Recent Progress in 5G NR NOMA

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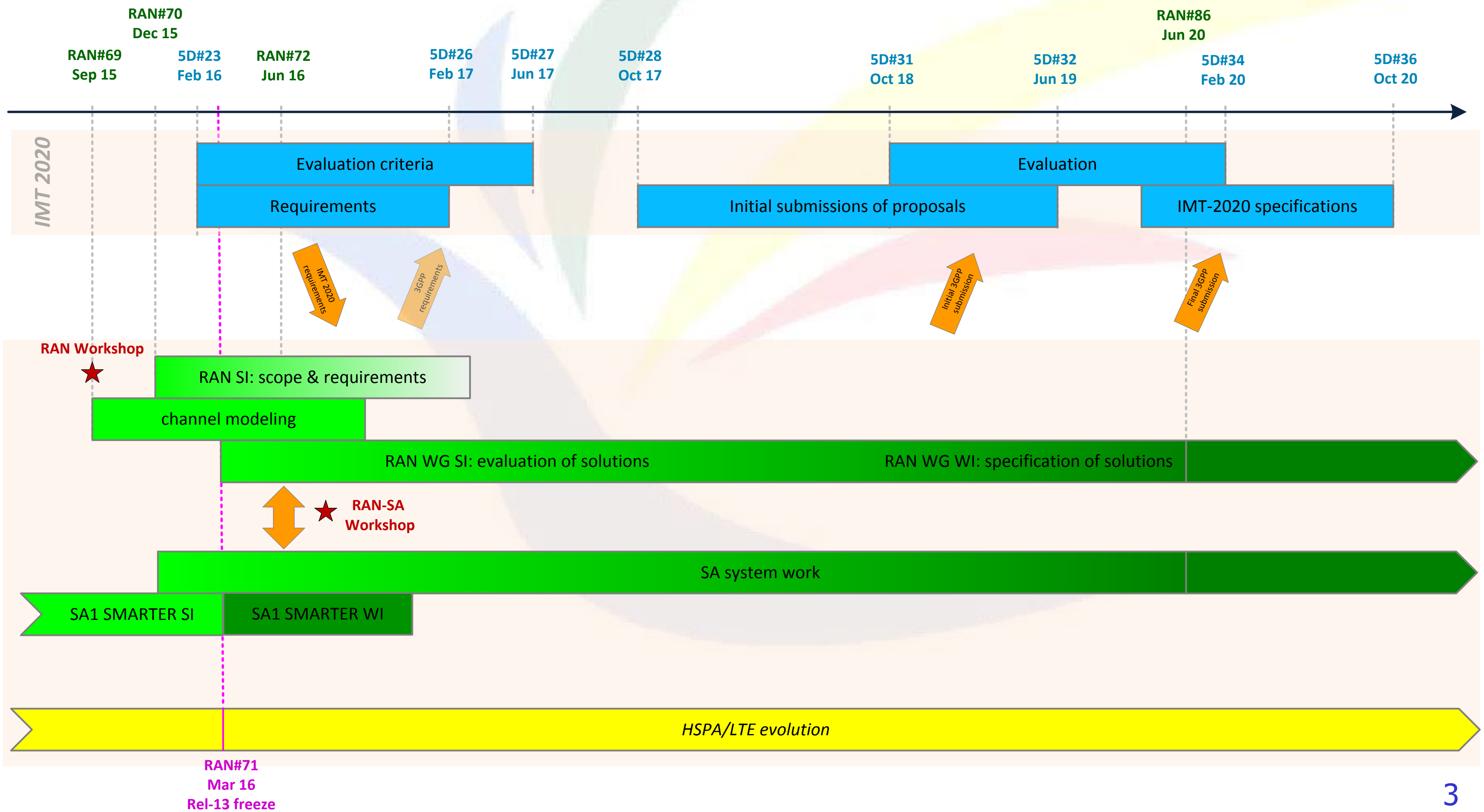
Outline

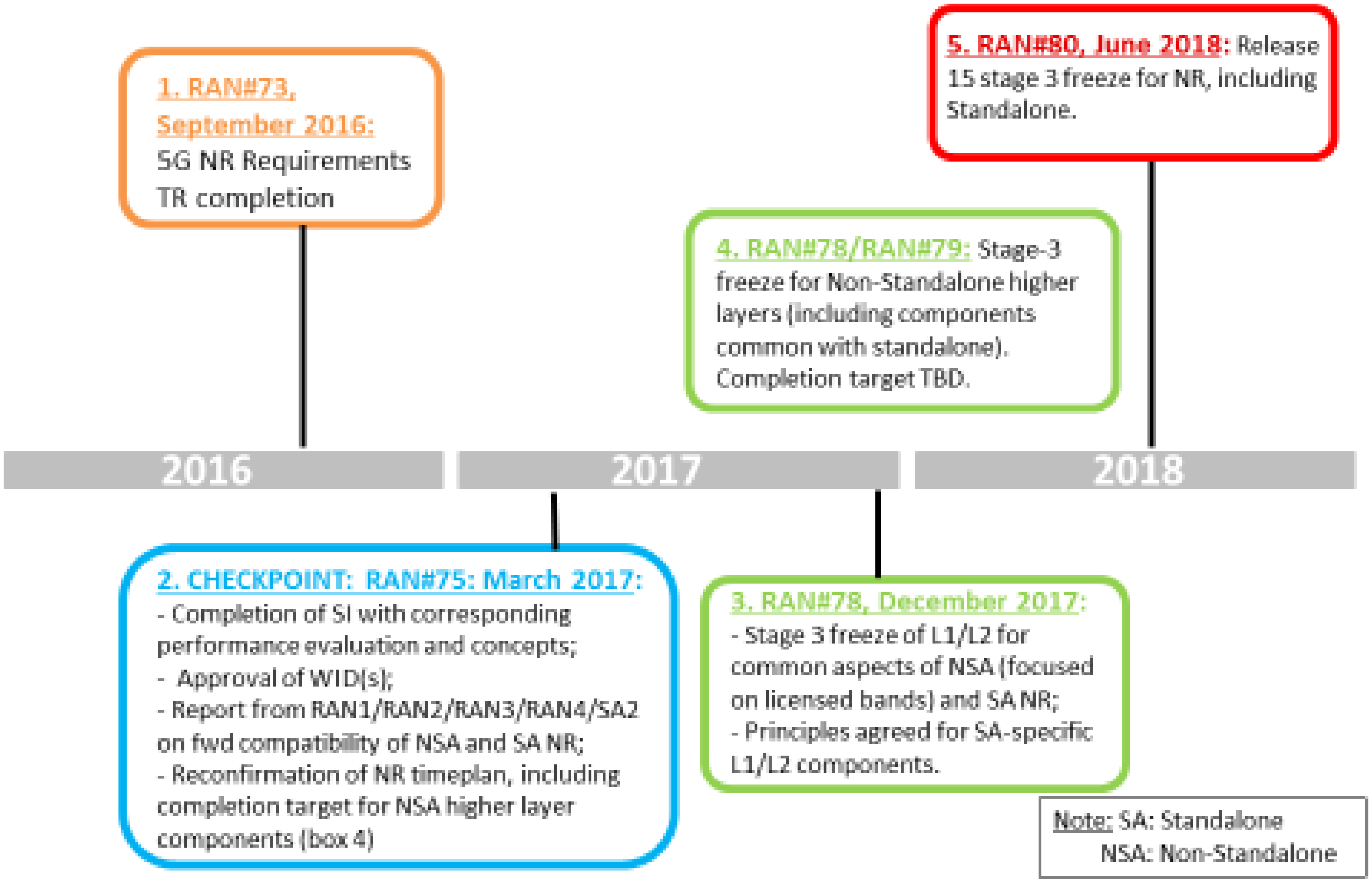
- 5G Activity in 3GPP
- Candidate Scenarios for NR NOMA
- NOMA timeline in LTE & New Radio
- Candidate NOMA Technologies in NR
- Conclusion and Future Work

5G Timeline in 3GPP



5G Timeline in 3GPP

Overall timeline for NR in TSG-RAN



5G Scenarios and Challenges

Source: IMT-2020

Mainly for Mobile Internet

Seamless Wide-Area Coverage

- User experienced data rate: 100 Mbps

High-Capacity Hot-Spot

- User experienced data rate: 1 Gbps
- Peak data rate: Tens of Gbps
- Traffic volume density: Tens of Tbps/km^2

Mainly for IoT (new scenarios)

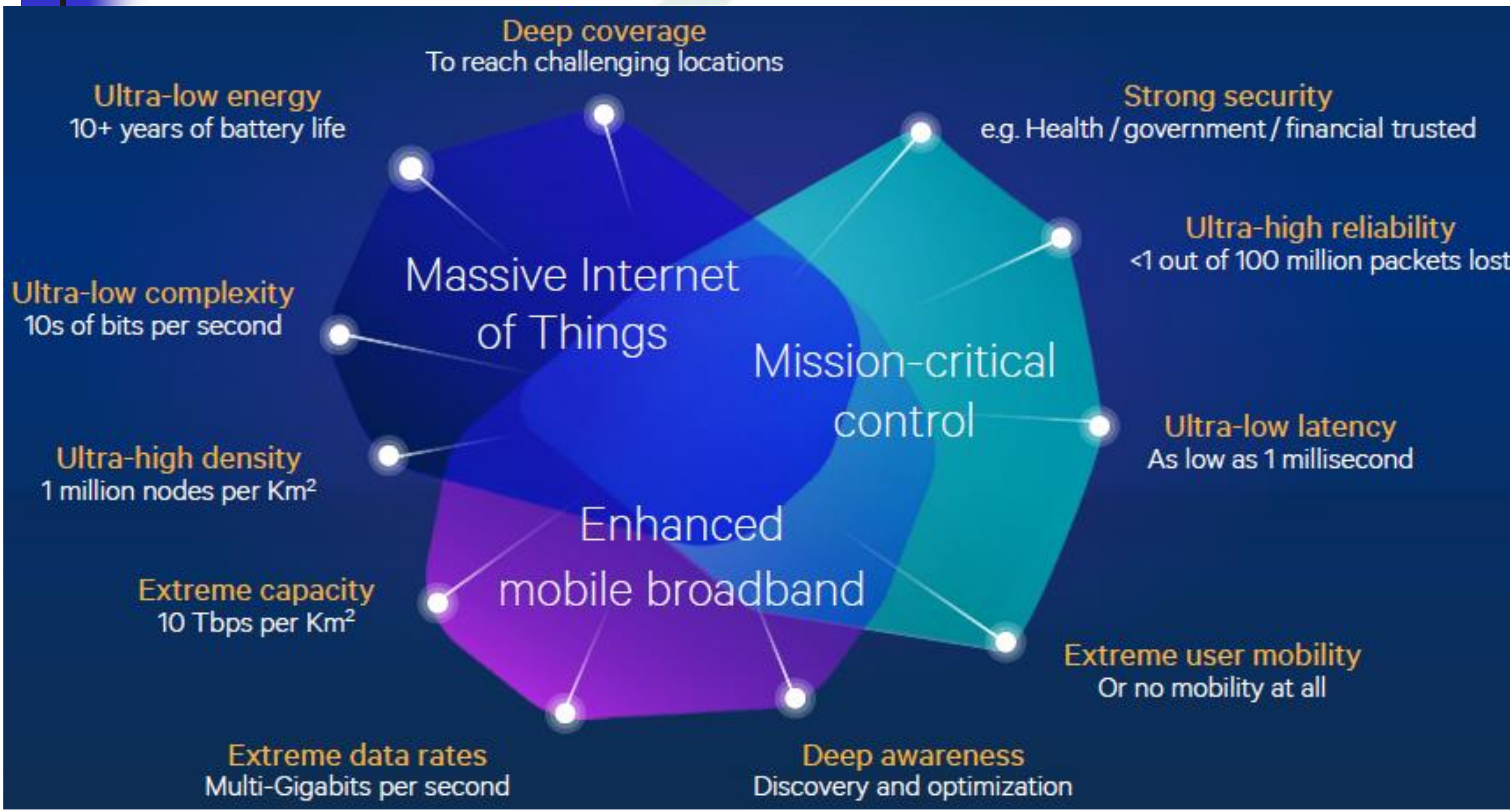
Low-Latency High-Reliability

- Air interface latency: 1 ms
- Reliability: nearly 100%

Low-Power Massive-Connections

- Connection density: 10^6 / km^2
- Ultra-low power consumption/Ultra-low cost

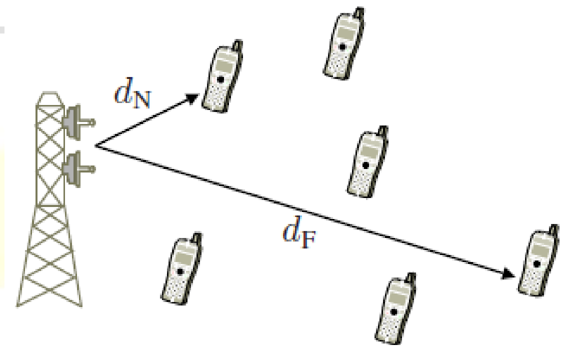
5G Scenarios and Challenges

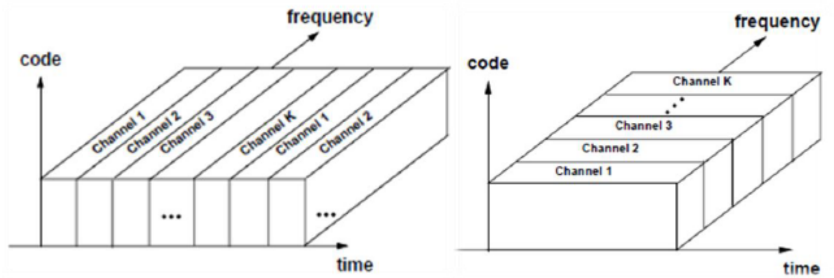


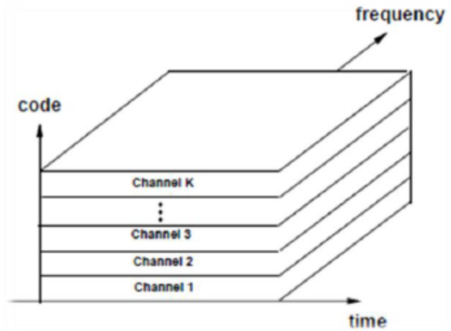
- 5G will not focus only on faster speed
- New application or service type maybe more important

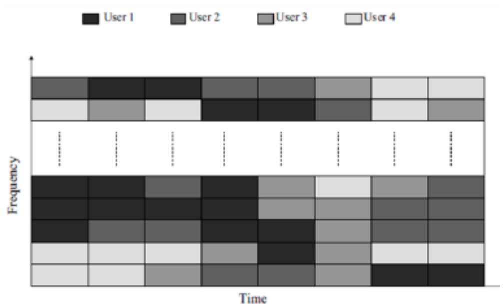
Multiple Access Techniques

- Multiple Access with Orthogonality
  - TDMA, FDMA, CDMA
  - OFDMA









TDMA/FDMA

- 2G Communication system, e.g. GSM
- Orthogonal in time or frequency domain
- Users are scheduled on orthogonal time slots

CDMA

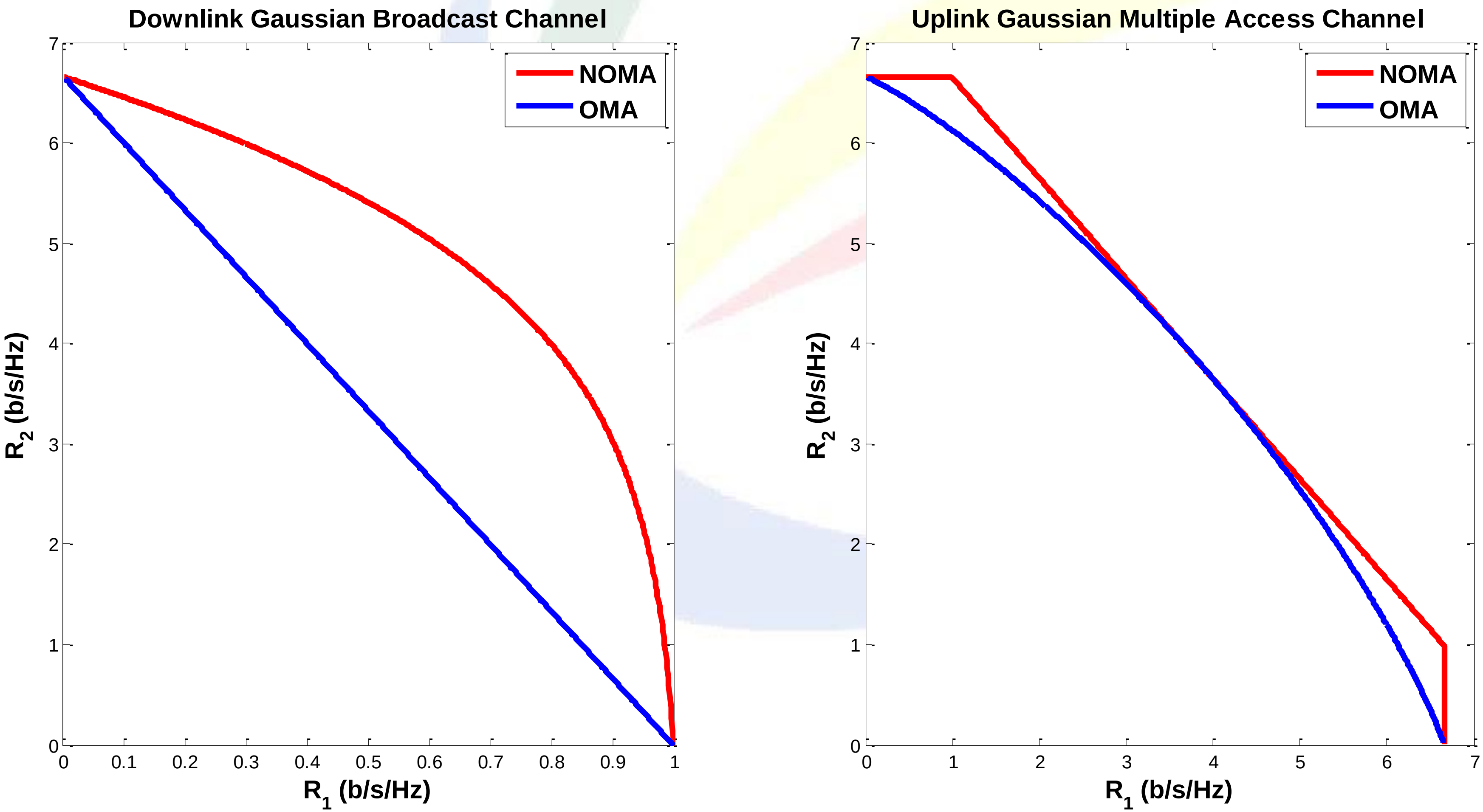
- 3G Communication system, e.g. WCDMA
- Non-orthogonal in time and frequency but orthogonal in code domain
- Users are scheduled on orthogonal sequences

OFDMA

- 4G Communication system, e.g. LTE
- Orthogonal in 2D time-frequency lattice domain
- Users are scheduled on orthogonal time-frequency lattice

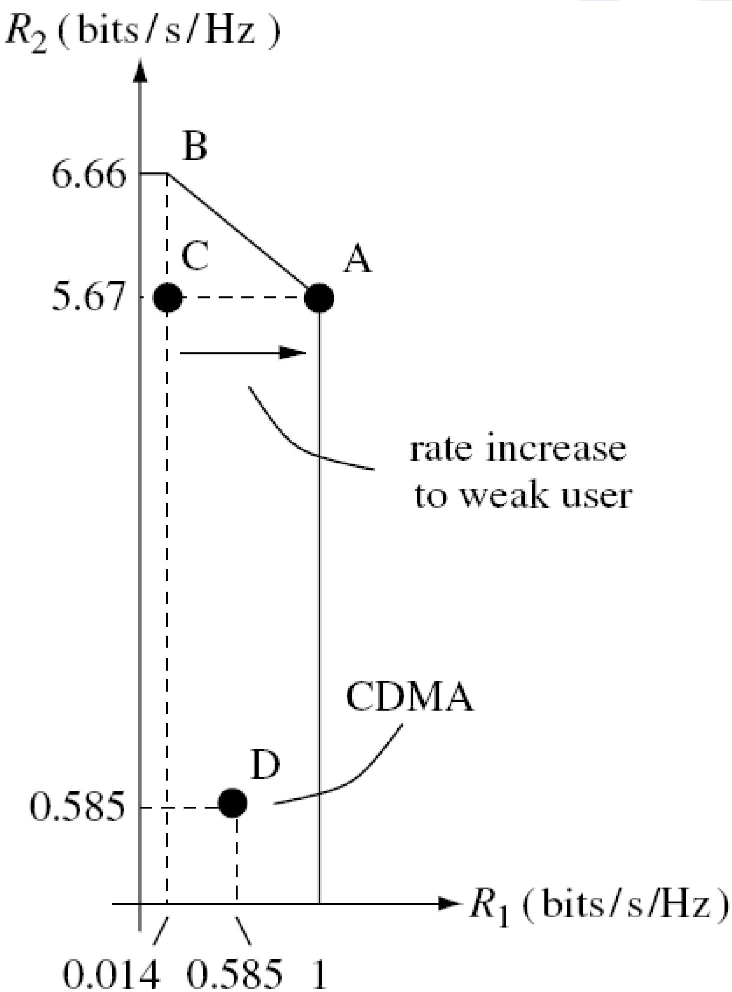
Multiple Access Techniques

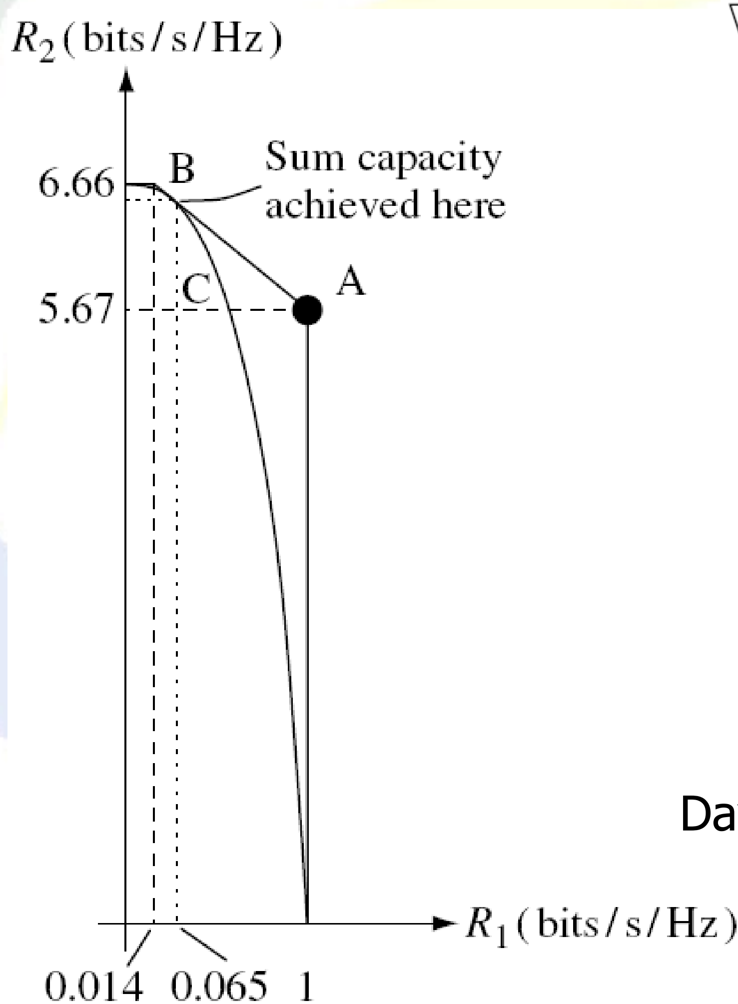
- Downlink and Uplink Non-Orthogonal Multiple Access

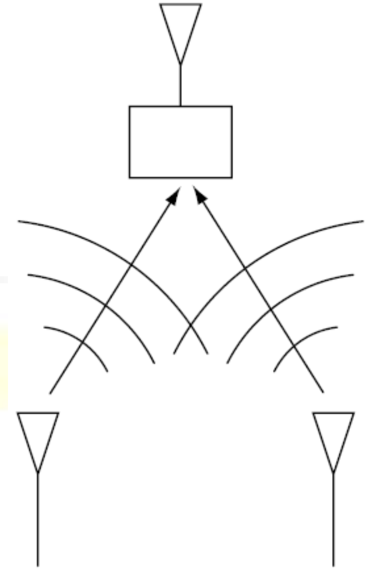


Information Theoretic Uplink NOMA Results

- CDMA + SIC Receiver







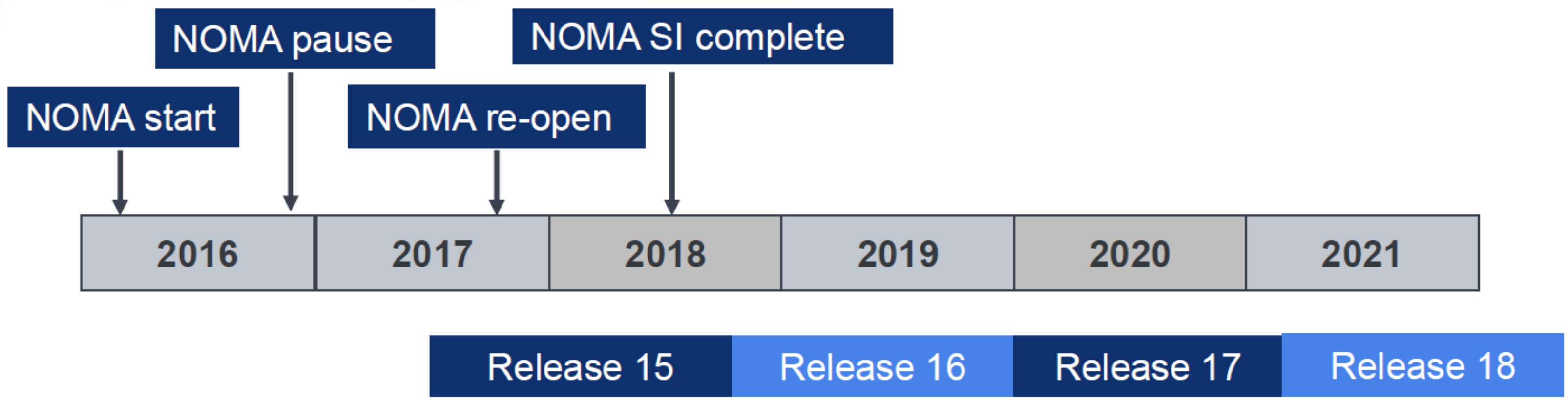
David Tse (2005)

NR NOMA Timeline

Original Plan

NR Study Item
for Multiple Access

NOMA Study Item



Nokia

NR NOMA Timeline

Revised Plan (early Dec.)

1/18 (2 TUs)

- Use scenarios, design targets, performance metrics, and baseline
- Simulation methodology & assumptions
- Initial discussion on Tx side design

Email discussion on simulation assumptions

Email discussion on details of receivers

02/18 (3 TUs)

- Tx side design
- Receivers for NOMA
- Initial perf. comparison
- Initial discussion on related procedures if time allows

System level simulation assumptions incl. related procedures

04/18 (3 TUs)

- Perf .evaluation & comparison
- Initial summary of designs
- Initial discussion on related procedures

Email discussion on initial TP for schemes and capturing results in TR

05/18 (4 TUs)

- Procedures related to NOMA
- Perf. evaluation & comparison
- Summary of different designs
- Recommendation and conclusion

Candidate Scenarios for NR NOMA

Use Scenarios

Closer to grant-based

Tend to be more technically challenging

Further away from grant-based

RRC-connected:
- Tight synchronization time & freq
- Tight power control, equal avg SNR
- No MA signature collision (incl. spreading code, interleaver /scrambling DMRS, preamble)

"Quasi"connected:
- Asynchronous or synchronous within CP
- Loose power control, un-equal avg. SNR
- Potential MA signature collision
- RRC inactive

"Cold" start:
- Asynchronous (may beyond CP)
- Very loose power control, significant near-far effect
- Potential MA signature collision
- RRC idle

- URLLC
- eMBB small data

- eMBB small data
- 2-step RACH, small coverage
- mMTC

Extended coverage

- 2-step RACH, wide coverage

ZTE View

Candidate Scenarios for NR NOMA

Design Targets & Performance Metrics

RRC connected	"Quasi" connected	"Cold" start
Low latency and small overhead of signaling Efficient resource utilization High reliability Moderate receiver complexity	Connection density /efficiency UE power consumption Receiver complexity per cell Coverage requirement	Connection density /efficiency UE power consumption and access latency Receiver complexity of system Coverage requirement
Baseline: Grant-free OMA	Baseline: Grant-free OMA	Baseline: 4-step RACH

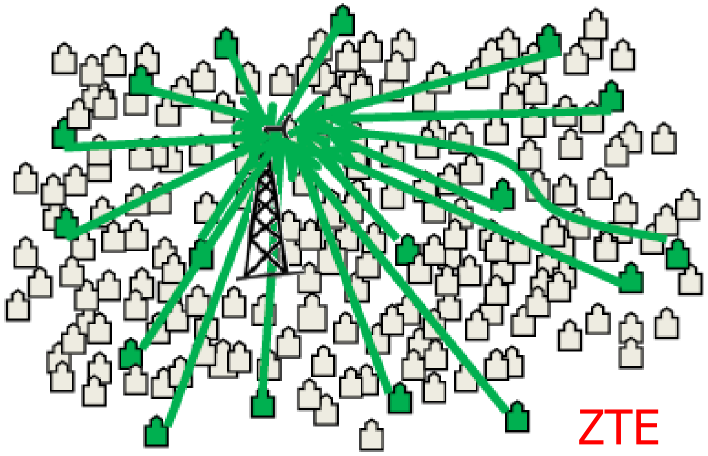
ZTE View

Candidate Scenarios for NR NOMA

- Enhanced Mobile BroadBand (eMBB)
  - Enhance user experienced data rate
  - User fairness
  - Infrequent small data
- Massive MTC (mMTC)
  - Massive connection
- Ultra Reliable and Low Latency Communication (URLLC)
  - Low latency uplink
  - 2-step random access
  - HARQ and retransmission

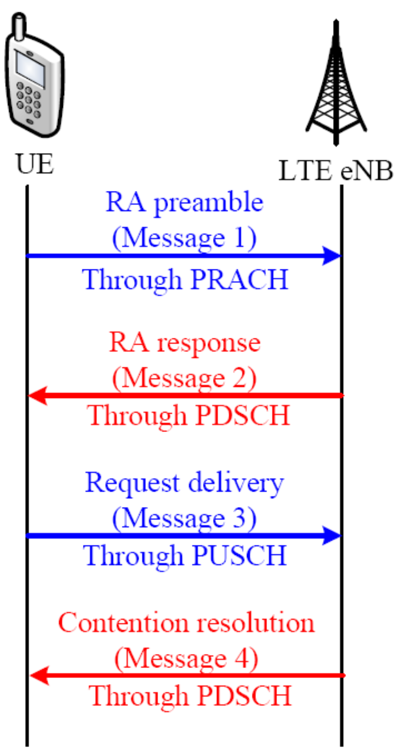
Candidate Scenarios for NR NOMA

- mMTC
- Massive connections with low cost & low power consumption
- 10^6 device/km^2 => BW*Cell*others
- Traffic characteristic:
  - Periodic traffic
  - Sporadic and infrequent small packets
- Limited knowledge/control of the channels
- Loose open-loop power control



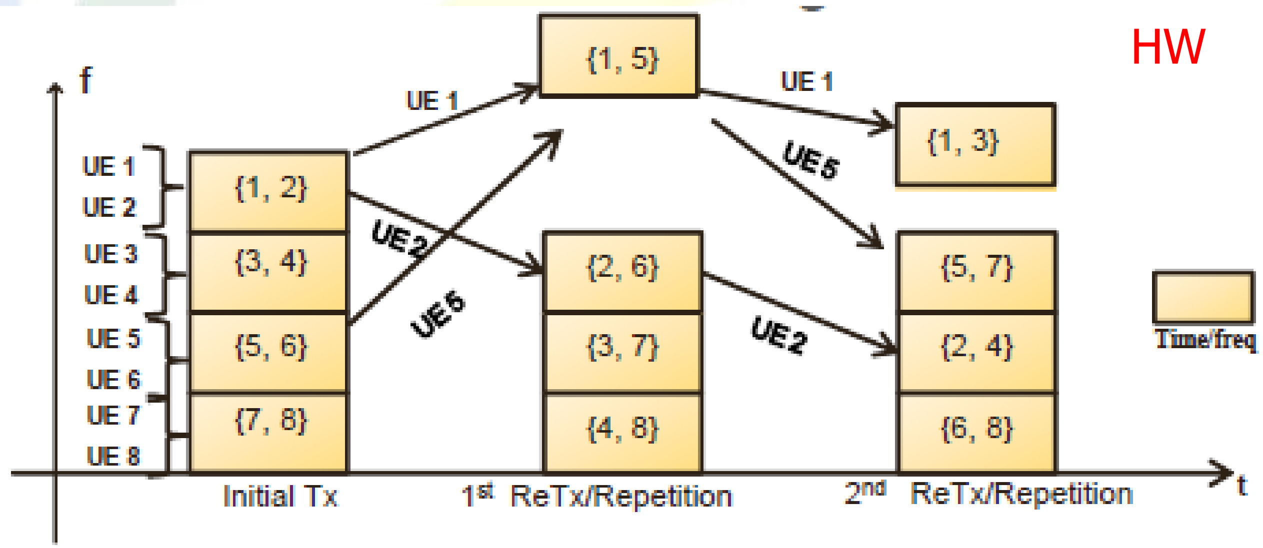
Candidate Scenarios for NR NOMA

- URLLC
- Uplink Grant Free Transmission with NOMA



LTE 4-Step RACH

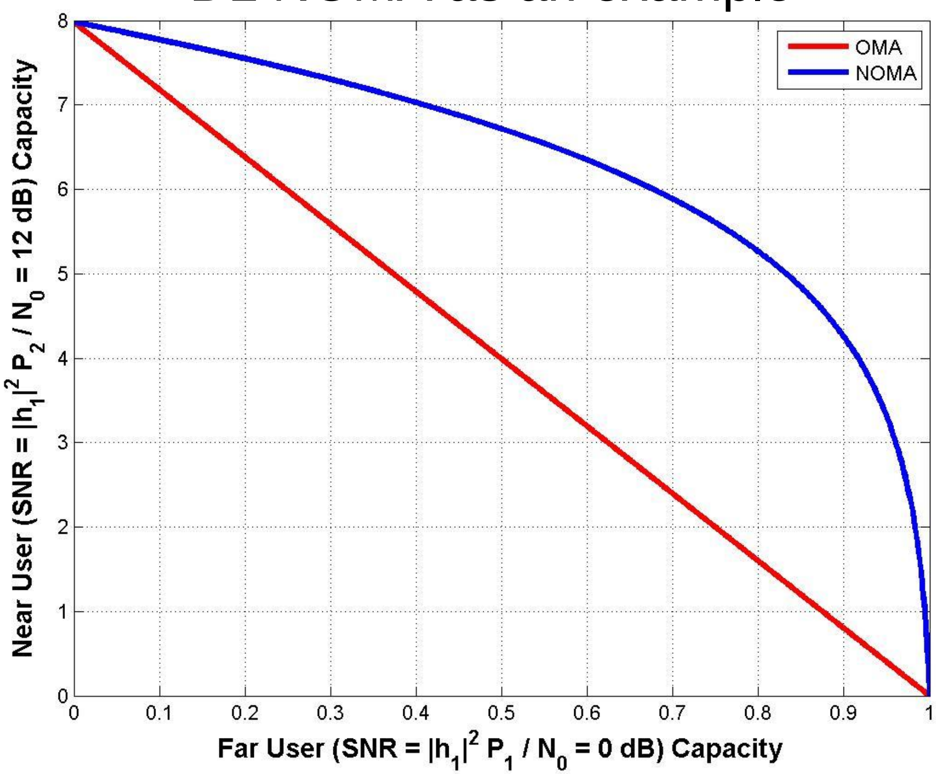
HW



- NR grant free transmission
- Pre-defined time-frequency resource Per UE
  - Orthogonal MA or
  - Partially overlapped MA
- Repeat K time transmission

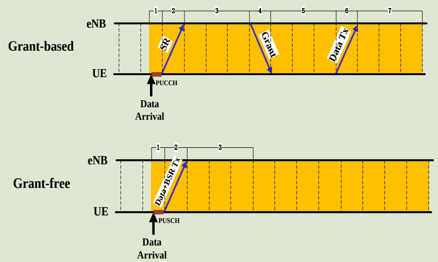
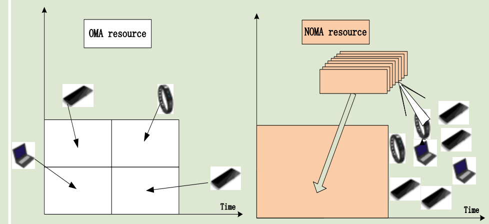
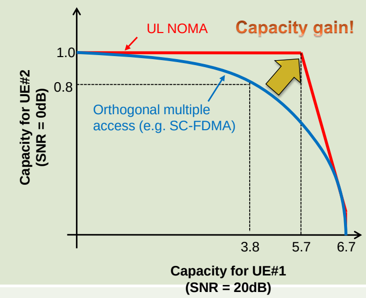
Candidate Scenarios for NR NOMA

- eMBB infrequent small data
- eMBB user experienced data rate
  - Fair scheduling for different SNR users
  - DL NOMA as an example



	OMA			NOMA	
	Water Filling	Round Robin	Fairness		
Near UE Capacity	8	4	0.89	6.8	4.2
Far UE Capacity	0	0.5	0.89	0.5	0.89
Sum Rate	8	4.5	1.78		
Fairness	☹		☺		

Candidate Scenarios for NR NOMA

Usage scenarios	uRLLC	mMTC	eMBB
Require-ment	Ultra low latency transmission; Ultra high reliability transmission 	Massive connectivity; Highly efficient small packets transmission; Coverage 	Large multi-user channel capacity High user density; Uniform user experience 
OMA	Connected devices limited by control channel availability; Higher scheduling latency	Limited number of simultaneous connections	Limitation of uplink single user capacity; Heavy CSI dependency for MU-MIMO
NOMA	Enabling reliable and low latency grant-free transmission; Reductions in latency and signaling overhead	Increase in number of connected devices: supporting overloaded transmission; Enabling grant-free transmission with lower signaling overhead	Achieving uplink multi-user channel capacity; Enabling open-loop MU multiplexing and CoMP
Key metric	Capacity and system load with given latency and BLER reliability	Connectivity Density; Coverage	BLER reliability, capacity and system load

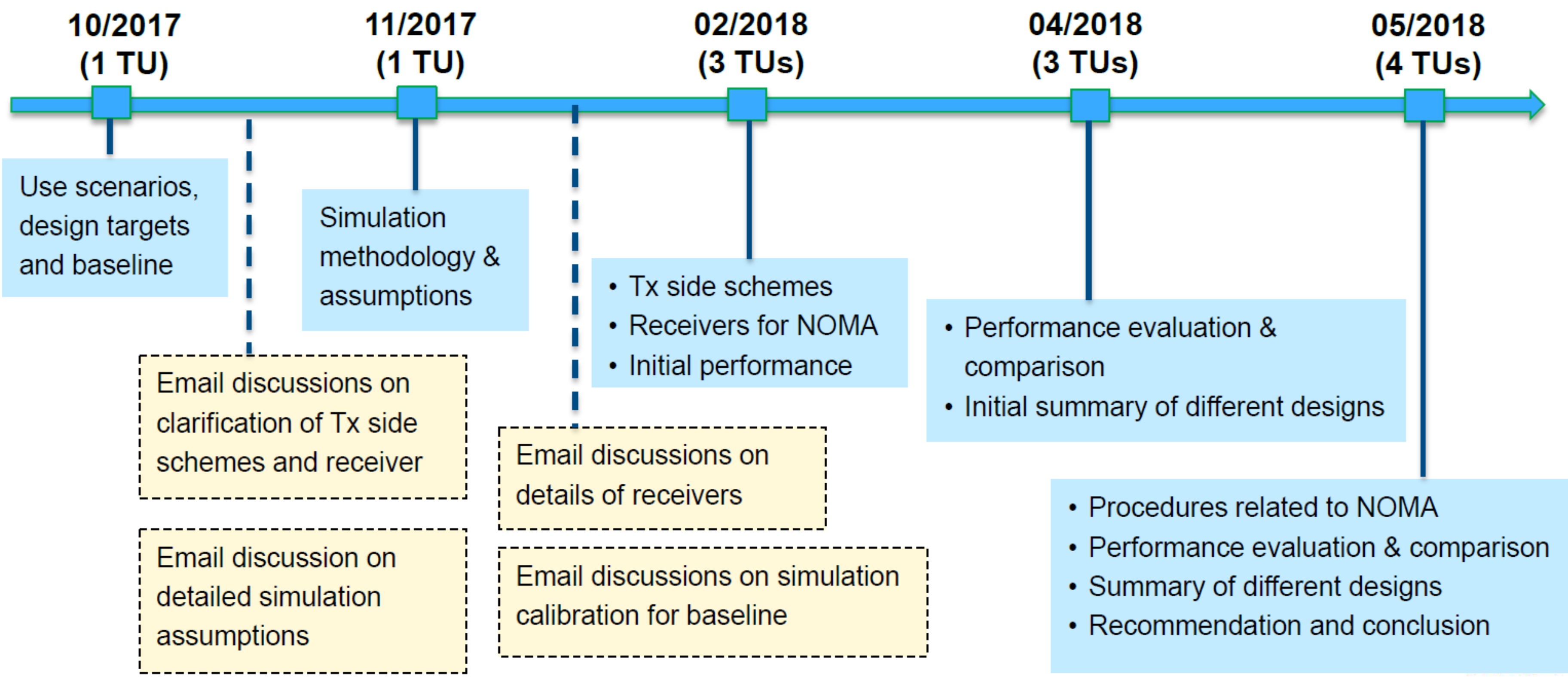
CATT

NOMA Workshops

- NOMA SID (RP-170829) agreed in RAN#75 Mar. 2017
- Starting point is postponed from 2017/Q3 to 2017/Q4 and again postponed to 2018/Q1
- 4 NOMA workshops were held by ZTE
  - WS #1 in May: Use scenario
  - WS #2 in June: Time plan
  - WS #3 in Aug: Link level simulation parameters for NOMA
  - WS #4 in Oct: Tx and Rx
- Around 51 people from 23 companies/institutes and/or universities participated
- Around 12 companies made presentations

NOMA Workshop #2

- Below is the ZTE's proposed time plan for Rel-15 NOMA SI, after taking into account of companies' feedbacks participating the 2nd NOMA workshop



Link-level evaluation assumptions

NOMA Workshop #3

Parameters	mMTC	URLLC	eMBB	Further specified values reported
Carrier Frequency	2 GHz	2 GHz	2 GHz	
Waveform (data part)	CP-OFDM and DFT-s-OFDM	CP-OFDM as starting point	CP-OFDM as starting point	
Numerology (data part)	SCS = 15 kHz, #OS = 14	SCS = 60 kHz #OS = 7	SCS = 15 kHz #OS = 14	
Allocated bandwidth	4 or 6 RB as baseline, single-tone, 1 RB as optional	4 or 6 RB as baseline, 12 RB as optional	4 or 6 RB as baseline, and 12 RB as optional	The same for non-orthogonal MA and baseline OFDMA
Target per UE spectral efficiency	[0.1-0.5] for normal coverage, [0.01-0.1] for extended coverage	[0.1-0.5]	[0.1-0.5]	The same total spectral efficiency (per UE SE * number of UEs) for non-orthogonal MA and OFDMA baseline. Company reports the MCS. Without short-term (per TTI) MCS adaptation.
Target BLER for one transmission	10%	0.1%	10%	
Number of UEs multiplexed in the same allocated bandwidth	To be reported by companies.	To be reported by companies	To be reported by companies	For OFDMA baseline, either simulate 1 UE per PRB (FDM for multiple UEs) and increase the MCS (per UE SE) accordingly, or keep the same number of UEs and MCS (resource collision is allowed)

Parameters	mMTC	URLLC	eMBB	Further specified values reported
BS antenna configuration	2Rx as baseline 4Rx as optional	2Rx as baseline 4Rx as optional	2Rx as baseline 4Rx as optional	
UE antenna configuration	1Tx			
Propagation channel & UE velocity	TDL-A 30ns and TDL-C 300ns in TR38.901, 3km/h			
Max number of HARQ transmission	1 as baseline			1
Channel estimation	Realistic channel estimation, Ideal channel estimation results should also be reported			
MA signature allocation (for data)	Fixed/Random	Fixed/Random	Fixed/Random	Proponents report the detais of random MA signature allocation
DMRS allocation	Proponents report the details of DMRS, and whether DMRS is randomly selected by UE or pre-configured by gNB with potential DMRS collision.			NR Rel-15 DMRS overhead for the baseline OMA
Timing/frequency offset	0 as starting point,	0 as starting point	0 as starting point	Non-zero timing and/or frequency offset to be considered later
Distribution of avg. SNR	Both equal and unequal	Equal	Both equal and unequal	For example, for unequal case, the long term SNR can have [3] values,30% users with x dB, 40% users with y dB, and 30% users with z dB
Receiver algorithm	Proponents provide details of receiver algorithms			MMSE-IRC for the baseline OMA

NOMA Workshop #4

- Transmitter/Receiver Techniques

Category	Scheme	Proposed by	Signature	Applicable Receivers
Codebook-based MA	SCMA	Huawei	Codebook	MPA, SIC-MPA
	PDMA	CATT		
Sequence-based MA	MUSA	ZTE	Symbol-level Complex Sequence	MMSE-SIC
	NCMA	LG		MMSE-SIC, ESE-PIC
	NOCA	Nokia, Alcatel-Lucent		
	GOCA	Media Tek.		MMSE-SIC
Interleaver/scrambler-based MA	IDMA	Nokia, InterDigital	Bit-level Interleaver	ESE-PIC
	IGMA	Samsung	Symbol-level Interleaver	ESE-PIC, MPA
	RDMA	Media Tek.		MMSE-SIC
	RSMA	Qualcomm	Symbol-level Scrambler	MMSE-SIC
Power-based MA	NOMA	NTT DoCoMo	NO	MMSE-SIC

NR Study Item Report 3GPP TR 38.802

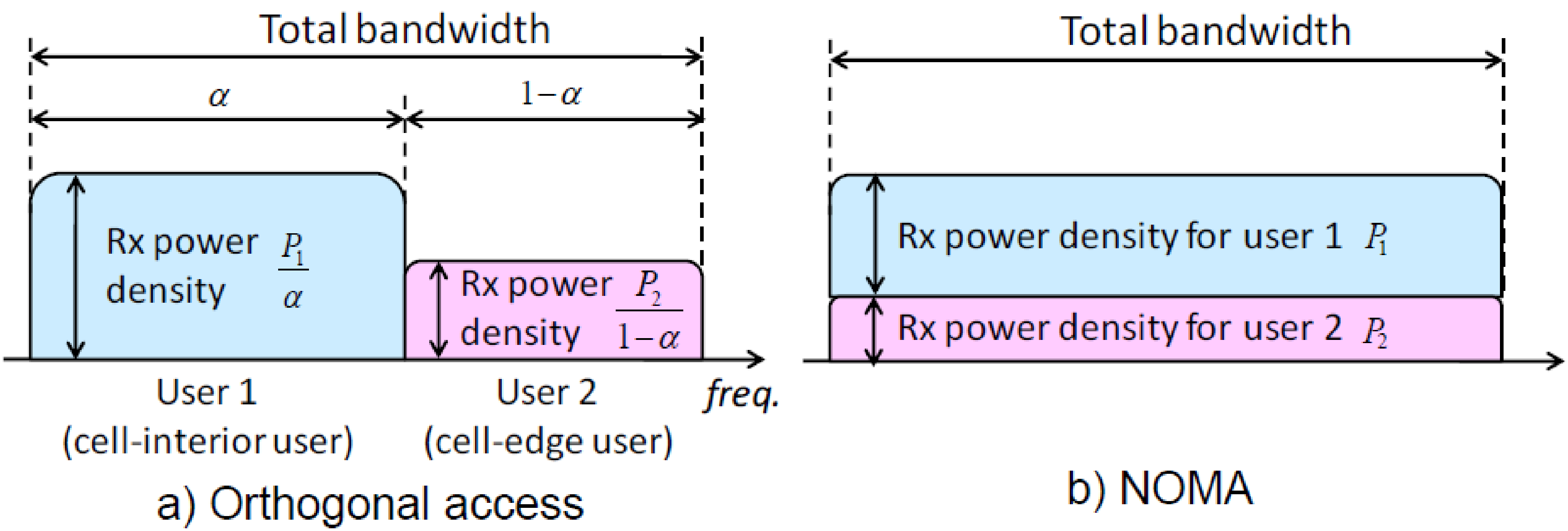
Table 9.1.2-5: Range of SNR gain of non-orthogonal multiple access over OFDMA with realistic channel estimation

Source		**Source 1**	**Source 3**	**Source 9**	**Source 9**	**Source 4**	**Source 6**	**Source 2**	**Source 5**	**Source 7**	**Source 8**	**Source 9**	**Source 11**
Multiple access scheme		SCMA	PDMA	GOCA	RDMA	LDS-SVE	NCMA	MUSA	IGMA	LSSA	NOMA	NB-IoT MU	LCRS
Receiver type		MPA	MPA	MF-based SIC	MF-based SIC	MPA w/o iterative decoding	MMSE-IRC w/ SIC	MMSE-SIC	Chip-by chip MAP	Iterative MMSE-PIC	MMSE-CWIC	SIC	MMSE-PIC
whether CRC is included		excluded	excluded	excluded	excluded	excluded	excluded	excluded	Excluded	included	excluded	excluded	excluded
MA signature setting		fixed & random	fixed	fixed	fixed	fixed	fixed	random	Fixed	fixed	fixed	fixed	fixed
# of UEs	**SE Range (bits/RE per UE)**	**Range/value of SNR gain (dB)**											
2	(0.2, 1.0]											[-1.3, 3.3]	
4	[0.05, 0.1]	[0, 0.4]	0.1[SE = 0.0833]	-	-	-	-1.4		-	-	-		
	(0.1, 0.2]	[0.8, 1.4]	0.2[SE = 0.2083]	-	-	-	-	[0.6,1]	-	-	0.2		
	(0.2, 1]	[1.6, 2.2]	0.5[SE = 0.3333]	-	-	-	0.3		-	-	-		[0.5, 1.5]
6	[0.05, 0.1]	[0, 1.1]	-	-	-	-	-1.7		0	-	-		
	(0.1, 0.2]	[2.2, 2.4]	-	-	-	-	-	[1.1,2.5]	0.6	-	-		
	(0.2, 1]	[3.1, 4.5]	-	[0.4, 0.8]	[0.2, 0.6]	[0.8,1.2]	1.1		1.7	-	-		
8	[0.05, 0.1]	[0.1, 1.8]	0.5[SE = 0.0833]	-	-	-	-1.9		0.4	-	-		
	(0.1, 0.2]	[2.5, 3.4]	2.2[SE = 0.2083]	[0.1, 0.7]	[-0.1, 0.5]	-	-	[0.5,1]	1.9	-	4.6		
	(0.2, 1]	[2.9, 6.7]	2.9[SE = 0.3333]	[0.5, 1.2]	[0.2, 0.8]	-	1.7		-	-	-		
12	[0.05, 0.1]	[1.0, 2.7]	-	-	-	-	-		-	-	-		
	(0.1, 0.2]	[5.1, 6.0]	-	[0.6, 1.5]	[0.1, 1.1]	-	-	[0.5,2.2]	-	-	4.6		
	(0.2, 1]	[7.2, 13.2]	-	-	-	-	-		-	-	-		
18	[0.05, 0.1]	-	-	-	-	-	-		-	4.6	-		
	(0.1, 0.2]	-	-	-	-	-	-		-	4.2	-		
	(0.2, 1]	-	-	-	-	-	-		-	-	-		
24	[0,1,0.2]							[0.9,1.4]					
26	[0.1, 0.2]							[1.6,1.7]					

Note 1: SNR is defined as total received SNR per RE per Rx antenna at eNB.
Note 2: The empty entries in the table are due to absence of simulation data.

Power Domain NOMA

- Power Domain NOMA
  - Power-domain user multiplexing

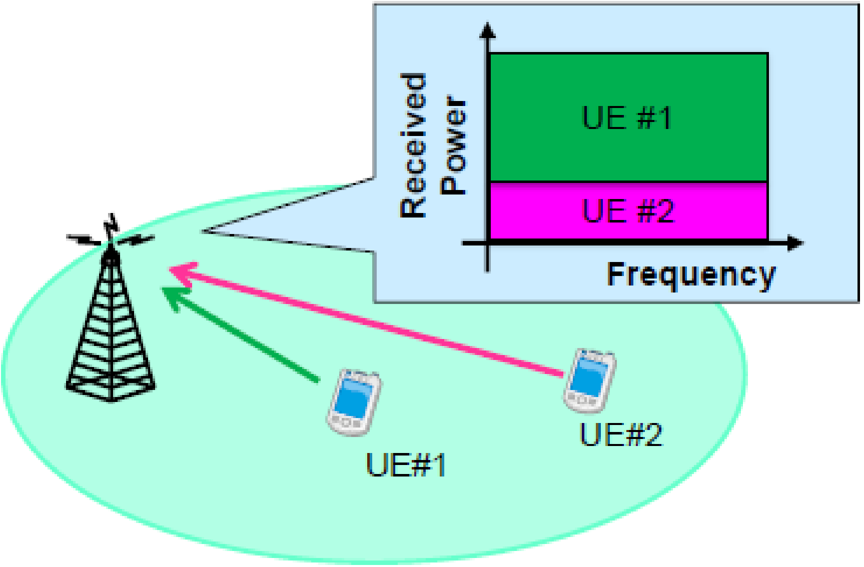


NTT DoCoMo

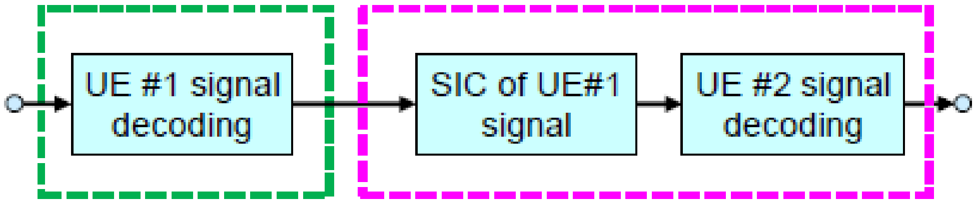
Power Domain NOMA

- Power Domain NOMA
  - Ex: two meter with scheduled data?
  - Power Control

NTT DoCoMo



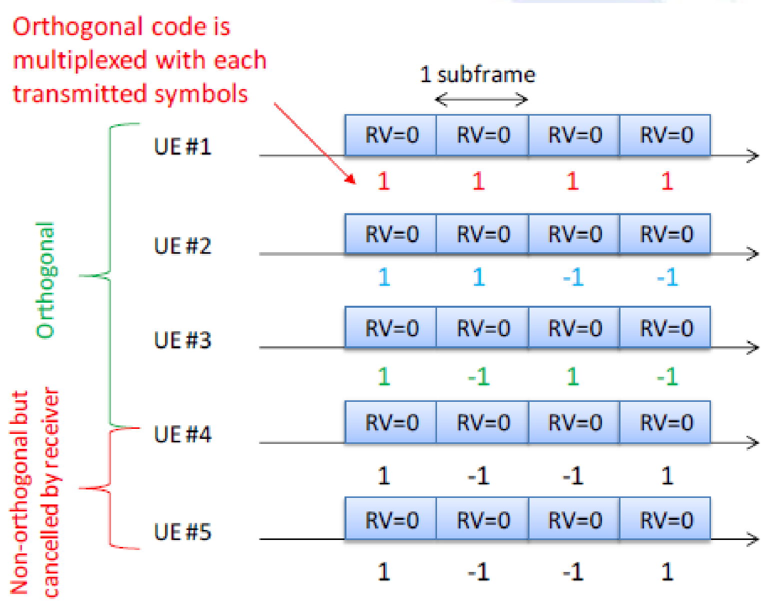
(c) SIC at BS

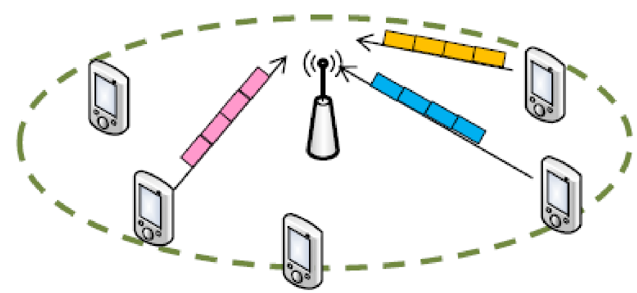


Code Spreading NOMA

NTT DoCoMo

- Code Spreading NOMA
  - Enhance NOMA to mitigate inter-user interference in a cell
  - Simple time domain (or frequency domain) code spreading on top of repetition





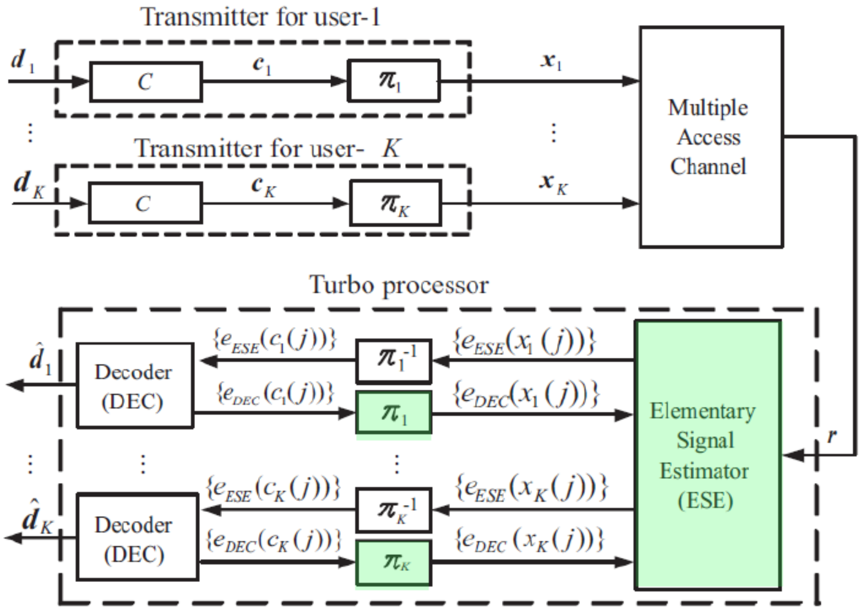
Spreading for NOMA

- ➢ In low traffic load, eNB can configure orthogonal code (e.g., OVSF code) to multiplexed users
- ➢ In high traffic load, eNB can configure non-orthogonal code to some multiplexed users

Interleaver Based NOMA

- Interleave Division Multiple Access(IDMA)
  - User discrimination by different interleaving/scrambling per user
  - High spreading through combination of low code rate and repetition
  - Inter-User Interference is processed
    - Interference statistics are utilized to enhance the LLR estimation
- ESE block is introduced to:
  - Estimate the statistics of the received signal (chip-by-chip processing)
  - Provide improved LLR for decoder

InterDigital



The received from K users:

$$r(j) = \sum_{k=1}^{K} h_k x_k(j) + n(j)$$

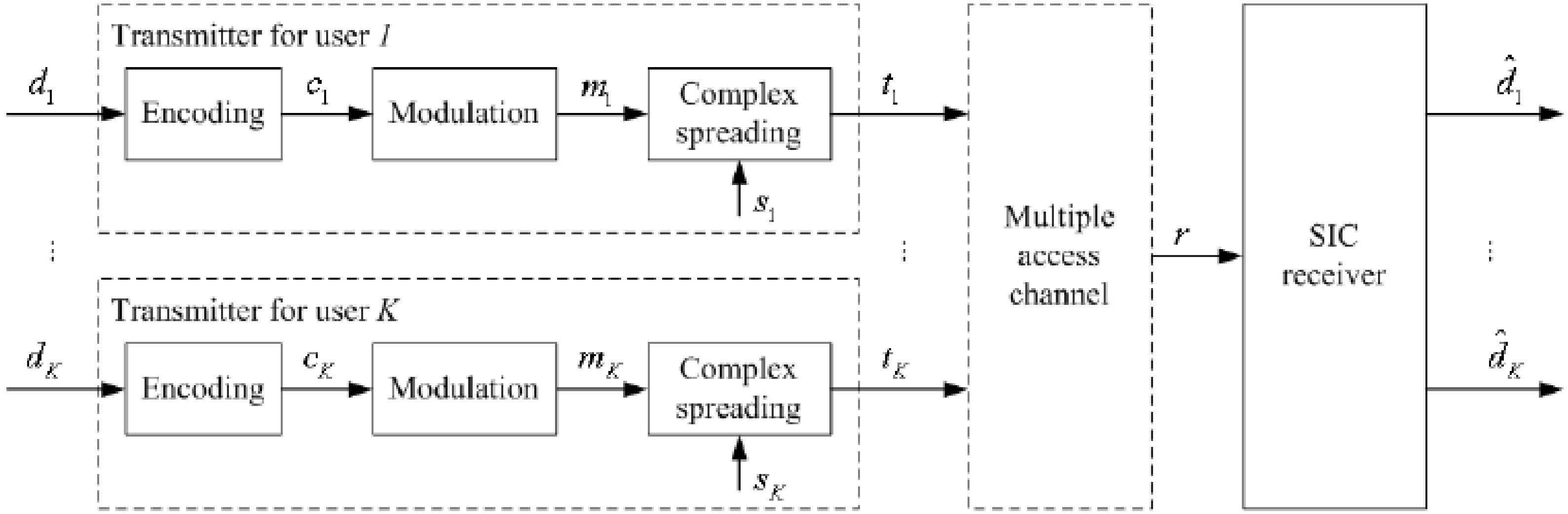
$$= h_k x_k(j) + \zeta_k(j) \; , j = 1,2, \dots , J$$

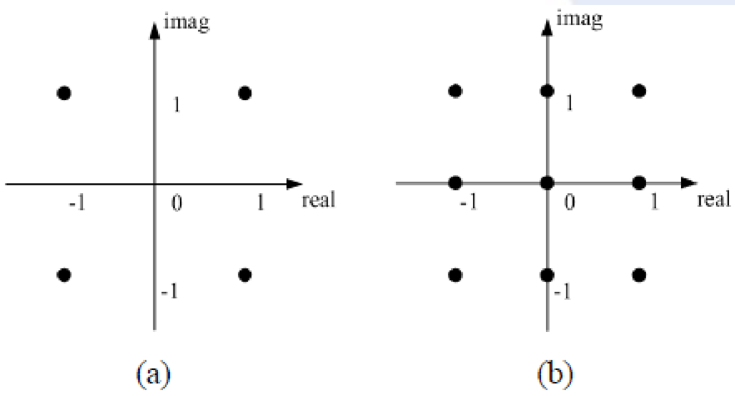
$$\zeta_k(j) = r(j) - h_k x_k(j) = \sum_{k' \neq k} h_{k'} x_{k'}(j) + n(j)$$

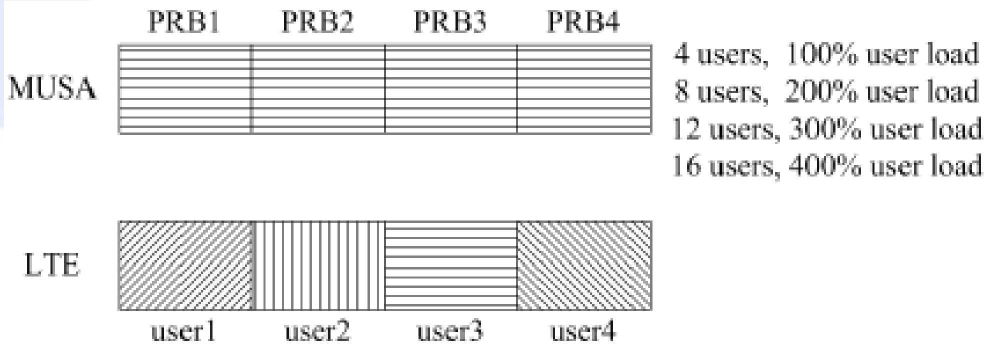
Sequence Based NOMA

- Multi-User Shared Access (MUSA)

ZTE







Codebook Based NOMA

CATT

- Pattern Division Multiple Access (PDMA)

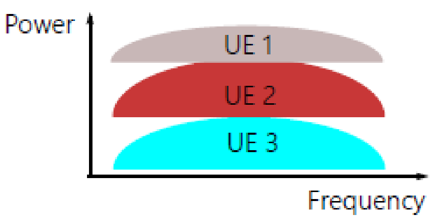
$$G^{[4,4]} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad G^{[4,8]} = \begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

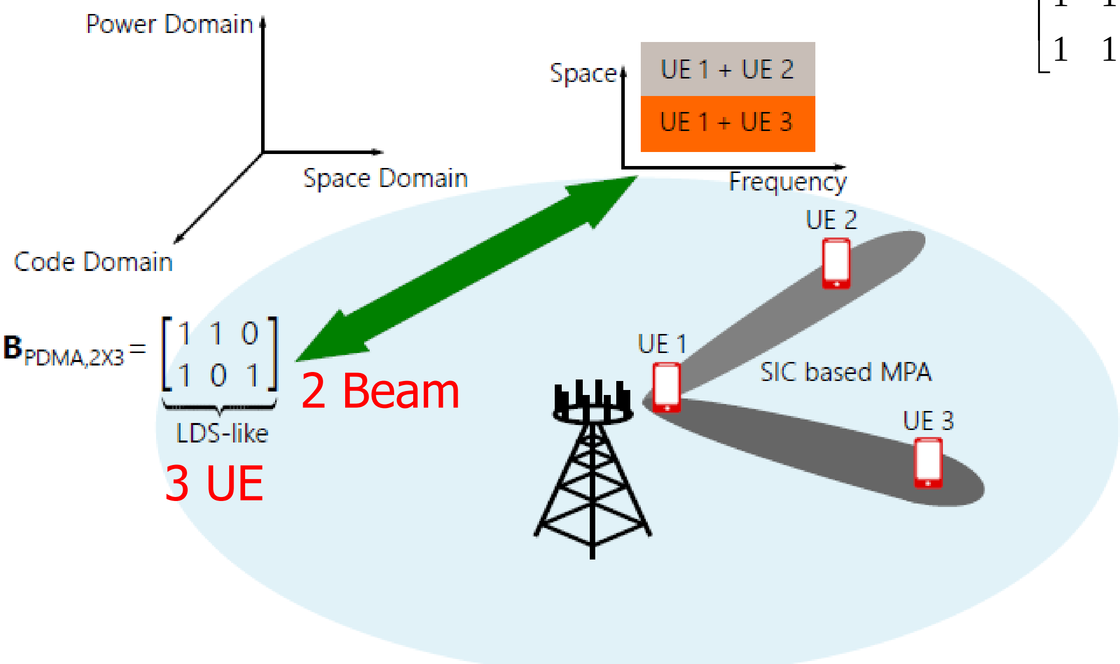
12 UE

4 RE

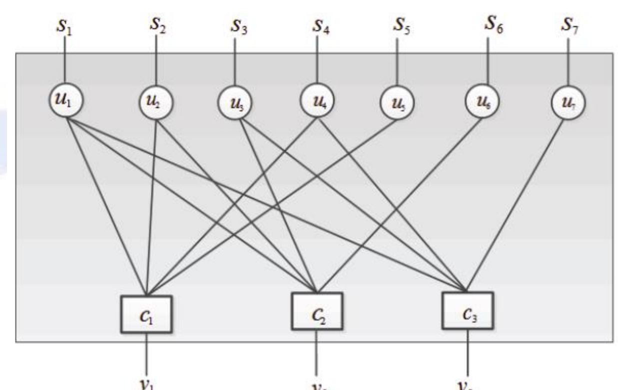
$$G^{[4,12]} = \begin{bmatrix} 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \end{bmatrix}$$

100%: PDMA pattern matrix 4×4
200%: PDMA pattern matrix 4×8
300%: PDMA pattern matrix 4×12





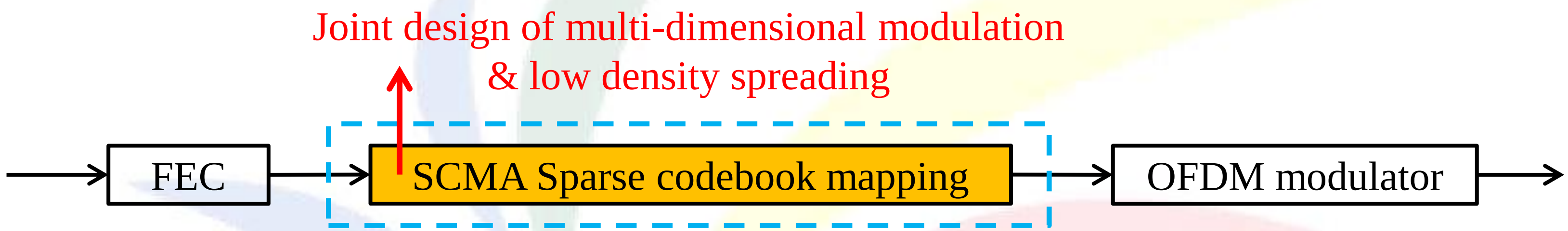
$$\mathbf{B}_{PDMA,2X3} = \underbrace{\begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}}_{\text{LDS-like}}$$

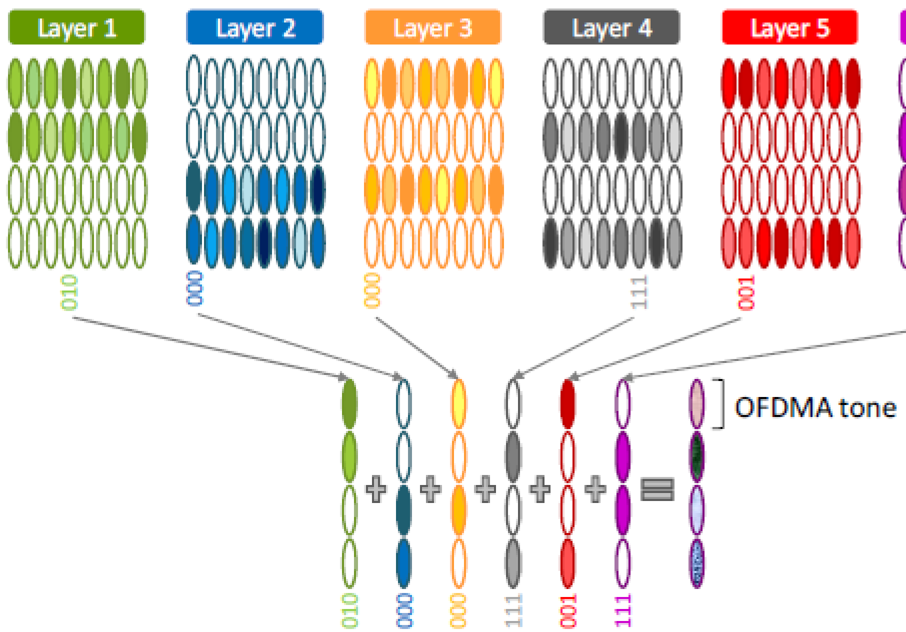


Codebook Based NOMA

Huawei

- Sparse Code Multiple Access (SCMA)

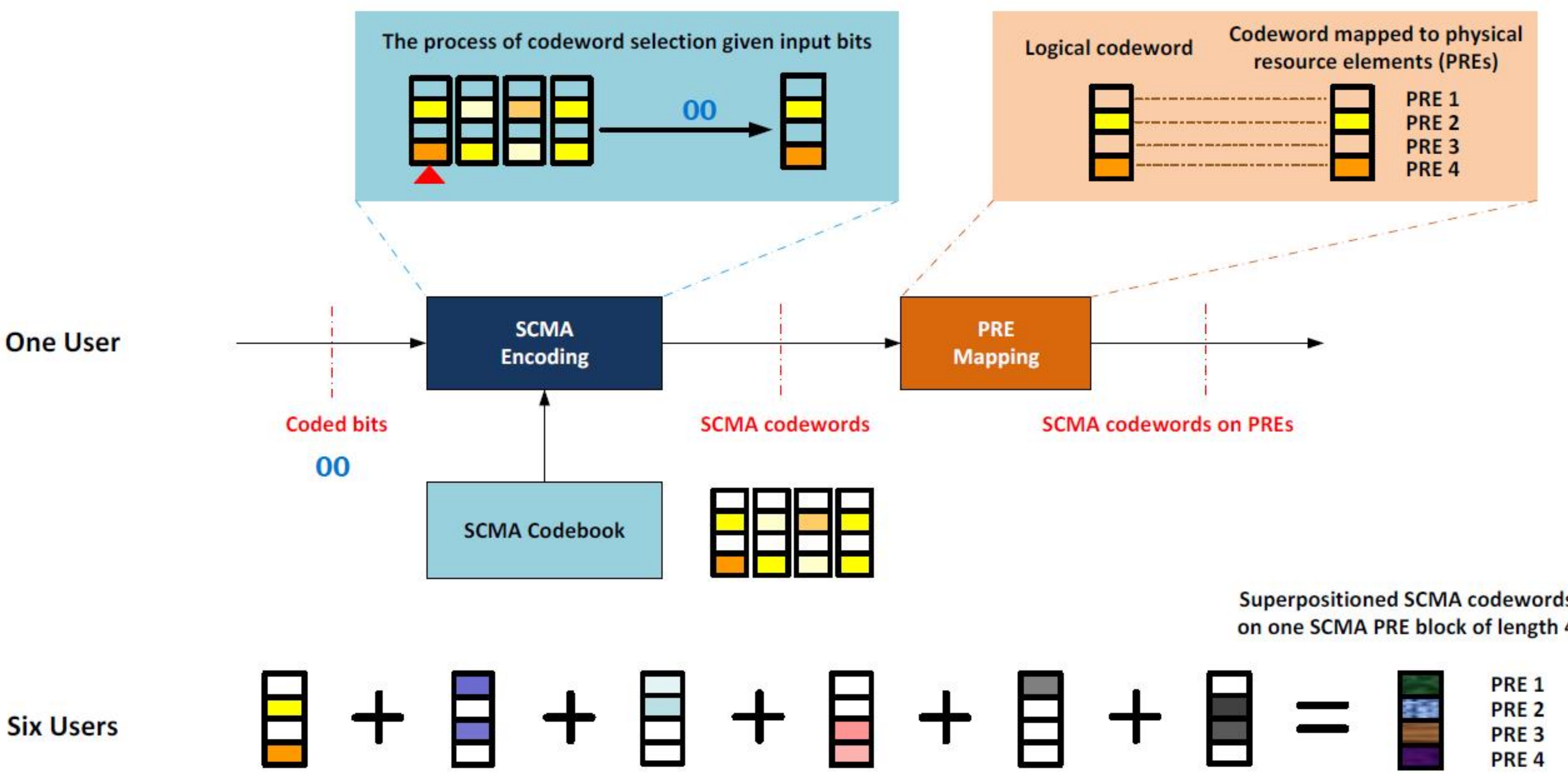




Codebook Based NOMA

Huawei

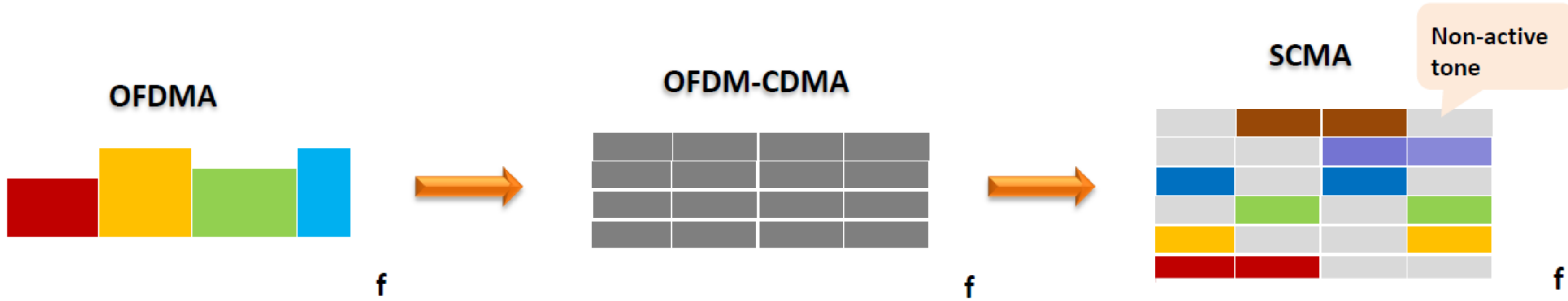
- Sparse Code Multiple Access (SCMA)



Codebook Based NOMA

Huawei

- From OFDMA -> LDS -> SCMA



Orthogonal multi-user multiplexing

- Users occupy orthogonal resources for communication
- Easy to implement (single user detection)
- Number of connections limited by the number of physical resource blocks that can be scheduled

Non-orthogonal multi-user multiplexing

- Users occupy the same resource blocks using CDMA
- Non-practically high multi-user joint detection complexity
- Limited number of concurrent users due to limited sequences
- Better coverage due to spreading gain

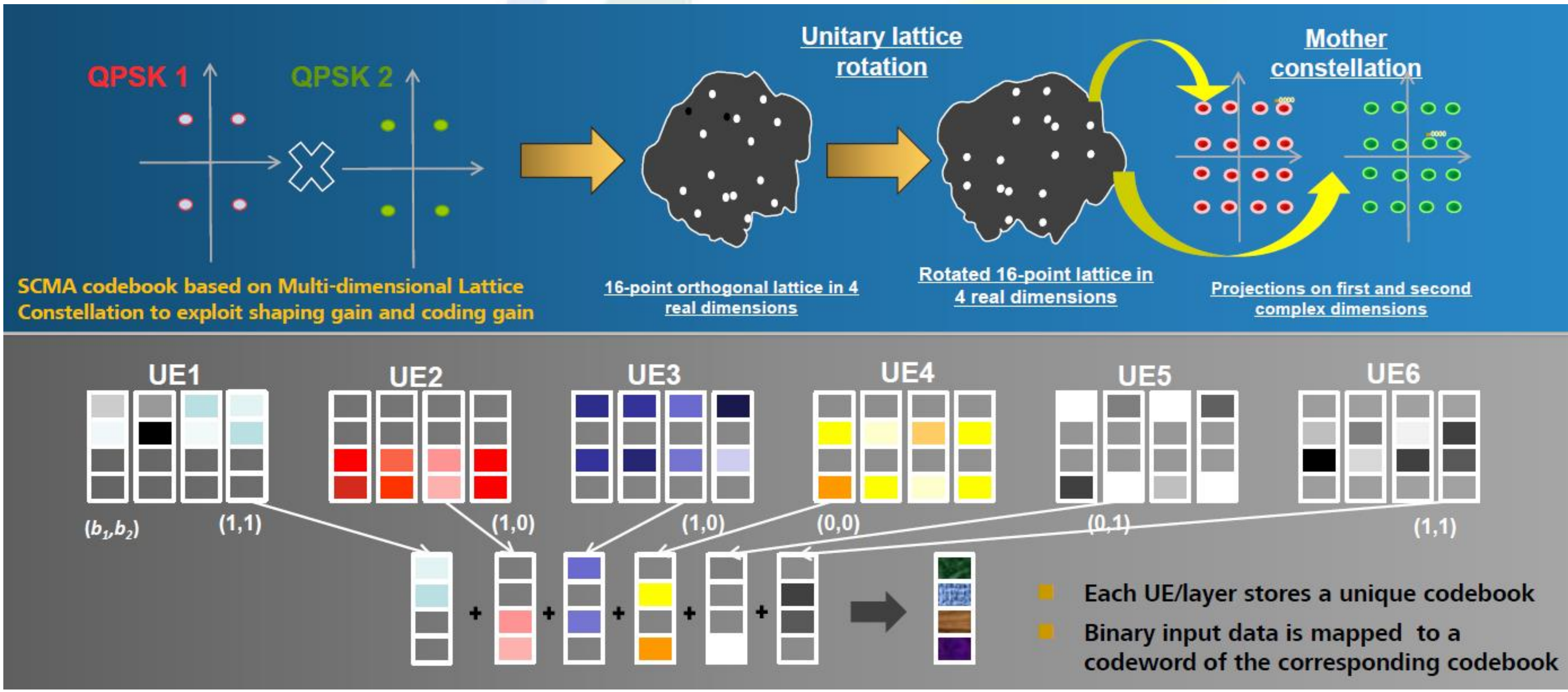
Overloaded multi-user multiplexing

- Users occupy the same resource blocks in a low density way
- Affordable low multi-user joint detection complexity
- Less collision even for large number of concurrent Users
- Better coverage due to spreading gain

Codebook Based NOMA

Huawei

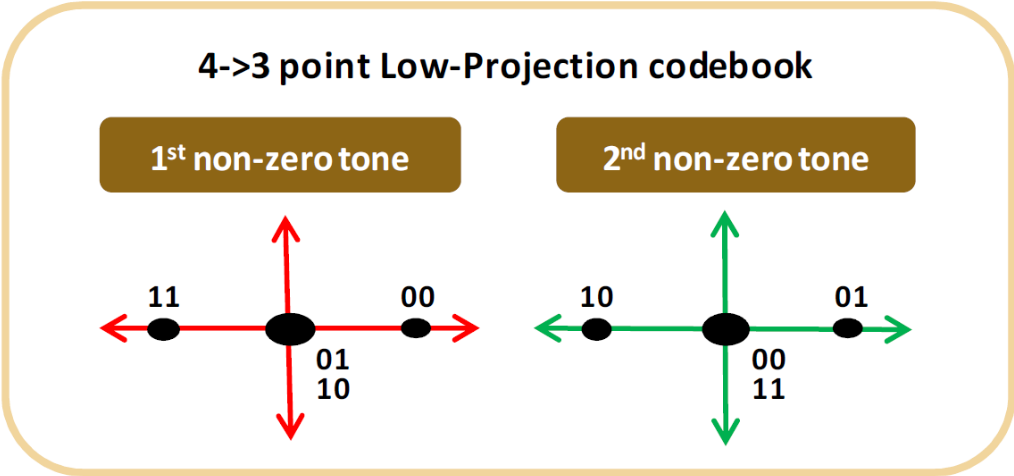
- SCMA codebook design



Codebook Based NOMA

Huawei

- SCMA codebook design
  - Shaping gain and coding gain
  - Joint optimization of the sparse spreading pattern design and the mulit-dimensional constellation design
  - Providing good distance properties (Euclidean and/or Product) among the points in the overall multi-dimensional constellation
  - The possibility of having lower number of projection points over each resource element

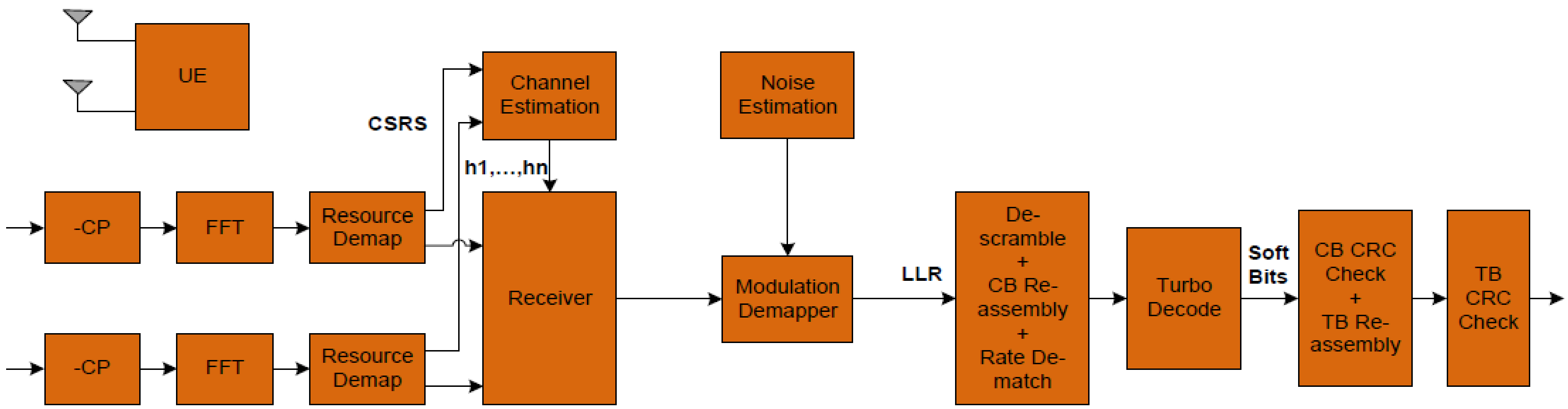


Codebook Based NOMA

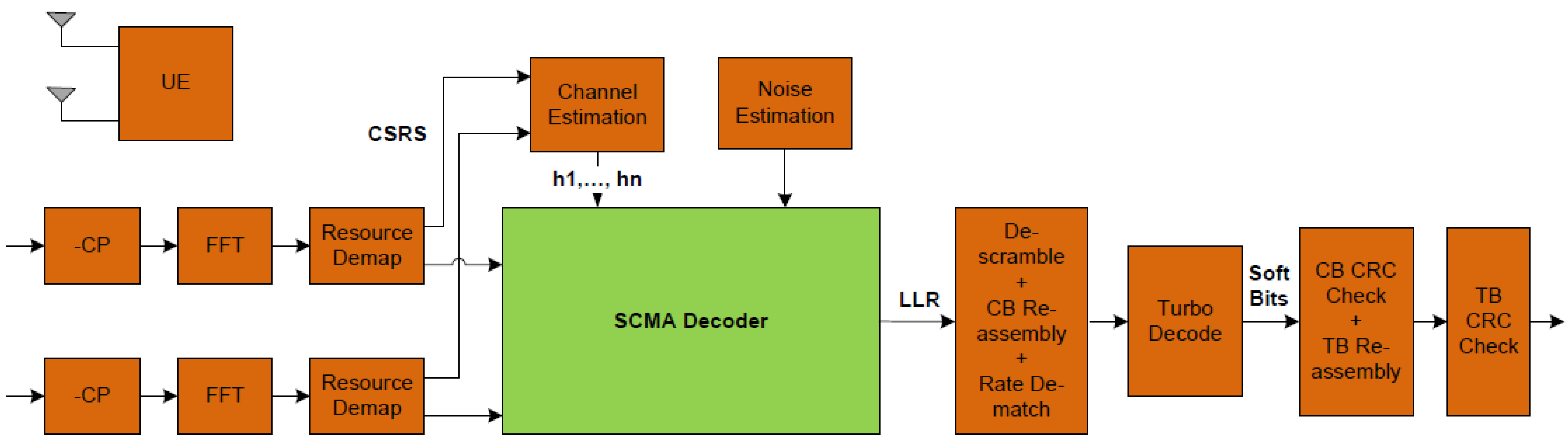
Huawei

- SCMA Receiver

LTE



SCMA



Codebook Based NOMA

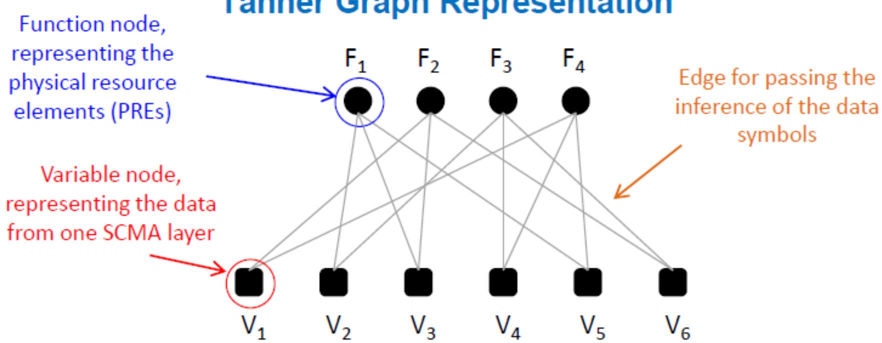
Huawei

- SCMA Receiver

Codebook Related Parameters

Related Variables	Typical value	Description
V	6	6 variable nodes (VN), number of data layers
F	4	4 function nodes (FN), number of physical resources
d_f	3	Each FN is connected to 3 VNs
d_v	2	Each VN is connected to 2 FNs
M	4	Number of codeword in each codebook
CB_i	F-by-M matrix	Codebook for one SCMA data layer

Tanner Graph Representation



Codebook in Storage (V=6, F=4, df=3, dv=2, M=4)

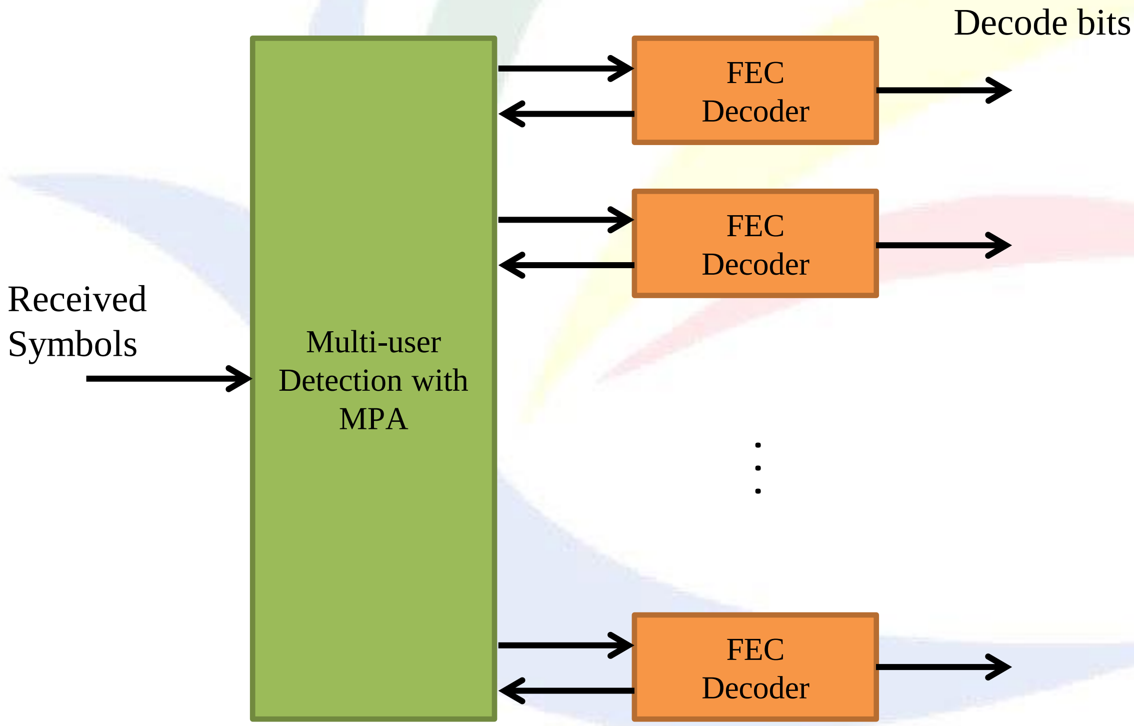
SCMA Codebook index	SCMA codebook for each layer
CB_1	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \end{bmatrix}$
CB_2	$\begin{bmatrix} 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0 & 0 & 0 & 0 \\ -0.1815-0.1318i & -0.6351-0.4615i & 0.6351+0.4615i & 0.1815+0.1318i \\ 0 & 0 & 0 & 0 \end{bmatrix}$
CB_3	$\begin{bmatrix} -0.6351+0.4615i & 0.1815-0.1318i & -0.1815+0.1318i & 0.6351-0.4615i \\ 0.1392-0.1759i & 0.4873-0.6156i & -0.4873+0.6156i & -0.1392+0.1759i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$
CB_4	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ -0.0055-0.2242i & -0.0193-0.7848i & 0.0193+0.7848i & 0.0055+0.2242i \end{bmatrix}$
CB_5	$\begin{bmatrix} -0.0055-0.2242i & -0.0193-0.7848i & 0.0193+0.7848i & 0.0055+0.2242i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0.6351+0.4615i & 0.1815-0.1318i & -0.1815+0.1318i & 0.6351-0.4615i \end{bmatrix}$
CB_6	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0.7851 & -0.2243 & 0.2243 & -0.7851 \\ 0.1392-0.1759i & 0.4873-0.6156i & -0.4873+0.6156i & -0.1392+0.1759i \\ 0 & 0 & 0 & 0 \end{bmatrix}$

4

Codebook Based NOMA

Huawei

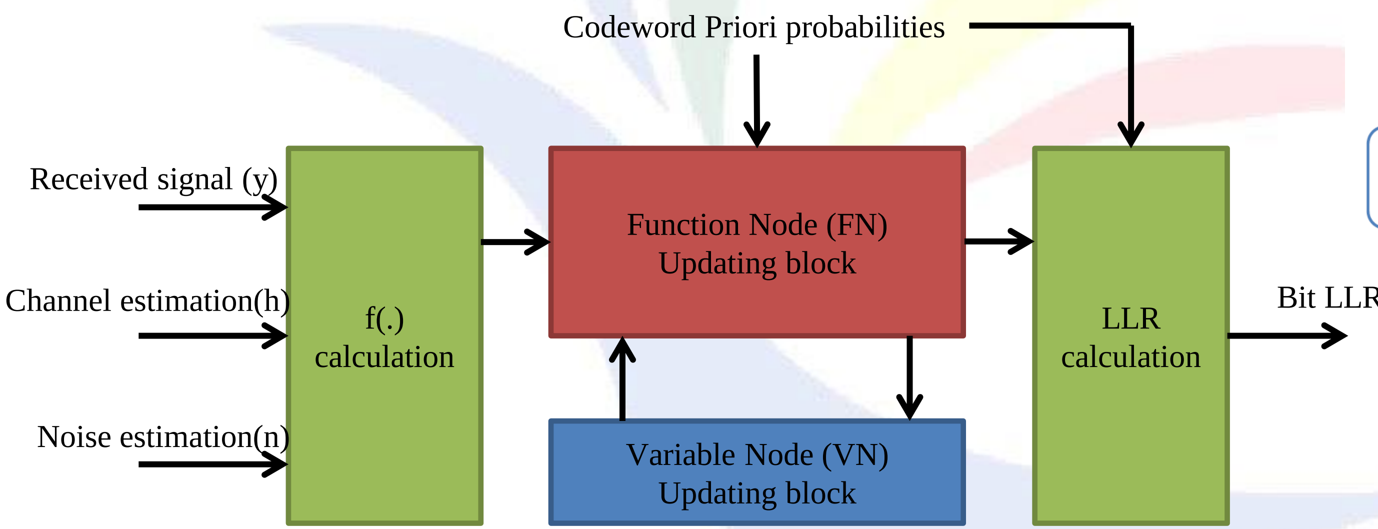
- MPA Receiver

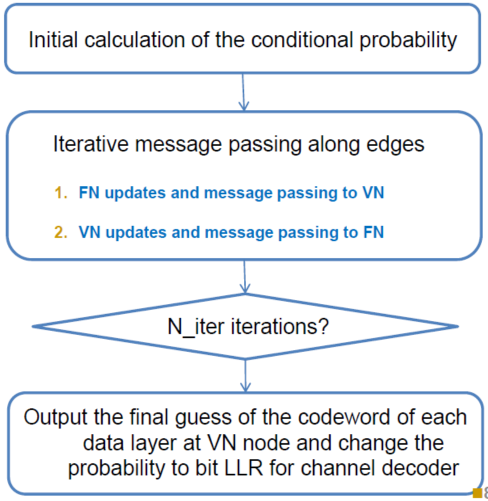


Codebook Based NOMA

Huawei

- MPA Receiver



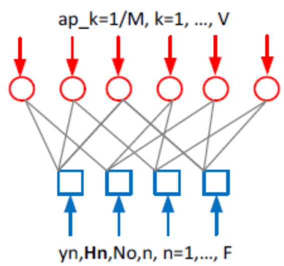


Codebook Based NOMA

Huawei

- MPA Receiver

Parameters	Description of the parameters
y_n, n=1,..., F	Received signal as input to the MPA decoder on resource n
m_k, k=1,..., V	Codeword selected by layer k, m_k = 1,..., M
No_n, n=1,..., F	Noise power estimation on physical resource n
C_k,n(m_k)	The constellation symbol of VN node k on physical resource n when using codeword m_k
H_n = {h_n,k}	Channel gain of user k on physical resource n
Ap_k, k=1,..., V	A prior probability of codeword k, assuming equal probability 1/M
LLR_k,b	logarithm of the likelihood ratio of layer k bit b
N_iter	Number of iterations in the MPA



Step 1: Initial calculation of the conditional probability

- For each function node FN, calculate the f_n() function, which is the set of all possible residual signals given the known or estimated channel h_n,k and the assumed transmitted codeword C_k,n(m_k)
- When d_f = 3, as in the example, for each FN node n, there are M*M*M combinations of transmitted signals, so there are in total F*M*M*M values to store for f() function calculation

$$f_n(y_n, m_1, m_2, m_3, N_{0,n}, \mathbf{H}_n) = \frac{-1}{N_{0,n}} \left\| y_n - \left(h_{n,1} \mathbf{C}_{1,n}(m_1) + h_{n,2} \mathbf{C}_{2,n}(m_2) + h_{n,3} \mathbf{C}_{3,n}(m_3) \right) \right\|^2$$

$$m_1 = 1, \dots, M \qquad m_2 = 1, \dots, M \qquad m_3 = 1, \dots, M \qquad n = 1, \dots, F$$

- Phi_n() function is actually the conditional probability for given codeword combination, for Gaussian noise case, it is the exponential operation over f_n function, so the storage needed is the same

P(yn|x1, x2, x3) ----- $\phi_n(y_n, m_1, m_2, m_3, N_{0,n}, \mathbf{H}_n) = \exp\left(f_n(y_n, m_1, m_2, m_3, N_{0,n}, \mathbf{H}_n) \right)$

- To prepare for the iterations, we assign the a prior probability for each codeword, which is assumed to be equal

P(x1), P(x2), P(x3) ----- $\mathbf{I}_{v_1 \to g}{}^{init}(m_1) = \mathbf{I}_{v_2 \to g}{}^{init}(m_2) = \mathbf{I}_{v_3 \to g}{}^{init}(m_3) = \frac{1}{M}$

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Codebook Based NOMA

Huawei

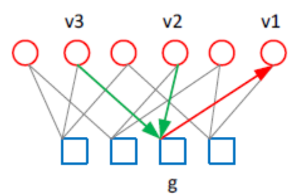
- MPA Receiver

Parameters	Description of the parameters
y_n, n=1,..., F	Received signal as input to the MPA decoder on resource n
m_k, k=1,..., V	Codeword selected by layer k, m_k = 1,..., M
No_n, n=1,..., F	Noise power estimation on physical resource n
C_k,n(m_k)	The constellation symbol of VN node k on physical resource n when using codeword m_k
H_n = {h_n,k}	Channel gain of user k on physical resource n
Ap_k, k=1,..., V	A prior probability of codeword k, assuming equal probability 1/M
LLR_k,b	logarithm of the likelihood ratio of layer k bit b
N_iter	Number of iterations in the MPA

Step 2: Iterative message passing along edges

[FN update]: message passing from FN to its neighboring VNs

- FN node g passes updates obtained from extrinsic information to its neighboring VN nodes (g to v1, information from v2 and v3 are extrinsic)
- The message passed to v1 contains the guess of what signal at g may be given all possibilities of v1



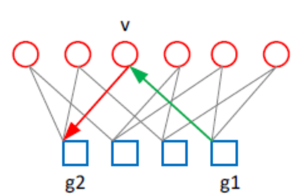
$$\mathbf{I}_{g\to v_1}(m_1) = \sum_{m_2=1}^{M}\sum_{m_3=1}^{M} \phi_n(y_n, m_1, m_2, m_3, N_{0,n}, \mathbf{H}_n)\left(\mathbf{I}_{v_2\to g}(m_2)\mathbf{I}_{v_3\to g}(m_3)\right) \quad m_1 = 1,\dots,M$$

$$\mathbf{I}_{g\to v_2}(m_2) = \sum_{m_1=1}^{M}\sum_{m_3=1}^{M} \phi_n(y_n, m_1, m_2, m_3, N_{0,n}, \mathbf{H}_n)\left(\mathbf{I}_{v_1\to g}(m_1)\mathbf{I}_{v_3\to g}(m_3)\right) \quad m_2 = 1,\dots,M$$

$$\mathbf{I}_{g\to v_3}(m_3) = \sum_{m_1=1}^{M}\sum_{m_2=1}^{M} \phi_n(y_n, m_1, m_2, m_3, N_{0,n}, \mathbf{H}_n)\left(\mathbf{I}_{v_1\to g}(m_1)\mathbf{I}_{v_2\to g}(m_2)\right) \quad m_3 = 1,\dots,M$$

[VN update]: message passing from VN to its neighboring FNs

- VN node v passes updates obtained from extrinsic information to its neighboring FN nodes (v to g1, information from g2 is extrinsic)
- In the dv=2 case, it is actually a "guess" swap at VN node



$$\mathbf{I}_{v\to g_1}(m) = \text{normalize}\left(ap_v(m)\,\mathbf{I}_{g_2\to v}(m)\right) \quad m = 1,\dots,M$$

$$\mathbf{I}_{v\to g_2}(m) = \text{normalize}\left(ap_v(m)\mathbf{I}_{g_1\to v}(m)\right) \quad m = 1,\dots,M$$

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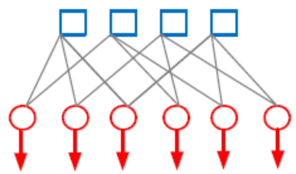
Codebook Based NOMA

Huawei

- MPA Receiver

Parameters	Description of the parameters
y_n, n=1,..., F	Received signal as input to the MPA decoder on resource n
m_k, k=1,..., V	Codeword selected by layer k, m_k = 1,..., M
No_n, n=1,..., F	Noise power estimation on physical resource n
C_k,n(m_k)	The constellation symbol of VN node k on physical resource n when using codeword m_k
H_n = {h_n,k}	Channel gain of user k on physical resource n
Ap_k, k=1,..., V	A prior probability of codeword k, assuming equal probability 1/M
LLR_k,b	logarithm of the likelihood ratio of layer k bit b
N_iter	Number of iterations in the MPA



Step 3: LLR output at variable node after N_iter iterations

- After N_iter iterations, we shall output the guess at each VN node (for each data layer) as the detection results
- The guess at VN node v for codeword m is a chain product of all guesses from all its neighboring FN nodes and the a prior probability

$$Q_v(m) = ap_v(m)\, \mathbf{I}_{g_1 \to v}(m)\, \mathbf{I}_{g_2 \to v}(m) \qquad m = 1, \dots, M$$

- After getting the probability guess of codeword at each layer, we then need to calculate the Log-Likelihood-Rate (LLR) for each coded bit, so that they can serve as the input for the turbo decoder (or any other channel decoder) directly after MPA

$$LLR_x = \log\left(\frac{P(b_x = 0)}{P(b_x = 1)}\right)$$

$$LLR_x = \log\left(\frac{\sum_{m:b_{m,x}=0} Q_v(m)}{\sum_{m:b_{m,x}=1} Q_v(m)}\right) = \log\left(\sum_{m:b_{m,x}=0} Q_v(m)\right) - \log\left(\sum_{m:b_{m,x}=1} Q_v(m)\right)$$

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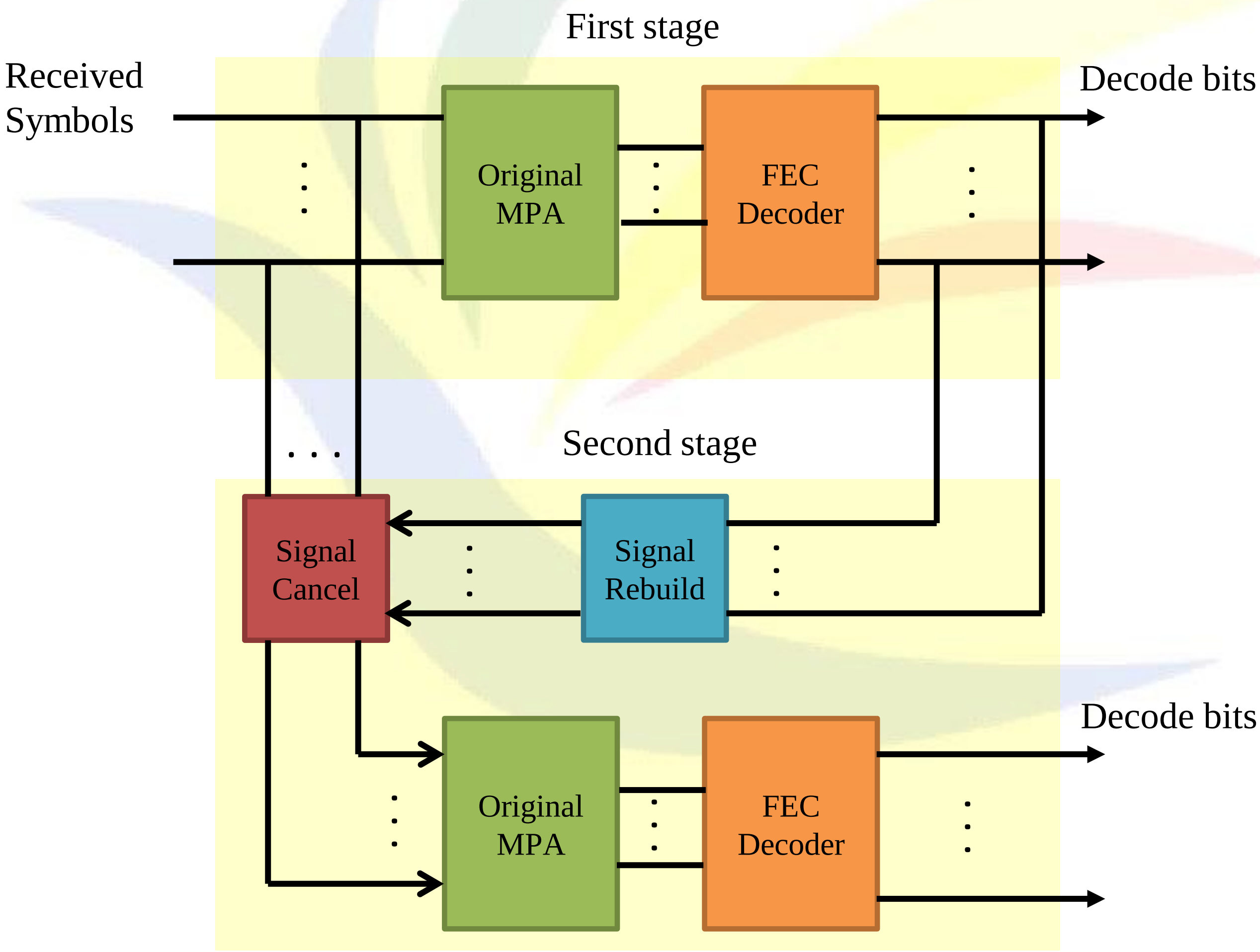
Codebook Based NOMA

Huawei

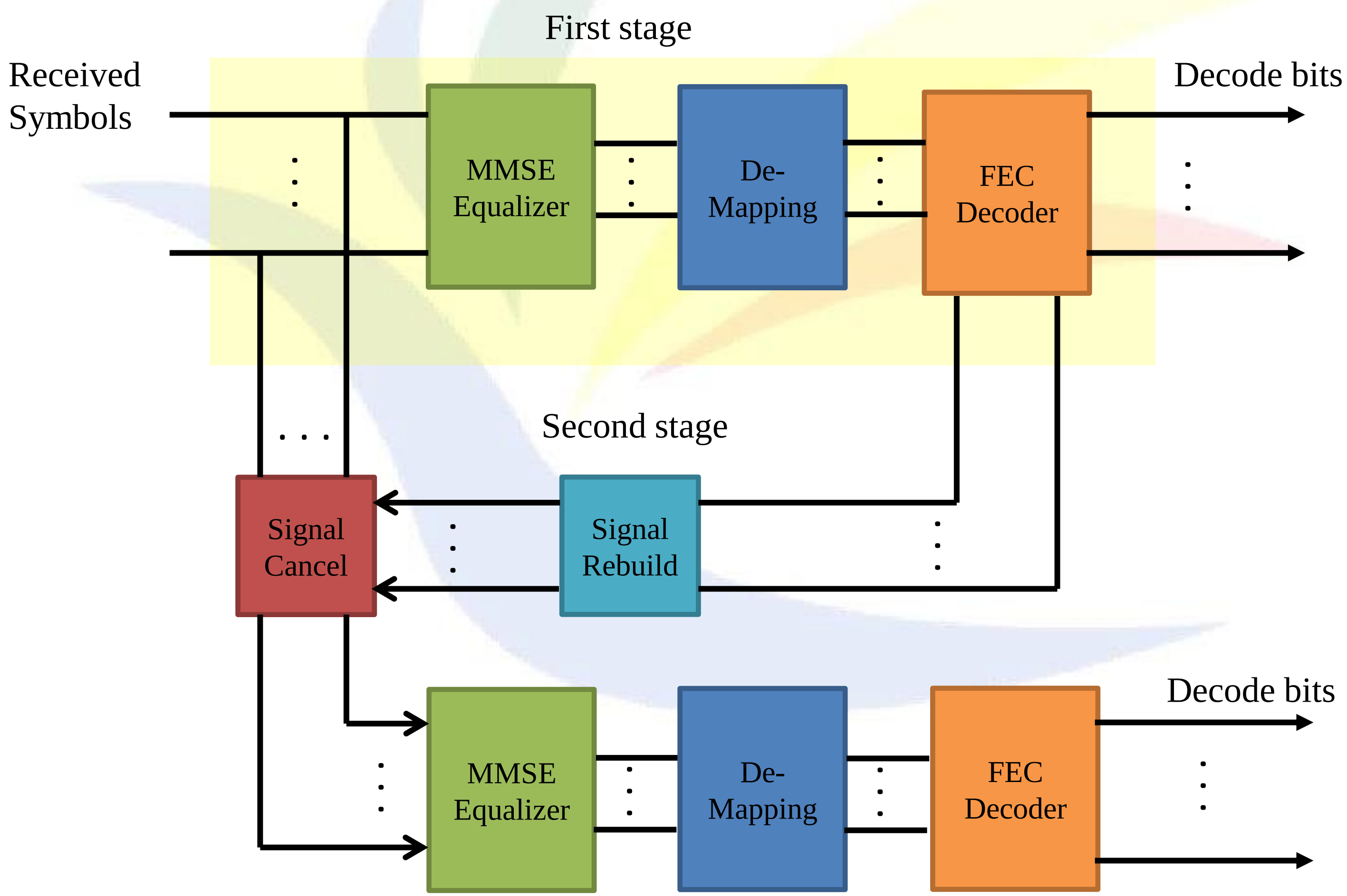
- SIC-MPA Receiver



Codebook Based NOMA

Huawei

- MMSE-MPA Receiver



Conclusion and Future Work

- NOMA is a promising technique for 5G new radio
- 4 NOMA workshops and email discussions virtually the study already
- Many uplink NOMA technologies are competing and hopefully candidate technologies can be reduced
- Performance under practical system design is under investigation
- Receiver implementation complexity may be high
- UE scheduling and resource allocation might have different considerations after NOMA is introduced

Thank you for your attention!
Comment & Question?