ISTC’18, Hongkong

Tomorrow never waits

NOMA Study in 3GPP for 5G

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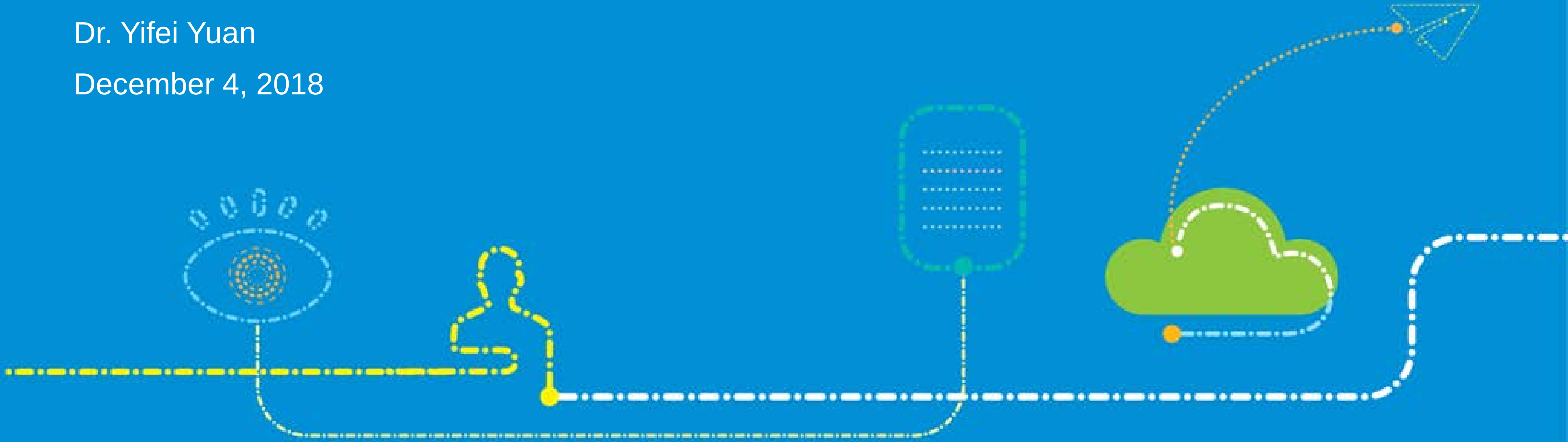
December 4, 2018



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NOMA Activities Involved by ZTE (in and out of 3GPP)

- **NOMA study item approved by 3GPP in March 2017, led by ZTE**
- **The SI postponed to Feb 2018, along with other Rel-15 SIs**
- **NOMA workshops in May, June, Aug and Oct of 2017**
  - 1st workshop (May): scenarios,12 presentations
  - 2nd workshop (June): work plan, 9 presentations
  - 3rd workshop (Aug.): simulation parameters, 8 presentations
  - 4th workshop (Oct.): preliminary simulation results, 10 presentations
- **Related activities in academia**
  - June 2017, chapter on NOMA in “5G signal processing algorithms” published by Wiley & IEEE
  - July 2017(Shanghai): 5G summit, panel for NOMA, focus on scenarios and design targets
  - Sept 2017 (Canada): NOMA workshop in VTC’ fall
  - Oct 2017 (Nanjing): 5G summit, keynote speech on NOMA
  - May 2018 (Kansas City): ICC NOMA workshop, keynote speech on NOMA development in 3GPP
  - Aug 2018 (Shanghai): NOMA symposium, keynote speech on NOMA in 3GPP

Timeline for NOMA Study Item in 3GPP

02/18 (1 TU)
- Simulation methodology & assumptions (link level)

04/18 (1.5 TU)
- Initial discussion on Tx side design & receivers for NOMA (with initial LLS results)
- Initial discussion on system level simulation methodology & assumptions

05/18 (2 TU)
- System level simulation methodology & assumptions
- Discussion on Tx side design & receivers for NOMA (with LLS results)

08/18 (2.5 TU)
- Initial system-level performance evaluation
- Initial harmonization of solutions
- Initial discussion on related procedures

10/18 (2.5 TU)
- Performance comparison and evaluation at link & system level
- Solution harmonization
- Discussion on related procedures

11/18 (2.5 TU)
- Summary of NOMA solution(s)
- Summary of evaluation results
- Recommendation and conclusion

Completion percentage (after November 2018): 100%

Use Scenarios

Significant control signalling overhead and latency → ***Reduced*** control signalling overhead and latency

RRC-connected:
- Tight synchronization in time & freq
- Tight power control, equal avg SNR
- No MA signature collision
- Support of low or medium number of simultaneous users

RRC-inactive/2-step RACH:
- Potentially asynchronous
- Loose power control, un-equal avg. SNR
- Potential MA signature collision
- Support of a large number of simultaneous users

RRC-connected use scenarios:
- **URLLC**
- **mMTC**
- **eMBB small data**

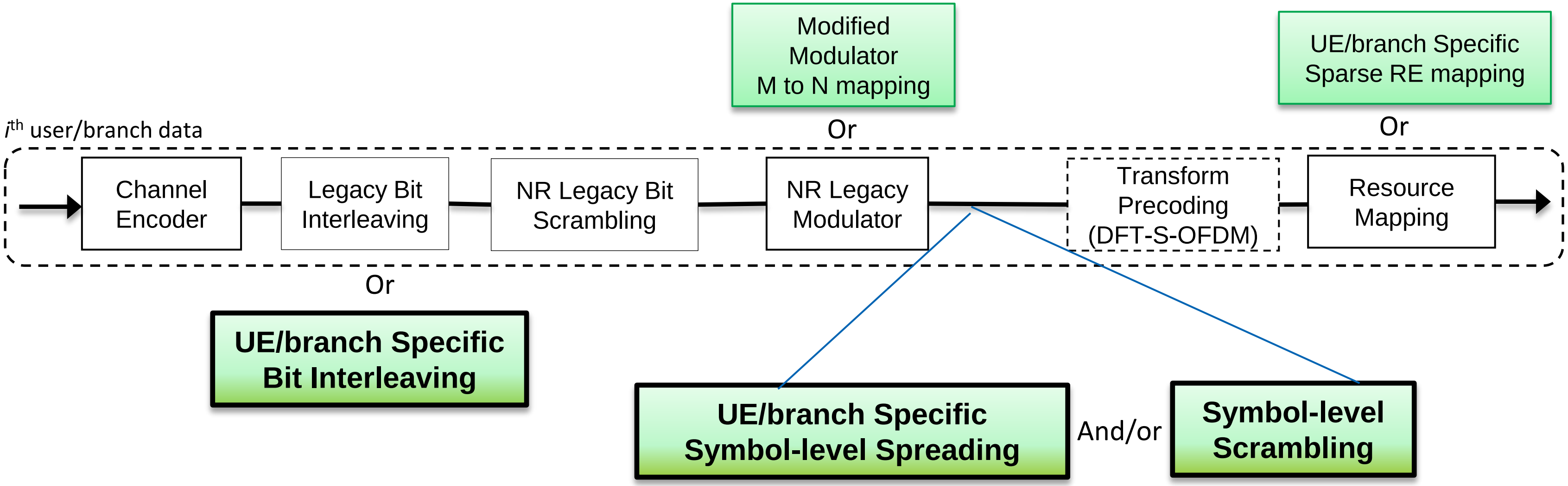
RRC-inactive/2-step RACH use scenarios:
- **mMTC**
- **eMBB small data**

CONTENTS

- Timeline and use scenarios
- **Transmitter side schemes**
- Receiver types and complexity
- Auxiliary designs
- Performance evaluations
- Conclusions

General Channel Structure of NOMA Transmitter

- **Multiple access (MA) signatures to differentiate users for NOMA purpose**



- **Channel coding can potentially be optimized to improve overloading capability**
  - This study is postponed in 3GPP due to the limited time before Dec. 2018
  - To assume Rel-15 NR LDPC for performance evaluation

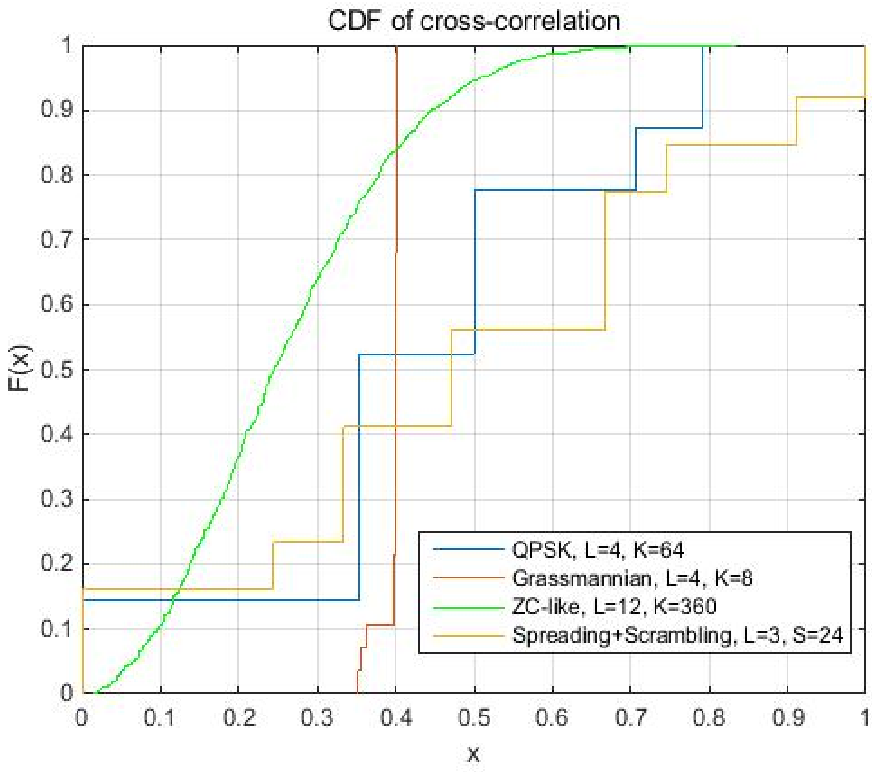
Candidate Schemes at Transmitter

- **Symbol-level spreading based**
  - MUSA (ZTE): elements of sequence correspond to QAM constellation, its subset satisfying WBE
  - NOCA (Nokia): compute generated low-correlation sequences
  - NCMA (LGE): Grassmannian sequences
  - WSMA (E///): Welch-bound approaching sequences
  - UGMA (DOCOMO): generalized WBE sequences
  - RSMA (QC): Chirp sequence + symbol level scrambling
  - PDMA (CATT): uneven diversity order
- **Bit-level processing based**
  - IDMA (InterDigital/Nokia): scrambler or interleaver
  - ACMA (Hughes): scrambler + channel coding optimization
  - LCRS (Intel): low code rate
- **Joint modulation & spreading**
  - SCMA (HW): sparse spreading with multi-dimensional modulation
- **Hybrid:**
  - IGMA (Samsung): bit level interleaving + sparse mapping

Types of Linear Spreading Sequences

- **Type 1: Welch-bound equality (WBE) approaching sequences**
  - Nested sequences whose elements correspond to QAM constellation (MUSA)
  - Grassmanian sequences (quantized)
  - Equiangular tight frames (ETF) or harmonic ETF sequences
  - Generalized WBE with unequal power constraint
  - Chirp sequences whose continuous-time function has closed-form formula
- **Type 2: Computer generated sequences with desired cross-correlation**
  - Also low peak-to-power-ratio (PAPR)
- **Type 3: Pseudo-random (PN) sequences, e.g., Gold code**
- **Type 4: Sequences with uneven diversity orders**

Cross-correlation Statistics of Spreading Sequences

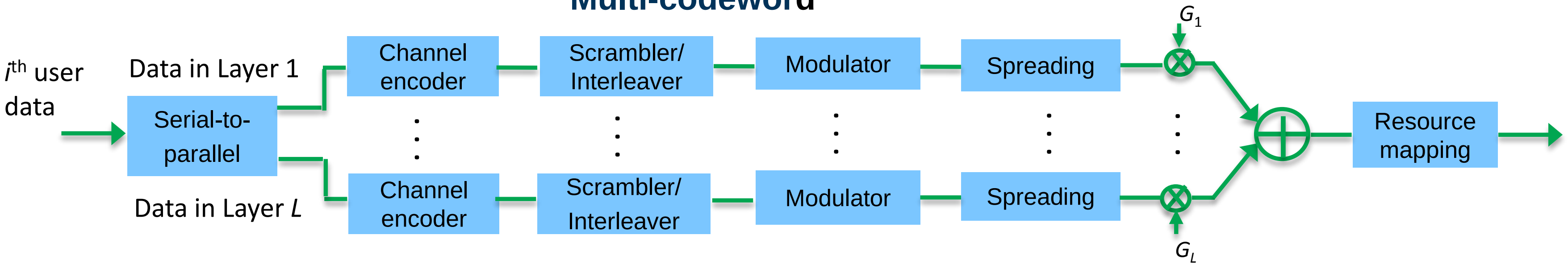


- Cross-correlation statistics are important indicator of potential performance
- Performance also affected by near-far effect and fast fading without tight power control
  - Benefit of some cross-correlation property, e.g., ETF, may be diluted to certain degree

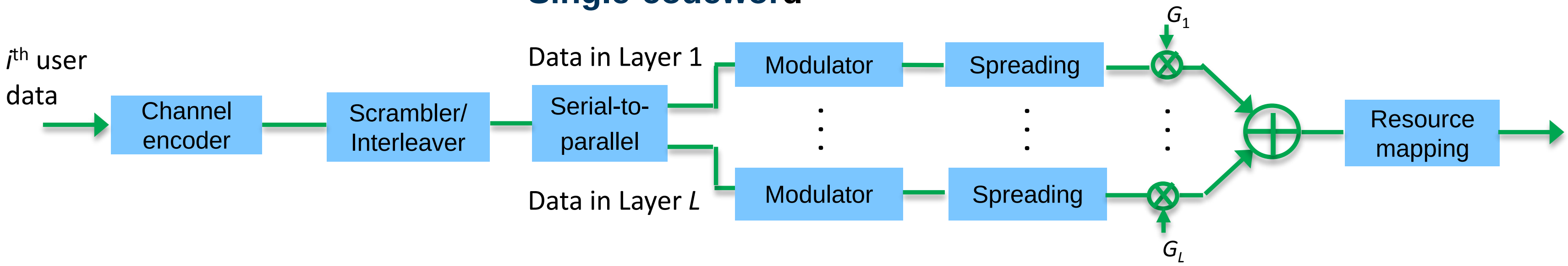
Multi-branch Transmission per User

- **Via linear superposition, to achieve high spectral efficiency**

Multi-codeword



Single-codeword



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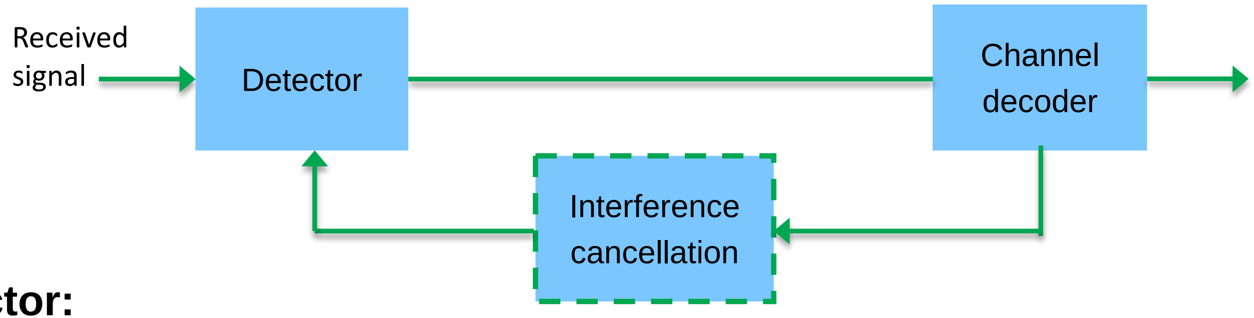
General Structure of Uplink NOMA Receiver



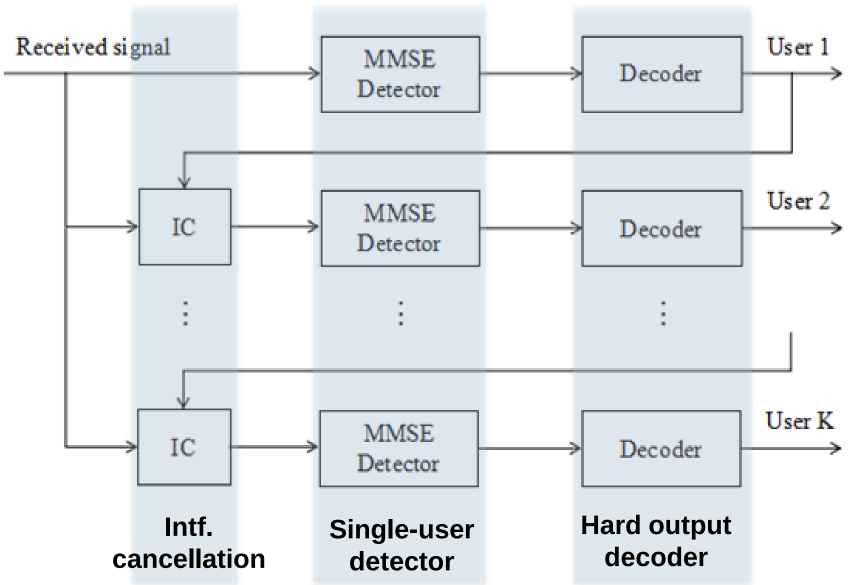
- **Detector:**
  - Single-user
  - Parallel multi-user
- **Channel decoder:**
  - Hard output
  - Soft-input-soft-output (SISO)
- **Interference cancellation resides in detector for iterative detection & decoding**

Tx schemes	Typical receiver
Symbol-level linear spreading	MMSE-hard IC
Bit-level interleaving	ESE + SISO
Multi-dimensional modulation	EPA + SISO

MMSE-hard Interference Cancellation Receivers

- Complexity linearly grows with #users
- Hard interference cancellation
- Hard-output decoder → legacy implementation
- Single-user MMSE detector with manageable complexity
- Can be implemented in serial, parallel or hybrid
- Typically for linear spreading schemes

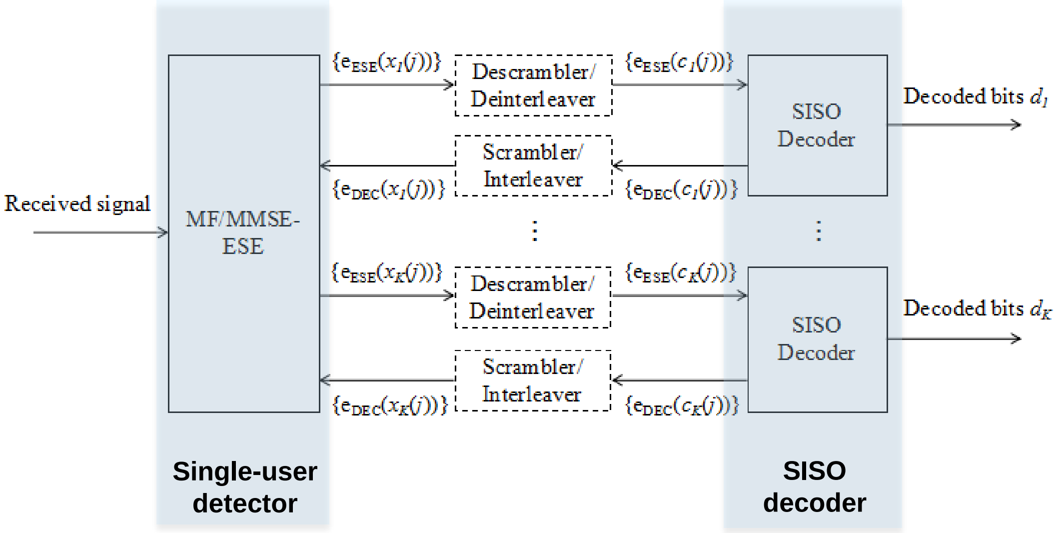
MMSE-SIC receiver



Elementary Signal Estimator (ESE) + SISO Receivers

- Complexity linearly grows with #users
- Soft cancellation in ESE detector
- Iterations between ESE and SISO decoder
- Typically for bit-level scrambling or interleaving
- ESE has two flavors: MMSE and matched filter (MF)
    - MMSE outperforms MF in presence of spatial dimension or spreading code

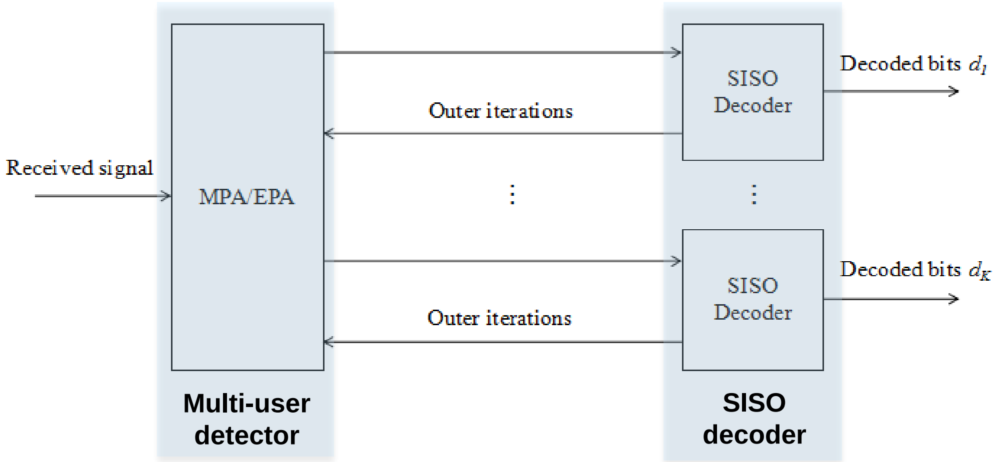
ESE + SISO receiver



MPA/EPA + SISO Receivers

- Message passing algorithm (MPA) and expectation propagation algorithm (EPA) are maximum-likelihood (ML) detector
- Inner iteration needed inside MPA/EPA detector
- Outer iteration needed between MPA/EPA and soft-output decoder
- Complexity of MPA exponentially grows with #users
- Complexity of EPA linearly grows with #users
- MPA/EPA can be used for any types of Tx side schemes

MPA/EPA + SISO receiver



Receiver Complexity Analysis

- Computation complexities quantified by O(.) analysis with key parameters, along several major types of receivers
- Relative complexity to MMSE-IRC, derived for {SF = 4, N_{rx} = 2, K = 12, TBS = 20 bytes, QPSK} in terms of #complex multiplications for (detector + IC) or #binary additions or comparisons for channel decoder

Receiver Component	MMSE-IRC	MMSE-hard IC	ESE+SISO	EPA+SISO
Detector + IC	1	2	5	10
Channel decoder	1	1.5	4	6

- Complexity of detection/IC and channel coding for ESE+SISO or EPA+SISO receivers is significantly higher than MMSE-hard IC receivers

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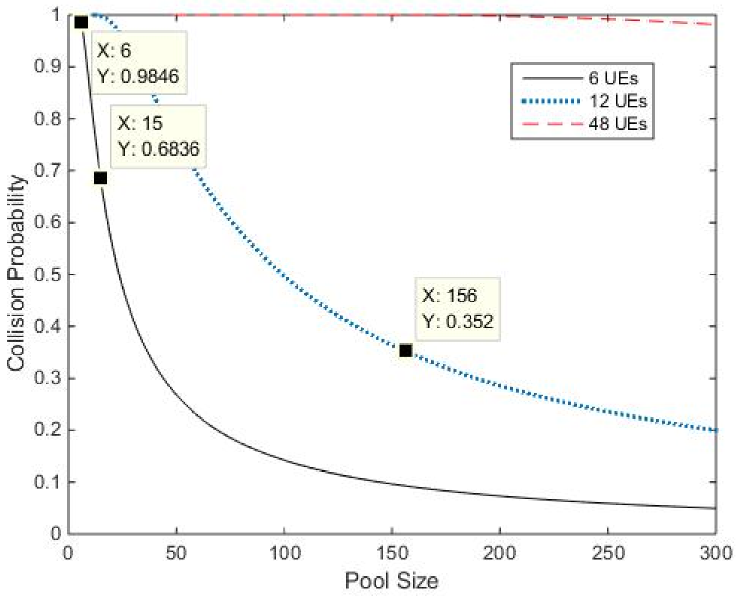
Candidate Signals for User Detection

- **Demodulation reference signal (DMRS)**
  - **Pros**: no need for blind detection of data
  - **Cons**: overhead, severe performance loss when DMRS sequences collide
- **Preamble**
  - **Pros**: no need for blind detection of data, and robustness to asynchronous operation
  - **Cons**: significant overhead, severe performance loss when preamble signature collide
- **Data itself**
  - **Pros**: no overhead, robust to MA signature collision (data of different users never to be the same)
  - **Cons**: complexity for blind detection of data (less of an issue for hard interf cancellation based)



Collision probability decreases with sequence pool size → more DMRS/preamble overhead and more blind detection

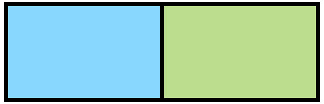
Candidate Channel Structures

- DMRS capacity enhancement is considered in many LLS
  - Necessary to support up to 24DMRS ports within one slot

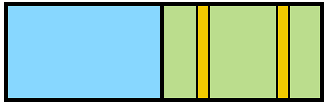
DMRS + data

For configured grant

- (Preamble + data) channel structure
  - Contention based
  - Support asynchronous operation



Preamble + Data



Preamble + Data + DMRS

For grant-free transmission and 2-step RACH

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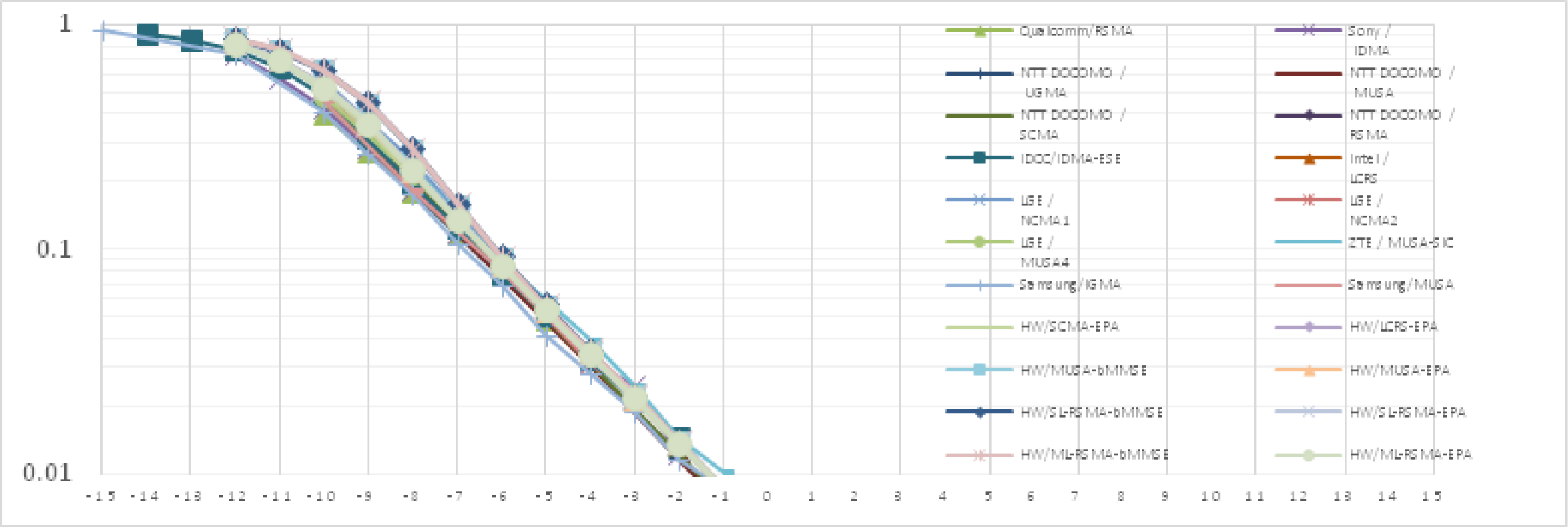
Link and System Simulation Effort

- **NOMA requires one of the most extensive link level simulations**
  - Link level simulation of uplink NOMA should be multi-user, with independent fading
  - More than 30 cases,
    - ✓ Scenarios: mMTC, URLLC, eMBB
    - ✓ Transport block size (TBS): 20, 40, 60, 75 bytes
    - ✓ Number of users: 6, 8, 12, 24
    - ✓ Number of receive antennas: 2rx, 4rx antennas,
    - ✓ Time/freq offset and MA signature collision
- **NOMA requires significant system level simulations**
  - Link-to-system mapping (PHY abstraction) to be verified for multi-user environment
  - Three scenarios: mMTC (w or w/o MA signature collision), URLLC, eMBB,
  - A large number of users to be dropped in SLS for mMTC → running time is long

Link Level Simulation Results (for low TBS)

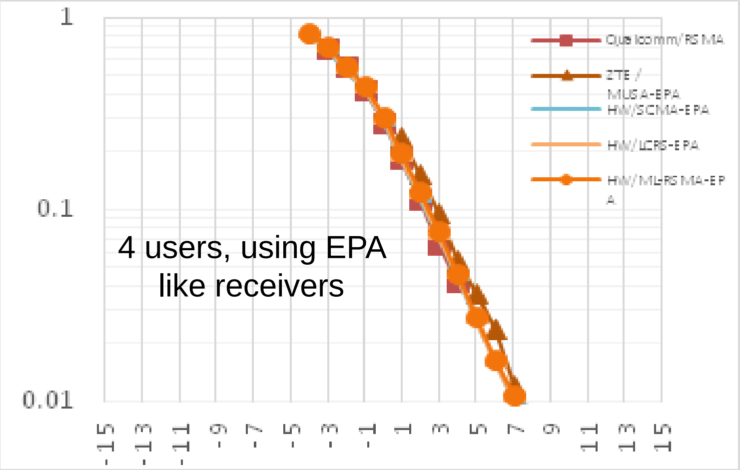
TBS = 10 bytes, 24 users, ICE

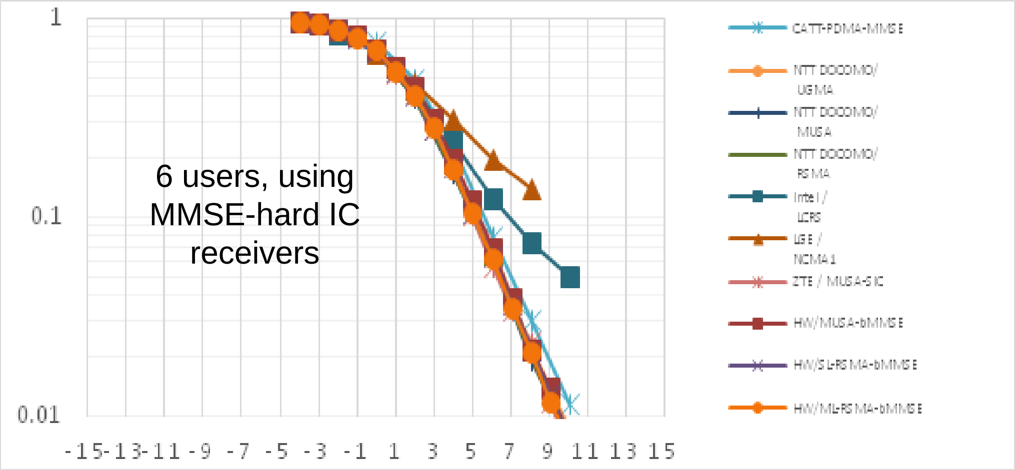


At low TBS, linear spreading with MMSE-hard IC receiver can achieve similar performance of multi-dimensional modulation with EPA receiver

Link Level Simulation Results (for high TBS)

TBS = 75 bytes, ICE





For high TBS, linear spreading can achieve similar performance as of multi-dimensional modulation when both use EPA like receivers

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System-level Performance Gains

Source	Gain (%) for eMBB	Gain (%) for mMTC	Gain (%) for uRLLC
R1-1814073	For MMSE-IRC: 150% - 275%, For MMSE-hard PIC: 67%-150%	For MMSE-IRC: 100% For MMSE-hard PIC: 71%-150%	140% - 300%
R1-1812969	91%	88%	N/A
R1-1813159	N/A	100% for low packet arrival rate	N/A
R1-1814341	N/A	46%	N/A
R1-1812612	19% for MUSA, 43% for PDMA	N/A	42% for MUSA, 55% for PDMA
R1-1814149	4% for 95 percentile, 18% for 50 percentile, 72% for 5 percentile	67%	N/A
R1-1814077	20%		

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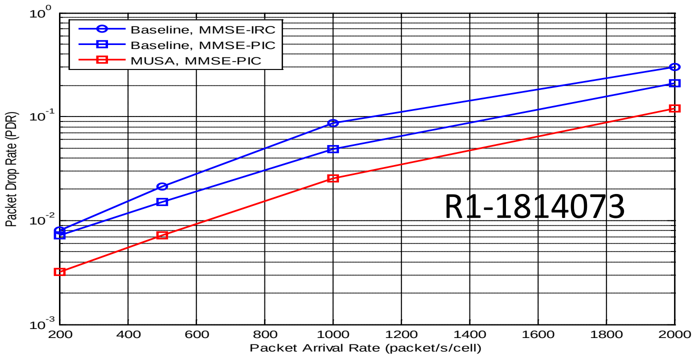
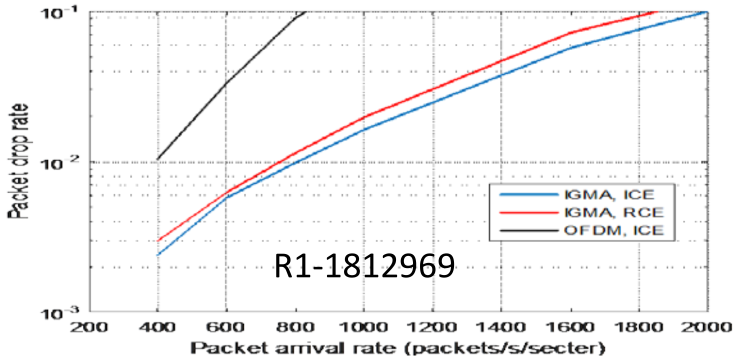
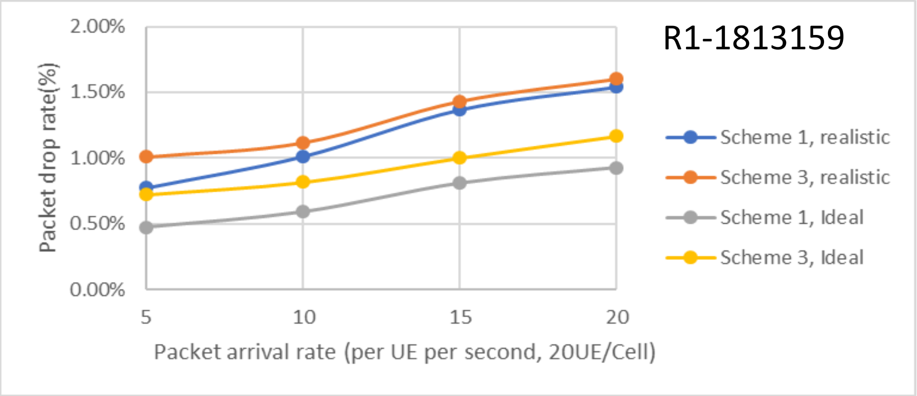
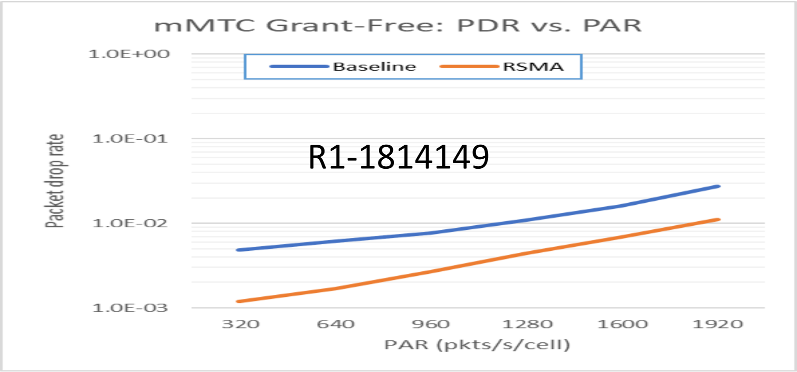
Performance Gain for mMTC

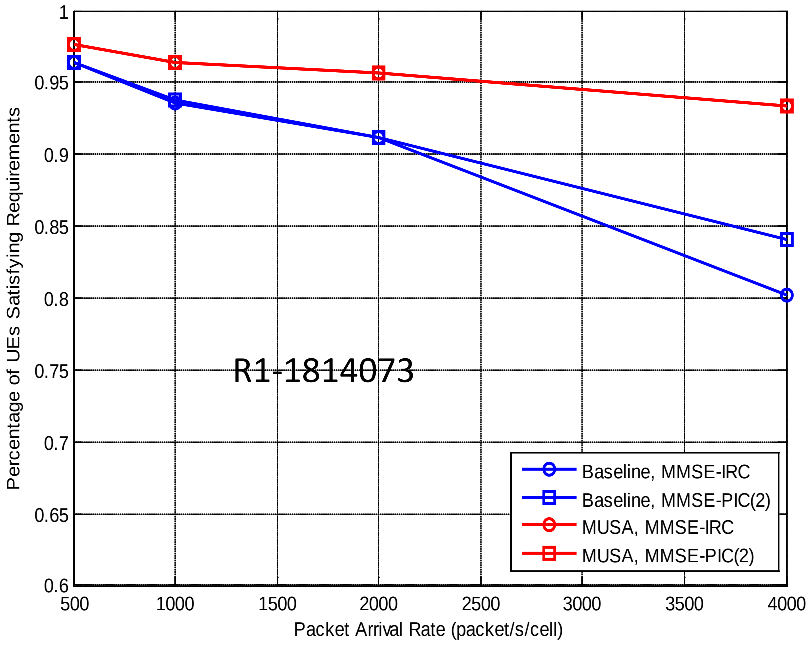


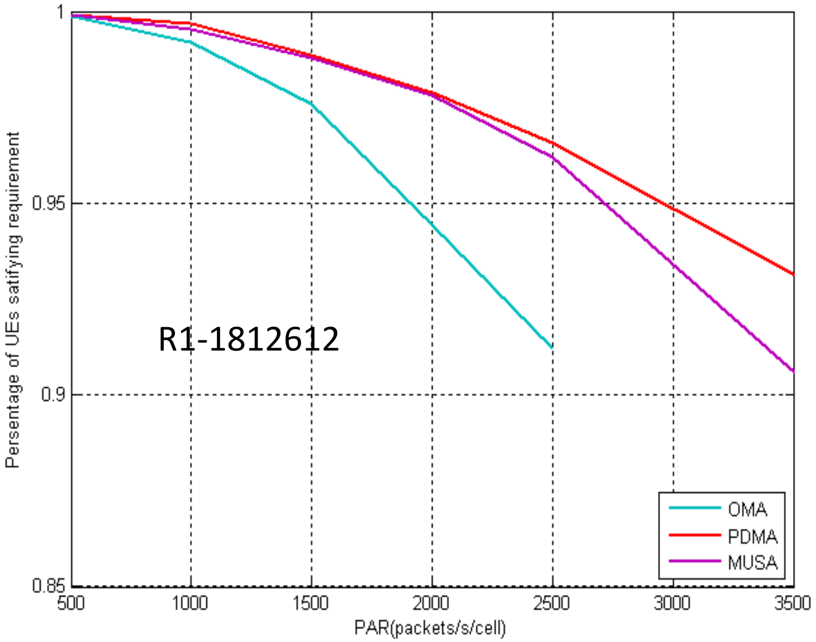




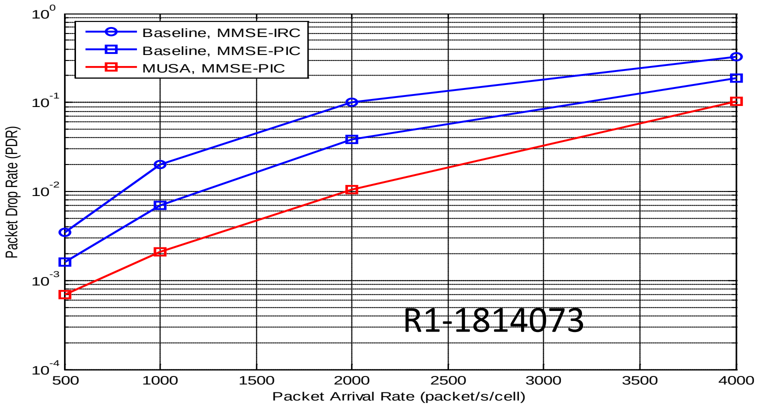


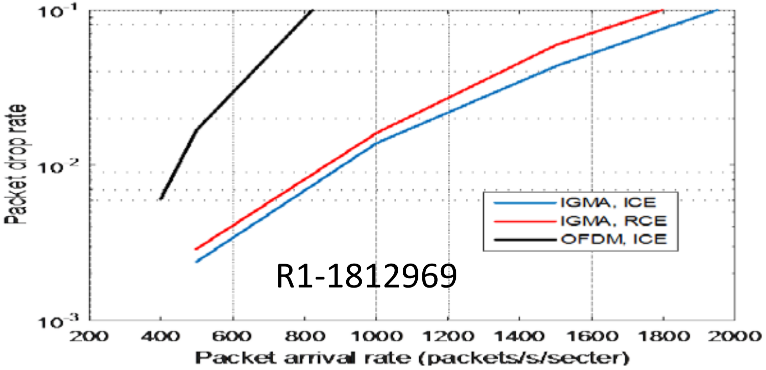
Performance Gain for URLLC

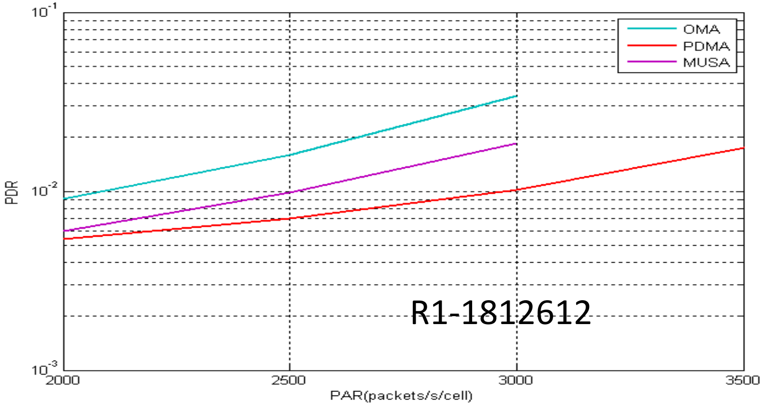


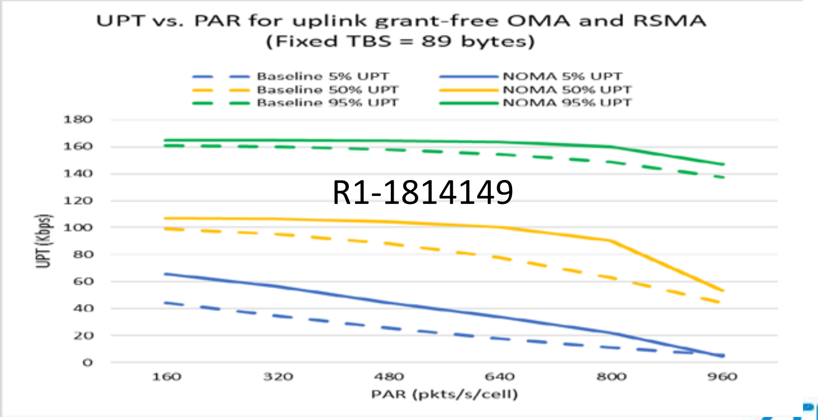


Performance Gain for eMBB



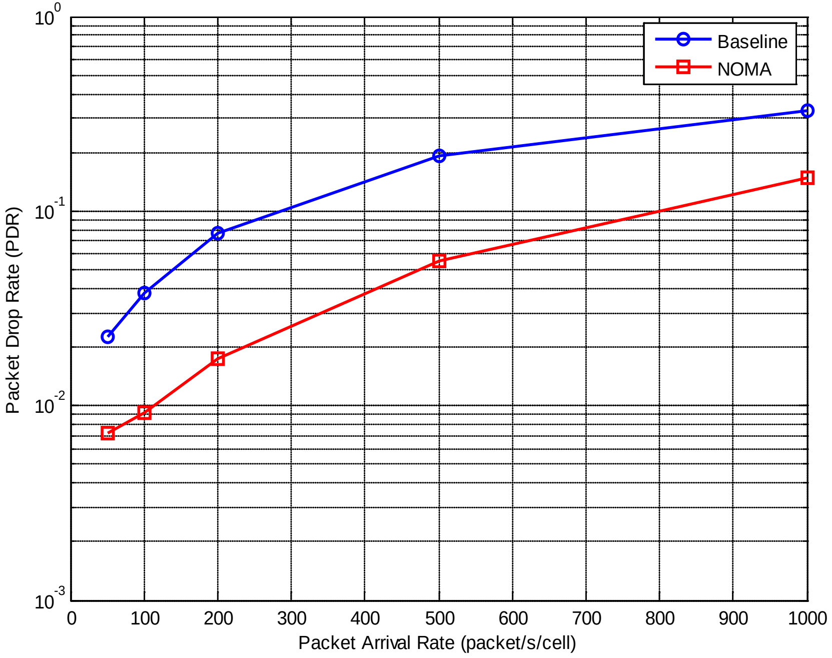






System-level Performance for (preamble + data)

- Asynchronous (TO up to 1.5 NCP)
- Preamble/spreading sequence randomly selected from the pool of size 64
- For NOMA simulation, spreading is applied to the data part
- Time domain spreading



NOMA can double the system capacity compared to the baseline

CONTENTS

- Timeline and use scenarios
- Transmitter side schemes
- Receiver types and complexity
- Auxiliary designs
- Performance evaluations
- **Conclusions**

Conclusions

- NOMA shows significant system performance gain for configured grant transmission
- NOMA shows significant system performance gain for data transmission in asynchronous operation with random selection of MA signature
- MMSE-hard IC has significantly lower complexity than ESE+SISO and EPA+SISO
- Multi-dimensional modulation requires extensive work for specification

	Symbol-level linear spreading/scrambling	Bit-level interleaving	Multi-dimensional modulation
Link level performance	Good	Good	Good
Receiver complexity	Low	Moderate	High
Standards impact	Moderate	Small	Extensive

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Thank you