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.

|  |  |
| --- | --- |
| 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 |
| 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. |
| 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, 1024QAM  Uplink 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 (replaced)

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

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

Proposal 2.1-2 (replaced)

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:

|  |  |
| --- | --- |
| 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 2.1-2  For 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 …~~ |
| AT&T | Support. Enhancements for modulation over DFT-s-OFDM should be based on study aspects of the 6G waveform, e.g., whether DFT-s-OFDM is supported for rank >1 |
| Xiaomi | Proposal 2.1-1:  Regarding 4096QAM, we are doubt of its feasibility and whether there is any realistic scenario could satisfy the stringent requirements. So, we prefer to delete the sub-bullet. In case it is kept, at least we need to also study the applicable scenarios.   * Further study 4096QAM, including scenarios, challenges, requirements, and solutions   Proposal 2.1-2  Our understanding of the proposal is only for UL data. For PUCCH, BPSK is also supported in NR, and this can be separately discussed.  Regarding 1024QAM, similar views as DOCOMO.  Regarding the two sub-bullets for pi/2 BPSK and QPSK, except for PRPR reduction which is to be discussed under waveform sub-agenda suggested in Section 2.3.1, we are not sure what other enhancements could be. More clarification is needed.  In addition, some of the sub-bullets start with ‘Further study’ while others with ‘FFS’. We are not sure whether it is intended to do so? If not, it’s better to align the wording to avoid any potential confusion. |
| Nokia | Proposal 2.1-1: Support  Regarding 4096QAM: impact of the stringent requirements, e.g EVM, SNR, PAPR etc. need to be carefully taken into account  Proposal 2.1-2: Support.  Regarding 1024QAM: impact of the stringent requirements, e.g EVM, SNR, PAPR etc. need to be carefully taken into account  Regarding the enhancement, it isn’t clear which enhancements are meant. Is it about PAPR? Then better to be discussed under waveform AI. |
| Rakuten | Proposal 2.1-1: We want to include BPSK for further study.  Proposal 2.1-2: Support. |
| Spreadtrum | Proposal 2.1-1: Support.  Proposal 2.1-2: Support. |
| OPPO | Proposal 2.1-1 support in principle. Regarding the study on 4kQAM, the study should consider the hardware requirement, like EVM. It also need to consider the applicability in real field deployment, i.e., how much chance this 4kQAM can be used due to the channel condition.  Furthermore, the ‘solution’ in further study is not clear. Does it mean the solution for 4kQAM  Proposal 2.1-1  For 6GR DL, uniform QPSK, 16QAM, 64QAM, 256QAM and 1024QAM are supported   * Further study 4096QAM, including challenges, requirements, applicability in real-field deployment and benefits in practical scenarios and solutions   Re Proposal 2.1-2: support the main bullet. And we also have concern on 1024QAM for UL considering the tight requirement which can be hardly met for UL. And we also think study low PAPR modulation is beneficial and critical for boosting the UL performance, which has been a bottleneck for long time. We are ok with the revision by DCM. |
| vivo | Suggestion on the wording for the bullets on 4k and 1k  DL: Further study the feasibility and performance of 4096QAM  UL: Further study the feasibility and performance of 1024QAM  For enhancements on pi/2-BPSK for DFTs, it seems to be overlapped with waveform. It’s better to have a clear guidance on where to discuss this particular issue. |
| ETRI | Proposal 2.1-1: Support.  Proposal 2.1-2: Support. |
| Tejas | For 6GR DL, we agree with the proposed further study for 4096QAM including its challenges, requirements and solutions.  For 6GR UL, we agree on further study of 1024 QAM including its challenges, requirements and feasible solutions. |
| ZTE, Sanechips | * **For Proposal 2.1-1**:   Support reuse uniform QPSK, 16QAM, 64QAM, 256QAM and 1024QAM for 6GR DL. For higher modulation order, such as 4096QAM, we think the EVM issues and high receive SNR requirement is different to fulfil in practical. No need to consider 4096QAM.   * **For Proposal 2.1-2**:   For uplink transmission, we think enhancement for pi/2-BPSK for DFTs should be considered for low PRPR modulation. We are ok to discuss it waveform agenda item. For other legacy QAM constellation for uplink, we need to keep the same modulation as 5G NR. For UL, we are okay to study 1024QAM with the consideration of EVM issues. |
| Ericsson | **Proposal 2.1-1:**  Support.  **Proposal 2.1-2:**  Support in principle.  Since the pi/2-BPSK and other low PAPR modulation proposal have dependency on waveform discussion related to DFT-s-OFDM, we should put the pi/2 BPSK also in FFS. We support to study other low PAPR related enhancements. |
| Panasonic | Proposal 2.1-1: Support  Proposal 2.1-2: We support DOCOMO’s update proposal with the update from “low PAPR modulation” to “low MPR modulation” or something. As we commented in offline of waveform, low PAPR does not always allow power boosting (or the amount of power reduction less = MPR reduction). Although PAPR can represent some, the final target is not low PAPR but low MPR. |
| CMCC | The “uniform QPSK, …” may lead misunderstanding. If we support uniform 64QAM, does it mean we do not support 64QAM based non-uniform modulation? For a given modulation order, supporting both uniform and non-uniform modulation is not preferred from our perspective. |
| Lenovo | Proposal 2.1-1: Support with additional considerations  Proposal 2.1-1  For 6GR DL, uniform QPSK, 16QAM, 64QAM, 256QAM and 1024QAM are supported   * Further study 4096QAM, including challenges, requirements, and solutions * Further study /2-BPSK for coverage enhancements, including benefits and caveats   Proposal 2.1-2: Share similar view as Docomo and support 2.1-2 with Docomo revisions. |
| IDC | Proposal 2.1-1: Support reuse of QPSK, 16QAM, 64QAM, 256QAM, and 1024QAM as the DL baseline. Regarding 4096QAM, we are open to study its feasibility including scenarios and practical requirements, which should be carefully assessed.  Proposal 2.1-2: Support pi/2-BPSK for DFT-s-OFDM, and QPSK through 256QAM as the UL baseline. Similar to several other companies, we think 1024QAM for UL deserves further study, but we note the practical challenges for realistic UE conditions. |
| CEWIT | For Proposal 2.1-1: We are fine to study 4096 QAM for DL, especially for rank deficient channel scenarios with high data rate requirement (E.g., FWA). Further, we propose to study lower order modulation schemes (E.g., bpsk and pi/2 bpsk) in DL, especially for control channels to make it more robust (E.g., for 6G large cell deployments, NTN, etc.). Accordingly, proposal can be modified as:  Proposal 2.1-1  For 6GR DL, pi/2-BPSK, BPSK, uniform QPSK, 16QAM, 64QAM, 256QAM and 1024QAM are supported   * Further study 4096QAM, including challenges, requirements, and solutions   For Proposal 2.1-2: We are fine to study 1024 QAM for UL, especially for rank deficient channel scenarios with high data rate requirement (E.g., FWA). |
| MediaTek | Offset-QPSK (O-QPSK) is a well-known modulation scheme that offers superior PAPR property without sacrificing performance. It can be considered as a modulation candidate for DFT-s-OFDM (or as an enhancement for pi/2-BPSK and/or QPSK for DFT-s-OFDM). Technical aspect: at a given sampling time instance, O-QPSK has a 50% chance of 90-degree phase change and a 50% chance of 0-degree phase change compared to 100% chance of 90-degree phase change for pi/2-BPSK, leading to a lower PAPR. |
| Samsung | We generally agree with the proposed modulation orders for both DL and UL. However, at this stage we do not agree with restricting the constellation shape to uniform QAM. We suggest that the statements be revised to specify modulation orders only, without fixing the constellation shape. |

Proposal 2.1-3

For 6GR DL, uniform QPSK, 16QAM, 64QAM, 256QAM and 1024QAM are supported with CP-OFDM

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

Proposal 2.1-4

For 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

* Further study 1024QAM, including applicable scenarios, challenges, requirements, and solutions
* FFS any enhancements targeting lower PAPR based on pi/2-BPSK for DFT-s-OFDM
  + TBD: This is studied in waveform AI or here
* FFS any enhancements targeting lower PAPR based on QPSK for DFT-s-OFDM
  + TBD: This is studied in waveform AI or here

## 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.

|  |  |
| --- | --- |
| 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 (replaced)

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:

|  |  |
| --- | --- |
| 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). |
| AT&T | Prefer adding the following:   * Scalability for different modulation order (number of modulation points) * Complexity at both Tx/Rx sides |
| Xiaomi | The proponents should first provide details of their PS/GS schemes. For other companies, after knowing the detailed schemes, can provide more focused evaluation and comparison on the proposals. |
| Nokia | These kinds of modulations could be only considered after showing a clear gain/advantage compared with the uniform QAM under realistic conditions considering ACM, implementation and MIMO detection complexity. The benefit shall be visible also in SLS under realistic traffic patterns. It is also to be clarified what the purpose of these modulations is: improving PAPR, spectral efficiency? We seek also clarification whether these modulations are targeting UL, DL, or both? |
| OPPO | For both PS and GS, the transmit structure of transmit chain and receive chain shall be provided for the proposed algorithm, instead of the algorithm itself.  Apart from the detailed algorithm and parameters, the complexity should also be provided for initial comparisons. Additionally, since 1D-NUC and 2D-NUC in GS and dmap in PS may be optimized in specific channel assumption, it is also recommended to disclosure channel condition for optimizing that. |
| ETRI | Support.  Also agree that only resulting constellations are needed whether they are designed by AI/ML or non-AI/ML (geometric shaping) |
| Tejas | Probabilistic and geometric shaping should be studied for performance improvement. Implementation details such as log-likelihood ratio and decoder specifications should be clearly specified for each shaping method used.  Following this, The trade-off between performance and implementation complexity, considering channel conditions, MIMO, TB size, and transmitter and receiver design, should be carefully analysed to determine the most effective constellation shaping approach. |
| CMCC | How does the PS algorithm details relate to source coding? |
| Lenovo | Support |
| IDC | We agree with the request for proponents to provide detailed descriptions of their PS/GS schemes, including distribution assumptions, mapping methods, and relationship to FEC processing. For evaluation, it is useful to clarify whether the aim is primarily PAPR/MPR reduction, spectral efficiency gain, or coverage improvement, etc. Considering that PCS and GCS can be the candidates for study with NR uniform QAM as the baseline, we see value in assessing both approaches under realistic channel conditions. |
| Samsung | We consider the two candidate shaping techniques – probabilistic shaping (PS) and geometric shaping (GS). For each technique, we generally agree with the proposed details, with some refinements:  Probabilistic Shaping (PS)   * Target probability distributions specified for each spectrum efficiency (defined by code rate and modulation order) * Relationship between shaping and FEC in both transmit and receive chains * Use of fixed-input-length to fixed-output-length distribution matching techniques * PS algorithm details and parameters (e.g., source-coding-based or channel-coding-based, block length, etc.)   Geometric Shaping (GS)   * Target constellation shapes for each spectrum efficiency (code rate and modulation order), such as 1D-NUC and 2D-NUC * Details of bit-to-symbol mapping (labelling) |

Proposal 2.2-2 (replaced)

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:

|  |  |
| --- | --- |
| Company | Comments |
| DOCOMO | For probabilistic shaping, specification impact to channel coding should be assessed in addition to transmitter/receiver complexity. |
| AT&T | Evaluation considers scenarios with different numbers of layers, i.e., verify whether modulation scheme remains common across layers, and with a common RI value |
| Xiaomi | On top of above metrics, we think it needs to at lest also consider the following aspects:   * PAPR/CM/MPR, since some of the schemes may increase the PAPR. * Latency, as some of the schemes require serial processing and introduce additional latency. * Robustness, which is to ensure the proposed scheme could ensure good performance for all the evaluated cases. * Hardware implementation impacts. Any impacts can only be justified with sufficient performance gain. * Specification impacts. This is to better understand the impacts on other aspects, e.g., coding chain and TBS/CB determination etc.   As for the evaluation channel, we don’t think AWGN should be the starting point as fading channel is equally (if not more) important. |
| Nokia | For PS, a complexity assessment on the transmitter side shall be provided particularly regarding the segmentation block length and the trade-off between complexity and quantization of the wished probabilities. Furthermore, we need to address the behaviour of PS at high SNR as it seems that there must be a fall back to uniform QAM to avoid having losses compared with uniform QAM of the same order. In any case, the evaluation shall be based on realistic channels (not AWGN) and include multi-layer scenarios. It is also understood that linear receivers cannot benefit from probabilistic shaping.  Simulations assumptions need to be further clarified, e.g. under ACM conditions. |
| Rakuten | Agree in principle and suggest some wording changes:  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)   + FFS MU-MIMO   Transmitter and receiver complexity and storage requirements |
| Spreadtrum | Constellation shaping technique will also affect the complexity of CSI calculation. This aspect also needs to be evaluated, and suggest the following change with red.   * Transmitter and receiver complexity and storage requirements and the complexity of CSI calculation   Regard the fading channel, multiple channel types with diverse set of parameters (e.g., speed, delay spread, …) should be considered and evaluated |
| OPPO | Ok to study both PS and GS, however, the proposal is not well formulated.  For the evaluation, (1) should consider both AWGN and fading channel (2) various evaluation metrics: BLER, PAPR, impact on processing latency, transmit and receive complexity, storage requirement, specification effort. (3) SISO should be the baseline and MIMO and MU-MIMO can be considered. (4) Impact to other components in the baseband, for example scramble.  The reason for MIMO shall be optional is because 6GR MIMO is not started yet and we do not have a good baseline for that.  Also, the issue of serial processing for PS may also be further studied, where the concurrency/latency-related metrics per code block can be considered. |
| vivo | On BLER performance, we suggest to treat AWGN and fading channel at same level, i.e.,   * BLER performance under AWGN channel ~~(as starting point)~~ and fading channel (SIMO and MIMO)   We suggest to add the following bullets as study aspects   * Level of potential impact on the current 5G coding chain * Coexistence issue with other modules currently used, e.g., scrambling, interleaving * Throughput/latency of the whole coding chain |
| ETRI | Support.  Different target BLER can be considered depending on use cases. |
| Tejas | We support the given proposal. |
| ZTE, Sanechips | We have 5 comments for evaluation assumption for shaping modulation:   1. Simulation BLER curve is enough. BICM capacity is not needed. BICM capacity characterizes the theoretical performance bound under infinite code length assumption over ergodic channels (e.g., AWGN and i.i.d. Rayleigh fading channels). It should be noted that this differs fundamentally from the fading channel models adopted in 3GPP evaluation methodologies. 2. We support evaluation on both AWGN channel and fading channel (SIMO and MIMO). 3. For MIMO channel evaluation, we support to provide assumptions on MIMO precoder used, including closed-loop MIMO, since closed-loop MIMO is a practical way for implementation. 4. Towards MIMO receiver, we think we need to decouple the assumption on receiver for DL and UL. 5. From the complexity evaluation assumption, the impact on current channel coding chain, including code block segmentation, rate matching, scrambling, interleaving and throughput, performance of initial and re-transmission should be considered. Besides, we think the overall receiver complexity should be considered, comprising demodulation complexity, decoding complexity and complexity of distribution de-matcher should be jointly considered. |
| Ericsson | For evaluation we can start with link level simulation, and if RAN1 reach consensus on candidates for 6G modulation based on convincing simulation results, we should move on to system level simulations.  Practical and realistic system settings should be reflected in the evaluation.  Typical settings include at least:  1. Tx and RX antenna setting: 32/64/128 Tx ports, 4/8 Rx ports.  2. Rank setting (not MIMO) , need to include different RANKs.  3. Fading channel including TDL/CDL model, considering LOS/NLOS channel. For TDL model, correlation, delay spread.  4. SISO/MIMO Precoder: **close loop** MIMO or SVD based  5. Allocation RBs/ uniformed bits size.  6. UE speed: 3km/h, 10km/h, 100km/h  7. Real channel estimation/ ideal channel estimation  8. Receiver algorithms: MMSE based receiver as baseline  9. Maximum number of HARQ retransmission: E.g, 4.  10. RAN4 impact, e.g., EVM assumption, MPR/A-MPR assumption  System level simulation shall be added once RAN1 has aligned the link level simulation results.  How to compare the complexity, hardware impact, and latency are still open issues. |
| Panasonic | On BLER performance, we share the similar view to vivo. It is better to treat AWGN and fading channel at same level. |
| CMCC | The comparation needs to consider the implementation complexity and the feasibility validation via EVM-like metric.  Regard the BICM, we wonder how to attribute the gain achieved through interleaving between encoding and modulation: should it be classified as coding gain or modulation gain? |
| Lenovo | To have a fair evaluation of the gains and the incurred costs, we need to know/collect more details of PS and GS, such as: possibility of parallel vs. serial processing and its impact on Latency, PAPR, Hardware implementation aspects, how the gains and complexity scale with constellation size, any possible impact to other baseband modules etc. |
| IDC | We support the proposed evaluation framework covering BICM capacity, BLER in AWGN and fading channels, and complexity at Tx/Rx. We suggest giving equal weight to AWGN and fading channel evaluations, as both provide valuable insights. For MIMO, it is important to clarify the assumed precoding and receiver models (e.g., MMSE, rML). We also recommend that PCS and GCS be compared directly against the NR uniform QAM baseline to assess shaping gains in a fair way, and that the implementation aspects such as distribution matcher complexity be included in the study. |
| MediaTek | * Since BICM capacity can only serve as an upper bound of the achievable rate and different shaping schemes may have different performance gap w.r.t. the capacity bound, we suggest to use BLER as the major performance evaluation metric. * For BLER evaluation, a corresponding FEC (e.g., NR LDPC code) should be specified. * The performance of constellation shaping might degrade due the inaccurate estimation of SNR or channel. We should also be careful if the shaping gain obtained by either GS or PS is very sensitive to perfect channel or SNR estimation. |
| Samsung | We generally agree with the proposal, though some additional details may be needed:   * We support the evaluation of BICM capacity for probabilistic- and geometric-shaped constellations. However, it is essential to reflect the entropy loss due to the non-uniform source distribution in the analysis. * We agree with evaluating BLER over SISO-AWGN (as a starting point) and fading MIMO channels. At the same time, the receiver algorithm assumptions (e.g., MMSE, rML) should be clearly specified. * We also agree that transmitter and receiver complexity must be considered. In addition, 5G–6G commonality aspects should be taken into account to ensure forward compatibility. |

Proposal 2.2-3

Geometric shaping (GS) and probabilistic shaping (PS) for CP-OFDM 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, needs to provide assumptions on MIMO precoder (e.g., open loop MIMO or closed loop MIMO such as SVD) and receiver assumed (e.g., MMSE or rML)
    - FFS MU-MIMO
  + For fading channel evaluation, needs to provide assumptions on rate adaptation (e.g, fixed MCS, or with closed loop rate control)
* Transmitter and receiver complexity, storage requirements, and impact to CSI computation
* Potential issues with respect to spec impact
* FFS: System level simulations

Discussion 2.2-4

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 for CP-OFDM
  + Target probabilistic distributions, each with the corresponding spectrum efficiency and target SNR
  + Relationship between shaping and FEC, and other modules (such as scrambling), 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 for CP-OFDM
  + 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 point mapping
  + Note: AI/ML can be used to generate the constellation, but for evaluation purposes, only the resulting constellation needs to be provided.

Proposal 2.2-5

Geometric shaping (GS) [and probabilistic shaping (PS)] for DFT-s-OFDM evaluation and comparison should consider at least the following:

* PAPR/CM of the resulting waveform
* BLER performance under AWGN channel and fading channel (SIMO)
  + For fading channel evaluation, needs to provide assumptions on rate adaptation (e.g, fixed MCS, or with closed loop rate control)
* Transmitter and receiver complexity and storage requirements

Discussion 2.2-6

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

* Probabilistic shaping for DFT-s-OFDM
  + Target probabilistic distributions, each with the corresponding spectrum efficiency and target SNR
  + Relationship between shaping and FEC, and other modules (such as scrambling), 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 for DFT-s-OFDM
  + 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 point mapping
  + Note: AI/ML can be used to generate the constellation, but for evaluation purposes, only the resulting constellation needs to be provided.

## 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.

|  |  |
| --- | --- |
| 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, constellation point labelling enhancements, multi-level coding, trellis coded modulation, etc.

Please provide your view below:

|  |  |
| --- | --- |
| Company | Comments |
| AT&T | Prefer to defer these discussion until outline of each of channel coding and modulation are discussed in the respective agendas |
| Xiaomi | Ok with the suggestions in general. Can further re-visit later whether any adjustment is needed. |
| Nokia | Some of the suggested techniques should be discussed under coding, some under waveform and some under AI. Categorization discussion might be a good way to start. |
| Spreadtrum | Similar view with AT&T. Propose to postpone the discussion until we have a conclusion on modulation and channel coding. |
| vivo | We agree on FL’s assessment on the scope of this agenda, i.e., we focus the discussion on how to map coded bits to modulation symbols, such as BICM enhancements, modulation labelling enhancements, multi-level coding, etc.  Following this principle, we suggest to form and discuss proposals to list candidate solutions, design targets/use cases, evaluation assumptions, etc.  We don’t think we need to postpone the discussion. This is not relevant with constellation shaping. As long as we have P2.1.1 and P2.1.2, we can start to discuss these issues based on these baselines. |
| ETRI | Support.  We may need to observe if there is any PAPR impact when PS/GS being used (e.g. UL DFT-s-OFDM) |
| ZTE, Sanechips | For PAPR reduction, we are okay to discuss it in waveform sub-agenda item. |
| Ericsson | What is the modulation labelling enhancement? |
| Panasonic | We think sequence-based DMRS-less transmission for small information block length could be a kind of joint coding and modulation. We would like to clarify where does such a proposal fit on the agenda. |
| CMCC | The PAPR evaluation method among different companies should be aligned first. We find the PAPR values of traditional modulations (e.g., BPSK/QPSK/QAM) are different among companies.  ZTE:  PAPR_0808  Figure 12 PAPR for modulation schemes  DOCOMO: |
| Lenovo | Okay with the suggested structuring of the proposals – this can be further refined, if necessary, after the scopes of the respective agenda items (coding, modulation, waveform) are clearer. |
| IDC | Support in principle the moderator’s suggestion to focus this sub-agenda on coded-bit to modulation mapping aspects (e.g., BICM enhancements, labeling, multi-level coding), while leaving PAPR-only schemes to waveform discussions and LDPC-dependent designs to channel coding. We think PCS/GCS can be mainly studied in this agenda item as candidates for joint coding and modulation. At this stage we are open to study various approaches, but emphasize that comparisons should use NR modulation as the baseline and include both performance and complexity perspectives. |
| OPPO | Given the tight interaction between channel coding and modulation, prefer to firstly discuss the categorization of joint modulation and coding issues. Additionally, a guideline may be needed for both coding agenda and modulation agenda to better coordinate the multiple ways ahead, i.e. shaping with NR coding, NR modulation with enhanced coding, shaping with enhanced coding, etc. |
| MediaTek | The intension is well understood, but since the agenda item is meant to discuss joint modulation and coding design, most proposals here involve both modulation and FEC, and it may be hard to separate the discussion.  For example, some constellation shaping schemes require specific bit to symbol mapping structure that may restrict the BICM interleaver design and affect the FEC performance. |
| Samsung | We generally agree with the proposal. In this sub-agenda, it would be more appropriate to focus the discussion on bit-to-symbol mapping methods, including coded modulation (CM), bit-interleaved coded modulation (BICM) and multi-level coding (MLC).  In addition, the design of bit-to-symbol mapping can only take place after the coding schemes (e.g., LDPC, polar codes) and modulation methods (constellations) are finalized. Since it is not practical to mix all sub-agenda items together, the discussion on bit-to-symbol mapping may need to be postponed until those prior decisions are made. |

# 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
4. R1-2505186, Modulation for 6GR air interface, Huawei, HiSilicon
5. R1-2505311, Modulation for 6GR, CATT
6. R1-2505419, Discussion on Modulation for 6GR air interface, vivo
7. R1-2505466, Discussion on modulation for 6GR interface, Xiaomi
8. R1-2505481, Discussion on modulation related aspects for 6GR air interface, TCL
9. R1-2505587, Discussion on modulation and BICM for 6GR, Samsung
10. R1-2505606, Discussion on modulation for 6GR, ZTE Corporation, Sanechips
11. R1-2505637, Performance of NU-QAM with 5G-NR LDPC codes, Tejas Network Limited
12. R1-2505696, Considerations on joint channel coding and modulation, Sharp
13. R1-2505703, Discussion on modulation for 6GR air interface, Panasonic
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