3GPP TR 38.883 V16.0.0 (2020-06)

Technical Report

**3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Study on support of NR downlink 256 Quadrature Amplitude
Modulation (QAM) for frequency range 2 (FR2)
(Release 16)**

3GPP

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Contents

Foreword

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The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

x   the first digit:

1   presented to TSG for information;

2   presented to TSG for approval;

3   or greater indicates TSG approved document under change control.

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.

In the present document, certain modal verbs have the following meanings:

shall   indicates a mandatory requirement to do something

shall not   indicates an interdiction (prohibition) to do something

NOTE 1: The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

NOTE 2: The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

should   indicates a recommendation to do something

should not   indicates a recommendation not to do something

may   indicates permission to do something

need not   indicates permission not to do something

NOTE 3: The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

can   indicates that something is possible

cannot   indicates that something is impossible

NOTE 4: The constructions "can" and "cannot" shall not to be used as substitutes for "may" and "need not".

will   indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

will not   indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

might   indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

might not   indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

is   (or any other verb in the indicative mood) indicates a statement of fact

is not   (or any other negative verb in the indicative mood) indicates a statement of fact

NOTE 5: The constructions "is" and "is not" do not indicate requirements.

1 Scope

The present document captures finding of the study on support of NR DL 256QAM for FR2. The purpose of this TR is to study the feasibility and performance benefits for NR DL 256QAM for FR2 as defined in Work Item "Add support of NR DL 256QAM for FR2" [2].

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-190760, "Add support of NR DL 256QAM for FR2", China Telecom

[3]   3GPP TR 38.803: "Study on new radio access technology: RF and co-existence aspects".

[4]   3GPP TS 38.306: "User Equipment (UE) radio access capabilities".

[5]   R4-1911087, "Updated link level simulation results for the feasibility study of FR2 DL 256QAM", China Telecom

[6]   R4-1909269, "Initial FR2 DL 256QAM link level simulation results", Nokia

[7]   R4-1913050, "Feasibility evaluation for NR FR2 DL256QAM", NTT DOCOMO

[8]   R4-1909186, "Simulation results on DL 256QAM", Huawei

[9]   R4-1909401, "Initial Link Simulation Results on DL 256 QAM FR2", Ericsson

[10]   R4-1908391, "Discussion on 256QAM for FR2", CATT

[11]   R4-1908211, "Discussion on feasibility of DL 256QAM in FR2 scenarios", Intel

[12]   R4-1911227, "Views on feasibility of 256QAM for FR2", Qualcomm

[13]   Staffan Ek et al., A 28-nm FD-SOI 115-fs Jitter PLL-Based LO System for 24-30-GHz Sliding-IF 5G Transceivers, IEEE Journal of Solid-State Circuits (Volume: 53 , Issue: 7 , July 2018)

[14]   R4-1909403, "Feasibility of UE demodulation testing", Ericsson

[15]   R4-1912892 "TP to TR: 38.883 FR2 DL 256QAM link level simulation results", Nokia, Nokia Shanghai Bell

[5.2.2.1-1]   R4-1713125, "Evaluation on BS Tx EVM for mmWave", Huawei, HiSilicon

[5.2.2.2-2]   R4-1906014, "System level simulation for 256QAM DL in FR2", Nokia, Nokia Shanghai Bell

[5.2.2.2-3]   T. Tuominen, N. Tervo, A.Pärssinen; Analyzing 5G RF System Performance and Relation to Link Budget for Directive MIMO, IEEE Transactions on Antennas and Propagation (Volume: 65 , Issue: 12 , Dec. 2017)

[5.2.2.3-4]   R4-1908211, "Discussion on feasibility of DL 256QAM in FR2 scenarios", Intel

[A-1] R4-1711777, WF on simulation assumption for NR BS EVM requirement, Huawei, HiSilicon

[A-2] R4-1709666, Simulation assumptions on UE Tx EVM for mmWave, Huawei, HiSilicon

[A-3] 3GPP Radio Access Network Working Group. 2016. "E-UTRA and UTRA Radio Frequency (RF) requirement background for Active Antenna System (AAS) Base Station (BS) (Release 13)". 3GPP TR 37.842 V13.0.0.

[A-4] Du Jinfeng, Chizhik Dmitry, Rodriguez Rodolfo Feick, Mauricio, Castro Guillermo, Valenzuela Reinaldo. A. 2018. "Suburban Fixed Wireless Access Channel Measurements and Models at 28 GHz for 90% Outdoor Coverage", arXiv: 1807:03763.

[A-5] 3GPP Radio Access Network Working Group. 2018. "Study on channel model for frequencies from 0.5 to 100 GHz (Release 15)". 3GPP TR 38.901 V15.0.0.

…

[x] <doctype> <#>[([up to and including]{yyyy[-mm]|V<a[.b[.c]]>}[onwards])]: "<Title>".

3 Definitions of terms, symbols and abbreviations

This clause and its three subclauses are mandatory. The contents shall be shown as "void" if the TS/TR does not define any terms, symbols, or abbreviations.

3.1 Terms

For the purposes of the present document, the terms 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].

Definition format (Normal)

<defined term>: <definition>.

example: text used to clarify abstract rules by applying them literally.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

Symbol format (EW)

<symbol> <Explanation>

3.3 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].

Abbreviation format (EW)

<ACRONYM> <Explanation>

4   Background

At the 3GPP RAN #83 meeting, the Work Item on "Add support of NR DL 256QAM for FR2" was approved for Rel-16. The objectives of the core part in the Work Item are as follows:

Phase 1:   Continue and complete the feasibility and performance benefit study to identify applicable scenarios

   1)   Both system and link simulations as well as RF and baseband implementation need to be considered in the Rel-16 evaluation to study the benefits of FR2 DL 256QAM.

   2)   This phase is planned from RAN4#91 and should end by RAN4#93.

Phase 2:   Specify BS and UE requirements for NR DL 256QAM for FR2 if applicable scenarios and feasible requirements are identified

   1)   The requirements for BS include Tx modulation quality, Tx power dynamic range etc.

   2)   The requirements for UE include Rx maximum input power level, FRC etc.

This TR aims to study the Phase 1 in the objectives and further capture the impact on the specification if applicable.

5   Feasibility study for DL 256QAM

5.1 General

The feasibility study for FR2 DL 256QAM will be carried out based on two following parts:

-   Simulation based feasibility study

-   Implementation based feasibility study

5.2 Simulation based feasibility study

For the simulation study, the methods shall be same as the usual ways we have adopted in the earlier times for modulation orders feasibility evaluation in LTE or in NR. Throughput performance is compared among different modulation orders with EVM variable to verify the benefit for higher order modulation and then define the minimum EVM requirement. However, for NR FR2 simulation study, the impact due to phase noise is no longer negligible comparing to FR1, for higher order modulations. The phase noise impairment is frequency dependent as stated in 6.1.9.5 of [3] *PN could increase by 6 dB every time when f_0 doubles*. Therefore, the phase noise impairment shall be considered and emphasized in the feasibility study for FR2 DL 256QAM. As in [3] different PN models and impacts were studied as part of the overall system and not just as part of the effect at the transmitter.

The impact of phase noise will induce two main effects which include

-   Rotate the phases of constellation points in the transmitted/received signal by a common value as termed as common phase error (CPE)

-   Break the orthogonal in the OFDM signal, each subcarrier is interfered by every other adjacent subcarrier as termed as inter-carrier interference (ICI)

The CPE impacts can be compensated based on the phase offset estimates obtained from the dedicated phase tracking reference signals (PTRS). Although the PTRS is mandatory with UE capability signalling [4], but it is necessary for transmitter/receiver to apply PTRS to remove the CPE, which will not only benefit for 256QAM but also for lower order modulation. On the other side, 256QAM is an optional feature for FR2, but it shall be more applicable with PTRS supporting.

5.2.1   Link level simulation

Link level simulation is targeted as mainstream way to evaluate if FR2 256QAM can achieve benefit by comparing to 64QAM. The simulation results from companies are listed as below.

5.2.1.1 Simulation assumptions

The link level simulation assumptions are listed as in table 5.2.1.1-1, based on which, to evaluate the throughput difference between 64QAM and 256QAM. The study aims to identify conditions where DL 256QAM provides performance benefits.

Table 5.2.1.1-1 link level simulation assumptions

Parameter	Value
Carrier frequency	29 GHz (n257) and 39 GHz (n260)
CBW	50 MHz, 100MHz
SCS	60kHz, 120 kHz;
Allocated RBs	Full allocation
Propagation	TDL-A 30ns delay spread, 35Hz Doppler frequency TDL-D 30ns delay spread, 35Hz Doppler frequency Static (AWGN)
MCS	64QAM: MCS 23, 24, 26, 28 in TS 38.214 Table 5.1.3.1-1, and other MCSs are not precluded 256QAM: MCS 21, 23, 25, 27 in TS 38.214 Table 5.1.3.1-2, and other MCSs are not precluded Baseline: fixed MCSs
Precoding	Precoding configuration defined in 38.101-4 Section 7.2 for fading channels and Section 7.5 for static channel; follow PMI
Symbol type	CP-OFDM
HARQ	8, None
Antenna configuration	Fading channel: 2x2 for Rank1 and Rank2, Low correlation Static channel: 1x2 for Rank1, 2x2 for Rank2
Channel estimation	Practical
Receiver type	MMSE
PDSCH configuration	Type A mapping, Start symbol 1, Duration 13 (for D slots)
DMRS configuration	Type 1, Single symbol, 1 additional DMRS
PTRS configuration	KPTRS : 2 (every 2 RBs), LPTRS : 1 (every 1 symbol)
Phase noise compensation	Practical based on PTRS
Phase noise model	TR 38.803 model (in section 6.1.10 and section 6.1.11) modelled Phase noise for TX and RX Option a): example1 (BS) + example1(UE) Option b): example2 (BS) + example2(UE) Option c): example2 (BS) + example2(BS) Option d):example2 (BS) + PN model config1: example1(UE) Option e): Other phase noise models, e.g. ones extracted from commercially available components or published results, are not excluded
txEVM + rxEVM excluding phase noise for 256QAM	txEVM: [1.0%-5.0%], rxEVM: [1.0%-5.0%] Option 1: txEVM <= rxEVM; Option2: no restriction
Other parameters	follow assumptions in 38.101-4 Section 7.2 for fading channels (e.g., case 2-6) and Section 7.5 for static channels

The assumptions adopted by each company are shown as following table 5.2.1.1-2 which are down-selected based on the table 5.2.1.1-1.

Table 5.2.1.1-2 link level simulation assumptions down-selected by companies

Parameter	CTC[5]	Nokia[6][15]	Docomo[7]	Huawei[8]	Ericsson[9]	CATT[10]	Intel[11]	Qualcomm[12]

Carrier frequency		29 GHz	29 GHz	29 GHz	29 GHz	•	29 GHz	•	•
CBW		50MHz	100MHz	100MHz	50MHz	50 MHz	50MHz	50MHz	100MHz
SCS		120kHz	60kHz	120kHz	120kHz	60kHz	60kHz	60kHz	120kHz
Allocated RBs		•	•	•	•	•	•	•	•
Propagation	TDL-A	•				•	•	•	•
	TDL-D	•	•		•	•	•	•	•
	Static	•		•			•	•	•
MCS	64QAM	28	26,28	24,25,26,28	23,24,26,28	23,24,26,28	23	23,24,26,28	26,27,28
	256QAM	23,27	21,23,25,27	21,23,25,27	21,23,25,27	21,23,25,27	21	21,23,25,27	20,21,22
Precoding		•	•	•	•	•	•	•	•
Symbol type		•	•	•	•	•	•	•	•
HARQ		None	None	None		•	8	8	8
Antenna configuration	Fading	2x2 for Rank1	2x2 for Rank1	2x2 for Rank2	•	1x2, 2x2 for Rank1	2x2 for Rank1	•	2x2 for Rank2
	Static	1x2 for Rank1		2x2 for Rank2			1x2 for Rank1	•	2x2 for Rank2
Channel estimation		•	•	Practical for AWGN Ideal for TDL-D	•	•	•	•	•
Receiver type		•	•	•	•	•	•	•	•
PDSCH configuration		•	•	•	•	•	•	•	•
DMRS configuration		•	•	•	•	No additional	•	•	•
PTRS configuration		None	•	•	•	•	•	•	•
Phase noise compensation		None	•	Ideal	•	•	•	•	•
Phase noise model	Option a)	•		•	•	•			
	Option b)						•		
	Option c)							•	•
	Option d)				•			•	
	Option e)		•						example1BS+example2UE internal PN model
txEVM + rxEVM excluding phase noise for 256QAM		Tx+Rx: 3%, 4%	txEVM: 2%-3%, rxEVM: 2%-5%	txEVM: 0%, 2%, 3%, rxEVM: 0%, 2%, 3%	txEVM: 1%-3%, rxEVM: 1%-3%	•	•	txEVM: 1%-3%, rxEVM: 1%-3%	Tx:3% Rx:internal
Other parameters		•	•	•	•	•	•	•	•
Note: The symbol of • means selecting the parameters corresponding to table 5.2.1.1-1.									

5.2.1.2   Results from China Telecom [5]

The key parameter of EVM is constructed of two values dependent on different kinds of distortions. One is fixed EVM which reflects the impairment by the component non-linearity attribute contributed from the full transmitter chain and the other one is derived EVM based on the phase noise of transmitter/receiver. So in the simulation, the EVM variable is defined as fixed EVM + explicit derived EVM by PN model, and then we evaluate the SE performance with 0%, 3%

and 4% EVM values to find if any performance benefit for 256QAM by comparing to 64 QAM, in which the case for 0% EVM is as baseline for reference.

Figure 5.2.1.2-1 to 5.2.1.2-3 depict the spectrum efficiency performance by comparing 256QAM to 64QAM for TDL-A, TDL-D and AWGN channel correspondingly.

The curve with red colour represents the performance for 256QAM without PTRS.

The curve with blue colour represents the performance for 64QAM without PTRS.
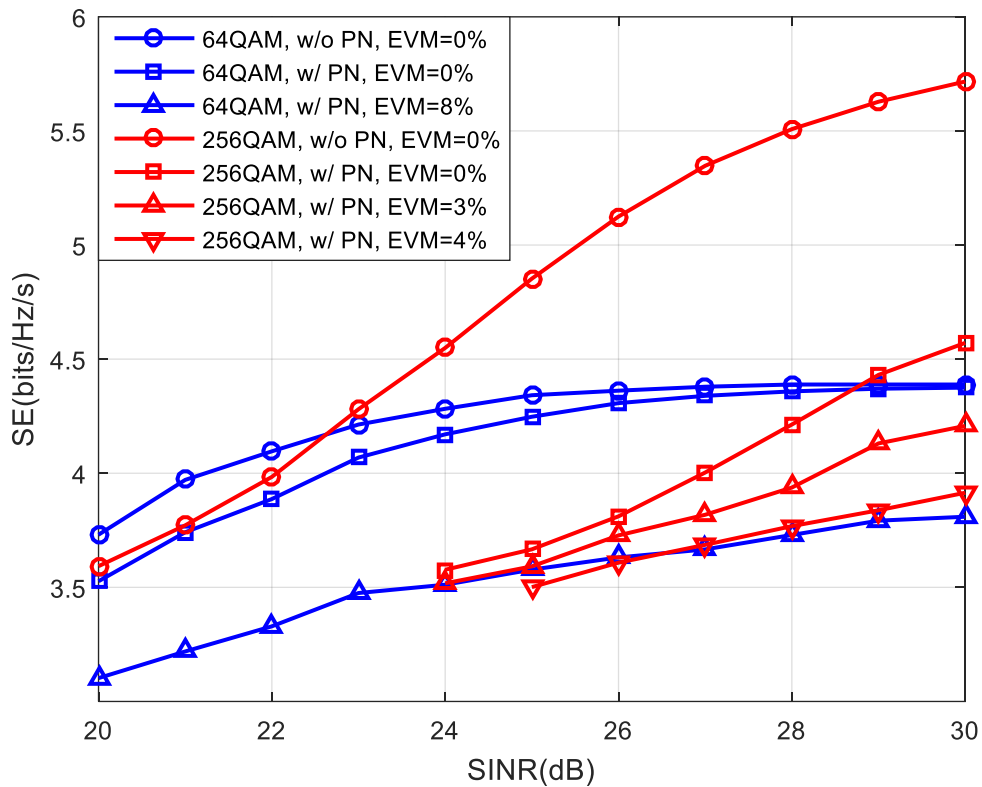

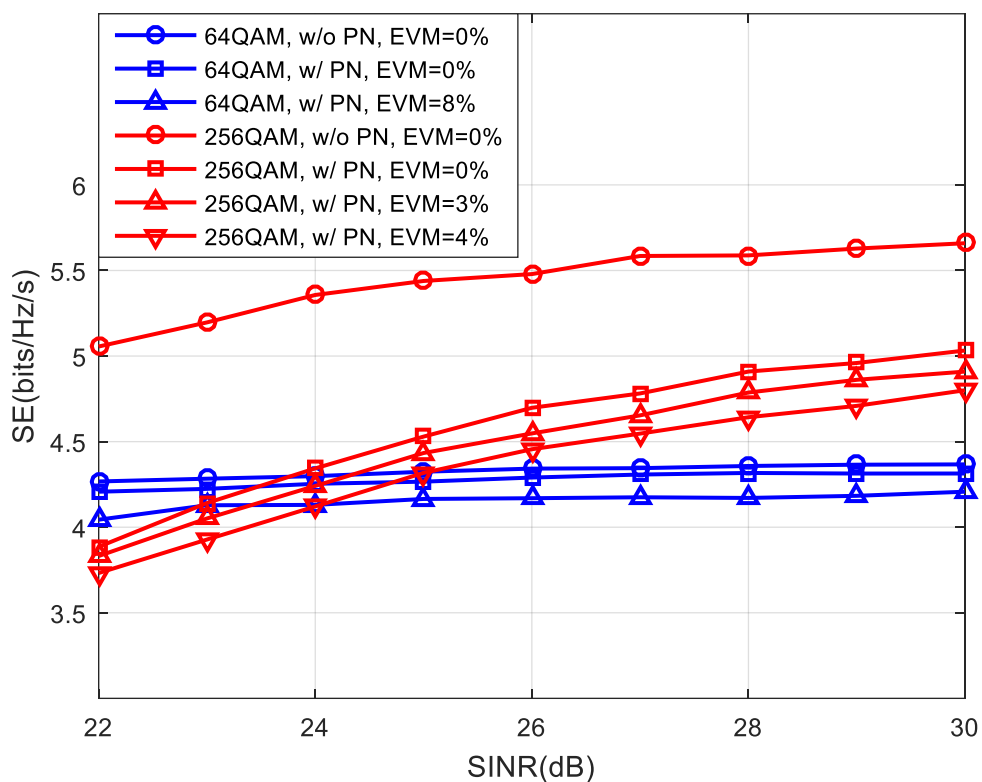**Figure 5.2.1.2-1: Spectrum efficiency performance by comparing 256QAM to 64QAM for TDL-A**

Figure 5.2.1.2-2: Spectrum efficiency performance by comparing 256QAM to 64QAM for TDL-D
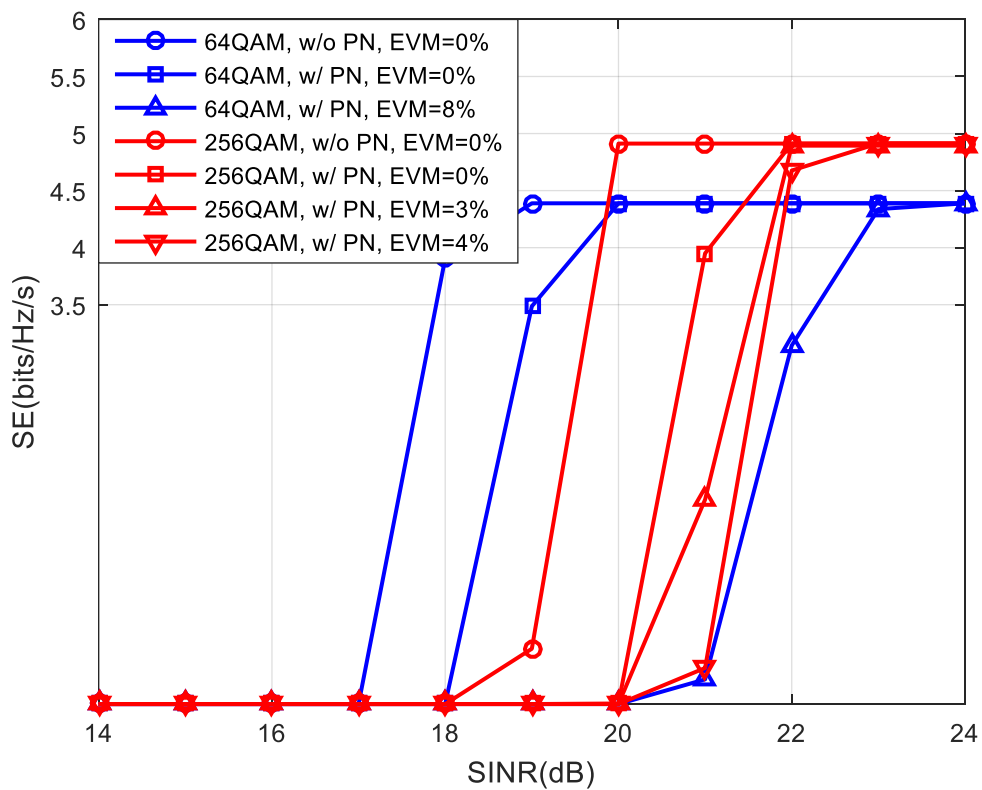

Figure 5.2.1.2-3: Spectrum efficiency performance by comparing 256QAM to 64QAM for AWGN

It is worth to note that all the EVM values in the figure have included the impact due to the phase noise which will contribute the -35dBc EVM in typically. Based on the figure above, we can observe that the phase noise will cause the SE performance degradation, the higher modulation order the more severe degradation. Although the PTRS is mandatory with UE capability signalling, but it is necessary for transmitter/receiver to apply PTRS to remove the CPE, which will not only benefit for 256QAM but also for lower order modulation. On the other side, 256QAM is an optional feature for FR2, but it shall be more applicable with PTRS supporting.

On the other side, even without PTRS which means no phase noise compensation, 256QAM still can achieve higher spectrum efficiency than 64QAM when SINR is larger than 25dB for TDL-A channel, 24dB for TDL-D channel, 20dB for AWGN channel with the total EVM is less than 4%.

5.2.1.3   Results from Nokia [6][15]

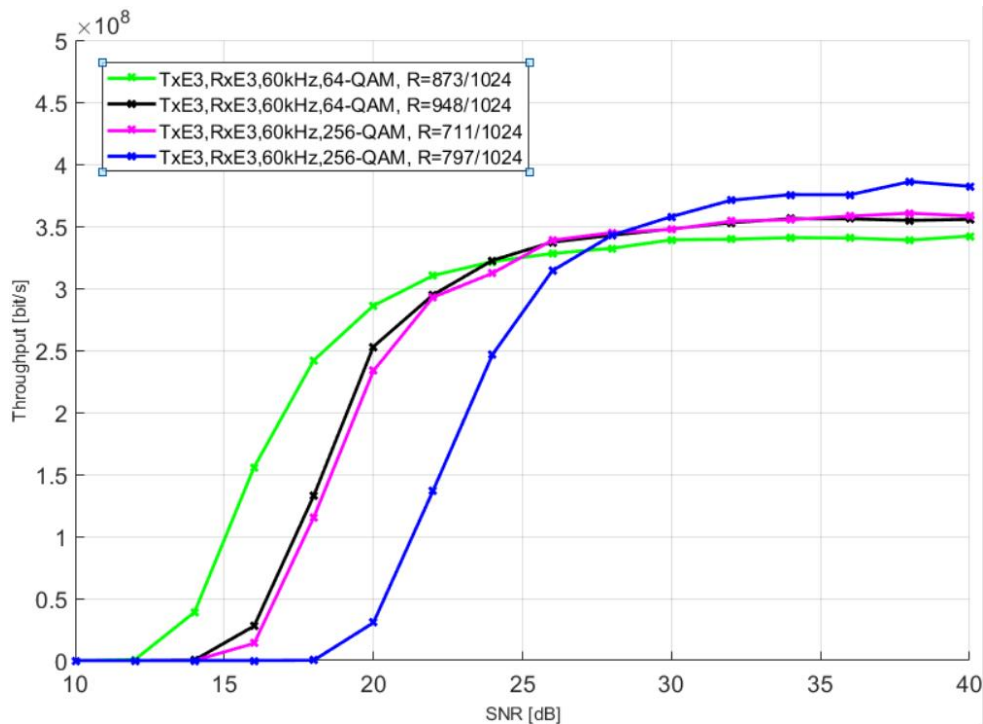Simulation results obtained with parameters in table 5.2.1.1-2 are shown in Figure 5.2.1.3-1.

Figure 5.2.1.3-1: Link level simulation results

In figure 5.2.1.3-1 it can be seen that the throughput with 256QAM exceeds throughput with 64QAM approximately at 28 dB SNR.

One important aspect to be taken into account when analysing the results is the used phase noise model. As shown in Figure 5.2.1.3-2, the phase noise performance is significantly worse that what is actually achievable with reasonable silicon area and power consumption [13]. On average the phase noise model is 6.5 dB worse than performance in [13]. Therefore with realistic phase noise assumptions more gains are expected.

One should also note that it may be overly optimistic to compare 64QAM and 256QAM with the same baseline EVM on Tx side, as 64QAM EVM budget is more relaxed and this can be utilized by heavier crest factor reduction.
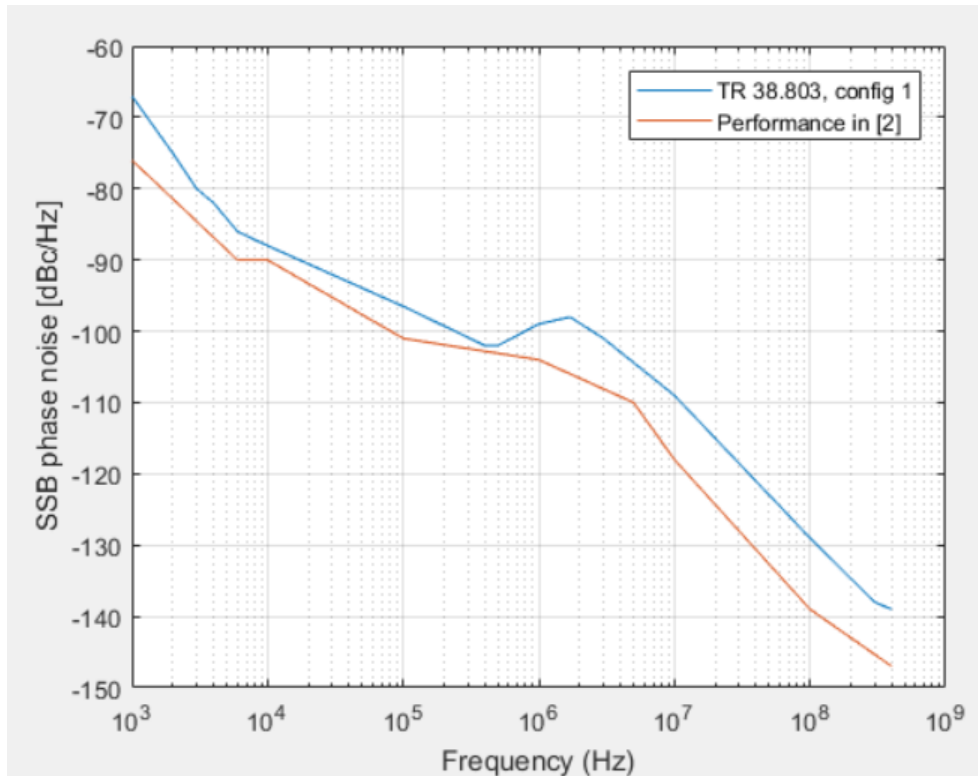
Figure 5.2.1.3-2: Comparison of the used phase noise model and published results

In addition, the results in Figure 5.2.1.3-1 are obtained using 3% Tx EVM, excluding the EVM impact from the phase noise. It should be noted the gain is observed with total EVM of the Tx chain of approximately 5.3 %, excluding the benefits from PT-RS based equalization. Further gains would be observed using EVM contribution which keeps the total EVM similar to FR1 requirement.

Based on the results and analysis the following observation is made.

Observation 1: Even with the used pessimistic phase noise and EVM assumptions throughput gains over 64QAM can be observed with 256QAM.

Observation 2: TR 38.803 config 1 PN model is too pessimistic compared to currently achievable performance. Therefore a [6.5] dB downscaling of the corresponding PN model should be considered.

After providing the results above new simulations were done and reported in [15].

Results in [6] were for rank-1 transmissions using the phase noise model from 38.803, section 6.1.10. These results have now been updated with the phase noise model from [13]. The updated results have been reported in Figures 5.2.1.3-3 and 5.2.1.3-4. Figure 5.2.1.3-3 shows rank-1 results with 2.0% EVM for Tx and Rx excluding the impact of phase noise. When the phase noise is calculated in, the total Tx EVM equals 3.0%. Figure 5.2.1.3-4 shows rank-1 results with 3.0% EVM for Tx and Rx excluding the impact of phase noise. When the phase noise is calculated in, the total Tx EVM equals 3.7%.

Figure 5.2.1.3-3: Link level simulation results for rank-1 with 2% EVM for Tx and Rx excluding EVM from phase noise
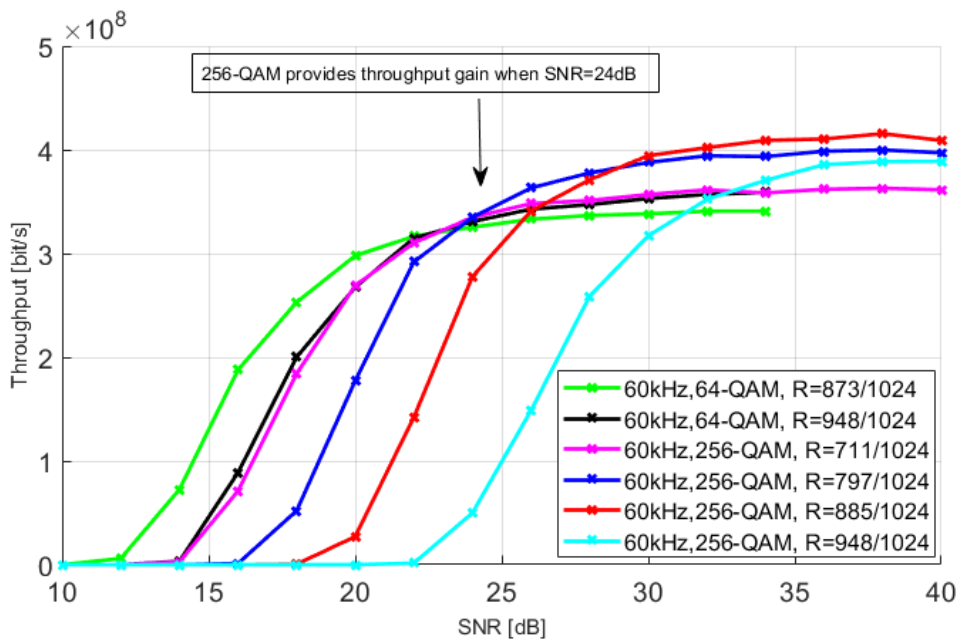
Figure 5.2.1.3-4: Link level simulation results for rank-1 with 3% EVM for Tx and Rx excluding EVM from phase noise

It can be seen that throughput with 256QAM exceeds throughput with 64 QAM at 23 dB SNR in Figure 5.2.1.3-3 and 24 dB SNR in Figure 5.2.1.3-4. It can also be seen that the very highest coding rate which theoretically should achieve highest throughput fails to improve the performance in Figure 2. This means that in the field link adaption needs to work properly to maximise the throughput.

Observation 3: With Rank-1 transmissions 256QAM provides performance gain over 64 QAM when SNR is better than 23..24 dB depending on Tx and Rx EVM.

To complete the evaluation using simulations were done also using rank-2 transmissions. It was also decided to use link adaptation instead of fixed MCS to observe whether Tx and Rx EVM impact link adaptation. The results are reported in Figures 5.2.1.3-5 and 5.2.1.3-6. Figure 5.2.1.3-5 shows rank-2 results with 2.0% EVM for Tx and Rx excluding the

impact of phase noise. When the phase noise is calculated in, the total Tx EVM equals 3.0%. Figure 5.2.1.3-6 shows rank-2 results with 3.0% EVM for Tx and Rx excluding the impact of phase noise. When the phase noise is calculated in, the total Tx EVM equals 3.7%.
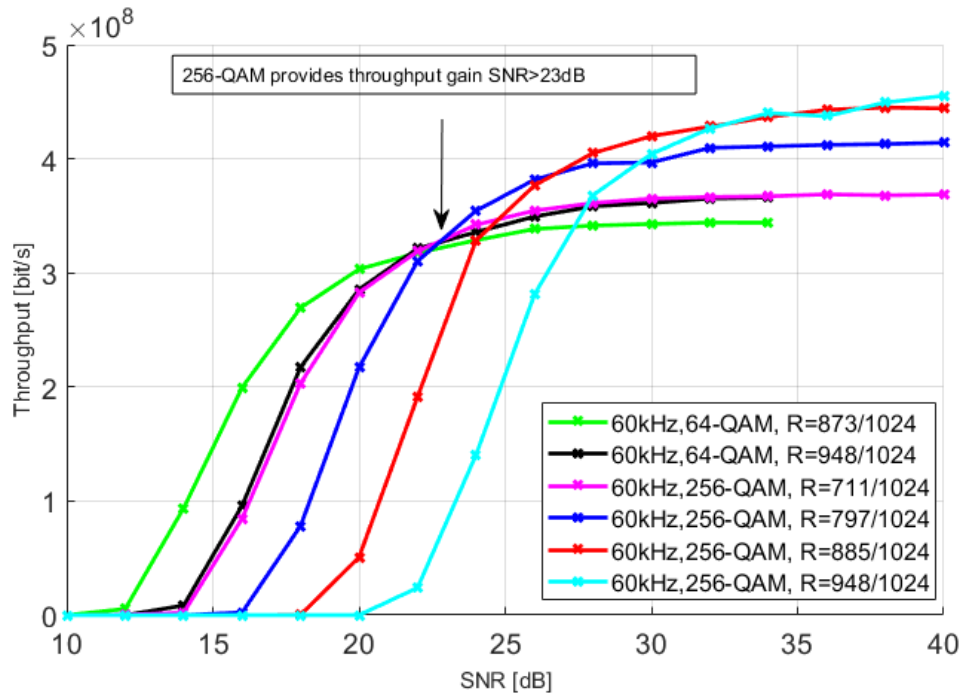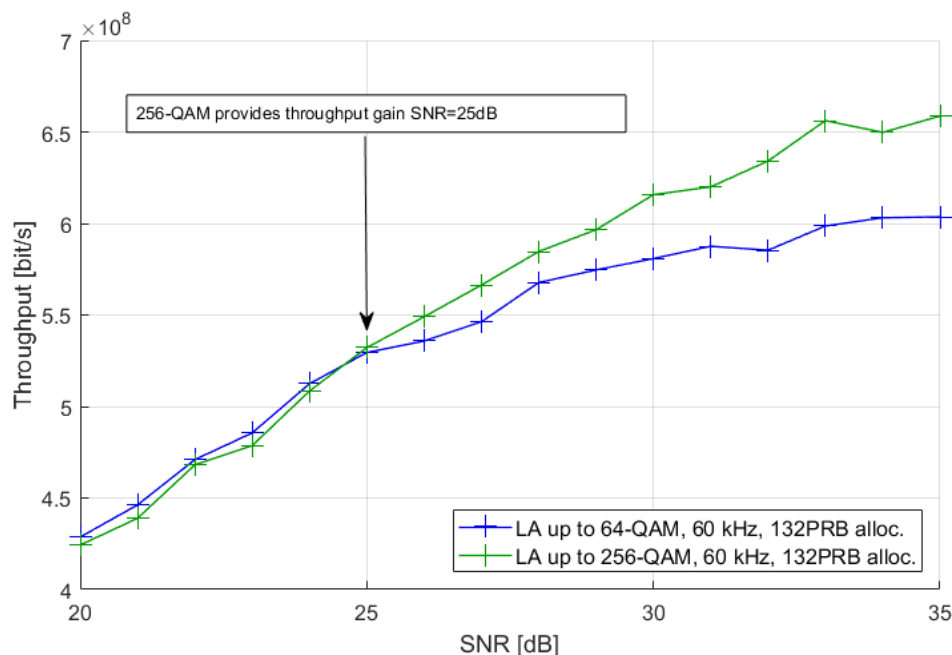

Figure 5.2.1.3-5: Throughput for rank-2 transmissions with 2% EVM for Tx and Rx excluding EVM from phase noise

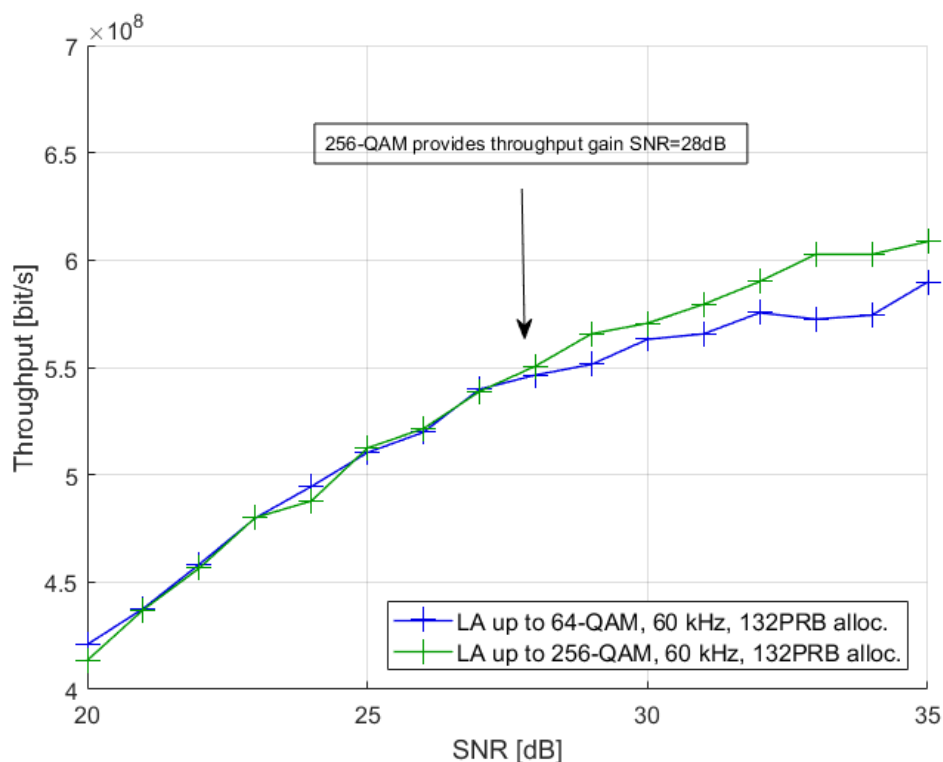**Figure 5.2.1.3-6: Throughput for rank-2 transmissions with 3% EVM for Tx and Rx excluding EVM from phase noise**

It can be seen that throughput with 256QAM exceeds throughput with 64 QAM at 25 dB SNR in Figure 5.2.1.3-5 and 28 dB SNR in Figure 5.2.1.3-5. It can also be seen that link adaptation works properly and similar effect as with fixed MCS is not observed.

Observation 4: With Rank-2 transmissions 256QAM provides performance gain over 64 QAM when SNR is better than 25..28 dB when Tx and Rx EVM vary from 2% to 3% excluding the impact of phase noise.

Finally we did also simulations to see the impact of varying Rx EVM when the Tx EVM is kept constant. The Tx EVM was kept at 2.0% excluding phase noise and total Tx EVM was therefore 3.0%. The results are shown in Figure 5.2.1.3-7.
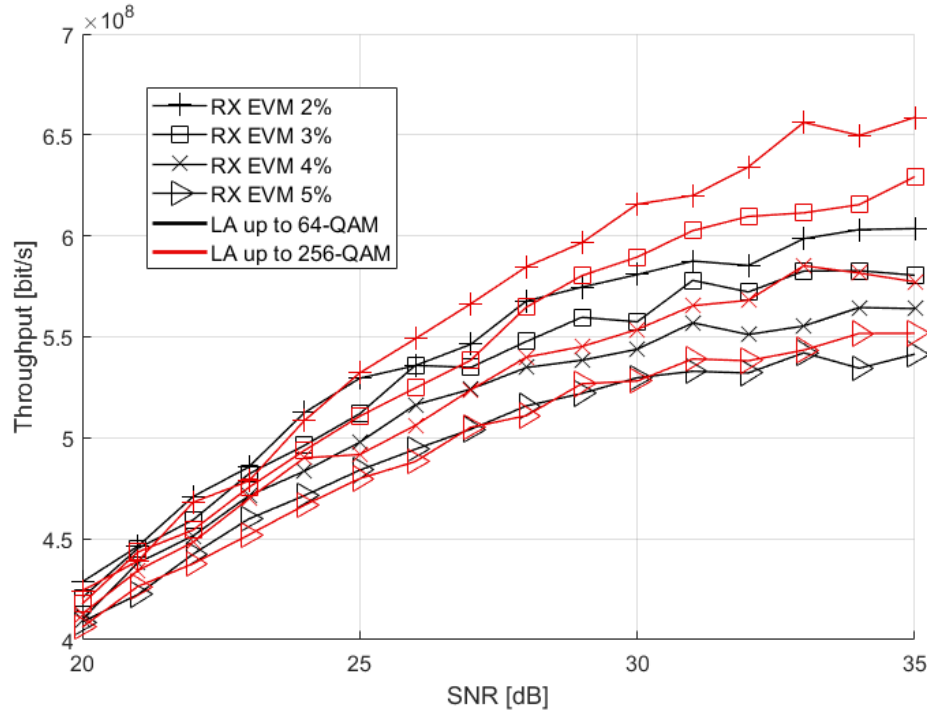
Figure 5.2.1.3-7: Throughput for rank-2 transmissions with total Tx EVM of 3% and varying Rx EVM.

It can be seen in Figure 5.2.1.3-7 that when Rx EVM is 5%, throughput gains are obtained only at SNRs above 30 dB, and overall Rx EVM has significant impact on the SNR level where 256QAM starts to provide gain over 64QAM. For this reason it is important that sufficiently strict Rx EVM needs to be assumed when setting the requirements.

Observation 5: Rx EVM has significant impact on SNR level where 256QAM start to provide gain over 64QAM, preferably 2% Rx EVM excluding phase noise needs to be assumed when setting the requirements.

5.2.1.4 Results from NTT DOCOMO [7]

Figure 5.2.1.4-1 and 5.2.1.4-2 show link level simulation results compared between 64QAM and 256QAM. On static channel and TDL-D with antenna configuration 2x2 and Rank 2, with 3% Tx EVM and 3% Rx EVM, the performance gain compared to 64QAM modulation is obtained over 21dB and 25dB SNR , respectively.
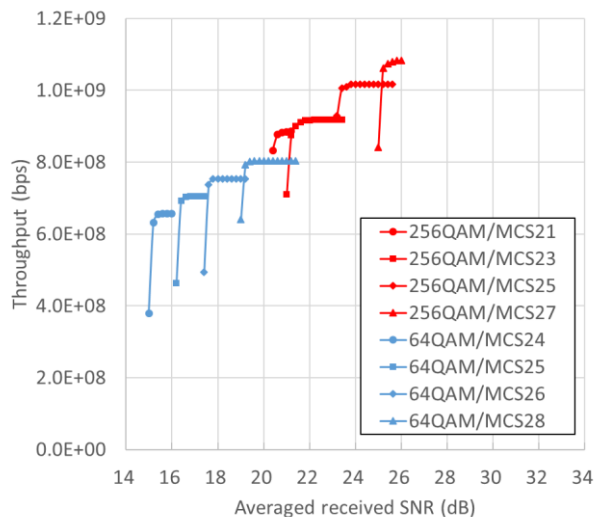
a) Tx EVM 0% and Rx EVM 0%
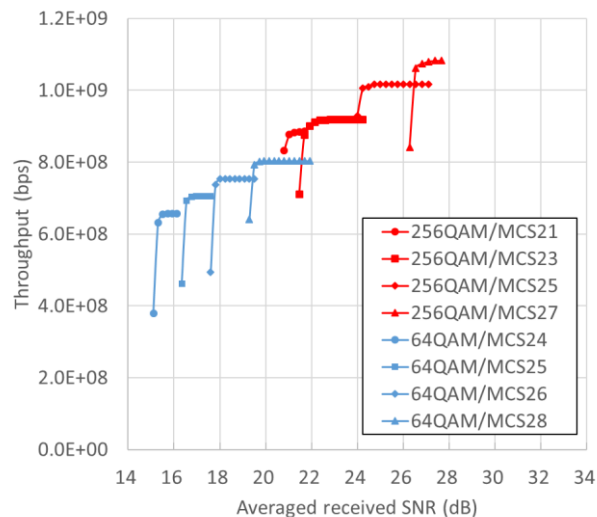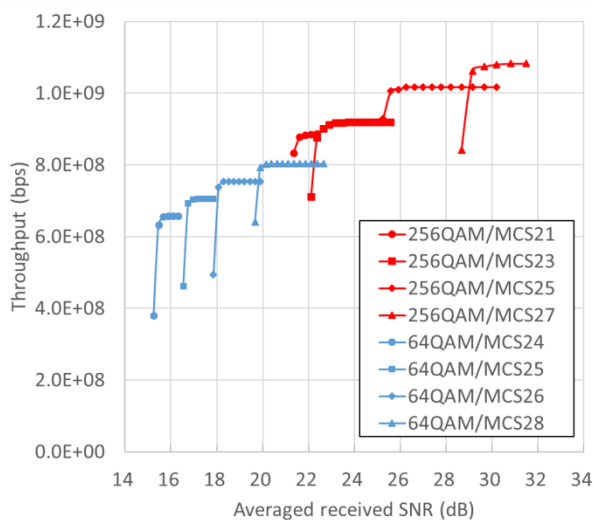
b) Tx EVM 2% and Rx EVM 2%

c) Tx EVM 3% and Rx EVM 3%

Figure 5.2.1.4-1: Simulation results on static channel
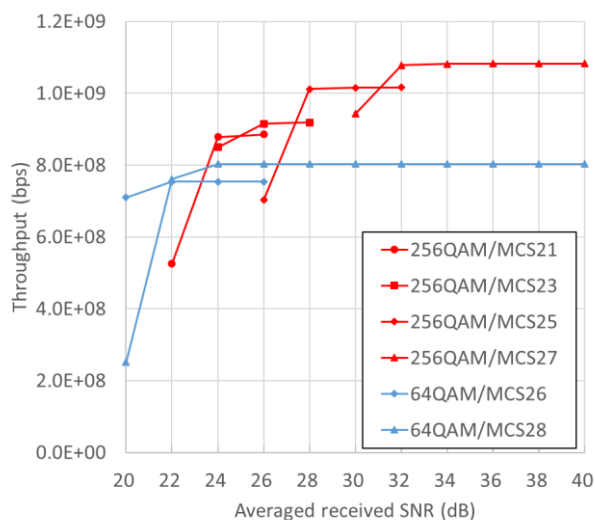
a) Tx EVM 0% and Rx EVM 0%
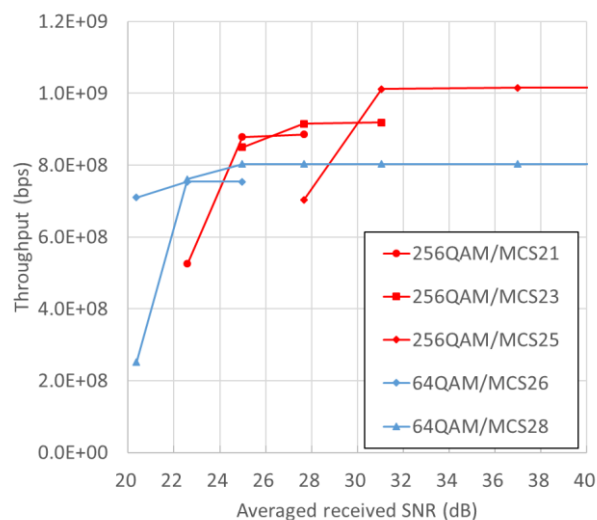
b) Tx EVM 2% and Rx EVM 2%
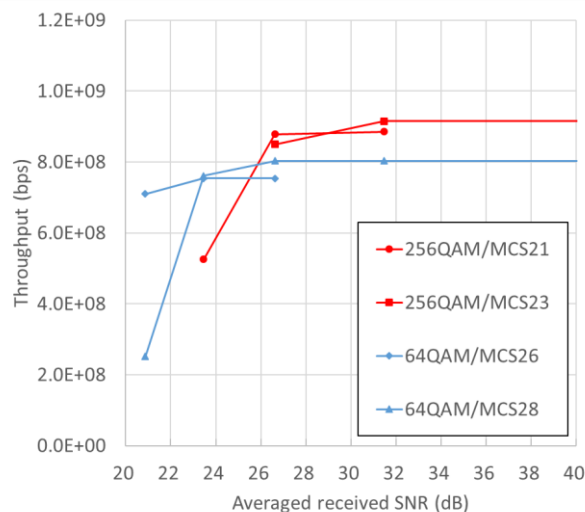
c) Tx EVM 3% and Rx EVM 3%

Figure 5.2.1.4-2: Simulation results on TDL-D channel

5.2.1.5 Results from Huawei [8]

Results for TDL-D channel with option d PN model are shown in Figure 5.2.1.5-1.
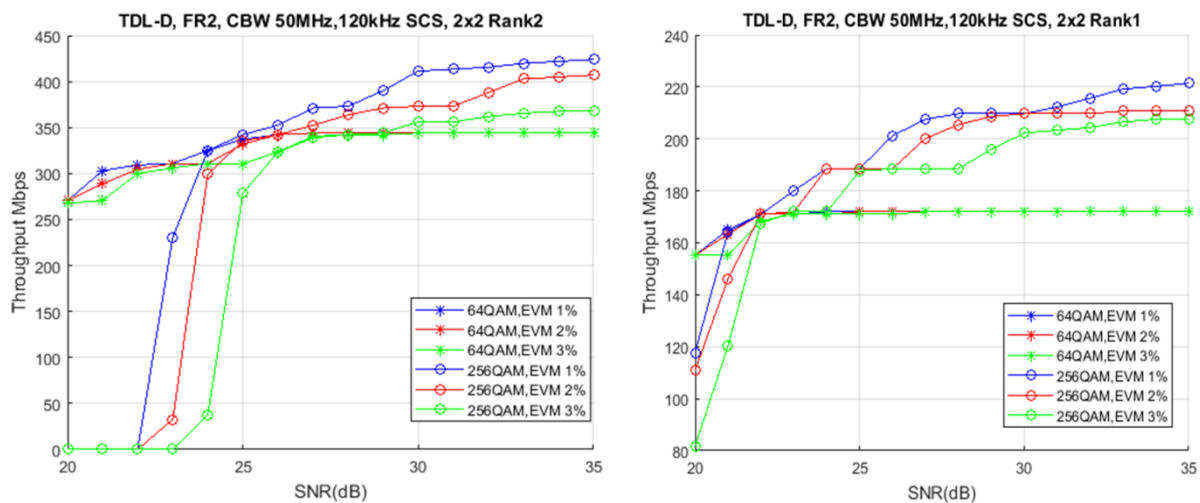
Figure 5.2.1.5-1: simulation results (Option d PN model)

Results for TDL-D channel with option a PN model are shown in Figure 5.2.1.5-2.
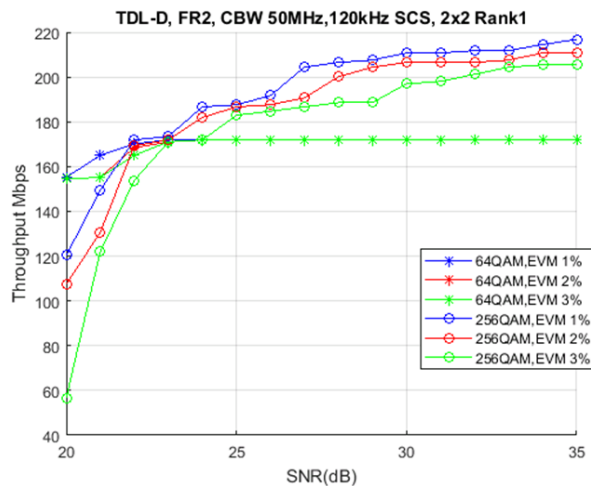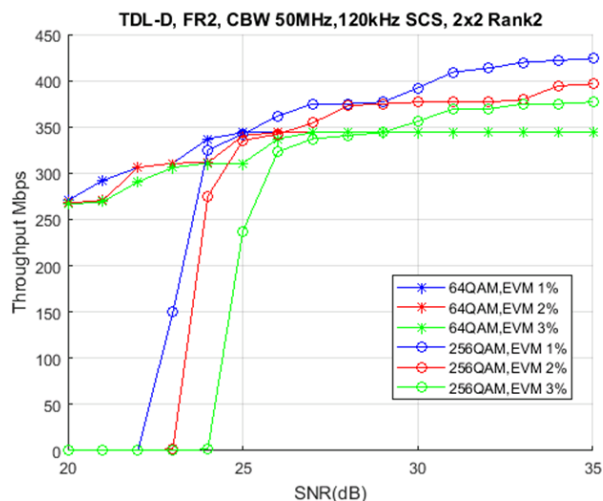
Figure 5.2.1.5-2: simulation results (Option a PN model)

Results for AWGN channel with option d PN model are shown in Figure 5.2.1.5-3.
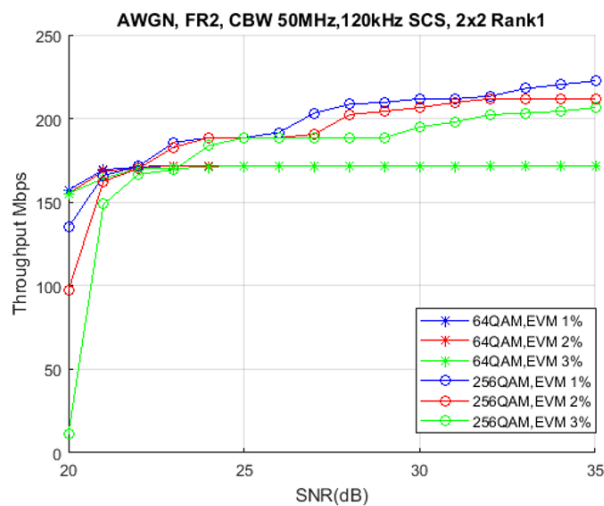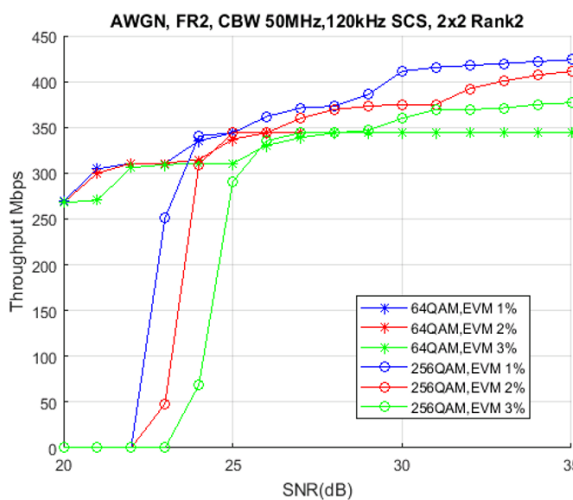
Figure 5.2.1.5-3: simulation results (Option d PN model)

Results for AWGN channel with option a PN model are shown in Figure 5.2.1.5-4.
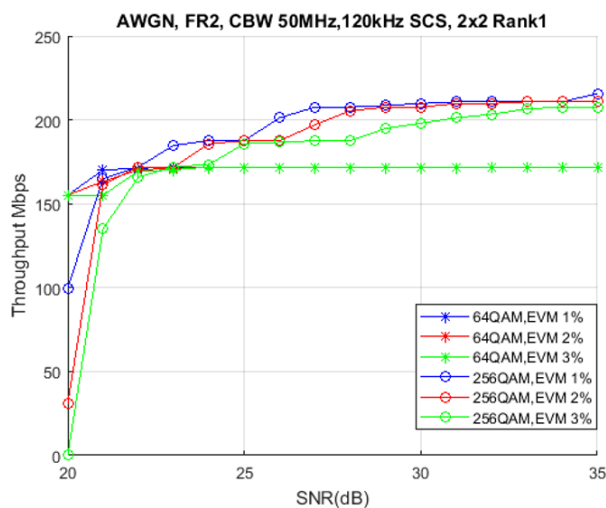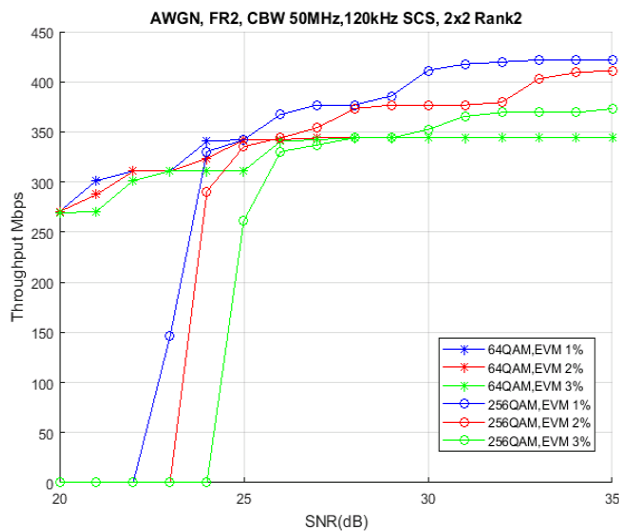
Figure 5.2.1.5-4: simulation results (Option a PN model)

From the simulation results, it is shown that support 256 QAM can provide significant performance gain over 64QAM where the UE is in good propagation condition. It is also found that the performance is more sensitive to RF impairment for 256 QAM

Observation 1: Support 256QAM can provide significant performance gain over 64QAM where the UE is in good propagation condition.

5.2.1.6 Results from Ericsson [9]

As part of the study a companion paper [14] discusses further the complications on testability for this feature when it comes to receiver demodulation and the required SINR. Looking at the parameters, the higher order MCS (256 QAM MCS 25 and 27) are not presented here as initial results yielded little to no throughput. Although to keep ease in simulation time, HARQ was not applied and it may be possible to see more tangible throughput numbers.

The following results show the throughput performance at 256 QAM in a TDL-A channel.
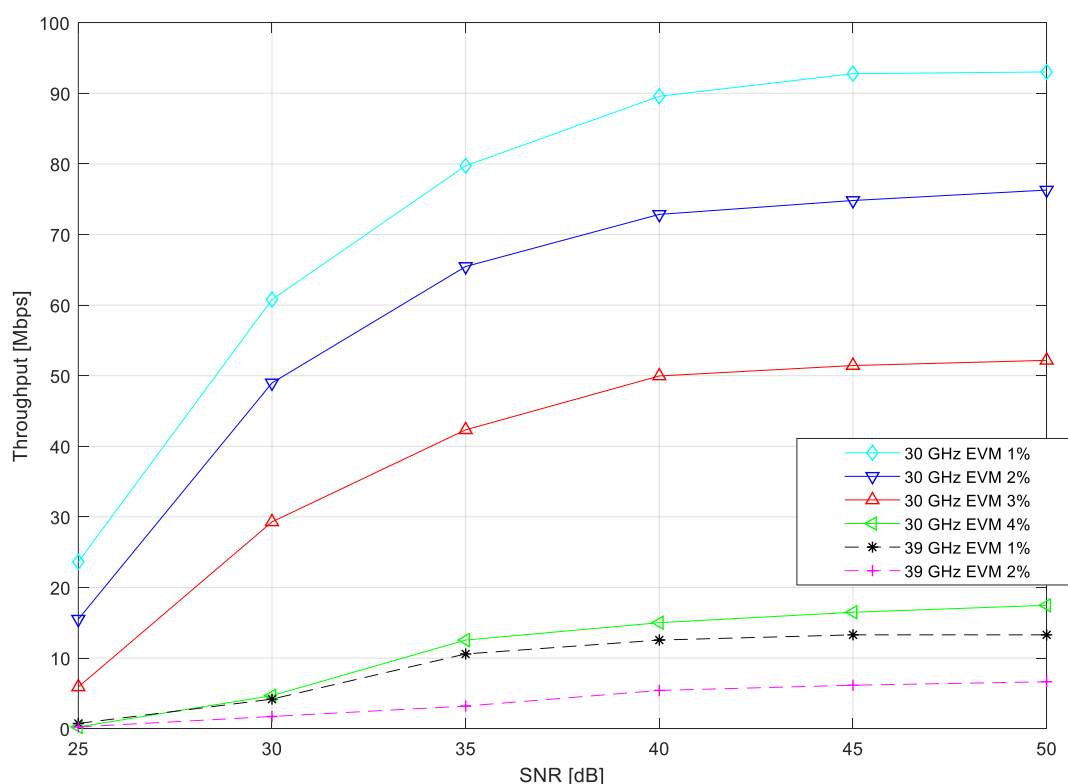
Figure 5.2.1.6-1: SCS 60 kHz, MCS 23

Comparably, when looking at 64 QAM throughput performance is better than 256 QAM when the expected EVM at transmitter and receiver is 5%. The overall performance of 256 QAM at low SNR is rather sensitive to any added receiver and/or transmitter noise. The fading channel conditions also provide some aspects to the results below. Further simulations using HARQ could help this aspect; no link adaptation was simulated for this scenario.
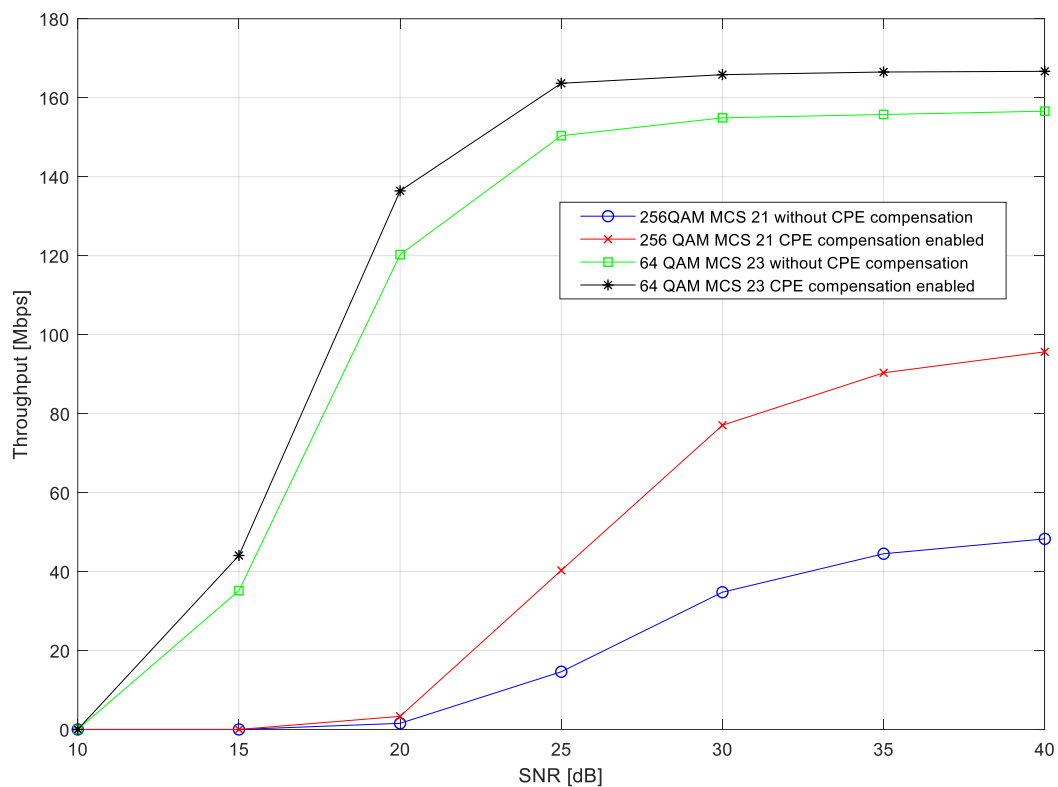
Figure 5.2.1.6-2: 256 QAM and 64 QAM throughput performance comparison

The following are results simulated at 29 GHz with TDL-D channel model with 256 QAM link adaptation with CPE compensation. The link adaptation adjusted different MCS specified in the simulation assumptions and HARQ of 8. On the left is 64 QAM with 8% while figure on the right hand side is 256 QAM with 3% EVM. To observe a gain in throughput towards a single user, a SNR of >22 dB is needed for the case of studying TLD-D channel conditions; a slightly lower expected SNR needed compared to that of TDL-A as shown in previous 2
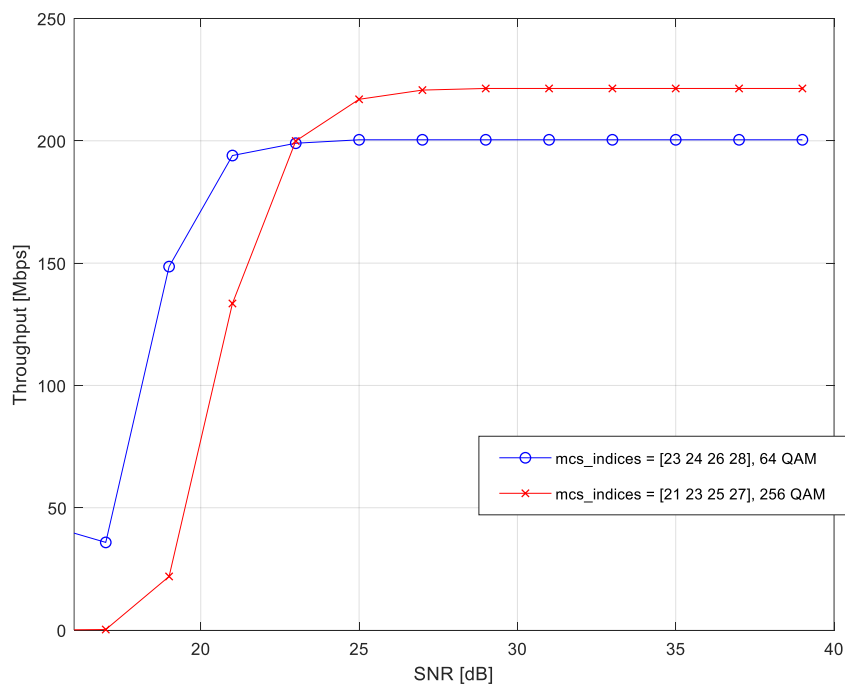
figures.

Figure 5.2.1.6-3: 64 QAM and 256 QAM throughput performance comparison in LOS scenario (TDL-D)

5.2.1.7   Results from CATT [10]

From the Figure 5.2.1.7-1(a) and 5.2.1.7-1(b), the achievable throughput for 256QAM is worse than 64QAM at 3.5% TX EVM and 3.5% RX EVM at SNR 40dB under TDL-A and TDL-D fading channel. The results for TDL-A and TDL-D fading channel indicate that the FR2 256QAM is hard to be deployed in scenarios include Homes, Roof-above or indoor, Commercial centre or official building. From the Figure 5.2.1.7-1(c), the achievable throughput for 256QAM is better than 64QAM at 3.5% TX EVM and 3.5% RX EVM in the SNR range from 30dB to 40dB in static channel. However there may be very limited scenarios with static channel condition in practice.

a) TDL-A   **b) TDL-D**

c) Static channel
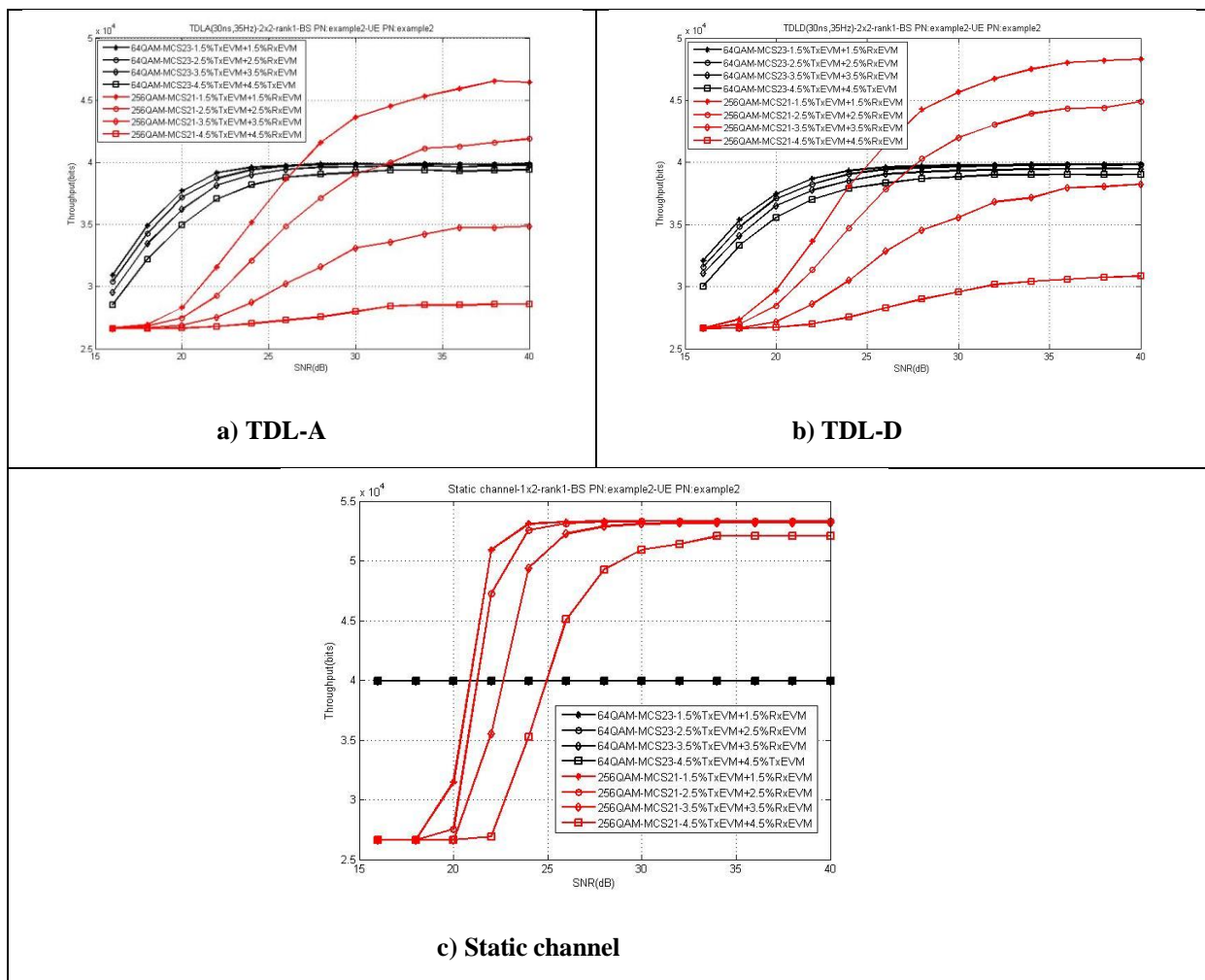
Figure 5.2.1.7-1: performance comparison of 64QAM and 256QAM in TDL-A in option b phase noise model

The performance improvement of 256QAM realative to 64QAM at 30 and 35 dB SNR point for all Tx EVM + Rx EVM cases are summaried and shown in Table 5.2.1.7-1.

Table 5.2.1.7-1 Performance improvement of 256QAM relative to 64QAM at 29 GHz

Channel model	Tx EVM+Rx EVM	Total EVM	SNR required to achieve gains for 256QAM [dB]	Performance improvement 256QAM relative to 64QAM at same Tx EVM + Rx EVM	
				@30dB	@35dB

TDL-A	1.5%+1.5%	2.1%	26	9%	14%
	2.5%+2.5%	3.5%	32	x[Note1]	4%
	3.5%+3.5%	5%	NO	x	x
	4.5%+4.5%	6.4%	NO	x	x
TDL-D	1.5%+1.5%	2.1%	25	15%	20%
	2.5%+2.5%	3.5%	27	6%	11%
	3.5%+3.5%	5%	NO	x	x
	4.5%+4.5%	6.4%	NO	x	x
Static channel	1.5%+1.5%	2.1%	20	33%	33%
	2.5%+2.5%	3.5%	21	33%	33%
	3.5%+3.5%	5%	22	30%	33%
	4.5%+4.5%	6.4%	25	27%	30%
Note 1: x denote no performance improvement.					

5.2.1.8 Results from Intel [11]

In Error! Not a valid bookmark self-reference.1 andError! Not a valid bookmark self-reference.2 we provide summary of simulation results and compare performance of 64QAM and 256QAM for 25, 30 and 35 dB SNR point. The table shows the relative throughput improvement in case of using 256QAM comparing to 64QAM.

Error! Not a valid bookmark self-reference.**1: Performance improvement of 256QAM over 64QAM for CF 29 GHz**

CF, GHz	Rank configuration	Channel model	Tx/ Rx EVM	Phase noise model C			Phase noise model D		
				25 dB	30 dB	35 dB	25 dB	30 dB	35 dB
29 GHz	Rank 1	Static	1%	19%	21%	24%	19%	19%	21%
			2%	15%	19%	20%	11%	19%	20%
			3%	11%	19%	19%	11%	18%	19%
		TDL-A	1%	5%	11%	19%	5%	10%	18%
			2%	5%	9%	16%	4%	9%	13%
			3%	3%	7%	11%	1%	5%	10%
		TDL-D	1%	4%	13%	17%	2%	9%	16%
			2%	2%	9%	15%	2%	8%	12%
			3%	1%	7%	10%	2%	5%	9%
	Rank 2	Static	1%	10%	19%	19%	10%	19%	19%
			2%	8%	15%	19%	4%	12%	19%
			3%	0%	11%	17%	0%	11%	15%
		TDL-A	1%	-2%	-9%	5%	-2%	-10%	0%
			2%	-1%	-8%	0%	-1%	-6%	-10%
			3%	0%	-6%	-11%	0%	-5%	-14%
		TDL-D	1%	-7%	3%	9%	-13%	3%	6%
			2%	-12%	2%	6%	-12%	0%	2%
			3%	-12%	-3%	3%	-12%	-9%	2%
	Adaptive Rank	Static	1%	10%	19%	19%	10%	19%	19%
			2%	8%	15%	19%	4%	12%	19%
			3%	0%	11%	17%	0%	11%	15%
		TDL-A	1%	-2%	-9%	5%	-2%	-10%	0%

			2%	-1%	-8%	0%	-1%	-6%	-10%
			3%	0%	-6%	-11%	0%	-5%	-14%
		TDL-D	1%	-7%	3%	9%	-13%	3%	6%
			2%	-12%	2%	6%	-12%	0%	2%
			3%	-12%	-3%	3%	-12%	-9%	2%

Error! Not a valid bookmark self-reference.**2: Performance improvement of 256QAM over 64QAM for CF 39 GHz**

CF, GHz	Rank configuration	Channel model	Tx/ Rx EVM	Phase noise model C			Phase noise model D		
				25 dB	30 dB	35 dB	25 dB	30 dB	35 dB
39 GHz	Rank 1	Static	1%	11%	16%	16%	11%	11%	11%
			2%	11%	11%	14%	10%	11%	11%
			3%	9%	11%	11%	1%	11%	11%
		TDL-A	1%	5%	9%	11%	3%	6%	11%
			2%	3%	6%	10%	1%	6%	9%
			3%	0%	2%	8%	-4%	3%	4%
		TDL-D	1%	1%	8%	10%	2%	6%	9%
			2%	1%	2%	9%	2%	1%	7%
			3%	1%	2%	7%	-2%	1%	2%
	Rank 2	Static	1%	0%	10%	10%	0%	10%	10%
			2%	0%	10%	10%	0%	9%	10%
			3%	0%	4%	8%	0%	0%	9%
		TDL-A	1%	-3%	-12%	-2%	-1%	-7%	-18%
			2%	-1%	-7%	-10%	0%	-5%	-14%
			3%	0%	-6%	-16%	0%	-6%	-8%
		TDL-D	1%	-14%	1%	2%	-12%	-6%	1%
			2%	-12%	-3%	2%	-12%	-16%	-2%
			3%	-11%	-14%	1%	-11%	-15%	-14%
	Adaptive Rank	Static	1%	0%	10%	10%	0%	10%	10%
			2%	0%	10%	10%	0%	9%	10%
			3%	0%	4%	8%	0%	0%	9%
		TDL-A	1%	-3%	-12%	-2%	-1%	-7%	-18%
			2%	-1%	-7%	-10%	0%	-5%	-14%
			3%	0%	-6%	-16%	0%	-6%	-8%
		TDL-D	1%	-14%	1%	2%	-12%	-6%	1%
			2%	-12%	-3%	2%	-12%	-16%	-2%
			3%	-11%	-14%	1%	-11%	-15%	-14%

Observations: From link level results we can conclude

- Static channel model
  - 29 GHz carrier frequency:
    - Sufficient performance improvement of 256QAM over 64QAM (> 5%) is observed for MIMO Rank 1 and 2 transmissions and all considered SNR operating points for most of considered scenarios.
  - 39 GHz carrier frequency
    - MIMO rank 1: sufficient performance improvement is observed for almost all considered SNR points.
    - MIMO rank 2: sufficient performance improvement is observed for SNR > 30 dB only
- Fading channel models
  - Sufficient performance improvement of 256QAM over 64QAM (> 5%) is observed for scenarios with Rank 1 transmission and high SNR conditions (i.e. ≥ 30dB)

o Limited or no performance improvement of 256QAM over 64QAM is observed for Rank 2 transmission

o For phase noise model (i.e. model D), significant performance improvement of 256QAM over 64QAM (> 10%) is observed only for scenarios with 29 GHz carrier frequency, Rank 1 transmission and 35dB SNR

5.2.1.9 Results from Qualcomm [12]

Table 5.2.1.9−1 compares the SNR points at 90% of peak throughput for two cases under AWGN conditions.

Table 5.2.1.9-1: Comparison of RAN4 and Internal IPN models under AWGN channel condition

Test Cases	SNR (dB) at 90% of peak throughput using RAN4 Example1 BS + Example 2 UE IPN model	SNR (dB) at 90% of peak throughput using internal IPN model	SNR (dB) at 90% of peak throughput using RAN4 Example2 BS + Example 2 BS IPN model	Peak Throughput (Mbps)
64QAM, MCS 26, 2x2, Rank2	20.51	19.30	19.31	700.72
64QAM, MCS 27, 2x2, Rank2	21.93	20.27	20.31	731.60
64QAM, MCS 28, 2x2, Rank2	24.10	21.30	21.38	762.95
256QAM, MCS 21, 2x2, Rank2	23.38	20.94	21.25	762.95
256QAM, MCS 22, 2x2, Rank2	27.03	22.27	22.50	809.97

Based on above results, we have following observations:

Observation 1: Peak Throughput for 64QAM MCS28 is exactly equal to that for 256QAM MCS21.

Observation 2: RAN4 IPN model with example 2 BS on both gNB and UE side is the closest to practical implementation.

Observation 3: SNR needed to achieve 90% of peak throughput for 64QAM MCS28 is slightly higher than that for 256QAM MCS21 under AWGN conditions.

As RAN4 **Example1 BS + Example 2 UE** IPN model is very pessimistic, we now focus on our internal IPN model and RAN4 **Example2 BS + Example 2 BS IPN model** for the rest of the simulations.

Simulation Results without EVM

In this section, we compare the 64QAM and 256QAM performance under different channel conditions and carrier frequencies to determine whether 256QAM can provide gains over 64QAM under FR2. Here, we look at 70% and 90% of peak throughput since most of the RAN4 fixed MCS requirements are defined at 70% of peak throughput. For all simulations, we assumed our internal IPN model.

Table 5.2.1.9-2 and Table 5.2.1.9-3 list the SNRs required to achieve 70% and 90% of peak throughput under different channel conditions with carrier frequency of 29GHz and 39GHz, respectively without considering any Tx/Rx EVM for internal IPN model. Table 5.2.1.9-4 and Table 5.2.1.9-5 list the same for RAN4 Example2 BS + Example2 BS IPN model.

Table 5.2.1.9-2: SNR required to achieve 70% and 90% of peak throughput without EVM, carrier frequency = 29GHz for internal IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)		TDL-A 30ns 35Hz SNR (dB)	
% of Peak Throughput	**70%**	**90%**	**70%**	**90%**	**70%**	**90%**
64QAM, MCS 26, 2x2, Rank2	18.90	19.30	20.72	22.15	25.49	28.03
64QAM, MCS 27, 2x2, Rank2	19.81	20.27	21.53	23.18	27.00	29.60
64QAM, MCS 28, 2x2, Rank2	20.90	21.30	22.90	24.28	28.93	32.15
256QAM, MCS 20, 2x2, Rank2	19.89	20.30	21.56	23.25	26.30	28.59
256QAM, MCS 21, 2x2, Rank2	20.12	20.94	22.34	24.00	27.22	29.72
256QAM, MCS 22, 2x2, Rank2	21.78	22.27	23.72	25.58	28.77	31.50

Table 5.2.1.9-3: SNR required to achieve 70% and 90% of peak throughput without EVM, carrier frequency = 39GHz for internal IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)		TDL-A 30ns 35Hz SNR (dB)	
% of Peak Throughput	**70%**	**90%**	**70%**	**90%**	**70%**	**90%**
64QAM, MCS 26, 2x2, Rank2	18.90	19.30	21.01	22.34	26.01	28.59
64QAM, MCS 27, 2x2, Rank2	19.90	20.30	21.80	23.62	27.55	30.33
64QAM, MCS 28, 2x2, Rank2	20.94	21.37	23.32	24.91	29.87	-
256QAM, MCS 20, 2x2, Rank2	19.91	20.32	21.80	23.65	26.88	29.42
256QAM, MCS 21, 2x2, Rank2	20.87	21.31	22.87	24.29	27.87	30.43
256QAM, MCS 22, 2x2, Rank2	22.00	22.53	24.41	26.18	29.79	-

Table 5.2.1.9-4: SNR required to achieve 70% and 90% of peak throughput without EVM, carrier frequency = 29GHz for RAN4 Example2 BS + Example2 BS IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)		TDL-A 30ns 35Hz SNR (dB)	
% of Peak Throughput	**70%**	**90%**	**70%**	**90%**	**70%**	**90%**
64QAM, MCS 26, 2x2, Rank2	18.90	19.31	20.78	22.12	26.04	28.77
64QAM, MCS 27, 2x2, Rank2	19.88	20.31	21.60	23.29	27.58	30.51
64QAM, MCS 28, 2x2, Rank2	20.94	21.38	23.14	24.46	30.00	-
256QAM, MCS 20, 2x2, Rank2	19.91	20.32	21.71	23.49	26.94	29.65
256QAM, MCS 21, 2x2, Rank2	20.70	21.25	22.81	24.24	28.00	30.99
256QAM, MCS 22, 2x2, Rank2	21.98	22.50	24.44	26.17	30.11	-

Table 5.2.1.9-5: SNR required to achieve 70% and 90% of peak throughput without EVM, carrier frequency = 39GHz for RAN4 Example2 BS + Example2 BS IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)		TDL-A 30ns 35Hz SNR (dB)	
% of Peak Throughput	70%	90%	70%	90%	70%	90%
64QAM, MCS 26, 2x2, Rank2	19.05	19.80	21.26	22.63	27.06	30.22
64QAM, MCS 27, 2x2, Rank2	20.09	20.91	22.27	24.06	28.88	-
64QAM, MCS 28, 2x2, Rank2	21.55	22.37	23.98	26.09	-	-
256QAM, MCS 20, 2x2, Rank2	20.17	21.07	22.54	24.22	28.09	-
256QAM, MCS 21, 2x2, Rank2	21.11	22.03	23.62	25.75	29.58	-
256QAM, MCS 22, 2x2, Rank2	22.93	24.30	26.07	-	-	-

Based on above results, we have following observations:

Observation 5: SNR needed to achieve high throughput regime using 64QAM or 256QAM is very high for TDL-A channel model.

Observation 6: For AWGN, 256QAM shows gains for SNR > ~20dB and for TDL-D, 256QAM shows gains for SNR > ~22dB over 64QAM without considering EVM for internal IPN model.

Observation 7: There is < 0.5dB degradation in performance when going from carrier frequency of 29GHz to 39GHz for lower MCS for 256QAM regime under AWGN and TDL-D channel conditions without considering EVM for internal IPN model.

Simulation Results with EVM

In previous sections, we focused on best case scenarios to determine the upper limit of performance. In this section, we present simulation results with EVM since that will be more practical scenario.

As shown in above, very high SNR is needed to achieve high throughput regime under TDL-A condition. Therefore, we will only focus on AWGN and TDL-D channels in this section. We assume Tx EVM of 3% (current RAN4 assumption for 256QAM) for both 64QAM and 256QAM. Rx EVM is assumed as per our internal UE implementation.

Table 5.2.1.9-6 and Table 5.2.1.9-7 list the SNRs required to achieve 70% and 90% of peak throughput under different channel conditions with carrier frequency of 29GHz and 39GHz, respectively with Tx/Rx EVM for internal IPN model. Table 5.2.1.9-8 and Table 5.2.1.9-9 list the same for RAN4 Example2 BS + Example2 BS IPN model.

Table 5.2.1.9-6: SNR required to achieve 70% and 90% of peak throughput with EVM, carrier frequency = 29GHz for internal IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)	
% of Peak Throughput	70%	90%	70%	90%
64QAM, MCS 26, 2x2, Rank2	18.90	19.30	21.18	22.50
64QAM, MCS 27, 2x2, Rank2	19.90	20.30	22.02	23.84
64QAM, MCS 28, 2x2, Rank2	20.95	21.40	23.54	25.35
256QAM, MCS 20, 2x2, Rank2	19.91	20.32	22.06	23.89
256QAM, MCS 21, 2x2, Rank2	20.91	21.33	23.09	24.58
256QAM, MCS 22, 2x2, Rank2	21.99	22.48	24.78	26.40

Table 5.2.1.9-7: SNR required to achieve 70% and 90% of peak throughput with EVM, carrier frequency = 39GHz for internal IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)	
% of Peak Throughput	70%	90%	70%	90%
64QAM, MCS 26, 2x2, Rank2	18.95	19.39	21.42	23.12
64QAM, MCS 27, 2x2, Rank2	19.98	20.46	22.54	24.14
64QAM, MCS 28, 2x2, Rank2	21.68	22.25	24.06	25.96
256QAM, MCS 20, 2x2, Rank2	20.09	20.87	22.55	24.21
256QAM, MCS 21, 2x2, Rank2	21.02	21.63	23.55	25.47
256QAM, MCS 22, 2x2, Rank2	22.85	23.38	25.60	27.79

Table 5.2.1.9-8: SNR required to achieve 70% and 90% of peak throughput with EVM, carrier frequency = 29GHz for RAN4 Example2 BS + Example2 BS IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)	
% of Peak Throughput	70%	90%	70%	90%
64QAM, MCS 26, 2x2, Rank2	18.95	19.40	21.22	22.46
64QAM, MCS 27, 2x2, Rank2	19.97	20.43	22.19	23.94
64QAM, MCS 28, 2x2, Rank2	21.39	22.17	23.86	25.80
256QAM, MCS 20, 2x2, Rank2	20.02	20.64	22.46	24.10
256QAM, MCS 21, 2x2, Rank2	20.98	21.46	23.53	25.41
256QAM, MCS 22, 2x2, Rank2	22.72	23.40	25.69	28.05

Table 5.2.1.9-9: SNR required to achieve 70% and 90% of peak throughput with EVM, carrier frequency = 39GHz for RAN4 Example2 BS + Example2 BS IPN model

Test Cases	AWGN SNR (dB)		TDL-D 30ns 35Hz SNR (dB)	
% of Peak Throughput	70%	90%	70%	90%
64QAM, MCS 26, 2x2, Rank2	19.55	20.26	21.68	23.57
64QAM, MCS 27, 2x2, Rank2	20.68	21.35	23.11	24.89
64QAM, MCS 28, 2x2, Rank2	22.12	23.14	25.22	27.85
256QAM, MCS 20, 2x2, Rank2	20.82	21.42	23.32	25.42
256QAM, MCS 21, 2x2, Rank2	21.78	22.53	24.73	27.32

256QAM, MCS 22, 2x2, Rank2	23.84	25.60	28.23	-

Based on above results, we have following observations:

Observation 8: For AWGN, 256QAM shows gains for SNR > ~21dB and for TDL-D, 256QAM shows gains for SNR > ~23dB over 64QAM with EVM consideration for internal IPN model.

5.2.1.10 Conclusion

Based on the simulation results and observations provided above, the following table summarizes the minimum required SNR in which 256QAM shows benefit by comparing to 64QAM below in table 5.2.1.10-1. Also, Table 5.2.1.10-2 provides information about performance benefit of 256QAM over 64QAM proposed by companies.

Table 5.2.1.10-1: SNR required to achieve gains for 256QAM

Contributor	AWGN SNR (dB)	TDL-D SNR (dB)	TDL-A SNR (dB)
China Telecom	> 20dB	> 24dB	> 25dB
Nokia		> 23dB	
DoCoMo	> 21dB	> 25dB	
Huawei	> 23dB	> 24dB	
Ericsson		> 24dB	No benefit
CATT	> 21dB	> 27dB	> 32dB
Intel	> 25dB	> 30dB	> 35dB
Qualcomm	> 21dB	> 23dB	
Average	> 22dB	> 25dB	

Table 5.2.1.10-2: Performance benefit of 256QAM over 64QAM based on company-specific SNR, EVM, phase noise and channel rank

Contributor	AWGN channel	TDL-D channel	TDL-A channel
China Telecom	12%	12%	10%
Nokia		14%	
DoCoMo			
Huawei			
Ericsson		10%	No benefit
CATT			
Intel	12%	2%	No benefit
Qualcomm	17%	4%	No benefit

It can be concluded that from link level simulation point, FR2 DL 256QAM is feasible at line of sight channel condition including at static channel with SNR> 22dB and at TDL-D channel with SNR> 25dB. The proposed performance benefits of 256QAM over 64QAM can be observed in Table 5.2.1.10-2.

5.2.2 System level simulation

System simulation is targeted as supplementary for link level simulation to further confirm the scenario that FR2 256QAM is applicable. The simulation results from companies are listed as below and corresponding assumptions are captured in Annex A.

5.2.2.1 Results from Huawei

The simulation results and proposals are based on contribution [5.2.2.1-1]

Figure 5.2.2.1-1 to 5.2.2.1-4 show the SINR CDF by a range of tx EVM for different modulation orders. On the right of SINR CDF are the corresponding curves for throughput loss versus tx EVM values.
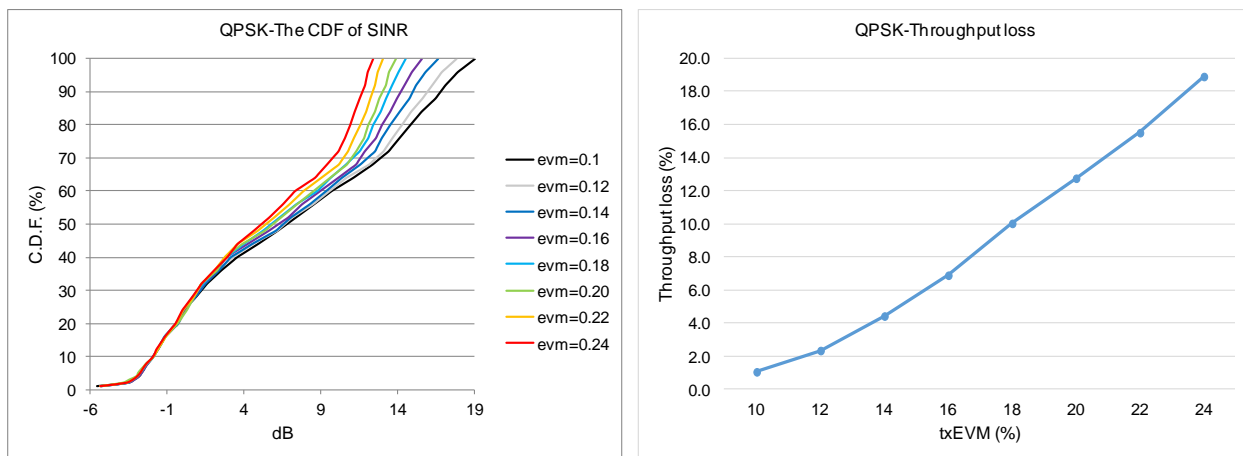
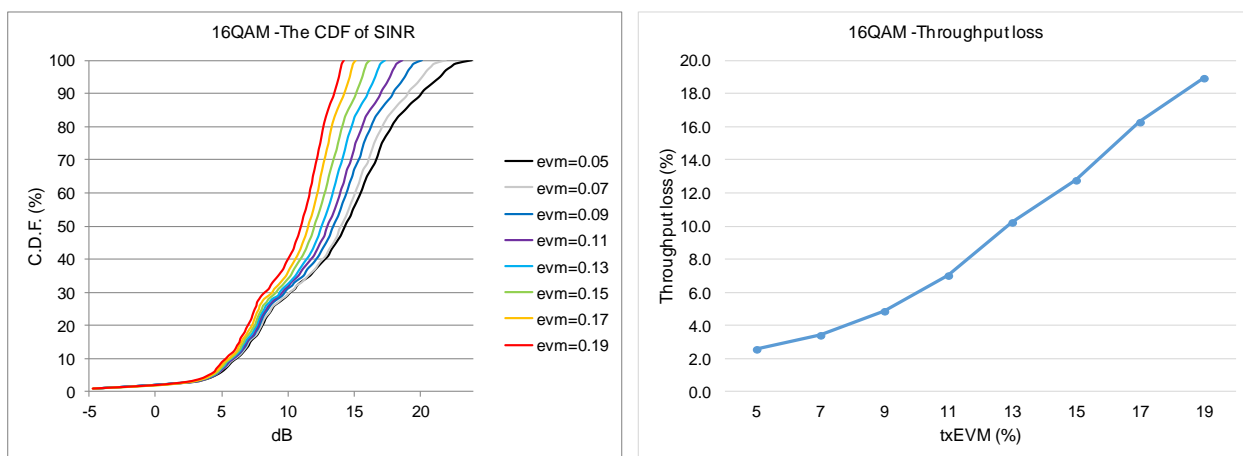**Figure 5.2.2.1-1: SINR CDF and throughput loss versus BS tx EVM for QPSK**

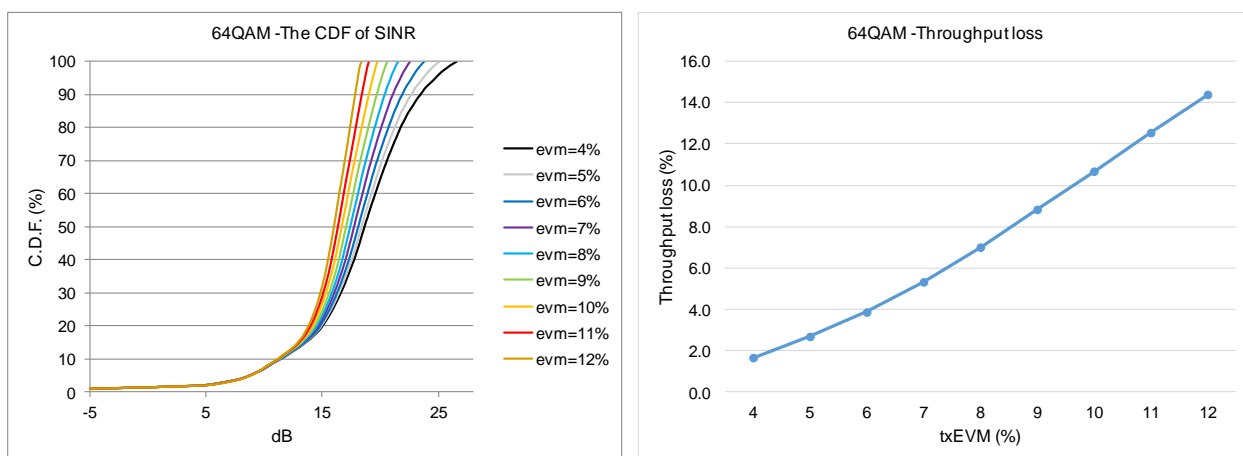**Figure 5.2.2.1-2: SINR CDF and throughput loss versus BS tx EVM for 16QAM**

Figure 5.2.2.1-3: SINR CDF and throughput loss versus BS tx EVM for 64QAM
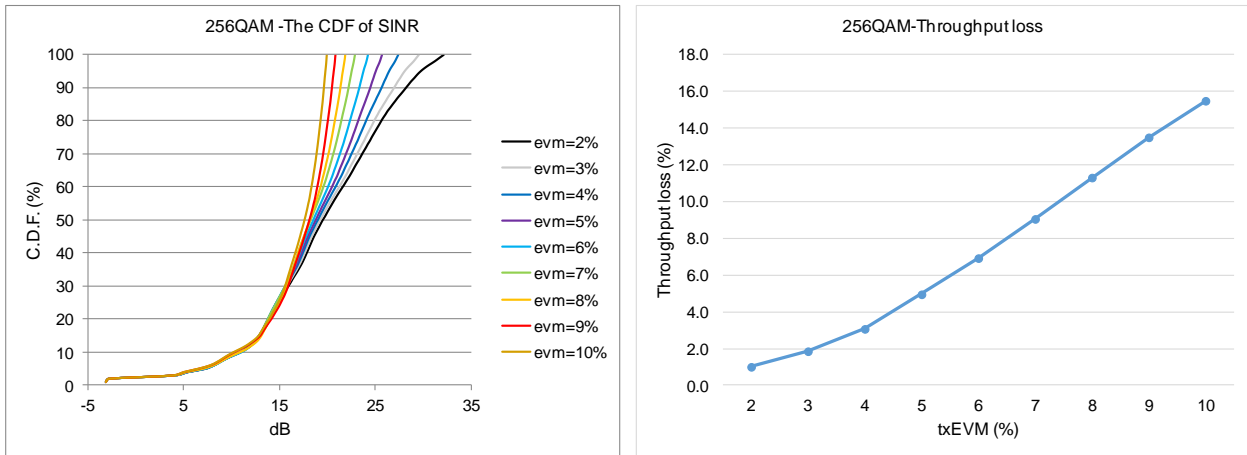
Figure 5.2.2.1-4: SINR CDF and throughput loss versus BS tx EVM for 256QAM

It can be observed from the SINR CDF that the receiving SINR will be improved when the tx EVM requirement becomes more tighter. However it seems difficult to find a trade-off Tx EVM value since the SINR improvement looks like being averaged across the tx EVM values. Thus we map the SINR CDF to throughput to quantize the improvement to SINR for different tx EVM values. It is worth to note that there is little difference for the throughput loss baseline when EVM is lowest value in the certain given range or 0%.

For the series of modulation orders, the figures show more stringent requirement is needed to meet the 5% throughput loss threshold, however by considering the feasibility and LTE requirement as baseline, and also a little margin for degradation due to phase noise, it is proposed to reuse LTE UE BS EVM requirement for QPSK, 16QAM, 64QAM and 256QAM modulation orders for NR.

5.2.2.2   Results from Nokia

The simulation results and proposals are based on contribution [5.2.2.2-2]

Figure 5.2.2.2-1 presents CDF of DL SINR results for two configurations:

- BS with 16x8 antenna array and total Tx power of 31dBm; UE with 1x1 antenna (blue curve),

- BS with 16x8 antenna array and total Tx power of 31dBm; UE with 2x2 antenna array (red curve).
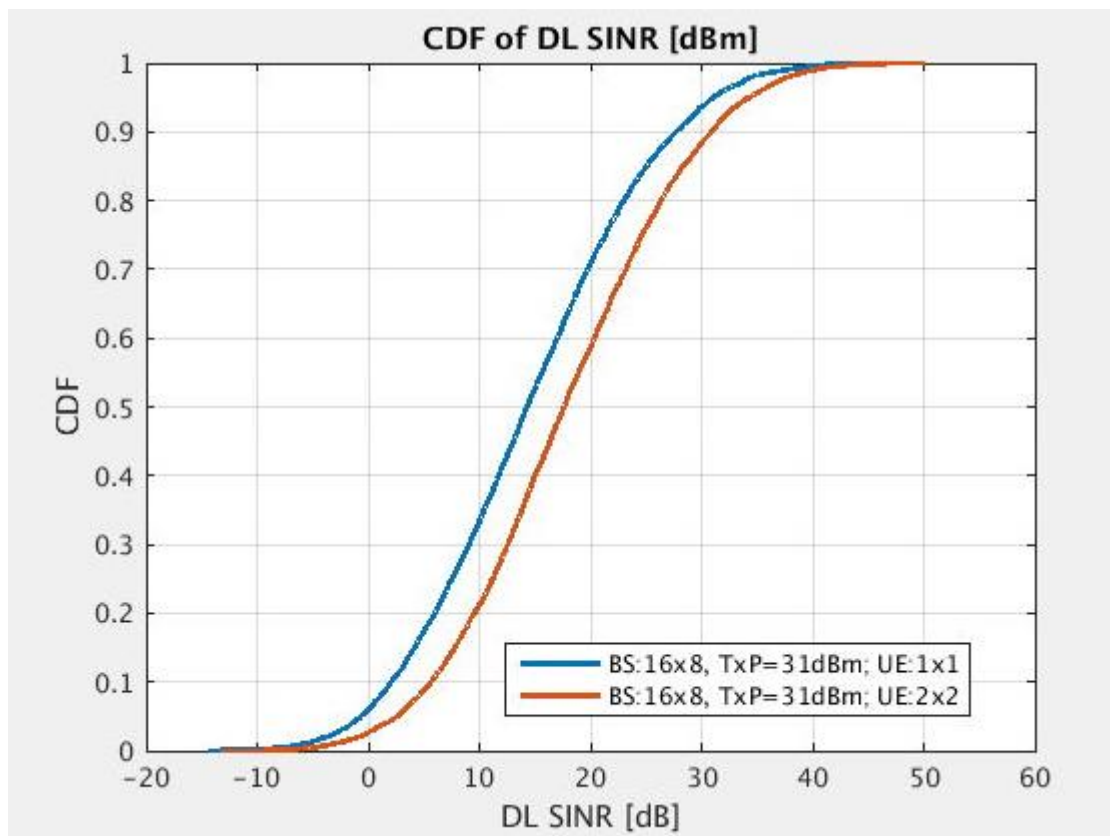
Figure 5.2.2.2-1: CDF of DL SINR for 256QAM

It can be observed that for the first configuration (UE 1x1) the SINR equal or higher than 25dB is obtained for 15% of the best DL links, whereas SINR equal or higher than 28dB is obtained for 10% of the best DL links. In case of second configuration (UE 2x2) the same levels of SINR are accessible for 24% and 16% of the best DL links, respectively.

According to studies presented in [5.2.2.2-3] the SINR of 25dB at the receiver is required to ensure sufficent link quality for 256QAM modulation, the results of presented simulation study indicate that up to 25 % of users in assumed scenario will benefit from higher DL data rate, given that other Tx and Rx impairments have limited impact.

It was observed that in fixed wireless access scenario up to 25% of the users are in propagation conditions which enable benefits from 256 QAM.

5.2.2.3 Results from Intel

The simulation results and proposals are based on contribution [5.2.2.3-4]

Figure 5.2.2.3-1 shows large scale SINR distribution for considered scenarios.

Figure 5.2.2.3-1: System-level large scale SINR distribution

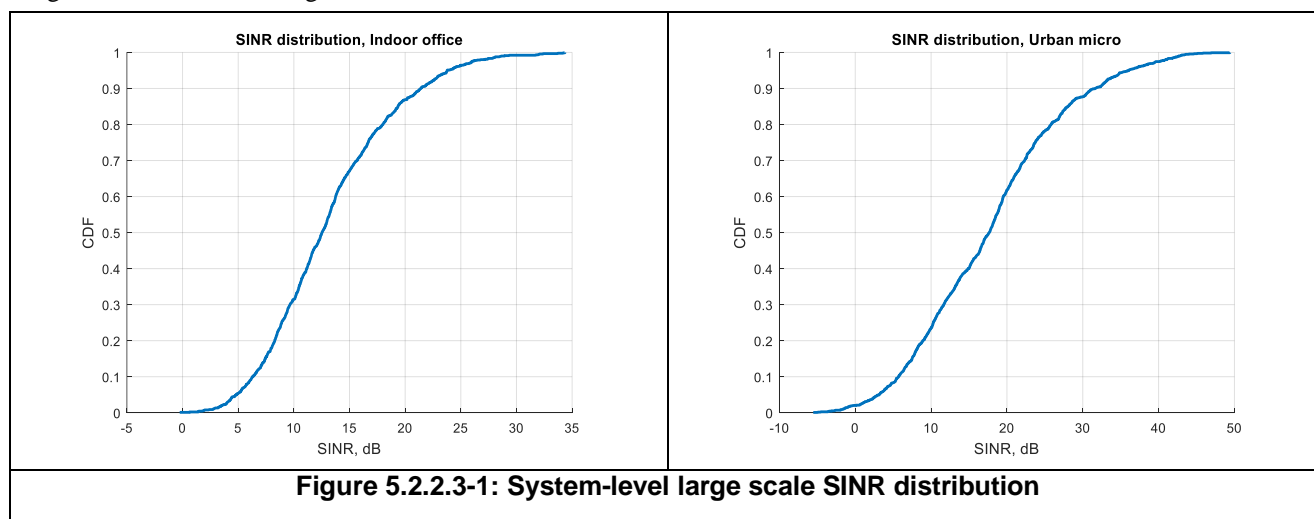***Observations:*** *From system-level simulation results we can observe that:*

- *Indoor office scenario: 5% of users have SINR $\geq$ 25 dB*

- *Urban micro scenario: 20% of users have SINR $\geq$ 25 dB*

5.2.2.4 Results from Ericsson

The following results are based upon the assumptions outlined in Section A.4

It has been discussed that there are two scenarios that should focus the study for indoor and urban micro where both scenarios are LOS between UE and BS. The rationale for studying only these two edge case scenarios is that these are the only possible scenarios for deployment for millimeter wave that may experience benefit of higher MCS.

With an observed user data rates higher than 170 Mbps, there is a 30% benefit due to higher modulation. For UEs utilizing 256 QAM an SINR upwards of 25 dB is needed. For higher modulation a small power back off 3dB is applied.
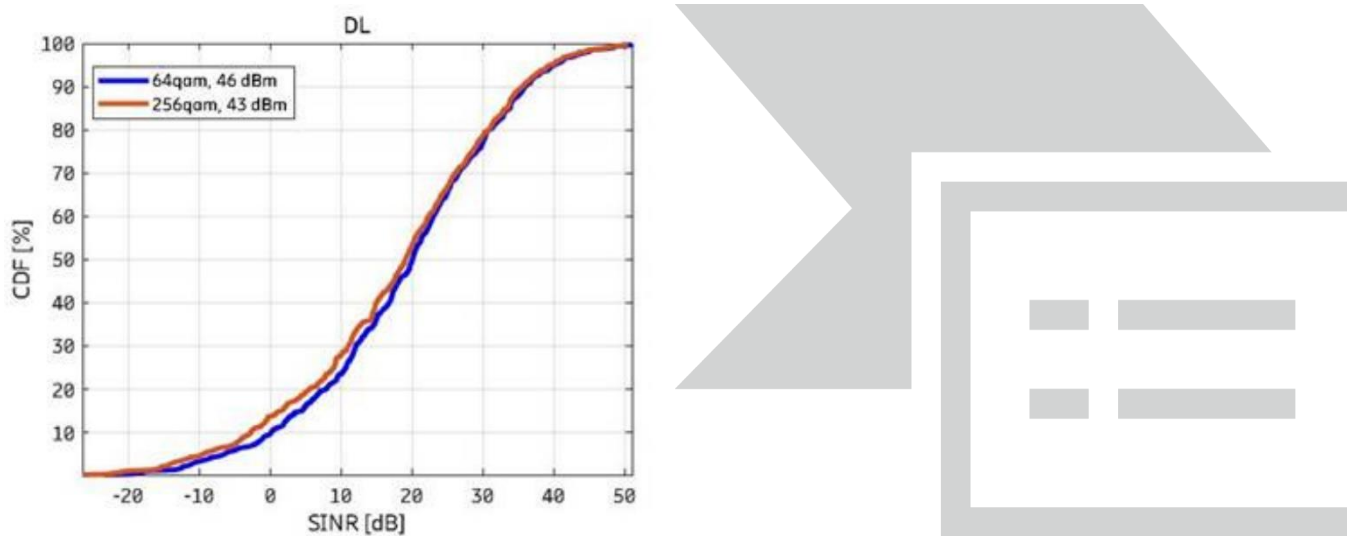
Figure 5.2.2.4-1: System-level macro base station scenario SINR distribution and observed user bitrates

For the above simulation results, the average user throughput for users with 64 QAM is 77.2 Mbps and for 256 QAM is 83.7 Mbps this gives an overall system gain of 8% for those users utilizing the higher modulation. The average user throughput considered is calculated by sum(all observed user throughput)/(total number of users observed). Additionally, user throughput distributions are also estimated for each user node and is taken into account whilst in Figure 5.2.2.4.-1 the bitrate map is considered does not consider any post-processing.
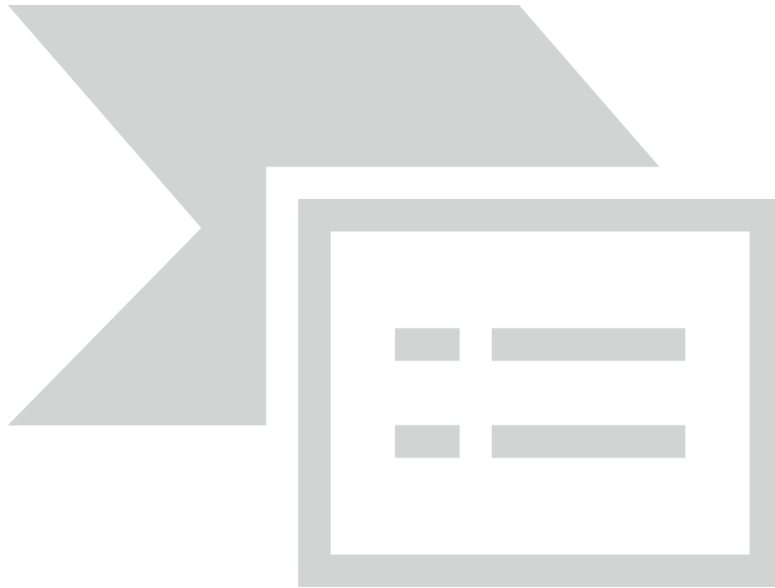
Figure 5.2.2.4-1: User throughput considering simple traffic assumptions

The simulation results below come from the indoor scenario where the results yield no benefit of 256 QAM over 64 QAM. Both user throughput and SINR distributions are equal.

Figure 5.2.2.4-2: System-level indoor base station scenario SINR distribution and average user throughput

The overall average cell throughput gains in the above simulations are 6% and 3% for macro and indoor solutions respectively. Although the capacity gains are modest, there are limited circumstances that during peak data rates

5.2.2.5 Results from NTT DOCOMO

Figure 5.2.2.5-1 shows the system level simulation result [7]. From the result, around 30% of UEs can achieve more than 25dB SINR.
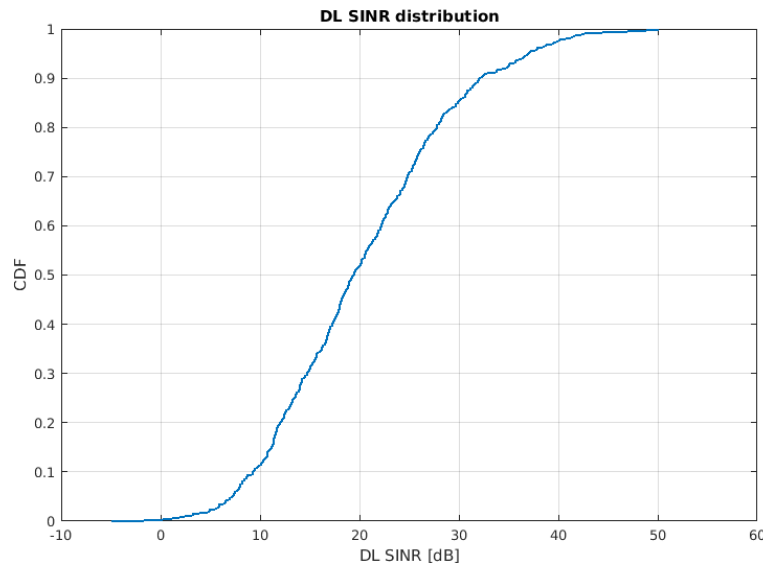
Figure 5.2.2.5-1: System level simulation results

5.2.2.6 Conclusion

Based on the simulation results and observations provided above, it can be concluded that from system level simulation point:

- For fixed wireless access scenario, up to 25% users operate in SINR greater than 25dB region required for 256QAM (TDL-D).

- For urban micro scenario in LOS (TDL-D), 8% to 20% users operate whose SINR is greater than 25dB region required for 256QAM.

- For indoor office environments, 5% users to no user can be observed to see benefits of 256 QAM.

The analysis herein shows that cell capacity gain by comparing with 256QAM to without 256QAM will depend on network scheduling.

5.3 Implementation based feasibility study

5.3.1 BS implementation

The BS EVM consists of several contributing impairments such as phase noise, peak reduction distortion, PA non-linearities, digital impairments etc. For example consider 3.5% EVM as a target limit, the following analysis was made for these impacts especially for one dominant aspect ACLR or Tx non-linearity, and EVM budget was given as an example. It is worth to note that examples of improved ACLR and/or TX non-linearity are compiled from two vendors' inputs, which reflect different implementations. Actually, in a practical implementation process the impact of each of the EVM contributors need to be traded off with each other to meet the final EVM requirement.

Figure 5.3.1-1 presents a simulated relationship between the ACLR achieved at the output of a 30GHz CMOS PA and a GaN PA, respectively, and EVM from one vendor's perspective. The figure indicates the PA must be dimensioned such that it would be capable to meet an ACLR of around 7dB greater than the SNR implied by the EVM. For 3.5% EVM (256QAM), the corresponding SNR is ~29dB, implying a PA operating with an ACLR of around 36dB.
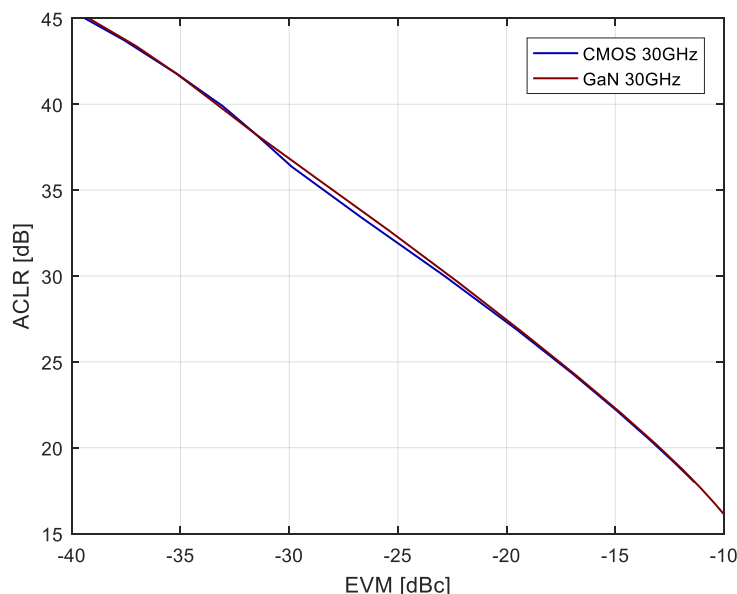
Figure 5.3.1-1: A relationship between ACLR achieved at 30GHz CMOS PA and GaN PA, respectively and EVM.

In another example for 256 QAM 3.5% EVM is an example target limit, and the corresponding SNR is ~29 dB. In order to achieve the target EVM limit, some power back-off is needed in the given example from one vendor. It should be noted that power back-off would also be needed to support for high MCS 64QAM. Table 5.3.1-1 shows one example of EVM budget on BS Tx. From the EVM budget it can be found that less than 3% EVM is achievable for BS Tx with 34.9dBc Tx non-linearity contribution to EVM. The presented result is an example and should not be considered as minimum requirements.

Table 5.3.1-1: Example of EVM budget

Tx EVM contributor	EVM (%)	SNR(dBc)
Tx non-linearity	1.80%	34.9
Digital part	1.50%	36.5
Phase noise	1.60%	35.9
IQ imbalance	0.80%	41.9
Total	2.95%	30.6

Although the above analysis from individual vendors shows improved ACLR, the exact impact to the implementation cannot be generalized as it depends on the implementation specific trade-offs between different EVM contributors, including ACLR. For example, in case the EVM performance is limited by PA non-linearity, then it follows that the logical way to improve the performance is to improve the PA, or back-off transmission power. Power back-off will have also negative impact on the efficiency of the PA. One example of of PAE from a single vendor is shown in Figure 5.3.1-2.
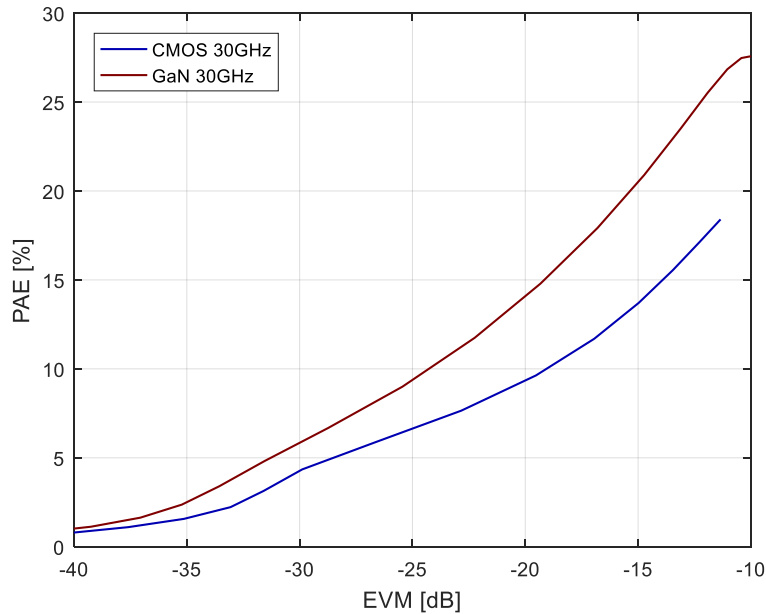
Figure 5.3.1-2 Simulation of 30 GHz CMOS and GaN power amplifier models showing PAE as a function of EVM.

Lower PA efficiency has only limited impact to the efficiency of the whole BS, as other aspects such as digital processing also consume significant percentage of the total power. On the other hand, if EVM performance is limited by phase noise, one design option to improve performance can be by selecting a better PLL. In this case impact to maximum output power and BS efficiency is negligible.

Based on the analysis it can be said that there are cases where the Tx chain which can be used for BS supporting modulations up to 64QAM cannot be fully re-used for a base station supporting 256QAM. However, based on the analysis it can be also said that commercial components exist which enable support of 256QAM. Therefore BS Tx impairments or other implementation considerations do not preclude feasibility of 256QAM or performance benefit from 256QAM.

As a conclusion support of FR2 DL 256QAM is feasible from BS implementation perspective.

5.4 Conclusion

The feasibility of FR2 DL 256QAM has been evaluated, including link level simulation, system level simulation and implementation study. Based on the study output, it can be concluded that FR2 DL 256QAM is feasible and beneficial as concluded in section 5.2.1.10, 5.2.2.6 and 5.3, and corresponding requirements shall be discussed and specified afterwards.

6 Specification impact for DL 256QAM

6.1 BS part

The specification impacts for BS part include EVM and OTA RE power control dynamic range.

The EVM requirement for FR2 DL 256QAM is listed in table 6.1-1.

Table 6.1-1: EVM requirements for *BS type 2-O* carrier

Modulation scheme for PDSCH	Required EVM (%)
QPSK	17.5
16QAM	12.5
64QAM	8
256QAM	3.5%

For OTA RE power control dynamic range, since no request to do power boosting/de-boosting for especially 256QAM for FR2, by following the same story with other modulation order, there is no need to define RE power control dynamic range for FR2 DL 256QAM.

6.2 UE part

The specification impacts for UE part include maximum input level and reference measurement channel.

The maximum input level is UE Rx requirement which reflects the UE receiver linearity capability. If the maximum input level for 256QAM share the same requirement as for QPSK, then the linearity of the receiver need to be improved. Thus, considering the same story with FR1, it is proposed to also relax 2dB by comparing with QPSK to define maximum input power level for 256QAM as -27dBm. The corresponding modifications for single carrier and intra-band CA are shown in the table 6.2-1 and table 6.2-2. The Reference measurement channels for 256QAM are shown in the table 6.2-3 and 6.2-4.

Table 6.2-1: Maximum input level

Rx Parameter	Units	Channel bandwidth			
		50 MHz	100 MHz	200 MHz	400 MHz
Power in transmission bandwidth configuration	dBm	-25 (NOTE 2)			
		-27 (NOTE 3)			
NOTE 1: The transmitter shall be set to 4 dB below the lower limit of the $P_{UMAX,f,c}$ inequality defined in subclause 6.2.4, with uplink configuration specified in Table 7.3.2.1-2 in 38101-2.					
NOTE 2: Reference measurement channel is specified in Annex A.3.3.2: QPSK, R=1/3 variant with one sided dynamic OCNG Pattern as described in Annex A in 38101-2.					
NOTE 3: Reference measurement channel is specified in Annex table 6.2-3: 256QAM, R=4/5 variant with one sided dynamic OCNG Pattern as described in Annex A in 38101-2.					

Table 6.2-2: Maximum input level for CA

Rx Parameter	Units	All CA configurations included in BCS 0
Power summed over transmission bandwidth configurations of all active DL CCs	dBm	-25 (NOTE 2)
		-27 (NOTE 3)
NOTE 1: The transmitter shall be set to 4 dB below the lower limit of the $P_{UMAX,f,c}$ inequality defined in subclause 6.2.4, with uplink configuration specified in Table 7.3.2.1-2		
NOTE 2: Reference measurement channel in each CC is specified in Annex A.3.3.2: QPSK, R=1/3 variant with one sided dynamic OCNG Pattern as described in Annex A.		
NOTE 3: Reference measurement channel is specified in Annex table 6.2-4: 256QAM, R=4/5 variant with one sided dynamic OCNG Pattern as described in Annex A in 38101-2.		

Table 6.2-3: Fixed Reference Channel for Receiver Requirements (SCS 60 kHz, TDD)

Parameter	Unit	Value		
Channel bandwidth	MHz	50	100	200
Subcarrier spacing configuration μ		2	2	2
Allocated resource blocks		66	132	264
Subcarriers per resource block		12	12	12
Allocated slots per Frame		23	23	23
MCS index		24	24	24
Modulation		256QAM	256QAM	256QAM
Target Coding Rate		4/5	4/5	4/5
Maximum number of HARQ transmissions		1	1	1
Information Bit Payload per Slot				
For Slots 0 and Slot i, if mod(i, 5) = {3,4} for i from {0,…,39}	Bits	N/A	N/A	N/A
For Slot i, if mod(i, 5) = {0,1,2} for i from {1,…,39}	Bits	44040	88064	176208
Transport block CRC	Bits	24	24	24
LDPC base graph		1	1	1
Number of Code Blocks per Slot				
For Slots 0 and Slot i, if mod(i, 5) = {3,4} for i from {0,…,39}	CBs	N/A	N/A	N/A
For Slot i, if mod(i, 5) = {0,1,2} for i from {1,…,39}	CBs	6	11	21
Binary Channel Bits Per Slot				
For Slots 0 and Slot i, if mod(i, 5) = {3,4} for i from {0,…,39}	Bits	N/A	N/A	N/A
For Slot i, if mod(i, 5) = {0,1,2} for i from {1,…,39}	Bits	54648	109296	218592
Max. Throughput averaged over 1 frame	Mbps	101.292	202.547	405.278
NOTE 1: Additional parameters are specified in Table A.3.1-1 and Table A.3.3.1-1 in 38.101-2.				
NOTE 2: If more than one Code Block is present, an additional CRC sequence of L = 24 Bits is attached to each Code Block (otherwise L = 0 Bit).				
NOTE 3: SS/PBCH block is transmitted in slot 0 of each frame				
NOTE 4: Slot i is slot index per frame				
NOTE 5: PTRS is configured on symbols containing PDSCH with 1 port, per 2PRB in frequency domain, per symbol in time domain. Overhead for TBS calculation is assumed to be 6.				

Table 6.2-4: Fixed Reference Channel for Receiver Requirements (SCS 120 kHz, TDD)

Parameter	Unit	Value			
Channel bandwidth	MHz	50	100	200	400
Subcarrier spacing configuration μ		3	3	3	3
Allocated resource blocks		32	66	132	264
Subcarriers per resource block		12	12	12	12
Allocated slots per Frame		47	47	47	47
MCS index		24	24	24	24
Modulation		256QAM	256QAM	256QAM	256QAM
Target Coding Rate		4/5	4/5	4/5	4/5
Maximum number of HARQ transmissions		1	1	1	1
Information Bit Payload per Slot					
For Slots 0 and Slot i, if mod(i, 5) = {3,4} for i from {0,…,79}	Bits	N/A	N/A	N/A	N/A
For Slot i, if mod(i, 5) = {0,1,2} for i from {1,…,79}	Bits	21504	44040	88064	176208
Transport block CRC	Bits	24	24	24	24
LDPC base graph		1	1	1	1
Number of Code Blocks per Slot					
For Slots 0 and Slot i, if mod(i, 5) = {3,4} for i from {0,…,79}	CBs	N/A	N/A	N/A	N/A
For Slot i, if mod(i, 5) = {0,1,2} for i from {1,…,79}	CBs	3	6	11	21
Binary Channel Bits Per Slot					
For Slots 0 and Slot i, if mod(i, 5) = {3,4} for i from {0,…,79}	Bits	N/A	N/A	N/A	N/A
For Slot i, if mod(i, 5) = {0,1,2} for i from {1,…,79}	Bits	26496	54648	109296	218592
Max. Throughput averaged over 1 frame	Mbps	101.069	206.988	413.901	828.178

NOTE 1: Additional parameters are specified in Table A.3.1-1 and Table A.3.3.1-1 in 38.101-2.
NOTE 2: If more than one Code Block is present, an additional CRC sequence of L = 24 Bits is attached to each Code Block (otherwise L = 0 Bit).
NOTE 3: SS/PBCH block is transmitted in slot 0 of each frame
NOTE 4: Slot i is slot index per frame
NOTE 5: PTRS is configured on symbols containing PDSCH with 1 port, per 2PRB in frequency domain, per symbol in time domain. Overhead for TBS calculation is assumed to be 6.

Annex A (informative): System level simulation assumptions

A.1 Assumptions from Huawei

According to the approved WF in [A-1], the system simulation assumptions for mmWave were agreed as following

- *The assumptions agreed for UE in [A-2] can be used as a reference for urban macro scenario*

The simulation methodology for EVM model and simulation metrics are as follows.

EVM model

> The tx EVM is modeled corresponding to the MCS by adding a certain white noise to the transmitter, and the white noise follows the distribution as $\sim N(0, EVM^2)$.

Simulation metrics

The simulation results are for SINR statistics at the UE side, of which the interference is consisted by own system co-channel interference. Considering the co-channel interference variation with tx EVM, the tx EVM requirement shall be determined by comparing SINR degradation across a range of EVM values. Further, the SINR degradation for the certain EVM can be quantized by mapping to the corresponding throughput loss to evaluate the system performance more directly.

A.2 Assumptions from Nokia

Figure A.2-1 presents simulation layout in suburban area with single-storey or double-storey buildings and vegetation with area of 700m x 600m, consist of 16 blocks with 20 buildings each. For each block two sectors BS is used, with one sector per 10 buildings. There is assumption that 90% of buildings have outside CPEs, and 10% of buildings closest to BS use inside CPEs. Geometry and details are presented in figure A.2-1. Table A.2-1 provides parameters used in simulations for BS and CPE.
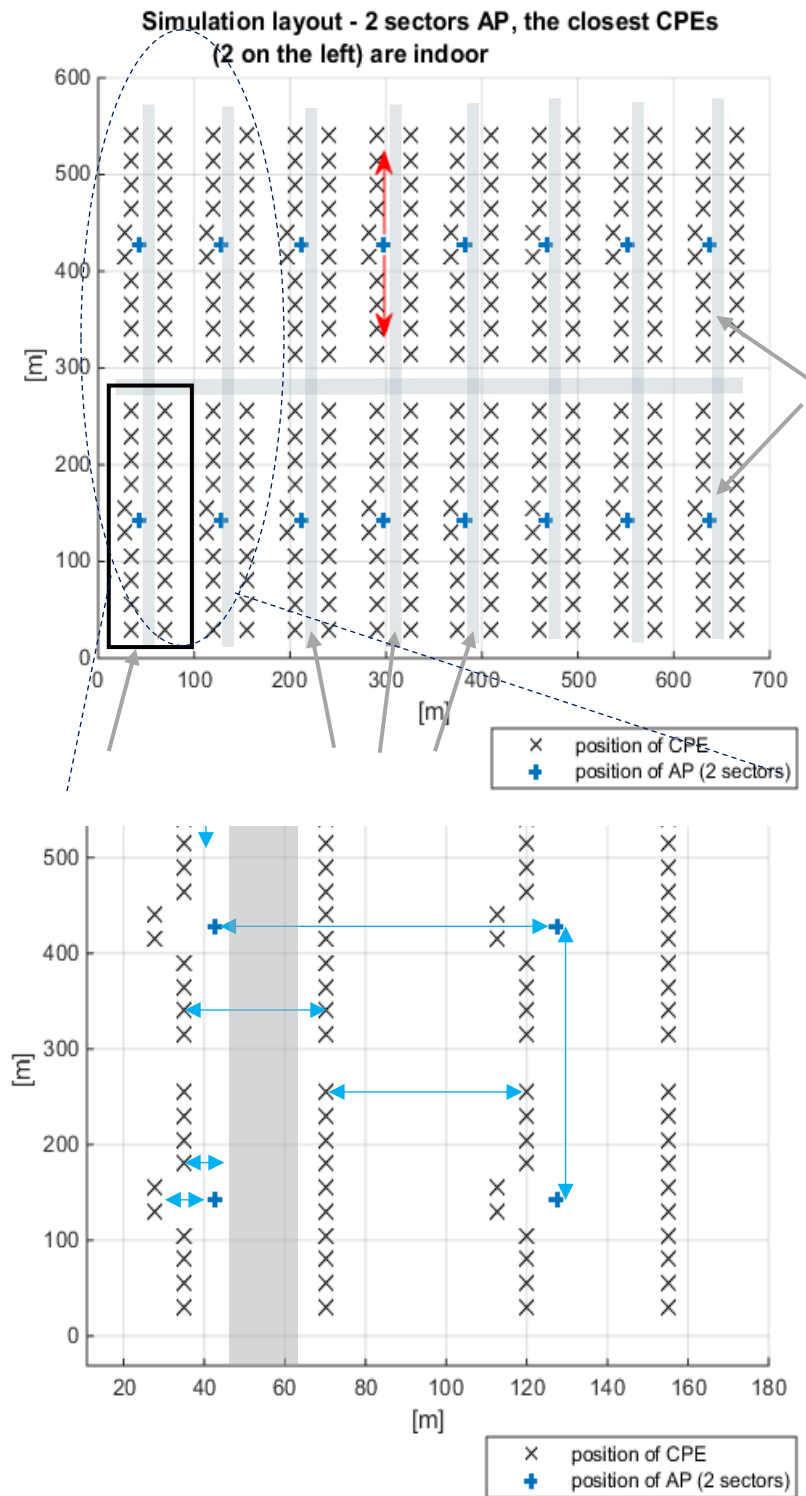
Figure A.2-1: Simulation layout

Table A.2-1: Simulation parameters

BS	
Carrier frequency	28 GHz
Channel Bandwidth	800 MHz
Antenna pattern	According to [A-3]
Gain of antenna element	6 dBi
Antenna array (H × V)	16x8
Tx power (without loss) / polarization	31 dBm
Height of antenna	8 m
CPE	
UE density	1 UE / sector
Antenna pattern	According to [A-3]
Gain of antenna element	6 dBi
Antenna array (H × V)	1x1 / 2x2
Height of antenna	1,5 m
Orientation in horizontal plane	Towards BS
Orientation in vertical plane	Towards BS
Noise Factor	9 dB

As 3GPP TR 38.901 does not specify channel model for suburban area, the 3GPP UMi Street Canyon model has been used, with modification of path loss and angular spread characteristics according to measurement campaign performed in real suburban campaign in 28 GHz frequency band [A-4].

Propagation conditions that are assumed in simulations are described in table A.2-2. Path loss channel models used in simulations are described in table A.2-3.

Table A.2-2: Assumed propagation conditions

BS – CPE separation in 2D	Conditions	Note
Up to 20 m	LOS/Indoor	BS and CPE on the same street. All LOS CPEs are Indoor
Beyond 20 m	VLOS/Outdoor	BS and CPE on the same street. LOS with Vegetation (VLOS) [A-4]
Different street	NLOS/Outdoor	BS and CPE on different streets.

Table A.2-3: Path loss channel model according to [A-4]

Propagation conditions	Path loss [dB] (d [m]: distance between BS and CPE)	Standard deviation [dB]
LOS	$61,4 + 24,0 \cdot \log_{10}(d)$	4,2
VLOS	$45,1 + 40,6 \cdot \log_{10}(d)$	6,4
NLOS	$80,3 + 31,3 \cdot \log_{10}(d)$	4,8
O2I	15,1	2,5

Angular spread models for departure and arrival (Azimuth Spread of Departure (ASD); Zenith Spread of Departure (ZSD); Azimuth Spread of Arrival (ASA); Zenith Spread of Arrival (ZSA)) used in simulations are presented in table A.2-4.

Table A.2-4: Angular spread model for departure and arrival

Propagation conditions	$\log_{10}$ (ASD/1º)	$\log_{10}$ (ZSD/1º)	$\log_{10}$ (ASA/1º)	$\log_{10}$ (ZSA/1º)
LOS	3GPP UMi SC [A-5]	3GPP UMi SC [A-5]	$\mu = 1,21$ $\sigma = 0,12$ [A-4]	3GPP UMi SC [A-5]
VLOS	$\mu = 0,82$ $\sigma = 0,24$ [A-4]	3GPP UMi SC [A-5]	$\mu = 1,21$ $\sigma = 0,12$ [A-4]	3GPP UMi SC [A-5]
NLOS	$\mu = 0,82$ $\sigma = 0,24$ [A-4]	3GPP UMi SC [A-5]	$\mu = 1,21$ $\sigma = 0,12$ [A-4]	3GPP UMi SC [A-5]

A.3 Assumptions from Intel

The simulation assumptions are from TR 38.802 and TR 38.855. Table A.3-1**Table** provides information on the main simulation assumptions.

Table A.3-1: System level simulation assumptions

		Indoor Hotspot	**Urban Micro**
Layout		Indoor floor: (12BSs per 120m x 50m), TRP number per floor:12, Inter-gNB distance = 20m	Hexagonal grid, 19 macro sites, 3 sectors per site, ISD = 200m
UE drop procedure		100% indoors, uniformly distributed	100% outdoors, uniformly distributed
Channel model		Indoor open office from TR 38.901	UMi Street Canyon from TR 38.901
Traffic model		Full buffer	
gNB parameters	Antenna configuration	$(M, N, P, M_g, N_g) = (4, 8, 2, 1, 1)$ $d_H = d_V = 0.5\lambda$	$(M, N, P, M_g, N_g) = (4, 8, 2, 2, 2)$ $d_H = d_V = 0.5\lambda$
	Antenna radiation pattern	TR 38.802 Table A.2.1-7	TR 38.802 Table A.2.1-6
	Number of beams	8	16
	Beam selection	Optimal beam for Serving cell, random for neighboring cells	
	Antenna height	3 m	10 m
	TX power	24dBm	37dBm (per panel)
UE parameters (FR2 PC3 UE , Handheld)	Antenna configuration	4 antenna elements, 2 panels	
	Antenna radiation pattern	Omni, 0dBi	
	Antenna height	1.5 m	
	Avg. element gain	5 dBi	
	Implementation loss	10 dB	
	Noise figure	10 dB	

A.4 Assumptions from Ericsson

Macro scenario:

Parameters	
Macro site distance	200 m
Number of sites	19
Frequency range	30GHz
Beamforming	Yes
Simulation bandwidth	200MHz
Number of UEs in the network	1 active UE/sector
Traffic Model	Full buffer
Channel Model	nr-uma from TR 38.900
Propagation conditions	LOS
gNB Tx power	33 dBm for macro.
gNB antenna height	25m for macro cells
gNB receiver noise figure	10 dB
BS antenna configuration	(Mg, Ng, M, N, P) = (1, 1, 8, 16, 1)
UE Tx power (dBm)	22.4 dBm
UE noise figure (dB)	10

Indoor:

Parameters	
Indoor layout	Open office 50x120m
Number of sites	6
Frequency range	30GHz
Simulation bandwidth	200MHz
Number of UEs in the network	1 active UE/sector
Traffic Model	Full buffer
Channel Model	nr-inh-open from TR 38.900
Propagation conditions	LOS
gNB Tx power	23 dBm
gNB receiver noise figure	10 dB
UE Tx power (dBm)	22.4 dBm
UE noise figure (dB)	10

A.5 Assumptions from NTT DOCOMO

Table A.5-1 shows the simulation assumption for system level simulation, which is based on TR 38.802 and modified for the feasibility study.

Table A.5-1: Simulation assumption for system level simulation

Parameter	Value
Deployment	Single macro layer, Hex. Grid
ISD	200m
Carrier frequency	28GHz (n257)
CBW	100MHz
SCS	120kHz
Channel model	TR38.901 UMi-Street canyon
BS Tx power	33 dBm
Num. of beams	64
BS antenna config	(M,N,P,Mg,Ng) = (8,16,2,1,1) (dH,dV,dHg,dVg) = (0.5,0.5,NA,NA)λ
BS antenna height	10m
UE antenna height	1.5m (all outdoor)
UE receiver NF	13dB
UE distribution	3 users per TRP

Annex B (informative): Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2019-08	RAN4#92	R4-1910478				TR skeleton: Study on support of NR downlink 256 Quadrature Amplitude Modulation (QAM) for frequency range 2 (FR2)	0.0.1
2019-10	RAN4#92 bis	R4-1911086				Implemented TPs from RAN4 #92: R4-1910591, "TP for TR 38.8xx: Simulation assumptions for the feasibility study of FR2 DL 256QAM", China Telecom R4-1910480, "TP for TR 38.8xx: Link level simulation results for the feasibility study of FR2 DL 256QAM", China Telecom R4-1910479, "TP for TR 38.8xx: System level simulation results for the feasibility study of FR2 DL 256QAM", China Telecom	0.1.0
2019-11	RAN4#93	R4-1913902				Implemented TPs from RAN4 #92bis: R4-1910847, "Additional simulation results on DL 256QAM", Huawei, HiSilicon R4-1912892, "TP to TR 38.883: FR2 DL 256QAM link level simulation results", Nokia, Nokia Shanghai Bell R4-1912893, "TP to TR 38.883: Section 5.2.1 Link level simulation", Ericsson R4-1911088, "TP for TR 38.883: Updated link level simulation for FR2 DL 256QAM", China Telecom R4-1913051, "TP to TR 38.883 NR FR2 256QAM link level and system level simulation results", NTT DOCOMO, INC R4-1912894, "TP to TR 38.883: Section 5 System level simulation", Ericsson R4-1912895, "TP to TR: BS Implementation aspects", China Telecom R4-1912896, "TP for TR 38.883: Conclusion for the feasibility study of FR2 DL 256QAM", China Telecom	0.2.0
2019-12	RAN #86	RP-192727				Update to change history	1.0.0
2020-02	RAN4#94 -e	R4-2000909				Implemented TPs from RAN4 #93: R4-1913493, "TP to TR 38.883 Updated link level simulation results for FR2 DL 256QAM", Qualcomm Incorporated R4-1913734, "TP for TR 38.883: Updated link level simulation for 256QAM for FR2", CATT R4-1914081, "TP to TR 38.883 Updated FR2 DL 256QAM link level simulation results", NTT DOCOMO, INC. R4-1914568, "TP to TR 38.883: Updated Section 5 System level simulation", Ericsson	1.1.0
2020-04	RAN4#94 -e-Bis	R4-2003656				Implemented TPs from RAN4 #94-e: R4-2000910, "TP for TR 38.883 BS RF requirements for FR2 DL 256QAM", China Telecom	1.2.0
2020-05	RAN4#95 -e	R4-2006927				Implemented TPs from RAN4 #94-e-Bis: R4-2003658, "TP for TR 38.883 UE RF requirements for FR2 DL 256QAM", China Telecom	1.3.0
2020-05	RAN4#95 -e	R4-2008968				Implemented TPs from RAN4 #95-e: R4-2006928, "TP for TR 38.883 Editoral corrections", China Telecom	1.4.0
2020-06	RAN #88- e	RP-200862				Update to change history	2.0.0

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2020-06	RAN#88					Approved by plenary – Rel-16 spec under change control	16.0.0