3GPP TR 38.816 V15.0.0 (2017-12)

Technical Report

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Study on CU-DU lower layer split for NR;
(Release 15)

Keywords
<keyword[, keyword]>

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Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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1 presented to TSG for information;

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

1 Scope

The purpose of the present document is to record the discussion and agreements that arise from the study item "CU-DU lower layer split for NR" in RP-170818 [2]. The study is continued from that which was conducted within the NR Access Technology Study Item, where the results are captured in sub-clause 11.1 and Annex A of TR 38.801 [3].

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] RP-170818: "New SID on CU-DU lower layer split for New Radio ".

[3] 3GPP TR 38.801: " Study on new radio access technology: Radio access architecture and interfaces ".

3 Definitions, symbols and abbreviation

3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

lls-CU: When lower layer split applies, gNB CU which hosts layers above PHY (i.e. MAC, RLC, PDCP, SDAP and RRC) and also some higher parts of PHY layer depending on the lower layer functional split option, and which controls the operation of one or more lls-DUs.

lls-DU: When lower layer split applies, gNB DU which hosts all or some lower parts of PHY layer depending on the lower layer functional split option, and *which* is partly controlled by lls-CU.

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

4 Functionalities and distribution between lls-CU and lls-DU

4.1 One possible implementation of NR L1 processing chain

One possible implementation of NR L1 processing chain at gNB is illustrated in Figure 4.1-1.

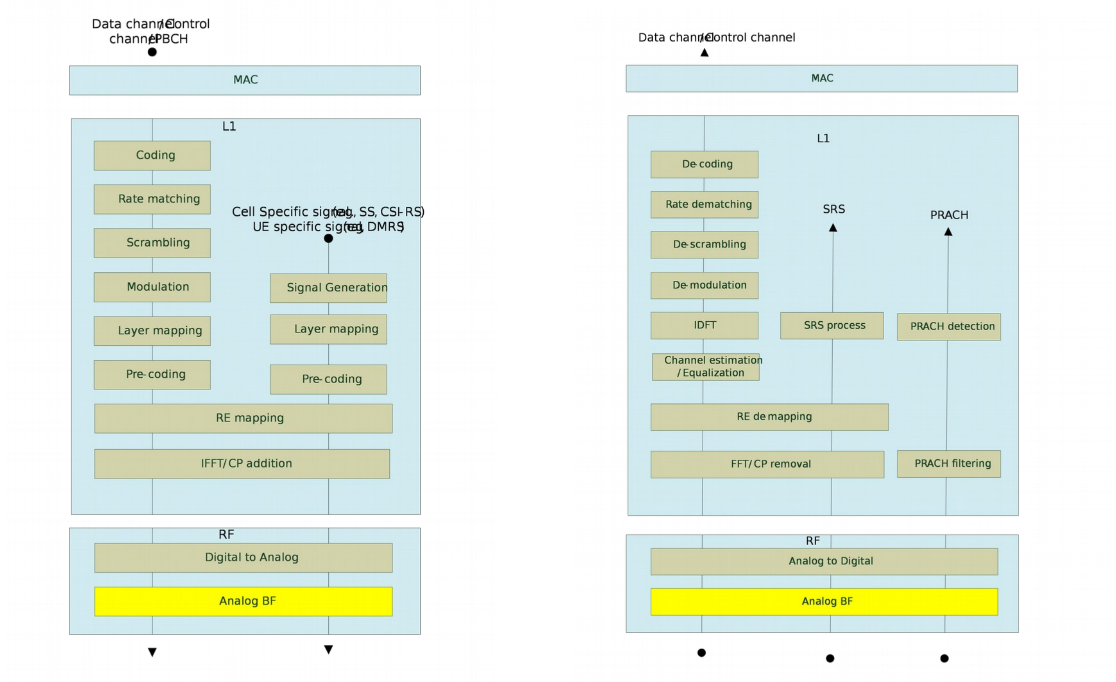

Figure 4.1-1: One possible implementation of NR L1 processing chain at gNB for DL (left) and UL (right)

It should be noted that Figure 4.1-1 just illustrates one possible implementation which is considered solely for the purpose of study. Other implementations are possible and possibly different in terms of functions description and functional chain order. A digital beamforming function may be supported by means of implementation. Such function may be concentrated in one block along the function chain or it might be spread across different functions of the PHY, but this is not illustrated in Figure 4.1-1.

A non-exhaustive list of disclaimers is provided below:

- 3GPP Specifications do not describe any base station receiver functionality.
- Future 3GPP work, including extended focus on new types of services such as mMTC/NB-IoT may impact the functionality of the physical layer, including rearrangement of functionality as well as adding new functional blocks.
- Beam-forming, including the open-loop beam-forming, e.g., precoder cycling, and analog beam-forming, will largely be a specification-transparent functionality that may be implemented at different places within the sequence of transmitter steps.

- Regarding the receiver processing chain, IDFT block doesn't exist when CP-OFDM is applied for UL transmission. It should be noted that the uplink waveform can vary per UE, and different PUCCH formats may be transmitted with different waveforms.

- In the UL-L1, the receive path may not be linear as the figure in appendix suggests. It is possible to use iterative reception (such as SIC or Turbo Equalization), where the data might be moved back and forth between 1 or more functional blocks multiple times.

For the DL, the bandwidth depends on implementation of Pre-coding and digital beamforming. As an example, if DL digital spatial weight is applied only in the Pre-coding block, the numbers of signal dimension are transmission layers and antenna ports before and after the Pre-coding block, respectively. As another example, if DL digital spatial weight is applied in the Pre-coding block and also somewhere after the Pre-coding block, the numbers of signal dimension are transmission layers before the Pre-coding block and antenna ports after the point where all DL digital spatial weight are applied. In this case, the signal dimension between Pre-coding and the point where all DL digital spatial weight are applied is up to gNB implementation. Similarly, the UL is up to gNB implementation.

4.2 Functions distribution between lls-CU and lls-DU

Taking the NR L1 processing chain described in clause 4.1, possible (non-exhaustive) functional split options are illustrated in Figure 4.2-1.

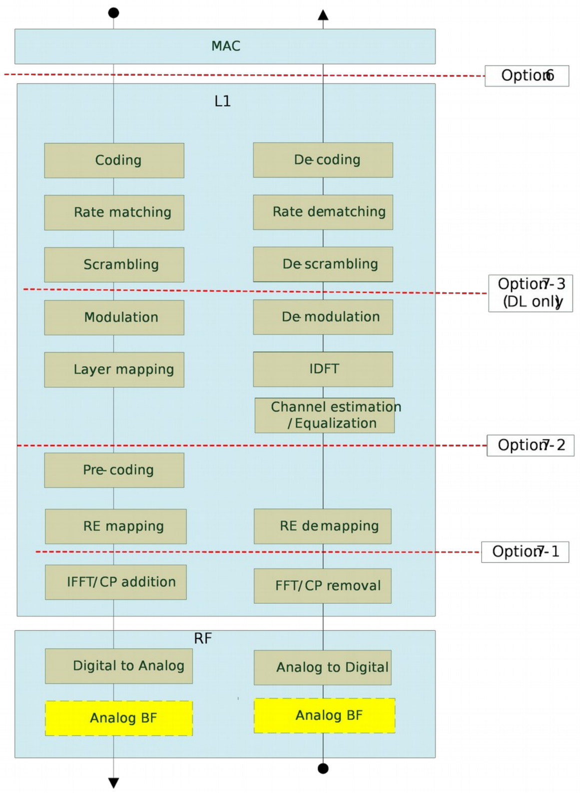

Figure 4.2-1: Possible, non-exhaustive, functional split options for DL (left) and UL (right)

It should be noted that Figure 4.2-1 only focuses on the data and control channels, and it leaves out reference signals, PRACH, etc. It should be also noted that the functional split options for DL and UL are independent, and that any combinations of DL split option and UL split option are not precluded.

Option 7-1, Option 7-2, Option 7-3 (DL only) and Option 6 are the same as those which were identified during the Rel-14 NR SI and captured in TR 38.801 [3].

Option 7-1

In the UL, FFT and CP removal functions reside in the lls-DU, the rest of PHY functions reside in the lls-CU.

In the DL, iFFT and CP addition functions reside in the lls-DU, the rest of PHY functions reside in the lls-CU.

Option 7-2

In the UL, FFT, CP removal and resource de-mapping functions reside in the lls-DU, the rest of PHY functions reside in the lls-CU.

In the DL, iFFT, CP addition, resource mapping and precoding functions reside in the lls-DU, the rest of PHY functions reside in the lls-CU.

Option 7-3 (Only for DL)

Only the encoder resides in the lls-CU, and the rest of PHY functions reside in the lls-DU.

Option 6

All of the PHY functions reside in the DU.

Additional potential functional split options were also raised during the study. For the UL, there was a proposal to split between IDFT and Channel estimation / Equalization. Also, for both DL and UL, the possibility to split somewhere between Option 7-1 and Option 7-2 was proposed in light of digital beamforming.

5 Evaluation criteria and comparison of options

The required fronthaul bandwidth is identified as evaluation criteria for lower layer split options. Keeping other parameters like signal bandwidth or modulation type fix, the fronthaul bandwidth changes dependent on number of transmission layers and number of antenna ports involved. The example calculation on the required fronthaul bandwidth for the split options in subclause 4.2 is shown in Annex A. It is noted that the required fronthaul bandwidth figures shown in the Annex are the worst case figures.

6 Low Layer Split operation

6.0 General

The Low Layer Split should fulfill the normal network operations in term of features support, UE capabilities, deployments, etc. This clause describes a set of network operations expected to be supported by the Low Layer Split.

6.1 Simultaneous use of different split architectures

6.1.1 Description

In case more than one of the architectural split options are feasible and need to be supported, the following cases can be analysed either in isolation or combined:

- Different low layer splits can be adopted for UL and DL communication with the UE.
- Different low layer splits can be adopted for communication over different carriers and bands.
- E-UTRA and NR can share the same carrier and serve the UE (FFS).
- Different low layer splits can be adopted for communication via different RF (FFS).

Figure 6.1.1-1 provides an example case reflecting the above operation cases.

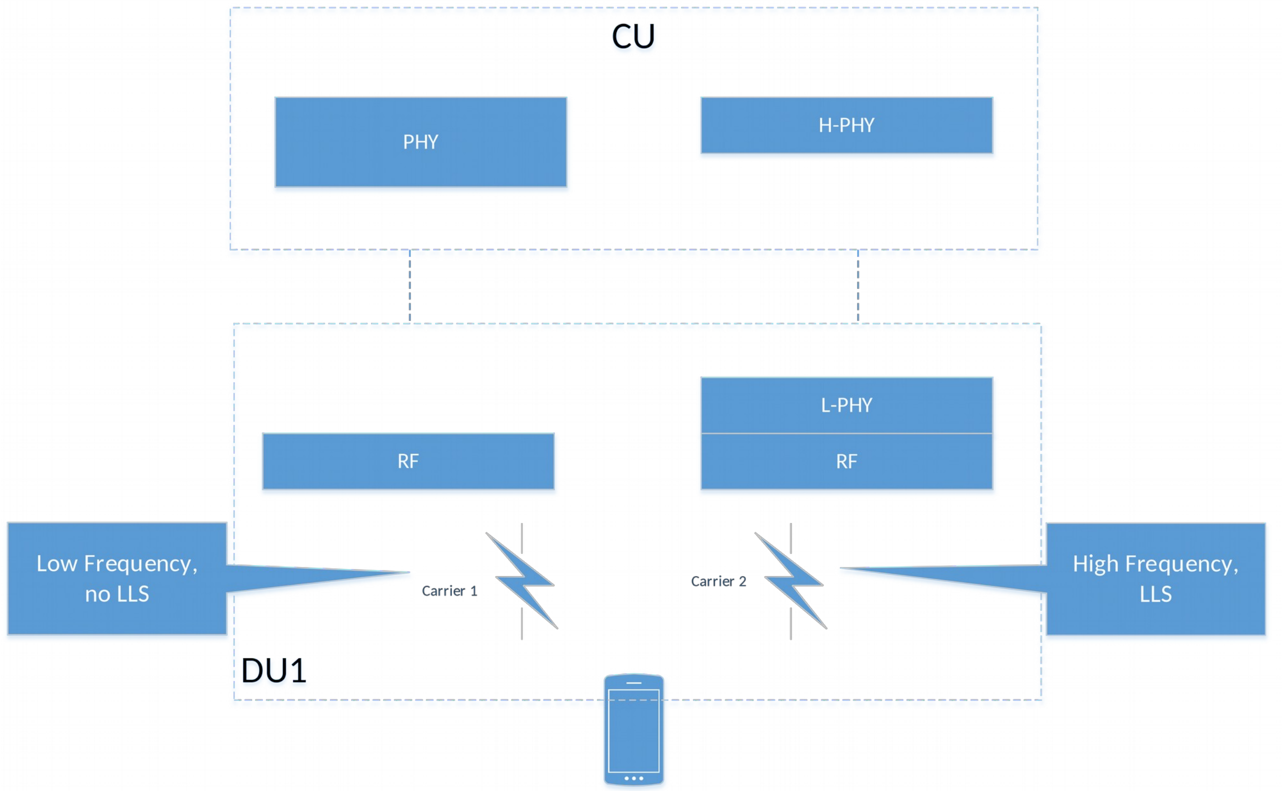

Figure 6.1.1-1: Example of different architecture usage to serve same UE

The study should analyse the implications of these cases on the design of possible interfaces between different entities of the low layer splits.

The study should analyse how coordination of control and data transmissions over different low layer split architectures can be achieved.

The study should analyse how the lls-gNB-CU and lls-gNB-DU can schedule traffic over different transports serving different low layer splits.

The study should analyse whether carrier sharing between LTE and NR has any implications on LLS architectures and what are the conditions needed to efficiently design systems supporting carrier sharing between LTE and NR. (FFS).

7 Conclusion

The following is concluded:

- The Study on CU-DU lower layer split for New Radio has extended the analysis already carried out in the Rel 14 Study on New Radio (NR) Access Technology [3]. An overall good and detailed amount of information has been produced regarding low layer split architecture options.

- RAN1 specifications themselves do not provide a single standardised functional model for a low layer split architecture, as functions which are specification transparent (e.g. beamforming) may be implemented at the base station (for both DL and UL) and RAN1 specifications do not specify base station receiver functionality (i.e. UL).

- Regardless, efforts were made during the study to consider possible implementations, and several lower layer split options were identified. However, actual implementations may be different due to various reasons (as outlined in clause 4.1). RAN3 could not converge on down-selection of a single option.

- Further, from the attempt on fronthaul bandwidth evaluations, it can be observed that the fronthaul bandwidth depends greatly on the particular split option. But it can also be observed that fronthaul bandwidth depends greatly on radio configuration (e.g. system bandwidth, number of MIMO layers and antenna ports) too, and all of the identified lower layer split options are feasible depending on the particular radio configuration.

- It is concluded that all identified low layer split options are technically feasible.

Based on the above, the following can be concluded: as of today, there is a preference for 3GPP to be open to all of the identified lower layer split options (and even further to the variants thereof). It appears difficult to converge on a single split option.

Annex A:
Fronthaul bandwidth

The example calculation on the required fronthaul bandwidth for the split options in subclause 4.2 is shown in this Annex. The required fronthaul bandwidth figures in this Annex are the worst case figures.

Following Tables A-2 and A-3 show the calculation on the required fronthaul bandwidth for the parameter sets in Table A-1.

Table A-1: Parameter sets for fronthaul bandwidth evaluation

Parameter set	Channel BW [MHz]	Modulation scheme	Number of MIMO layer	IQ bitwidth [bit]	Number of antenna ports
TR 38.801 [3]	100 (DL/UL)	DL:256QAM UL:64QAM (NOTE 1)	DL:8 UL: 8	DL: 2x(7~16) UL: 2x(10~16)	32 (DL/UL)
#1	100 (DL/UL)	256QAM (DL/UL)	DL:8 UL: 4	DL: 2x16 UL: 2x16 (NOTE 2)	32 (DL/UL)
#2					8 (DL/UL)
#3	200 (DL/UL)				32 (DL/UL)
#4					8 (DL/UL)
#5	400 (DL/UL)				32 (DL/UL)
#6					8 (DL/UL)
NOTE 1: While Table A-2 in TR 38.801 states "256QAM" for UL, the calculation in Table A-1 in TR 38.801 is based on 64QAM. NOTE 2: For IQ bit width, only 2x16 is used (for Parameters set#1-6) since the intention is to show the maximum values.					

Table A-2: The required fronthaul bandwidth for split points and parameter sets in DL

			Option 6 (NOTE 1)	Option 7-3 (NOTE 1)	Option 7-2	Option 7-1
Required FH BW [Gbps] (assuming worst case)	TR 38.801 [3]		4.133	4.133	10.1~22.2 (NOTE 2)	37.8~86.1 (NOTE 2)
	Parameter sets	#1	4.546	4.546	29.3	113.6
		#2	4.546	4.546	29.3	28.4
		#3	9.092	9.092	58.6	227.3
		#4	9.092	9.092	58.6	56.82
		#5	18.18	18.18	117.2	454.6
		#6	18.18	18.18	117.2	113.6
NOTE 1: Required FH BW figures are the same since coding rate r = 1 is assumed. With coding rate r < 1, Required FH BW figure for Option 6 would be less than that for Option 7. NOTE 2: Required FH BW figures are shown as a range to illustrate the dependence on IQ bitwidth.						

Option 6 and 7-3

For DL, Required FH BW [Gbps] for TR 38.801 [3] was calculated as follows:

- A1 = A0 * B1 * C1 * D1 + E1;
- Where:
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - A0 = Peak data rate of LTE reference = 150 Mbps;
  - B1 = System BW scaling = (100 MHz / 20 MHz);
  - C1 = MIMO layer scaling = (8 layer / 2 layer);
  - D1 = QAM scaling = (8bits per symbol / 6 bits per symbol);

- E1 = Overhead = 133 Mbps (accounts for scheduling/control signalling).

For DL, Required FH BW [Gbps] for Parameter sets are calculated as follows:

- A2 = A1 * B2 * C2 * D2 * E2 *F2;
- Where:
  - A2 = Required FH BW [Gbps] for Parameter set {#1 - #6}
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B2 = System BW scaling = ({100 MHz, 200 MHz, 400 MHz} / 100 MHz);
  - C2 = MIMO layer scaling = (8 layer / 8 layer);
  - D2 = QAM scaling = (8 bits per symbol / 8 bits per symbol);
  - E2 = Spectrum Usage scaling (NOTE 1) = (99 % / 90 %);
  - F2 = Margin for an upper bound estimation (NOTE 2) = (120 % / 100 %);

Option 7-2

For DL, Required FH BW [Gbps] for TR 38.801 [3] was calculated as follows:

- A1 = B1 * C1 * D1 * E1* F1 + G1;
- Where:
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B1 = Num of Sub-Carrier of LTE reference for 20 MHz = 1200 SC / 20 MHz;
  - C1 = System BW scaling = (100 MHz / 20 MHz);
  - D1 = OFDM symbol rate = 14 symbol / ms
  - E1 = MIMO layer = 8 layer;
  - F1 = IQ bitwidth = 2*16 bits;
  - G1 = Overhead = 713.9 Mbps (accounts for scheduling/control signalling).

For DL, Required FH BW [Gbps] for Parameter sets are calculated as follows:

- A2 = A1 * B2 * C2 * D2 * E2 * F2;
- Where:
  - A2 = Required FH BW [Gbps] for Parameter set {#1 - #6}
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B2 = System BW scaling = ({100 MHz, 200 MHz, 400 MHz} / 100 MHz);
  - C2 = MIMO layer scaling = (8 layer / 8 layer);
  - D2 = IQ bitwidth scaling = (2 x 16 bits / 2 x 16 bits);
  - E2 = Spectrum Usage scaling (NOTE 1) = (99 % / 90 %);
  - F2 = Margin for an upper bound estimation (NOTE 2) = (120 % / 100 %);

Option 7-1

For DL, Required FH BW [Gbps] for TR 38.801 [3] was calculated as follows:

- A1 = B1 * C1 * D1 * E1 * F1+ G1;

- Where:

  - A1 = Required FH BW [Gbps] for TR 38.801 [3];

  - B1 = Num of Sub-Carrier of LTE reference for 20 MHz = 1200 SC / 20 MHz;

  - C1 = System BW scaling = (100 MHz / 20 MHz);

  - D1 = OFDM symbol rate = 14 symbol / ms

  - E1 = Antenna port = 32 Ant;

  - F1 = IQ bitwidth = 2 x 16 bits;

  - G1 = Overhead = 121 Mbps (accounts for scheduling/control signalling).

For DL, Required FH BW [Gbps] for Parameter sets are calculated as follows:

- A2 = A1 * B2 * C2 * D2 * E2 * F2;

- Where:

  - A2 = Required FH BW [Gbps] for Parameter set {#1 - #6}

  - A1 = Required FH BW [Gbps] for TR 38.801 [3];

  - B2 = System BW scaling = ({100 MHz, 200 MHz, 400 MHz} / 100 MHz);

  - C2 = Num of Ant port scaling = ({8 Ant, 32 Ant} / 32 Ant);

  - D2 = IQ bitwidth = (2 x 16 bits / 2 x 16 bits);

  - E2 = Spectrum Usage scaling (NOTE 1) = (99 % / 90 %);

  - F2 = Margin for an upper bound estimation (NOTE 2) = (120 % / 100 %);

NOTE 1: The maximum spectrum usage of LTE and NR are 90 % and 99 % respectively.

NOTE 2: 20 % of margin (due to e.g. additional traffic such as scheduling and beamforming command and extra overhead of the transport layer) is considered as an upper bound estimation while actual values will be expected to be smaller.

Table A-3: The required fronthaul bandwidth for split points and parameter sets in UL

			Option 6	Option 7-2	Option 7-1
Required FH BW [Gbps] (assuming worst case)	**TR 38.801 [3]**		5.64	13.6~21.6 (NOTE)	53.8~86.1 (NOTE)
	Parameter sets	#1	4.93	14.25	113.6
		#2	4.93	14.25	28.4
		#3	9.92	28.51	227.3
		#4	9.92	28.51	56.8
		#5	19.85	57.0	454.6
		#6	19.85	57.0	113.6
NOTE: Required FH BW figures are shown as a range to illustrate the dependence on IQ bitwidth.					

Option 6

For UL, Required FH BW [Gbps] for TR 38.801 [3] was calculated as follows:

- A1 = A0 * B1 * C1 * D1 + E1;

- Where:

  - A1 = Required FH BW [Gbps] for TR 38.801 [3];

- A0 = Peak data rate of LTE reference = 50 Mbps;
- B1 = System BW scaling = (100 MHz / 20 MHz);
- C1 = MIMO layer scaling = (8 layer / 1 layer);
- D1 = QAM scaling = (6 bits per symbol / 4 bits per symbol);
- E1 = Overhead = 2640 Mbps (accounts for control signalling).

For UL, Required FH BW [Gbps] for Parameter sets are calculated as follows:

- A2 = A1 * B2 * C2 * D2 * E2 *F2;
- Where:
  - A2 = Required FH BW [Gbps] for Parameter set {#1 - #6}
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B2 = System BW scaling = ({100 MHz, 200 MHz, 400 MHz} / 100 MHz);
  - C2 = MIMO layer scaling = (4 layer / 8 layer);
  - D2 = QAM scaling = (8 bits per symbol / 6 bits per symbol);
  - E2 = Spectrum Usage scaling (NOTE 1) = (99 % / 90 %);
  - F2 = Margin for an upper bound estimation (NOTE 2) = (120 % / 100 %);

Option7-2

For UL, Required FH BW [Gbps] for TR 38.801 [3] was calculated as follows:

- A1 = B1 * C1 * D1 * E1* F1 + G1;
- Where:
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B1 = Num of Sub-Carrier of LTE reference for 20 MHz = 1200 SC / 20 MHz;
  - C1 = System BW scaling = (100 MHz / 20 MHz);
  - D1 = OFDM symbol rate = 14 symbol / ms
  - E1 = MIMO layer = 8 layer;
  - F1 = IQ bitwidth = 2 x 16 bits;
  - G1 = Overhead = 120 Mbps (accounts for control signalling).

For UL, Required FH BW [Gbps] for Parameter sets are calculated as follows:

- A2 = A1 * B2 * C2 * D2 * E2 * F2;
- Where:
  - A2 = Required FH BW [Gbps] for Parameter set {#1 - #6}
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B2 = System BW scaling = ({100 MHz, 200 MHz, 400 MHz} / 100 MHz);
  - C2 = MIMO layer scaling = (4 layer / 8 layer);
  - D2 = IQ bitwidth = (2 x 16 bits / 2 x 16 bits);
  - E2 = Spectrum Usage scaling (NOTE 1) = (99 % / 90 %);

- F2 = Margin for an upper bound estimation (NOTE 2) = (120 % / 100 %);

Option7-1

For UL, Required FH BW [Gbps] for TR 38.801 [3] was calculated as follows:

- A1 = B1 * C1 * D1 * E1 * F1+ G1;
- Where:
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B1 = Num of Sub-Carrier of LTE reference for 20 MHz = 1200 SC / 20 MHz;
  - C1 = System BW scaling = (100 MHz / 20 MHz);
  - D1 = OFDM symbol rate = 14 symbol / ms
  - E1 = Antenna port = 32 Ant;
  - F1 = IQ bitwidth = 2 x 16 bits;
  - E1 = Overhead = 80 Mbps (accounts for scheduling/control signalling).

For UL, Required FH BW [Gbps] for Parameter sets are calculated as follows:

- A2 = A1 * B2 * C2 * D2 * E2 * F2;
- Where:
  - A2 = Required FH BW [Gbps] for Parameter set {#1 - #6}
  - A1 = Required FH BW [Gbps] for TR 38.801 [3];
  - B2 = System BW scaling = ({100 MHz, 200 MHz, 400 MHz} / 100 MHz);
  - C2 = Num of Ant port scaling = ({8 Ant, 32 Ant} / 32 Ant);
  - D2 = IQ bitwidth = (2 x 16 bits / 2 x 16 bits);
  - E2 = Spectrum Usage scaling (NOTE 1) = (99 % / 90 %);

- F2 = Margin for an upper bound estimation (NOTE 2) = (120 % / 100 %);

Annex B: Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2017-08	RAN3#97	R3-174135				Initial Skeleton	0.0.1
2017-10	RAN3#97bis	R3-174257				Capturing the agreements from RAN3#97bis	0.1.0
2017-12	RAN3#98	R3-175070				Capturing the agreements from RAN3#98	0.2.0
2017-12	RAN#78	RP-172441				Presentation to RAN for information (no change in contents compared to v0.2.0).	1.0.0
2017-12	RAN#78					TR is approved by RAN plenary	15.0.0