**3GPP TSG-RAN WG1 Meeting #112 R1-23xxxxx**

**Athens, Greece, February 27 – March 3, 2023**

**Agenda Item: 8.17**

**Source: Huawei, HiSilicon**

**Title: Summary of discussion on LS on reduced 1024 QAM capability**

**Document for: Discussion and Decision**

# Introduction

This contribution summarizes the discussion on questions in RAN2 LS [1] regarding reduced 1024 QAM capabilities, over the following agreements and assumptions in RAN2.

* [1] Clarify that UE shall at most report one of *pdsch-1024QAM-2MIMO-FR1-r17*and *pdsch-1024QAM-FR1-r17*.
* [2] Assume to Extend *supportedModulationOrderDL* to include 1024 QAM (confirm with R1).
* [3] The MIMO layer for 1024 QAM is Min (2, *maxNumberMIMO-LayersPDSCH*) for the CC where 1024 QAM is reported
* [4] Assume that Max data rate shall be derived from the higher data rate between 1024 QAM or 256 QAM for CC where 1024 QAM is indicated and the UE support reduced 1024 capability (confirm with R1)
* [5] Assume to Clarify that both *scalingFactor* and *scalingFactor-1024QAM-FR1-r17* can be included for in one per CC capability and legacy *scalingFactor* is used when non-1024 QAM is scheduled (confirm with R1)

# Companies’ proposals

For the bullets requiring RAN1 confirmation, companies have the following proposals:

For bullet 2:

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| Companies | Proposals |
| Huawei, Hisilicon [2] | Another option is to explicitly indicate the supported modulation order for max data rate calculation as legacy for modulation orders lower than 256QAM. From RAN1 point of view, there’s no difference on implicit or explicit indication of *supportedModulationOrderDL*.However, in LS [1], RAN2 has decided to include 256QAM and 1024QAM in *supportedModulationOrderDL*, to avoid any potential issue in future extension. We do not identify any issue from RAN1 perspective.**Proposal 1: the following is confirmed from RAN1 perspective:*** + **Assume to Extend *supportedModulationOrderDL* to include 1024 QAM.**
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| ZTE, Sanechips [3] | For the second bullet, even though the *supportedModulationOrderDL* is not extended to 1024QAM in current specification [3], it would work according to the current specification. We agree it may have a forward compatible issue, e.g. if the modulation order higher than 1024QAM was introduced in the future, the absent of *supportedModulationOrderDL* would not be able to imply 1024 QAM anymore. Therefore, we support RAN2’s assumption to extend *supportedModulationOrderDL* to include 1024 QAM.1. Support RAN2’s assumption to extend *supportedModulationOrderDL* to include 1024 QAM.
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| Intel [4] | Our understanding is that the intention for extending supportedModulationOrderDL to include 1024 QAM is to allow UE to report 1024 QAM for max data rate calculation in the hypothetical case it supports a larger modulation order e.g. 4096 QAM. While this assumption was proposed and did not have consensus in RAN1 in the past, we may discuss it further. Additionally, the following may be clarified

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| ***supportedModulationOrderDL***Indicates the maximum supported modulation order to be applied for downlink in the carrier in the max data rate calculation as defined in 4.1.2. If included, the network may use a modulation order on this serving cell which is higher than the value indicated in this field as long as UE supports the modulation of higher value for downlink. If not included:- for FR1, the network uses the modulation order signalled per band i.e. ~~[pdsch-1024QAM-FR1]~~ pdsch-1024QAM-FR1-r17 or pdsch-1024QAM-2MIMO-FR1-r17 when ~~[pdsch-1024QAM-FR1]~~ pdsch-1024QAM-FR1-r17 or pdsch-1024QAM-2MIMO-FR1-r17 is signalled for the band, otherwise the network uses the modulation order signalled in *pdsch-256QAM-FR1*.- for FR2, the network uses the modulation order signalled per band i.e. *pdsch-256QAM-FR2* if signalled. If not signalled in a given band, the network shall use the modulation order 64QAM.In all the cases, it shall be ensured that the data rate does not exceed the max data rate (*DataRate*) and max data rate per CC (*DataRateCC*) according to TS 38.214 [12]. |

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| Samsung [5] | For bullet 2, the main motivation of extending the field to include 1024QAM is to provide forward compatibility when higher modulation order than 1024QAM is supported in future. However, it is note that current specification doesn’t have any issue, and the time of supporting higher modulation than 1024QAM is unknown. The issue is not critical issue at this stage. In this sense, bullet 2 can be discussed later with other candidate solutions when higher modulation than 1024QAM is discussed in future. **Proposal 1: It is premature to confirm bullet 2 from RAN1 understanding.**  |
| Ericsson [6] | The purpose of supportedModulationOrderDL is to indicate a fake modulation order per CC that is used to calculate a data rate value for the carrier in the data rate formula. RAN1 discussed extending supportedModulationOrderDL in the 1024-QAM UE features discussion but did not agree to it because the scaling factors (*scalingFactor and scalingFactor-1024QAM-FR1-r17*) were considered sufficient to indicate lower peak data rate. 1. Extension of supportModulationOrderDL is not required for indication of lower peak data rates for modulation orders larger than 256-QAM.
2. Extension of supportModulationOrderDL increases signaling overhead (per-CC-per-band-per-BC) without providing any meaningful peak data rate reduction benefits.

When the supportedModulationOrderDL is absent, the value of Qm in the data rate calculation according to a given modulation order (e.g. 256-QAM, 1024-QAM or even 4096-QAM capability) is set to the corresponding modulation order indicated per band. Therefore, there is no need to have an explicit extension of supportedModulationOrderDL to support 1024-QAM or larger modulation orders – it also unnecessarily increases signaling overhead.Based on above discussion, we propose following. If needed, RAN1 can also provide more background to this answer in the LS to RAN2.1. Regarding issue [2] in RAN2 LS, send below reply to RAN2
	* RAN1 does not see a need to extend the supportedModulationOrderDL to include 1024 QAM.
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| Qualcomm [7] | For issue #2, RAN1 agrees with RAN2 proposed assumption to extend *supportedModulationOrderDL* to include 1024 QAM. However, it should be a separate UE capability from Rel-15 capability for backward compatibility.  |
| NTT DOCOMO [8] | Regarding the bullet 2 in the RAN2 LS, TS38.306 describes how to handle 1024 QAM without changing *supportedModulationOrderDL* for the max data rate calculation as below.

| ***supportedModulationOrderDL***Indicates the maximum supported modulation order to be applied for downlink in the carrier in the max data rate calculation as defined in 4.1.2. If included, the network may use a modulation order on this serving cell which is higher than the value indicated in this field as long as UE supports the modulation of higher value for downlink. If not included:- for FR1, the network uses the modulation order signalled per band i.e. [pdsch-1024QAM-FR1] when [pdsch-1024QAM-FR1] is signalled for the band, otherwise the network uses the modulation order signalled in *pdsch-256QAM-FR1*.- for FR2, the network uses the modulation order signalled per band i.e. *pdsch-256QAM-FR2* if signalled. If not signalled in a given band, the network shall use the modulation order 64QAM.In all the cases, it shall be ensured that the data rate does not exceed the max data rate (*DataRate*) and max data rate per CC (*DataRateCC*) according to TS 38.214 [12]. | FSPC | No | N/A | N/A |
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In the RAN2 LS, it is described that “If a higher modulation order is introduced in the future, the absence of *supportedModulationOrderDL* cannot imply 1024 QAM anymore. Therefore RAN2 assumes to extend *supportedModulationOrderDL* to include 1024 QAM is better”.However, in our understanding, the absence of *supportedModulationOrderDL* does not imply 1024 QAM even in current description. Actually, the network needs to check whether [*pdsch-1024QAM-FR1*] is signalled or not according to the current description. Therefore, even if higher modulation order e.g., 2048 QAM is introduced in the future, it is possible to continue avoiding the extension of *supportedModulationOrderDL* as below example.

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| If not included:* for FR1, the network uses the modulation order signalled per band in [pdsch-2048QAM-FR1] when [pdsch-2048QAM-FR1] is signalled for the band. If [pdsch-2048QAM-FR1] is not signalled for the band, the network uses the modulation order signalled per band in [pdsch-1024QAM-FR1] when [pdsch-1024QAM-FR1] is signalled for the band. Otherwise, the network uses the modulation order signalled in pdsch-256QAM-FR1.
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In addition, for backward compatibility, UE capable of extended *supportedModulationOrderDL* needs to report both existing *supportedModulationOrderDL* and extended *supportedModulationOrderDL*. So, it seems that the extension of *supportedModulationOrderDL* is not so necessary even considering potential higher modulation order in future.**Observation 1: It seems that the extension of *supportedModulationOrderDL* is not so necessary even considering potential higher modulation order in future.** |

For bullet 4:

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| Companies | Proposals |
| Huawei, Hisilicon [2] | The max data rate is calculated according to the #layers, max modulation order, scaling factor etc. reported by UE, in order to limit the gNB scheduling so that the scheduled PDSCH/PUSCH does not exceed UE capability. If UE reports support 1024QAM with up to 2 layers, then a higher data rate can be achieved using 256QAM with 4 layers, which is still within the UE processing capability. Therefore, the higher data rate between 1024QAM and 256QAM should be used as the max data rate.**Proposal 2: the following is confirmed from RAN1 perspective:*** + **Assume that Max data rate shall be derived from the higher data rate between 1024 QAM or 256 QAM for CC where 1024 QAM is indicated and the UE support reduced 1024 capability**
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| ZTE, Sanechips [3] | For the fourth bullet, according to current specification, when 1024QAM is indicated and the UE supports reduced 1024 capability, the maximum number of MIMO layers can be assumed as 2 if *maxNumberMIMO-LayersPDSCH* is not absent. Then the max data rate for 1024QAM with 2 MIMO layers can be less than that of 256QAM and larger MIMO layers. So we support RAN2’s assumption to assume that max data rate shall be derived from the higher data rate between 1024 QAM or 256 QAM for CC where 1024 QAM is indicated and the UE support reduced 1024 capability.1. Support RAN2’s assumption that max data rate shall be derived from the higher data rate between 1024 QAM or 256 QAM for CC where 1024 QAM is indicated and the UE support reduced 1024 capability.
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| Intel [4] | A UE may report 256 QAM using supportedModulationOrderDL that allows a higher rate than 1024 QAM in this case. However, the max data rate calculation in 38.306 currently depends on max modulation order and max MIMO layers thereby treating both pdsch-1024QAM-2MIMO-FR1-r17 and pdsch-1024QAM-FR1-r17 in the same way for 4 MIMO layers for example. This issue could be further discussed. |
| Samsung [5] | For bullet 4, it is understood that RAN2 agreed to avoid the situation where 1024QAM with 2 MIMO layers should not be considered for calculating supported max data rate since 256QAM with 4 MIMO layers provide higher data rate. However, the concern situation does not seem to happen in current specification. According to the definition of ***supportedModulationOrderDL*** shown in table below, UE would assume 256QAM for the max data rate calculation even though the UE reports ***pdsch-1024QAM-2MIMO-FR1-r17***.

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| ***supportedModulationOrderDL*** Indicates the maximum supported modulation order to be applied for downlink in the carrier in the max data rate calculation as defined in 4.1.2. If included, the network may use a modulation order on this serving cell which is higher than the value indicated in this field as long as UE supports the modulation of higher value for downlink. If not included: - for FR1, the network uses the modulation order signalled per band i.e. [pdsch-1024QAM-FR1] when [pdsch-1024QAM-FR1] is signalled for the band, otherwise the network uses the modulation order signalled in pdsch-256QAM-FR1. - for FR2, the network uses the modulation order signalled per band i.e. pdsch-256QAM-FR2 if signalled. If not signalled in a given band, the network shall use the modulation order 64QAM. In all the cases, it shall be ensured that the data rate does not exceed the max data rate (DataRate) and max data rate per CC (DataRateCC) according to TS 38.214 [12].  |

 Since 4 MIMO layers is mandatory capability in FR1 for single CC standalone NR, there is no ambiguity issue. 256QAM with 4 MIMO layers is considered to calculate the max data rate even though the UE reports ***pdsch-1024QAM-2MIMO-FR1-r17***. For multiple CC, it is understood that ***maxNumberMIMO-LayersPDSCH*** would be applicable for both 256QAM and 1024QAM. The main motivation of introducing ***pdsch-1024QAM-2MIMO-FR1-r17*** is that it is likely that the UE couldn’t support 1024QAM with 4MIMO layers in single CC standalone NR. Therefore, the case where a UE simultaneously supports multiple CCs and ***pdsch-1024QAM-2MIMO-FR1-r17*** needs further discussion in RAN1. **Proposal 2: Current specification doesn’t have any problems for calculating max data rate. Thus, it is unnecessary to confirm bullet 4. However, it needs to discuss whether pdsch-1024QAM-2MIMO-FR1-r17 can be considered or not in case of multiple CC.** |
| Ericsson [6] | Note 3 in 38.306, 4.1.2 covers the max data rate “*The approximate maximum data rate can be computed as the maximum of the approximate data rates computed using the above formula for each of the supported band or band combinations.*”. This is applicable for both 1024-QAM capabilities, pdsch-1024QAM-2MIMO-FR1-r17and pdsch-1024QAM-FR1-r17 since different scaling factors may apply to 256-QAM and 1024-QAM as well. Our understanding is that Note 3 above covers the RAN2 assumption for issue 4. Based on above discussion, we propose following. 1. Regarding issue [4] in RAN2 LS, send below reply to RAN2
	* RAN1 confirms the RAN2 assumption for issue [4] and it is RAN1 understanding that Note 3 in TS38.306, subclause 4.1.2 covers the agreement [4] in RAN2 LS.
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| Qualcomm [7] | For issue #4, RAN1 confirms that the maximum data rate should be computed as the higher data rate between two-layers MIMO with 1024-QAM and maximum MIMO layers for PDSCH with 256-QAM. For example, if UE reports capability of maximum of four MIMO layers by ‘*maxNumberMIMO-LayersPDSCH*’, then maximum data rate should be computed as the higher data rate between 4-Layers with 256-QAM and 2 layers with 1024-QAM. |
| NTT DOCOMO [8] | Regarding the bullet 4 in the RAN2 LS, FG36-1a and 36-2 are “reduced 1024 capability” and UE may support 256QAM with higher maximum number of MIMO layers and/or higher value of scaling factor compared with 1024QAM. In such case, we have same understanding with RAN2 assumption that “max data rate shall be derived from the higher data rate between 1024 QAM and 256 QAM for CC where 1024 QAM is indicated and the UE support reduced 1024 capability”.**Proposal 1: RAN1 confirms following RAN2 assumption in bullet 4.*** **Max data rate shall be derived from the higher data rate between 1024 QAM and 256 QAM for CC where 1024 QAM is indicated and the UE support reduced 1024 capability.**
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For bullet 5:

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| Companies | Proposals |
| Huawei, Hisilicon [2] | Considering that there are legacy gNB, it should be clarified that both scalingFactor and scalingFactor-1024QAM-FR1-r17 can be included in one CC, and legacy scalingFactor is used when non-1024 QAM is scheduled. Therefore,**Proposal 3: the following is confirmed from RAN1 perspective:*** + **Assume to Clarify that both scalingFactor and scalingFactor-1024QAM-FR1-r17 can be included for in one per CC capability and legacy scalingFactor is used when non-1024 QAM is scheduled**
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| ZTE, Sanechips [3] | For the fifth bullet, according to current specification, when 1024QAM is used for data scheduling, only the *scalingFactor-1024QAM-FR1-r17* is available for the maximum data rate calculation. And if the legacy *scalingFactor* and *scalingFactor-1024QAM-FR1-r17* are absent, the scaling factor 1 shall be used for 1024QAM. However, because there is no description that *scalingFactor* is not used for non-1024QAM in [3], whether the legacy *scalingFactor* or the scaling factor 1 is used for 1024QAM should be clarified if the legacy *scalingFactor* is presented and *scalingFactor-1024QAM-FR1-r17* is absent. Therefore, we support RAN2’s assumption to clarify that both *scalingFactor* and *scalingFactor-1024QAM-FR1-r17* can be included for in one per CC capability and legacy *scalingFactor* is used when non-1024 QAM is scheduled.1. Support RAN2’s assumption to clarify that both *scalingFactor* and *scalingFactor-1024QAM-FR1-r17* can be included for in one per CC capability and legacy *scalingFactor* is used when non-1024 QAM is scheduled.
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| Intel [4] | This assumption is not clear. We think it is okay to clarify that scalingFactor-1024QAM-FR1-r17 should be applied if support of 1024 QAM is indicated for the band, if not, legacy scaling factor is applied. |
| Samsung [5] | For bullet 5, it is shown that ***scalingFactor-1024QAM-FR1-r17*** is considered for max data rate calculation when 1024QAM for PDSCH is signaled in the band in the table below. ***scalingFactor*** is used for max data rate calculation. It needs further clarification on “legacy *scalingFactor* is used when non-1024 QAM is scheduled” explained in RAN2 agreements. Based on the current specification, ***scalingFactor*** is applied when Q value in the max data rate equation is modulation order other than 1024QAM, while ***scalingFactor-1024QAM-FR1-r17*** is applied when Q value is 1024QAM. Thus, it should be discussed first before deciding whether to confirm bullet 5 or not.

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| ***scalingFactor-1024QAM-FR1-r17*** Indicates the scaling factor to be applied to the band in the max data rate calculation for 1024-QAM as defined in 4.1.2 when support of 1024-QAM for PDSCH is signalled for the band. Value f0p4 indicates the scaling factor 0.4, f0p75 indicates 0.75, and so on. If absent, the scaling factor 1 is applied to the band in the max data rate calculation for 1024-QAM. UE indicating support of this feature shall also indicate support of pdsch-1024QAM-FR1-r17 or pdsch-1024QAM-2MIMO-FR1-r17 to the band.  |

**Proposal 3: RAN1 needs to discuss whether two different scaling factors can be used in the same band for the max data rate calculation.** |
| Ericsson [6] | There are two parts to this issue: * “Whether both scalingFactor and scalingFactor-1024-QAM-FR1-r17) can be included in the capability”
* “legacy scalingFactor is used when non-1024 QAM is scheduled”

For the first part, it is correct that both scalingFactor and scalingFactor-1024QAM-FR1-r17 can be included in the capability. For the second part however, the legacy scalingFactor is used when non-1024 QAM is “configured”. When 1024-QAM is configured, the max data rate calculated in 38.306 follows the data rate calculated for 1024-QAM and it does not vary with the scheduled MCS value or modulation order value. Based on above discussion, we propose following including the clarification in red that it is based on configuration and not based on the scheduled modulation order. 1. Regarding issue [5] in RAN2 LS, send below reply to RAN2

It is RAN1 understanding that “both scalingFactor and scalingFactor-1024QAM-FR1-r17 can be included for in one per CC capability and legacy scalingFactor is used when non-1024 QAM is configured”. |
| Qualcomm [7] | For issue #5, when a UE indicates the support of ‘*pdsch-1024QAM-FR1-r17’or ‘pdsch-1024QAM-2MIMO-FR1-r17*’, the UE can report a 1024-QAM scaling factor,‘*scalingFactor-1024QAM-FR1-r17’,* that is used for the computation of maximum data rate with 1024-QAM*.* if not reported by the UE, gNB can assume the scaling factor equal to 1. Then, a UE can report two scaling factors per CC, the legacy ‘*scalingFactor*’ and ‘*scalingFactor-1024QAM-FR1-r17’*. The motivation for adding 1024-QAM scaling factor was for backward compatibility with legacy gNB that doesn’t support 1024-QAM. Similar to issue #4, the maximum data rate is computed per carrier based on the higher data rate between 1024 QAM and 256 QAM using the associated scaling factor ‘*scalingFactor-1024QAM-FR1-r17’*’ and ‘*scalingFactor*’ respectively. |
| NTT DOCOMO [8] | Regarding the bullet 5 in the RAN2 LS, FG36-2 (*scalingFactor-1024QAM-FR1-r17*) is dedicated to 1024QAM, and legacy scaling factor can also be included for other modulation orders. Therefore, we have same understanding with RAN2 assumption that “both *scalingFactor* and *scalingFactor-1024QAM-FR1-r17* can be included for in one per CC capability and legacy *scalingFactor* is used when non-1024 QAM is scheduled”.**Proposal 2: RAN1 confirms following RAN2 assumption in bullet 5.*** **both *scalingFactor* and *scalingFactor-1024QAM-FR1-r17* can be included for in one per CC capability and legacy *scalingFactor* is used when non-1024 QAM is scheduled**
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# Discussion

## Bullet 2

**Assume to Extend *supportedModulationOrderDL* to include 1024 QAM (confirm with R1).**

Companies (Huawei, HiSilicon, ZTE, Sanechips, Qualcomm) propose to confirm RAN2 assumption.

Intel proposes to further discuss it, and also proposes to clarify the description in 38.306.

Samsung’s view is that the time to support higher modulation order is unknown, thus not critical.

Ericsson’s view is that the scaling factor can be used to indicate lower peak data rate.

DOCOMO provides an example how to indicate higher order modulation.

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| Companies | Comments |
| Moderator | @Intel, whether to use pdsch-1024QAM-FR1-r17 or pdsch-1024QAM-2MIMO-FR1-r17 instead of pdsch-1024QAM-FR1 may depend on whether comparison between 1024QAM-2layer and 256QAM-4layer, once RAN1 clarifies the understanding, the description in 38.306 will be clarified accordingly.@Ericsson, from RAN2’s LS, its motivation may be to clearly indicate which modulation order is used for max data rate calculation, and future extension.@DOCOMO, in the example, it seems UE cannot indicate supportedModulationOrderDL as 1024QAM when 2048QAM is supported.Moderator view: although the current way works after some careful clarification. RAN2’s assumption seems to be more straightforward and clearer, avoiding potential ambiguities or clarifications. From RAN1’s point of view, the functionality is more important, and the details on signaling can be left to RAN2 decision. |
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## Bullet 4

**Assume that Max data rate shall be derived from the higher data rate between 1024 QAM or 256 QAM for CC where 1024 QAM is indicated and the UE support reduced 1024 capability (confirm with R1)**

Companies (Huawei, HiSilicon, ZTE, Sanechips, Ericsson, Qualcomm, DOCOMO) propose to confirm RAN2 assumption.

Intel’s view is that the max data rate calculation can rely on the supportedModulationOrderDL reported by UE.

Samsung’s view is that UE can also assume 256QAM even though UE reports 1024QAM with 2 layers, but for multiple-CC case, this may depend on whether UE reports ***pdsch-1024QAM-2MIMO-FR1-r17*** in multiple-CC scenarios.

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| Companies | Comments |
| Moderator | Moderator view: there’s majority view to confirm RAN2’s assumption. The assumption seems to be aligned with the function of maximum data rate from RAN1 point of view. Please feedback whether you can accept to confirm RAN2’s assumption. |
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## Bullet 5

**Assume to Clarify that both scalingFactor and scalingFactor-1024QAM-FR1-r17 can be included for in one per CC capability and legacy scalingFactor is used when non-1024 QAM is scheduled (confirm with R1)**

Companies (Huawei, HiSilicon, ZTE, Sanechips, Ericsson, Qualcomm, DOCOMO) propose to confirm RAN2 assumption.

Intel’s view is that scalingFactor-1024QAM-FR1-r17 should be applied if support of 1024 QAM is indicated for the band, if not, legacy scaling factor is applied.

Samsung’s view is that the used scaling factor depends on the Q value in the max data rate calculation.

Ericsson agree that both legacy and new scaling factor can be included in the capability, but which scaling factor is used depends on the configuration of 1024QAM.

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| Companies | Comments |
| Moderator | Moderator view: companies agrees that both legacy and 1024QAM scaling factor can be included in one per CC capability. While which scaling factor is used depends on UE support of 1024QAM, Q value in max data rate calculation, or configured maximum modulation order.  |
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# Conclusion

TBD

# References

1. R1-2300019 (R2-2213343) LS on reduced 1024 QAM capability, Source: RAN2, To: RAN1, RAN2#120, Nov., 2022.
2. R1-2300135 Discussion on reduced 1024QAM capability Huawei, HiSilicon
3. R1-2300366 Discussion on 1024QAM capabilities ZTE, Sanechips
4. R1-2300928 Discussion on LS for reduced 1024 QAM capability Intel Corporation
5. R1-2301228 Discussion on LS related to reduced 1024 QAM capability Samsung
6. R1-2301552 Discussion on RAN2 LS on 1024-QAM UE capability Ericsson
7. R1-2301379 Draft Reply to RAN2 LS on reduced 1024 QAM capability Qualcomm Incorporated
8. R1-2301467 Discussion on LS on reduced 1024 QAM capability NTT DOCOMO, INC.
9. R1-2301755 Draft reply LS on reduced 1024QAM capability Huawei, HiSilicon