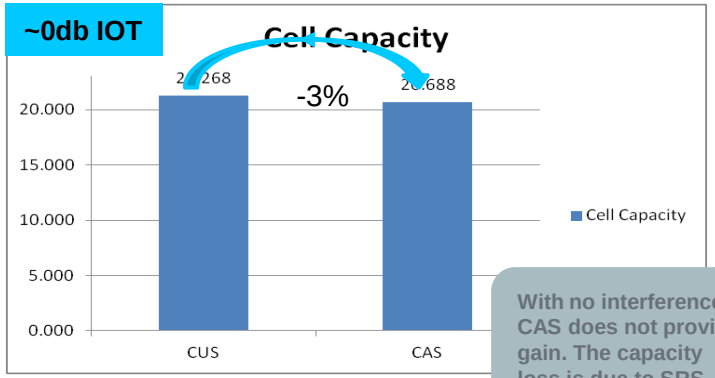
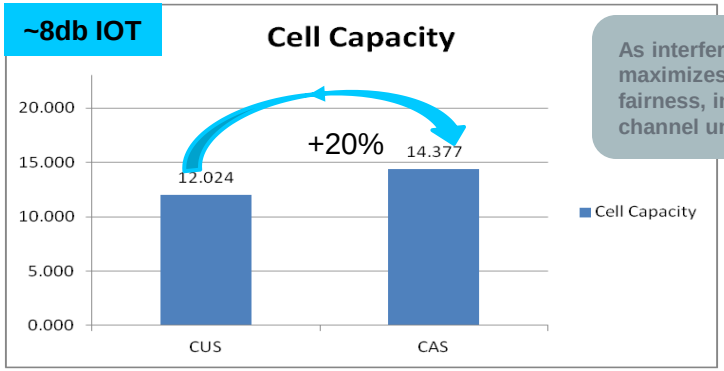
Feature benefits – capacity increase



With no interference CAS does not provide gain. The capacity loss is due to SRS

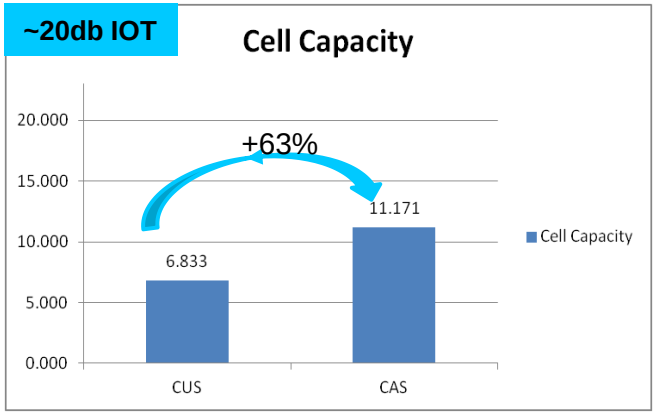


As interference increases , CAS maximizes cell capacity and fairness, in comparison to channel unaware scheduling.

The LTE46 Channel Aware Scheduler is expected to increase the uplink capacity in the interfered scenarios

The increase in capaciy is caused by the Channel State Information making it is possible to allocate optimal resources for UEs

This allows for increase of **Modulation and Coding Scheme (MCS)** and more robust transmission. As a result, both **uplink throughput** available for a given UE, and the **probability of successful transmission** are increased



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Results 10MHz

Cell Throughput

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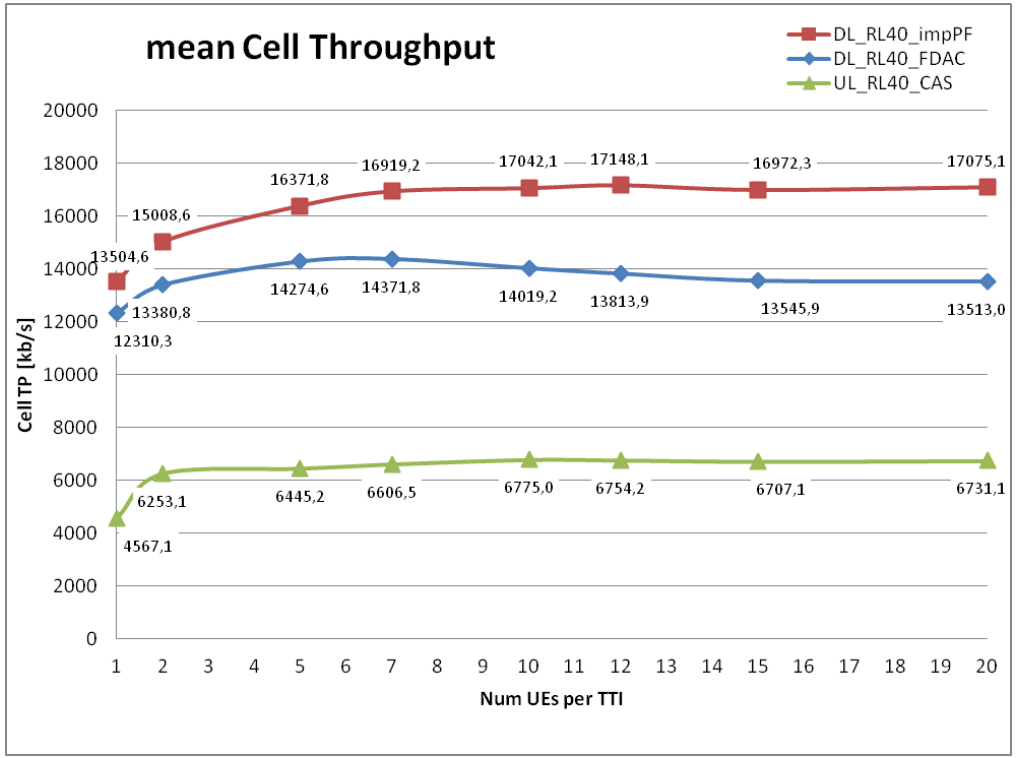

- impPF scheduler achieves the highest mean cell TP values with max for 12 UEs per TTI.
- FDAC scheduler has maximum at 7 UEs per TTI, then for increasing Num UEs per TTI Cell TP result is almost flat.
- UL CAS scheduler has maximum at 10 UEs per TTI, while is quite stable among 7 – 20 UEs per TTI.

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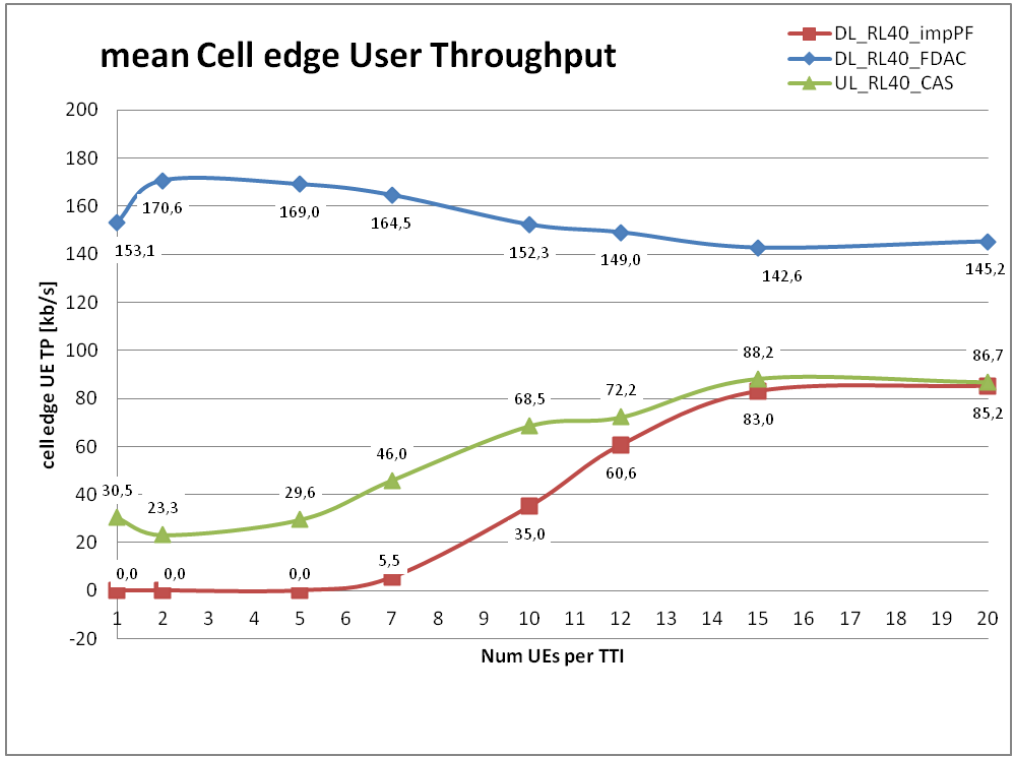
Results 10MHz

Cell edge User Throughput



- FDAC scheduler achieves the highest cell edge UE TP while is not the best with mean cell TP statistic.
- impPFsched is focused on maximizing cell TP, thus cell edge UE TP suffers significantly for low number of UEs per TTI.
- UL CAS and DL FDAC consider all UEs in FD scheduling step, thus cell edge TP is quite stable.

Results 10MHz

Number of scheduled UEs

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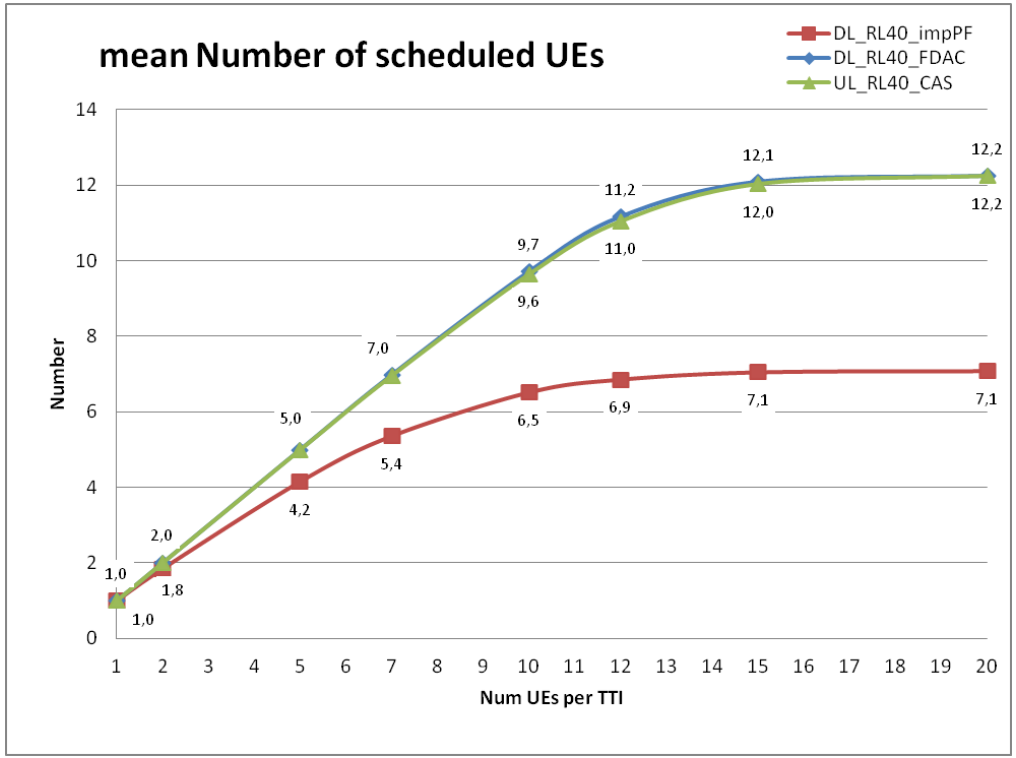

- impPFsched schedules lower number of UEs. It selects only the best UE per each RBG thus maximize cell TP.
- FDAC and UL CAS consider all UEs in CS2 (Candidate Set 2 = FD scheduling step).
- PDCCH blocking limits number of scheduled UEs for FDAC and UL CAS schedulers (saturation on 12 scheduled UEs), while impPF is limited by the algorithm itself (saturation for 7 scheduled UEs).

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Results 10MHz

PDCCH blocking

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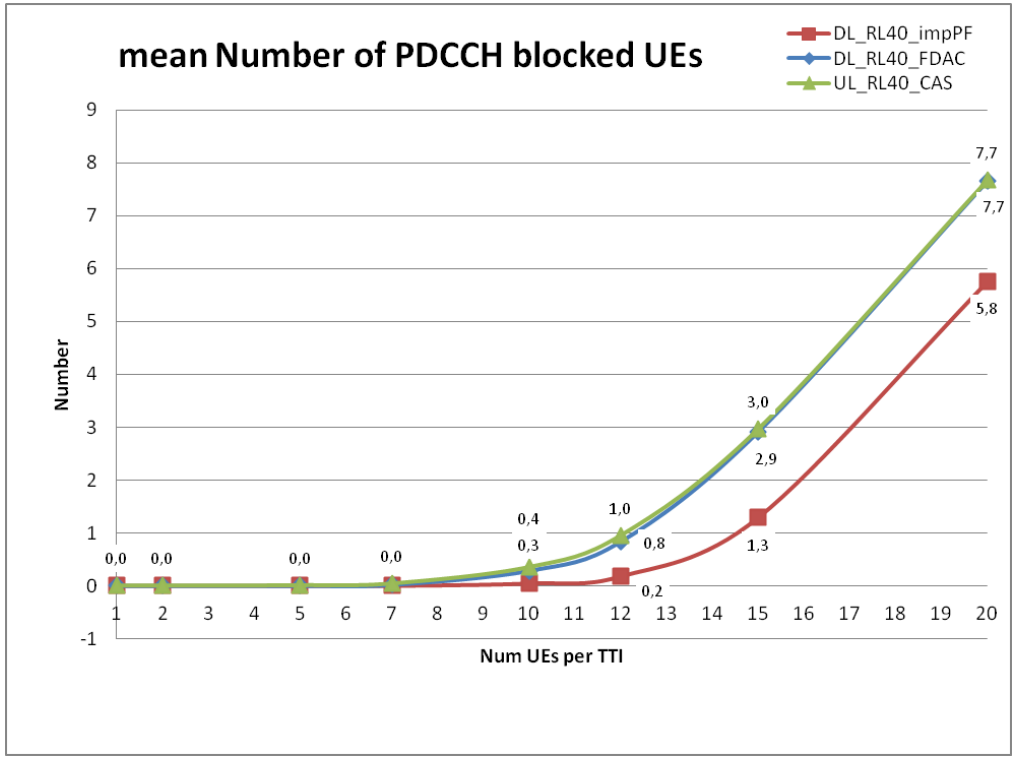

- Blocking figure considers both in CCE resource shortage and hashing function.
- Since FDAC and UL CAS put all UEs in FD scheduling step, PDCCH blocking is more visible for such cases.
- imPFsched selects lower number of UEs to CS2 – PDCCH blocking is not impacting so much.
- Higher PDCCH blocking rate does not impact cell and user TP for high load (full buffer) nonGBR traffic.

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Results 5MHz
Cell Throughput

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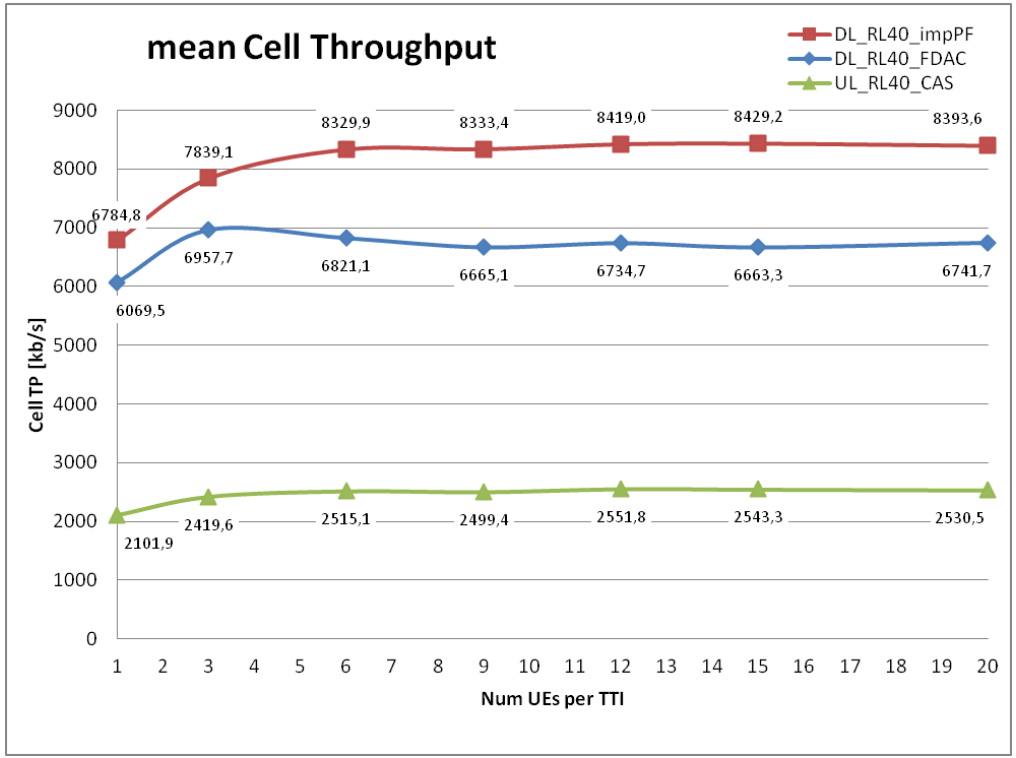

- impPF scheduler achieves the highest mean cell TP values with max for 15 UEs per TTI, while is quite stable among 6 – 20 UEs per TTI.
- FDAC scheduler has maximum at 3 UEs per TTI, then for increasing Num UEs per TTI Cell TP result is almost flat.
- UL CAS scheduler has maximum at 12 UEs per TTI, while is quite stable among 3 – 20 UEs per TTI.
- Mean cell TP is ~2x lower than for 10 MHz BW.

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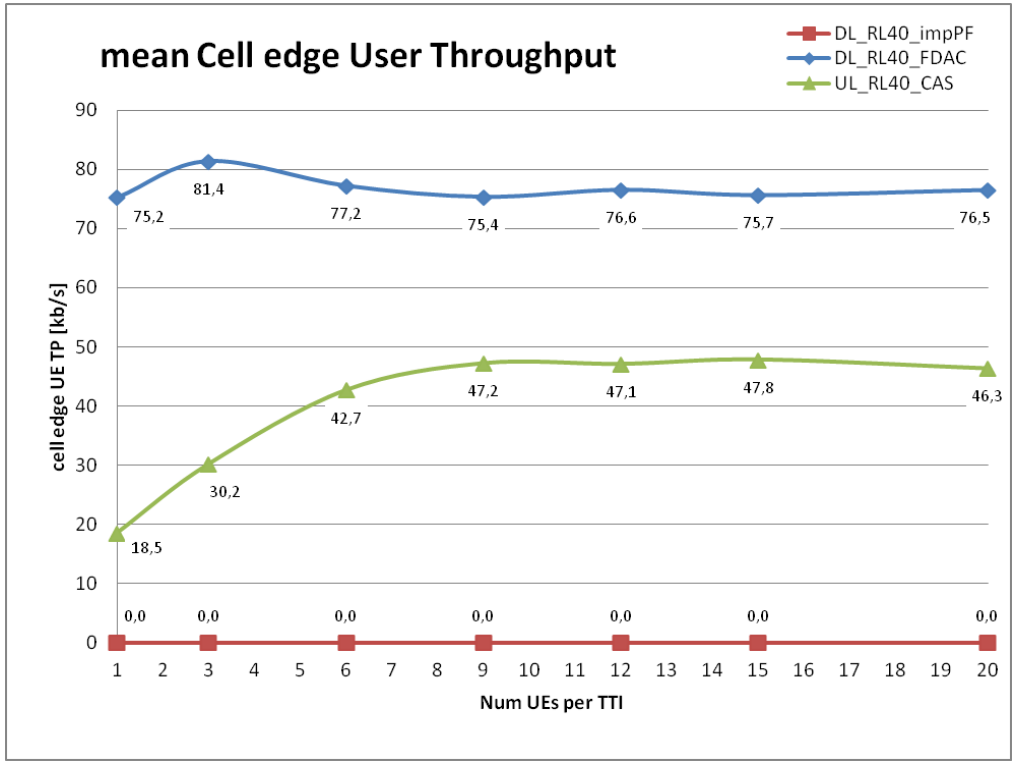
Results 5MHz
Cell edge User Throughput

Table of Contents



- FDAC scheduler achieves the highest cell edge UE TP while is not the best with mean cell TP statistic.
- impPFsched is focused on maximizing cell TP, thus cell edge UE TP suffers significantly. For 20 UEs registered per cell, throughput at the cell edge per UE is close to 0.
- UL CAS and DL FDAC consider all UEs in FD scheduling step, thus cell edge TP is quite stable.

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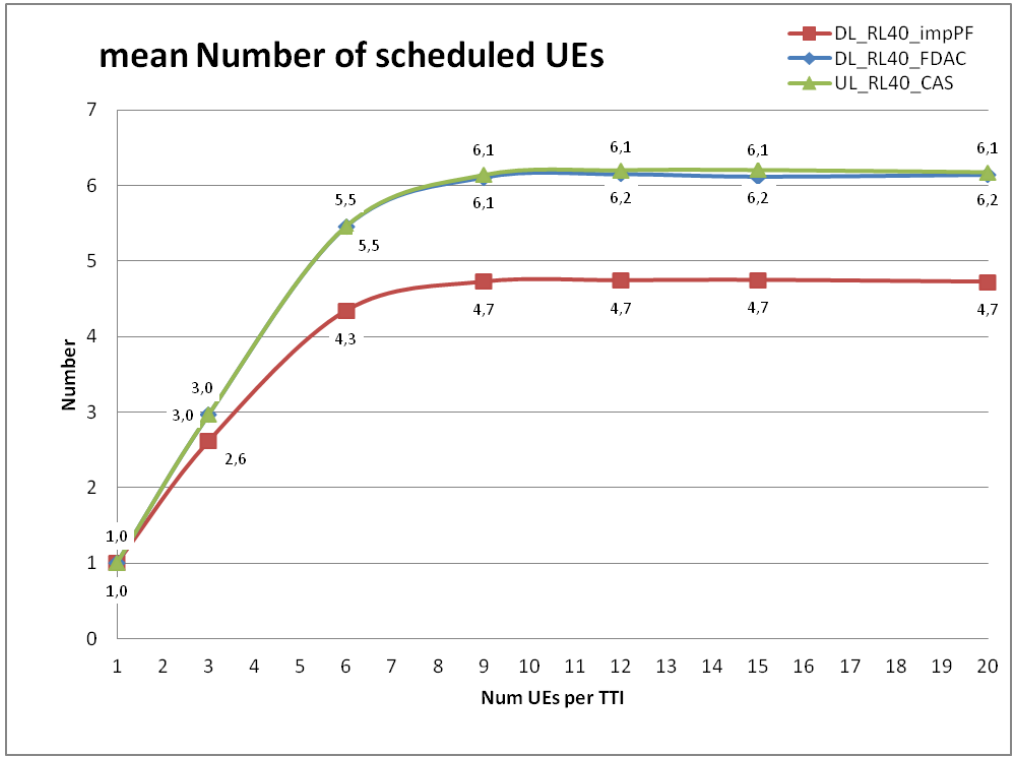
Results 5MHz
Number of scheduled UEs

Table of Contents



- impPFsched schedules lower number of UEs. It selects only the best UE per each RBG thus maximize cell TP.
- FDAC and UL CAS consider all UEs in CS2 (Candidate Set 2 = FD scheduling step).
- PDCCH blocking limits number of scheduled UEs for FDAC and UL CAS schedulers (saturation on 6 scheduled UEs), while impPF is limited by the algorithm itself (saturation for ~4,7 scheduled UEs).
- Saturation for DL FDAC and UL CAS is achieved for 2x lower number of UEs than for 10 MHz BW.

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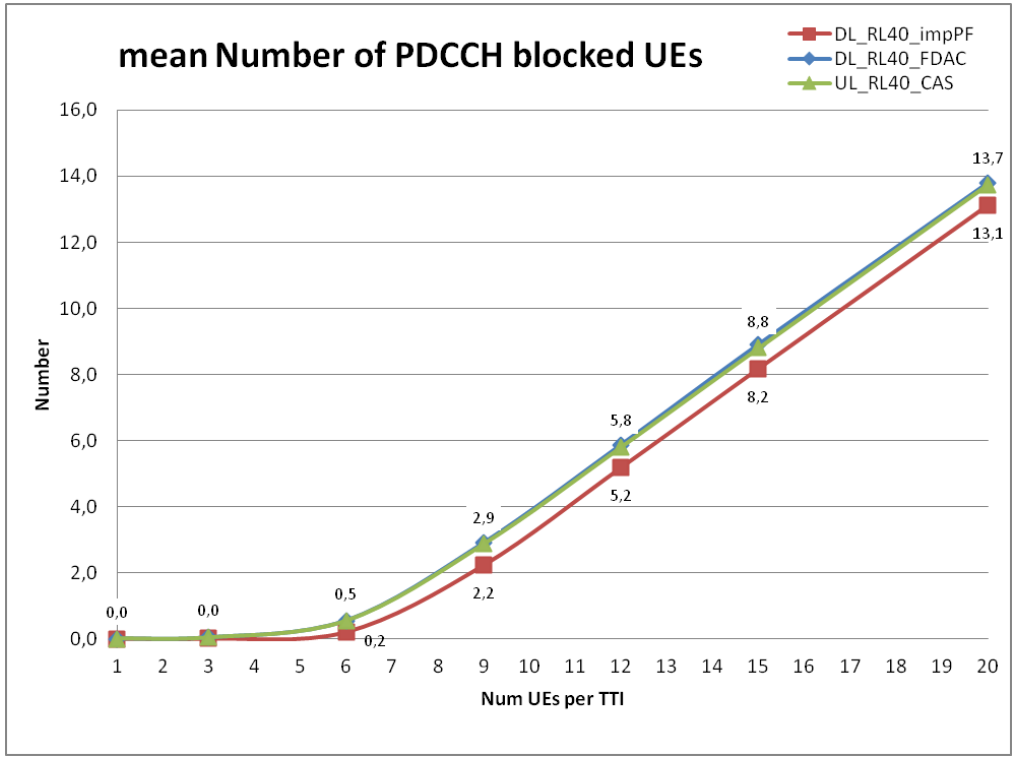
Results 5MHz
PDCCH blocking

Table of Contents



- Blocking figure considers both in CCE resource shortage and hashing function.
- Since FDAC and UL CAS put all UEs in FD scheduling step, PDCCH blocking is more visible for such cases.
- imPFsched selects lower number of UEs to CS2 – PDCCH blocking is lower.
- Comparing to 10 MHz BW curve is shifted to the left. Less resources cause PDCCH blocking for lower number of UEs per TTI.
- Higher PDCCH blocking rate does not impact cell and user TP for high load (full buffer) nonGBR traffic.
- It may reduce GBR performance due to increased packet delay.

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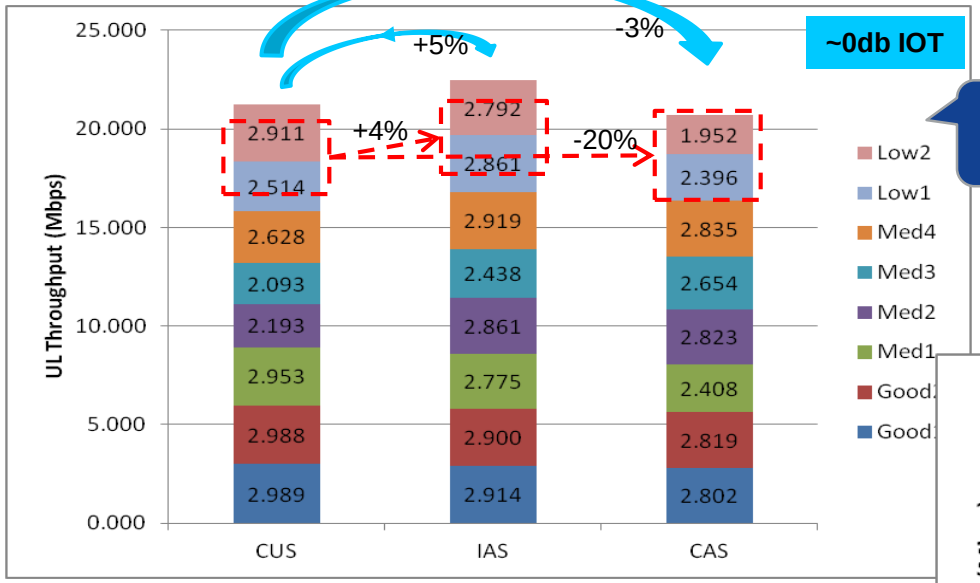
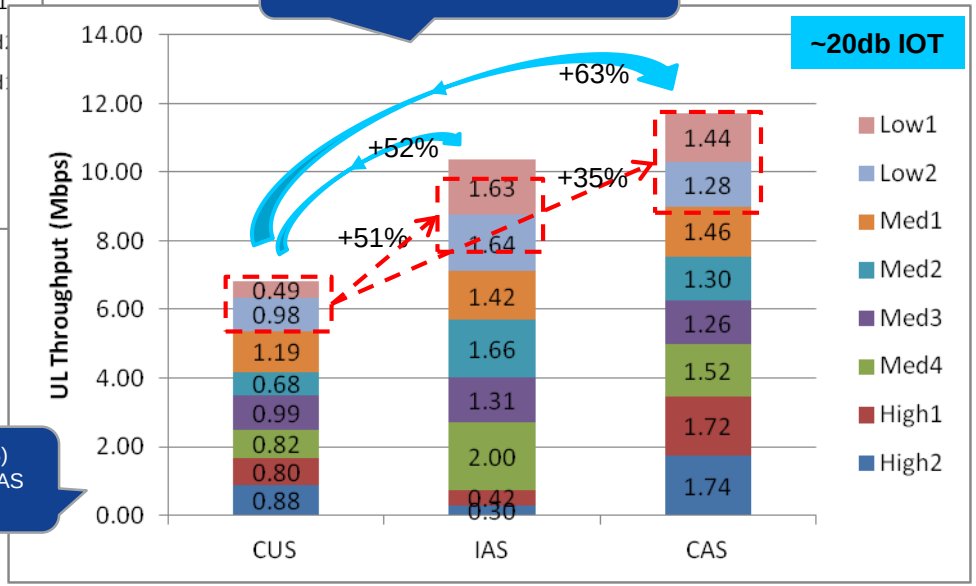
CUS vs. IAS vs. CAS gain in minimum and maximum load



With lower interference, cell capacity is almost similar for all scheduler types and impact of scheduler is small. Low overall throughput in CAS maybe because of variability in radio conditions

Low SINR UEs show best performance gain with IAS, but the overall system capacity is best in CAS.

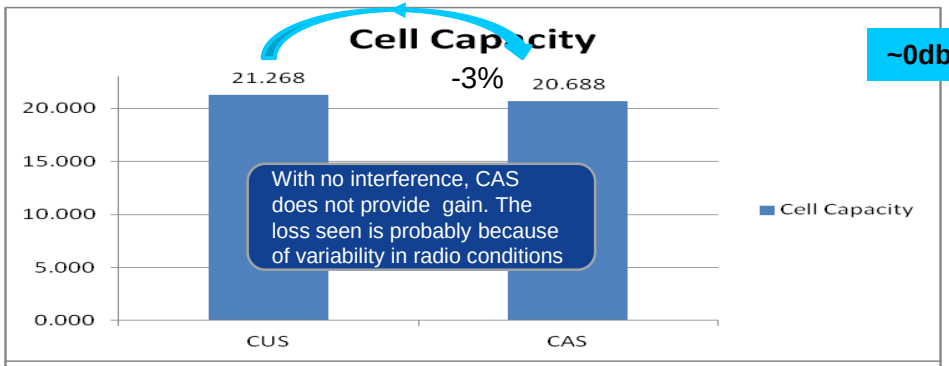


Under high interference, Channel aware scheduling (CAS) outperformed Interference Aware Scheduling (IAS), and IAS outperformed Channel Unaware scheduling (CUS).

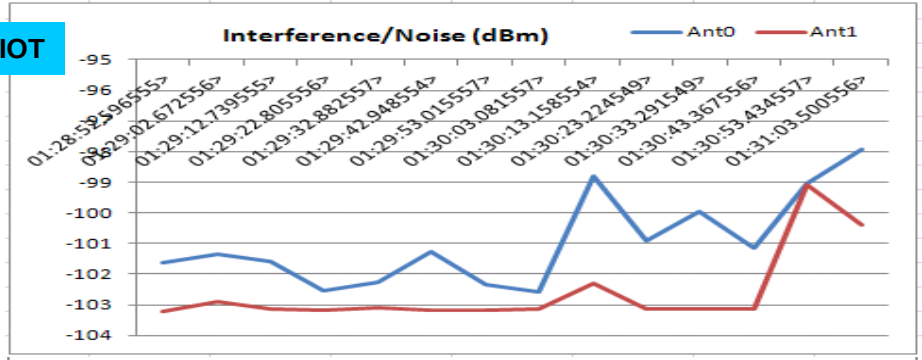
System Capacity

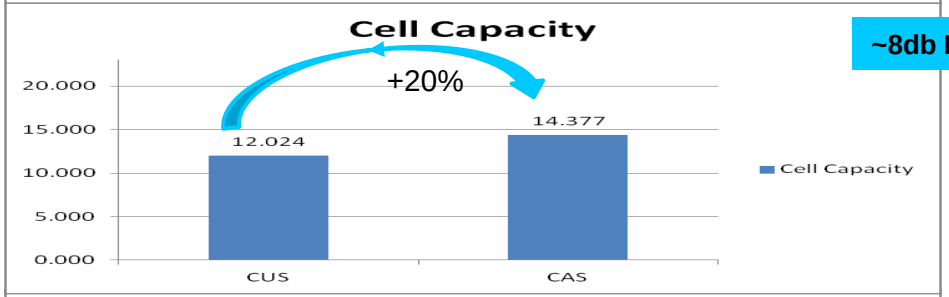
Low SINR UEs

CUS vs. CAS gain with increasing fading/interference

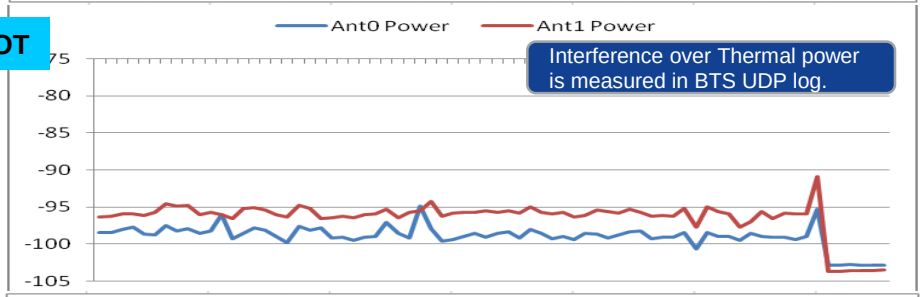


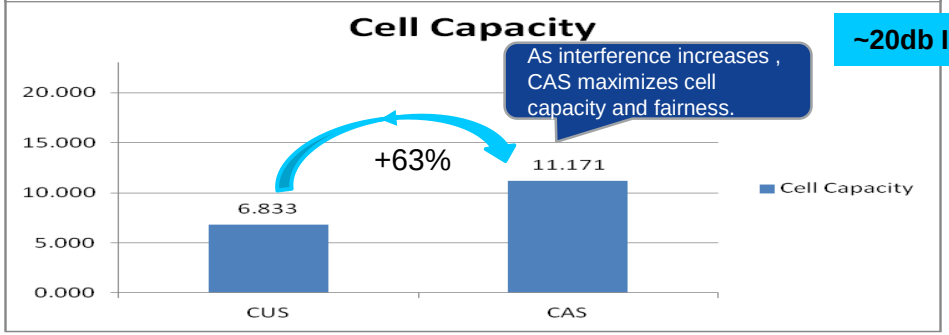
~0db IOT





~8db IOT





~20db IOT