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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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z the third digit is incremented when editorial only changes have been incorporated in the document.

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

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

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

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

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

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

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

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

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

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

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

In addition:

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

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

The constructions "is" and "is not" do not indicate requirements.

# 1 Scope

The present technical report documents the Phase I study outcome on the advanced receiver to cancel inter-user interference for MU-MIMO, with the detailed objectives as follows:

- Evaluate and specify advanced receiver to cancel inter-user interference for MU-MIMO

- Phase I: Study the performance gain, reference receiver assumption, interference modeling, testability, required signalling overhead, as well as impact on other WGs

- Further discuss reference receiver assumption with below candidates

- E-MMSE-IRC

- R-ML

- Target scenario: Focus on slot based transmission

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

# 3 Definitions, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

## 3.2 Symbols

Void

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

AL Aggregation level

AP Antenna port

BWP Bandwidth part

CBW Channel bandwidth

CDM Code division multiple

CORESET Control resource set

CSI-RS Channel state information reference signal

DCI Downlink Control Information

DMRS Demodulation reference signal

E-MMSE-IRC Enhanced Minimum mean square error - interference rejection combining

FD-CDM Frequency division - code division multiple

FDD Frequency Division Duplex

FDRA Frequency domain resource allocation

HARQ Hybrid Automatic Repeat Request

MCS Modulation and Coding Scheme

MMSE-IRC Minimum mean square error - interference rejection combining

MU-MIMO Multi-user-Multiple Input Multiple Output

NZP Non-zero-power

OFDM Orthogonal Frequency Division Multiplexing

PDSCH Physical Downlink Shared Channel

PRG Precoding resource block group

PSS Primary synchronization signal

PT-RS Phase-tracking reference signal

QAM Quadrature Amplitude Modulation

QCL Quasi co-location

RB Resource block

RE Resource element

R-ML Reduced complexity Maximum likelihood

RRC Radio Resource Control

SCS Subcarrier spacing

SNR Signal-to-noise ratio

SSB Synchronization signal block

SSS Secondary synchronization signal

TBS Transport block size

TCI Transmission configuration indicator

TDL Tapped delay line

TDRA Time domain resource allocation

TM Transmission mode

ULA Uniform Linear Array

# 4 Advanced receiver to cancel inter-user interference for MU-MIMO

## 4.1 Scenario and interference modelling

### 4.1.1 Scenario

MU-MIMO allows gNB to transmit data to multiple UEs in the same time-frequency resources through spatial multiplexing. The process of selecting paired UEs is called ‘pairing’. As illustrated in Figure 4.1.1-1, UE1 and UE2 are paired and gNB transmits data to both UEs with suitable precoders through the same time-frequency resources. However, the gNB cannot guarantee the perfect pairing of multiple users in the real network. The paired UEs may not perfectly spatially orthogonal to each other and this will induce the intra-cell interference between paired UEs.



Figure 4.1.1-1. gNB transmit data to paired UE1 and UE2 with the same time-frequency resources

To evaluate the performance of UE with intra-cell interference induced by spatial multiplexing, the following scenarios illustrated from Figure 4.1.1-2 to Figure 4.1.1-3 are considered for the case of number of paired UEs is 2. Moreover, scenario illustrated in Figure 4.1.1-4 is considered for the case of number of paired UEs is 3.

- Target UE with single DMRS antenna port:

- Scenario 1: Number of CDM group without data is 1

- AP1000 for target UE, AP1001 for interference UE

- Target UE with two DMRS antenna ports:

- Scenario 2: Number of CDM group without data is 2

- AP1000 and 1001 for target UE, AP1002 and 1003 for interference UE

- Target UE with single DMRS antenna port:

- Scenario 3: Number of CDM group without data is 1

- AP1000 for target UE, AP1001 for 2 interference UEs with different frequency domain allocation.



Figure 4.1.1-2: Scenario 1, number of CDM group without data is 1 and AP1000 for target UE, AP1001 for interference UE



Figure 4.1.1-3: Scenario 2, number of CDM group without data is 2 and AP1000 and 1001 for target UE, AP1002 and 1003 for interference UE



Figure 4.1.1-4: Scenario 3, number of CDM group without data is 1 and AP1000 for target UE, AP1001 for 2 interference UEs with different frequency domain allocation

### 4.1.2 Interference model

The PDSCH of the co-scheduled UE consists of QAM modulated uncoded random bits. The modulation order of PDSCH of paired UEs can be selected independently. The DMRS sequences of paired UEs are assumed to be known for channel estimation purposes for all paired UEs. Note that the DMRS scrambling sequences of paired UEs are assumed to be the same to guarantee orthogonality.

The PDSCH and DMRS of the paired UEs are precoded prior to transmission. The precoder for each user is denoted by and respectively.

In the scope of this technical report is the precoder matrix of ith UE, of size NTX x NLi from Type I single panel codebook as described in [3GPP TS 38.214]. Where, NTX is the number of TX antenna, NLi is the number of layers from ith UE. The combined precoder , of size NTX x NL where, NL is the total number layers across all users. In general, other codebooks are also valid for MU-MIMO scenarios with advanced receiver.

The precoder of the target UE is randomly selected. For the co-scheduled UE, the precoder is selected in one of the two ways below.

- Orthogonal precoder: is randomly selected from the codebook with a constraint that the combined precoder **W** has orthogonal columns, i.e., the off-diagonal entries of **WHW** are zero.

- Random precoder: is randomly selected from the codebook ensuring any column of is not identical to any column of

To maintain the average per UE signal power as NLi /NL, an additional scaling is applied to the each precoder as:

## 4.2 Receiver structure

### 4.2.1 General

In this clause, we provide the receiver structure to mitigate the intra-cell inter-user interference.

The NRx-dimensional received signal vector **r** of the -th subcarrier and the -th OFDM symbol is assumed to be expressed as a sum of target’s UE own signal , and co-scheduled UEs’ interference signals (j>1) and the white noise ;

Where,

 and represent the Nlayer,j x1 transmitted signal vector and the (NRx x Nlayer,j) channel matrix between the *j*-th co-scheduled UE’s interference and the UE containing the contribution from receiver branches, with for two receiver antennas and for four receiver antennas, where, channel-matrix of size Nlayer,j x1 for the *i*-th receiver antenna, respectively.

 is the number of paired UEs.

### 4.2.2 E-MMSE IRC receiver

To suppress the co-scheduled UE’s interference, the candidate E-MMSE IRC receiver type is captured in this subclause. The E-MMSE IRC receiver weight matrix is expressed as follow:

,

 .

Where,

 and denote the estimated channel matrix and the transmit signal of all UE’s DMRS symbols, respectively, where the estimated channel matrix is also based on DMRS.

 is the number of sampling REs of intra-user’s DMRS.

 *Pj* is the power of *j-*th UE.

### 4.2.3 R-ML receiver

ML receiver performs joint maximum likelihood detection of the useful and co-scheduled UE signals considering the constellations of both signals:

 =

 []

So the ML receiver can be rewritten as

Where,

 denotes the -norm of a vector.

 is the received signal vector.

is the channel matrix over target and interference layers for a RE at frequency location *k* and symbol *l*.

*S* is the set of all possible transmitted signal vectors across target and interference spatial layers.

Reduced complexity ML (R-ML):

Reduced complexity joint detection of useful and interference modulation symbols in accordance to the ML criterion (e.g. sphere decoding, QR-MLD, MLM, etc.).

## 4.3 Analysis on the required information

The agreed list of required information for advanced receiver is captured below:

|  |  |  |
| --- | --- | --- |
| Information | RAN4 Default assumption(If N/A, how could be obtained by the UE) | Signalling if RAN4 default assumption not valid |
| The DMRS port information for the co-scheduled UE | N/A (Obtained by UE blind detection) | N/A |
| PRB bundling size for the co-scheduled UEFrequency domain resource allocation for the co-UE within each PRG of the target UE | For the target and any co-scheduled UEs in different CDM groups and with the same DMRS sequence, the target UE assumes the precoding and resource allocation of the co-scheduled UE are the same in the PRG-level grid configured to the target UE when PRG=2 or 4. | Introduce dedicated RRC signalling to indicate whether the default assumptions valid or not |
| DMRS power boosting for the co-scheduled UE | Same as target UE | Introduce dedicated RRC signalling to indicate whether the default assumptions valid or not |
| Time domain resource allocation information of the co-scheduled UE | Same as target UE | Introduce dedicated RRC signalling to indicate whether the default assumptions valid or not |
| Frequency domain resource allocation for the co-UE across different PRGs of the target UE: | N/A (Obtained by UE blind detection) | N/A |
| CSI-RS location of co-scheduled UE (Only required for R-ML) | UE assumes the target PDSCH is not overlapped with the CSI-RS of the co-scheduled UE | No RRC signalling is needed |
| Modulation order of co-scheduled UE | N/AObtained by DCI based network assistance information or UE blind detection |  |

DCI based network assistance information for the co-scheduled UE existence and modulation order related information signalling is captured in the table below:

|  |  |
| --- | --- |
| Bit field mapped to index | Content |
| 0 | No co-scheduled UE(s) which has same DMRS sequence as target UE exists |
| 1 | In all the PRBs allocated to the target UE, all the co-scheduled UE(s), which has the same DMRS sequence as the target UE, have QPSK scheduled |
| 2 | In all the PRBs allocated to the target UE, all the co-scheduled UE(s), which has the same DMRS sequence as the target UE, have 16QAM scheduled |
| 3 | In all the PRBs allocated to the target UE, all the co-scheduled UE(s), which has the same DMRS sequence as the target UE, have 64QAM scheduled |
| 4 | In all the PRBs allocated to the target UE, all the co-scheduled UE(s), which has the same DMRS sequence as the target UE, have 256QAM scheduled |
| 5 | In all the PRBs allocated to the target UE, all the co-scheduled UE(s), which has the same DMRS sequence as the target UE, have 1024QAM scheduled |
| 6 | Not covered by cases corresponding to index 0~5. In each individual PRB allocated to the target UE, the following condition is satisfied:Only single modulation order is allocated for the co-scheduled UE(s) which has the same DMRS sequence as the target UE, if the co-scheduled UE(s) exist |
| 7 | Others |

## 4.4 Link performance characterization

### 4.4.1 Parameters for link level evaluation

General link level simulation parameters are captured in Table 4.4-1:

Table 4.4-1: General parameters

|  |  |  |
| --- | --- | --- |
| Parameter | Unit | Value |
| Target UE  | Co-scheduled UE |
| Channel Bandwidth/SCS | MHz/KHz | 10/15 |
| Duplex mode |  | FDD |
| Allocation for interference UE and target UE | Rank allocation |  | 1 | 1 |
|  | 2 | 2 |
| Scrambling ID  |  | Same scrambling ID for both UEs |
| MIMO configuration |  | Rank 1+1: 2T2R MediumRank 2+2: 4T4R Low |
| Port allocation |  | Rank 1+1: 1000Rank 2+2: 1000,1001 | Rank 1+1: 1001Rank 2+2: 1002,1003 |
| Number of CDM groups without data |  | 1 for paired UE allocated in same CDM groups and 2 for paired UE allocated in different CDM groups |
| HARQ process number |  | 4 |
| Maximum number of HARQ transmission |  | 4 |
| Precoding model  | Target UE |  | Random precoding with Single panel Type 1 per PRB bundling size per slot | Rank 2+2: Select the precoding matrix to ensure orthogonality with target UERank 1+1: Select the precoding matrix randomly ensuring the selected precoding matrix shall not be identical to the precoding matrix of target UE |
| PDSCH configuration | Mapping type |  | Type A |
| Starting symbol (S)  |  | 2 |
| Length (L) |  | 12 |
| PRB bundling size |  | 2 |
| PRB bundling type |  | Static |
| Frequency domain allocation |  | Full bandwidth allocation | Partial bandwidth allocationFull bandwidth allocation |
| PDSCH DMRS configuration  | DMRS Type |  | DMRS Type 1 |
| Number of additional DMRS |  | 1 |
| Maximum number of OFDM symbols for DL front loaded DMRS |  | 1 |
| Propagation conditions |  | Rank 1+1: TDLC300-100Rank 2+2: TDLA30-10 |
| Test metric |  | SNR @ %70 of maximum Throughput  | N/A |

Detailed link level simulation parameters are captured in Table 4.4-2:

Table 4.4-2: Simulation parameters

|  |  |  |  |
| --- | --- | --- | --- |
| Case | Target UE | Co-scheduled UE(s) | Receiver assumption  |
| Rank  | MCS | Rank  | Modulation order | RB allocation  |
| 1 | 1 | 4 | 1 | QPSK | Full allocation(52PRBs) | MMSE-IRC, E-MMSE-IRC,R-ML receiver with genie aided knowledge of all the required information of scheduled UE |
| 2 | 13 | QPSK |
| 3 | 2 | 13 | 2 | QPSK |
| 4 | 16QAM |
| 5 | 64QAM |
| 6 | 17 | QPSK |
| 7 | 16QAM |
| 8 | 64QAM |
| 9 | 1 | 13 | 1 | QPSK | Full allocation(52PRBs) | E-MMSE-IRC,R-ML receiver with genie aided knowledge of all the required information of scheduled UE except for DMRS port and frequency domain allocation which are blindly detected by target UE |
| 10 | Partial allocation(0~25PRBs) |
| 11 | 2 | 13 | 2 | 64QAM | Full allocation(52PRBs) |
| 12 | Partial allocation(0~25PRBs) |
| 13 | 1 | 13 | 1 | QPSK | Full allocation(52PRBs) | E-MMSE-IRC,R-ML receiver with genie aided knowledge of all the required information of scheduled UE except for DMRS port, frequency domain allocation and modulation order which are blindly detected by target UE |
| 14 | 2 | 17 | 2 | 16QAM | Full allocation(52PRBs) |
| 15 | 1 | 13 | 1 | 16QAM | Full allocation(52PRBs) | E-MMSE-IRC,R-ML receiver with genie aided knowledge of all the required information of scheduled UE except for DMRS port, frequency domain allocation and modulation order which are blindly detected by target UE |
| 16 | 1 | 13 | 1 | Co-scheduled UE1: QPSKCo-scheduled UE2: 16QAM | Co-scheduled UE1: PRB index 0~25  Co-scheduled UE2: PRB index 26~51  | E-MMSE-IRC,R-ML receiver with genie aided knowledge of all the required information of scheduled UE except for DMRS port, frequency domain allocation and modulation order which are blindly detected by target UE |
| Note 1: Case 1 to 15 are corresponding to 1 co-scheduled UE. Case 16 is corresponding to 2 co-scheduled UEs  |

### 4.4.2 Link level simulation results

In this sub-clause, link level simulation results from different companies are collected for analysis of PDSCH performance in scenario with inter-user interference for MU-MIMO. The link level analysis of PDSCH performance is performed under assumptions from sub-clause 4.4.1.

The detailed simulation results from different companies are provided in the attached file ‘Attachment 1 - R4-2301098 Simulation result collection for advanced receiver for MU-MIMO’ Table 4.4.2-1 provides the summary of simulation results from different companies.

Table 4.4.2-1: Summary of simulation

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Case Number (Note 1) | Co-scheduled UE number | Rank for the target UE | Rank for the Co-scheduled UE | MCS for the target UE (MCS Table 1) | Modulation order for the co-scheduled UE | MIMO | Channel model | Precoder selection for the Co-scheduled UE | FDRA of the Co-UE | SPAN | Average |
| R-ML | E-IRC | IRC (baseline) | Gain of R-ML | Gain of E-IRC |
| 1 | 1 | 1 | 1 | 4 | QPSK | 2Tx 2Rx ULA medium | TDLC300-100 | random | Full CHBW allocation (52PRBs) | 3.9 | 4.2 | 7.5 | 1.6 | 0.7 |
| 2 | 13 | 6.2 | 4.6 | 7.3 | 7.8 | 1.8 |
| 3 | 2 | 2 | 64QAM | 4Tx 4Rx ULA Low | TDLA30-10 | orthogonal | 3.7 | 1.9 | 3.8 | 0.7 | 0.3 |
| 4 | 16QAM | 3.4 | 2.4 | 4.1 | 1.2 | 0.4 |
| 5 | QPSK | 2.5 | 2.3 | 3.8 | 2.4 | 0.5 |
| 6 | 17 | 64QAM | 3.1 | 2.1 | 4.1 | 0.4 | 0.4 |
| 7 | 16QAM | 3.5 | 2.1 | 4.0 | 1.1 | 0.4 |
| 8 | QPSK | 3.2 | 2.1 | 4.0 | 2.8 | 0.4 |
| 9 | 1 | 1 | 13 | QPSK | 2Tx 2Rx ULA medium | TDLC300-100 | random | Full CHBW allocation (52PRBs) | 5.4 | 1.9 | 0.1 | 9.3 | 4.1 |
| 10 | Partial CHBW allocation (0~25 PRBs) | 1.2 | 3.1 | 4.0 | 3.8 | 2.5 |
| 11 | 2 | 2 | 64QAM | 4Tx 4Rx ULA Low | TDLA30-10 | orthogonal | Full CHBW allocation (52PRBs) | 1.1 | 0.4 | 0.7 | 1.4 | 0.9 |
| 12 | Partial CHBW allocation (0~25 PRBs) | 2.3 | 1.9 | 1.9 | 1.0 | 0.7 |
| 13 | 1 | 1 | 13 | QPSK | 2Tx 2Rx ULA medium | TDLC300-100 | random | Full CHBW allocation (52PRBs) | 6.9 | 2.7 | 3.7 | 7.8 | 3.0 |
| 14 | 2 | 2 | 17 | 16QAM | 4Tx 4Rx ULA Low | TDLA30-10 | orthogonal | 1.2 | 0.9 | 1.6 | 1.0 | 0.4 |
| 15 (Optional) | 1 | 1 | 13 | 16QAM | 2Tx 2Rx ULA medium | TDLC300-100 | random | 3.7 | 0.0 | 0.0 | 4.4 | 3.3 |
| 16 (Companies are encouraged to bring simulation results) | 2 | 1 | 1 for each Co-UE | 13 | Co-UE1: QPSK Co-UE2: 16QAM | 2Tx 2Rx ULA medium | TDLC300-100 | random | Co-UE1: 0~25 PRBs Co-UE2: 26~51 PRBs | 8.0 | 4.7 | 2.8 | 7.5 | 4.7 |

### 4.4.3 Summary of link level evaluation

The link level evaluation target was to compare differing receiver structures in combination with differing sources of interference parameters.

This section will summarize the observations for the decided phase I test configurations, for the combinations contributed.

All PDSCH link level evaluations in clause 4.4.2, have been carried out using a FDD 10MHz/15kHz scenario.

Summary for advanced receiver with genie aided knowledge of all the required information (simulation test cases 1-8):

- 1 co-scheduled scheduled UE,

- Environment with low ranks, medium correlation, multipath dominated channel, random precoding, and low to mid MCS, i.e., coverage challenged environment

- target UE rank 1, co-scheduled UE rank 1

- 2Tx 2Rx ULA medium, TDLC300-100, precoder selection for the Co-scheduled UE is random, FDRA of co-UE is full chBW.

- Observations (cases 1-2)

- 8 companies provided input with target UE MCS 13 and co-UE QPSK.

- The gain of R-ML over IRC baseline was observed to be between 5.2 dB and -0.1 dB, with average of 1.6 dB.

- The gain of E-IRC over IRC baseline was observed to be between 3.1 dB and -0.6 dB, with average of 0.7 dB.

- 10 companies provided input with target UE MCS 4 and co-UE QPSK.

- (9 companies) The gain of R-ML over IRC baseline was observed to be between 11.5 dB and 1.2 dB, with average of 7.8 dB.

- (8 companies) The gain of E-IRC over IRC baseline was observed to be between 4.8 dB and 0 dB, with average of 1.8 dB.

- Hence, for coverage challenged conditions with low or mid MCS for both target and co-UE served, using random precoding and with genie aided knowledge, R-ML outperforms E-IRC by up to 6.0 dB.

- Environment with higher ranks, low correlation, low delay spread channel, orthogonal precoding, and mid to high MCS, i.e., higher throughput environment

- target UE rank 2, co-scheduled UE rank 2

- 4Tx 4Rx ULA low, TDLA30-10, precoder selection for the Co-scheduled UE is orthogonal, FDRA of co-UE is full chBW.

- Observations (cases 3-8)

- 10 companies provided input with target UE MCS13 and co-UE 64QAM.

- (9 companies) The gain of R-ML over IRC baseline was observed to be between 1.8 dB and 0.1 dB, with average of 0.7 dB.

- (8 companies) The gain of E-IRC over IRC baseline was observed to be between 1.0 dB and 0.0 dB, with average of 0.3 dB.

- 8 companies provided input with target UE MCS 13 and co-UE 16QAM.

- The gain of R-ML over IRC baseline was observed to be between 2.9 dB and 0.3 dB, with average of 1.2 dB.

- The gain of E-IRC over IRC baseline was observed to be between 1.1 dB and 0 dB, with average of 0.4 dB.

- 10 companies provided input with target UE MCS 13 and co-UE QPSK.

- (9 companies) The gain of R-ML over IRC baseline was observed to be between 4.2 dB and 0.3 dB, with average of 2.4 dB.

- (8 companies) The gain of E-IRC over IRC baseline was observed to be between 1.2 dB and -0.1 dB, with average of 0.5 dB.

- 8 companies provided input with target UE MCS 17 and co-UE 64QAM.

- (7 companies) The gain of R-ML over IRC baseline was observed to be between 1.0 dB and -0.4 dB, with average of 0.4 dB.

- (7 companies) The gain of E-IRC over IRC baseline was observed to be between 0.8 dB and 0.0 dB, with average of 0.4 dB.

- 9 companies provided input with target UE MCS 17 and co-UE 16QAM.

- (8 companies) The gain of R-ML over IRC baseline was observed to be between 2.7 dB and 0.1 dB, with average of 1.1 dB.

- (7 companies) The gain of E-IRC over IRC baseline was observed to be between 0.9 dB and 0.0 dB, with average of 0.4 dB.

- 9 companies provided input with target UE MCS 17 and co-UE QPSK.

- (8 companies) The gain of R-ML over IRC baseline was observed to be between 5.4 dB and 0.5 dB, with average of 2.8 dB.

- (7 companies) The gain of E-IRC over IRC baseline was observed to be between 0.8 dB and 0.0 dB, with average of 0.4 dB.

- Hence, high throughput challenged conditions with mid or high MCS for target UE and low, mid or high MCS for co-UE served, using orthogonal precoding and with genie aided knowledge, R-ML outperforms E-IRC by up to 2.4 dB.

Summary for advanced receiver with blind detection of FDRA and DMRS ports (simulation test cases 9-12):

- 1 co-scheduled scheduled UE, target UE needs to blind detect the FDRA and DMRS port allocation information of the co-scheduled UE

- Environment with low ranks, medium correlation, multipath dominated channel, random precoding, and low to mid MCS, i.e., coverage challenged environment

- target UE rank 1, co-scheduled UE rank 1

- 2Tx 2Rx ULA medium, TDLC300-100, precoder selection for the Co-scheduled UE is random, FDRA of co-UE is either full or partial chBW.

- Observations cases 9-10

- 3 companies provided input with target UE MCS 13 and co-UE QPSK with full CHBW allocation.

- (2 companies) The gain of R-ML over IRC baseline was observed to be between 11.5 dB and 7.0 dB, with average of 9.3 dB.

- (2 companies) The gain of E-IRC over IRC baseline was observed to be between 5.0 dB and 3.2 dB, with average of 4.1 dB.

- 2 companies provided input with target UE MCS 13 and co-UE QPSK with partial CHBW allocation.

- The gain of R-ML over IRC baseline was observed to be between 5.2 dB and 2.4 dB, with average of 3.8 dB.

- The gain of E-IRC over IRC baseline was observed to be between 2.9 dB and 2.0 dB, with average of 2.5 dB.

- Hence, for coverage challenged conditions with mid MCS for target UE and low or mid MCS for co-UE served, full/partial CHBW allocation for co-UE, using random precoding and with blind detection of FDRA and DMRS ports, R-ML outperforms E-IRC by up to 5.2 dB.

- Environment with higher ranks, low correlation, low delay spread channel, orthogonal precoding, and mid to high MCS, i.e., higher throughput environment

- target UE rank 2, co-scheduled UE rank 2

- 4Tx 4Rx ULA low, TDLA30-10, precoder selection for the Co-scheduled UE is orthogonal, FDRA of co-UE is either full or partial chBW.

- Observations cases 11-12

- 3 companies provided input with target UE MCS 13 and co-UE 64QAM with full CHBW allocation.

- (2 companies) The gain of R-ML over IRC baseline was observed to be between 1.7 dB and 1.1 dB, with average of 1.4 dB.

- (2 companies) The gain of E-IRC over IRC baseline was observed to be between 1.0 dB and 0.7 dB, with average of 0.9 dB.

- 2 companies provided input with target UE MCS 13 and co-UE 64QAM with partial CHBW allocation.

- The gain of R-ML over IRC baseline was observed to be between 1.2 dB and 0.8 dB, with average of 1.0 dB.

- The gain of E-IRC over IRC baseline was observed to be between 0.7 dB and 0.7 dB, with average of 0.7 dB.

- Hence, high throughput challenged conditions with MCS13 for target UE and mid MCS for co-UE served, full/partial CHBW allocation for co-UE, using orthogonal precoding and with blind detection of FDRA and DMRS ports, R-ML outperforms E-IRC by up to 0.6 dB.

Summary for advanced receiver with blind detection of FDRA and DMRS ports and blind detection of co-UE modulation order (simulation test cases 13-16):

- 1 co-scheduled scheduled UE, target UE needs to blind detect the FDRA, DMRS port allocation information and modulation order of the co-scheduled UE

- Environment with low ranks, medium correlation, multipath dominated channel, random precoding, and low to mid MCS, i.e., coverage challenged environment

- target UE rank 1, co-scheduled UE rank 1

- 2Tx 2Rx ULA medium, TDLC300-100, precoder selection for the Co-scheduled UE is random, FDRA of co-UE is full chBW.

- Observations cases 13 and 15

- 5 companies provided input with target UE MCS 13 and co-UE QPSK

- (4 companies) The gain of R-ML over IRC baseline was observed to be between 9.7 dB and 6.0 dB, with average of 7.8 dB.

- (4 companies) The gain of E-IRC over IRC baseline was observed to be between 5.0 dB and 1.1 dB, with average of 3.0 dB.

- 2 companies provided input with target UE MCS 13 and co-UE 16QAM

- (1 company) The gain of R-ML over IRC baseline was observed to be 4.4 dB.

- The gain of E-IRC over IRC baseline was observed to be 3.3 dB.

- Hence, for coverage challenged conditions with mid MCS for target UE and low or mid MCS for co-UE served, full CHBW allocation for co-UE, using random precoding and with blind detection of FDRA, DMRS ports and modulation order, R-ML outperforms E-IRC by up to 4.9 dB.

- Environment with higher ranks, low correlation, low delay spread channel, orthogonal precoding, and mid to high MCS, i.e., higher throughput environment

- target UE rank 2, co-scheduled UE rank 2

- 4Tx 4Rx ULA low, TDLA30-10, precoder selection for the Co-scheduled UE is orthogonal, FDRA of co-UE is full chBW.

- Observations cases 14

- 4 companies provided input with target UE MCS 17 and co-UE 16QAM

- (3 companies) The gain of R-ML over IRC baseline was observed to be between 1.8 dB and 0.5 dB, with average of 1.0 dB.

- (3 companies) The gain of E-IRC over IRC baseline was observed to be between 0.8 dB and 0.1 dB, with average of 0.4 dB.

- Hence, high throughput challenged conditions with MCS17 for target UE and mid MCS for co-UE served, full CHBW allocation for co-UE, using orthogonal precoding and with blind detection of FDRA, DMRS ports and modulation order, R-ML outperforms E-IRC by up to 0.6 dB.

- 2 co-scheduled UEs, target UE needs to blind detect the FDRA, DMRS port allocation information and modulation order of the co-scheduled UEs, each co-UE occupies half of the available PRBs

- Environment with low ranks, medium correlation, multipath dominated channel, random precoding, and low to mid MCS, i.e., coverage challenged environment

- target UE rank 1, co-scheduled UE rank 1

- 2Tx 2Rx ULA medium, TDLC300-100, precoder selection for the Co-scheduled UEs is random, FDRA of each co-UE is partial chBW.

- Observations case 16

- 3 companies provided input with target UE MCS 13, 1st co-UE QPSK and 2nd co-UE 16QAM

- The gain of R-ML over IRC baseline was observed to be between 11.2 dB and 5.1 dB, with average of 7.5 dB.

- The gain of E-IRC over IRC baseline was observed to be between 5.8 dB and 2.7 dB, with average of 4.7 dB.

- Hence, for coverage challenged conditions with MCS13 for target UE and low and mid MCS respectively for the two co-UEs served, partial CHBW allocation for each co-UE equally distributed, using random precoding and with blind detection of FDRA, DMRS ports and modulation order, R-ML outperforms E-IRC by up to 2.8 dB.

# 5 Conclusions

This technical report has documented the RAN4 evaluation on techniques to cancel downlink intra cell inter-user interference. The major work includes the determination of network scenario, interference modelling, interference suppressing receiver structure, required information analysis for each candidate receiver, link-level simulation parameters and performance evaluations.

MU-MIMO scenario with gNB transmits PDSCH to the paired UEs through the same time-frequency resources is evaluated.

gNBs equipped with 2Tx and 4Tx antennas are considered in the RAN4 performance evaluation. However, for the UEs capable of inter-user interference suppression ability discussed in this TR, they can also be used in the deployments with larger number of Tx ports configuration. For the interference suppressing receiver, both E-MMSE-IRC and R-ML are evaluated as candidate advanced receivers.

RAN4 reaches consensus on the required information for both E-IRC and R-ML receiver. In addition, RAN4 has agreed the network default configuration assumptions. Therefore, the advanced receiving algorithm can be performed under these default assumptions. For some of the default assumptions, it is required for the network to indicate the UE whether the default assumption is valid or not by RRC signalling. For UE with R-ML receiver, DCI based network assistant signalling is required.

PDSCH link-level simulations are performed to evaluate the performance gain of the candidate E-IRC and R-ML receiver over the baseline MMSE-IRC receiver under intra-cell inter-user interference scenario. 16 simulation cases that covers the advanced receiver with genie-aided required information, with co-scheduled UE DMRS port and FDRA information blind detection, and with co-scheduled UE modulation order blind detection (for R-ML receiver only), are selected for the evaluation. Different antenna and rank configurations for target and interference UEs, different propagation condition, and CBW configurations are included.

Based on the simulation results, the performance gain of R-ML receiver over the baseline MMSE-IRC receiver is verified.

Based on the above evaluations, it is recommended to select R-ML as the new advanced receiver for inter-user interference suppression receiver for MU-MIMO scenario in Rel-18, and to introduce necessary new UE capability and network assistant signalling for the selected receiver.

It is also recommended to define NR PDSCH demodulation requirements for the selected inter-user interference suppression receiver for MU-MIMO scenario in Rel-18.

Annex A:
Change history

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| **Change history** |
| **Date** | **TSG #** | **TSG Doc.** | **CR** | **Rev** | **Subject/Comment** | **Old** | **New** |
| 2023-03 | RAN4 #106 | R4-2300127 |  |  | TR skeleton |  | 0.0.1 |
| 2023-08 | RAN4#108 | R4-2311100 |  |  | Implemented the following TPs endorsed at RAN4#108:R4-2313969, TP to TR38.878: on the phase I conclusion for advanced receiver for MU-MIMO, China TelecomR4-2313970, TP to TR38.878: Symbols and abbreviations, China TelecomR4-2313994, TP for TR 38.878 Receiver structure of MU-MIMO, ZTE CorporationR4-2313972, TP for TR38.878: Summary of link level evaluation, Nokia, Nokia Shanghai BellR4-2313973, MU-MIMO TR TP, QualcommR4-2313974, TP to TR38.878 on Scenario and interference modelling, MediaTek incR4-2313975, TP to TR38.878: Link level simulation results, EricssonR4-2313976, Draft TP on TR 38.878 Introduction on parameters for link level evaluation, Huawei, HiSilicon | 0.0.1 | 0.1.0 |
| 2023-09 | RAN #101 | RP-232282 |  |  | Presented at RAN#95e for approval. | 0.1.0 | 1.0.0 |

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| Change history |
| Date | Meeting | TDoc | CR | Rev | Cat | Subject/Comment | New version |
| 2023-09 | RAN #101 |  |  |  |  | Put under change control | 18.0.0 |
| 2023-12 | RAN#102 | RP-233364 | 0001 |  | F | CR for TR38.878 on Summary of link level evaluation | 18.1.0 |