**3GPP TSG RAN WG1 #122 R1-250xxxx**

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Agenda Item: 11.4.1

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Title: FL summary #2 for AI 11.4.1 on Control Channel Coding

Document for: Discussion/Decision

# Introduction

The scope of 6G study was agreed to in RAN# 108 meeting. According to study item description in [1], the physical layer structure for 6GR will be the main focus for RAN1.

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| --- |
| 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]    2. Frame structure, including compatibility with 5G NR to allow for efficient 5G-6G Multi-RAT Spectrum Sharing (MRSS). [RAN1]    3. Channel coding, using LDPC and Polar Code as baseline, considering applicable extensions to satisfy 6G requirements and characteristics with acceptable performance/complexity trade-off [RAN1]    4. Channel Bandwidth (at least minimum and maximum), Numerology, avoiding multiple numerologies for the same band / sub-range (e.g., enabling synergies among frequency bands in the ~7GHz range) [RAN1, RAN4]    5. Physical layer control, data scheduling and HARQ operation [RAN1, RAN2]    6. MIMO operation [RAN1, RAN4]    7. Duplexing [RAN1, RAN4]    8. Initial access [RAN1, RAN2, RAN4]       * Studies on synchronization signal and raster, broadcast signals/channel and physical random access channel [RAN1, RAN4]       * Studies on initial access procedure, random access procedures, system information and paging [RAN2, RAN1, RAN4]    9. 6GR spectrum utilization and aggregation. [RAN1, RAN2, RAN4]    10. Other physical layer signals, channels and procedures [RAN1, RAN2, RAN4]    11. Evaluate performance of at least energy efficiency, spectrum efficiency, and coverage compared to 5G NR, and deliver the initial result at the end of study [RAN1].    * RAN4 can be involved, if necessary, based on the LS from RAN1 |

This contribution provides discussions related to the control channel coding.

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# Topics for discussion

According to WID, the channel coding using LDPC and Polar code as baseline, considering applicable extension to satisfy 6G requirements and characteristics with acceptable performance/complexity trade-off.

In NR, the usage of channel coding scheme for TrCHs and control information is illustrated in the following tables of TS 38.212. This FL summary focuses on control information coding and BCH coding, which uses polar code and block code in NR.

A screenshot of a computer program

AI-generated content may be incorrect.

## Topic #1: Control channel coding schemes

### Background

**5G polar code**

Polar codes show good BLER performance in small block size and low code rate region, which enables it being selected as 5G control channel coding schemes (e.g., PDCCH, PUCCH and PBCH, etc.).

Polar encoder kernel is a generator matrix composed of an *n*-th Kronecker power of matrix . This implies the block size of a polar code is always an integer power of 2, i.e., . In 5G, the block size of a polar code is between 32 and 512 for downlink, between 32 and 1024 for uplink, and is determined based on payload size and number of bits to be transmitted. The assignment of information bits to polar encoder kernel relies on the ranking of bit channel reliabilities. The ranked bit channel reliabilities are in a nested structure to save memory, i.e., the ranking of a block size polar code is derived from the ranking of a block size polar code.

Three rate matching schemes are designed for polar codes: repetition, puncturing and shortening. The selection among these rate matching schemes depends on payload size, polar code block size and number of bits to be transmitted. The polar encoded bits are saved to a circular buffer, after performing sub-block interleaving. Depending on determined rate matching scheme, different bits in the circular buffer are selected for transmissions.

For 5G downlink control channel coding (i.e., PDCCH), up to 7 out of 24 CRC bits are distributed to earlier positions, together with payload bits reordering, in order to support early polar decoding termination.

For 5G uplink control channel coding (i.e., PUCCH), either 6-bit CRC or 11-bit CRC is appended, depending on payload size. Additionally, 3 parity-check bits may be inserted to facilitate pruning the list of candidate paths at decoder side in order to improve the error-correction performance. For large payload size or large number of bits to be transmitted, up to 2 code block segments are supported. Finally, a triangular interleaving is applied on the rate matching output bits to improve the diversity gain under high-order modulation.

In 6G, the control channel code and data channel code have been discussed by companies. In this FL summary, we shall focus on control channel code (PxCCH). The data channel code (PxSCH) is handled in a separate FL summary. The case of coding for UCI multiplexing PUSCH and PBCH code can also be processed in this FL summary.

**6G control channel code**

For control channel code (PxCCH) with large payload size (e.g., larger than 11 bits), companies (Nokia, Spreadtrum, CATT, vivo, Xiaomi, Huawei, OPPO, Interdigital, LG, DCM, Fujitsu, Ericsson, CEWiT, NEC) consider polar codes as candidate coding schemes. Additionally,

* Ericsson additionally mentioned whether or not PUCCH is supported for 6GR (e.g., send UCI on L2) may be discussed in other agenda items of 6GR.
* Lekha mentions BCH codes are particularly effective for short block lengths, making them suitable for low-latency applications; RS codes are adept at handling burst errors, which makes them valuable in specific scenarios, such as non-terrestrial networks. AT&T considers remapping channel codes to physical channels.
* AT&T proposes to evaluate for the association of channel codes for different channels.

FL would like to collect companies’ views on the possible channel coding scheme(s) for PDCCH. This is in Question 1-1. Also, FL would like to collect companies’ views on the possible channel coding scheme(s) for PUCCH with large payload size. This is in Question 1-2.

For control channel code (PUCCH) with small payload size (e.g., smaller than 12 bits), companies (Nokia, Spreadtrum) mentioned Reed-Muller/Simplex/Repetition coding schemes are used. FL would like to collect companies’ views on PUCCH with small payload size. This is in Question 1-3.

For PBCH channel code, companies (Huawei, ZTE) consider polar codes are used. FL would like to collect companies’ views on the possible channel coding scheme(s) for PBCH. This is in Question 1-4.

The following table provides a summary of company proposals on the general control channel codes.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Nokia | Proposal 1: For 6G channel coding, LDPC codes are used for data channels, while polar codes are used for control channels as in 5G.  Proposal 15: For 6G, block codes for small block lengths should be kept the same as in 5G. |
| Spreadtrum, UNISOC | Proposal 1: 5G NR channel coding schemes should be adopted for 6GR, including LDPC coding for data channel, Polar coding for control channel (payload≥12 bits), and Reed-Muller/Simplex/ Repetition coding schemes for control channel (payload < 12 bits). |
| Huawei | Proposal 5: Keep polar codes for channel coding of control information in 6GR, including:   * Downlink control information (DCI) on DL control channel * Uplink control information (larger than 11 bits) on both uplink control channel and uplink shared channel.   Proposal 6: Keep polar codes for channel coding of PBCH payload bits in 6GR. |
| CATT | Proposal 5: Polar code should be reused for 6G control channel coding. |
| Vivo | Proposal 1: NR design should be the baseline for 6GR channel coding. Specifically, 6GR should maintain polar coding for control channels with payload size larger than 11 bits and LDPC coding for data channels. |
| Xiaomi | Proposal 1: For 6GR, LDPC and polar are taken as data and control channel FEC respectively.   * Thorough and vigorous evaluation is needed to justify peak data rate oriented incremental enhancement for LDPC * The increase of UCI/DCI payload size(s), if any, shall be triggered by relevant discussion instead of channel coding discussion |
| ZTE | Proposal 13: Use Polar code for 6GR PBCH encoding with necessary enhancement on coding chain if needed. |
| OPPO | Proposal 4: The 6GR study on Polar code, which is already decided as the baseline, should focus on the potential extensions of Polar coding, without looking for an alternative. |
| Lekha | Proposal 1: Turbo codes, polar codes, and LDPC codes remain strong contenders for the next generation of mobile communication standards. These three coding schemes are well established and investigated. Turbo and LDPC codes for code lengths required for data channels are capable of outperforming other codes at reasonable complexity. Similarly, polar codes outperform other codes for the code lengths required for control channels.  Proposal 3: The legacy channel codes, including BCH and RS codes, can still have applications in 6G networks. BCH codes are particularly effective for short block lengths, making them suitable for low-latency applications. On the other hand, RS codes are adept at handling burst errors, which makes them valuable in specific scenarios, such as non-terrestrial networks. |
| Interdigital | Proposal 1: Reuse LDPC and Polar codes for 6G channel codes for data and control channels respectively and study potential enhancements of LDPC and Polar codes |
| LG | Proposal 1: Consider the 5G NR channel coding schemes, LDPC for the data channel and Polar code for the control channel, as a starting point for 6G channel coding design. |
| Fujitsu | Proposal 3:   * In 6GR, 5G Polar codes could be reused for control channel coding. * The maximum code length of polar codes could be enhanced at least for UCI transmissions. |
| Ericsson | [Proposal 1: For the study of channel coding, the following high-level principles are adopted,](#_Toc206156665)   1. NR channel coding scheme is the baseline for 6G channel coding, i.e. NR LDPC for data, NR Polar for control. Any code extensions beyond NR shall be required to demonstrate significant complexity/implementation benefits. 2. For data channel, 5G LDPC coding is applied to the 6G scenarios with KPI covered by 5G capabilities. 3. Study and applicability of channel coding extension on top of the NR baseline should focus on KPI for a much higher peak data rate target such as [50] Gbps (if such a value is agreed for 6G). 4. Channel coding extensions should facilitate hardware reuse between 5G and 6G, e.g. considering MRSS deployments, etc. 5. Avoid minor performance/complexity optimizations (e.g. improving performance by a few tenths of a dB) that do not provide meaningful benefit at system level.   Proposal 4: NR Polar coding is reused for 6GR control channels (PXCCH). |
| AT&T | Proposal 1: For 6GR, strive to reuse the same channel code types supported in 5G NR.  Proposal 3: For 6GR, evaluate whether the association of channel codes with different channels and control information sequences follows legacy NR rules. |
| DCM | Proposal 1: In the early stage of discussions on channel coding for 6GR, the following three points should be clarified as early as possible, which would be in line with the intention of the corresponding objectives in the SID   * 6G requirements and characteristics which should be considered in channel coding * Evaluation metrics for performance/complexity trade-off * Analysis on the need of coding scheme enhancements beyond 5G NR   Proposal 5:   * Reusing 5G NR channel coding scheme as much as possible should be considered as baseline * Any enhancements for channel coding scheme should be justified by clear gain   + Which code to apply to which CH: Prefer no change from 5G NR, but open to discuss whether/how to enhance   + Design of LDPC/Polar codes: Open to discuss whether/how to enhance   + Coding chain: Open to discuss whether/how to enhance |
| CEWiT | Proposal 1: Consider NR coding schemes (Polar and LDPC) as baseline for channel coding schemes in 6G. |
| NEC | Proposal 1: Polar code and LDPC code are baseline for 6GR. 6GR could study enhancements on:   * Polar code to support more size of encoding bits and reduced processing complexity * LDPC code to support more size of encoding bits and reduced processing complexity |

### [Closed] First round discussions

#### [H] Question 1-1

*Question 1-1: What do you consider as candidate channel coding scheme(s) for PDCCH?*

|  |  |  |
| --- | --- | --- |
| **Company** | **Channel code(s)** | **Comments** |
| Xiaomi | Polar for DL control |  |
| vivo | Polar |  |
| AT&T | Polar codes | Assuming 6G adopts similar limitation as NR to DCI size (~140 bits) |
| OPPO | Polar |  |
| MTK | Polar |  |
| NEC | Polar |  |
| Rakuten | Polar |  |
| Intel | Polar |  |
| Apple | Polar codes | We should reuse the schemes from 5G control channel codes |
| NTT DOCOMO | Polar | Reusing Polar codes for PDCCH is sufficient. We don’t find any motivation to introduce alternative coding scheme(s).  Separate coding schemes per block length/coding rate (e.g., Polar for PDCCH with short payload, LDPC for PDCCH with longer payload) could be over optimization. |
| ZTE, Sanechips | Polar code | The Polar code used for the [PDCCH in 5G-NR](https://www.google.com/search?sca_esv=7fb9df9863b39f3b&cs=0&q=PDCCH+in+5G-NR&sa=X&ved=2ahUKEwjGqa_C-KePAxV0xjgGHS-PAP8QxccNegQIAxAB&mstk=AUtExfDWNUcabz3HTpSxvCVlMyt-g-iKFCchZJEKV56N-i9SilxRezooOOyzVwR7ZX1FtruCBtvpGS9sx_pfezpm8N48pRFDP-kkLoTiiTB3zhRtr6S-jcKPOaRdV7hjtS8XB_M&csui=3) is because they offer excellent error correction performance, achieve channel capacity, and has a computationally efficient encoding/decoding complexity. These characteristics make them well-suited for the low-latency, high-reliability control information that must be reliably conveyed on the PDCCH. |
| Tejas | Polar Codes | Polar codes can be re-used and further enhancements can be studied for 6GR changes. |
| CMCC | Polar codes | The maturity, proven reliability, and efficient hardware implementation of Polar codes — particularly their superior performance for small block lengths — make them a robust and low-risk choice for 6G PDCCH, ensuring both backward compatibility and a smooth evolution. |
| Ericsson | NR CA-Polar Code | We do not see a need to change the existing scheme for PDCCH, ie. CA-Polar codes. |
| Lenovo | Polar |  |
| Samsung | Polar codes | It is necessary to consider enhancements building upon the 5G NR polar code. |
| Fujitsu | Polar |  |
| Nokia | Polar |  |
| LGE | Polar code | 5G NR coding scheme should be baseline. Open to study potential enhancements based on 5G NR polar code. |
| ETRI | Polar |  |
| IDC | Polar | Support continuing to use Polar codes for PDCCH, consistent with 5G NR design. This provides backward compatibility and proven performance for short block lengths. At this stage, we do not see strong need for alternatives, but we are open to study incremental enhancements if clear gains are demonstrated. |
| Huawei | Polar codes | Keep polar codes for channel coding of control information in 6GR, including DCI |
| Qualcomm | Polar codes |  |

#### [H] Question 1-2

*Question 1-2: What do you consider as candidate channel coding scheme(s) for PUCCH with large payload size if existing?*

|  |  |  |
| --- | --- | --- |
| **Company** | **Channel code(s)** | **Comments** |
| Xiaomi |  | We don’t think we need to presume large payload size for the timing being |
| vivo |  | Not clear about this question. What is the range of payload when referred as “large” for PUCCH? |
| AT&T | UCI over PUCCH 🡪 Polar codes  UCI over PUSCH 🡪 FFS | Polar coding in NR is used for both UCI over PUCCH and UCI over PUSCH.  For PUCCH signaling, our preference remains to be polar coding  For PUSCH signaling, UCI overhead has exceeded 1700 bits in NR. Given the worse performance and higher complexity of polar decoding for large blocks, further discussion is needed. |
| OPPO |  | Follow the same channel coding schemes as in 5G for PUCCH with similar payload size |
| MTK |  | First of all, we suggest to replace “PUCCH” by UCI since UCI can also be multiplexed on PUSCH as mentioned by AT&T.  Regarding the question on the potential increased UCI payload size, we suggest to settle down this discussion asap. Before that, what we can try to conclude is: If UCI payload size in 6G is the same as 5G, then we adopt Polar.  If UCI payload size in 6G is much larger than what we have in 5G, then our preference is still using Polar. However, depending on the payload size range, other coding scheme can be further evaluated and discussed. |
| NEC |  | We share similar view to update PUCCH to UCI. For larger UCI payload in 6GR, we also prefer using polar code with potential enhancement. |
| Rakuten |  | We view that Polar will be adopted for larger payload size and it can be considered as baseline for performance and complexity comparison. |
| Intel |  | We prefer to continue use Polar for UCI in PUCCH. |
| Apple | Polar codes | We should reuse the schemes from 5G control channel codes. In 5G, if UCI payload larger than 11 bits, polar code is used. |
| NTT DOCOMO | Polar | Reusing Polar codes for PUCCH is sufficient. We don’t find any motivation to introduce alternative coding scheme(s).  Separate coding schemes per block length/coding rate (e.g., Polar for PUCCH with short payload, LDPC for PUCCH with longer payload) could be over optimization. |
| ZTE, Sanechips | Polar code | Similar comments as other companies that “PUCCH” should be “UCI”.  We think polar code should be used for UCI with large payload size transmission in 6GR.  The determination of the “large payload size” should be clarified.  Moreover, with targeted optimizations, the error-correction performance of Polar codes under large payload sizes can be further improved. |
| Tejas | Polar Code | Polar codes can be re-used and further enhancements can be studied for higher payload sizes. |
| CMCC | Polar codes | The maturity, proven reliability, and efficient hardware implementation of Polar codes — particularly their superior performance for small block lengths — make them a robust and low-risk choice for 6G PUCCH, ensuring both backward compatibility and a smooth evolution. |
| Ericsson | NR CA-Polar Codes for PUCCH | We prefer that the proposal discusses how to code the UCI, rather than referring to the control channel. Mapping of UCI to a physical channel can be discussed in the channel design agenda.  We think the discussion can be limited to the exisiting payload size limit of 1706bits (NR limit).  For payload sizes beyond NR limit, we think that first a clearer need should be identified in the relevant agendas (e.g. MIMO, control information discussion). Additionally, these agenda may also discuss whether to still carry control information as L1 UCI or instead use L2 signalling for such large payloads. |
| Lenovo |  | We regard NR Polar as baseline for UCI.  For UCI over PUCCH preference is to preserve Polar coding scheme.  For UCI over PUSCH, we consider Polar as candidate (incl. enhancements to better cater to larger payload sizes, as needed). Yet, further discussions and evaluations are necessary, depending on the payload size range. |
| Samsung | Polar codes | It is necessary to consider enhancements building upon the 5G NR polar code. |
| Fujitsu | Polar | Suggest replacing PUCCH with UCI. |
| Nokia | Polar |  |
| LGE | Polar code | 5G NR coding scheme should be baseline. Open to study potential enhancements based on 5G NR polar code. |
| ETRI | Polar |  |
| IDC | Polar | For large UCI payloads, Polar codes remain the baseline. If payload sizes increase beyond current NR limits, targeted enhancements or segmentation approaches can be studied, but we prefer to clarify realistic payload size requirements first, if needed. |
| Huawei | Polar codes | 1) Keep polar codes for channel coding of control information in 6GR, including UCI (larger than 11 bits)  2) it is not clear yet on whether UCI payload is increased in 6GR. |
| Qualcomm |  | We think the discussion can be limited to the exisiting payload size limit of 1706bits (NR limit).  For payload sizes beyond (i.e., greater than) NR limit, we think that the code design should discussed further if the need to support larger UCI size is justified. |

#### [H] Question 1-3

*Question 1-3: What do you consider as candidate channel coding scheme(s) for PUCCH with small payload size if existing?*

|  |  |  |
| --- | --- | --- |
| **Company** | **Channel code(s)** | **Comments** |
| Xiaomi |  | RM/Simplex/Repetition can be used as starting point |
| vivo |  | Similar question as above. What is the range of payload when referred as “small” for PUCCH? |
| AT&T | Linear code | Reuse NR Reed-Muller code variant. Open to discuss further enhancements, with design considerations for all device types/ capabilities |
| OPPO |  | Follow the same channel coding schemes as in 5G for PUCCH with similar payload size |
| MTK |  | 5G design should be the baseline. |
| NEC |  | Reuse 5G channel coding design as much as possible. |
| Rakuten |  | We need to be clear what is considered as small payload. It could fall in multiple ranges and different candidates, e.g., repetition and RM, can be used. |
| Intel |  | Reuse 5G design for small payload. |
| Apple | Reed-Muller, simplex, repetition | For 1-bit UCI, we could reuse repetition code  For 2-bit UCI, we could use Simplex code  For more than 3-bit UCI, we could use Reed-Muller. |
| NTT DOCOMO | Reed-Muller/Simplex/Repetition | Reusing Reed-Muller/Simplex/Repetition codes for PUCCH with small payload size is sufficient. We don’t find any clear motivation to introduce alternative coding scheme(s) at this point.  If there are probable enhancement candidates which will lead clear gains, we are OK to study them. |
| ZTE, Sanechips |  | Similar comments as other companies that “PUCCH” should be “UCI”.  The determination of the “large payload size” should be clarified.  As we pointed out in our Tdoc, we observe some error floor with the legacy RM code, which need to be fixed. And the detailed solutions can be further discussed, e.g., using sequence based solution, or RM code enhancements. |
| Tejas | Simplex, Repetition, Reed-Muller, Polar Code | A focused evaluation of Simplex, Repetition, enhanced Reed-Muller, and enhanced Polar codes should be conducted to identify the most suitable coding scheme for small payload sizes, based on their performance. |
| CMCC | Further study | Unified coding schemes for PUCCH with small payload sizes (1-11bits) are preferred, to avoid excessive variety of codes (e.g., Reed-Muller, Simplex, and Repetition coding schemes). |
| Ericsson | Block codes (simplex, RM) | For small size UCI, existing codes in 5G are tried and true for multiple releases. We should avoid additional study bringing unjustified potential hardware impact. |
| Lenovo |  | We consider 5G design to be the baseline for small payload size (<12 bits). |
| Samsung | Repetition (1-bit)  Simplex code (2-bit)  RM codes (>= 3 bits) | Same as in NR |
| Fujitsu |  | Reuse 5G channel coding for small payload sizes. |
| Nokia | As 5G NR for blocklength<12 |  |
| LGE | Existing 5G coding scheme | 5G NR coding scheme should be baseline. Open to study potential enhancements based on 5G NR polar code, if necessary. |
| IDC |  | Support reusing the simple codes, for small payload sizes (<12 bits), as in 5G NR. If error floor issues are identified, study of necessary enhancements may be reasonable, but new coding families do not appear necessary at this stage. |
| EURECOM |  | In our contribution, we show that there are coding schemes (e.g. product codes) that offer significant gains compared to NR RM codes. We therefore propose to study and evaluate alternatives and enhancements to the existing NR solutions. |
| Qualcomm |  | As explained in our contribution, the NR modified Reed Muller codes has performance issues, many (K,N) combinations are not decodable. We support to study new code design for the small UCI payload regime. |

#### [H] Question 1-4

*Question 1-4: What do you consider as candidate channel coding scheme(s) for PBCH?*

|  |  |  |
| --- | --- | --- |
| **Company** | **Channel code(s)** | **Comments** |
| Xiaomi | Polar |  |
| vivo | Polar |  |
| OPPO | Polar |  |
| NEC | Polar |  |
| Rakuten | Polar |  |
| Intel | Polar |  |
| Apple | Polar |  |
| NTT DOCOMO | Polar | Reusing Polar codes is sufficient. We don’t find any clear motivation to introduce alternative coding scheme(s). |
| ZTE, Sanechips | Polar code | Polar code is a candidate for the 5G Physical Broadcast Channel (PBCH), it offers excellent error performance with no error floor, which can be reused for 6G. |
| Tejas | Polar codes | Polar codes can be re-used. |
| CMCC | Polar code | The maturity, proven reliability, and efficient hardware implementation of Polar codes — particularly their superior performance for small block lengths — make them a robust and low-risk choice for 6G PBCH, ensuring both backward compatibility and a smooth evolution. |
| Ericsson | NR CA-Polar Codes | We do not see a need to discuss changes for PBCH. |
| Lenovo | Polar |  |
| Samsung | Polar codes | It is necessary to consider enhancements building upon the 5G NR polar code. |
| Fujitsu | Polar |  |
| Nokia | Polar |  |
| LGE | Polar code | 5G NR coding scheme should be baseline. Open to study potential enhancements based on 5G NR polar code, if necessary. |
| ETRI | Polar |  |
| IDC | Polar |  |
| Huawei | Polar codes | Keep polar codes for channel coding of control information in 6GR, including PBCH |
| Qualcomm |  | We suggest to postpone the discussion of channel coding for PBCH, since the channel structure for PBCH in 6G is not clear yet. |

### [Closed] Second round discussions

#### [H] Proposal 1-1-c

The following proposal is planned for Thursday online discussion. However, due to time limitation, we do not have time to discuss it online. Here, FL makes some changes (marked in red font). This is in Proposal 1-1-c.

*Proposal 1-1-c: Polar code is supported for PDCCH with payload size between 12 bits and 140 bits, where the polar code refers to one of the following alternatives:*

* *Alt 1: 5G polar transform only*
* *Alt 2: 5G polar sequence plus transform*
* *Alt 3: 5G polar sequence plus transform plus concatenated coding (CA polar code) (i.e., TS 38.212/Section 5.3.1.2)*
* *Alt 4: 5G interleaving (CRC distribution), 5G polar sequence plus polar transform plus concatenated coding (i.e., TS 38.212/Section 5.3.1.1 and TS 38.212/Section 5.3.1.2)*

**Companies are welcome to provide comments.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** | **Yes or No** | **Most preferred alternative** | **Comments** |
| LG |  | Alt. 4 | Alt. 4 can be baseline. It may be required to clarify the maximum payload size of 140 bits. If larger mother code size may be considered, larger mother code size than 512 can be selected depending on rate matching output size for equal to or less than information size of 140 bits. Additionally, we can consider enhancement for Alt. 4, if necessary |
| Ericsson | yes | Alt3 |  |
| Vivo |  |  | We’re a bit hesitate to say “is supported” for now given PDCCH payload size is not known.  If we assume maximum PDCCH payload size is exactly as in NR, then our preference is Alt 4.  However, in case of PDCCH payload size larger than 140, we prefer to have a unified control coding scheme to cover the whole range of PDCCH payload. |
| Samsung |  |  | The supported bit range (i.e., 12 to 140) should be revisited and discussed again.  Note: In 5G NR, PDCCH payloads of 1–11 bits are encoded with polar codes and zero padding. |
| NTT DOCOMO |  |  | At least Alt-1 seems agreeable as a starting point. In our understanding, 5G polar transform has no room for enhancement. Instead, Alt-2, 3, and 4 sound a little bit restrictive at this point. Polar sequence and/or interleaving could have probability to contribute to satisfaction of 6G requirement. RAN1 shouldn’t preclude such direction at this point.  BTW, what’s the intention of the change to “supported”? Does this mean that there is a possibility of supporting additional coding schemes other than polar for DCI? If so, we don't see a need for them at this point. |
| Huawei, HiSilicon | Yes if Alt.4 is used.  Other Alternatives need to be justified for the necessity. | Keep the polar code, as defined in 5G NR, for PDCCH with payload size in the range from 12 bits to 140 bits | This is not the proposal 1-1-c as the outcome of offline discussion.  Within the DCI payload size between 12 bits and 140 bits, there is no motivation to change polar code as define in 5G NR. The necessity should be firstly motivated before the discussion Alt.1, Alt.2 and Alt.3. |
| Apple | Yes | Alt 1 | We think at this stage, we should not restrict the 6G DL polar code design.  Although the proposal discusses payload size between 12 and 140 bits, we prefer a unified design for DCI payload size larger than 140 bits (if supported). This requires the re-design of multiple components.  Even with 140 bit payload limitation, we think the PDCCH decoding performance (e.g., BLER, FAR), latency, complexity and power consumption have the space to enhance. |
| Nokia |  | Alt. 4 |  |

#### [H] Proposal 1-2-c

The following proposal is planned for Thursday online discussion. However, due to time limitation, we do not have time to discuss it online. Here, FL makes some changes (marked in red font). This is in Proposal 1-2-c.

*Proposal 1-2-c: At least for UCI payload size between X bits and Y bits, if UCI is treated as layer 1 information, polar code is supported for UCI, where the polar code refers to one of the following alternatives:*

* *Alt 1: 5G polar transform only*
* *Alt 2: 5G polar sequence plus transform*
* *Alt 3: 5G polar sequence plus transform plus concatenated coding (CA or PC polar code) (i.e., TS 38.212/Section 5.3.1.2)*
* *Alt 4: 5G code block segmentation, 5G polar sequence plus polar transform plus concatenated coding (i.e., TS 38.212/Section 5.2.1 and TS 38.212/Section 5.3.1.2)*
* *FFS value of X (e.g., X= 12)*
* *FFS value of Y (e.g., Y=1706)*

**Companies are welcome to provide comments.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** | **Yes or No** | **Most preferred alternative** | **Comments** |
| LG |  | Alt. 3 | Alt. 3 can be baseline. We prefer X value of 12 as in NR. Additionally, we can consider enhancement for Alt. 3, if necessary |
| Ericsson | yes | Alt3 |  |
| vivo |  |  | We’re a bit hesitate to say “is supported” for now given the maximum UCI payload size is not known. If we assume the maximum UCI payload size is exactly as in NR, then our preference is Alt 4.  However, in case of UCI payload size Y is larger than 1706, we prefer to have a unified control coding scheme to cover the range of UCI payload from X to Y. |
| Samsung | Yes | Alt. 1 | X and Y should be determined appropriately (e.g., Y ≤ 500). |
| NTT DOCOMO |  |  | We strongly suggest keeping the added description “if UCI is treated as layer 1 information,”. The wording of UCI is very sensitive. Potentially, 6G uplink information regarding control may be transmitted via Layer 2 depending on the result of the control discussion, then if so, the discussion for the coding scheme of this should be conducted more carefully. Additionally, the details of control information in 6G will be discussed separately in control session. If the added description is missed, this proposal can be restrictive for the discussion on control session.  Our comments for the alternatives are same as one for Proposal 1-1-c. |
| Huawei, HiSilicon | See our comments |  | 1. Similarly, the necessity of the change of polar codes as in NR TS 38.212 needs to be justified first.   If X and Y is not clear, it is difficult for the discussion. For the UCI payload size in the range from 12bits to 1706 bits, the polar code, as defined for 5G NR (i.e. Alt.4), is supported. |
| Apple | Yes | Alt 1 | We think at this stage, we should not restrict the 6G UL polar code design.  Although the proposal discusses payload size between X and Y bits, we prefer a unified design for UCI payload size larger than 1706 bits (if supported). This requires the re-design of multiple components.  Even with 1706 bit payload limitation, we think the UCI decoding BLER performance has the space to enhance. |
| Nokia |  | Alt. 4 | X and Y values are as in 5G. |

#### [H] Proposal 1-3-a

The following proposal is planned for Wednesday offline discussion. However, due to time limitation, we do not have time to discuss it online. Here, FL triggers the discussions for second round.

*Proposal 1-3-a: The following channel coding schemes for UCI are used:*

* *For 1-bit UCI, repetition as in 5G*
* *For 2-bit UCI, simplex as in 5G*
* *For UCI payload size between 3 bits and X bits, Reed-Muller code*
  + *FFS value of X (e.g., X =11)*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| EURECOM |  | RM codes have significant shortcomings as identified by multiple companies. 6G should study enhancements and alternatives to offer significantly increased uplink coverage for small UCI payloads. |
| Tejas |  | Include study of further enhancements to RM code. |
| LG | Y | NR coding scheme should be baseline. |
| Ericsson | Yes |  |
| vivo | Yes |  |
| Samsung |  | Open to further study, especially considering improvements in error detection. |
| NTT DOCOMO | Yes (in general) | Reusing Reed-Muller/Simplex/Repetition codes for PUCCH with small payload size is sufficient. We don’t find any clear motivation to introduce alternative coding scheme(s) at this point.  If there are probable enhancement candidates which will lead clear gains, we are OK to study them. |
| Apple | Yes |  |

#### [H] Proposal 1-4-b

The following proposal is planned for Wednesday offline discussion. However, due to time limitation, we do not have time to discuss it online. Here, FL triggers the discussions for second round. The corresponding definition of polar code is added.

*Proposal 1-4-b: Polar code is supported for PBCH, where the polar code refers to one of the following alternatives:*

* *Alt 1: 5G polar transform only*
* *Alt 2: 5G polar sequence plus transform*
* *Alt 3: 5G polar sequence plus transform plus concatenated coding (CA polar code) (i.e., TS 38.212/Section 5.3.1.2)*
* *Alt 4: 5G interleaving (CRC distribution), 5G polar sequence plus polar transform plus concatenated coding (i.e., TS 38.212/Section 5.3.1.1 and TS 38.212/Section 5.3.1.2)*

**Companies are welcome to provide comments.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** | **Yes or No** | **Most preferred alternative** | **Comments** |
| LG |  | Alt. 4 | Alt. 4 can be baseline. |
| Ericsson | yes | Alt3 |  |
| vivo |  |  | Assuming a similar PBCH payload as in NR, we’re OK with Alt 3 and Alt 4. |
| Samsung |  |  | PBCH should use the same scheme as PDCCH |
| NTT DOCOMO |  |  | Same as for Proposal 1-1-c. |
| Huawei, HiSilicon | Yes if Alt.4 is used.  All other alternatives need to be justified for the necessity. |  | We don’t see any necessity/justification to use the coding scheme different from the polar codes for PBCH as defined for 5G NR (i.e. Alt.4). |
| Apple | Yes | Alt 1 |  |
| Nokia |  | Alt. 4 |  |

## Topic #2: Design principle

### Background

From SID [1], polar code design considers applicable extensions to satisfy 6G requirements and characteristics with acceptable performance/complexity trade-off.

The following design principle of 6G control channel codes are proposed by different companies.

* Satisfy requirements for 6G use cases: Nokia
  + Large DCI/UCI payload size: Spreadtrum, NEC, CMCC, Mediatek, ZTE, OPPO, CATT, Apple
* Hardware commonality between 5G and 6G: Nokia
* Lower decoding complexity: Spreadtrum, NEC, Qualcomm, Apple
* Lower decoding latency: Qualcomm, Apple
* Lower decoding power consumption: Apple, DCM
* Balance between performance improvement and complexity: Nokia, Huawei, LG, Rakuten
* Better (BLER, FAR) performance: Samsung, Apple

Based on companies’ inputs, the FL lists the potential considerations for 6G control channel coding enhancement. This is in Proposal 2-1.

The following table provides a summary of company proposals on the design principles of 6G control channel coding.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Nokia | Proposal 2: For the study of 6G channel coding, the scope of potential extensions of the 5G channel coding schemes is to satisfy requirements for 6G use cases.  Proposal 3: For the study of 6G channel coding, RAN1 should study a design that keeps hardware commonality between 5G NR and 6G.  Proposal 4: Given the need for an early conclusion latest by RAN#112 on fundamental aspects such as channel coding, RAN1 should avoid considering/studying channel coding proposals that do not offer significant performance improvement to justify the added implementation complexity on top of existing 5G baseline.  Proposal 14: RAN1 to study the necessity of any applicable extension on top of 5G polar codes considering acceptable performance/complexity trade-off. |
| Spreadtrum | Proposal 2: The following aspects should be evaluated the trade-off for the extension of 6GR channel coding:   * Lower encoding or decoding complexity * Support higher data rate * Support lager payload size |
| NEC | Proposal 1: Polar code and LDPC code are baseline for 6GR. 6GR could study enhancements on:   * Polar code to support more size of encoding bits and reduced processing complexity * LDPC code to support more size of encoding bits and reduced processing complexity |
| LG | Proposal 2: Discuss and agree on the evaluation metrics to assess the performance/complexity trade-offs of applicable extensions. |
| CMCC | Observation 1: 5G Polar code may not be optimal for the case of longer DCI/UCI straightforwardly, due to higher decoding latency, degraded error performance and inherent short-block optimization.  Proposal 1: 5G Polar code enhancement for 6G could be considered for larger payload size. |
| Rakuten | Proposal 4: Alternative channel codes for short-length blocks, used in and beyond control channels, should be evaluated in terms of error performance and decoding complexity, using the existing NR Polar Code as the baseline reference. |
| Qualcomm | Proposal 1: For channel coding in 6GR,   * LDPC codes should be used for data channel (i.e., PxSCH) * Polar codes should be used for control channel (i.e., PxCCH) * Study potential enhancement for small block length coding for uplink control channel (i.e., payload size<=X bits), FFS: X. * For each family of codes, support unified channel code structures across different device types (eMBB/IoT).   Proposal 8: In 6GR, study polar code designs that support lower decoding complexity and latency.  Proposal 9: In 6GR, strive to keep the same polar code size as 5G for both uplink and downlink.   * New feature design effort should focus on those bring meaningful performance/implementation gains. |
| DCM | Proposal 2: Discussion and consensus about 6G requirements and characteristics which should be considered for channel coding are needed. Following candidates can be discussed:   * Peak Data Rate and/or User Plane Latency, as same as the SI for 5G NR * Reliability, User Experienced Data Rate, and/or Sustainability/Energy Efficiency, as new candidate requirements for channel coding for 6GR * Other candidates are not precluded |
| Apple | Proposal 1: 6G channel coding to consider facilitation of the two-stage decoding to improve the power consumption of blind decoding.  Proposal 2: 6G channel coding to consider facilitation of the two-stage decoding to improve error correction performance of blind decoding.  Proposal 3: 6G channel coding to consider an optimized precoding scheme of polar codes to enhance early termination complexity savings without negatively impacting false alarm rate. |
| CATT | Proposal 6: Polar code could be designed/enhanced with longer mother code if the requirement of 6G UCI size increases to more than 1024 bits. The corresponding sequence designs should preserve the nested property to ensure efficient code construction.  Proposal 8: If larger UCI is supported for 6G, segmentation schemes with more than two segments should be considered. |
| Vivo | Observation 1: The NR polar coding design has well supported the control channel requirements of DCI not exceeding 140 bits and UCI not exceeding 1706 bits.  Proposal 2: Support to reuse the NR polar coding design for the control channels with payload size larger than 11 bits, unless the need for enhancing the polar coding design is well justified, e.g., a much larger DCI/UCI payload is necessary for 6GR. |
| ZTE | Observation 1: The support of larger frequency bandwidth, ultra-massive MIMO and new services will increase the UCI payload in 6G. |
| Mediatek | Observation 6: Due to the limitation of maximum 140bit payload sizes and the support of only QPSK QAM, the 5G Polar code design for DCI is limited on scheduling flexibility and resource efficiency to support 6G applications. |
| OPPO | Proposal 5: Study solutions to increase polar code payload size in 6G. |

### [Closed] First round discussions

#### [H] Proposal 2-1-a

*Proposal 2-1-a: 6G control channel code design shall consider the following aspects:*

* *Larger DCI and/or UCI payload size*
* *Lower decoding complexity*
* *Lower power consumption*
* *Lower decoding latency*
* *Better (BLER, FAR) performance*
* *Balance between performance and implementation complexity*
* *Hardware commonality between 5G and 6G*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Xiaomi |  | We think this principle is a bit too early. We would like to focus on the issues with the control channel code of 5G firstly subject to an agreed set of evaluation metrics and methodologies instead of providing a list of 6G channel coding design principles.  For example, what we can discuss is the actual quantifiable metrics for decoding complexity, power consumption and performance and implementation |
| vivo | No | First of all, we’d like to clarify our view. We proposed “reuse the NR polar coding design…. unless the need for enhancing the polar coding design is well justified”. As a matter of fact, it’s not clear to us about large DCI/UCI payload size for now. Please capture our views correctly and remove us from proponent company due to large DCI/UCI payload.  We think it’s better and appropriate for the control and MIMO session to have a solid common understanding/conclusion on the range of control payload for 6GR before channel coding session jump to enhancement based on some assumptions which may not match real 6GR design requirements.  Regarding lower power consumption aspect for control channel coding design, we believe that there are many efficient ways to reduce the power consumption. In particular, with respect to power consumption due to unnecessary PDCCH monitoring and blind decoding, wake-up signal and PDCCH skipping as supported in 5G are good examples and we believe those will be supported in 6G day-1 as essential UE power saving features. On top of those, additional power saving benefit by further reducing PDCCH monitoring/enhanced early termination during the active time where PDCCH is monitored is expected to be small, if any. Therefore, if companies want to study such enhancements, we think the proponents should simulate the UE power consumption based on realist traffic model and power model and the comparison should be made against and/or on top of other power saving features (two examples as above) to see the real gain.  In general, we think the motivation for any enhancement needs to be justified with meaningful/real gain to begin with before RAN1 commit on those design principle. |
| AT&T |  | When terms like “lower decoding complexity” are used, is this referring to 5G control channel code design?  We prefer preliminary consideration on performance of potential solutions, followed by considerations mentioned above |
| OPPO |  | “shall” is a too strong wording here. “may” or “can” sounds more appropriate. |
| MTK |  | Few suggestions.  1 . suggest to replace “consider” with “study.” Also add ”at least” to not preclude other aspects  2. we also agree with vivo and other companies that we should first look into the motivations before deciding what should be enhanced. However, to encourage companies to check other companies’ proposal, we suggest following wording *Proposal 2-1-a: For 6G control channel code design, ~~shall~~ at least study ~~consider the~~ following aspects:*   * *~~Larger~~ DCI and/or UCI payload size* * *~~Lower~~ decoding complexity* * *~~Lower~~ power consumption* * *~~Lower~~ decoding latency* * *~~Better (BLER, FAR)~~ performance* * *Balance between performance and implementation complexity* * *Hardware commonality between 5G and 6G* |
| NEC |  | We support the 1st sub-bullet and open to discuss other sub-bullets. |
| Rakuten |  | Different aspects will be associated with different criterion, which will be conflict and cannot optimize. Suggest the companies to discuss to short-list a small group of top priority aspect, following lists of second and third priorities. |
| Intel |  | We agree with MTK’s suggestion. In general, this is a good list of KPIs for control channel coding. However, whether we want to put “lower” or “better” depends on the need. It is better to first clarify the expectations on control channel coding and see if 5G Polar can already meet these expectations. |
| Apple |  | We support the proposal to further study these areas. |
| NTT DOCOMO |  | In general, we have a similar view to Xiaomi. In the initial discussion, RAN1 should have common understanding about 6G KPIs/requirements/characteristics to be addressed on channel coding context (if any) and evaluation metrics to be improved/monitored. And then, RAN1 could proceed to the discussion on design principles.  We are OK to consider Lower decoding complexity, Lower power consumption, Lower decoding latency and Better (BLER, FAR) performance to satisfy 6G KPIs/requirements/characteristics. Balance of multiple aspects is also worth considering but it shouldn’t be limited only the combination between performance and implementation complexity.  To make this more structured, We suggest grouping these aspects together under the heading "Improvement beyond 5G control channel code" and place it as a sub-bullet.  In our perspective, Hardware commonality between 5G and 6G is also important.  For us, “Larger DCI and/or UCI payload size” is unclear. Clarification like “Larger DCI and/or UCI maximum payload size than 5G NR” should be added. If this clarification is valid, in my understanding, Larger DCI and/or UCI maximum payload size than 5G NR (especially UCI) isn’t motivated from channel coding perspective. Necessity of enhancements targeting them depends on the result of discussion in the control sessions. We suggest adding note like “Necessity of larger DCI and/or UCI payload size should be separately discussed in the control session. Only if there is a consensus that it is necessary in the control session, enhancement(s) regarding it can be applied.” to clarify. |
| ZTE, Sanechips |  | In our views, a trade-off between performance and implementation complexity should also be considered.  Additionally, we think the aspect of lower energy consumption overlaps with low decoding complexity, as it can be reflected through decoding complexity and decoding latency.  For other aspects, we are open to discuss.  We don’t think hardware commonality needs to be listed here. For the related operations, whether it is in hardware or software is a implementation issue. |
| Tejas | Yes | We agree with listed aspects but Hardware commonality between 5G and 6G should not be considered as the main/priority factor for design selection. |
| CMCC | Yes, but clarification is needed. | The mentioned aspects can be considered.  For the 2nd-5th bullet, we wonder what is the baseline? If the baseline is 5G Polar, does the proposal mean lower power consumption/higher reliability are the design target for 6G? In addition, if UCI/DCI becomes longer, do the decoding complexity/decoding latency/power consumption have to become lower?  For the last bullet, we wonder how to evaluate hardware commonality? |
| Ericsson | No | First and foremost the priority should be hardware commonality. Based on that constrain we can study ways to enhance the exisiting scheme without hardware impact.  Before targeting changes on payload size, it should be clear that this is needed based on other agendas decisions  We can discuss enhancements to improve BLER/FAR or reducing complexity such as distributed CRC for DL NR CA-polar. |
| Lenovo |  | We appreciate the proposal and try to carve out general study directions. Albeit the bullets capture well the areas to be looked into, we find it premature to add quantifiers (“lower”/”larger”) as companies have divergent views at this time. Therefore, it is fine to keep MTK’s suggested wording of Proposal 2-1-a.  Furthermore, we would appreciate focusing more at this stage on reaching a common understanding of metrics necessary to evaluate *decoding complexity*, *power consumption*, *decoding latency*, and *performance*. This is similarly applicable for control, and data channel coding aspects. |
| Samsung | No | Focusing solely on the following subset for consideration is reasonable:   * Larger DCI and/or UCI payload size * Better (BLER, FAR) performance * Hardware commonality between 5G and 6G |
| Fujitsu |  | We are fine with MTK’s update. |
| Nokia | No | As discussed in our Tdoc, hardware commonality is our priority and that should be studied. We are fine to discuss potential performance improvement in the study. Overall, we have similar views as Ericsson.  For 1, it is not clear yet that there is a need for larger DCI/UCI.  For the others, at this stage of the 6GR SI on channel coding, the proposal should be “*6G control channel code study shall consider the following aspects…”* |
| LGE |  | It is preferable to consider larger DCI and/or UCI payload sizes when designing control channel coding schemes for 6G. However, further discussion may be needed to determine whether other aspects should also be taken into account.  In 5G channel coding study, performance, complexity, and latency were considered to assess proposed channel coding schemes. It is reasonable to apply the same metrics to control channel coding design. It may consider other aspects related to a specific control channel design. |
| ETRI | Yes | Support larger payload size. |
| IDC |  | OK in principle studying these aspects, with the understanding that further clarification of metrics (e.g., how to measure complexity, latency, power) will be needed. Hardware commonality with 5G is especially important for smooth migration. At the same time, we agree with others that enhancements should be motivated by meaningful gains. |
| Huawei, HiSilicon | See comments | Before we jump to the discussion on the design principles, one important step is the discussion on the motivation for the change of channel coding of control information.  In details, we have the following comments:  For larger DCI and/or UCI payload size, it is not clear whether they will increase.  For lower decoding complexity, low power consumption and low decoding latency, as commented by a number of companies, the motivation is not justified.  Similarly, the motivation of better (BLER, FAR) performance needs to be also justified first. As commented online, the RNTI-FAR can be resolved by gNB allocation of RNTIs and also UE side implementation. Furthermore, there is also proposals in 6GR control channel discussion to use two stage DCIs, which can significantly improve the FAR performance.  Regarding “Balance between performance and implementation complexity”, the control channel processing is not the bottleneck of processing. There is no clear motivation to redesign the control channel to re-balance the performance and the implementation complexity.  For the potential design principle of “*Hardware commonality between 5G and 6G*”, it is controversial among companies based on Monday online session. Meanwhile, there seems also different understanding on “*Hardware commonality between 5G and 6G*” .  We can continue the discussion on the motivation of the change of channel coding for control information. And we propose to firstly agree that 5G control channel code design is kept as a baseline. |
| Qualcomm |  | We share similar view that the term “*Hardware commonality between 5G and 6G*” may not be well defined (different companies may have different understanding), and it is implementation specific. |

### [Closed] Second round discussions

#### [H] Proposal 2-1-b

The following proposal is planned for Wednesday offline discussion. However, due to time limitation, we do not have time to discuss it online. Here, FL triggers the discussions for second round.

*Proposal 2-1-b: For 6G control channel code design, study the necessity of at least the following motivations:*

* *DCI and UCI payload size*
* *Decoding complexity*
* *Decoding power consumption*
* *Decoding latency*
* *Performance (e.g., BLER, FAR)*
* *Balance between performance and implementation complexity*
* *Hardware commonality between 5G and 6G*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Tejas | Yes | We agree with listed motivations but Hardware commonality between 5G and 6G should not be considered as the main/priority factor for deciding coding for control channel. |
| LG |  | It is preferable to consider at least larger DCI and/or UCI payload sizes when designing control channel coding schemes for 6G. |
| Ericsson | comment | On the sub-bullets:   * + First bullet is up to the control agenda   + Power consumption is not directly possible to study without a power model, we suggest to instead discuss complexity which anyway turns into power consumption.   We understand the general spirit of the proposal to be to provide guidance toward how to perform the study. We propose the following rewording, to account for the alternatives to study of polar codes proposed by the FL in earlier proposal:  *Proposal 2-1-b: For 6G control channel code design, the potential enhancements to polar codes consider the following:*   * *DCI and UCI payload size as identified by the relevant agenda in 6GR study.*   + *Note: the need for new payload sizes depends on separate agenda items.* * *Decoding complexity* * *~~Decoding power consumption~~* * *Decoding latency* * *Performance (e.g., BLER, FAR)* * *Balance between performance and implementation complexity* * *Hardware commonality between 5G and 6G* * *Note: the definition of the scope of enhancement is discussed in a separate proposal/agreement* |
| vivo |  | We’re not sure the maximum DCI/UCI payload size should be discussed in channel coding.  Some of the bullet points listed are more like a KPI instead of motivations, unless some adjective words are added, for example, lower decoding complexity.  SID tasked us to study performance and complexity tradeoff. We don’t think that’s the same as “implementation complexity”.  Furthermore, the definition of hardware commonality between 5G and 6G should be clarified. |
| Samsung |  | Only the following three aspects should be considered:   * DCI and UCI payload size * Performance (e.g., BLER, FAR) * Hardware commonality between 5G and 6G   where FAR should be explicitly defined as the false positive rate (FPR) in the context of no-signal or randomly modulated (e.g., QPSK) signal conditions. |
| **NTT DOCOMO** |  | Similar discussion to the previous online for data channel could be also needed for the control channel coding. At a high level, any study of control channel coding should also be aligned with the description of SID. RAN1 need to clarify the mapping between the proposed aspect to SID description such as “performance”, “complexity” and so on. Similar clarification to data channel could be needed at this time. |
| Huawei, HiSilicon |  | 1. Decoding complexity, decoding power consumption, and decoding latency are similar motivation; 2. The first bullet should be “larger DCI or UCI payload size”. However, this should be discussed in other sessions. 3. The control channel is not the bottleneck, we don’t understand why we should discuss “balance between *performance and implementation complexity”* here. |
| Apple | Yes | We are open to consider the necessity of all these motivations. |

## Topic #3: Handling large UCI payload size

### Background

In NR, the largest supported UCI payload size is 1706 bits.

Regarding the maximum UCI payload size in 6G,

* the maximum UCI payload size may exceed 1706 bits: ZTE, NEC, Lenovo, CATT, LG, Fujitsu, CMCC, Samsung
* unclear of maximum UCI payload size increase: Nokia, Ericsson
* Relevant discussion not in channel coding AI: Xiaomi

In case of UCI payload size increase, the potential solutions are proposed by companies:

* increase the maximum code block length of polar code from 1024 bits: CATT, Fujitsu, NEC, Lenovo, Apple
* enhance the segmentation scheme (e.g., segmentation rules, more than 2 segments): CATT, ZTE, CMCC
* study approaches to enhance flexibility and scalability (e.g., PAC code): Samsung

It is clear that the discussions on the maximum UCI payload size are dependent on some other agenda items’ (AI) decision (e.g., MIMO, uplink control). If the channel coding study on this topic is held until the maximum UCI payload size is determined by other AI, then there will not be enough time for channel coding study if the maximum UCI payload size is turned out to be increased from 1706 bits. Subsequently, the early conclusion on channel coding (expected by June 2026) is infeasible.

Considering that, FL would like to collect companies’ views on whether to consider the issues resulting from the increased maximum UCI payload size. This is in Question 3-1.

The following table provides a summary of company proposals related to 6G UCI payload size and corresponding solutions for large UCI payload size.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Nokia | Observation: Motivation/requirement for polar codes with block length greater than 1024 bits is unclear given that the increase of UCI/DCI bits is still unknown. Enhancements for short block lengths can be marginal and at the cost of additional standardization and implementation effort.  Proposal 12: 5G Polar Code should be used for 6G for the block length up to 1024 bits. |
| CATT | Observation 2: The BLER performance improves as the maximum mother code length increases.  Proposal 6: Polar code could be designed/enhanced with longer mother code if the requirement of 6G UCI size increases to more than 1024 bits. The corresponding sequence designs should preserve the nested property to ensure efficient code construction.  Observation 3: The current segmentation rule results in significant performance loss up to about 0.5dB over AWGN channel and does not effectively estimate the crossover point between segmented and non-segmented performance.  Proposal 7: NR segmentation rules should be re-optimized based on simulation results and only applied when a clear performance advantage is demonstrated.  Proposal 8: If larger UCI is supported for 6G, segmentation schemes with more than two segments should be considered. |
| Vivo | Observation 1: The NR polar coding design has well supported the control channel requirements of DCI not exceeding 140 bits and UCI not exceeding 1706 bits.  Proposal 2: Support to reuse the NR polar coding design for the control channels with payload size larger than 11 bits, unless the need for enhancing the polar coding design is well justified, e.g., a much larger DCI/UCI payload is necessary for 6GR. |
| ZTE | Observation 20: The support of larger frequency bandwidth, ultra-massive MIMO and new services will increase the UCI payload in 6G.  Observation 21: As the UCI length increases, performance degradation is observed due to the segmentation in 5G Polar codes.  Proposal 9: Polar coding enhancement should be considered for large UCI lengths.  Proposal 10: The maximum mother code length of Polar codes is 1024 for uplink.  Proposal 11: Polar coding enhancement for segmentation, e.g., increase the maximum number of segments for UCI, can be considered in 6GR. |
| NEC | Proposal 4: For UL, enhanced polar code schemes to support larger mother code length can be considered for 6G. |
| Lenovo | Proposal 7: Study larger Polar reliability sequence by extending current sequence or considering a new sequence to enable better BLER performance for different SNR ranges and different code block sizes. |
| LG | Proposal 4: Polar code enhancement can be considered as a topic for 6G channel coding study, including supports for large UCI payload. |
| Apple | Proposal 4: 6G channel coding to enhance frozen bitmap sequence designs with considerations of various rate-matching protocols and code-length extensions. |
| Fujitsu | Proposal 3:   * In 6GR, 5G Polar codes could be reused for control channel coding. * The maximum code length of polar codes could be enhanced at least for UCI transmissions.   Proposal 4: In 6GR, more flexible lengths of mother codes of polar codes should be introduced.  Proposal 5: In 6GR, multi/mixed polar kernels can be introduced to support more flexible code lengths, e.g., . |
| Ericsson | Observation 9: The necessity of extending channel code design for 6G control channels beyond the NR control channel coding schemes is unclear. This can be revisited based on additional needs (if identified) in other 6GR discussions. |
| CMCC | Observation 1: 5G Polar code may not be optimal for the case of longer DCI/UCI straightforwardly, due to higher decoding latency, degraded error performance and inherent short-block optimization.  Proposal 1: 5G Polar code enhancement for 6G could be considered for larger payload size.  Proposal 2: Prefer Polar enhancement that preserves - rather than expands - the overlapping bit-length range between Polar codes and LDPC codes, such as leveraging 5G Polar code implementations through message segmentation.  Proposal 3: If segmented Polar coding is adopted, enhancement such as outer/inner code across sub-blocks could be considered to provide additional error protection across the sub-blocks. |
| Samsung | Observation 3: NR polar codes have performance degradation when supporting larger payload size.  Proposal 4: Study approaches to enhance flexibility and scalability, for example through the adopting PAC (polarization-adjusted convolutional) coding. |
| Xiaomi | Proposal 1: For 6GR, LDPC and polar are taken as data and control channel FEC respectively.   * Thorough and vigorous evaluation is needed to justify peak data rate oriented incremental enhancement for LDPC * The increase of UCI/DCI payload size(s), if any, shall be triggered by relevant discussion instead of channel coding discussion |
| Qualcomm | Proposal 9: In 6GR, strive to keep the same polar code size as 5G for both uplink and downlink.   * New feature design effort should focus on those bring meaningful performance/implementation gains. |

### [Closed] First round discussions

#### [M] Question 3-1

*Question 3-1: Do you agree that 6G control channel codes should study the issues resulting from increased maximum UCI payload size?*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Xiaomi |  | Prefer discussion after control channel agenda decision. |
| vivo | No | First of all, we’d like to clarify our view. We proposed “reuse the NR polar coding design…. unless the need for enhancing the polar coding design is well justified”. As a matter of fact, it’s not clear to us about large UCI payload size for now. Please capture our views correctly and remove us from proponent company due to large UCI payload.  We think it’s better and appropriate for the control and MIMO session to have a solid common understanding/conclusion on the range of control payload for 6GR before channel coding session jump to enhancement based on some assumptions which may not match real 6GR design requirements.  Companies can study based on their assumption. However, we don’t think there’s a common understanding in RAN1 for now that the maximum UCI payload will be increased. |
| AT&T | Yes | Agree. For some NR scenarios, e.g., UCI carrying CSI over PUSCH in NR, UCI payload is up to ~1700 bits, which may require special handling in container, content and channel code |
| OPPO |  | RAN1 may need to justify first (in control channel agenda) that the maximum UCI payload size should be increased and how large it is increased. |
| MTK |  | We support to investigate the issues if UCI size is agreed to be increased. |
| NEC |  | We agree to study issues resulting from increased maximum UCI payload size if it is agreed. |
| Rakuten |  | Although we are not clear what will exactly be the increased maximum payload size and what will be the issues, we are open for the need of investigation if issues are identified. |
| Intel |  | We are open to study this. |
| Apple | Yes | We think UCI payload size could be more than 1706 bits, due to larger channel bandwidth and MIMO size. We need to support forward compatibility for the potentially increased UCI payload size increase from channel coding aspects, considering that channel coding design is only in the first release of 6G. |
| NTT DOCOMO |  | Before starting the study, there should be common understanding like “Necessity of larger UCI payload size should be separately discussed in the control session. Only if there is a consensus that it is necessary in the control session, enhancement(s) regarding it can be applied.” |
| ZTE, Sanechips | YES | Due to large bandwidth and increased number of antennas, larger UCI payload size is expected in 6GR, it would be prudent to initiate early studies on enhanced solutions for larger UCI payloads.  On the other hand, we would like to point out that even when the UCI size does not exceed 1706, performance degradation still occurs with large UCI. Therefore, it is worth considering enhanced Polar code schemes that can accommodate both UCI sizes above and below 1706. |
| Tejas | Yes | UCI payload size is expected to increase due to larger CSI reports (from increased MIMO configurations) and additional ISAC-related measurement data. |
| CMCC | Yes | The upper limit of larger UCI length could be discussed before control channel codes design, because the length will impact the coding enhancement direction/method. |
| Ericsson | No (at least for now) | The study should be done if maximum UCI payload size is increased. It may not necessarily mean that the control channel is used for such case. However, such decision does not come from this agenda item. We need to wait for decisions from relevant agenda items (MIMO, control channel, etc) for that. |
| Lenovo | Yes | We believe this is worth investigating. UCI payload size range should however be decided by control channel agenda. |
| Samsung | Yes | Due to new spectrum availability and potential bandwidth increase, the CSI feedback size should be expanded accordingly. |
| Fujitsu | Yes | The maximum UCI payload size could be larger in 6GR. |
| Nokia | No | It is not clear yet that there is a need for larger DCI/UCI. |
| LGE | Y | It is better to identify potential solutions for the increased UCI size. Then, after confirming the increased UCI, we can evaluate potential solutions based on the metrics |
| ETRI | Yes |  |
| IDC |  | Larger UCI payloads may arise in 6G due to wider bandwidths and massive MIMO. While final payload size ranges should be clarified in control channel discussions, initiating studies early may be beneficial, and enhancements to Polar code length, segmentation, or related schemes can be considered if needed. |
| Huawei, HiSilicon | No | It is not clear whether a larger UCI is needed. Therefore, we suggest this should be deprioritized. |
| Qualcomm |  | We are open to study issues resulting from increased maximum UCI payload size, if this is agreed. |

## Topic #4: Handling large DCI payload size

### Background

In NR, the largest supported DCI payload size is 140 bits. This limitation is because the interleaver size is 140 bits.

Regarding the maximum DCI payload size,

* The maximum DCI payload size could be more than 140 bits: NEC, Lenovo, Apple, Mediatek, Samsung, CMCC, OPPO, ZTE.
* Unclear of maximum DCI payload size increase: Nokia, Ericsson
* Relevant discussion not in channel coding AI: Xiaomi

In case the maximum DCI payload size in 6G is larger than 140 bits, the potential solutions are proposed by companies:

* Remove interleaver completely: Ericsson
* Code block segmentation: CMCC, ZTE, Apple
  + Two stage PDCCH decoding: Apple
* Revisit/redefine interleaver pattern design: NEC, ZTE, OPPO
* Increase the maximum code block length: Lenovo, Apple
* Optimize precoding scheme to achieve better early decoding termination performance: Apple
* Apply the legacy interleaver over the last (140+24) bits: OPPO
* Study approaches to enhance flexibility and scalability (e.g., PAC code): Samsung

Like the UCI case, it is clear that the discussions on the maximum DCI payload size are dependent on other agenda items’ (AI) decision (e.g., downlink control). If the channel coding study on this topic is held until the maximum DCI payload size is determined by other AI, then there will not be enough time for channel coding study if the maximum DCI payload size is turned out to be increased from 140 bits. Subsequently, the early conclusion on channel coding (expected by June 2026) is infeasible.

Considering that, FL would like to collect companies’ views on whether to consider the issues resulting from the increased maximum DCI payload size. This is in Question 4-1.

The following table provides a summary of company proposals related to 6G DCI payload size and corresponding solutions for large DCI payload size.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Nokia | Observation: Motivation/requirement for polar codes with block length greater than 1024 bits is unclear given that the increase of UCI/DCI bits is still unknown. Enhancements for short block lengths can be marginal and at the cost of additional standardization and implementation effort.  Proposal 12: 5G Polar Code should be used for 6G for the block length up to 1024 bits. |
| Vivo | Observation 1: The NR polar coding design has well supported the control channel requirements of DCI not exceeding 140 bits and UCI not exceeding 1706 bits.  Proposal 2: Support to reuse the NR polar coding design for the control channels with payload size larger than 11 bits, unless the need for enhancing the polar coding design is well justified, e.g., a much larger DCI/UCI payload is necessary for 6GR. |
| NEC | Proposal 2: Revisit the interleaving pattern design with larger length to support larger DCI payload size for 6G.  Proposal 3: For DL, enhanced polar code scheme with improved BLER performance for short mother code length should be studied in 6G. |
| Lenovo | Proposal 7: Study larger Polar reliability sequence by extending current sequence or considering a new sequence to enable better BLER performance for different SNR ranges and different code block sizes.  Proposal 8: Evaluate hybrid online/offline Polar reliability sequence design methods to accommodate different channel conditions, code rates and code block lengths while targeting acceptable memory and computational requirements. |
| Apple | Proposal 1: 6G channel coding to consider facilitation of the two-stage decoding to improve the power consumption of blind decoding.  Proposal 2: 6G channel coding to consider facilitation of the two-stage decoding to improve error correction performance of blind decoding.  Proposal 3: 6G channel coding to consider an optimized precoding scheme of polar codes to enhance early termination complexity savings without negatively impacting false alarm rate.  Proposal 4: 6G channel coding to enhance frozen bitmap sequence designs with considerations of various rate-matching protocols and code-length extensions. |
| Ericsson | Observation 8: The NR coding schemes are quite flexible and can be reused/simplified for potential control channel extension needs, e.g. removing distributed CRC interleaver for PDCCH enables extending DCI payload size to larger than 140 bits (if needed).  Observation 9: The necessity of extending channel code design for 6G control channels beyond the NR control channel coding schemes is unclear. This can be revisited based on additional needs (if identified) in other 6GR discussions. |
| Mediatek | Observation 6: Due to the limitation of maximum 140bit payload sizes and the support of only QPSK QAM, the 5G Polar code design for DCI is limited on scheduling flexibility and resource efficiency to support 6G applications. |
| CMCC | Observation 1: 5G Polar code may not be optimal for the case of longer DCI/UCI straightforwardly, due to higher decoding latency, degraded error performance and inherent short-block optimization.  Proposal 1: 5G Polar code enhancement for 6G could be considered for larger payload size.  Proposal 2: Prefer Polar enhancement that preserves - rather than expands - the overlapping bit-length range between Polar codes and LDPC codes, such as leveraging 5G Polar code implementations through message segmentation.  Proposal 3: If segmented Polar coding is adopted, enhancement such as outer/inner code across sub-blocks could be considered to provide additional error protection across the sub-blocks. |
| Samsung | Observation 3: NR polar codes have performance degradation when supporting larger payload size.  Proposal 4: Study approaches to enhance flexibility and scalability, for example through the adopting PAC (polarization-adjusted convolutional) coding. |
| Xiaomi | Proposal 1: For 6GR, LDPC and polar are taken as data and control channel FEC respectively.   * Thorough and vigorous evaluation is needed to justify peak data rate oriented incremental enhancement for LDPC * The increase of UCI/DCI payload size(s), if any, shall be triggered by relevant discussion instead of channel coding discussion |
| OPPO | Proposal 5: Study solutions to increase polar code payload size in 6G.  Proposal 6: Study the following schemes of interleaving to enable the maximum Polar code payload size to be larger than the one (140+24) in 5G.   * Scheme 1: Follow the legacy design principle to re-define the interleave table (i.e., defined in TS38.212) to support a maximum Polar code payload size that is larger than (140+24). * Scheme 2: Only apply the legacy interleaving over the last (140+24) bits. |
| Samsung | Proposal 4: Study approaches to enhance flexibility and scalability, for example through the adopting PAC (polarization-adjusted convolutional) coding. |
| ZTE | Observation 22: In 6GR, the DCI size may further increase.  Proposal 12: To support large DCI, the followings alternatives can be considered for Polar coding  Alt1: design a larger interleaving length for distributed CRC  Alt2: Support segmentation for DCI |

### [Closed] First round discussions

#### [M] Question 4-1

*Question 4-1: Do you agree that 6G control channel codes to study the issues resulting from increased maximum DCI payload size?*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Xiaomi |  | Prefer discussion after control channel agenda decision. |
| vivo | No | First of all, we’d like to clarify our view. We proposed “reuse the NR polar coding design…. unless the need for enhancing the polar coding design is well justified”. As a matter of fact, it’s not clear to us about large DCI payload size for now. Please capture our views correctly and remove us from proponent company due to large DCI payload.  We think it’s better and appropriate for the control session to have a solid common understanding/conclusion on the range of control payload for 6GR before channel coding session jump to enhancement based on some assumptions which may not match real 6GR design requirements. Again, companies can study based on their assumption. However, we don’t think there’s a common understanding in RAN1 for now that maximum DCI payload will be increased. |
| AT&T | No | Assuming the 6G DCI payload will be in the same range of values as in NR (~140 bits), we don’t see this a priority |
| OPPO | Yes | The DCI payload upper-bound of 140bits has already been a bottleneck in 5G evolution (e.g, in multicarrier enhancement with DCI 0\_3/1\_3). This should be taken care of in Day-1 of 6G if RAN1 does not want to repeat the issue in 6G. In our view, the question is not about whether to lift the restriction, but about how to relax the restriction. To answer this question, RAN1 should study the design based on different potential payload size. In this case, the payload size is not a design requirement; instead it is a design choice based on performance, complexity and etc, which do not need input from control channel agenda. |
| MTK | Yes | We support this proposal in principle. On the other hand, we also agree that we should have an agreeable payload size range first and then identify the issues. |
| NEC |  | Similar to previous comment, we agree to study issues resulting from increased maximum DCI payload size if it is agreed. |
| Rakuten | No | DCI payload size can happen but large PDCCH should be avoided as PDCCH monitoring and blind decoding become costly. DCI fragmentation of a large DCI message, if exists, to load into multiple PDCCHs could be considered as a solution. |
| Intel |  | We are open to study this but it is preferrable to first understand the need to increase the DCI payload. |
| Apple | Yes | We think DCI payload size could be more than 140 bits, due to multiple cell scheduling. We need to support forward compatibility for the potentially increased DCI payload size increase from channel coding aspects, considering that channel coding design is only in the first release of 6G. In 5G, due to the limitation of DCI payload size, some scheduling flexibilities are restricted in a later 5G release. |
| NTT DOCOMO |  | Before starting the study, there should be common understanding like “Necessity of larger DCI payload size should be separately discussed in the control session. Only if there is a consensus that it is necessary in the control session, enhancement(s) regarding it can be applied.” |
| ZTE, Sanechips | Yes | There exist one DCI scheduling multiple cells mechanism for carrier aggregation cases. In that case, we think DCI size would be enlarged, since some DCI fields indicate per cells. |
| Tejas | Yes | To support larger DCI following options should be explored  • Enhancement to inter-leaver to support higher payload size  • Utilization of segmentation schemes  RAN1 to decide appropriate approach based on performance vs decoder complexity analysis. |
| CMCC | Yes | The upper limit of DCI length could be discussed before control channel codes design, because the length will impact the coding enhancement direction/method.  When discussing the upper limit, the overlapping bit-length range between Polar codes and LDPC codes should be considered. We prefer to preserve rather than expand the overlapping bit-length range. |
| Ericsson | No (at least for now) | Same comment as 3.3 |
| Lenovo | Yes | Yet, the DCI design and payload ranges should be agreeable at first to better scope the problem space. Like UCI, DCI payload ranges for 6G should be determined in control channel agenda. |
| Samsung | Yes | Scalability on *increased maximum DCI payload size* is necessary to support future service requirements. |
| Fujitsu | No | Postpone this discussion until the consensus is reached in the control session. |
| Nokia | No | It is not clear yet that there is a need for larger DCI/UCI. |
| LGE | Y | It is better to identify potential solutions for the increased DCI size. Then, after confirming the increased DCI, we can evaluate potential solutions based on the metrics |
| IDC |  | Similar to UCI, support in principle studying possible solutions for larger DCI payload sizes, if required. While the necessity should be confirmed in control channel agendas, early consideration of potential impacts on Polar coding, interleaving, and segmentation will help ensure forward compatibility. |
| Huawei, HiSilicon | No | It is not clear whether a larger DCI is needed. For example, if two stage DCI is used, the DCI payload size is not necessarily increased. Therefore, we think channel coding change justified by this potential increment of DCI should be deprioritized. |
| Qualcomm |  | It is not clear yet that there is a need for larger DCI. |

## Topic #5: Polar code construction, polar sequence and rate matching design

### Background

In 5G DL polar codes, the CRC-aided (CA) polar code is applied. Basically, 24-bit CRC is first generated based on DCI payload bits. The payload bits and CRC bits are interleaved for early decoding termination purpose. The interleaved bits are passed through Polar encoder kernel. The coded bits are saved in circular buffer for rate matching.

In 5G UL polar codes with payload larger than 19 bits, the CA polar code is also applied, without CRC distribution. In 5G UL polar codes with payload between 12 and 19 bits, the parity check (PC) polar code is applied, where up to 3 parity check bits are generated to facilitate pruning the list of candidate paths at decoder side in order to improve the error-correction performance.

For 6G polar code construction, Samsung proposes that a unified and scalable polarization-adjusted convolutional (PAC) coding scheme could be adopted to support both downlink and uplink control channels. PAC codes are considered as an evolution of the polar coding paradigm by incorporating a convolutional pre-transform prior to the standard polar encoding stage. The scheme of using rate-1 pre-transform to reduce the number of CRC bits is also mentioned by Apple. The unfied UL and DL polar code is also proposed by Qualcomm.

ZTE proposes to reuse 5G polar code encoding chain with necessary enhancements for 6G.

In NR polar code, three rate matching schemes are designed for polar codes: repetition, puncturing and shortening. The selection among these rate matching schemes depends on payload size, polar code block size and number of bits to be transmitted. The polar encoded bits are saved to a circular buffer, after performing sub-block interleaving. Depending on determined rate matching scheme, different bits in the circular buffer are selected for transmissions.

Some proposals related to joint polar code sequence and rate matching scheme designs are listed below:

* Enhance frozen bitmap sequence designs with considerations of various rate-matching protocols: ZTE, Apple
* Consider rate matching design under increased maximum code block length: Apple
* Flexible lengths of mother code of polar codes for rate matching purpose: Fujitsu
* Lower decoding complexity and latency by introducing more special nodes in polar sequence: Qualcomm

For 6G control channel code, we need to study/determine the polar code construction scheme(s), as well as joint polar code sequence and rate matching scheme design. Hence, FL has Proposal 5-1.

The following table provides a summary of company proposals on 6G polar code construction schemes, as well as joint polar code sequence and rate matching schemes.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Samsung | Observation 3: NR polar codes have performance degradation when supporting larger payload size.  Proposal 3: Study enhancements of polar or PAC coding schemes to support larger payload size.  Observation 4: NR polar codes exhibit scalability and flexibility limits, which PAC codes could address while reusing existing SCL decoder.  Proposal 4: Study approaches to enhance flexibility and scalability, for example through the adopting PAC (polarization-adjusted convolutional) coding. |
| Apple | Proposal 4: 6G channel coding to enhance frozen bitmap sequence designs with considerations of various rate-matching protocols and code-length extensions.  Proposal 5: 6G channel coding to consider reducing the number of CRC bits for polar precoding by incorporating a rate-1 pre-transformation. |
| ZTE | Proposal 8: 5G Polar code encoding chain can be reused with necessary enhancements for 6G.  Proposal 14: Reuse 5G Polar code rate matching scheme for 6GR.  Observation 23: 5G Polar codes shows a significant performance degradation due to the reliability order impacted by rate matching.  Proposal 15: Further study on the information bit mapping for Polar code. |
| Fujitsu | Observation 3: For 5G polar codes, the lengths of mother codes can only be the power of 2 which may lead to excessive puncture/shorten operations in rate-matching operations.  Proposal 4: In 6GR, more flexible lengths of mother codes of polar codes should be introduced.  Proposal 5: In 6GR, multi/mixed polar kernels can be introduced to support more flexible code lengths, e.g., . |
| Qualcomm | Proposal 8: In 6GR, study polar code designs that support lower decoding complexity and latency.  Proposal 9: In 6GR, strive to keep the same polar code size as 5G for both uplink and downlink.   * New feature design effort should focus on those bring meaningful performance/implementation gains. |

### [Closed] First round discussions

#### [M] Proposal 5-1-a

*Proposal 5-1-a: 6G control channel codes to study the polar code construction scheme(s), as well as joint polar code sequence and rate matching scheme design.*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Xiaomi |  | Is joint polar code sequence and rate matching scheme part of polar code construction? What’s the intention of the proposed joint sequence and rate matching scheme? |
| vivo |  | It’s not clear to us on the intention of this proposal.  As indicated by the SID, NR Polar is the base line. Is the intention of this proposal to encourage companies to study the issue of NR Polar code?  For sure, companies can study based on their preference and assumptions. However, we’re not sure we need any agreement in RAN1 for now saying such study is needed. |
| OPPO |  | “polar code construction scheme(s)” is a broad topic. Maybe the proponents can be more specific which construction schemes are referred to. |
| MTK |  | We suggest to discuss the motivation first. |
| Rakuten |  | Same here. We are not clear about the motivation. |
| Intel |  | We share similar view as previous comments. Motivation needs to be clarified first. |
| Apple | Yes | In 5G channel code, we do not have a chance to carefully design the joint polar code sequence and rate matching scheme. It is a good opportunity to revisit this aspect for 6G.  Also, new polar code construction scheme was proposed after Rel-15 in academic domain. It is a good chance to evaluate its performance in 6G. |
| NTT DOCOMO |  | We prefer to consider reusing 5G coding chain as a starting point. If there are probable enhancement candidates which will lead clear gains, we are OK to study them. BTW, we think the definition of “joint polar code sequence” is not clear, so we want to clarify it. |
| ZTE, Sanechips | No | We propose to reuse the 5G polar code encoding chain, other enhancements need sufficient justification.   * **Study the polar code construction scheme(s):** too generic, the CA-Polar, PC-Polar, D-CRC Polar can be all considered as code construction. It is unclear what the current proposal includes. * **Joint polar code sequence and rate matching scheme design:** we believe the polar code sequence and rate matching scheme from 5G can be reused. Based on our observation, the performance degradation is due to bit pre-freezing operation, not the Polar code sequence or rate matching scheme. |
| Tejas | Yes |  |
| CMCC | YES | The performance gain and complexity should be justified/analyzed. |
| Ericsson | No. | We don’t see any justification to change the existing NR CA-polar code structure. |
| Lenovo |  | We regard this as part of polar code construction and in scope of potential proposals for enhancing Polar coding scheme depending on needs/objectives.  Therefore, we would appreciate some additional clarifications on the meaning and motivation of the proposal. |
| Samsung |  | **To ensure efficient implementation commonality, it may be preferable to retain the 5G polar code sequence and rate matching methods. Nevertheless, these aspects can be revisited should significant benefits be demonstrated.** |
| Fujitsu | Yes | More flexible code length of polar mother codes could be studied. |
| Nokia | No | The motivation for designing a new polar code structure different than the 5G NR polar should be further investigated before discussing solutions. |
| LGE |  | NR polar code should be baseline. If a significant gain can be seen, we can consider them |
| IDC |  | At this stage, it will be important to clarify the motivation and expected benefits first. |
| Huawei, HiSilicon | No | There is no issue for 5G control channel codes. The motivation needs to be justified firstly before the introduction of the change on channel coding for 5G NR polar codes. |
| Qualcomm |  | The proposal seems too broad, new feature design effort should focus on those bring meaningful performance/implementation gains. |

## Topic #6: PDCCH early decoding termination

### Background

The PDCCH decoding latency was considered in NR, via distributed CRC scheme. For 5G downlink control channel coding (i.e., PDCCH), up to 7 out of 24 CRC bits are distributed to earlier positions, together with payload bits reordering, in order to support early polar decoding termination.

Mediatek mentions 5G distributed CRC design for DCI delivers limited early termination benefit at the UE, resulting in increased power consumption and latency. Several companies (NEC, OPPO, Ericsson, Mediatek, Apple) mention to revisit the interleaving pattern design to

* Accommodate larger DCI payload size
* Enhance the early decoding termination benefit
* Reduce decoding latency and power

Besides distributed CRC scheme, other schemes for PDCCH early decoding termination are proposed

* Embedding RNTI sequences into the codeword that can be identified earlier in the decoding process: Apple
* Study a new data integrity check mechanism with the aim to improve payload size scalabilityand early termination rate over 5G distributed CRC design: Mediatek

Note that the trigger of PDCCH early decoding termination could be beyond maximum DCI payload size increase. In other words, even the maximum DCI payload size is 140 bits, the enhancement of PDCCH early decoding termination scheme is considered in this topic.

For 6G control channel code, we need to study/determine whether and how to enhance PDCCH early decoding termination scheme(s). Hence, FL has Proposal 6-1.

The following table provides a summary of company proposals on 6G PDCCH early decoding termination solutions.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| NEC | Proposal 2: Revisit the interleaving pattern design with larger length to support larger DCI payload size for 6G |
| OPPO | Proposal 5: Study solutions to increase polar code payload size in 6G.  Proposal 6: Study the following schemes of interleaving to enable the maximum Polar code payload size to be larger than the one (140+24) in 5G.   * Scheme 1: Follow the legacy design principle to re-define the interleave table (i.e., defined in TS38.212) to support a maximum Polar code payload size that is larger than (140+24). * Scheme 2: Only apply the legacy interleaving over the last (140+24) bits. |
| Ericsson | Observation 8: The NR coding schemes are quite flexible and can be reused/simplified for potential control channel extension needs, e.g. removing distributed CRC interleaver for PDCCH enables extending DCI payload size to larger than 140 bits (if needed). |
| Mediatek | Observation 6: Due to the limitation of maximum 140bit payload sizes and the support of only QPSK QAM, the 5G Polar code design for DCI is limited on scheduling flexibility and resource efficiency to support 6G applications.  Observation 7: The 5G distributed CRC design for DCI delivers limited early termination benefit at the UE, resulting in increased power consumption and latency.  Observation 8: The 5G RNTI scrambling mechanism for DCI is not optimized for RNTI-based false alarm rate among UEs with different RNTIs and endanger DCI reliability especially in denser and more demanding 6G scenarios.  Proposal: Study the feasibility of increasing DCI payload size limit to >140bits  Proposal: Study a new data integrity check mechanism with the aim to improve payload size scalability and early termination rate over 5G distributed CRC design  Proposal: Consider following metric and methodology to facilitate early termination rate evaluation   * Early termination rate:   + : payload size   + m : number of total data integrity check bits   + : the smallest number of decoded information bits (including data intefrity check bits) when none of the candidates in the list can pass the current CRC check(s) after decoding informations bits   + E[] is estimated under SCL with the assumption of list size=8 and pure AWGN noise is transmitted. |
| Apple | Proposal 3: 6G channel coding to consider an optimized precoding scheme of polar codes to enhance early termination complexity savings without negatively impacting false alarm rate.  Proposal 6: 6G channel coding to consider alternative methods of embedding RNTI sequences into the codeword that can be identified earlier in the decoding process. |
| Huawei | Proposal 4: Study the channel coding schemes to support higher reliability and lower decoding latency. |
| DCM | Proposal 2: Discussion and consensus about 6G requirements and characteristics which should be considered for channel coding are needed. Following candidates can be discussed:   * Peak Data Rate and/or User Plane Latency, as same as the SI for 5G NR * Reliability, User Experienced Data Rate, and/or Sustainability/Energy Efficiency, as new candidate requirements for channel coding for 6GR * Other candidates are not precluded |

### [Closed] First round discussions

#### [M] Proposal 6-1-a

*Proposal 6-1-a: 6G control channel codes to study the PDCCH early decoding termination scheme(s).*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Xiaomi |  | We are open for such discussion, but we believe some quantifiable metric for comparing the different early decoding schemes need to be defined firstly. |
| vivo |  | Again, it’s not clear to us on the intention of this proposal.  As indicated by the SID, NR Polar is the base line. Is the intention of this proposal to encourage companies to study the issue of NR Polar code in terms of PDCCH early termination?  If the motivation is for power saving in terms of PDCCH decoding, as we mentioned before in our comments in section 3.2.2, we believe that there are many efficient ways to reduce the power consumption due to unnecessary PDCCH monitoring and blind decoding, wake-up signal and PDCCH skipping as supported in 5G are good examples and we believe those will be supported in 6G day-1 as essential UE power saving features. On top of those, additional power saving benefit by further reducing PDCCH monitoring/enhanced early termination during the active time where PDCCH is monitored is expected to be small, if any. Thus, if companies are willing to study such enhancements, we think proponents should simulate the UE power consumption based on realist traffic model and power model and the comparison should be made to other power saving features (two examples as above) to see the real power gain to justify such coding design study. |
| OPPO |  | We do not think the early decoding termination would come prioritized than the Polar payload size restriction issue. |
| MTK |  | We support to study this aspect. To facilitate discussion, maybe (the first) part of the study should be whether to reuse the same design (distributed CRC) from 5G or not? |
| Rakuten |  | Early termination may only be useful for some selected use cases. We need to be clear what can be the use cases the early termination should be used instead of the one like 5G PDCCH encoding/decoding scheme. Based on this we will see if we can go forward. |
| Apple | Yes | As a UE vendor, we think PDCCH early decoding termination is a very important feature. 5G distributed CRC scheme has limited early decoding termination gain, and we hope to enhance the PDCCH early decoding termination performance for 6G channel code. |
| NTT DOCOMO |  | We think that it’s too early to focus on the specific solution candidate at this point. First, RAN1 should have consensus that “Lower power consumption” should be treated as one of key aspect for 6G control channel coding. After that, we can put the solution candidate(s) targeting it on a table and study them. |
| ZTE, Sanechips |  | We are open to such discussions. But we believe that the practical effectiveness of early termination should be carefully evaluated, along with its impact on complexity and performance (especially FAR). |
| Tejas | Yes | With 6GR supporting higher payload sizes and lower latency, it is important to explore early decoding termination schemes to improve efficiency and enable energy savings. |
| Ericsson | No | Low priority in our view. |
| Lenovo |  | Open to further consider this. |
| Samsung |  | Open to study. |
| Fujitsu |  | Open to study. |
| Nokia | No | The motivation for designing a new polar code structure different than the 5G NR polar should be further investigated before discussing solutions. |
| LGE |  | There were extensive discussions in NR standard phase. Any new suggestion should provide significant benefit.  In case of larger DCI payload is supported, we may need to study extension based on the 5G NR feature. Otherwise, existing early decoding termination scheme in 5G NR would be enough. |
| Huawei, HiSilicon | No | 5G polar codes already support early termination (ET), and has proven to have a balanced performance between BLER, FAR and early termination.  The motivation for the further optimization of early decoding is not justified and the benefit/gain is concerned by companies in online session. |

## Topic #7: Polar code performance enhancement

### Background

Besides the basic functionality of polar code, companies also propose to enhance the performance of polar codes.

1. Lenovo proposes to evaluate hybrid online/offline Polar reliability sequence design methods to accommodate different channel conditions, code rates and code block lengths while targeting acceptable memory and computational requirements. Also, Lenovo proposes to have universal decoding schemes.
2. Fraunhofer consider enhancing the DL polar code BLER performance by relocating the low priority DCI bits (e.g., zero-padded bits, bits with fixed value(s)).
3. Mediatek proposes to study new mechanism of RNTI scrambling to reduce RNTI false alarm rate and study high order QAM polar code for DCI spectral efficiency.
4. Apple proposes a scrambling method before polar transformation to enhance the randomness of unintended PDCCH codewords, in order to reduce false alarm rate.
5. Qualcomm proposes to study conventional (i.e., non-AI/ML) channel coding designs that facilitate exploitation of side information available at the transmitter/receiver about the source information.,

The following table provides a summary of company proposals on enhancing polar code performance.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Apple | Proposal 7: 6G channel coding to consider adding a scrambling method prior to the polar transformation to enhance the randomness of unintended PDCCH codewords. |
| Mediatek | Proposal: Study high order QAM polar code for DCI spectral efficiency enhancement  Proposal: Study new mechanism of RNTI scrambling to reduce RNTI-FA rate  Proposal: Consider following methodology to facilitate DCI RNTI false alarm evaluation.   * Given a target UE , random payload with size K, aggregation level AL, and AWGN channel * Evaluate   + is the list of 8 candidates from SCL decoding   + is the function that recovers the original unscrambled information sequence from a candidate in the list and RNTI |
| Fraunhofer | Observation 1: The message bits from a DCI format comprises zero-padding bits, reserved bits and in some cases, bit indices of fixed value, which are typically known to the UE.  Proposal 1: To improve the reliability of the PDCCH, RAN1 shall study the strategic assignment of “low-priority” bits of a DCI format such as the zero-padded bits, bits with fixed value(s), etc. to bit-indices in the -bit vector for polar encoding based on the reliability of the bit-indices. |
| Lenovo | Proposal 8: Evaluate hybrid online/offline Polar reliability sequence design methods to accommodate different channel conditions, code rates and code block lengths while targeting acceptable memory and computational requirements.  Proposal 10: Study whether Universal decoding is to be considered in 6G study with regards to workload and early-decision targets. |
| Qualcomm | Proposal 11: 6GR should study conventional (i.e., non-AI/ML) channel coding designs that facilitate exploitation of side information available at the transmitter/receiver about the source information. |

### First round discussions

#### [M] Question 7-1

*Question 7-1: Do you have any comments on enhancing 6G polar code performance (e.g., BLER, FAR, etc.)*

**Companies are welcome to provide comments.**

|  |  |
| --- | --- |
| **Company** | **Comments** |
| Xiaomi | We prefer to have consensus on the performance issue with 5G polar code firstly before having this discussion. |
| OPPO | It seems different companies proposed different study direction. There seems no direction gaining common/majority interest. |
| MTK | We suggest to look into the motivation first. In our Tdoc, we identify RNTI related FAR is an issue from 5G design and 6G design should address this. |
| Apple | We support to further enhance 6G polar code performance, including BLER performance and FAR performance. |
| NTT DOCOMO | We tend to have a similar view to Xiaomi. We prefer to identify the performance issue of 5G NR polar codes to be addressed.  And then, if there are probable enhancement candidates which will lead clear gains, we are OK to study them. While, at this point, we don’t have enough information to determine the necessity of each candidate method. |
| ZTE, Sanechips | This question is too generic. Sure, it would be good to achieve better performance. But it should be clarified what the solutions/cost are. |
| Tejas | To support higher reliability DCI/UCI, we need further enhancement to polar coding. |
| Samsung | Number of parity bits (dynamic frozen bits) to be considered |
| Nokia | Performance enhancements to satisfy new 6G requirements, if needed, should be evaluated taking into account the implementation complexity and hardware commonality. |
| ETRI | Need to support low error rate for HRLLC and NTN use cases |
| Huawei, HiSilicon | 5G polar codes have been extensively studied regarding BLER, FAR and ET, and strike a good balance between them. In 6G, we do not see a major change in the requirements for control channel and thus no enough motivation for a redesign for control channel codes. |

## Topic #8: Small block length code

### Background

In NR, for UCI payload size <= 11 bits, short linear codes (i.e., not Polar codes) are used. Specifically, repetition for 1-bit UCI, (3,2) simplex code for 2-bit UCI, and RM coding for 3–11 bit UCI payload.

For 6G, Nokia mentions that small block length block code reuses 5G coding schemes. On the other hand, ZTE, EURECOM and Qualcomm mention that for small UCI block, the BLER and FAR performance should be considered. Qualcomm mentions that Reed-Muller based linear block block has the problem of rank deficiency and decoding ambiguity for some cases. CMCC and Qualcomm propose to reconsider the payload size range for RM code.

The following table provides a summary of company proposals on 6G small block length code.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Nokia | Proposal 15: For 6G, block codes for small block lengths should be kept the same as in 5G. |
| ZTE | Observation 24: According to Shannon’s channel capacity theorem, small block codes has limited error correction capability.  Observation 25: In 5G NR, for UCI transmission in a higher code rate (e.g. K=3~6 at R=2/3), the channel coding scheme cannot ensure a good transmission performance and suffer from error floor.  Proposal 17: Performance enhancement of 6GR small-block UCI transmission should be further considered.  Proposal 18: For the performance metrics of small UCI block, the BLER and FAR performance should be considered. |
| Qualcomm | Observation 3: 5G NR Reed-Muller based linear block code has the problem of rank deficiency and decoding ambiguity for some (N,K) cases.  Proposal 10: 6GR shall study new code design (including rate matching) for the small payload sizes for uplink control channel.   * FFS the maximal payload size K and coded bits N values supported by this new code. |
| CMCC | Proposal 7: If RM code for UCI ranging from 3 to 11 bits is replaced by an optimized coding scheme in 6G, the upper limit of 11 bits could be reconsidered. |
| EURECOM | Observation 1: The performance of 3GPP Short Block-Length codes is far from optimal and there is significant room for improvement.  Proposal 1: Study novel encoding/modulation schemes for transmission of short packages.  Observation 2: For Short Block Length, DMRS introduce a significant amount of sub-optimality and potential novel coding strategies should aim to reduce this overhead.  Observation 3: Simulations of novel coding strategies show significant performance improvements over NR Short Block-Length Codes. |

### [Closed] First round discussions

#### [M] Proposal 8-1-a

*Proposal 8-1-a: RAN1 to study small block length codes for small UCI payload.*

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| EURECOM | Yes | We agree to study new small block-lengths codes for small payloads. However, at this point we do *not* want to restrict this study to UCI payloads. In NR, also LP-WUS uses RM codes to encode the WUS for instance.  Hence, we suggest to remove “UCI” in the proposal and update as follows:  *Proposal 8-1-a: RAN1 to study small block length codes for small ~~UCI~~ payload sizes.* |
| Xiaomi |  | We are open for this discussion, but we prefer to take the same approach, after the consensus on the performance issue with 5G codes are established firstly. |
| vivo |  | Companies can study based on their preference. It’s not clear to us why RAN1 need such agreement. |
| AT&T |  | Open to discuss, conditioned on clear performance gains and reasonable complexity compared with legacy design |
| OPPO |  | Similar comments as from Xiaomi. |
| MTK |  | Is this proposal similar to Q1-3? If they are the same, then please see our comment to Q1-3. If not, then we would like to have discussion on what issues should be studied. |
| NEC |  | We prefer to reuse 5G channel coding schemes as much as possible. |
| Intel |  | We prefer to reuse 5G channel coding schemes for small UCI payloads. |
| Apple |  | We are open to further consider Reed-Muller code for its performance enhancement. |
| NTT DOCOMO |  | We have similar view to Nokia’s. We tend to think the 5G scheme should be reused unless RAN1 finds critical issue(s) regarding small block length codes. First, we can start from identifying the issue of 5G NR small block length codes to be addressed. |
| ZTE, Sanechips |  | For 4G and 5G PUCCH transmission, RM codes are used for small payloads (e.g., smaller than 12 bits). While based on our evaluation, in the cases that UCI transmitted in PUSCH, there are some higher code rate (e.g. R≥2/3) cases that performance of RM code is inferior, e.g. error floor is occurred. However, the detailed solution can be further discussed. Therefore, we have the following suggestion.  *RAN1 to study performance improvement for ~~small block length codes for~~ small UCI payload.* |
| Tejas | Yes |  |
| CMCC | Yes | Unified coding schemes for PUCCH with small payload sizes (1-11bits) are preferred, to avoid excessive variety of codes (e.g., Reed-Muller, Simplex, and Repetition coding schemes). |
| Ericsson | No | The exisiting 5G solution is sufficient. |
| Samsung | No | Prefer to reuse 5G solutions (repetition, simplex, and RM codes). |
| Fujitsu | No | Prefer to reuse 5G schemes. |
| Nokia | No | Motivation is not clear. |
| LGE |  | NR coding scheme should be baseline. If a new coding scheme may show a significant gain, we can consider it. |
| Qualcomm |  | As explained in our contribution, the NR modified Reed Muller codes has performance issues, many (K,N) combinations are not decodable. We support to study code design for the small UCI payload regime.  For the proposal, it may be good to clarify the range of the payload size, e.g., smaller than X, FFS X.  *RAN1 to study performance improvement for ~~small block length codes for~~ channel coding for small UCI payload (e.g., payload size <=X bits).* |

## Topic #9: Evaluation assumptions

### Background

The evaluation assumptions for control channel coding have been proposed by companies.

1. Nokia mentions the polar code decoding is based on SCL with L=8 or 16
2. Xiaomi proposes that evaluation need to reflect the requirements for IC/hRLLC/MC, including the BLER level
3. Lenovo proposes to consider multiple performance metrics beyond coding gain, including latency, complexity, energy efficiency
4. AT&T proposes to evaluate whether the association of channel codes with different physical channels/signals
5. DCM proposes a list of candidate evaluation metrics, including BLER, complexity, flexibility, latency, energy efficiency and area efficiency
6. Xiaomi, Apple, Samsung, ZTE mention simulation assumptions for control channel

The following table provides a summary of company proposals on control channel evaluation assumptions.

|  |  |
| --- | --- |
| **Company** | **Company proposal related to this issue** |
| Nokia | Proposal 13: For 6G Polar Codes evaluation, a baseline receiver should use successive cancellation list (SCL) decoding with a list size of or The key performance metrics for this evaluation are the overall and undetected error probabilities. |
| Xiaomi | Proposal 2: For 6GR, channel coding evaluation shall be performed channel wise instead of scenario wise.   * LDPC is the data channel candidate and the evaluation assumptions need to reflect the requirements for at least IC/hRLLC/MC * Polar is the control channel candidate and the evaluation assumptions need to reflect the requirements for at least IC/hRLLC/MC   Proposal 3: For 6GR, the following evaluation assumptions can be used to check whether the channel coding candidates fulfill the 6GR requirements.   * Evaluate the block error rate (BLER) performance versus SNR  |  |  |  | | --- | --- | --- | | Evaluated Channel Type  Evaluation Assumption | Data Channel | Control Channel | | Modulation | QPSK | QPSK, 64 QAM, 256 QAM | | Coding Scheme | LDPC | Polar | | Code rate | 1/12, 1/6, 1/5, 1/3, 2/5, 1/2, 2/3, 3/4, 5/6, 8/9 | 1/12, 1/6, 1/5, 1/3 | | Decoding algorithm\*\* | min-sum | List decoding | | Info. block length\*\*\* (bits w/o CRC) | 20, 40,100, 200, 400, 600, 1000, 2000, 4000, 6000, 8000  Optional(12K, 16K, 32K, 64K) | | | Channel\* | AWGN | | | \* Fading channels will be simulated in the next stage  \*\* These algorithms are starting points for further study. Other variants of agreed algorithms can be used for encoding and decoding (Complexity details should be illustrated)  \*\*\* At least these info. block length and code rate shall be evaluated. Other info. block lengths and code rates are not precluded. Similar info. and encoded block lengths should be used for the evaluation. Total coded bits = info. Block length/code rate.  Note: these info. block length and code rate are only for initial performance evaluations. They are not interpreted as design targets or assumptions for complexity analysis. | | |  * General guidelines   + BLER simulations down to 10-1 is recommended (to observe the error floor) for IC/MC   + BLER simulations down to 10-4 is recommended (to observe the error floor) for hRLLC |
| Lenovo | Proposal 1: Consequently, 6G Radio channel coding evaluation should consider multiple performance metrics beyond coding gain, such as latency, complexity, energy efficiency, and adaptability to diverse service requirements.  Proposal 11: Evaluate and capture different performance metrics, such as throughput, decoding latency, computational and implementation complexity and energy efficiency, for 6G channel coding schemes beyond BLER vs. SNR performance.  Proposal 12 BLER vs. SNR performance evaluation should consider 5G setup as baseline, while additional configurations could be defined when evaluating enhancements not supported by 5G NR, such as a new base graph (BG3). |
| AT&T | Proposal 1: For 6GR, evaluate whether the association of channel codes with different channels and control information sequences follows legacy NR rules. |
| DCM | Proposal 3: At least, the following evaluation metrics should be treated as candidates to evaluate whether 6G requirements and characteristics are satisfied with acceptable performance/complexity trade-off   * BLER, Complexity, Flexibility, Encoding/Decoding latency, Energy efficiency, and Area efficiency   Proposal 4: Discuss the relationship between 6G requirements/characteristics and channel coding-specific evaluation metrics to have common understanding. For each 6G requirement/characteristic, following can be discussed as its pair:   * Metrics that should be improved/monitored (to evaluate the effectiveness of enhancements) * Metrics that can be in trade-off (to evaluate the potential side effects of enhancements) |
| Apple | Table 1: Simulation assumptions for data channel   |  |  | | --- | --- | | Parameters | Values or assumptions | | Channel | AWGN | | Modulation | QPSK, 64 QAM, 256 QAM | | Coding Scheme | LDPC | | Code rate | 1/5, 1/3, 2/5, 1/2, 2/3, 3/4, 5/6, 8/9 | | Decoding algorithm | Min-sum (8/16/32/64 BP decoding iterations) | | Info. block length (w/o CRC) | 100, 400, 1000, 2000, 4000, 6000, 8000, 12000, 16000, 32000, 64000 |   Table 2: Simulation assumptions for control channel   |  |  | | --- | --- | | Parameters | Values or assumptions | | Channel | AWGN | | Modulation | QPSK, 16 QAM, 64 QAM | | Coding Scheme | Reed Muller, Polar | | Code rate | 1/12, 1/6, 1/3, 1/2, 2/3 | | Decoding algorithm | FHT, SC list | | Info. block length (w/o CRC) | 4, 8, 16, 32, 48, 64, 80, 120, 200, 400, 1000, 2000, 4000 |   Proposal 11: 6G channel coding to define the evaluation assumptions, based on Tables 1 and 2. |
| Huawei | Table 3: Complexity evaluation methodology for LDPC and Polar code   |  |  |  |  | | --- | --- | --- | --- | | Coding Scheme | LDPC | Polar | | | Decoder | LMS | SCL | Simplified SC (SSC) | | Addition | I∙M(2dc+2) | L∙Nlog2N+(N-K)L/2+L∙K |  | | Comparison | I∙M(2dc-3) | 2K∙L∙log22L | 0 | | Total Computational Complexity | I∙M(4dc-1) | L∙N∙log2N+2K∙L∙log22L+(N-K)L/2+L∙K |  |   Proposal 1: Adopt the complexity evaluation methodology in Table 3, and BLER performance shall be compared under the same-complexity assumption. |
| Samsung | Simulation assumptions: Polar codes   * Evaluate the flexibility and block error rate (BLER) performance versus SNR  |  |  | | --- | --- | | Channel | AWGN | | Modulation | QPSK | | Coding Scheme | Polar code | | Code rate | 1/6, 1/5, 1/3, 2/5, 1/2, 2/3, 3/4 | | Decoding algorithm | SCL decoding with list-8 | | Info. block length (bits w/o CRC) | DL: 10:10:1000  UL: 10:10:100, 400, 1000, 2000 |   Evaluation metrics and criteria   * Performance: Target transport block error rate (BLER) [10-2 or 10-3] * Complexity * Latency * False Alarm Rate (FAR) * Total saved computational complexity ratio (TSCCR\*) for early termination gain   \*TSCCR = 1- No. of information bits decoded with early termination / No. of information bits decoded without early termination |
| ZTE | Table 5 Simulation assumption for UCI   |  |  | | --- | --- | | Channel | AWGN | | Modulation | QPSK | | Polar code | 5G Polar code with Nmax=1024 | | Decoding Scheme | CA-SCL decoder with L=8 | | Code rate | 1/8, 1/6, 1/5, 1/3, 2/5, 7/16, 1/2, 9/16, 5/8, 2/3, 5/6 | | Info. block length | 20:4:256,264:8:512,528:16:1706 |   Table 8 Simulation assumption   |  |  | | --- | --- | | Channel | AWGN | | Modulation () | QPSK | | Encoding Scheme | 5G Block code | | CRC length | 0 | | Decoding Scheme | ML | | Code rate | 2/3 | | Payload size (K) | 3~6 | | Rate matching length (E) |  |   For UCI:   * Target BLER:1% * Undetected‑error rate: ≤ 5% * DTX to ACK error rate, ACK miss detection (including ACK to NACK and ACK to DTX) error rate:1% * NACK to ACK error rate: 0.1%   Proposal 18: For the performance metrics of small UCI block, the BLER and FAR performance should be considered. |

### [Closed] First round discussions

#### [M] Proposal 9-1-a

*Proposal 9-1-a: For polar code evaluation, the following evaluation assumptions are considered as starting point.*

|  |  |
| --- | --- |
| Channel | AWGN |
| Modulation | QPSK, (FFS: QAM) |
| Coding Scheme | Polar code |
| Code rate | 1/12, 1/6, 1/5, 1/3, 2/5, 1/2, 2/3, 3/4 |
| Decoding algorithm | SCL decoding (FFS list size) |
| Info. block length (bits w/o CRC) | FFS |
| Performance metrics | BLER, FAR, complexity, latency, energy efficiency (FFS other metrics and metric details) |

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Xiaomi |  | We prefer to put BLER and FAR there firstly, for the other metrics, we prefer to have aligned understanding and clear definition before putting up the metrics there. |
| vivo |  | For control channel coding design, we think BLER and FAR are essential.  As we commented before toward energy/power efficiency, if companies want to emphasize power saving gain, we think proponents should simulate the UE power consumption based on realist traffic model and power model and the comparison should be made against and/or on top of other power saving features (two examples as above) to see the real gain. |
| OPPO | Yes |  |
| MTK |  | We suggest to conclude the enhancements companies want to study. Then we can decide what is the related simulation assumption. Therefore, we suggest to postpone the simulation assumption discussion till we have consensus on what to study. |
| Apple | Yes | This is considered as starting point of evaluation assumptions for polar code. |
| NTT DOCOMO |  | Support in general.  Granularity of code rate could be a discussion point, but we don’t have any strong views about it at this point. |
| ZTE, Sanechips |  | The code rates should include 1/8, as the lowest code rate supported in 5G is 1/8.  BLER and FAR are two fundamental performance metrics. The target BLER value may be set to 0.01 or 0.001. As for complexity, latency, and energy efficiency, they should be clearly defined first before including in the performance evaluation assumptions. |
| Tejas | Yes | We agree with the proposed evaluation assumptions. |
| CMCC |  | QAM should not be supported at least for PDCCH, due to the high blind detection complexity.  Down select three code rates for evaluation is enough (e.g., 1/6, 1/2, 3/4).  More details should be provided to explain how to evaluate the energy efficiency. |
| Ericsson | Yes | OK. However, we would need to clarify the methodology for energy efficiency. We do not have a power model for such evaluations. |
| Lenovo | Yes |  |
| Samsung | No | All aspects are acceptable except for latency, energy efficiency, and complexity. Defining energy efficiency is challenging because it depends heavily on implementation-specific factors, which underscores the need for proper quantification.     |  |  | | --- | --- | | Channel | AWGN | | Modulation | QPSK, (FFS: QAM) | | Coding Scheme | Polar code | | Code rate | 1/12, 1/6, 1/5, 1/3, 2/5, 1/2, 2/3, 3/4 | | Decoding algorithm | SCL decoding (FFS list size) | | Info. block length (bits w/o CRC) | FFS | | Performance metrics | BLER, FAR (FFS other metrics and metric details) | |
| Fujitsu |  | Generally fine with this assumption. But for the latency and energy efficiency, we are unclear how to evaluate. |
| Nokia | Yes | 5G NR parameter values should be included to calibrate the evaluation results. |
| LGE | Y | The metrics (e.g., BLER, complexity, and latency) were used in NR standard phase are OK. FAR and energy efficiency can be considered for a specific physical control channel. |
| ETRI | Yes | Need to support low error rate for HRLLC and NTN use cases |
| Huawei, HiSilicon | See comments | It is not clear on the target of the evaluation assumptions, and we suggest that firstly discuss the motivations on the further change of 5G NR. |
| Qualcomm |  | OK in principle. However, it may be challenging to define energy efficiency. |

### [Closed] Second round discussions

#### [M] Proposal 9-1-b

*Proposal 9-1-b: For polar code evaluation, the following evaluation assumptions are considered as starting point.*

|  |  |
| --- | --- |
| Channel | AWGN |
| Modulation | QPSK (FFS: QAM) |
| Coding Scheme | Polar code |
| Code rate | 1/6, 1/3, 1/2, 2/3, 3/4 |
| Decoding algorithm | SCL decoding (FFS list size) |
| Info. block length (bits w/o CRC) | 12:4:256, 264:8:512, 528:16:1706 |
| Performance metrics | BLER, FAR (FFS: other metrics) |

**Companies are welcome to provide comments.**

|  |  |  |
| --- | --- | --- |
| **Company** | **Yes or No** | **Comments** |
| Tejas | Yes | We agree with the proposed evaluation assumptions. |
| LG | Y | Acceptable. FAR can be applied to a specific physical channel. |
| Ericsson | Yes | OK. |
| vivo |  | It is unclear why CR of 1/12 is removed. In NR, the lowest CR can be 1/8. |
| Samsung | Yes | OK, To avoid ambiguity, the false alarm rate (FAR) should be explicitly defined as the false positive rate (FPR) in the context of no-signal or randomly modulated (e.g., QPSK) signal conditions. |
| Apple | Yes | The evaluation assumptions serve as starting point. All the feature related evaluation assumptions could be added later based on needs. |

## Others

Besides the issues discussed in above sections for control channel coding, FL would like to collect companies’ views on any other topics to be studied. This is in Question 10-1.

*Question 10-1: Do you think any other topics could be studied for control channel coding?*

|  |  |
| --- | --- |
| **Company** | **Comments** |
| **MTK** | **For better SE, we suggest to study DCI with high order QAM.**  **For RNTI FA issued identified in our Tdoc, if it is not included in other FL proposals, we suggest to study this aspect.** |
| Huawei | 1. ***Keep polar codes for channel coding of control information in 6GR, including:***  * ***Downlink control information (DCI) on DL control channel*** * ***Uplink control information (larger than 11 bits) on both uplink control channel and uplink shared channel.***  1. ***Keep polar codes for channel coding of PBCH payload bits in 6GR.*** |

# Proposals for offline discussions

## Proposals for Wednesday online discussions

### Proposal 1-1-a

In the first round, 22 companies commented on Question 1-1. All 22 companies support that polar code is the channel coding scheme for PDCCH.

Ericsson particularly mentions to use 5G CA-polar code for 6G PDCCH, while some companies (Samsung, LG) mention to consider enhancements on top of 5G DL polar code. At this moment, the common part among companies is to use polar code for 6G PDCCH. The detailed polar code construction can be discussed later.

Hence, FL has the following proposal for PDCCH channel coding scheme.

*Proposal 1-1-a: Polar code is the channel coding scheme for PDCCH.*

### Proposal 1-2-a

In the first round, 22 companies commented on Question 1-2. Most companies think polar code should be used for UCI with large payload size.

One comment from companies (e.g., AT&T, MTK, NEC, Intel, Ericsson, Fujitsu) is about the proposal could be extended to coding scheme for UCI, which could be carried over by either PUCCH or PUSCH. This is captured in Proposal 1-2-a.

One comment from companies (e.g., Xiaomi, vivo, ZTE) is about the range of “large payload size”. Although some companies mention to follow the same channel coding schemes as in 5G for PUCCH with similar payload size, there is still a proposal to keep the lower bound open. To clarify on this UCI payload size range, in proposal 1-2-a, FL provides an example of the lower bound.

AT&T mentions for UCI over PUCCH, it is polar code; for UCI over PUSCH whose payload is more than 1706 bits, then the coding scheme is FFS.

MTK mentions if UCI payload size in 6G is the same as 5G, it always uses polar code. Even if UCI payload size is more than 1706 bits, then the coding scheme is polar code.

Ericsson particularly mentions to use 5G CA-polar code for 6G PDCCH. FL thinks this detailed design could be left for further discussion. For payload sizes beyond NR limit (1706 bits), Ericsson thinks that first a clearer need should be identified in the relevant agendas (e.g. MIMO, control information discussion). Additionally, these agenda may also discuss whether to still carry control information as L1 UCI or instead use L2 signalling for such large payloads. This is captured on the upper bound of UCI payload size.

*Proposal 1-2-a: At least for UCI payload size between X bits and 1706 bits, polar code is the channel coding scheme for UCI.*

* *FFS value of X (e.g., X= 12)*

### Proposal 1-3-a

In the first round, 20 companies commented on Question 1-3. Most of the companies support to reuse 5G design as the baseline.

One comment from companies is about the range of “small payload size”. This is captured in Proposal 1-3-a.

CMCC wants to have a unified coding scheme for UCI with payload size smaller than 12 bits. ZTE is open on using sequence based solution, or RM code enhancement for payload size smaller than 12 bits.

*Proposal 1-3-a: The following channel coding schemes for UCI are used:*

* *For 1-bit UCI, repetition as in 5G*
* *For 2-bit UCI, simplex as in 5G*
* *For UCI payload size between 3 bits and X bits, Reed-Muller code*
  + *FFS value of X (e.g., X =11)*

### Proposal 1-4-a

In the first round, 20 companies commented on Question 1-4. All 20 companies support that polar code is the channel coding scheme for PBCH.

Ericsson particularly mentions to use 5G CA-polar code for 6G PBCH, while some companies (Samsung, LG) mention to consider enhancements on top of 5G DL polar code. At this moment, the common part among companies is to use polar code for 6G PBCH. The detailed polar code construction can be discussed later.

Hence, FL has the following proposal for PBCH channel coding scheme.

*Proposal 1-4-a: Polar code is the channel coding scheme for PBCH.*

### Proposal 2-1-b

In the first round, 22 companies commented on Proposal 2-1-a.

Several companies want to focus on the issues of control channel code. Specifically, the motivation of updating from 5G control channel code should be clarified. Hence, FL proposal is modified to provide a list of potential motivations for study.

Some companies commented on supporting or not supporting a certain motivation. FL thinks that we do not exclude some candidate of the motivation at this stage. Instead, the full list allows companies to first study it and then we could have the conclusion. Hence, FL has the following proposal to study the motivation of 6G control channel code.

*Proposal 2-1-b: For 6G control channel code design, study the necessity of at least the following motivations:*

* *DCI and UCI payload size*
* *Decoding complexity*
* *Decoding power consumption*
* *Decoding latency*
* *Performance (e.g., BLER, FAR)*
* *Balance between performance and implementation complexity*
* *Hardware commonality between 5G and 6G*

### Proposal 9-1-b

In the first round, 17 companies commented on Proposal 9-1-b.

For the performance metrics, BLER and FAR are prioritized by some companies, while other metrics are questioned by some companies. Hence, FL keeps BLER and FAR as the performance metrics in the table.

Some companies comment on code rate, e.g., to reduce the number of code rate for evaluation. This is reflected in the modified proposal.

Furthermore, the information block lengths (w/o CRC) are added to complete the table.

Hence, FL has the following proposal for the evaluation assumptions for polar code.

*Proposal 9-1-b: For polar code evaluation, the following evaluation assumptions are considered as starting point.*

|  |  |
| --- | --- |
| Channel | AWGN |
| Modulation | QPSK (FFS: QAM) |
| Coding Scheme | Polar code |
| Code rate | 1/6, 1/3, 1/2, 2/3, 3/4 |
| Decoding algorithm | SCL decoding (FFS list size) |
| Info. block length (bits w/o CRC) | 12:4:256, 264:8:512, 528:16:1706 |
| Performance metrics | BLER, FAR (FFS: other metrics) |

## Proposals for Thursday offline discussions

### Proposal 1-1-c

*Proposal 1-1-c: Polar code is baseline for PDCCH with payload size between 12 bits and 140 bits, where the polar code refers to one of the following alternatives:*

* *Alt 1: 5G polar transform only*
* *Alt 2: 5G polar sequence plus transform*
* *Alt 3: 5G polar sequence plus transform plus concatenated coding (CA polar code) (i.e., TS 38.212/Section 5.2.1, 5.3.1.2)*
* *Alt 4: 5G interleaving (CRC distribution), 5G polar sequence plus polar transform plus concatenated coding (i.e., TS 38.212/Section 5.2.1, 5.3.1.1 and TS 38.212/Section 5.3.1.2)*

### Proposal 1-2-c

*Proposal 1-2-c: At least for UCI payload size between X bits and Y bits, if UCI is treated as layer 1 information, polar code is considered for UCI, where the polar code refers to one of the following alternatives:*

* *Alt 1: 5G polar transform only*
* *Alt 2: 5G polar sequence plus transform*
* *Alt 3: 5G polar sequence plus transform plus concatenated coding (CA or PC polar code) (i.e., TS 38.212/Section 5.3.1.2)*
* *Alt 4: 5G code block segmentation, 5G polar sequence plus polar transform plus concatenated coding (i.e., TS 38.212/Section 5.2.1 and TS 38.212/Section 5.3.1.2)*
* *FFS value of X (e.g., X= 12)*
* *FFS value of Y (e.g., Y=1706)*

### Proposal 9-1-c

*Proposal 9-1-c: For polar code evaluation, the following evaluation assumptions are considered as starting point.*

|  |  |
| --- | --- |
| Channel | AWGN (FFS: fading channel) |
| Modulation | QPSK, (FFS: QAM) |
| Coding Scheme | Polar code |
| Code rate | 1/12, 1/6, 1/3, 1/2, 2/3, ¾ (UL only), 5/6 (UL only) |
| Decoding algorithm | SCL decoding (FFS list size) |
| Info. block length (bits w/o CRC) | 12:4:140, 140:4: 256 (UL only) 264:8:512 (UL only), 528:16:1706 (UL only) (FFS other values) |
| Performance metrics | BLER, FAR (FFS: other metrics and detailed definition) |

*Note: When company reports the results, it provides the definition of polar code scheme.*

*Note: Performance is provided with the justification of necessity of enhancement.*

### Proposal 10-1-a

*Proposal 10-1-a: For 6GR control channel coding, for each proposed scheme, proponent companies are encouraged to study and report the following:*

* *Details of scheme, target scenario, whether and how to meet 6G requirements and characteristics with acceptable performance/complexity trade-off*
* *Evaluation assumption including decoding algorithm, information sizes, code rates, channel type, target BLER, target FAR*
* *Evaluation methodology, e.g.,*
  + *BLER results*
  + *FAR results*
  + *Complexity evaluation methodology and results*
  + *Latency evaluation methodology and results*

*Proposal 10-1-a: For 6GR control channel coding, study channel coding extension based on the following:*

* *Evaluations can be provided in form of BLER and FAR results.*
* *Evaluations/analysis can be provided for computational complexity, decoding latency, [impact to hardware]*
  + *Other metrics are not precluded.*
* *Proponent companies to provide evaluation assumptions and methodologies for respective evaluation.*
* *Proponent companies to provide details of channel coding extension.*
* *Proponent companies to provide their justification for the channel coding extension, compared with control channel codes as defined in 5G NR.*

# Proposals for online discussions

## Proposals for Thursday online discussions

*Proposal 1-1-b: Polar code is the channel coding scheme for PDCCH with payload size between 12 bits and 140 bits, where the polar code refers to one of the following alternatives:*

* *Alt 1: 5G polar transform only*
* *Alt 2: 5G polar sequence plus transform*
* *Alt 3: 5G polar sequence plus transform plus concatenated coding (CA polar code) (i.e., TS 38.212/Section 5.3.1.2)*
* *Alt 4: 5G interleaving (CRC distribution), 5G polar sequence plus polar transform plus concatenated coding (i.e., TS 38.212/Section 5.3.1.1 and TS 38.212/Section 5.3.1.2)*

*Proposal 1-2-b: At least for UCI payload size between X bits and Y bits, if UCI is treated as layer 1 information, polar code is the channel coding scheme for UCI, where the polar code refers to one of the following alternatives:*

* *Alt 1: 5G polar transform only*
* *Alt 2: 5G polar sequence plus transform*
* *Alt 3: 5G polar sequence plus transform plus concatenated coding (CA or PC polar code) (i.e., TS 38.212/Section 5.3.1.2)*
* *Alt 4: 5G code block segmentation, 5G polar sequence plus polar transform plus concatenated coding (i.e., TS 38.212/Section 5.2.1 and TS 38.212/Section 5.3.1.2)*
* *FFS value of X (e.g., X= 12)*
* *FFS value of Y (e.g., Y=1706)*

## Proposals for Friday online discussions

*Proposal 10-1-b: For 6GR control channel coding, study channel coding extension based on the following:*

* *Evaluations can be provided in form of BLER and FAR results.*
* *Evaluations/analysis can be provided for computational complexity, decoding latency, [impact to hardware]*
  + *Other metrics are not precluded.*
* *Proponent companies to provide evaluation assumptions and methodologies for respective evaluation.*
* *Proponent companies to provide details of channel coding extension.*
* *Proponent companies to provide their justification for the channel coding extension, compared with control channel codes as defined in 5G NR.*

*Proposal 9-1-d: For polar code evaluation, the following evaluation assumptions are considered as starting point.*

|  |  |
| --- | --- |
| Channel | AWGN (FFS: fading channel) |
| Modulation | QPSK, (FFS: QAM) |
| Coding Scheme | Polar code |
| Code rate | 1/12, 1/6, 1/3, 1/2, 2/3, ¾ (UL only), 5/6 (UL only) |
| Decoding algorithm | SCL decoding (FFS list size) |
| Info. block length (bits w/o CRC) | 12:4:140, 140:4: 256 (UL only) 264:8:512 (UL only), 528:16:1706 (UL only) (FFS other values) |
| Performance metrics | BLER, FAR (FFS: other metrics and detailed definition) |

*Note: When company reports the results, it provides the definition of polar code scheme.*

*Note: Performance is provided with the justification of necessity of enhancement.*

# Outcomes of RAN1 #122 meeting

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