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Adaptive Modulation and Coding

LTE Radio Parameters 1 [FL18A]

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Module Objectives

After completing this learning element, the participant should be able to describe discuss and analyze:

- Principles of OLQC
- DL and UL Adaptive Modulation and Coding
- UL link adaption

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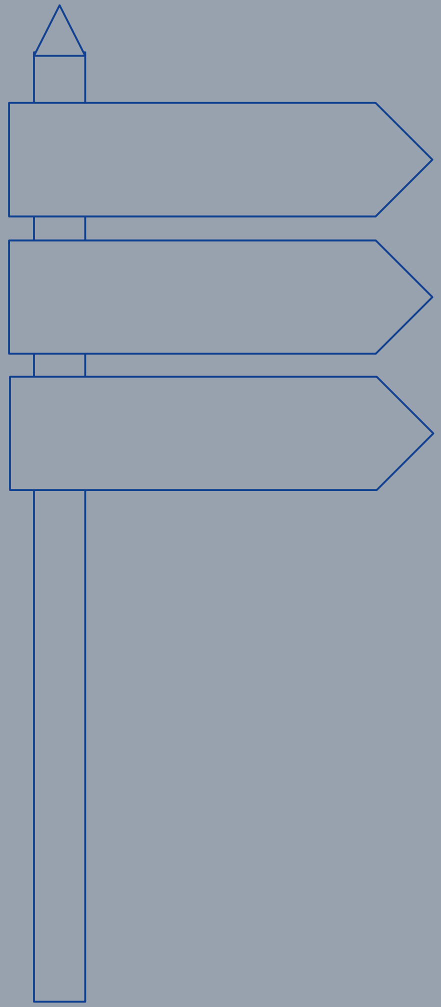


- **DL Adaptive Modulation and Coding (AMC)**
- Outer Loop Quality Control (OLQC)
- UL Adaptive Modulation and Coding (AMC)
- Outer Loop Link Adaptation (OLLA)
- Adaptive Transmission Bandwidth (ATB)
- Extended UL Link Adaptation (E-ULA)
- Fast Uplink Adaptation (F-ULA)

DL AMC

- The target of the DL Adaptive Modulation and Coding (AMC) algorithm is to improve system capacity, peak data rate and coverage reliability

- The transmitted signal by a particular user is modified to account for the signal quality variation through link adaptation.

- The aim of the link adaptation is to estimate the **transport block size** for a UE **and a certain set of allowed resource blocks** (frequency resources) for transmission

- For the Downlink Data Channel a fast Adaptive Modulation and Coding (AMC) functionality based on UE reported CQI is performed by the AMC algorithm

- **AMC selects a suitable Modulation and Coding Scheme (MCS)** for the PRBs/RBGs assigned to a UE as indicated by the downlink scheduler.

LNCEL: actModulationSchemeDL;

Selects the **highest** modulation scheme for link adaptation use in PDSCH.

QPSK (0), 16QAM (1), 64QAM (2), 256QAM (3),

Default: QPSK (0)

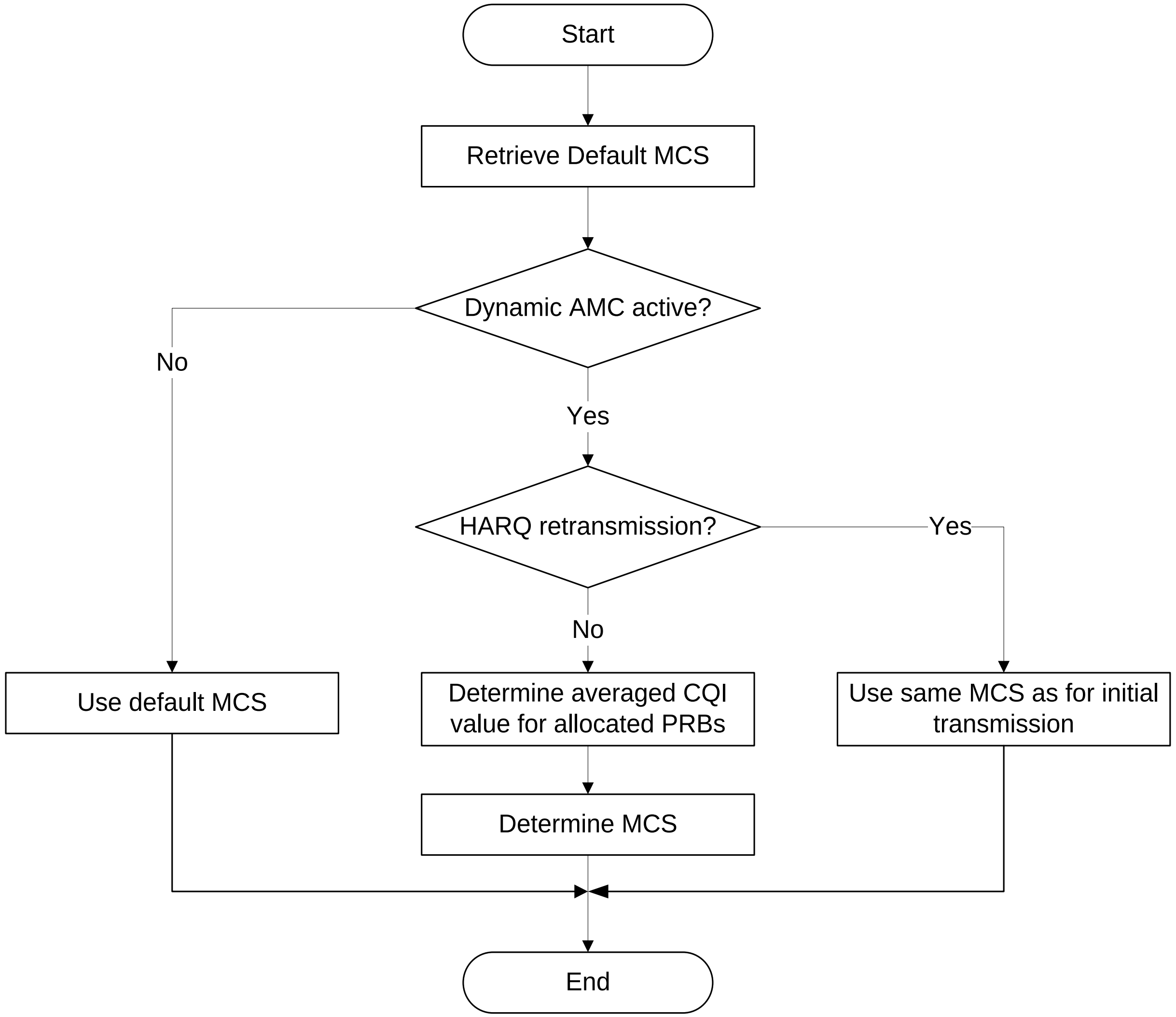
DL AMC

DL AMC is enabled via dlamcEnable

For retransmissions the same MCS as for the original transmission is applied

For new transmissions the MCS is decided based on CQI reports from the UE

LNCEL: dlamcEnable;
Enable DL AMC;
0 (false), 1 (true);
Default: 1 (true)



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DL AMC

MCS selection for initial transmissions

For the first transmissions where no previous CQI information is available from the UE the DL AMC will provide the initial MCS to be used for the UE

- Initial MCS is specified by iniMcsDl
- If DL AMC is disabled via dlamcEnable, then no link adaptation will be performed and a fixed MCS shall be applied according to iniMcsDl (Initial MCS for the DL) and the applied MCS shall never be changed over the time

LNCEL: iniMcsDl;
Initial MCS in downlink;
0...28, step 1;
Default: 4

DL AMC

MCS selection for new transmissions

- In case of the averaged CQI value falling in-between two CQI indices with different corresponding modulation scheme, the scheme with the lower modulation order will be chosen

- For dual codeword transmission link adaptation has to be performed per codeword if CQI information per codeword is available (i.e. for closed loop MIMO transmission mode).

- If only wideband CQI information is available for a UE the corresponding MCS level can be mapped directly (without a preceding averaging step).

- If no new CQI values were received for a UE, and the UE is scheduled nevertheless, the MCS shall be determined as described above provided the latest available CQI information is not older than **dlamcTHistCqi (hidden parameter)**
- If dlamcTHistCqi is exceeded (or CQI values are not yet available) the initial MCS (iniMcsDl) shall be applied.

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Channel Quality Indicator Table

- The CQI is defined as a table containing 16 entries with modulation and coding schemes (MCSs)
- The UE shall report back the highest CQI index corresponding to the MCS for which the transport block BLER shall not exceed 10%

	64 QAM support			256 QAM support		
CQI index	modulation	code rate x 1024	Efficiency	modulation	code rate x 1024	Efficiency
0	out of range			out of range		
1	QPSK	78	0.1523	QPSK	78	0.1523
2	QPSK	120	0.2344	QPSK	193	0.3770
3	QPSK	193	0.3770	QPSK	449	0.8770
4	QPSK	308	0.6016	16QAM	378	1.4766
5	QPSK	449	0.8770	16QAM	490	1.9141
6	QPSK	602	1.1758	16QAM	616	2.4063
7	16QAM	378	1.4766	64QAM	466	2.7305
8	16QAM	490	1.9141	64QAM	567	3.3223
9	16QAM	616	2.4063	64QAM	666	3.9023
10	64QAM	466	2.7305	64QAM	772	4.5234
11	64QAM	567	3.3223	64QAM	873	5.1152
12	64QAM	666	3.9023	256QAM	711	5.5547
13	64QAM	772	4.5234	256QAM	797	6.2266
14	64QAM	873	5.1152	256QAM	885	6.9141
15	64QAM	948	5.5547	256QAM	948	7.4063

UE reports highest MCS that it can decode with a TB Error rate < 10% ⇒ taking into account UE's receiver characteristic

Modulation and TBS Index

	64 QAM support		256 QAM support	
MCS Index I_{MCS}	Modulation Order Q_m	TBS Index I_{TBS}	Modulation Order Q_m	TBS Index I_{TBS}
0	2	0	2	0
1	2	1	2	2
2	2	2	2	4
3	2	3	2	6
4	2	4	2	8
5	2	5	4	10
6	2	6	4	11
7	2	7	4	12
8	2	8	4	13
9	2	9	4	14
10	4	9	4	15
11	4	10	6	16
12	4	11	6	17
13	4	12	6	18
14	4	13	6	19
15	4	14	6	20
16	4	15	6	21
17	6	15	6	22
18	6	16	6	23
19	6	17	6	24
20	6	18	8	25
21	6	19	8	27
22	6	20	8	28
23	6	21	8	29
24	6	22	8	30
25	6	23	8	31
26	6	24	8	32
27	6	25	8	33/33A
28	6	26/26A	2	reserved
29	2	reserved	4	
30	4		6	
31	6		8	

New modulation and values for I_{TBS}

LTE3073 - 256 QAM Extensions

MCS conversion

- 256QAM UE reports CQI lower than 64QAM UE → Then 256QAM UE MCS is lower
- Some algos (link adaptation …) use MCS as input

  → Then, in order to have same algos decisions, MCS table conversion is needed
- MCS conversion is always activated (no parameter) when 256QAM is activated

Configured parameter value (MCS index)	Converted parameter value for 256QAM UE
2	1
4	2
6	3
8	4
11	5
12	6
13	7
14	8
15	9
16	10
18	11
19	12
20	13
21	14
22	15
23	16
24	17
25	18
26	19
27,28	20

LTE3073 - 256 QAM Extensions

CQI conversion

- 256QAM UE reports CQI lower than 64QAM UE
- Some algos (link adaptation, scheduler …) use CQI as input

  → Then, in order to have same algos decisions, CQI table conversion is needed
- CQI conversion is always activated (no parameter) when 256QAM is activated

Note: The table contains the main CQI indexes (as defined by 3GPP). As a result of OLQC –, a final CQI can be adjusted with the calculated Δ_{CQI}.

CQI reported by 256QAM UE	Converted CQI
1	1
2	3
3	5
4	7
5	8
6	9
7	10
8	11
9	12
10	13
11	14
12	15
13	15
14	15
15	15

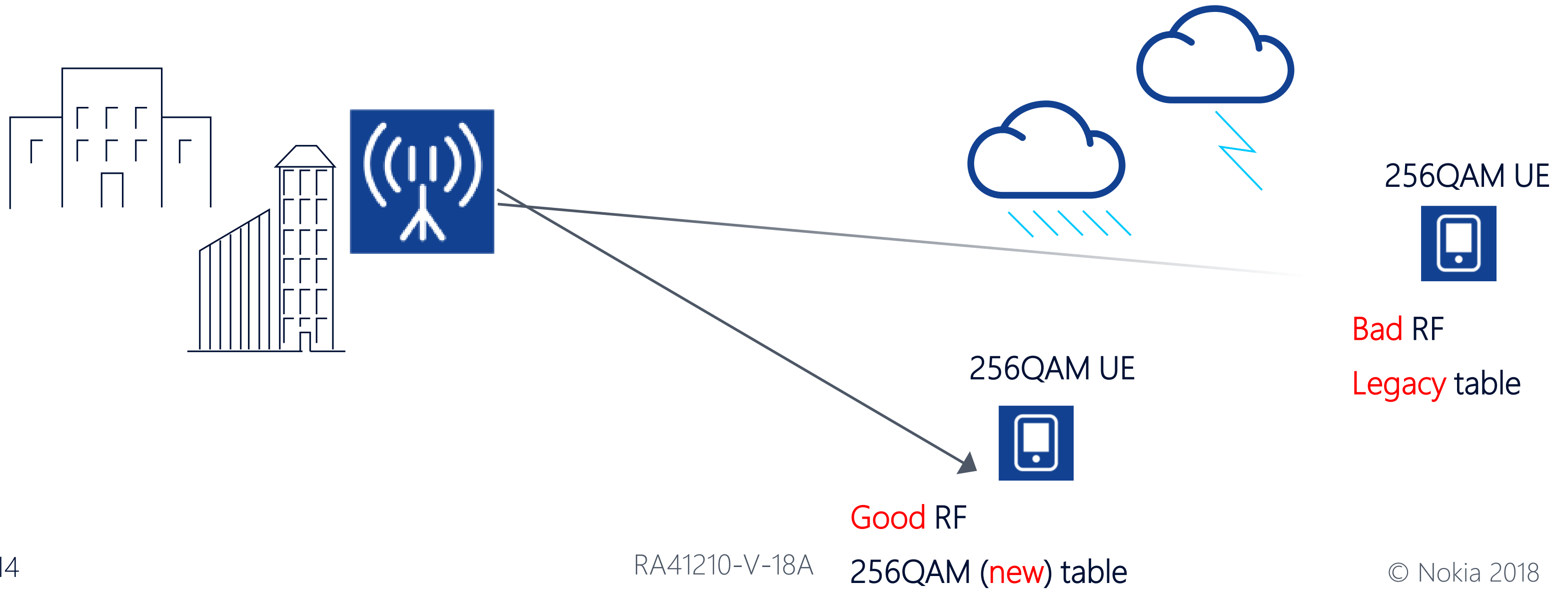
LTE3073 - 256 QAM Extensions

256QAM performance monitor

- Without Performance monitor :
  - ➢ 256QAM UEs always use new MCS / CQI tables
  - ➢ Consequence : worse performance at the cell edge

- With Performance monitor :
  - ➢ 256QAM UEs use new MCS / CQI tables only if good RF
  - ➢ Consequence : improvement of performance at the cell edge

- 256QAM capable UE is always initially configured with 256QAM relevant configuration
- Performance monitor is enabled with parameter actDl256QamChQualEst



LNCEL: actDl256QamChQualEst;

Activate channel quality monitoring for 256QAM usage;

false (0), true (1);

Default: false

LTE3073 - 256 QAM Extensions

256QAM activation / deactivation due to MCS

256QAM activated if radio link good enough – indicated by scheduling of high MCS

256QAM deactivated again, if radio link quality goes down – indicated by scheduling of low MCS

LNCEL: dl256QamReactChQualThr;

MCS threshold for deactivating 256QAM for the UE;

18..24, step 1;

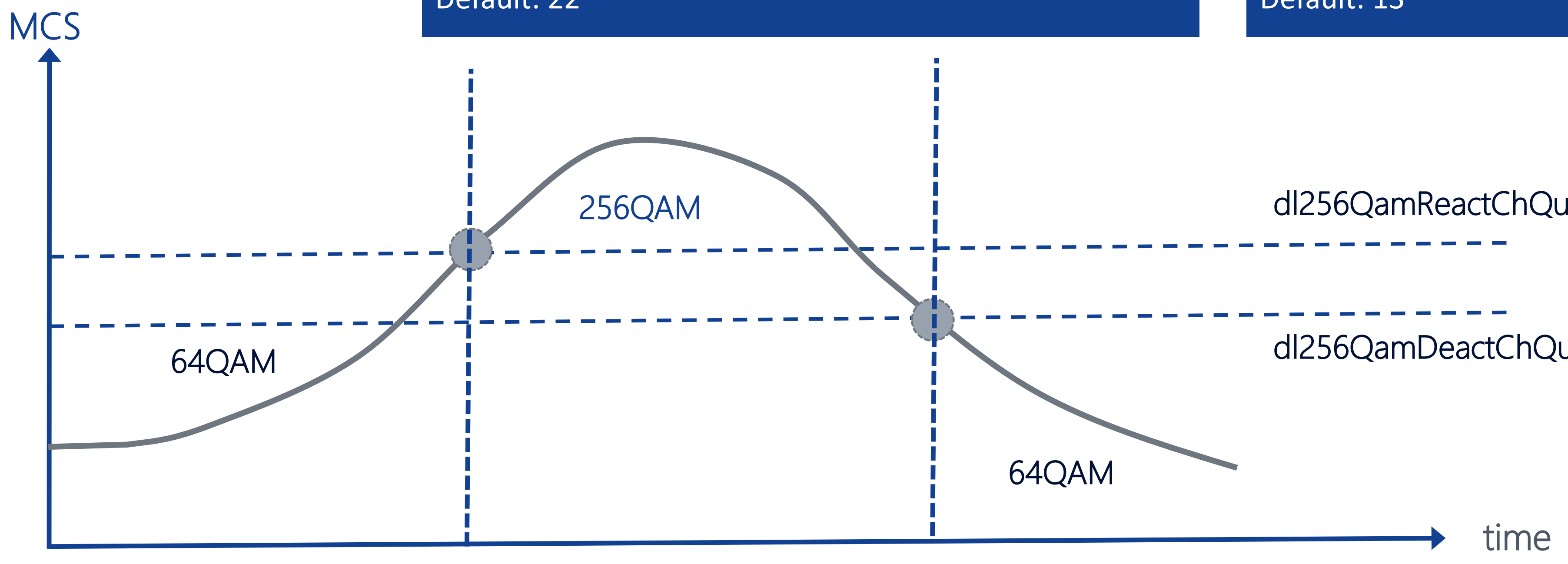
Default: 22

LNCEL: dl256QamDeactChQualThr;

MCS threshold for deactivating 256QAM for the UE;

9..15, step 1;

Default: 13



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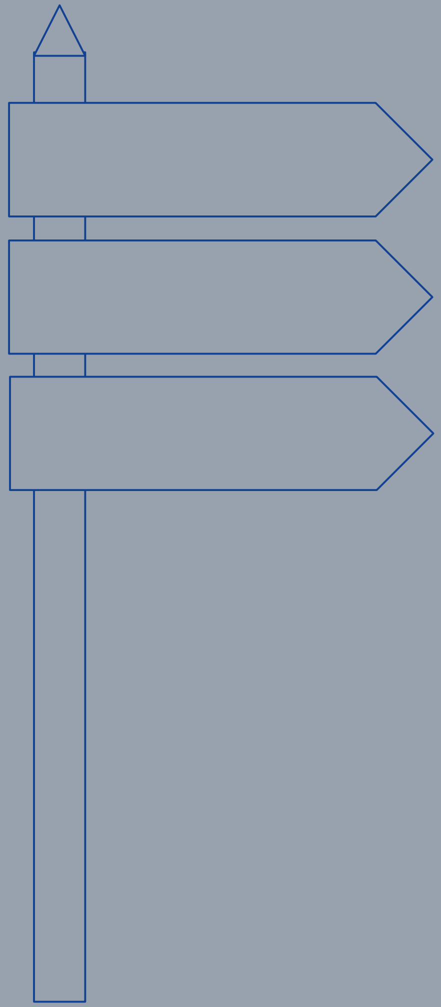


OLQC – CQI Adaptation

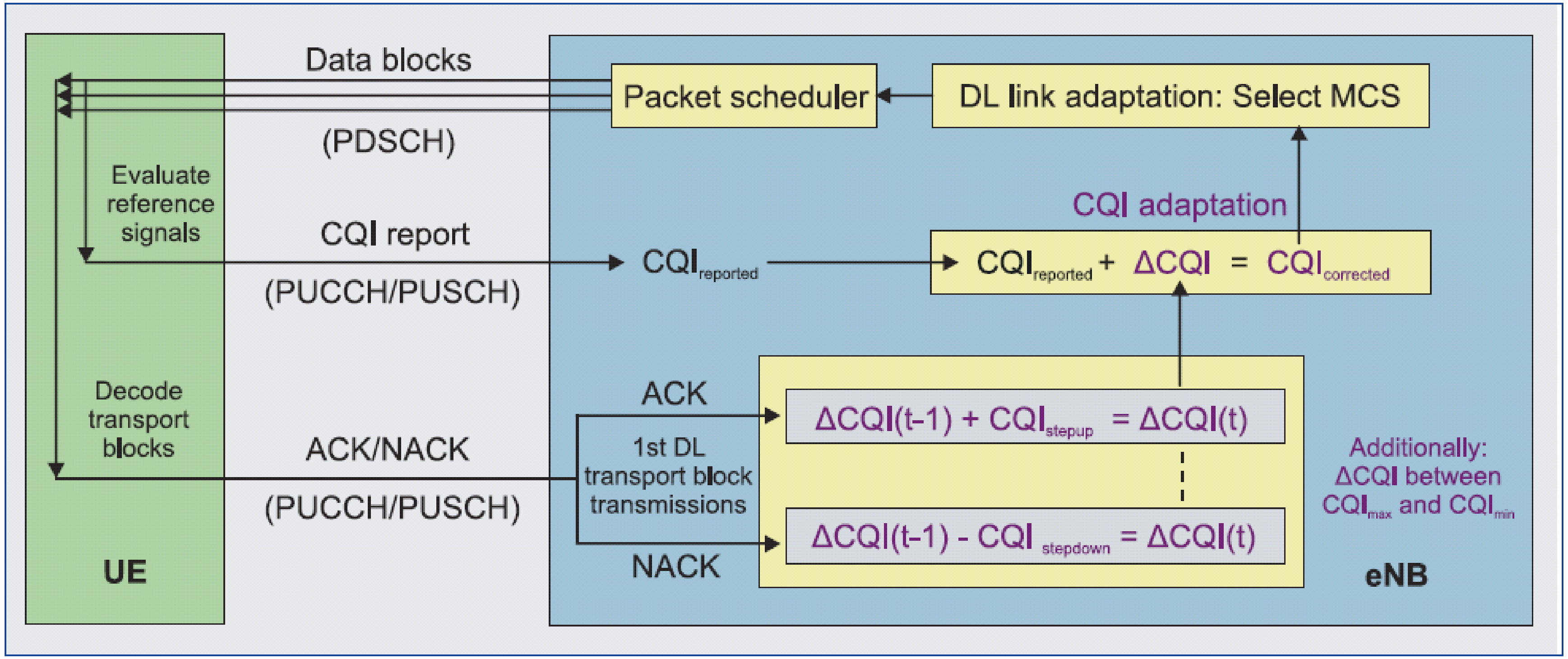
Outer Link Quality Control (OLQC)

- Adapts the channel quality information that is used by the scheduler and link adaptation to achieve the **target block error ratio (BLER)** for the first transmission of a Transport Block.
- OLQC compensates any non-idealities of the link adaptation
    - CQI estimation error of the UE
    - CQI quantization error
    - CQI reporting error
    - Time delay between CQI measurement and the reception of the subsequent data block
    - CQI interpolation error
    - Errors due to CQI averaging of PRBs
- dlOlqcEnable parameter is used to enable/disable the outer link quality control. When outer link quality control is disabled then the corrected CQI values correspond to the reported CQI values.

LNCEL: dlOlqcEnable;
Enable OLQC;
0 (false), 1 (true);
Default: 1 (true)

OLQC – CQI Adaptation

Principle of CQI adaptation



OLQC – CQI Adaptation

- OLQC algorithm targets to achieve a Target DL BLER (dlTargetBler)
- Based on the Target BLER, OLQC will determine whether the reported CQI is increased or decreased
- CQI offset is defined by considering the CQI increase and decrease steps which should be balanced.
- Assuming that a CQI decrease will occur with a probability $BLER_{target}$ for the first transmission whereas a CQI increase occurs with the complementary probability ($1-BLER_{target}$) the balance equation can be formulated as:

$$\boxed{(1-BLER_{target}) \cdot CQI_{stepup} = BLER_{target} \cdot CQI_{stepdown}.}$$

- Therefore, $CQI_{stepdown}$ can be calculated from the parameters CQI_{stepup} and the dlTargetBler as:

$$\boxed{CQI_{stepdown} = CQI_{stepup} \cdot \frac{1 - BLER_{target}}{BLER_{target}}.}$$

LNCEL: dlTargetBler;
DL target BLER
0.1...99.9% step 0.1%
Default: 10%

OLQC – CQI Adaptation

Single Code Word

For a correct received transport block the CQI report will be increased by a value CQI_{stepup}

For an incorrect transport block the value will be decreased by $CQI_{stepdown}$

No change will be done when no ACK/NACK is available or when it is a retransmission of the corresponding transport block.

A maximum and a minimum CQI offset is defined (called $DCQI_{max}$ and $DCQI_{min}$) in order to suppress very large fluctuations that may arise in extreme situations

$$\boxed{\overline{\mathrm{CQI}}_{\mathrm{corrected}}(x,t) = \overline{\mathrm{CQI}}_{\mathrm{reported}}(x,t) + \Delta\mathrm{CQI}(t).}$$

$$\Delta\mathrm{CQI}(t) = \begin{cases} \min(\,\Delta\mathrm{CQI}(t-1) + \mathrm{CQI}_{\mathrm{stepup}}, \Delta\mathrm{CQI}_{\max}\,), & \text{for first HARQ feedback} = \mathrm{ACK}, \\ \max(\,\Delta\mathrm{CQI}(t-1) - \mathrm{CQI}_{\mathrm{stepdown}}, \Delta\mathrm{CQI}_{\min}\,), & \text{for first HARQ feedback} = \mathrm{NACK}, \\ \Delta\mathrm{CQI}(t-1), & \text{for first HARQ feedback} = \mathrm{N/A}. \end{cases}$$

dlOlqcDeltaCqiIni, dlOlqcDeltaCqiMax,
dlOlqcDeltaCqiMin, dlOlqcDeltaCqiStepUp

Hardcoded values

OLQC – CQI Adaptation

Two Code Words

$$\overline{\mathrm{CQI}}_{\mathrm{corrected}}(x,t) = \overline{\mathrm{CQI}}_{\mathrm{reported}}(x,t) + \Delta\mathrm{CQI}(t).$$

$$\Delta\mathrm{CQI}(t) = \begin{cases} \min(\Delta\mathrm{CQI}(t-1) + \mathrm{CQI}_{\mathrm{stepup}}, \Delta\mathrm{CQI}_{\max}), & \text{for new transmission HARQ feedbacks} = \mathrm{ACK}^{*} + \mathrm{ACK}^{*}, \\ \max(\Delta\mathrm{CQI}(t-1) - \mathrm{CQI}_{\mathrm{stepdown}}, \Delta\mathrm{CQI}_{\min}), & \text{for new transmission HARQ feedbacks} = \mathrm{NACK}^{**} + \mathrm{NACK}^{**}, \\ \min(\max(\Delta\mathrm{CQI}(t-1) + (\mathrm{CQI}_{\mathrm{stepup}} - \mathrm{CQI}_{\mathrm{stepdown}})/2, & \\ \quad \Delta\mathrm{CQI}_{\min}), \Delta\mathrm{CQI}_{\max}), & \text{for new transmission HARQ feedbacks} = \mathrm{ACK}^{*} + \mathrm{NACK}^{**}, \\ \min(\Delta\mathrm{CQI}(t-1) + \mathrm{CQI}_{\mathrm{stepup}}, \Delta\mathrm{CQI}_{\max}), & \text{for new transmission HARQ feedbacks} = \mathrm{ACK}^{*} + \mathrm{N/A}, \\ \max(\Delta\mathrm{CQI}(t-1) - \mathrm{CQI}_{\mathrm{stepdown}}, \Delta\mathrm{CQI}_{\min}), & \text{for new transmission HARQ feedbacks} = \mathrm{NACK}^{**} + \mathrm{N/A}, \\ \Delta\mathrm{CQI}(t-1), & \text{for new transmission HARQ feedbacks} = \mathrm{N/A} + \mathrm{N/A}. \end{cases}$$

LTE2026: RRC Signaling Robustness Improvement

- LTE2026 provides increased reliability for:
  - downlink RRC signaling on the PDSCH
  - PDCCH signaling when used to allocate resources for downlink RRC signaling
- Achieved by adjusting CQI value used by Link Adaptation
- Tends to increase Resource Block utilization, i.e. payload is transmitted with greater redundancy
  - impact upon cell load is not expected to be large due to relatively low volume of SRB messages when compared to user plane content
  - impact decreased by reducing the requirement for re-transmissions
- Feature helps to reduce latency and improve call setup and handover success rates

LTE2026: RRC Signaling Robustness Improvement

- This feature allows an SRB 1 Link Adaptation offset to be configured
  - decreases the MCS allocated for SRB 1 transmissions
  - tends to increase Resource Block utilization of PDSCH (but on the other side reduced re-transmission)
  - tends to increase the aggregation level used by the PDCCH
- The Link Adaptation offset is applied to the CQI used by Outer Loop Quality Control (OLQC)
- The offset is applied when SRB 1 is sent on its own and also when SRB 1 is multiplexed with another bearer, e.g. a data bearer
- SRB 2 is not affected by this feature

LNCEL: dlSrbCqiOffset;
Downlink SRB1 CQI offset;
-15...0, step 0.1;
Default: -2

LNCEL; actSrb1Robustness;
Activate SRB1 robustness;
0 (false), 1 (true);
Default: 0 (false),

CQI used = CQI reported + OLQC correction + dlSrbCqiOffset

LTE2026: RRC Signaling Robustness Improvement

Impact of SRB1 transmission on link adaptation

Non SRB1 PDSCH link adaptation impact :

- Positive HARQ acknowledgements for SRB 1 transmissions are not used to adjust the PDSCH Link Adaptation for non-SRB 1 transmissions
  - they do not reflect the quality of reception for other bearers
- Negative and DTX HARQ acknowledgements for SRB 1 transmissions are used to adjust the PDSCH Link Adaptation for non-SRB 1 transmissions
  - ensures that negative feedback is taken into account

Non SRB1 PDCCH link adaptation impact :

- Neither Positive nor negative HARQ acknowledgements for SRB 1 transmissions are not used to adjust the PDCCH Link Adaptation for non-SRB 1 transmissions
  - any acknowledgement indicates that the UE received the PDCCH successfully
- DTX HARQ acknowledgements for SRB 1 transmissions are used to adjust the PDCCH Link Adaptation for non-SRB 1 transmissions

SRB1 transmission	PDCCH of non SRB1	PDSCH of non SRB1
ACK	Not used	Not used
NACK	Not used	Used
DTX	Used	Used

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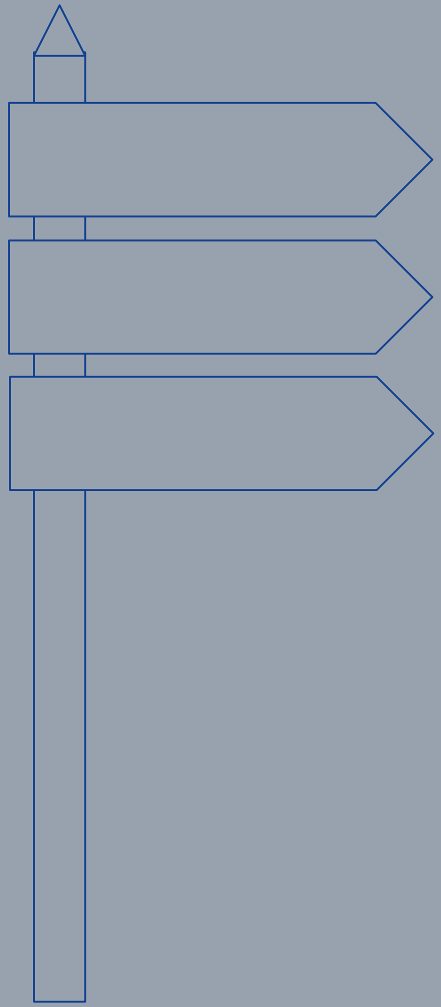

- DL Adaptive Modulation and Coding (AMC)
- **Outer Loop Quality Control (OLQC)**
- **UL Adaptive Modulation and Coding (AMC)**
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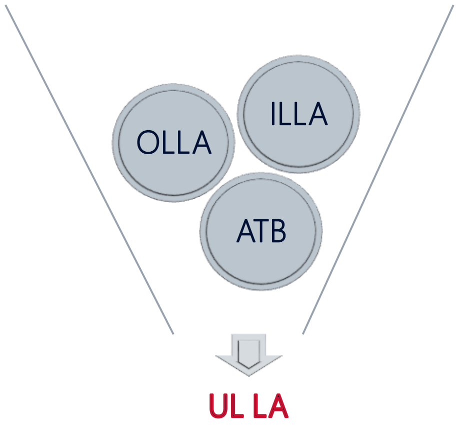
- Extended UL Link Adaptation (E-ULA)
- Fast Uplink Adaptation (F-ULA)

Uplink Link Adaptation entities

- Purpose of UL LA is to improve system capacity, peak data rate and coverage reliability by the adaptation of transmission settings to the radio channel conditions

- UL Adaptive Modulation and Coding (UL AMC) *selects appropriate MCS* for UL transmission taking into account actual transmission reliability (BLER)
- UL AMC is split into
  - Inner Loop Link Adaptation (ILLA) – slow periodic AMC
    - Periodic ACK/NACK information is used for calculating BLER (Block Error Rate) after 1st transmission or *n*th retransmission
    - With extended UL link adaptation ILLA is switched off (see later in this module)
  - Outer Loop Link Adaptation (OLLA) – event-triggered aperiodic AMC
    - Periodic ACK/NACK information is used for calculating BLER after 1st transmission of a Transport Block in order to derive a compensation factor
- Adaptive Transmission Bandwidth (ATB)
  - responsible for *defining maximum number of PRBs* that can be assigned to a particular UE on UL SCH



UL AMC

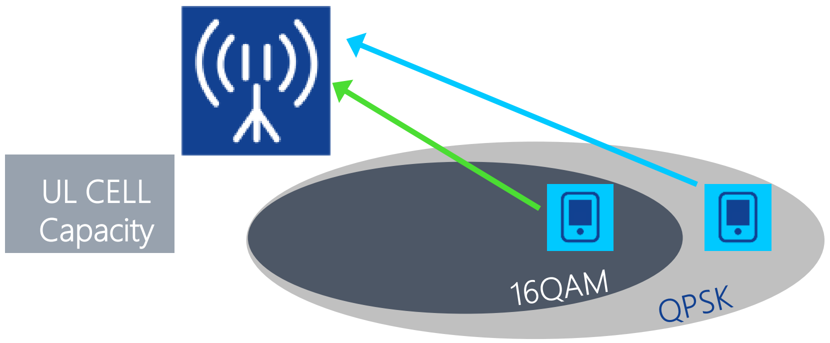
- UL AMC shall select the MCS to be employed from the table below according to the radio conditions
- **LTE829** allows for extending the range of MCSs used for 16QAM UEs to MCS 24 → Approximately 25% higher UL peak rates compared to MCS 20.
- **LTE44: Uplink 64 QAM** (FL16) introduces 64 QAM modulation scheme in UL increasing maximum achievable UE uplink throughput in very good radio conditions and improving average cell capacity.

LNCEL: actModulationSchemeUL;

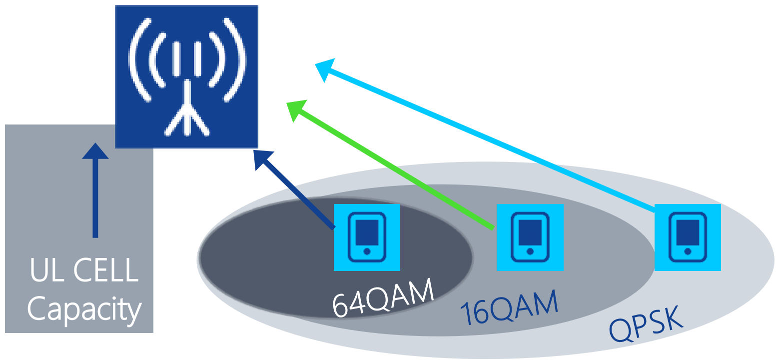
Selects the **highest** modulation scheme for link adaptation use in PUSCH.

QPSK (0), 16QAM (1), 16QAMHighMCS (2), 64QAM (3), 64QAMand16QAMHighMCS (4);

Default: QPSK (0)



Up to FL16



FL16 LTE44 – 64QAM in UL

UL AMC

- Used to adapt PUSCH to different link conditions by variable modulation and coding scheme, and variable bandwidth
- Inputs
  - Ack/Nack information (BLER)
  - SINR Measurements
  - Power Headroom reports
- Outputs
  - modulation
  - code rate
  - maximum amount of PRBs

MCS Index	Modulation Order	TBS Index	Redundancy Version rv_{idx}
0	2	0	0
1	2	1	0
2	2	2	0
3	2	3	0
4	2	4	0
5	2	5	0
6	2	6	0
7	2	7	0
8	2	8	0
9	2	9	0
10	2	10	0
11	4	10	0
12	4	11	0
13	4	12	0
14	4	13	0
15	4	14	0
16	4	15	0
17	4	16	0
18	4	17	0
19	4	18	0
20	4	19	0
21	6	19	0
22	6	20	0
23	6	21	0
24	6	22	0
25	6	23	0
26	6	24	0
27	6	25	0
28	6	26	0
29	Reserved		1
30			2
31			3

UL AMC

- The uplink AMC consists of 2 main components:

1. An inner loop LA (ILLA) based on BLER acting on either 1st Transmission Errors of TBs or on all TBs transmission errors derived from HARQ process.
2. An outer loop LA (OLLA) acting on the 1st Transmission Errors on TBs

- ILLA is a slow LA which will be performed every **ulamcSwitchPer**
- OLLA is an event based driven LA and will provide the capability to adjust to fast changing radio conditions by performing emergency downgrades or fast upgrades of the MCS

LNCEL: ulamcAllTbEn;
counting of all Transport Blocks instead of the 1st transmission Transport Blocks
0 (false), 1 (true);
Default: 0 (false)

LNCEL: ulamcSwitchPer;
UL AMC MCS switch period;
10...500 transport blocks,
Default: 30 transport blocks

UL AMC

- UL AMC can be enabled/disabled with **actUlLnkAdp**
- If UL AMC is disabled, then no LA will be performed and a fixed MCS shall be applied according to **iniMcsUl** (Initial MCS for the UL) and the applied MCS shall never be changed over the time
- If UL AMC is enabled then the data transfer of every UE shall start with iniMcsUl and the MCS shall change over time according to radio conditions.
- UL AMC shall provide the following functions:
  - **BLER averaging**
  - OLLA which provides **Emergency Downgrade (EDG)** and **Fast Upgrade (FUG)** Events
  - **MCS selection** based on BLER providing the optimum MCS depending on radio link conditions
  - UL ATB derived from selected MCS according to radio conditions. UL ATB process results in an **upper PRB allocation limit submitted** to the UL scheduler.

LNCEL: actUlLnkAdp;
Activate uplink link adaptation;
off (0), slowAmcOllaATB (4), eUlLa (5), fUlLa (6);
Default: eUlLa (5)

LNCEL: iniMcsUl
Initial MCS in uplink;
0...28,
Default: 5

UL AMC – ILLA

- Inner loop compares **BLER obtained during ulamcSwitchPer with BLER target**
- Following actions, if measured BLER deviates from target BLER at least by a hardcoded factor of 1.2
  - BLER ≥ round (BLER target * 1.2) [%] → reduce MCS by **one level**
  - BLER ≤ round (BLER target / 1.2) [%] → increase MCS by **one level**

LNCEL: ulTargetBler;
UL target BLER
1..50 % step 1 %
Default: 10 %

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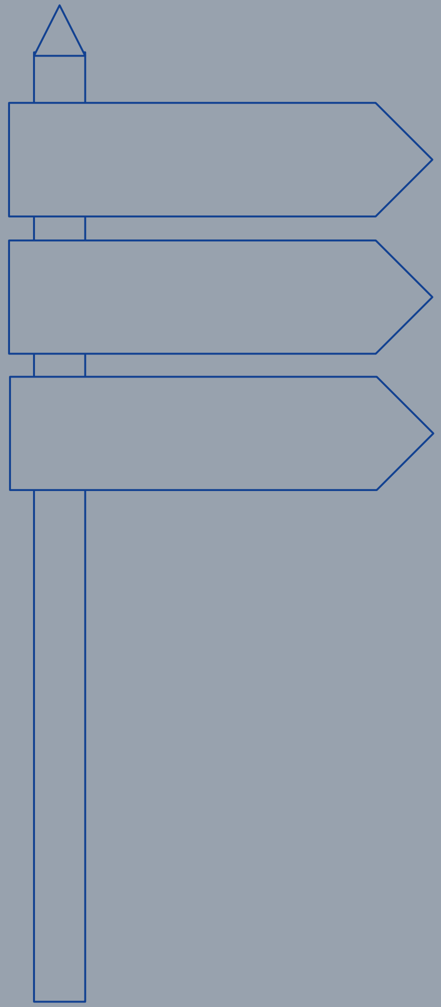

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OLLA

- OLLA is based on the 1st transmission ACK/NACK information provided by L1/L2 HARQ.
- OLLA provides a quicker adaptation to radio conditions compared to the inner loop LA which typically will act every 100-500 ms defined by ulamcSwitchPer
- OLLA basically counts the BLER based on 1st transmissions (ΔC)

$$\Delta C(t) = \begin{cases} \min(\Delta C(t-1) + C_{stepup}, \Delta C_{max}), & \text{for first HARQ feedback} = \text{ACK}, \\ \max(\Delta C(t-1) - C_{stepdown}, \Delta C_{min}), & \text{for first HARQ feedback} = \text{NACK}, \\ \Delta C(t-1), & \text{for first HARQ feedback} = \text{N/A}. \end{cases}$$

- Where:
  - ΔC_{max} and ΔC_{min} give upper and lower limits on the compensation defined by hardcoded parameters
    - ulamcDeltaCmax = 5
    - ulamcDeltaCmin = -5
  - C_{stepup} and $C_{stepdown}$ are incremental compensation steps sizes, which obey to the following formula:

$$C_{stepdown} = C_{stepup} \cdot \frac{1 - BLER_{target}}{BLER_{target}}.$$

  - Where C_{stepup} and $BLER_{target}$ are parameters
    - ulamcCStepUp = 0.2 hardcoded
    - ulTargetBler configurable (already discussed)

OLLA

Every time OLLA is initialized or reset ΔC is set to ulamcDeltaCini = 0 (hardcoded)

OLLA compensation value ΔC is reset at each AMC period, EDG and FUG event.

Emergency Downgrade (EDG) shall be triggered, whenever the compensation value ΔC is equal to ΔC_{min}
AMC shall switch immediately to the next lower (i.e. more robust) MCS

Fast Upgrade (FUG) shall be triggered, whenever the compensation value ΔC is equal to ΔC_{max}
AMC shall switch immediately to the next higher (i.e. less robust) MCS

ulamcDeltaCini	ulamcDeltaCmin	ulamcDeltaCmax	ulamcCStepUp
0	-5	5	0.2
Hard coded parameter	*Hard coded parameter*	*Hard coded parameter*	*Hard coded parameter*

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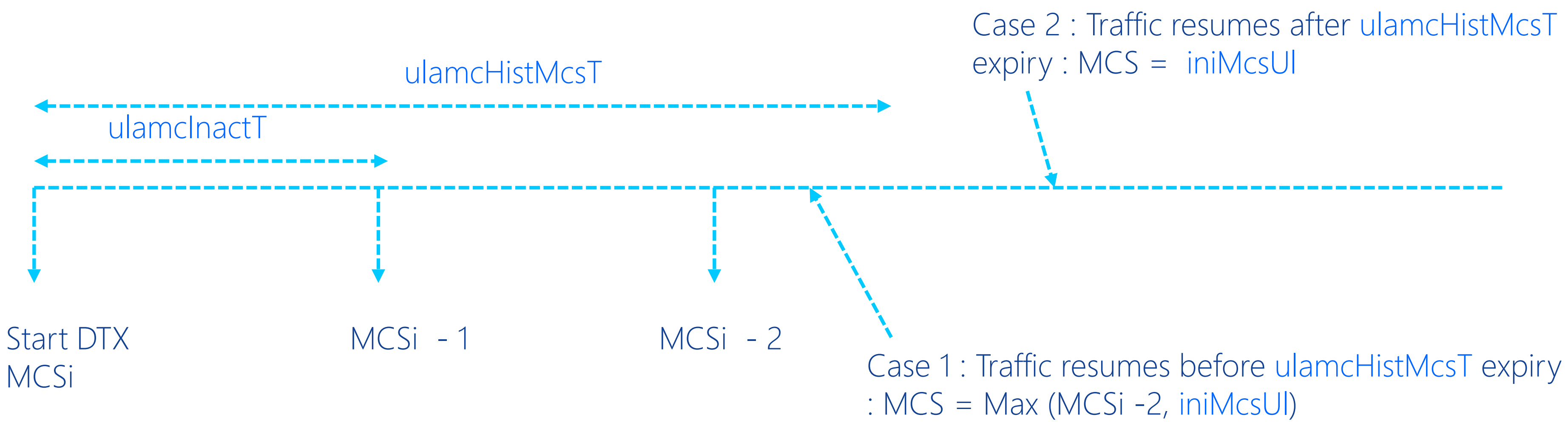
UL AMC During DRX/DTX

LNCEL: iniMcsUl
Initial MCS in uplink;
0...28,
Default: 5

- At the end of data transfer the currently selected MCS shall be stored and a Timer for “historical MCS” shall be started.
- If the same UE proceeds with a data transfer within the time period 1000ms, then the historical MCS shall be reloaded from memory and applied instead of the iniMcsUl
- Before starting an UE specific DTX period or entering an Inactivity period the actual MCS shall be stored and a Timer for Inactivity shall be started. For every 100ms period the MCS shall be decreased, but the selected MCS shall not go below the initial MCS iniMcsUl.
- If the currently selected MCS is below iniMcsUl then no action during DRX/DTX and/or Inactivity period shall be required.



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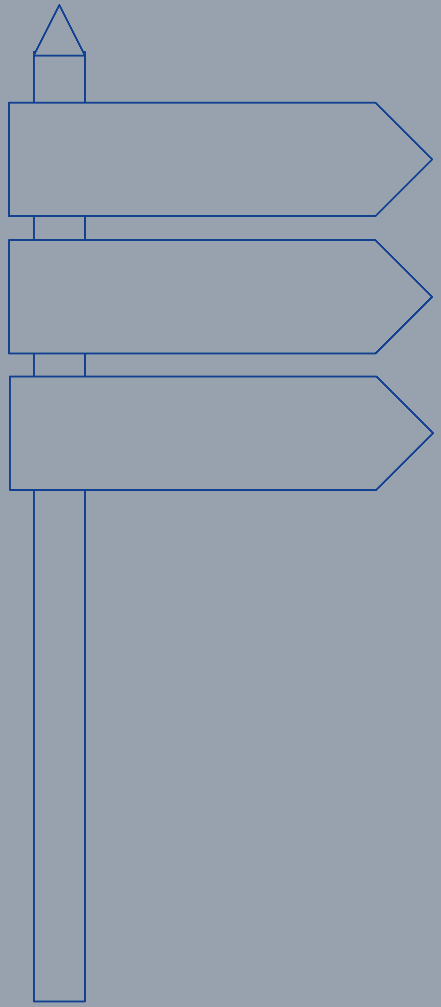

Adaptive Transmission Bandwidth (ATB)

- Besides selecting the most appropriate MCS according to radio conditions, the UL AMC shall also perform slow ATB in parallel (fast means every TTI)

- ATB is necessary in case of lack of UE power to concentrate the remaining power on less PRBs, thus allowing a regular data transmission in UL even up to the cell edge.

- ATB will inform the scheduler about the maximum Number of PRBs per TTI that can be assigned to a UE based on the UE's power headroom reports

- The periodicity of ATB is defined by the parameter ulatbEventPer which defines a multiple of AMC events (periodic changes, EDG, FUG) after which ATB will be carried out

- ATB functionality can be enabled/disabled with actUlLnkAdp

LNCEL: ulatbEventPer;
UL ATB period;
1...50, step 1;
Default: 1

LNCEL: actUlLnkAdp;
Activate uplink link adaptation;
off (0), slowAmcOllaATB (4), eUlLa (5), fUlLa (6);
Default: eUlLa (5)

Adaptive Transmission Bandwidth (ATB)

- Trigger conditions for UE to send Power headroom reports:
  - dlPathlossChg : When UE surpasses a defined threshold for path loss fluctuation it shall report power headroom to the eNodeB. This event driven report will handle fast variations of the path loss
  - tPeriodicPhr: Parameter to set periodic reporting of the power headroom
  - tProhibitPhr: Parameter to define minimum interval between power headroom reports sent to eNodeB

LNCEL: dlPathlossChg;	LNCEL: tPeriodicPhr	LNCEL: tProhibitPhr
Downlink pathloss change;	Periodic PHR timer;	Prohibited PHR timer;
1 db (0), 3 db (1), 6 db (2), infinite (3);	10sf (0), 20sf (1), 50sf (2), 100sf (3), 200sf (4), 500sf (5), 1000sf (6), infinity (7);	0sf (0), 10sf (1), 20sf (2), 50sf (3), 100sf (4), 200sf (5), 500sf (6), 1000sf (7);
Default: 3 db (1)	Default: 20sf (1)	Default: 0sf (0)

1 sf = 1 sub-frame = 1 ms

Adaptive Transmission Bandwidth (ATB)

ATB Algorithm:

1) At call setup the maximum number of PRB's that can be allocated to a single UE shall be limited by the parameter iniPrbsul

2) ATB events shall act synchronously with the slow AMC, based on ulatbEventPer (this restriction is not existing anymore if ILLA is switched off)

LNCEL: iniPrbsul;
Initial amount of PRBs in UL
1...100; step 1;
Default: 10

LNCEL: ulatbEventPer;
UL ATB period;
1...50, step 1;
Default: 1

Adaptive Transmission Bandwidth (ATB)

3) During ongoing call ATB calculates a running average filter acting continuously on all of the incoming power headroom reports of a certain UE.

- Power head room reports depend on the number of PRB's which were scheduled to the UE. Information on the number of scheduled PRB's is obtained from the UL Scheduler

- The equivalent possible PRBs derived from PWR_HEADR_UL (reported power headroom) and UE_PRBs_UL (current scheduled UL PRBs) for a certain time instance t shall be given by:

  - PWR_HEADR_PRBs(t) = UE_PRBs_UL(t) * PWR_HEADR_UL(t).

- For this PWR_HEADR_UL has to be **converted from dB into linear scale**, e.g. 3 dB is factor 2 and -3 dB is factor 1/2 and 0 dB is a factor 1.

- The running average filter output is given by
  - RUNAVG_PRBs(0) = iniPrbsul.
  - RUNAVG_PRBs(n) = (1 – 0.9) * RUNAVG_PRBs(n-1) + 0.9 * PWR_HEADR_PRBs(n).

Adaptive Transmission Bandwidth (ATB)

4) At any ATB decision the present value of the running average filter is read and the max number of PRB's is set to a rounded integer value by:

- MAX_NUM_PRBs = floor (RUNAVG_PRBs).

5.Ensure that PRB's are within and upper and lower limit boundaries:

- UPPER_LIMIT_PRBs = MAX_BITRATE_UL (given by Admission Control and QoS) / [MCS_THROUGHPUT_per_PRB * (1 - ULAMC_TARGET_BLER)]
- The upper Limit shall not exceed #PRBs_UL given by the Carrier Bandwidth.

- The lower Limit is given by:
- LOWER_LIMIT_PRBs = MIN_BITRATE_UL (given by Admission Control and QoS) / [MCS_THROUGHPUT_per_PRB * (1 - ULAMC_TARGET_BLER)]

- MCS_THROUGHPUT_per_PRB is the MCS dependent UE throughput under ideal radio conditions (0% BLER) assuming a fictive allocation of 1 PRB per TTI.

ATB during DTX/DRX

If no Power headroom indications are received during the previous reporting period, then ATB running average filter stays with the previous settings (no change).

If no Power headroom indications are received during the whole call at all, then ATB running average filter stays with the initial static setup iniPrbsul.

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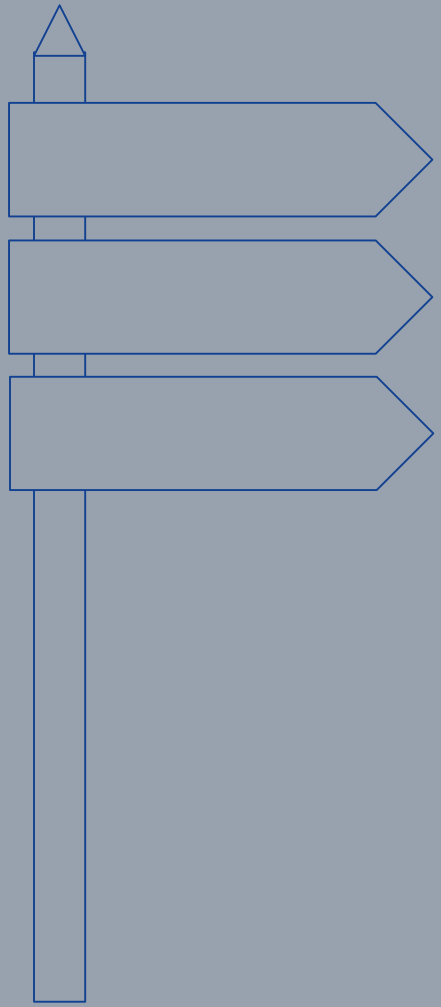


- DL Adaptive Modulation and Coding (AMC)
- **Outer Loop Quality Control (OLQC)**
- UL Adaptive Modulation and Coding (AMC)
- Outer Loop Link Adaptation (OLLA)
- Adaptive Transmission Bandwidth (ATB)
- **Extended UL Link Adaptation (E-ULA)**
- Fast Uplink Adaptation (F-ULA)

Extended Uplink Link Adaptation – motivation

- If a UE is power limited (corresponding to bad RF conditions)
  - It is more efficient to distribute the power over a wider bandwidth (more PRBs) using lower MCS than transmitted with less PRBs using higher MCS
  - This fact is due to **Shannon's formula for the channel capacity** of a bandwidth and power limited channel.

$$\boxed{C = B_w \log_2\left(1 + \frac{S}{N}\right)}$$

Bad RF →

More efficient

Wider bandwidth
(more PRBs)

Lower MCS

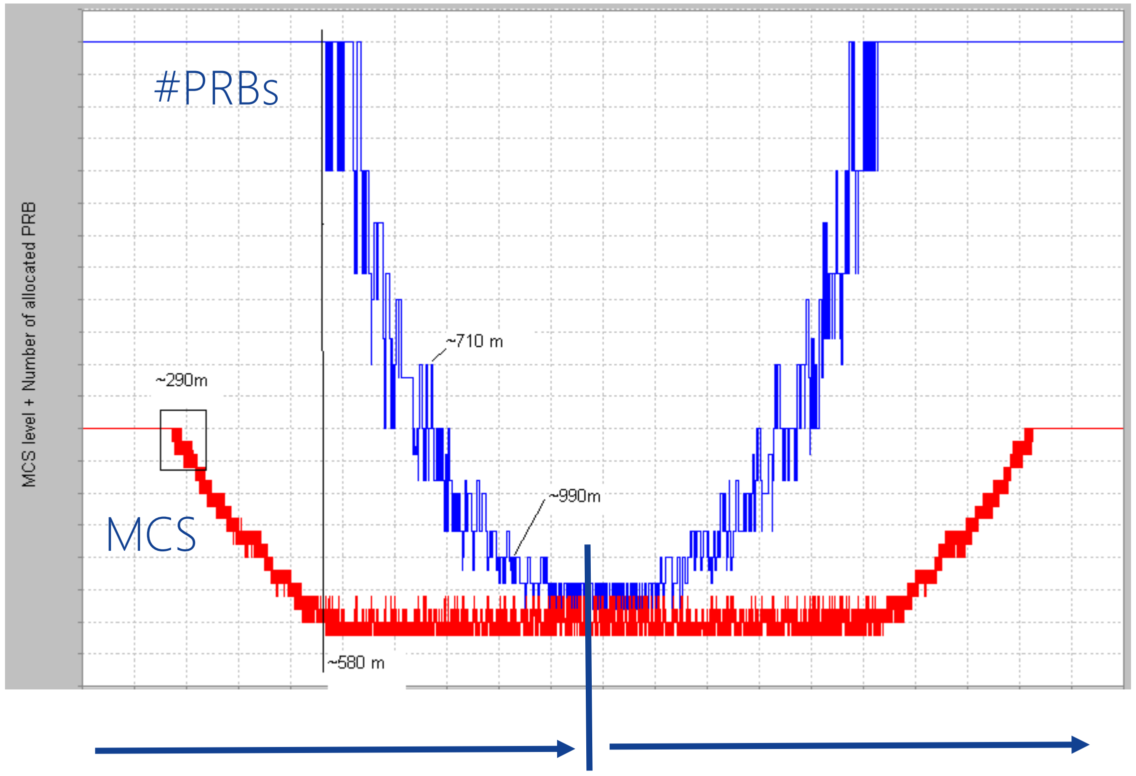
Less efficient

Few PRBs

Higher MCS

LTE1034 E-ULA basic idea

- at worse radio conditions
  - reduce first MCS
  - reduce #PRBs only if min. MCS has been reached
- At improving radio conditions
  - Increase first #PRBs
  - Increase MCS only if max. #PRBs have been reached



Feature ID(s): LTE1034

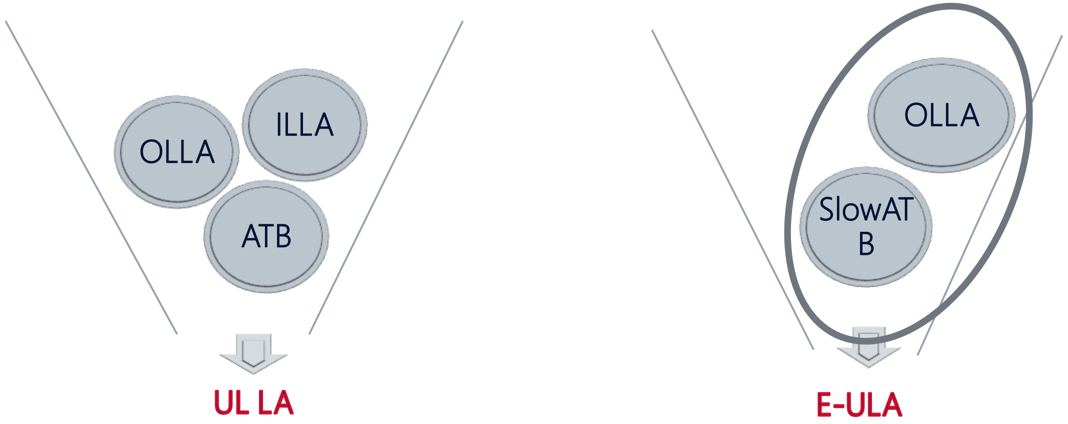
LTE1034 E-ULA concept

With LTE1034 the 3 processes (ILLA, OLLA and ATB) work synchronized but independently to each other :

→ OLLA and ATB are coupled with each other, while ILLA is switched off

E-ULA is activated with the parameter **actUlLnkAdp**

LNCEL: actUlLnkAdp; Activate uplink link adaptation; off (0), slowAmcOllaATB (4), eUlLa (5), fUlLa (6); Default: eUlLa (5)



E-ULA concept

Eliminate any possibility of BLER target drifting by

- stopping the SLOW AMC algorithm (ILLA)
- leaving for MCS regulation the OLLA algorithm

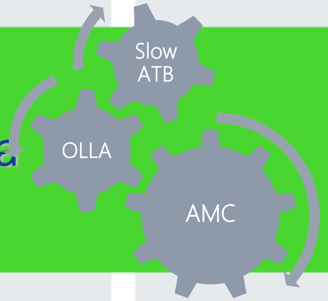
OLLA reacts relatively fast when it comes to reduce MCS index and slowly enough when it comes to upgrade MCS index

1

Therefore OLLA algorithm is unchanged and become the only one ruling the MCS index up and down

2

The main idea



3

ATB is no longer PHR based but BLER based (with PHR correction)

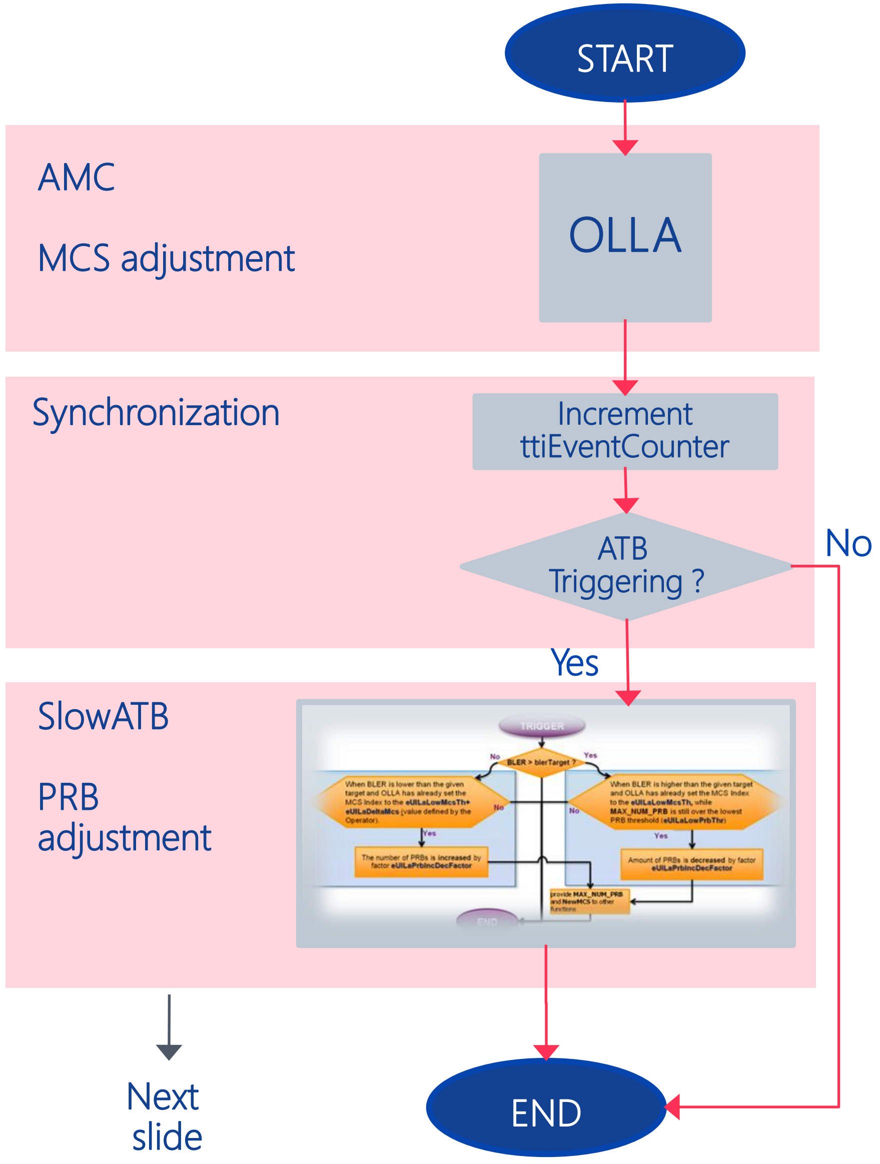
It will become active only when the OLLA has already reached the lower possible limit for the MCS index

4

Most of all Slow ATB is coordinated with OLLA

This means that Slow ATB acts only when OLLA has no longer margin left in terms of reaction.

E-ULA algorithm overview



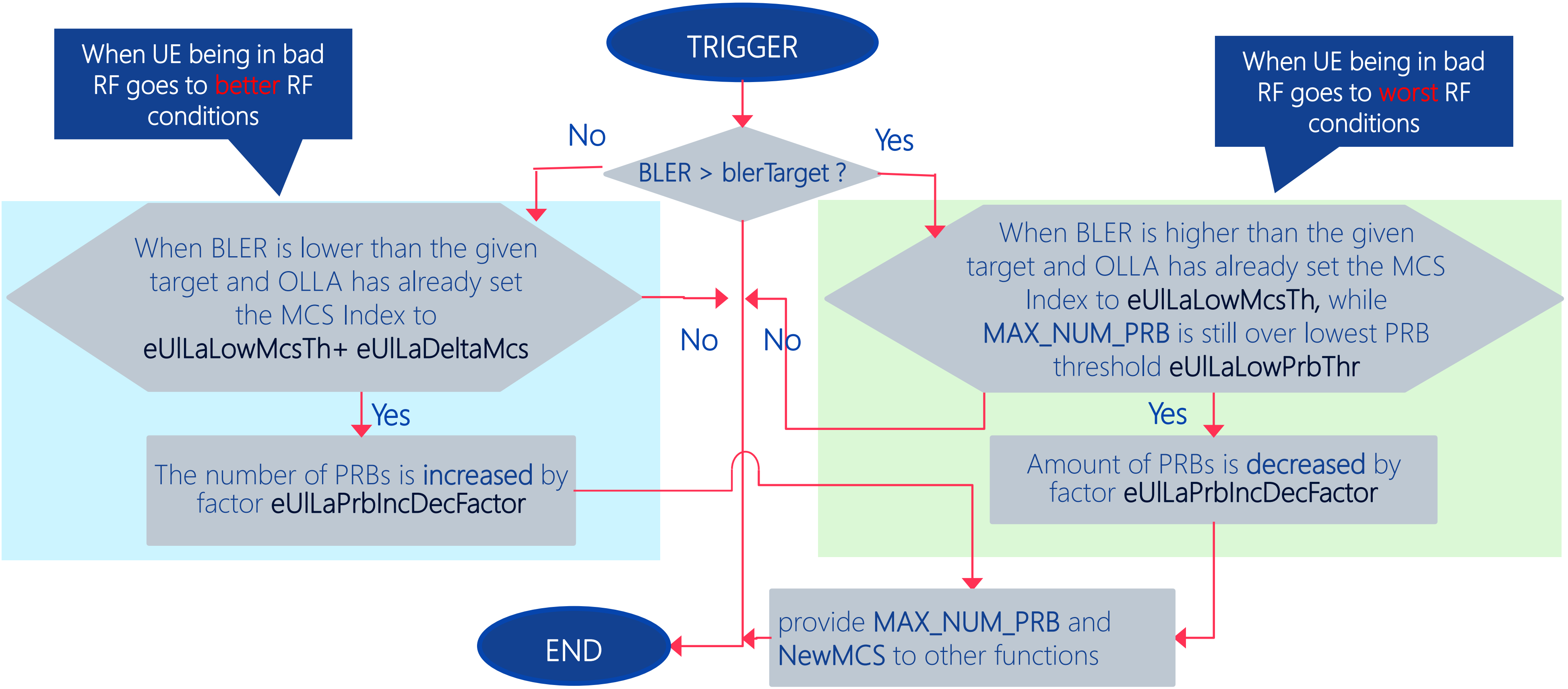
- **OLLA verifies BLER** conditions and **triggers FUG or EDG** events when necessary as in former releases
- Counter (# of transport blocks) is **incremented in every TTI** when user is **actively scheduled**
- **ATB is triggered by**
  - <u># of transport blocks (ttiEventCounter)</u> for periodical ATB triggering (eUlLaAtbPeriod)

  OR

  - <u>EDG</u>
    - *Sent by OLLA when EDG event happens and the lowest MCS Index has been already **reached**.*
    - *Therefore **EDG cannot further decrease** this MCS index. In this case **OLLA triggers the earlier activation** of the Slow ATB process.*

LNCEL:eUlLaAtbPeriod
Extended uplink link adaptation ATB periodicity
10..50 TTIs, step 5 TTIs
Default: 30 TTIs

E-ULA and BLER based ATB



LNCEL:eUlLaLowPrbThr
Extended uplink link adaptation low PRB threshold
1...5, step 1
Default: 1

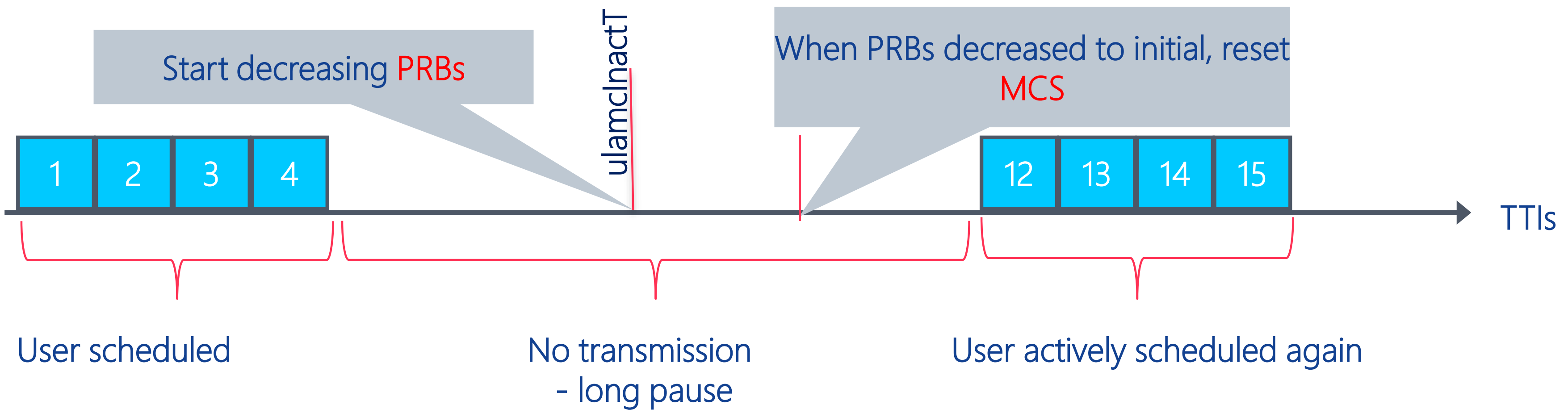
LNCEL:eUlLaLowMcsThr
Extended uplink link adaptation low MCS threshold
1...4, step 1
Default: 1

LNCEL: eUlLaDeltaMcs
Extended uplink link adaptation delta MCS
1...6, step 1
Default: 3

LNCEL:eUlLaPrbIncDecFactor
Extended uplink link adaptation PRB factor
0.5...0.9, step 0.05
Default: 0.8

Resetting the algorithm after long pause between active scheduled TTIs 1/3

- It is necessary to define how to react to long pauses between TTIs where UE is actively scheduled.
- UL-AMC defines already the timer *ulamcInactT* (hardcoded to 200 ms) for the purpose of resetting the MCS-index to **iniMcsUl** after the expiration of this timer.
- To avoid parameter multiplications those parameters are utilized with a similar function in E-ULA
- But in E-ULA the algorithm reset acts as well on the number of allocable PRBs and not on the MCS Index only.



Resetting the algorithm after long pause between active scheduled TTIs 2/3

If user is still not active after expiration of timer, its resource assignments should be gradually decreased

User is not scheduled

- No transmission – long pause
- Wait until counter *ulamcInactT* is reached

If meantime user was scheduled again, the counter is reset and no further LA adjustment is done

Start decreasing PRBs

- When counter reached (*ulamcInactT*) and PRB > *iniPrbsUl* –> start decreasing PRBs by *eUlLaPrbIncDecFactor*

Reset MCS

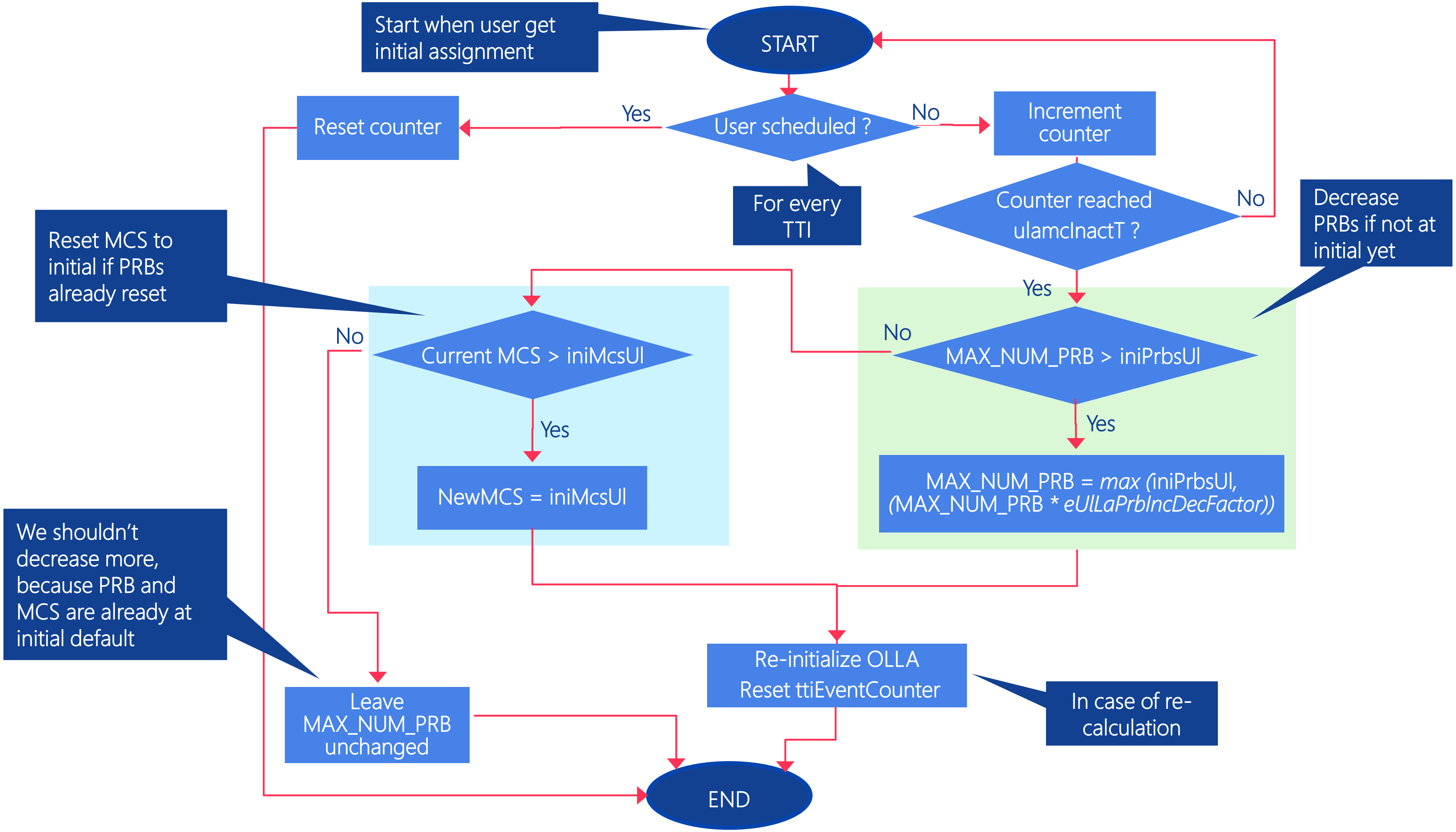
- When PRBs already at *iniPrbsUl* set MCS to *iniMcsUl*

Reset counters and re initialize OLLA in case of any recalculation

LNCEL: iniPrbsul;
Initial amount of PRBs in UL
1…100; step 1;
Default: 10

LNCEL: iniMcsUl
Initial MCS in uplink;
0…28,
Default: 5

Resetting the algorithm after long pause between active scheduled TTIs 3/3



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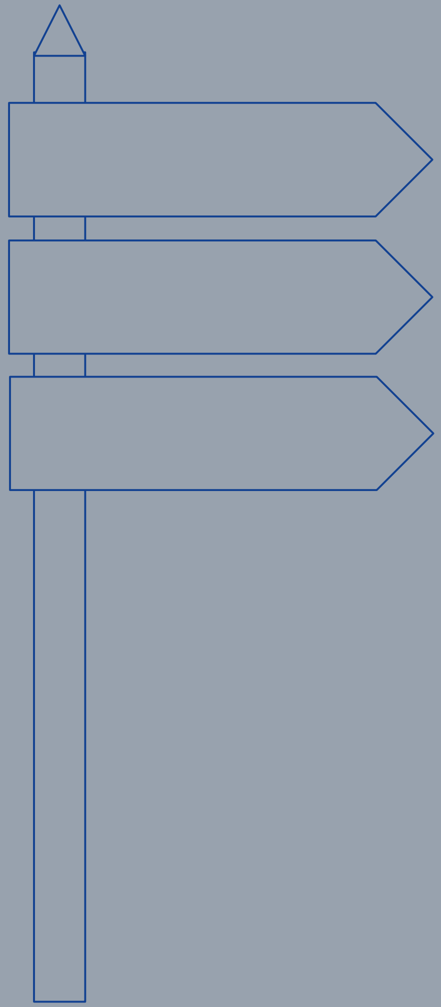
UL link adaptation summary

Parameter actUlLnkAdp activates Link Adaptation and defines its mode

actUlLnkAdp	OLLA	ATB	
		PHR based	BLER based
off	✗	✗	✗
eUlLa	✓	✓	✓
slowAmc	✗	✗	✗
slowAmcATB	✗	✓	✗
slowAmcOlla	✓	✗	✗
slowAmcOllaATB	✓	✓	✗

Index



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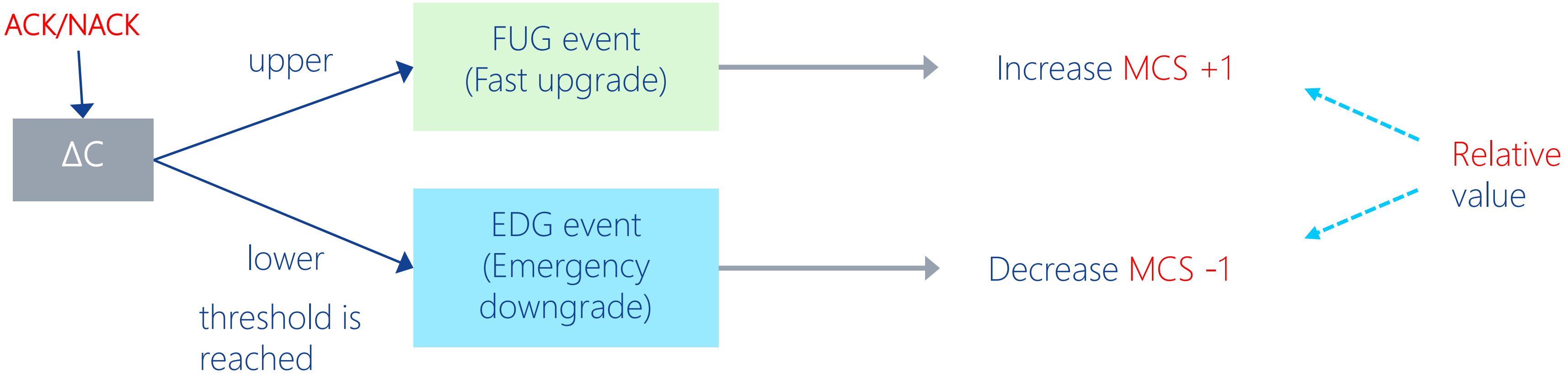
- **Fast Uplink Adaptation (F-ULA)**

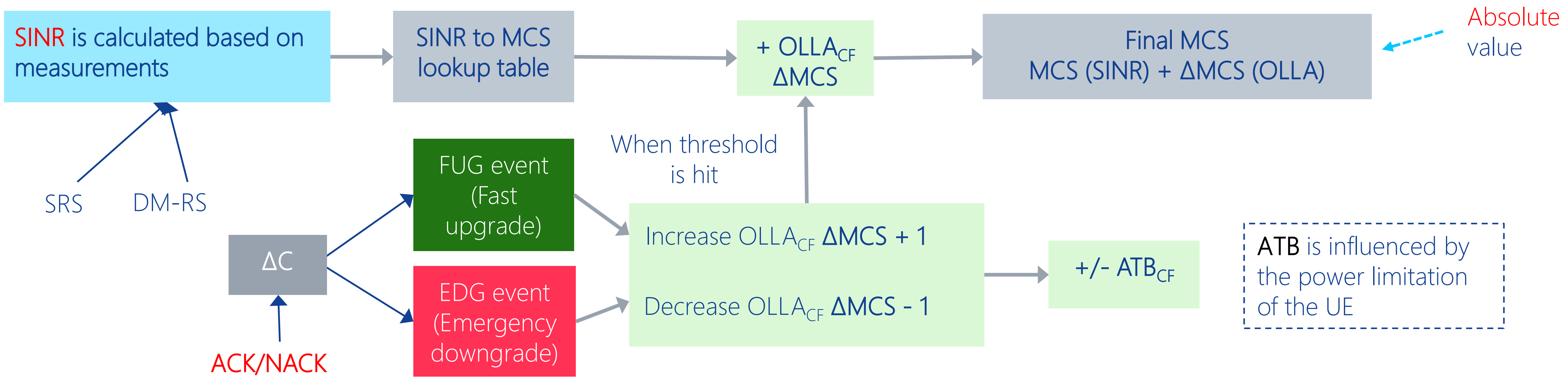
LTE1495 Fast Uplink Adaptation (F-ULA)

- Before : E-ULA (LTE1034) as open loop link adaptation



LTE1495 Fast Uplink Adaptation (F-ULA)

- After : F-ULA (LTE1495)



The mechanism to trigger a FUG or an EDG event **is the same** in E-ULA and F-ULA and is based on the defined BLER target.

LNCEL: actUlLnkAdp;
Activate uplink link adaptation;
off (0), slowAmcOllaATB (4), eUlLa (5), fUlLa (6);
Default: eUlLa (5)

Fast Uplink Adaptation (F-ULA)

- Range of ΔMCS is proportional to the maximum MCS index supported by the cell:

Calculation of OLLA correction factor ($OLLA_{CF}$)

$OLLA_{CF,new} = OLLA_{CF,old} + OLLAstep$

OLLAstep = +1 if triggered by FUG or
OLLAstep = -1 if triggered by EDG

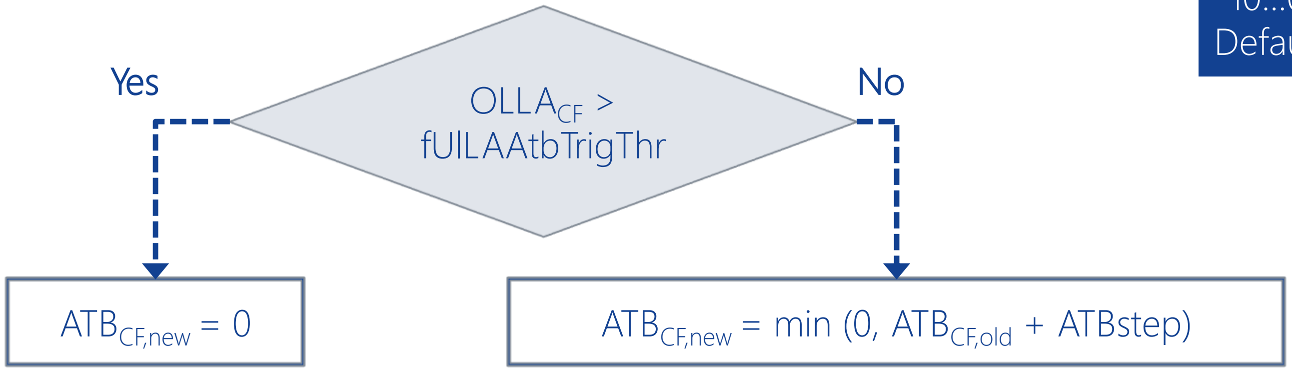
LNCEL:actModulationSchemeUL	$OLLA_{CF}$ range for **ΔMCS**
QPSK	-10…+10
16QAM	-20…+20
16QAMHighMCS	-24…+24

Fast Uplink Adaptation (F-ULA)

ATB_{CF} is calculated when the $OLLA_{CF}$ has reached a certain value **fUlLAAtbTrigThr**

Calculation of ATB correction factor (ATB_{CF}):

LNCEL: fUlLAAtbTrigThr;
Fast uplink link ATB trigger threshold;
-10...0, step 1;
Default: -2



ATBstep = +1 if triggered by FUG or
ATBstep = -1 if triggered by EDG

fUlLAAtbTrigThr is always < 0
ATB_{CF} is always ≤ 0

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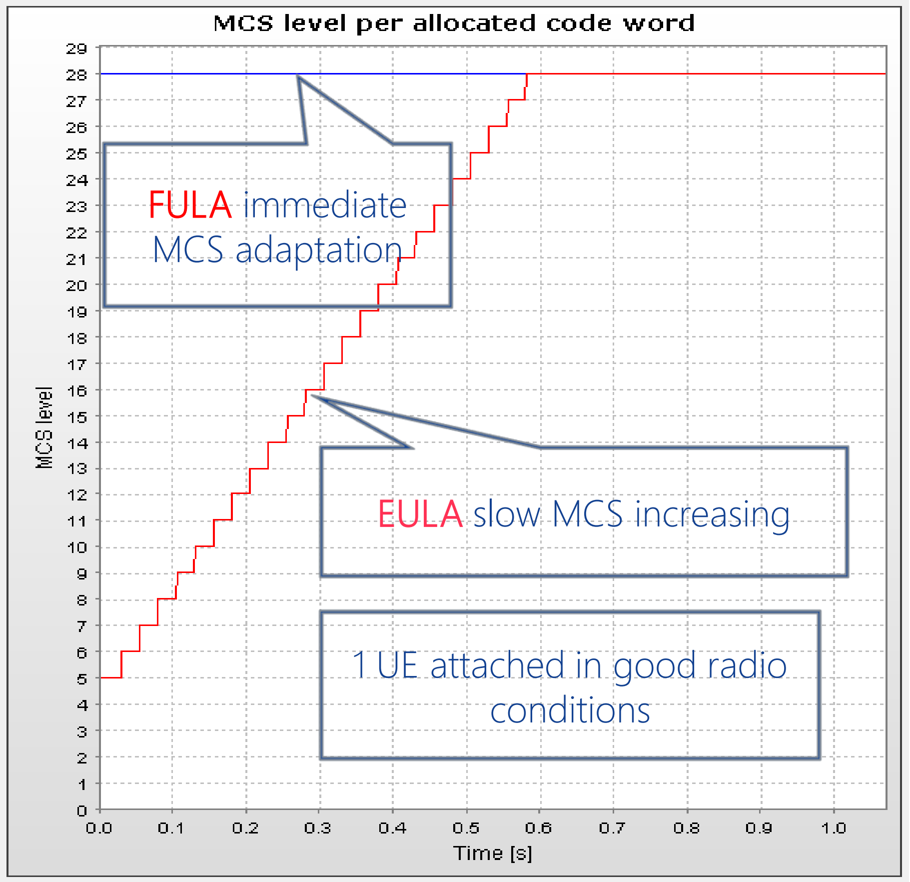
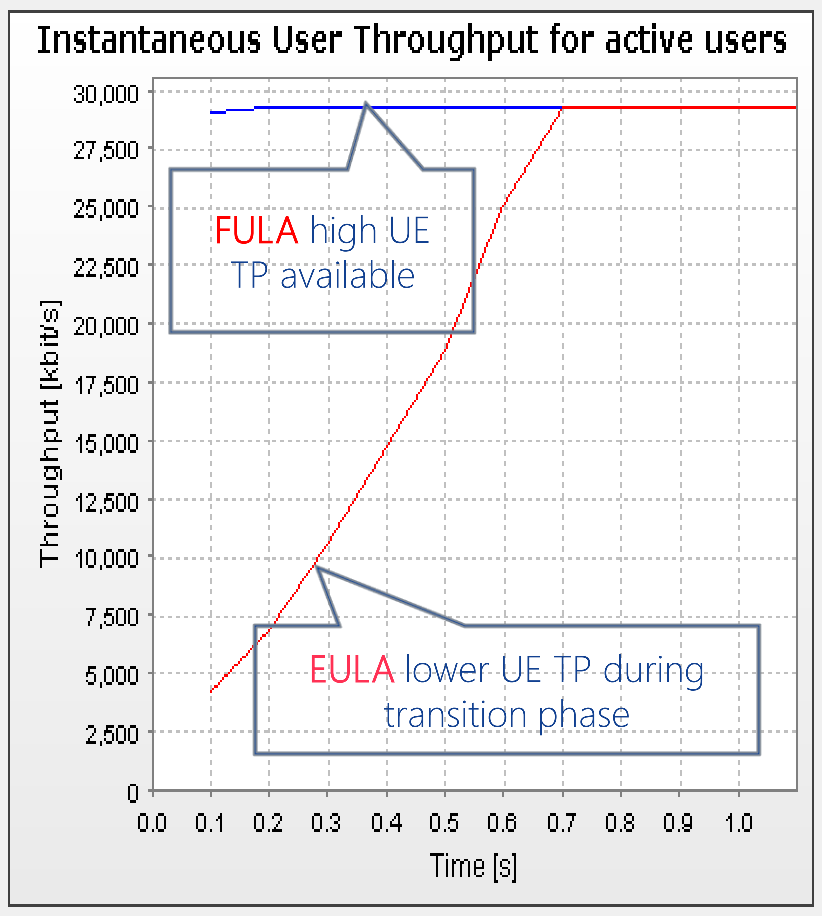
Fast Uplink Adaptation (F-ULA)

System level simulation results



MCS



Throughput

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Fast Uplink Adaptation (F-ULA)

Evolution of Link Adaptation:

Link Adaptation		UL LA	E-ULA	F-ULA
AMC	ILLA	Slow AMC -BLER based -MCS target = +/-1	Not used with E-ULA	Fast AMC (per TTI) -SINR & BLER based -MCS target = absolute
	OLLA	OLLA -BLER based -MCS target = +/-1	OLLA unchanged	Modified OLLA (offset) - Apply offset to MCS target
ATB		Slow ATB - PHR based	New ATB - PHR and BLER based	Modified ATB (OLLA offset) - Apply OLLA offset to ATB
Parameter activation		LNCEL:ulamcEnable = True LNCEL:ulatbEnable = True	LNCEL:actUlLnkAdp = eUlLa	LNCEL:actUlLnkAdp = fUlLa
Comment			OLLA and ATB synchronization	F-AMC core integrates all functional blocks

AMC: Adaptive Modulation & Coding
ILLA: Inner Loop Link Adaptation
OLA: Outer Loop Link Adaptation

ATB: Adaptive Transmission Bandwidth
PHR: Power Headroom Report
BLER: Block Error Rate

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