3GPP TSG RAN WG1 Meeting #122 R1-2506445
Bangalore, India
25th – 29th August 2025

**Agenda item: 11.4.2**

**Title: FL summary #1 on modulation, joint channel coding and modulation**

**Source: Modulator (Qualcomm Incorporated)**

**Document for: Discussion/Decision**

# Introduction

From [1], for Physical Layer structure for 6GR, we have the following objective

1. Physical Layer structure for 6GR,
	1. Waveforms (OFDM-based) and modulations. 5G NR Waveforms and modulation should be considered for 6GR and is also the benchmark for other potential proposals. [RAN1, RAN4]

The following email thread is assigned for the discussion

[122-R20-6GR-Channel coding and Modulation] Email discussion on Rel-20 6GR- Channel coding and Modulation – Mengzhu (ZTE), Jing(Qualcomm)

* To be used for sharing updates on online/offline schedule, details on what is to be discussed in online/offline sessions, tdoc number of the moderator summary for online session, etc

In this contribution, we summarize the contributions submitted to agenda item 11.4.2 on modulation, joint channel coding and modulation, and discussion during the meeting.

# Discussion

## Discussions on legacy uniform QAM constellations

According to SID [1], 5G NR modulation should be considered for 6GR. There are various proposals to further enhance modulation. The following tries to capture the discussion on the topic.

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| Company | Position |
| Nokia | Coding and modulation in 6G Radio to be based on Gray-Coded QAM and bit-interleaved coded modulation. Constellation sizes from QPSK to at least 1024QAM for DL and from Pi/2 BPSK to at least 256QAM for UL should be adopted as the baseline. |
| Spreadtrum | 5G NR modulation schemes should be adopted for 6GR, including BPSK, pi/2 BPSK, QPSK, 16QAM, 64QAM, 256QAM, 1024QAM for DL and BPSK, pi/2 BPSK, QPSK, 16QAM, 64QAM, 256QAM for UL. Study the feasibility and flexibility of 4096 QAM for DL and 1024 QAM for UL in 6GR day 1. |
| Huawei | NR modulation order should be the baseline of 6GR modulation: * For any other higher modulation order to be adopted by 6G, it must be carefully studied, taking into account the potential challenging requirements.
 |
| CATT | 1024-QAM is recommended for downlink reuse, while uplink modulation should be limited to a maximum of 256-QAM due to UE transmit power constraints. |
| Vivo | The modulation in NR should be the baseline of 6GR modulation design, including* Downlink: QPSK, 16QAM, 64QAM, 256QAM, 1024QAM
* Uplink with DFT precoding disabled: QPSK, 16QAM, 64QAM, 256QAM
* Uplink with DFT precoding enabled: pi/2 BPSK, QPSK, 16QAM, 64QAM
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| Xiaomi | 5G NR modulation, at least including π/2-BPSK, QPSK, 16QAM, 64QAM, 256QAM and 1024QAM, is introduced for 6GR. * The same constellation mapping as used in 5G NR is the baseline.

Regarding the maximum modulation order, up to 1024QAM for DL and up to 256QAM for UL is the baseline for 6GR.* FFS the applicable frequency ranges for 1024QAM.
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| ZTE | QAM constellation can be considered as the starting point for 6GR.Do not support 2048QAM or 4096QAM in 6G Day 1. |
| Sharp | Support OFDM with 1024-QAM for UL and 4096-QAM for DL in different frequency bands. |
| Panasonic | 5G NR modulation schemes (i.e., uniform modulation such as pi/2-BPSK (for UL), QPSK, 16QAM, 64QAM, 256QAM, and 1024QAM (for DL)) can be baseline for 6GR.Any enhancements must demonstrate clear and justified advantages over 5G NR modulation schemes.RAN1 can assess the need to introduce higher order modulation than 5G NR for meeting the higher performance demands expected in 6G. |
| Oppo | As a starting point, modulation scheme in 5G NR (i.e., up to 1024QAM for DL and up to 256QAM for UL following BICM architecture) is the starting point for 6GR modulation scheme.* Other potential enhancements of modulation scheme can be studied considering both performance gain and complexity.
 |
| Lekha | To enable practical deployment of higher order modulation schemes in 6G, advanced adaptive signal processing techniques and intelligent link adaptation strategies should be developed to dynamically select modulation orders based on real-time channel conditions.Shaped Offset Quadrature Phase Shift Keying based Orthogonal Frequency Division Multiplexing (SOQPSK-OFDM) is proposed for 6G to provide bandwidth efficiency, reduced spectral leakage, and Bit Error Rate (BER). |
| Lenovo | Study and evaluate benefits (e.g., BLER, EE gains) vs. caveats (e.g., SE losses) of utilizing π/2-BPSK modulation in 6GR for DL narrowband extended coverage applications.Study for high throughput and high capabilities UEs (e.g., residential FWA) 4096QAM modulation for DL transmissions and characterize its realistic performance (incl. BLER, BER, LLR) and achievable spectral gains over existing 5G NR schemes. |
| Ericsson | Adopt 5G NR uniform QAM constellation as baseline modulation scheme for 6G. Support at least QPSK, 16 QAM, 64 QAM and 256 QAM for uplink.Support at least QPSK, 16 QAM, 64 QAM, 256 QAM and 1024 QAM for downlink. |
| Charters | All 5G NR modulation orders should be considered in 6GR.For 6GR, RAN1 to study higher modulation orders for both DL and UL transmissions (e.g., modulation order of at least 1024 for UL and modulation order(s) 2048+ for DL).RAN1 to study the feasibility of more layers with higher modulation orders to support higher data rates and spectral efficiency requirements in 6GR. |
| InterDigital | At least the following constellations should be supported for 6G.Downlink data channels: QPSK, 16QAM, 64QAM, 256QAM, 1024QAMUplink data channels: pi/2 BPSK (for DFT-s-OFDM), QPSK, 16QAM, 64QAM and 256QAM |
| Apple | For DL QAM, reuse NR modulation scheme up to 1024QAM. For UL QAM, reuse NR modulation scheme up to 256QAM.For UL, support pi/2 BPSK with low PAPR waveform. For modulation evaluation, consider MIMO transmission with TDL/CDL channel model with advanced receiver algorithm.  |
| MTK | Support QAM as the baseline modulation scheme for 6G. Study if higher-order modulations beyond 1024-QAM are needed. |
| CMCC | 2m-QAM defined in 5G NR can be considered as a baseline modulation scheme for the 6GR study when it is designed under OFDM waveforms. |
| Rakuten | The modulation scheme should support a flexible range from 1 coded bit per channel use (BPSK) to 10 coded bits per channel use (1024-QAM) for both uplink and downlink, enabling dynamic adaptation to varying channel conditions. |
| Qualcomm | Support max modulation order at least 1024 QAM for DL and 256 QAM for UL for eMBB in 1st 6G release.* FFS: 4096 QAM for lower MIMO order, e.g., for stationary UE with LoS channel use cases (e.g., FWA).
 |
| AT&T | Study the gains and challenges of supporting higher modulation orders in 6GR, including 4096-QAM and 1024-QAM for PDSCH and PUSCH, respectively. |
| DCM | Study QPSK Rotation and Constellation Shaping for PAPR reduction. Performance gain over UE/gNB complexity should be assessed. |
| CEWiT | Support higher order modulation schemes (E.g., >1024 QAM) at least for FWA devices* 4096 QAM in DL and 1024 QAM in UL

In 6GR, to have a robust control channel coverage, lower modulation (BPSK/Pi/2 BPSK) for the PDCCH carrying DCI should be considered. |

### Round 1 discussion

Proposal 2.1-1

For 6GR DL, uniform QPSK, 16QAM, 64QAM, 256QAM and 1024QAM are supported

* Further study 4096QAM, including challenges, requirements, and solutions

Proposal 2.1-2

For 6GR UL, pi/2-BPSK is supported for DFTs, and uniform QPSK, 16QAM, 64QAM, and 256QAM are supported for both DFTs and CP-OFDM

* Further study 1024QAM, including challenges, requirements, and solutions
* FFS any enhancements for pi/2-BPSK for DFTs, such as …
* FFS any enhancements for QPSK for DFTs, such as …

Please provide your view below:

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| Company | Comments |
| Docomo | Proposal 2.1-1: Support.Proposal 2.1-2: We believe low PAPR modulation scheme should be studied for DFT-S-OFDM, because it is beneficial to extent coverage. Note that several companies are interested in this enhancement. From operator perspective, we believe “low PAPR modulation in realistic modulation order” is more beneficial than “modulation enhancements for high modulation order”. For 1024QAM for UL, we don’t think it is realistic, because target SNR is very high.Hence, we suggest to update to the following:Proposal 2.1-2For 6GR UL, pi/2-BPSK is supported for DFT-S-OFDM, and uniform QPSK, 16QAM, 64QAM, and 256QAM are supported for both DFT-S-OFDM and CP-OFDM* FFS: Enhancement(s) for low PAPR modulation for DFT-S-OFDM.
* ~~Further study 1024QAM, including challenges, requirements, and solutions~~
* ~~FFS any enhancements for pi/2-BPSK for DFTs, such as …~~
* ~~FFS any enhancements for QPSK for DFTs, such as …~~
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## Discussions on shaped constellations

Both probabilistic shaping and geometric shaping receive strong support for study from the contributions. An evaluation campaign will be needed before we can make a decision.

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| Company | Position |
| Spreadtrum | Not support non-uniform constellation in 6GR. |
| Huawei | The following aspects need to be studied for evaluation of modulation enhancements for 6GR:• Evaluation shall be performed under various fading channels, such as TDL, in addition to AWGN only;• Both link-level and system-level simulations shall be performed:• Evaluation shall be thoroughly investigated different combinations of QAM modulation orders and code rates; • For a fair comparison, all schemes shall be evaluated using the optimal combination of modulation order and code rate, targeting the best possible BLER performance;• The complexity of any proposed scheme shall be investigated, at least including:• Computational complexity;• Storage complexity;• Algorithm parallelism and its impact on throughput and latency. |
| CATT | It is recommended that constellation shaping is considered when the spectral efficiency is above 3 bits per two dimensions (bits/2D), or the constellation size is not less than 64. |
| Vivo | Support to study the feasibility and performance of geometric constellation shaping. |
| Xiaomi | Support at least the following design metrics for evaluating any potential new modulation schemes for 6GR. * Spectrum efficiency, PA efficiency, complexity, coverage and scalable and forward compatible design for diverse device types.

Any potential new modulation schemes for 6GR should not be pursued unless well justified, especially for those would impact hardware implementations. |
| Samsung | Study both geometric and probabilistic shaping for enhancing the performance. Including 1D-NUC in a dedicated study will enable the standard to select the most suitable shaping approach, balancing performance and complexity requirements. |
| ZTE | Proposal 3: The following metrics should be evaluated for shaping modulation* BLER performance for both initial transmission and re-transmission with varied TBS and spectrum efficiency
* Throughput
* EVM
* Complexity

NUC modulation for 6GR can be studied and considered.The following issues for PAS can be studied and evaluated:* Impact on coding chain
* Serial process and storage caused by current DM algorithms
* Performance
 |
| Tejas | Study Non-Uniform Constellation for 6GR |
| Panasonic | RAN1 can assess the need to introduce non-uniform constellation without increasing implementation complexity for PAPR/CM reduction and/or spectral efficiency improvement. |
| Oppo | Study the following modulation schemes as potential enhancement for modulation scheme in 6GR:* GS-based modulation;
* PS-based modulation;
	+ PAS-based modulation as one implementation method of PS.
* Note: performance gain, spec impact and hardware complexity should be taken into account for further study.
 |
| Lenovo | Study and evaluate trade-offs between performance gains and implementation complexity associated with constellation shaping. The performance metrics can include spectral efficiency, reliability (e.g., LLR, BLER/BER), and energy efficiency/power attributes (e.g., PAPR). Characterize transceiver design impacts, such as the need for additional modules and/or modification of existing processing blocks. |
| Ericsson | Modulation schemes based on constellation shaping appear to show gains in ideal settings but thorough evaluation considering realistic channels, transceiver impairments, and hardware settings are needed.It is essential to involve RAN4 early in discussions related to a new modulation scheme beyond the 5G schemes. RAN1 cannot unilaterally select a new modulation scheme without checking the practical considerations with RAN4. |
| InterDigital | Study PCS and GCS as candidates for 6G joint coding and modulation with uniform QAM of NR as the baseline |
| LGE | RAN1 should study the use of Non-Uniform Constellation for 6G |
| MTK | RAN1 to study geometric shaping for higher-order modulations, taking into consideration the operation over a range of SNR and channel conditions.RAN1 to study probabilistic constellation shaping for higher-order modulations.For constellation shaping, evaluate the shaping gain for various NR SE settings and shaper block sizes.For constellation shaping, evaluate the shaping gain for AWGN channel and MIMO fading channels. Evaluations under AWGN channel can serve as the starting point.For constellation shaping, evaluate its complexity impacts on the transmitter, the receiver, and MIMO operations. |
| ETRI | RAN1 to study and investigate the benefits of a non-uniform constellation.RAN1 to consider relevant channel conditions for intended 6G use cases (e.g., energy saving, NTN) when designing non-uniform constellations. |
| CMCC | The following aspects should be carefully considered for the study of modulation schemes for 6GR:* Universality over varying channel conditions
* Integration with channel coding
* Receiver implementation complexity
* Feasibility validation via EVM-like metric with RAN4 involved
 |
| Sony | RAN1 should study non-uniform SNR-dependent constellations that offer improved performance compared with legacy constellations.RAN1 should study the gains versus complexities of 1D and 2D constellation shaping.Proposal 4: RAN1 should consider constellation shaping using criteria other than code rate or SNR. |
| Rakuten | Explore joint channel coding and modulation schemes that may lead to a reconfiguration of the current constellation structure used in NR to enhance spectral efficiency, provided that suitable decoding algorithms exist to maintain acceptable receiver complexity. |
| Qualcomm | Study probabilistic shaping techniques for 6GR. |
| AT&T | Study the performance of non-uniform constellations based on geometric shaping and/or probabilistic shaping for 6GR air interface, focusing on high-order modulation values. |
| DCM | Study QPSK Rotation and Constellation Shaping for PAPR reduction. Performance gain over UE/gNB complexity should be assessed. |

### Round 1 discussion

Discussion 2.2-1

For 6GR study, each company is encouraged to provide details for the PS/GS schemes considered for evaluation and comparison, including at least the following

* Probabilistic shaping
	+ Target probabilistic distributions, each with the corresponding spectrum efficiency and target SNR
	+ Relationship between shaping and FEC in transmit and receive chains
	+ PS algorithm details (for example, source coding based, channel coding based, etc) and parameters (such as block length)
* Geometric shaping
	+ Target constellation shapes (1D-NUC, 2D-NUC, etc), each with the corresponding spectrum efficiency and target SNR
	+ GS mapping details, such as bit to constellation mapping
	+ Note: AI/ML can be used to generate the constellation, but for evaluation purposes, only the resulting constellation needs to be provided.

Please provide your view below:

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| Company | Comments |
| Docomo | For geometric shaping, the following 16QAM constellation shaping for low PAPR may be regarded as one of geometric shaping or may be regarded as enhancement of 16QAM/256QAM. The above Discussion 2.2-1 does not cover low PAPR aspect.(Question to FL) Is it correct understanding that all proposals for low PAPR modulation should be discussed under FFS of Proposal 2.1-2?Figure 3. Example of 16QAM-CS (selecting pseudo 16APSK points from 256QAM). |
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Proposal 2.2-2

Geometric shaping (GS) and probabilistic shaping (PS) evaluation and comparison should consider at least the following:

* BICM capacity of the proposed probabilistic shaped and geometric shaped constellations
* BLER performance under AWGN channel (as starting point) and fading channel (SIMO and MIMO)
	+ For MIMO channel evaluation, need to provide assumptions on MIMO precoder used (e.g., open loop MIMO or SVD based precoding) and receiver assumed (e.g., MMSE or rML)
* Transmitter and receiver complexity and storage requirements

Please provide your view below:

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| Company | Comments |
| DOCOMO | For probabilistic shaping, specification impact to channel coding should be assessed in addition to transmitter/receiver complexity. |
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## Discussions on joint channel coding and modulation

Multiple proposals received in the contributions submitted to 11.4.1, as summarized in the table below. In this section, we will treat proposals on joint channel coding and modulation only.

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| --- | --- |
| Company | Position |
| Spreadtrum | No support joint channel coding and modulation in 6GR.Note: it is not precluded to discuss “joint channel coding and modulation” use case in 6G AI. |
| Huawei | Study enhanced adaptive modulation and coding schemes designed to select the optimal MCS based on channel characteristics for performance improvement. |
| Vivo | At least for high-order modulation, consider the joint coding and modulation design to better leverage the unbalanced capacity of different bit subchannels in QAM modulated symbols.Further study the MGCM design as a solution for joint coding and modulation, considering at least the following two use cases:* Two SCH data blocks coded by LDPC using different coding rates
* Multiplexed UCI and UL-SCH data blocks, respectively coded by Polar and LDPC
 |
| Xiaomi | Reuse the 5G NR BICM framework in 6GR for coding-modulation concatenation. |
| Samsung | QC-block interleaver for BICM |
| Sharp | Study Joint Coding and Modulation (JCM) with Trellis-Coded Modulation (TCM) as baseline.Study Joint Source and Channel Coding (JSCC) methods including Unequal Error Protection (UEP) of different information bits. |
| Oppo | Joint optimization of channel coding and modulation can be studied, with taking into account the performance gain, complexity, robustness and impact to processing time for modulation and channel coding. |
| Lekha | Learning based joint channel coding and modulation are crucial for 6G systems, where low latency and high data rates are essential. Several applications including semantic communications are found to benefit from the joint modulation and coding scheme. |
| LGE | RAN1 should study the use of mixed modulation for 6G |
| Sony | RAN1 should consider adopting DBICM in 6G due to its improved performance and limited spec impact.RAN1 should consider adopting T-B DBICM in 6G. |
| Rakuten | Subject to the use of non-capacity-achieving channel codes, consider supplementing Gray-code labelling with additional modulation labelling schemes that align more effectively with joint demodulation and decoding strategies, potentially improving overall system performance. |
| Qualcomm | Study LDPC code enhancements for higher order modulation (including constellation shaping) in 6GR.Study joint modulation and coding design for iterative receivers, such as iterative decoding, demodulation, channel estimation, and interference cancellation in 6GR, if compelling use cases can be identified to justify the complexity & performance tradeoffs. |
| AT&T | Joint coding and modulation is not discussed as part of the modulation for 6GR interface agenda.* FFS: whether it is discussed under AI/ML study for 6GR air interface.
 |

To summarize, we have the following opinions or proposals on joint channel coding and modulation collected from the contributions:

* Reuse NR BICM and no additional joint channel coding and modulation designs supported (other than what will be discussed in 6G AI) – Spreadtrum, Xiaomi, AT&T
* Study MGCM design for high-order modulation - vivo
* QC-block interleaver for BICM – Samsung
* Joint coding and modulation with TCM – Sharp
* Mixed modulation with adjustable mixing ratio – LGE
* Tail-biting Delayed-BICM – Sony
* Alternative modulation labelling scheme - Rakuten
* LDPC enhancements for higher order modulation – Qualcomm
* Joint modulation and coding design for iterative receiver – Qualcomm
* Rotated QPSK for PAPR reduction - DCM

### Round 1 discussion

Consider there are many proposals in this area and many proposals are related to other sub-agenda items, here are some suggestions

* For proposals targeting PAPR reduction and do not involve fundamental modulation constellation change, may want to continue discussion in waveform sub-agenda item, to be compared with other PAPR reduction proposals there.
* For proposals requires LDPC code change or depends on LDPC code design, they should be discussed in channel coding sub-agenda item.
* In this sub-agenda item, we focus the discussion on how to map coded bits to modulation symbols, such as BICM enhancements, modulation labelling enhancements, multi-level coding, etc.

Please provide your view below:

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| Company | Comments |
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# References

1. RP-251881, New SID: Study on 6G Radio
2. R1-2505130, On Modulation for 6G Radio Air Interface, Nokia
3. R1-2505175, Discussion on modulation, joint channel coding and modulation for 6GR, Spreadtrum, UNISOC
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5. R1-2505311, Modulation for 6GR, CATT
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9. R1-2505587, Discussion on modulation and BICM for 6GR, Samsung
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14. R1-2505760, Discussion on modulation, joint channel coding and modulation for 6GR, OPPO
15. R1-2505784, Modulation, joint channel coding and modulation for 6GR Interface, Lekha Wireless Solutions
16. R1-2505796, Discussion on 6GR modulation, Lenovo
17. R1-2505825, Modulation for 6G, Ericsson
18. R1-2505830, Modulation for 6GR interface, Charter Communications, Inc
19. R1-2505839, Modulation, joint channel coding and modulation for 6GR air interface, InterDigital, Inc.
20. R1-2505857, Discussion on modulation for 6GR, LG Electronics
21. R1-2505916, On modulation for 6G air interface, Apple
22. R1-2506023, Modulation for 6GR interface, MediaTek Inc.
23. R1-2506068, Discussion on 6GR modulation, ETRI
24. R1-2506100, Discussion on modulation schemes for 6GR interface, CMCC
25. R1-2506119, Discussions on joint channel coding and modulation for 6GR, Sony
26. R1-2506143, Discussion on Modulation and Joint Channel Coding and Modulation for 6GR Air Interface, Rakuten Mobile, Inc
27. R1-2506221, Modulation, joint channel coding and modulation for 6GR, Qualcomm Incorporated
28. R1-2506236, Views on Modulation for 6GR Interface, AT&T
29. R1-2506242, Views on Modulation for 6GR Air Interface, DeepSig Inc
30. R1-2506309, Discussion on Modulation, NTT DOCOMO, INC.
31. R1-2506362, Modulation Schemes for 6G, CEWiT, IITM, Tejas, IITK