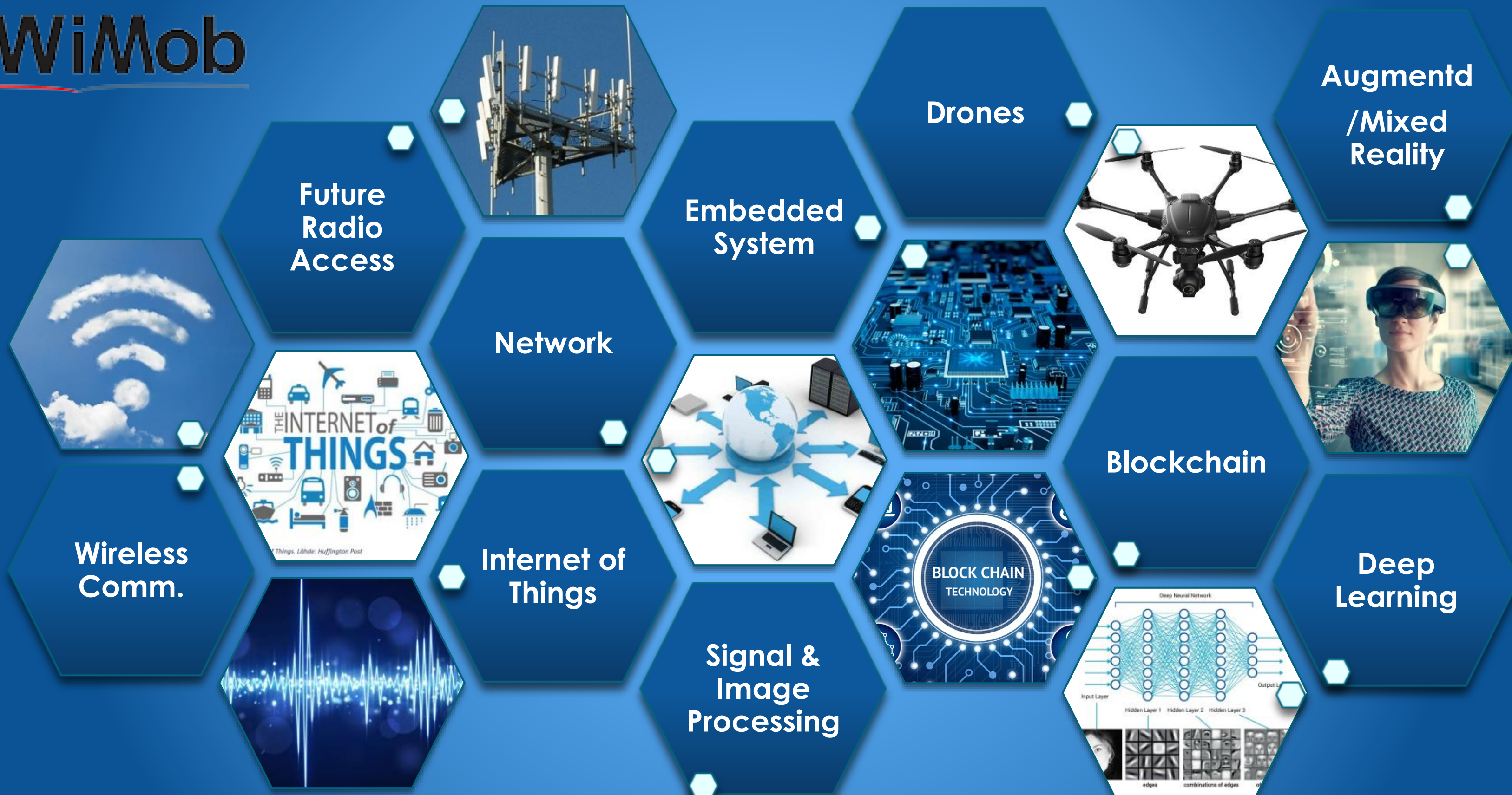


Toward a New Era of Radio Access Technologies for Beyond 5G and 6G

Soo Young Shin

Dept. of IT Convergence Engineering

Kumoh National Institute of Technology, Republic of Korea

11th Oct, 2023

Contents

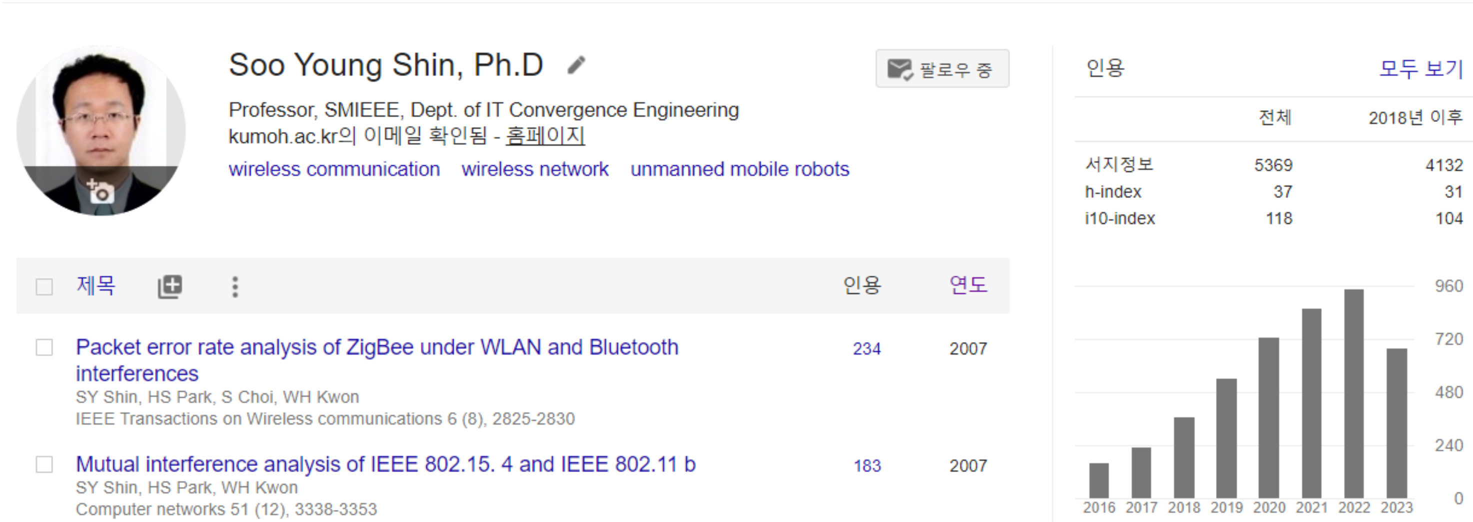
- Short Introduction of WENS lab.
- Overview of Beyond 5G/6G
- Potential RATs for B5G/6G
  - Breaking Orthogonality
  - Novel Domain based RATs
- Towards New RATs for B5G/6G in WENS
  - Massive MIMO
  - NOMA
  - Index Modulation
- Conclusion

RAT : Radio Access Technology

WENS lab.

Short Intro. On Speaker

- **Name : Soo Young Shin**
- **Contact**
  - **E-mail : wdragon@kumoh.ac.kr**
- **Career**
  - **1999/2001/2006 Seoul National University(SNU) Electrical Engineering (bachelor/MS/PhD)**
  - **2006.07 - 2007.06 University of Washington Electrical Engineering (Post Doc. Researcher)**
  - **2007.09 - 2010.08 Samsung Electronics Telecommunication Division System Design Lab. (senior researcher)**
  - **2010.09 - present Kumoh National Institute of Technology, School of Electronic Engineering (Professor)**
  - **2017.02 - 2018.01 University of British Columbia, Vancouver, Canada (Visiting Scholar)**



Wireless & Emerging Network System (WENS) Lab.

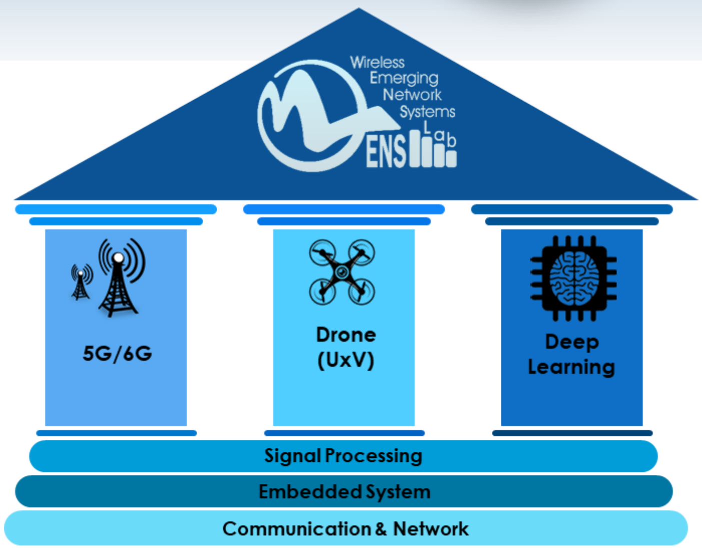
- **http://wens.re.kr**
- **Members (Sep. 2023)**
  - **Professor Soo Young Shin**
  - **4 Post Doc Researchers**
  - **8 PhD candidates**
  - **4 MS leading to PhD**
  - **14 MS students**

Feb 2023 Graduation Ceremony, kit

Research Area and Major Achievements

▶ Research Area

- Next generation wireless communications
  - 5G & Beyond, 6G
- Unmanned Mobility with ROS
- AI & deep learning based signal processing (video, audio)
- Internet of Things
- Communications and network-based embedded systems
- Augmented/Mixed Reality



▶ Major Achievements

- SCI(E) publications

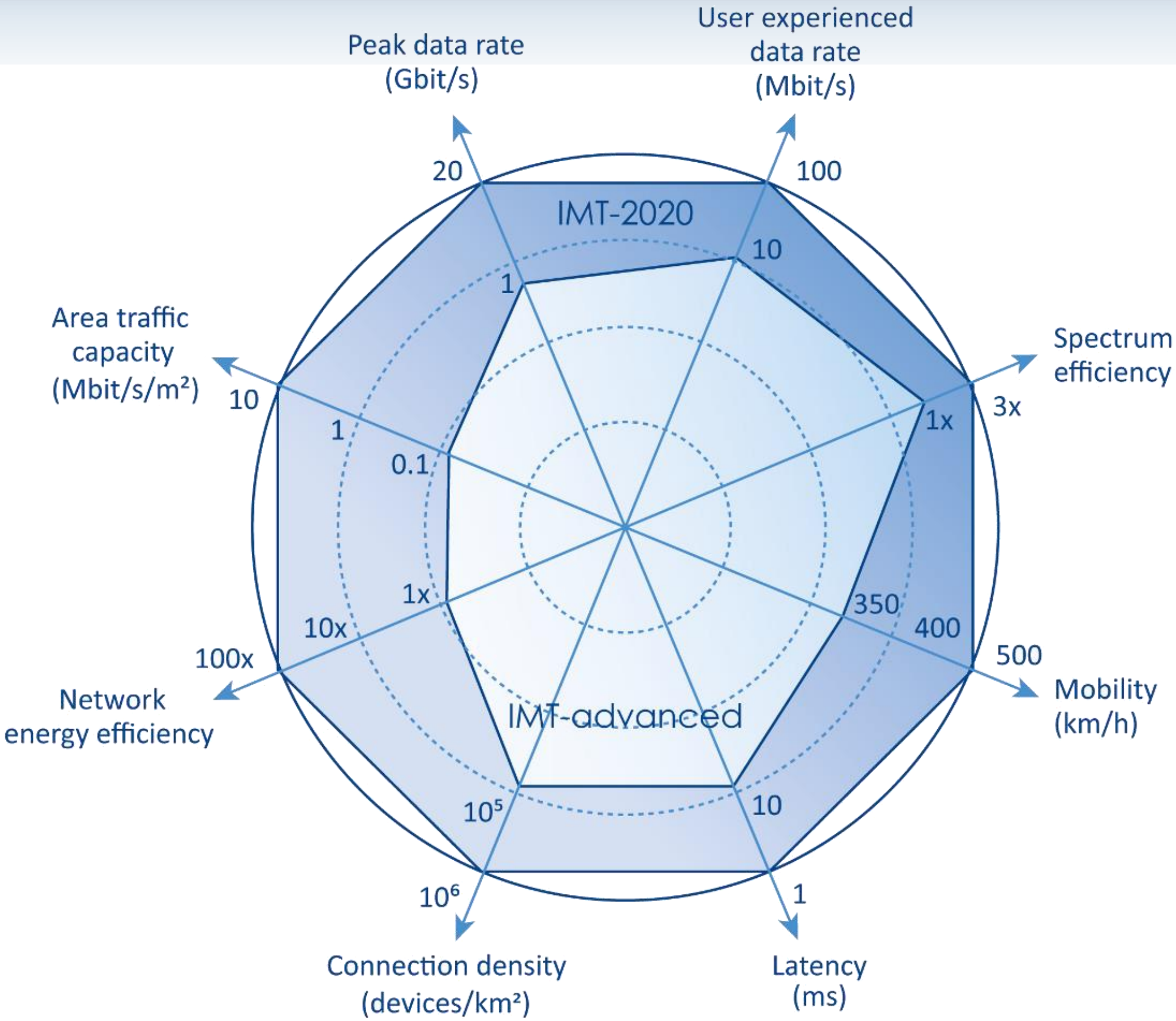
2016	2017	2018	2019	2020	2021	2022	2023	Total
8	13	15	13	10	15	20	11	105

- Alumni (Since 2010)
  - PhD : 17
  - MS: 57

ROS : Robot Operating System

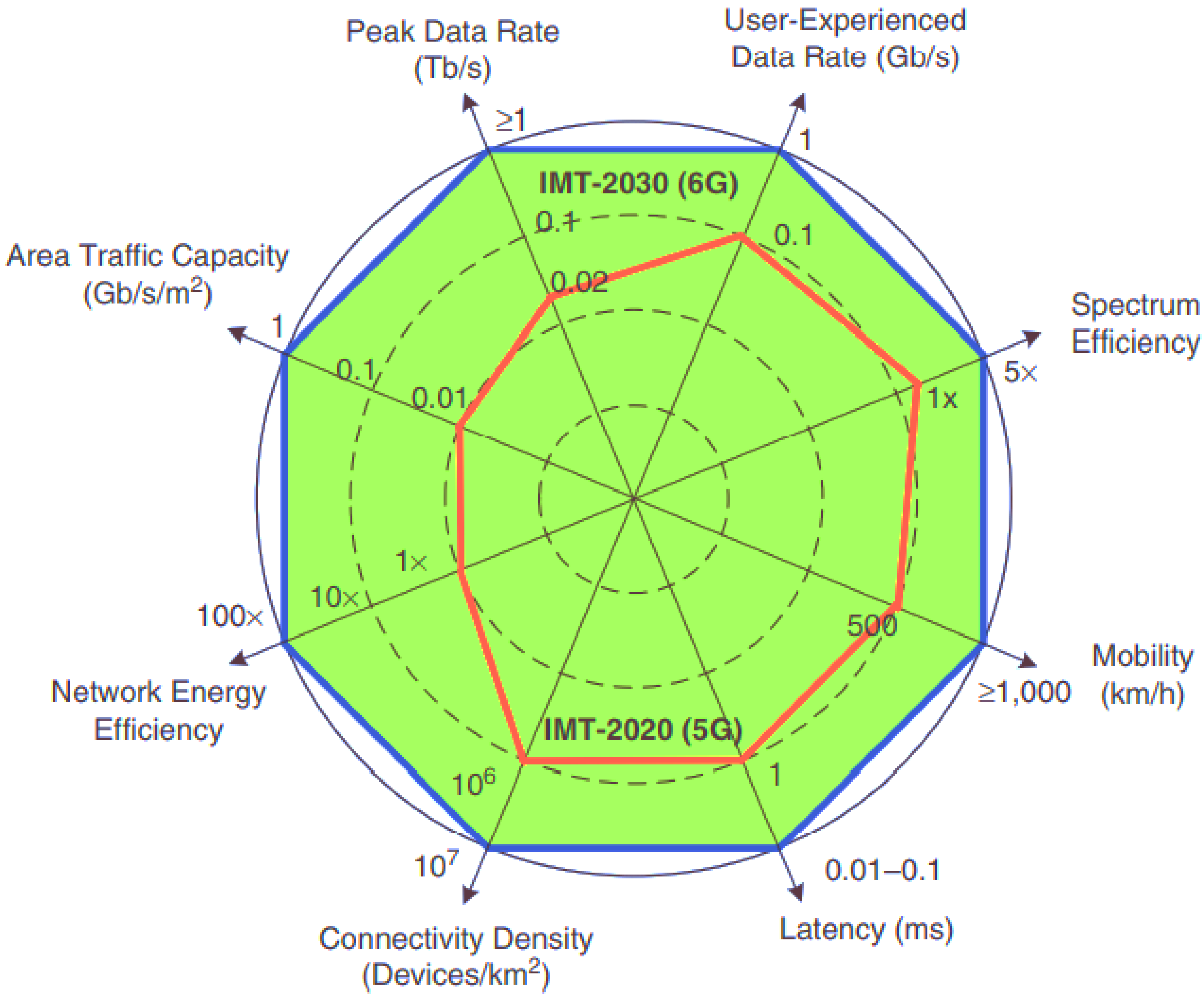
Overview of Beyond 5G/6G

5G Evolution



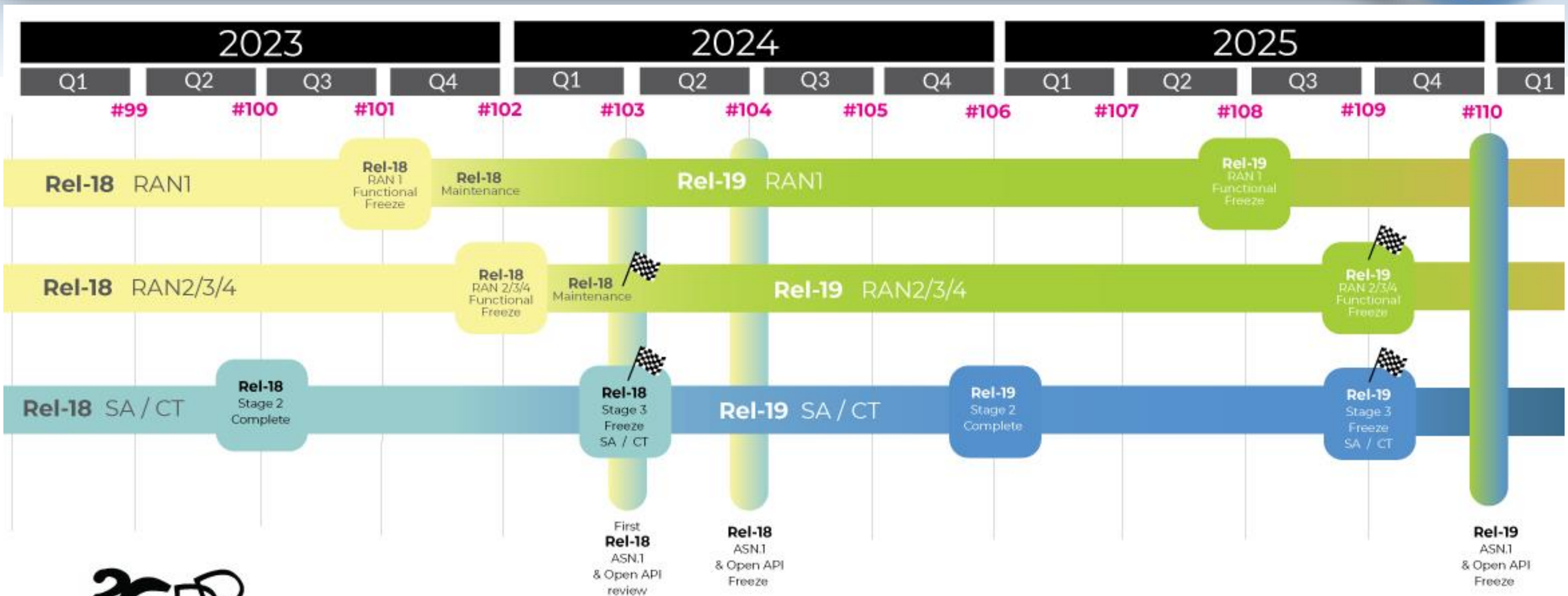
https://www.etsi.org/technologies/5G

6G KPI



http://www.5gsummit.org/lisbon/slides/4_3_Colin_Langtry.pdf

3GPP Timeline & Research Activities

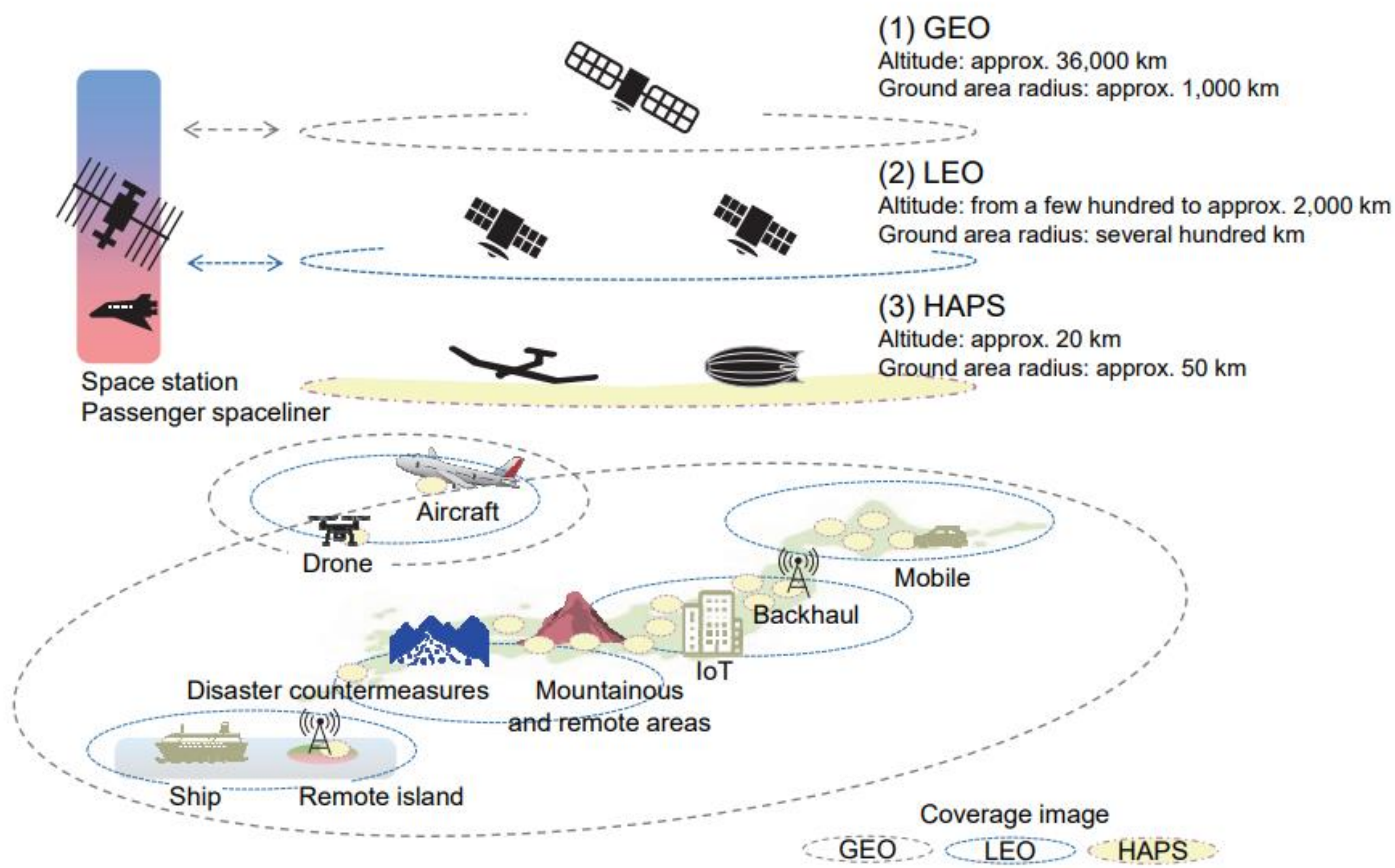


Rel-18 : 5G Advanced
Rel-19~20 : 5G Advanced cont'd & 6G studies
Rel-21 : 6G standard (expected '27 or '28)

https://www.3gpp.org/specifications-technologies/releases

Emerging Applications by 6G

NTN : Non-Terrestrial Network



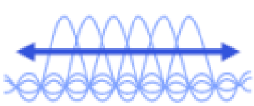
https://www.docomo.ne.jp/english/binary/pdf/corporate/technology/rd/technical_journal/bn/vol23_2/vol23_2_004en.pdf

Key Enablers of 5G

3GPP Rel-15 establishes a solid foundation for 5G NR

For enhanced mobile broadband and beyond

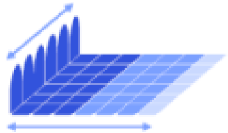
Scalable OFDM-based air interface



Scalable OFDM numerology

Efficiently address diverse spectrum, deployments and services

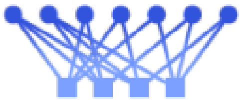
Flexible slot-based framework



Self-contained slot structure

Key enabler to low latency, URLLC and forward compatibility

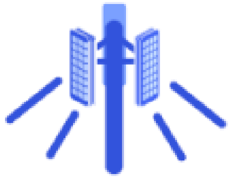
Advanced channel coding



ME-LDPC and CA-Polar[1]

Efficiently support large data blocks and a reliable control channel

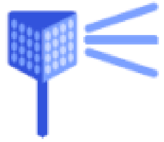
Massive MIMO



Reciprocity-based MU-MIMO

Efficiently utilize a large # of antennas to increase coverage / capacity

Mobile mmWave



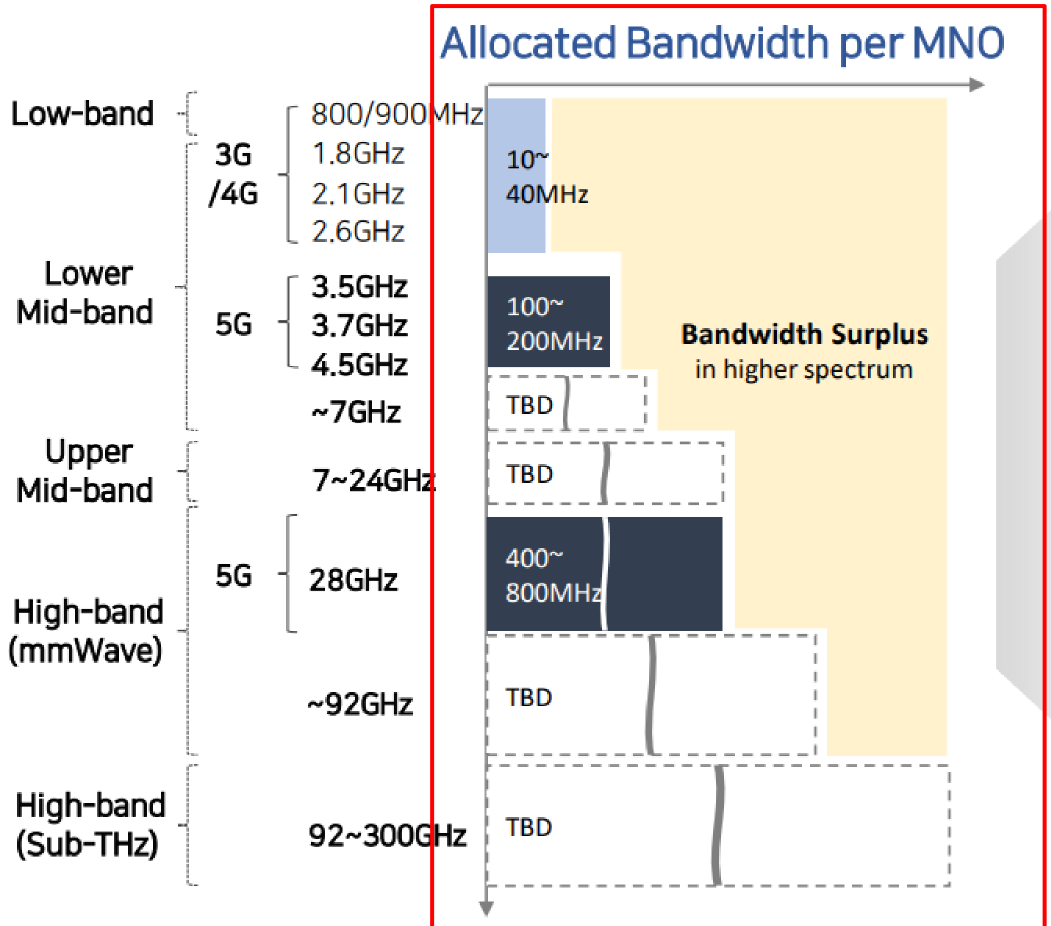
Beamforming and beam-tracking

Enables wide mmWave bandwidths for extreme capacity and throughput

Courtesy from Qualcomm

Higher Frequency

【Spectrum vs. Bandwidth】



○ **Lower Mid-band** — Below 100Gbps

- There might be several 100MHz bandwidth in new spectrum (above 3.5GHz)
- Should consider "Spectrum Refarming"

○ **Upper Mid-band** — Below 100Gbps

- There might be several 100MHz and more bandwidth

○ **mmWave** — Up to 100Gbps

- There might be a few GHz and more bandwidth

○ **Sub-THz** — Up to 1Tbps

- There might be several GHz and more bandwidth
- Should develop the RF technology of Sub-THz

Higher Frequency

Updated : Friday, October 06, 2023, 13:43

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3 Mobile Carriers Give Up 5G 28 GHz Frequency Band after Record Fines

Yoon Young-sil | 2023.06.02 16:27

Dark Horse Rising?

MOST POPULAR

1 Intense Competition between Korean Battery Makers for Solid-state Battery

2 US-China Semiconductor War Enters 'Round 2'

3 Samsung Partners with 'Semiconductor Legend' Jim Keller to Manufacture

4 Samsung Electronics' Exynos Making a Comeback?

5 Korean Semiconductors Reach US$9.9 Billion in Exports in September, One-year

Wireless Emerging Network System Lab

Higher Frequency

주파수 특성 비교

구분	5G 3.5GHz	5G 28GHz
총 대역폭 (국내 사업자)	SKT·KT 100MHz LG유플러스 80MHz	(3사 공통) 800MHz
직진성	중	강
투과율	중	약
도달거리 (반경)	약 1km	약 100~150m
최고속도 (이론상)	1.5Gbps (100MHz 기준)	4.2Gbps (800MHz 기준)
주요 서비스	초고화질 영상, 메타버스, 자율주행, 재난로봇 등	
커버리지		전파 특성상 한계 극복 못해 3.5GHz/LTE 대비 열위

그래픽=유상연 기자 prtsy201@

BUSINESS watch

https://v.daum.net/v/20220610171707993

Higher Frequency for 6G

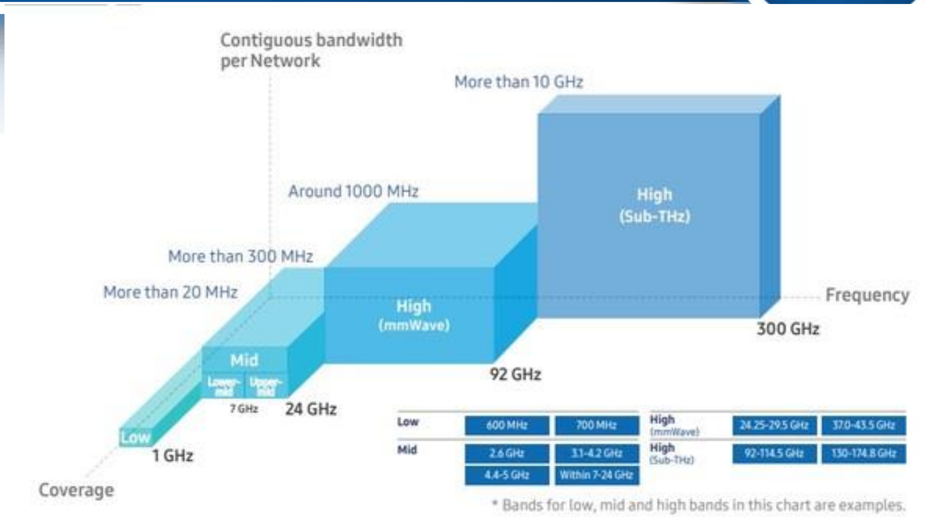
▶ Sub-THz (92~300GHz)

Advantages:

- Greater bandwidth -> Increasing capacity
- Smaller antenna size
- Minimum effects on human body

Disadvantages:

- Short range due to scattering and absorption by cloud, dust, rain etc.
- Less penetration
- Still very earlier stage : not cost effective



LG Electronics Succeeds in 6G Wireless Transmission

(155~175GHz)

Jung Min-hee | 2022.09.15 12:10

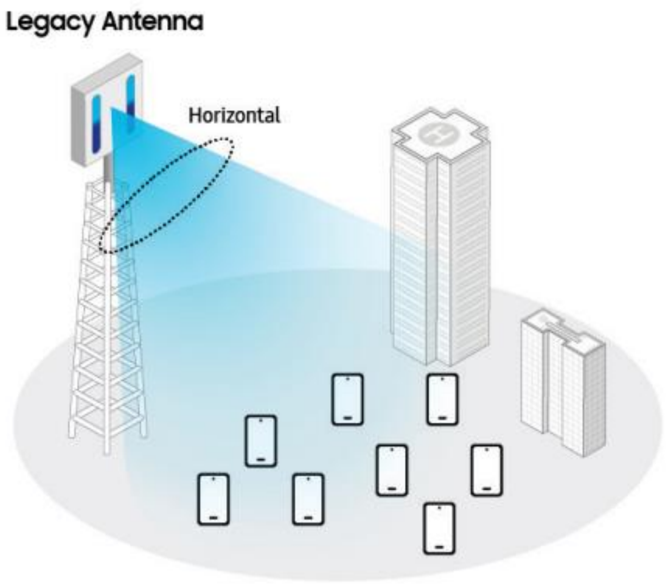
Over a Distance of 320 Meters

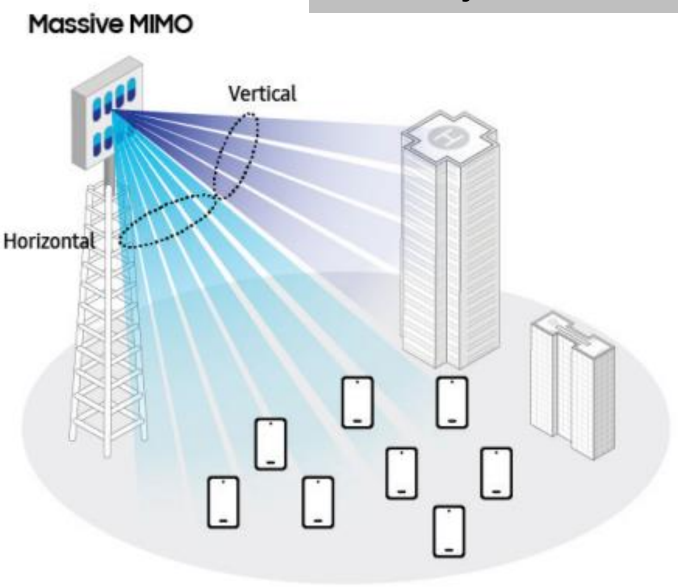
Kim Byung-hoon (right), vice president and CTO of LG Electronics, discusses 6G technology with German engineers at the Fraunhofer Heinrich Hertz Research Center in Berlin, Germany.

Massive MIMO

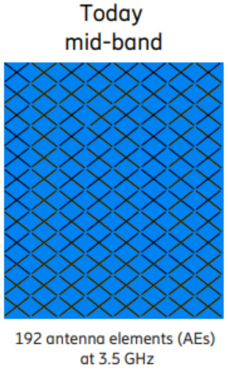
- 3D beamforming

Courtesy from Samsung



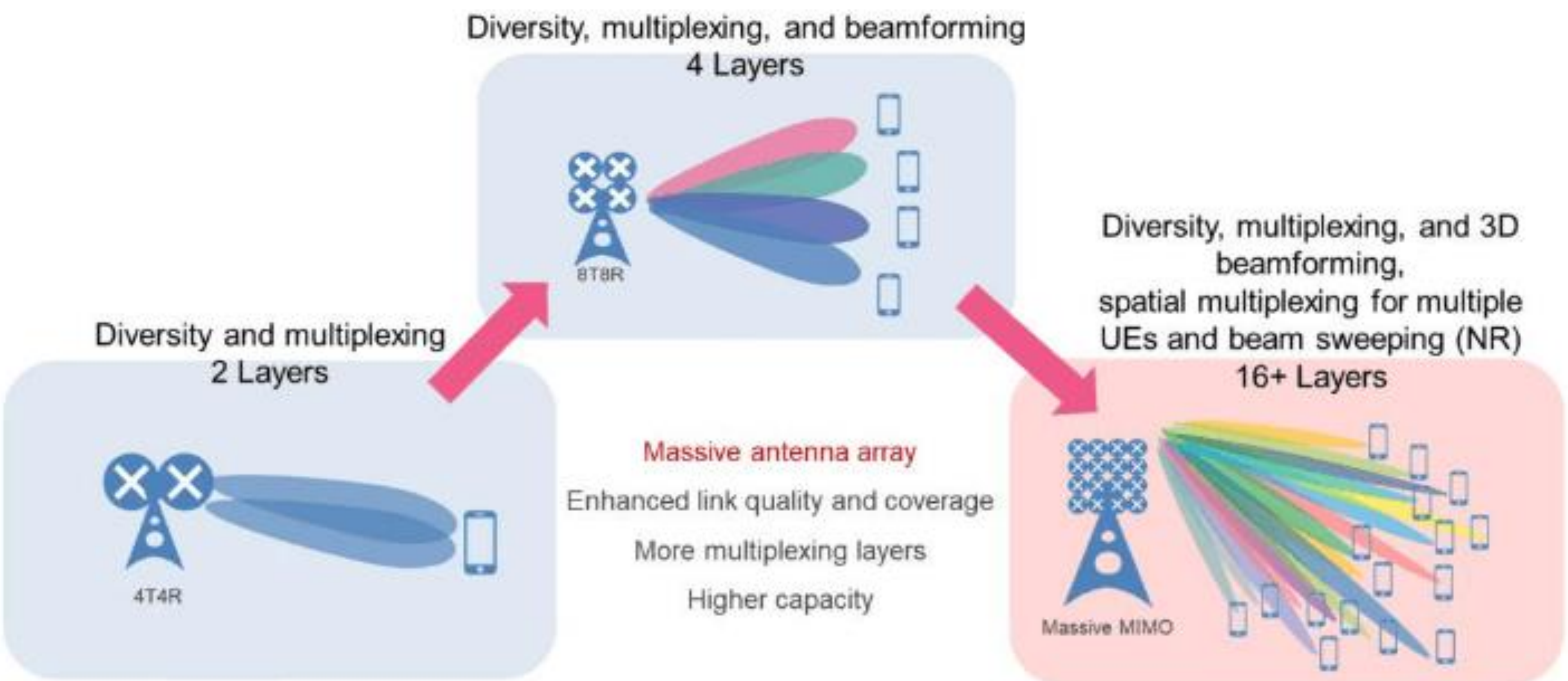


- Typical # of antennas
  - Base station : 128 or 192
  - Mobile station : up to 8



Courtesy from Ericsson

3GPP Evolution for MIMO



https://www.5gworldpro.com/blog/2022/04/17/evolution-from-mimo-to-massive-mimo/

Massive MIMO

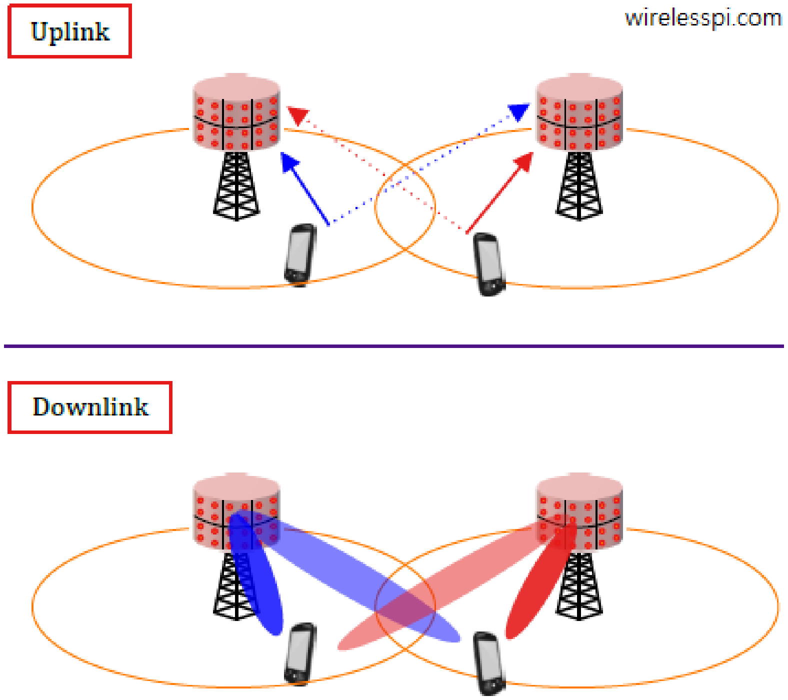
Main Radio Access Technology for 5G !!!

Advantages:

- Improved spectrum efficiency
- Improved energy efficiency

Disadvantages:

- Pilot contamination
  - limited orthogonal pilot subcarriers
- High signal processing complexity
  - large number of antennas and multiplexing of UEs
- Power Consumption
- Spectral Efficiency Saturation
- Interference
- Channel Estimation Challenges



https://wirelesspi.com/what-is-pilot-contamination-in-massive-mimo/

Massive MIMO in 6G

- eXtreme MIMO (X-MIMO) / giga MIMO
  - X-MIMO : Up to 4 times antenna than 5G
  - Giga-MIMO : order of magnitude more antennas than 5G massive MIMO

4G	5G	5G Advanced	6G
Spatial Multiplexing	Beamforming	improve performance for UEs with medium or high mobility by enhancing CSI reporting.	AI / ML, i.e Deep learning based algorithm
Spatial Diversity	Beam management; Multiple Transmission and Reception Point (mTRP)	Full duplex operation	Cell Free mMIMO, mmMIMO/ Extreme mMIMO, Sub TeraHz frequency
DL-4T4R , UL-2T2R LTE Adv. DL 8T8R UL 4T4R	DL 64T64R 16 layer DL + 8 Layer UL Mu-MIMO	256 Antenna elements	Extreme mMIMO = 1024 antenna elements + 512 TRXs + 64 layer MU-MIMO
3GPP Rel 8, 10,13	3GPP Rel 15, 16, 17	3GPP Rel. 18 +	Scope to be defined

Radio Access Technology (RAT)

- In other word, wireless access technology
- Definition
  - Underlying physical connection method for a radio communication network (wiki)
  - Includes frequency, bandwidth, antenna (tx, rx), time, etc. → radio resources
  - Related to physical layer (PHY), Medium access control layer (MAC), radio resource control layer (RRC)

Key for B5G/6G, Higher Frequency, More Antennas !!

↓

Via RATs, Spectral Efficiency Enhancement in Lower-Band !!!

Potential RATs for B5G/6G

Breaking Orthogonality

Breaking the Orthogonality

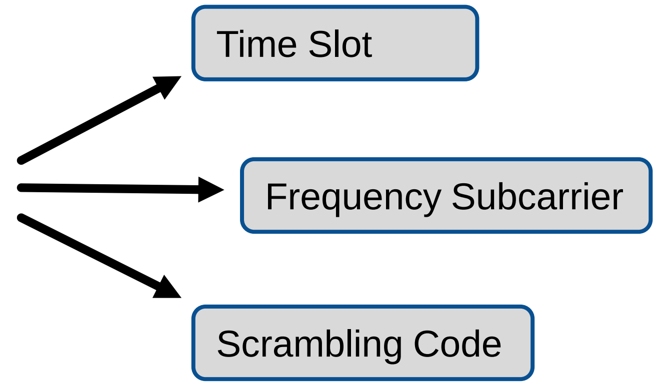
- **Orthogonality**
  - **"In telecommunications, multiple access schemes are orthogonal when an ideal receiver can completely reject arbitrarily strong unwanted signals from the desired signal using different basis functions" (from wikipedia)**
- **Breaking orthogonality**
  - **Non-Orthogonal Multiple Access (NOMA)**
    - **Serve multiple users in the same resource → improving spectral efficiency and achieving massive connectivity**
  - **Spectral efficient frequency division multiplexing (SEFDM)**
    - **Achieves higher spectral efficiency compared to OFDM by violating the orthogonality of its sub-carriers**

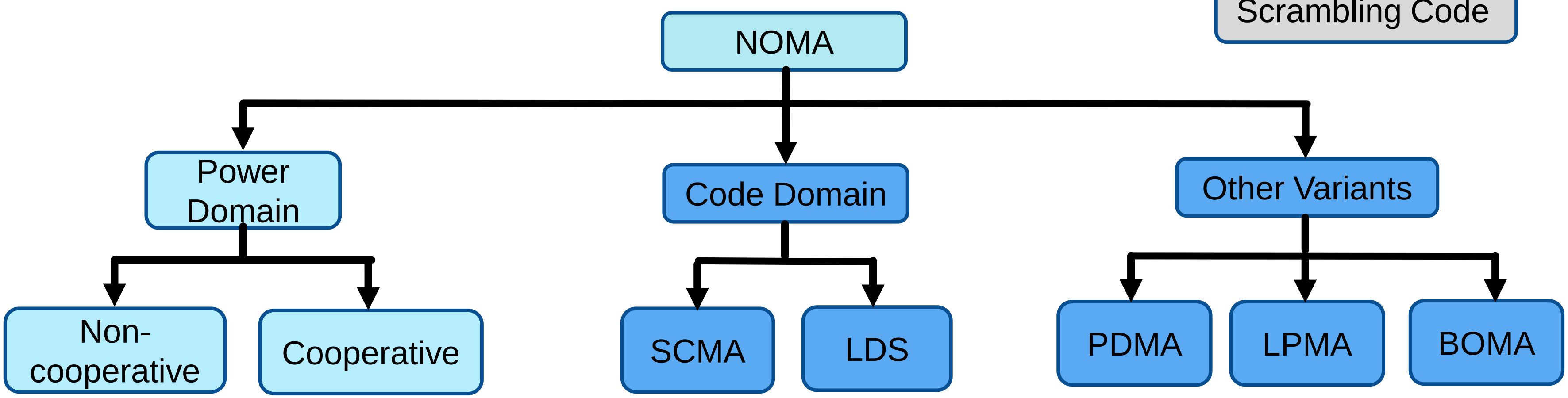
Non-Orthogonal Multiple Access (NOMA)

L. Dai, B. Wang, Z. Ding, Z. Wang, S. Chen and L. Hanzo, "A Survey of Non-Orthogonal Multiple Access for 5G," in IEEE Communications Surveys & Tutorials, vol. 20, no. 3, pp. 2294-2323, thirdquarter 2018, doi: 10.1109/COMST.2018.2835558.

What is NOMA?

- Multiple users using the same resource block (RB)
- High capacity and massive connectivity
- Classification of NOMA





SCMA: Sparse Code Multiple Access

LDS: Low Density Spreading

PDMA: Pattern Division Multiple Access

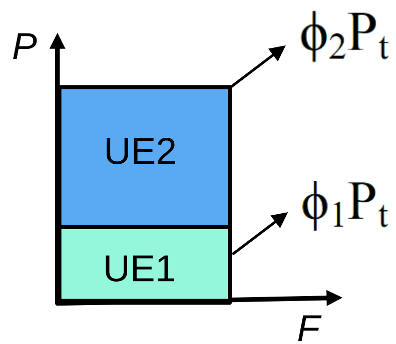
BOMA: Building Block Sparse Constellation Based Orthogonal Multiple Access

LPMA: Lattice Partition Multiple Access

Downlink Power Domain-NOMA

How it works?

Successive interference cancellation



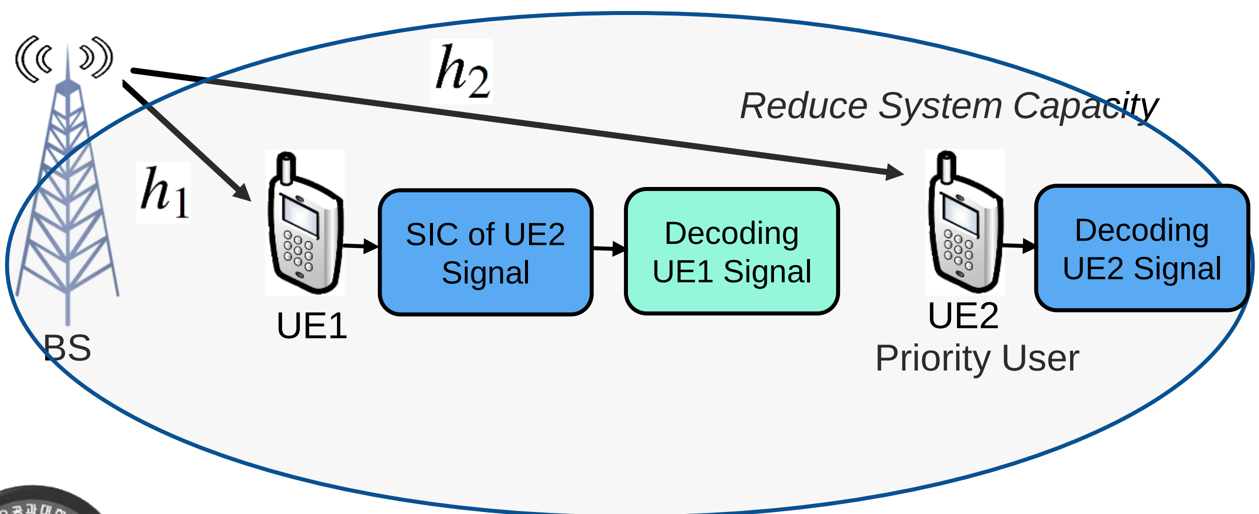
$$\Phi_1 < \Phi_2$$

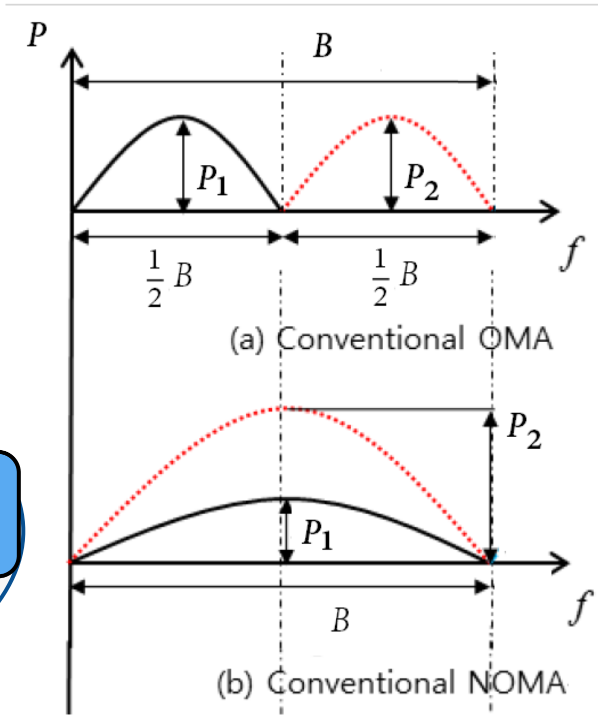
Transmitted Signal

$$x = \sqrt{\Phi_1 P}\, s_1 + \sqrt{\Phi_2 P}\, s_2$$

$$y_i = h_i x + w_i$$

Received Signal

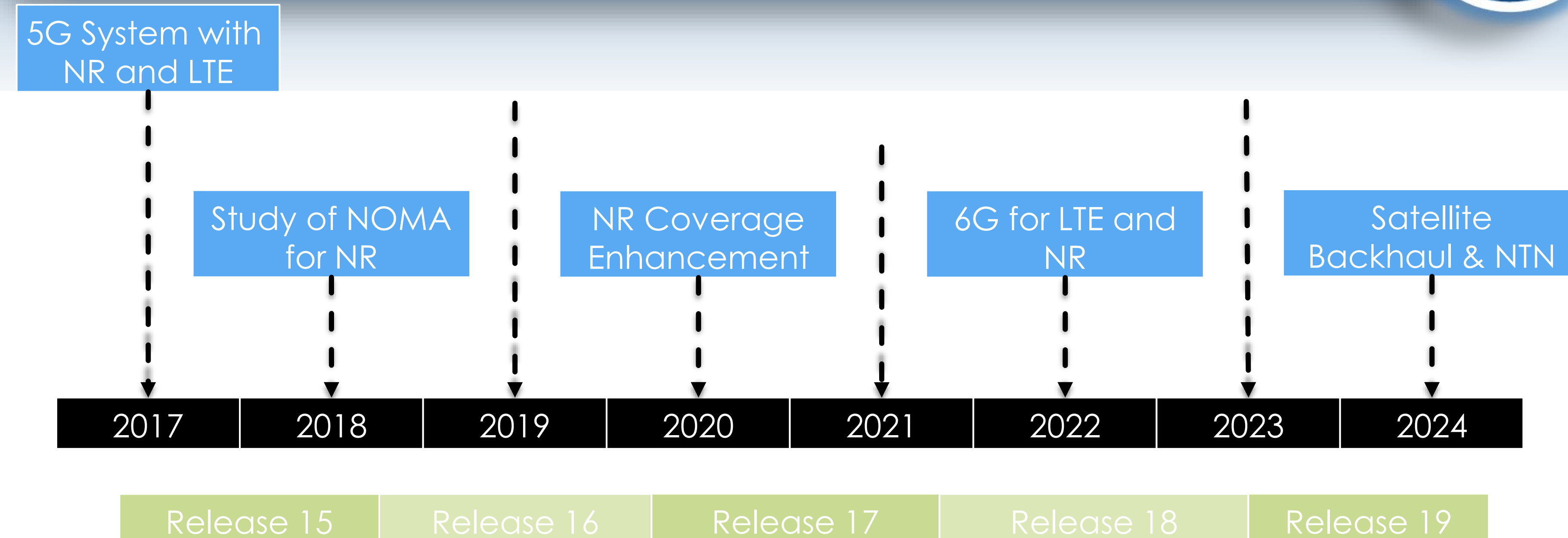




High — Low

Received SINR

NOMA in 3GPP



- ❖ Modified transmitter of NR 5G (NOMA)
- ❖ NOMA trials:
  - No clear gain over release 15
  - Implementation complexity
  - B5G for new use case (Expected)

Expected more trials on NOMA

- 3GPP List of Work Items
- 5G-Advanced: The Next Step of 5G Evolution (zte.com.cn)
- 3GPP_Poster v2
- Al-Dulaimi, O. M. K., Al-Dulaimi, A. M. K., Alexandra, M. O., & Al-Dulaimi, M. K. H. (2023). Strategy for Non-Orthogonal Multiple Access and Performance in 5G and 6G Networks. Sensors (Basel, Switzerland), 23(3), 1705. https://doi.org/10.3390/s23031705
- B. Makki, K. Chitti, A. Behravan and M. -S. Alouini, "A Survey of NOMA: Current Status and Open Research Challenges," in IEEE Open Journal of the Communications Society, vol. 1, pp. 179-189, 2020, doi: 10.1109/OJCOMS.2020.2969899.

Downlink NOMA

Advantages:

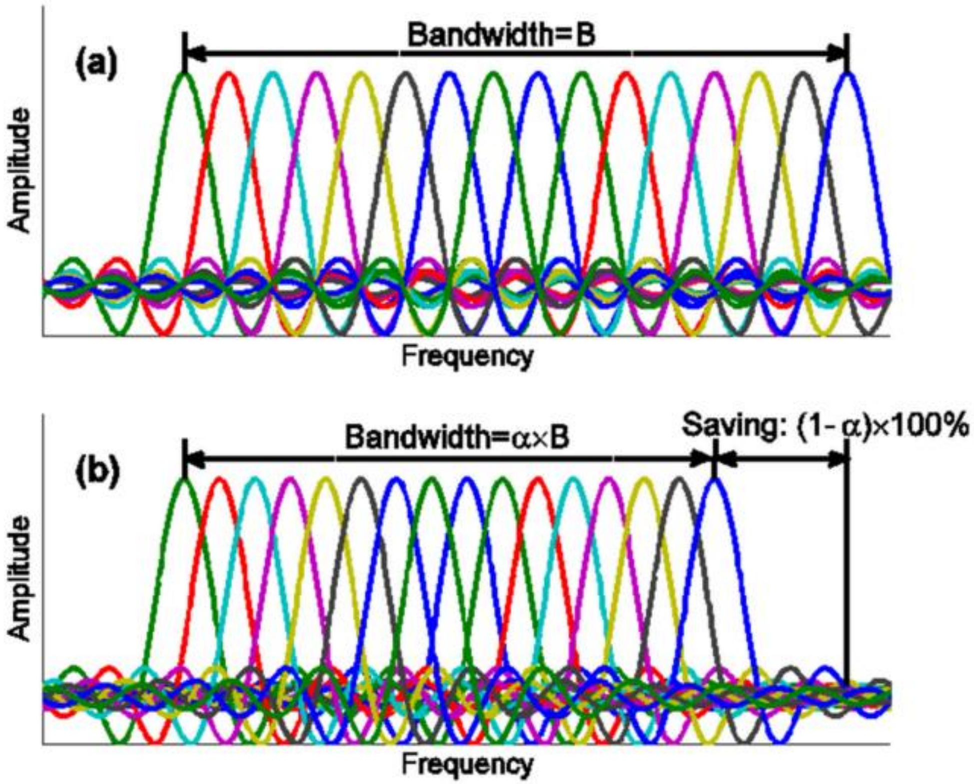
- ✓ High System Capacity
- ✓ Mass Connectivity
- ✓ Fairness (Quality of Service)

Disadvantages:

- ✓ Breaking orthogonality
- ✓ SIC complexity at the receiver
- ✓ Drawback of implementing SIC is the inter-user error propagation issue resulting in residual interference.

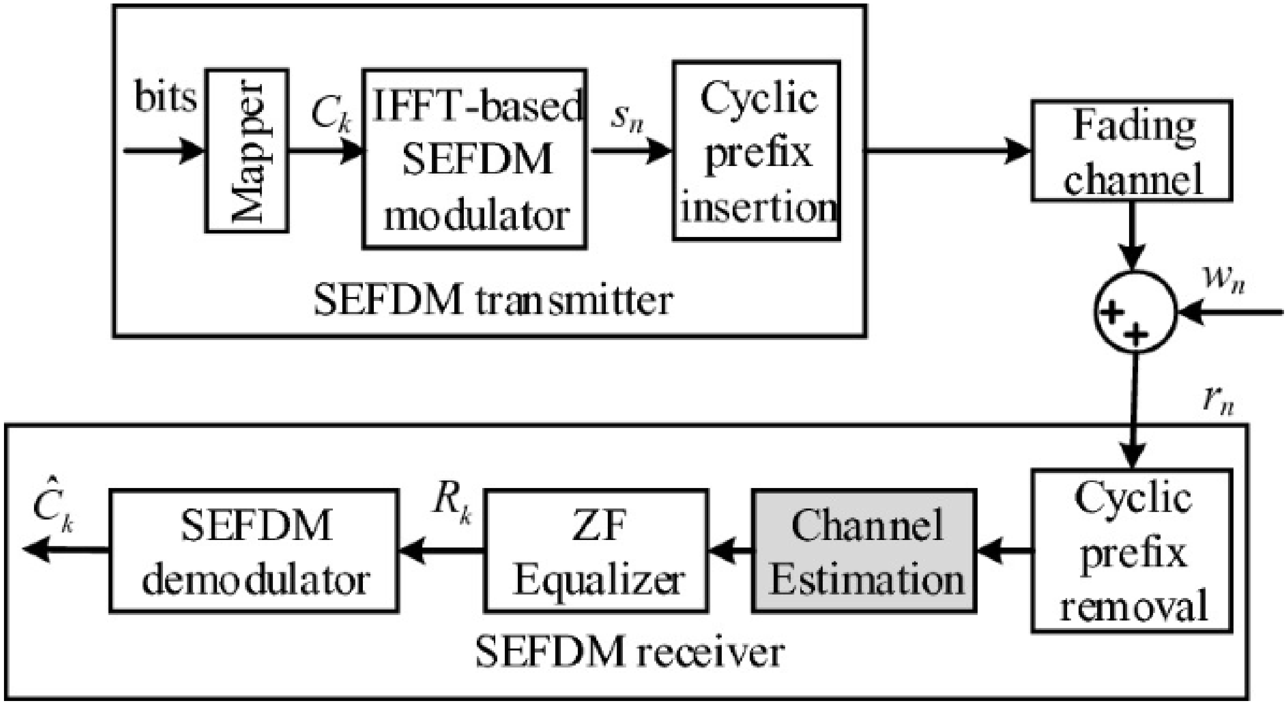
SEFDM

- Pack more subcarriers, relative to OFDM, in a given bandwidth to improve capacity



SEFDM

▶ Transmitter receiver diagram



- N-point IFFT→ OFDM
- $\frac{N}{\alpha}$-point IFFT→ SEFDM
- $\alpha = 1 \rightarrow$ OFDM
- $0 < \alpha < 1 \rightarrow$ SEFDM

Salnikov, Valentin, et al. "Ber performance of sefdm signals in lte fading channels with imperfect channel knowledge." *Internet of Things, Smart Spaces, and Next Generation Networks and Systems: 20th International Conference, NEW2AN 2020, and 13th Conference, ruSMART 2020, St. Petersburg, Russia, August 26–28, 2020, Proceedings, Part I 20.* Springer International Publishing, 2020.

SEFDM

Advantages:

- ✓ Improved spectral efficiency compared to OFDM.
- ✓ Lower peak to average power ratio (PAPR) compared to OFDM
- ✓ Efficiently implemented using inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT)
- ✓ Low sensitivity to frequency offset.

Disadvantages:

- ✓ Breaking orthogonality
- ✓ High inter-carrier interference
- ✓ More complex signal detection
- ✓ More complex time-domain equalization has to be used.

Novel Domain based RATs

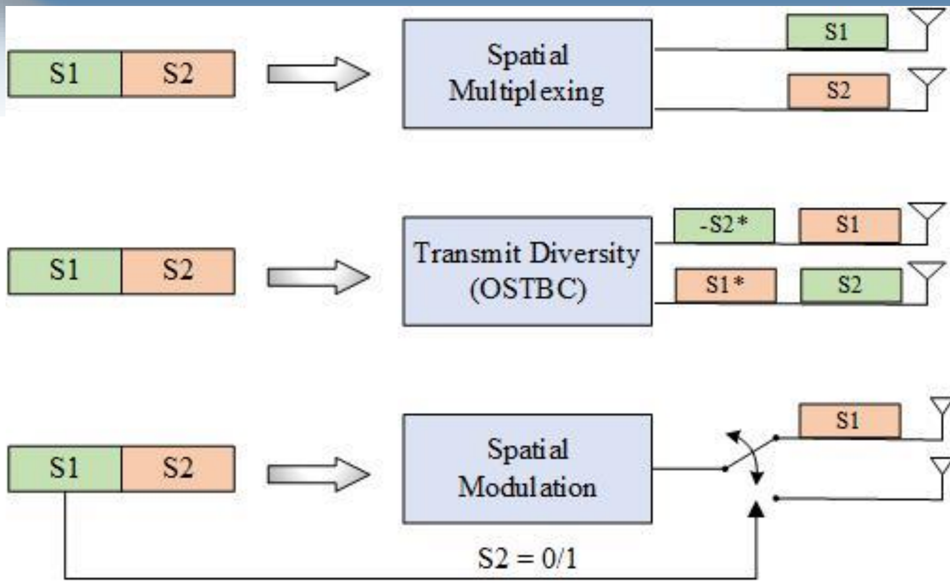
Novel Domain based RAT

- **Novel Domain based RAT**
  - **Introduce new domain for new radio resources**
  - **MIMO : spatial multiplexing → spatial domain**

- **Index Modulation**
  - Transmit additional data bits via the indices of the available transmit entities compared with classical communication schemes such as antenna indices, subcarriers, radio frequency (RF) mirrors, time slots, codes, etc.

- **OAM (Orbital Angular Momentum)**
  - **Vortex domain**

Index Modulation



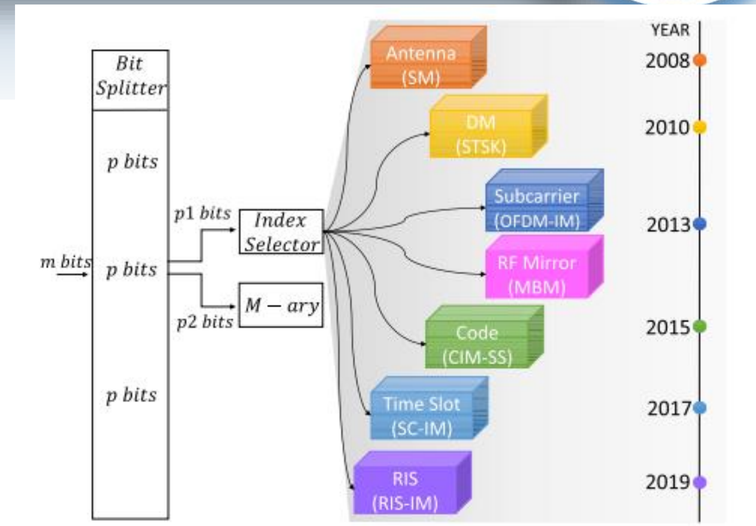


Fig. 3. ***Basic implementation of IM, and the timeline of substantial IM techniques.***

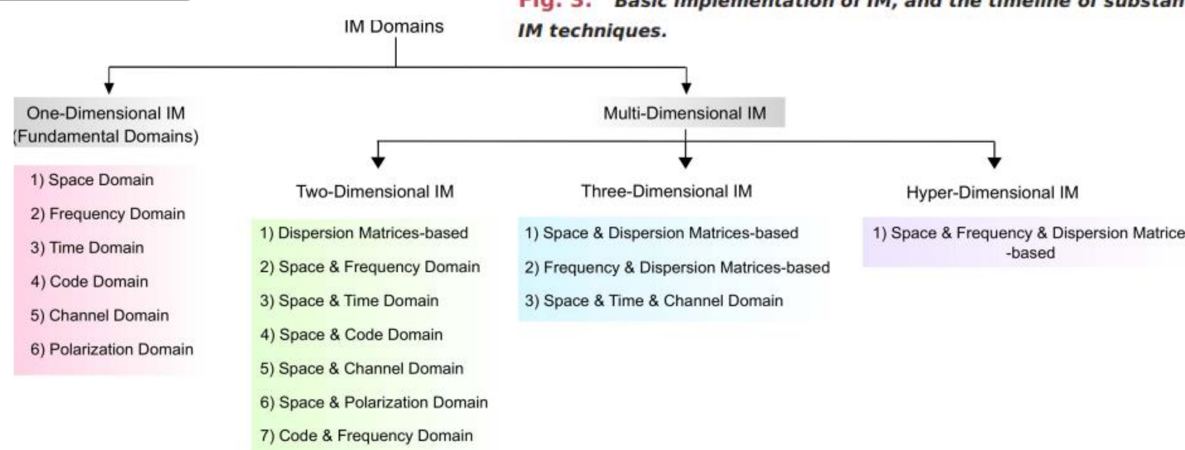
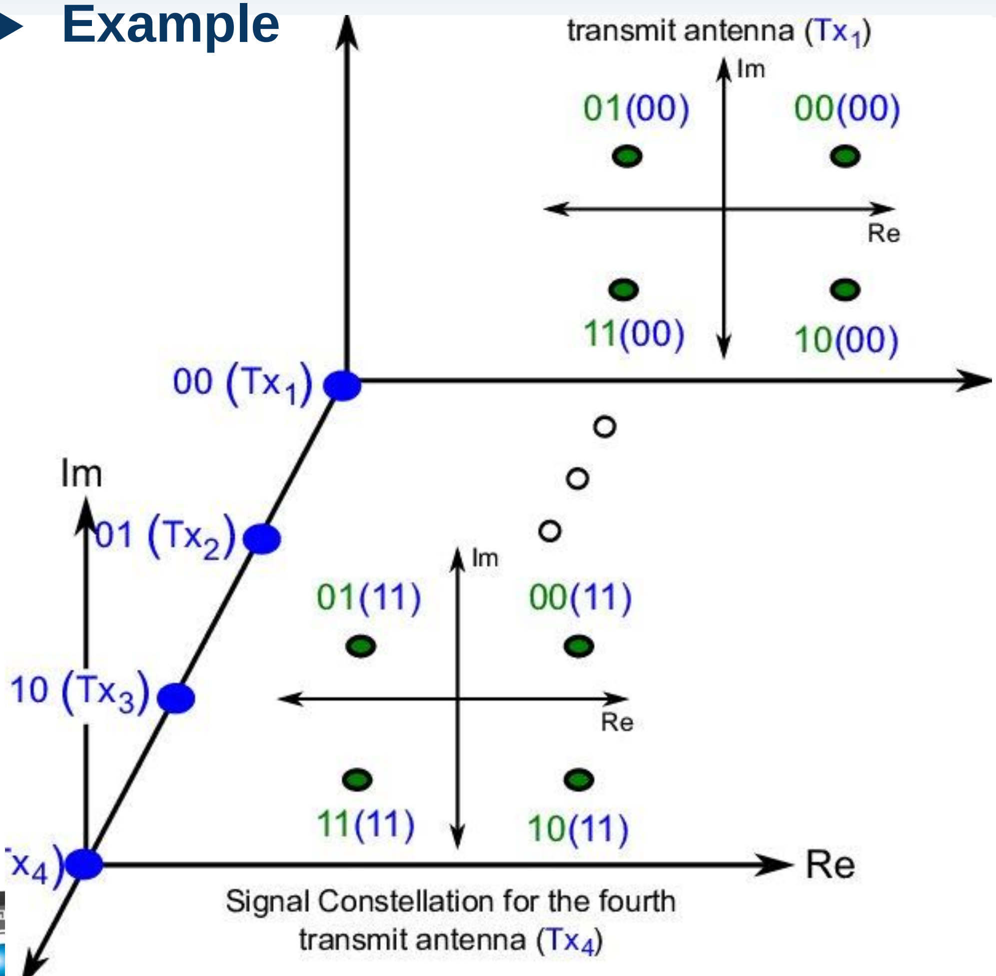


Fig. 4. ***Dimensional-based categorization of the existing IM domains in the literature.***

S. Doğan Tusha, A. Tusha, E. Basar and H. Arslan, "Multidimensional Index Modulation for 5G and Beyond Wireless Networks," in Proceedings of the IEEE, vol. 109, no. 2, pp. 170-199, Feb. 2021, doi: 10.1109/JPROC.2020.3040589.

Index Modulation

- **Example**



N. Serafimovski *et al*., "Practical Implementation of Spatial Modulation," in *IEEE Transactions on Vehicular Technology*, vol. 62, no. 9, pp. 4511-4523, Nov. 2013, doi: 10.1109/TVT.2013.2266619.

Index Modulation

- Higher bpcu (bit per channel use)
- Low complexity

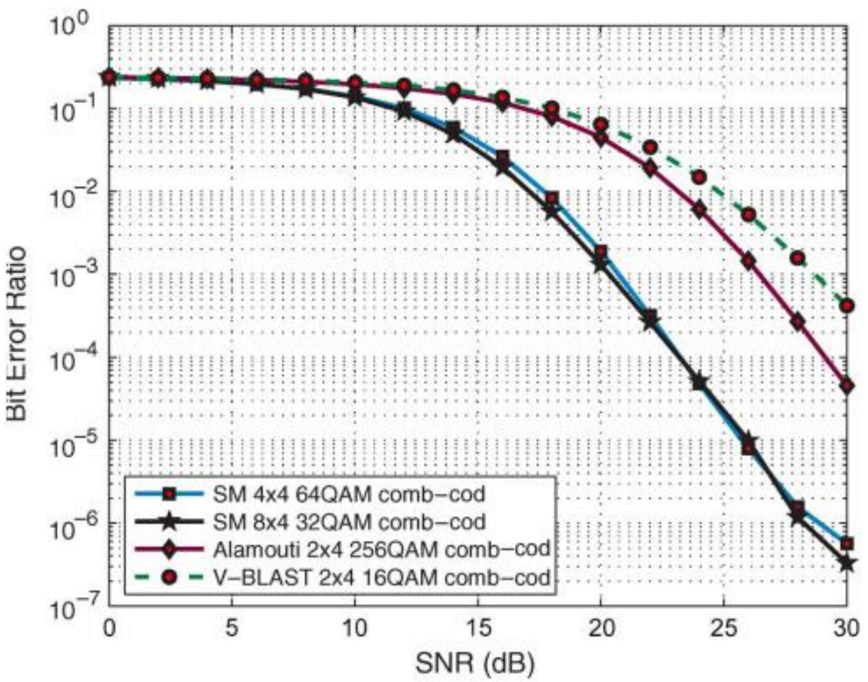
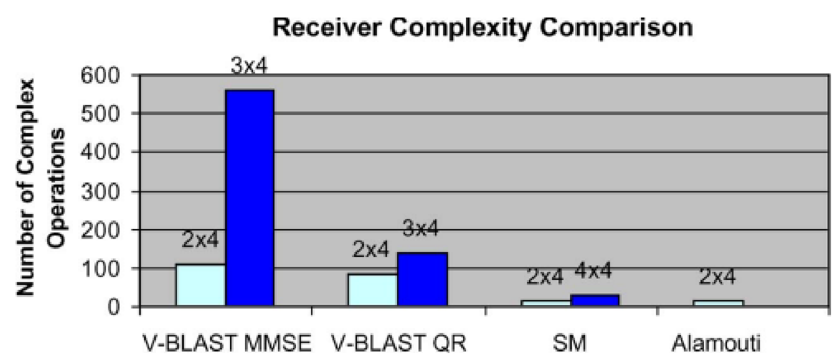


Fig. 13. BER versus SNR for the case of an 8-b/s/Hz transmission (coded combined channel imperfections).

RECEIVER COMPLEXITY COMPARISON FOR A 6-b/s/Hz TRANSMISSION

V-BLAST				SM		Alamouti
MMSE		QR		MRRC		ML
2x4 8QAM	3x4 4QAM	2x4 8QAM	3x4 4QAM	4x4 16QAM	2x4 32QAM	2x4 64QAM
110	560	85	140	28	14	15



Mesleh, Raed Y., et al. "Spatial modulation." *IEEE Transactions on vehicular technology* 57.4 (2008): 2228-2241.

Index Moduation

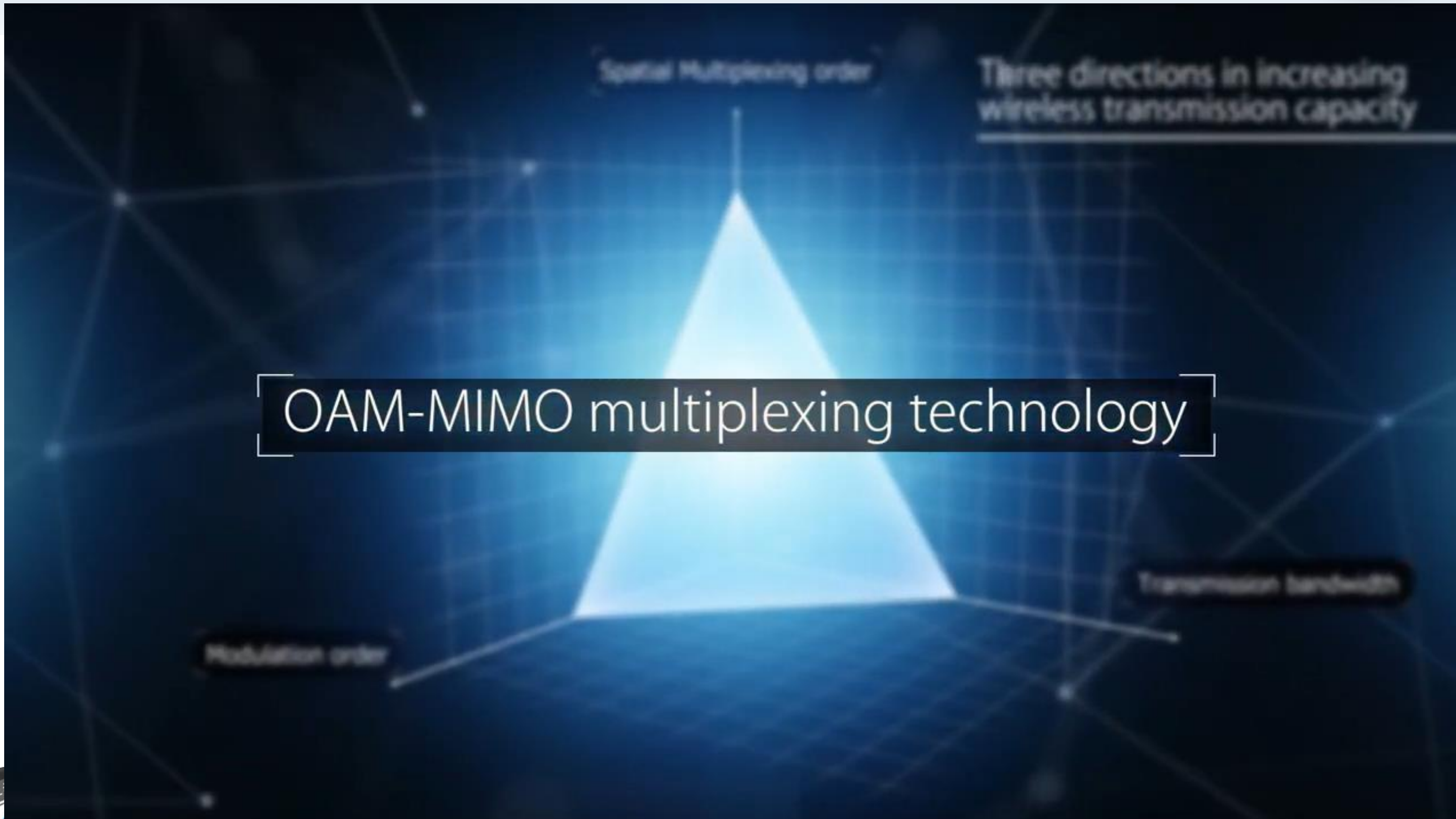
Advantages:

- ✓ Enhanced System Capacity
- ✓ Reduce BER

Disadvantages:

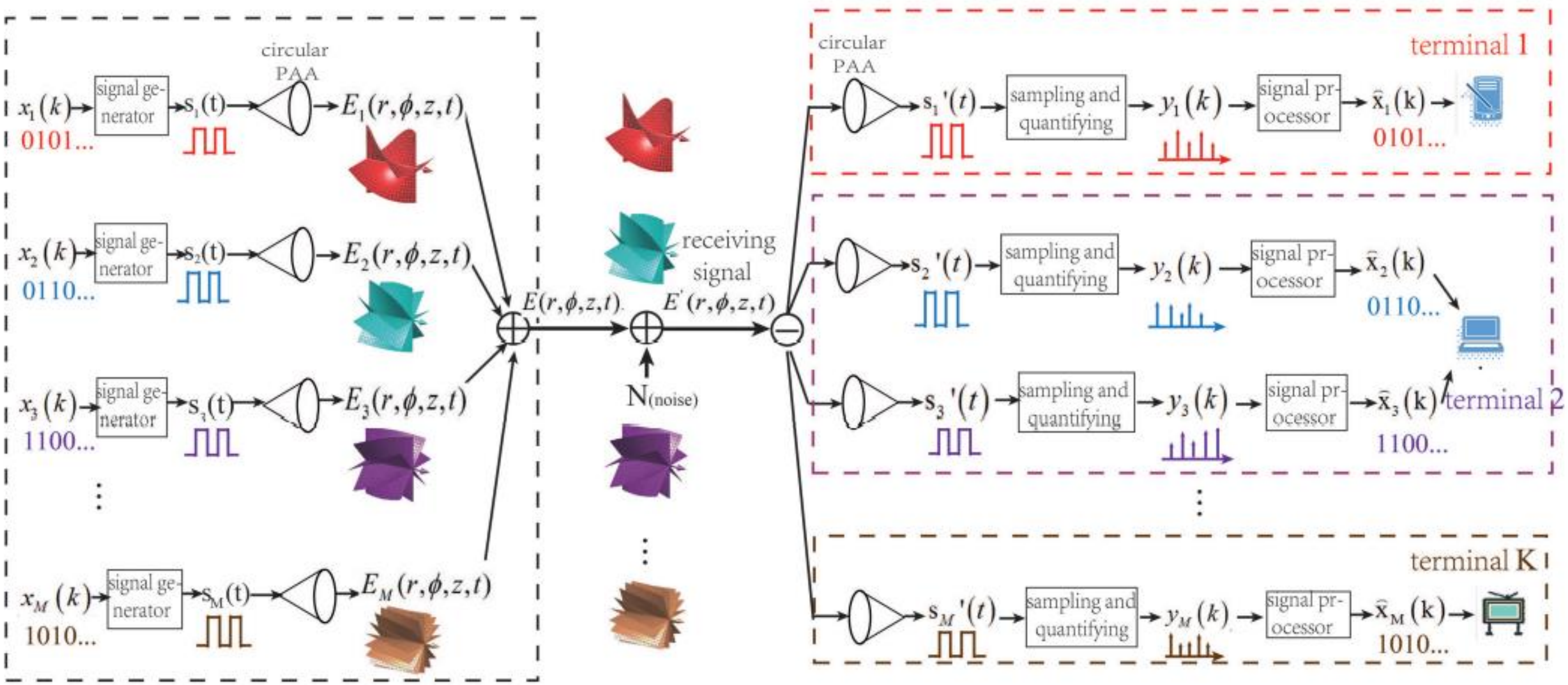
- ✓ Limited Resources (Index)
- ✓ All the indexes not available at the same time
- ✓ Not fully researched (How to integrate with massive MIMO)

OAM (Orbital Angular Momentum)



Courtesy from NTT (https://www.youtube.com/watch?v=5P6Igla2krg)

OAM

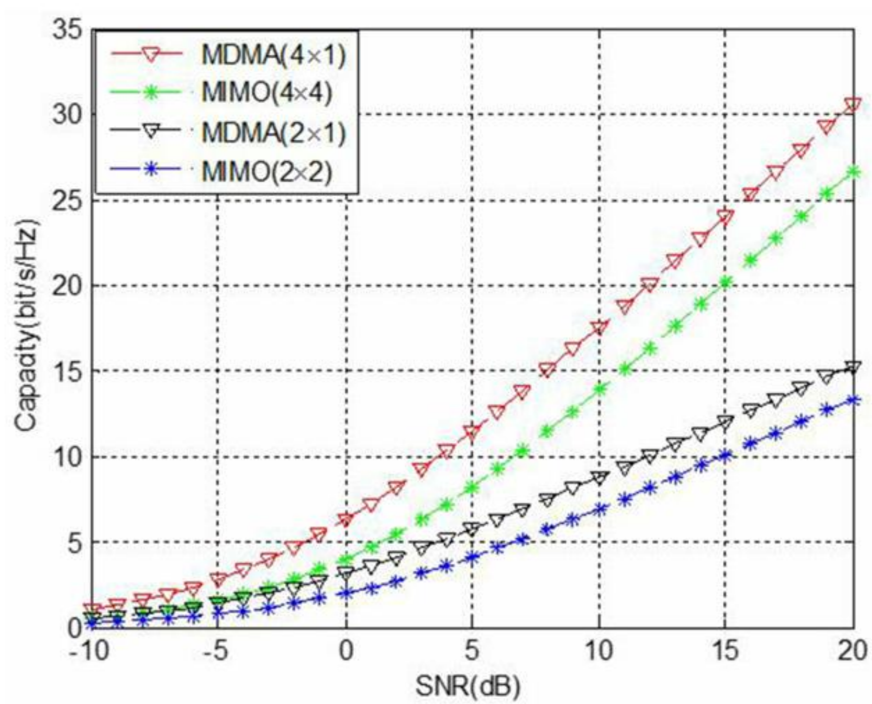


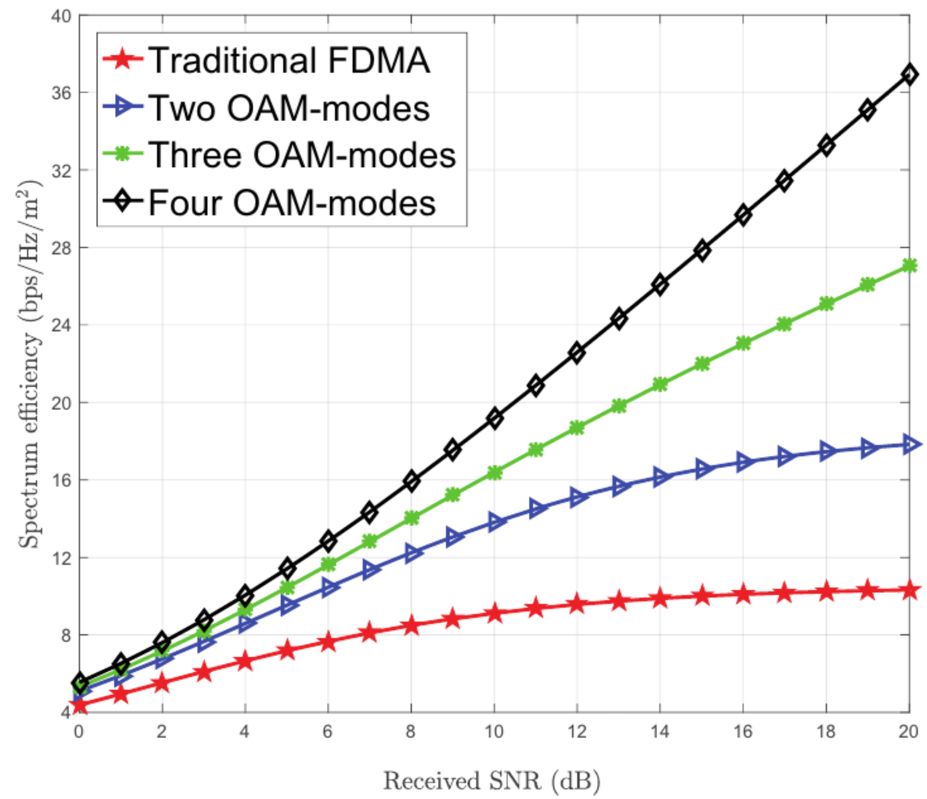
- Multiple Orthogonal channel by different OAM modes
- High SE.
- Interference free transmission (No ICI or IMI).

Wang, L., Jiang, F., Yuan, Z., Yang, J., Gui, G. and Sari, H. (2018), Mode division multiple access: a new scheme based on orbital angular momentum in millimetre wave communications for fifth generation. IET Communications, 12: 1416-1421.

OAM

▶ **Overlapping multiple modes → SE enhancement**





Cheng, Wenchi, et al. "Orbital angular momentum for wireless communications." *IEEE Wireless Communications* 26.1 (2018): 100-107.

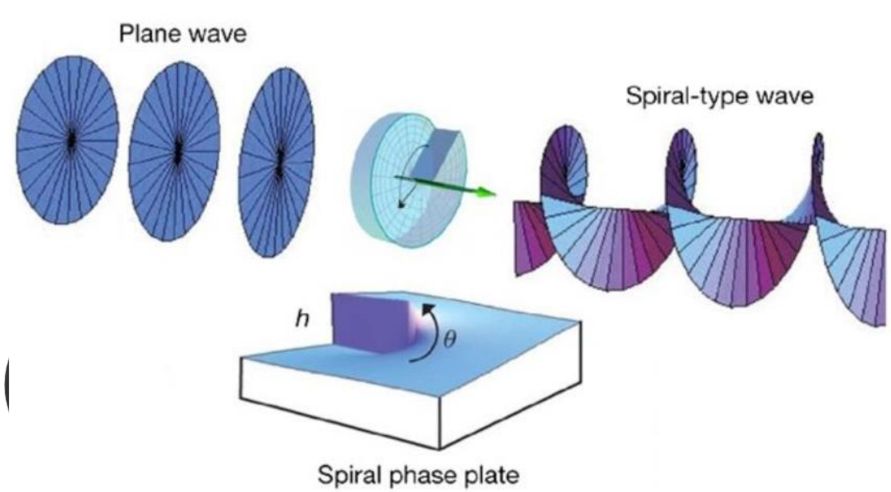
OAM

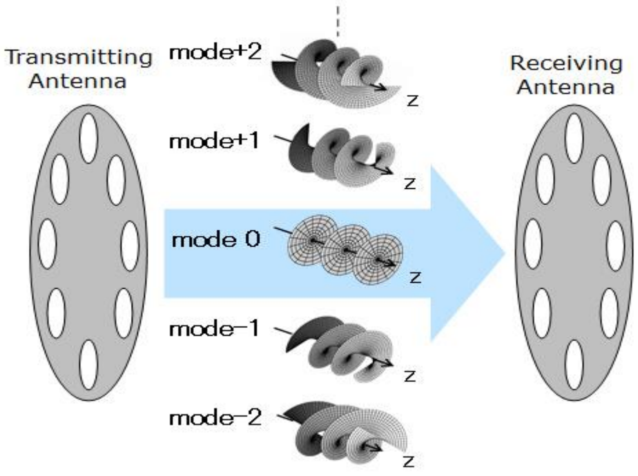
Advantages:

- ✓ High System Capacity : orthogonality
- ✓ Higher degree of freedom

Disadvantages:

- ✓ Special type of antenna required : SPP or circular array antenna
- ✓ Beam Divergence
- ✓ Misalignment



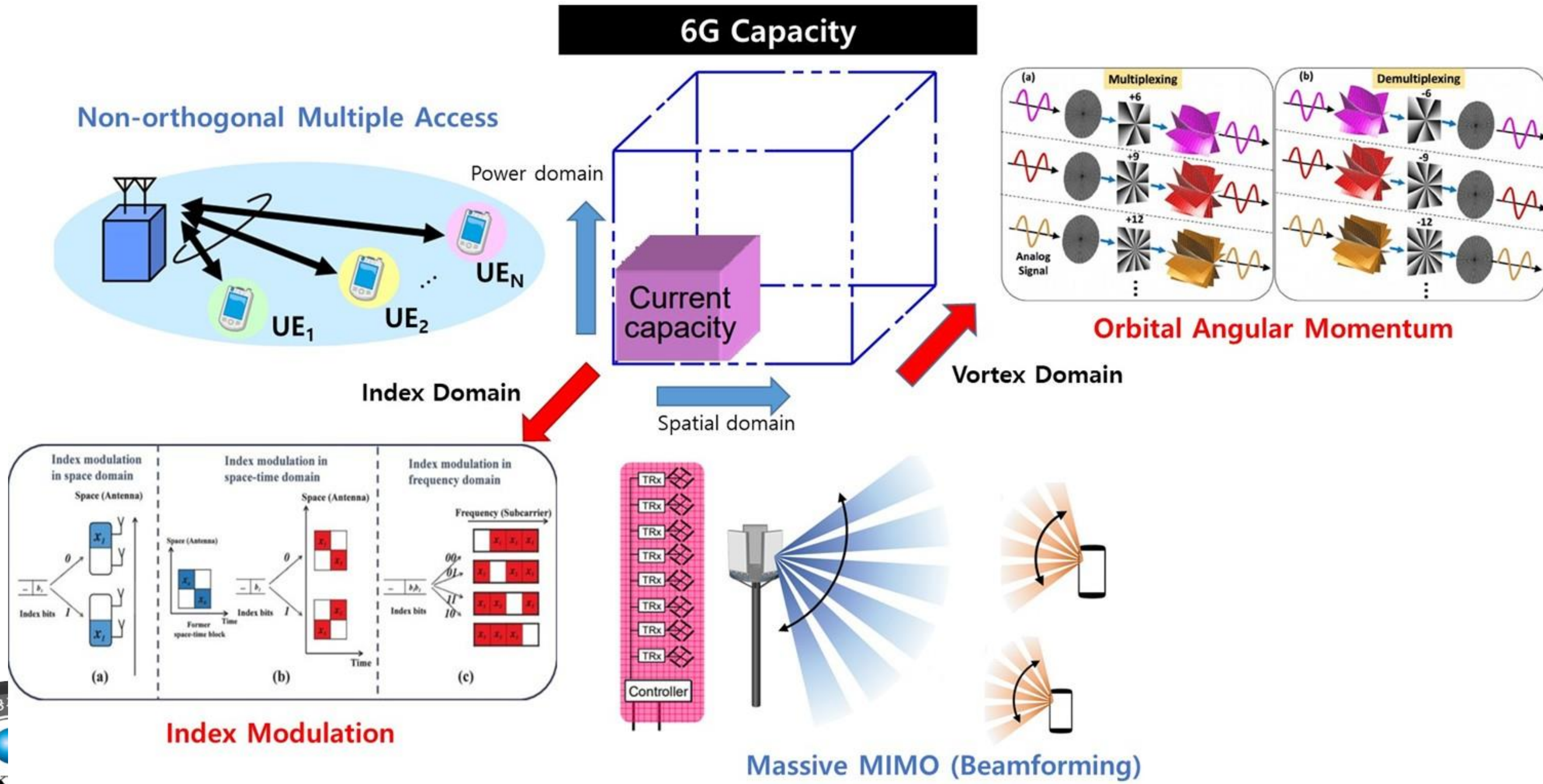


Circular Antennas

Towards New RATs for B5G/6G in WENS

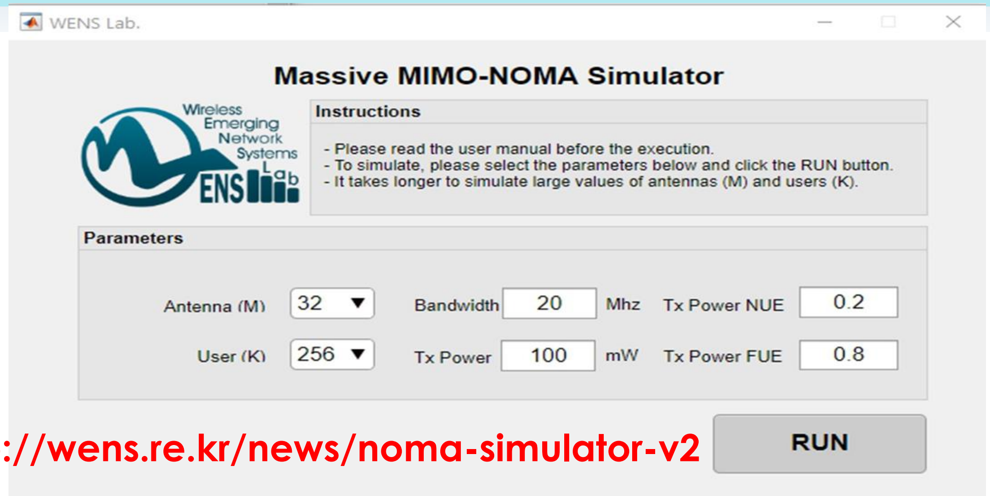
Further Spectrum Efficiency Enhancement

❖ Our Radio Access Technology Direction



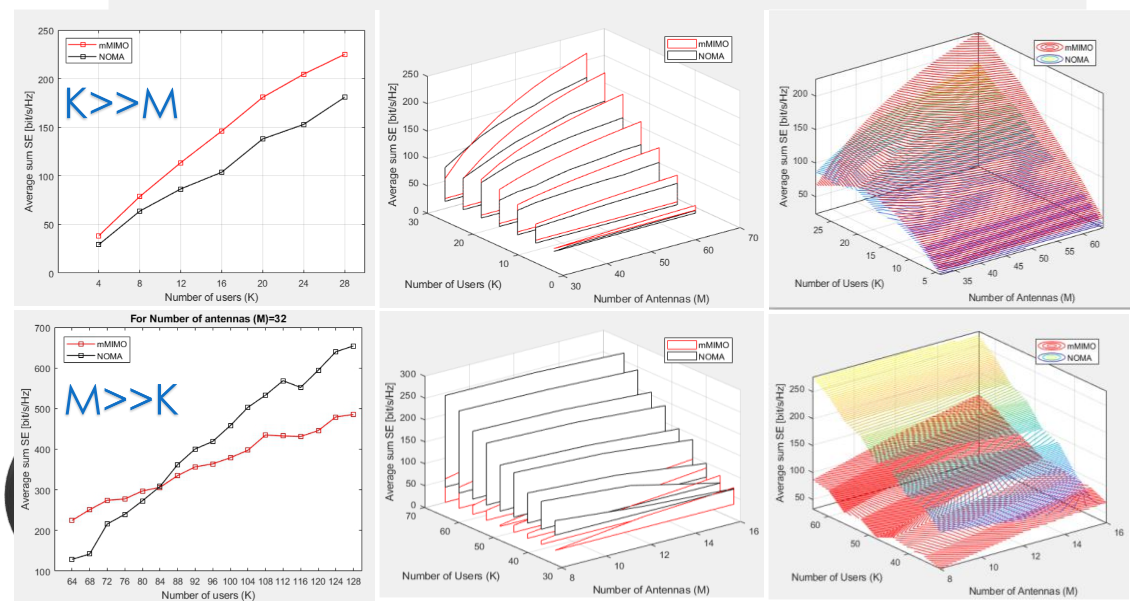
Massive MIMO-NOMA simulator

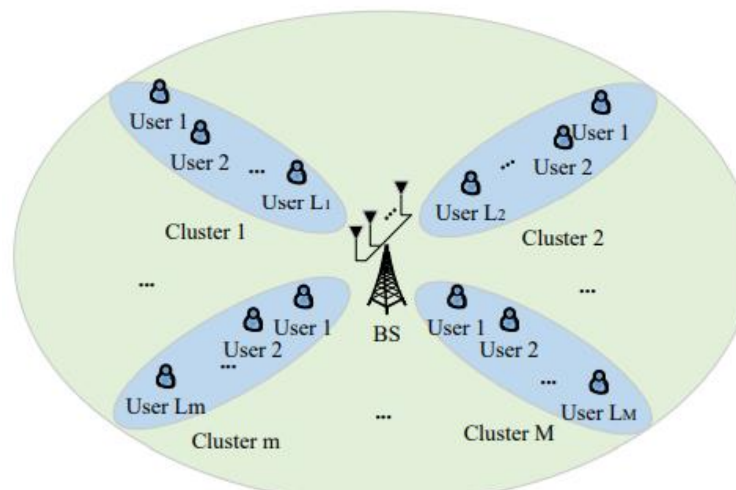
NOMA along with MIMO delivers enhanced performance



http://wens.re.kr/news/noma-simulator-v2

Parameters	mMIMO-OMA & mMIMO-NOMA
No. of Cell (L)	Single Cell
No. of Users (K)	2^k users (k=2,3,4,…,10)
No. of Tx Antennas (M)	2^m Antennas (m=2,3,4,…,10)
No. of Rx Antennas	Single Antenna
User Deployment	Random User
Network Setup	Downlink with Perfect CSI
Beamforming Technique	Zero Forcing (ZF)
Bandwidth (B)	20 MHz-100 MHz
Power Allocation	Fixed Power
Channel Model	NLOS
Interference Cancellation	Perfect SIC
Performance Parameter	Spectral Efficiency
Performance Comparison	mMIMO-OMA vs mMIMO-NOMA



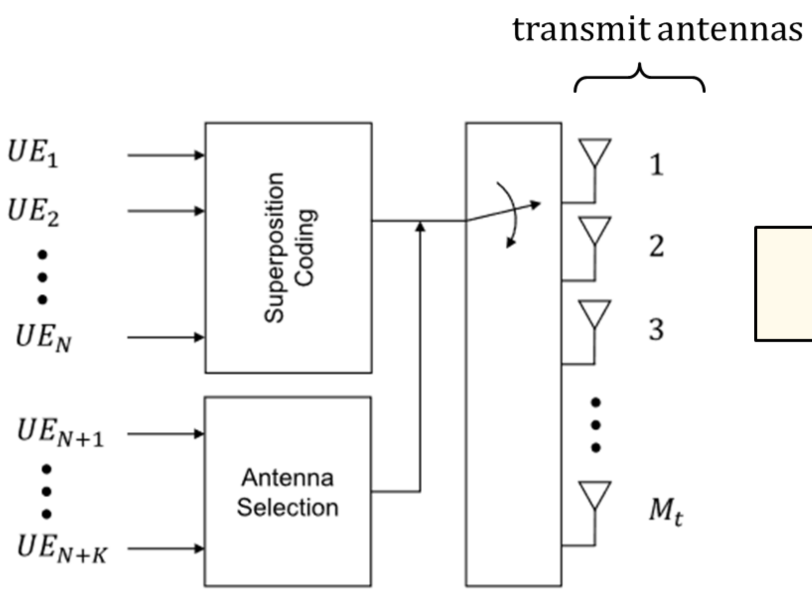


NOMA - IM

NOMA with Generalized Space Shift Keying (NOMA-GSSK)

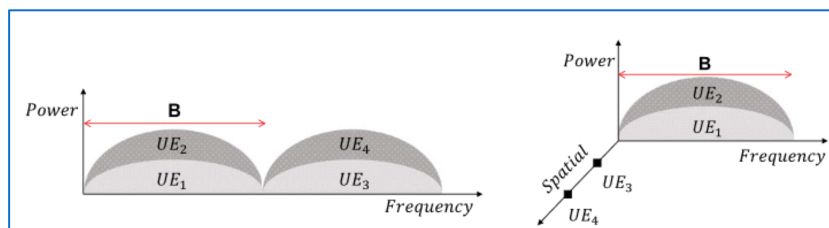
Utilize power & frequency domains

Utilize **spatial**, power, & frequency domains



GSSK: utilize M_a active antennas

M_t : total number of transmit antennas

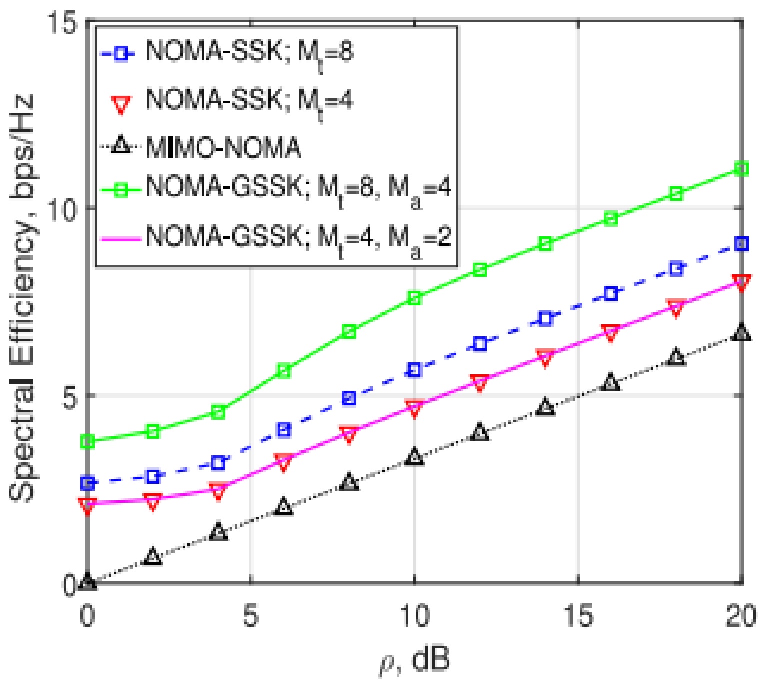


(a) NOMA (b) NOMA-GSSK

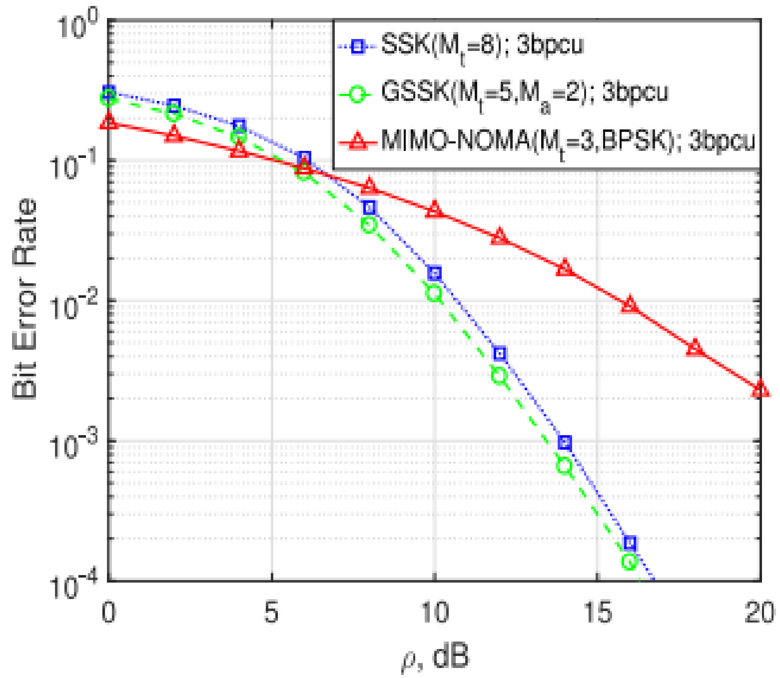
J. W. Kim, S. Y. Shin, and V. C. M. Leung, "Performance Enhancement of Downlink NOMA by Combination With GSSK," IEEE Wireless Communications Letters, Oct. 2018.

NOMA - IM

NOMA with Generalized Space Shift Keying (NOMA-GSSK)



(b) Spectral Efficiency



(d) BER of cell-edge user

SEFDM-IM

▶ OFDM-IM

- Information transmitted by both M-ary signal constellations as in classical OFDM and activating some subcarriers only accordingly

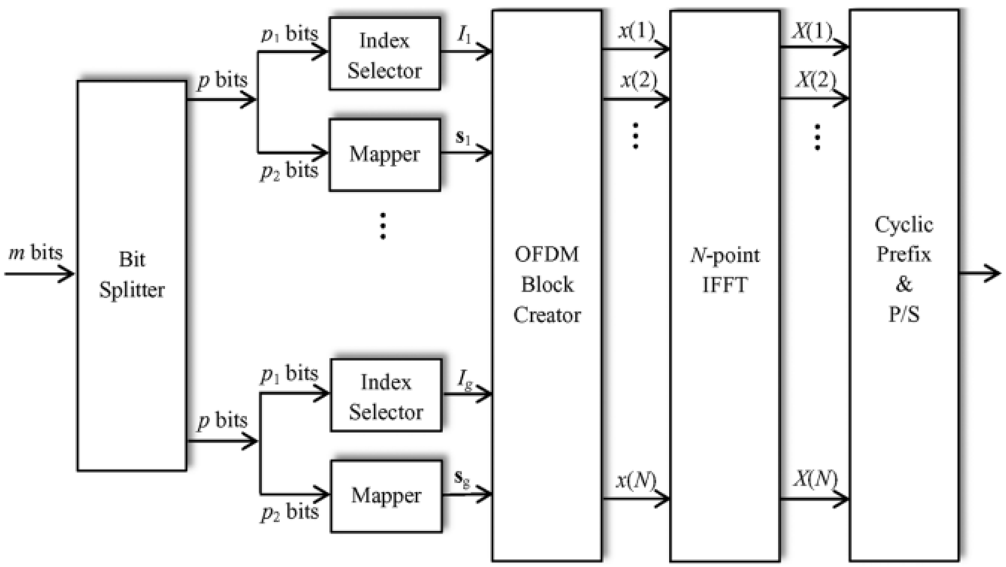
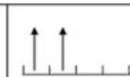
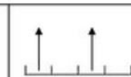
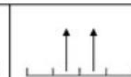
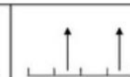


Fig. 1. Block diagram of the OFDM-IM transmitter.

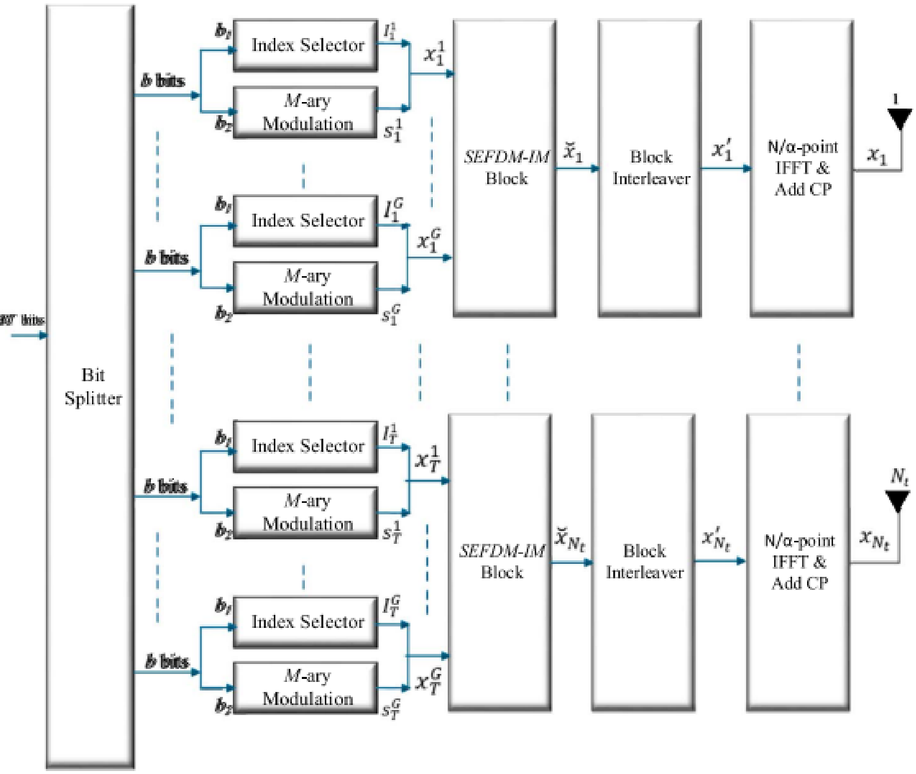
TABLE I
A LOOK-UP TABLE EXAMPLE FOR $n = 4$, $k = 2$ AND $p_1 = 2$

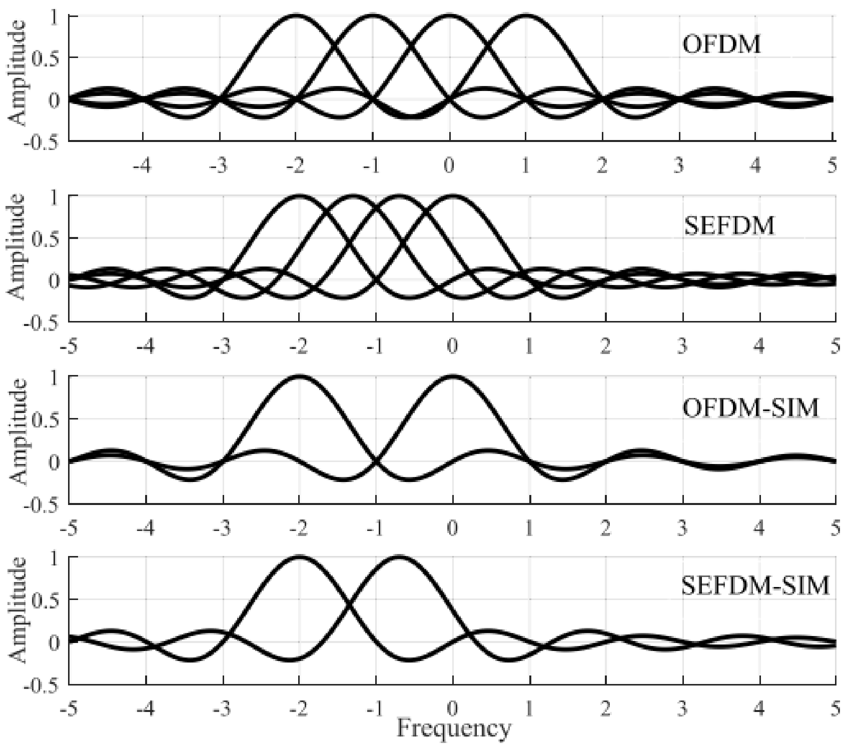
Bits	*Indices*	*subblocks*
$[0\ \ 0]$	$\{1, 2\}$	$[s_\chi\ s_\zeta\ 0\ 0]^T$
$[0\ \ 1]$	$\{2, 3\}$	$[0\ s_\chi\ s_\zeta\ 0]^T$
$[1\ \ 0]$	$\{3, 4\}$	$[0\ 0\ s_\chi\ s_\zeta]^T$
$[1\ \ 1]$	$\{1, 4\}$	$[s_\chi\ 0\ 0\ s_\zeta]^T$

OFDM-IM	Patterns of activating subcarriers				
	Number of used subcarriers	4	4	4	4

E. Basar et al, "Orthogonal frequency division multiplexing with index modulation," IEEE Trans. Signal Process., vol. 61, no. 22, pp. 5536–5549, 2013.

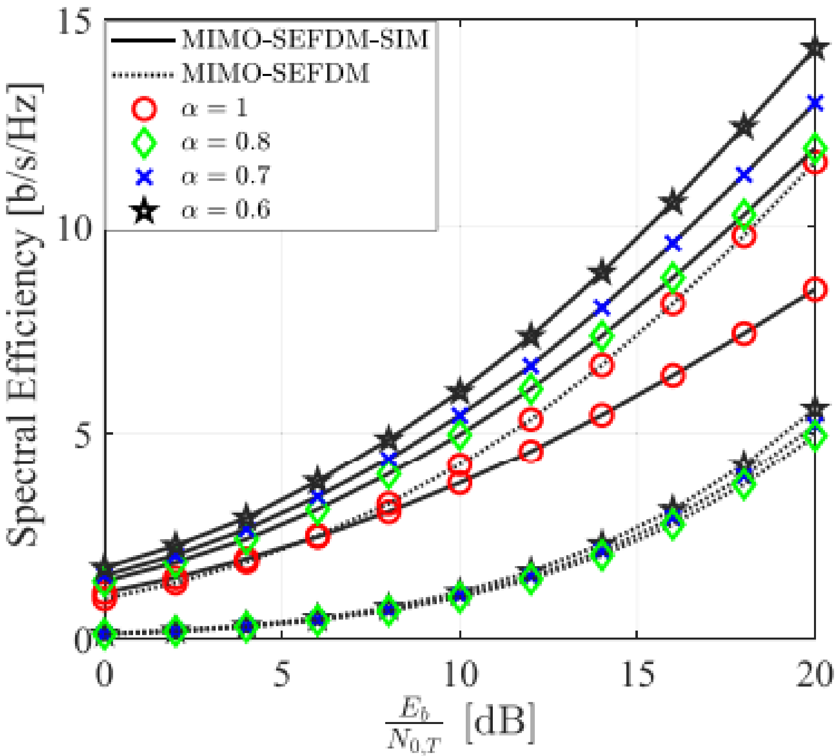
SEFDM-IM



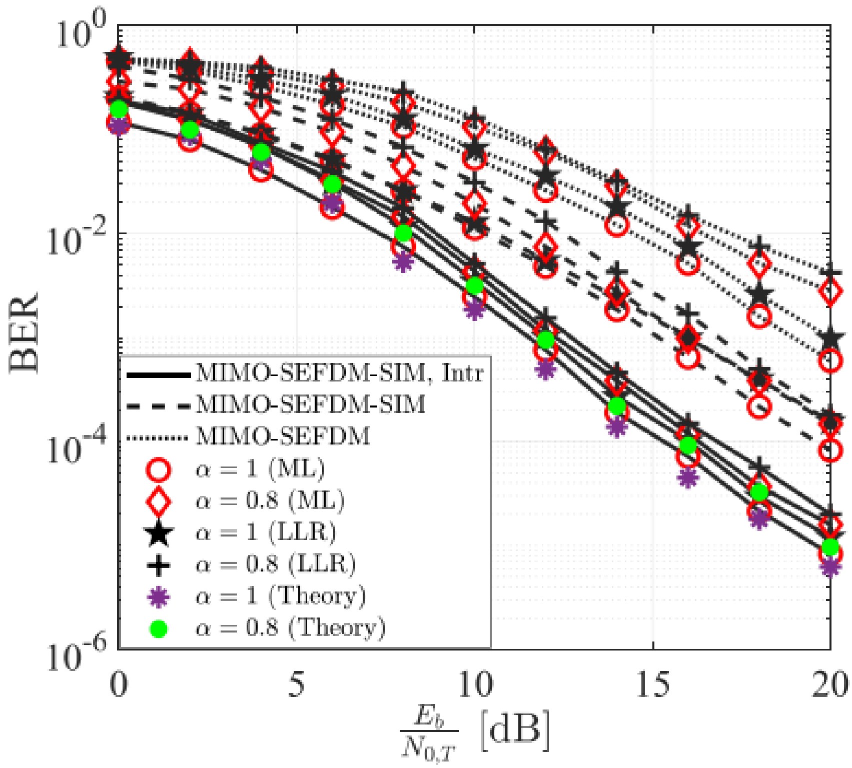


M. S. Sarwar, M. Ahmad and S. Y. Shin, "Subcarrier Index Modulation for Spectral Efficient Frequency Division Multiplexing in Multi-Input Multi-Output Channels," in IEEE Transactions on Vehicular Technology, vol. 72, no. 2, pp. 2678-2683, Feb. 2023, doi: 10.1109/TVT.2022.3213011.

SEFDM-IM



MIMO-SEFDM-SIM
MIMO-SEFDM
α = 1
α = 0.8
α = 0.7
α = 0.6
Spectral Efficiency [b/s/Hz]
15
10
5
0
0
5
10
15
20
Eb/N0,T [dB]



MIMO-SEFDM-SIM, Intr
MIMO-SEFDM-SIM
MIMO-SEFDM
α = 1 (ML)
α = 0.8 (ML)
α = 1 (LLR)
α = 0.8 (LLR)
α = 1 (Theory)
α = 0.8 (Theory)
BER
10^0
10^-2
10^-4
10^-6
0
5
10
15
20
Eb/N0,T [dB]

OAM-IM

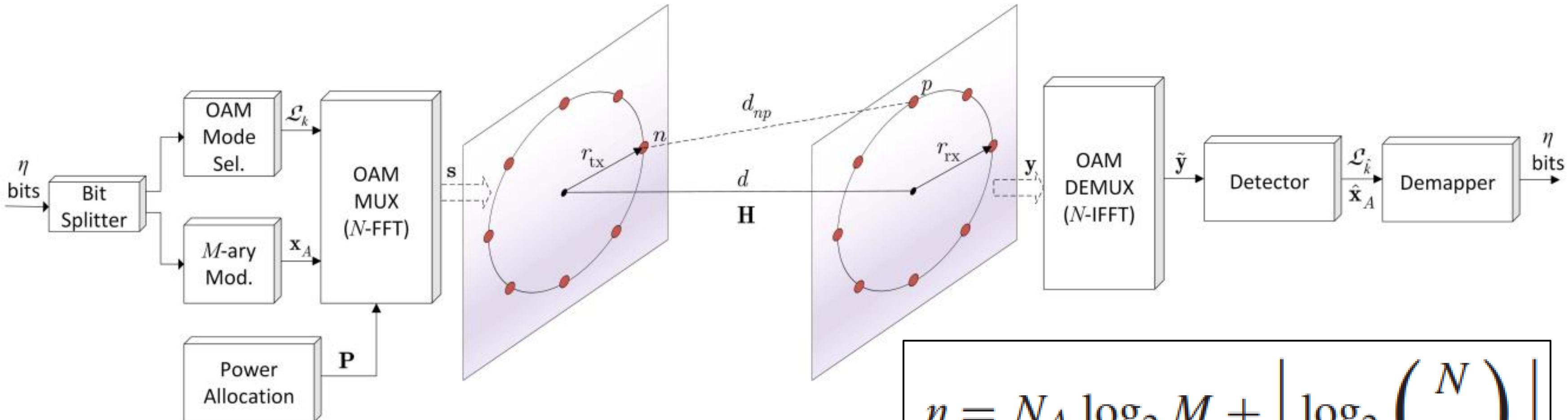


Fig. 1. Block diagram of the OAM-IM transceiver.

$$\eta = N_A \log_2 M + \left\lfloor \log_2 \binom{N}{N_A} \right\rfloor$$

N	N_A	M	n_c	n_d	n_s	$d_{\min}^{S}$	$d_{\min}^{\text{OAM}}$	$d_{\min}$	η	$\{\theta_i\}_{i=2}^{n_s}$	Active Mode Combinations $\{\mathcal{L}_k\}_{k=1}^{n_c}$
4	1	2	4	4	1	16	8	8	3	-	$\{(0),(1),(2),(3)\}$
4	2	2	4	2	2	8	8	8	4	$\{\pi/2\}$	$\{(0,1),(2,3),(0,2),(1,3)\}$
4	2	4	4	2	2	4	5.172	4	6	$\{\pi/4\}$	
4	2	16	4	2	2	0.8	0.878	0.8	10	$\{0.445\}$	
4	2	64	4	2	2	0.190	0.196	0.190	14	$\{0.236\}$	
4	3	2	4	1	4	5.333	4.229	4.229	5	$\{\pi/4,\pi/2,3\pi/4\}$	$\{(0,1,2),(0,1,3),(0,2,3),(1,2,3)\}$
4	3	4	4	1	4	2.667	3.073	2.667	8	$\{\pi/8,\pi/4,3\pi/8\}$	
4	3	8	4	1	4	0.889	0.978	0.889	11	$\{\pi/8,\pi/4,3\pi/8\}$	

Basar, Ertugrul. "Orbital angular momentum with index modulation." *IEEE Transactions on Wireless Communications* 17.3 (2018): 2029-2037.

OAM-IM

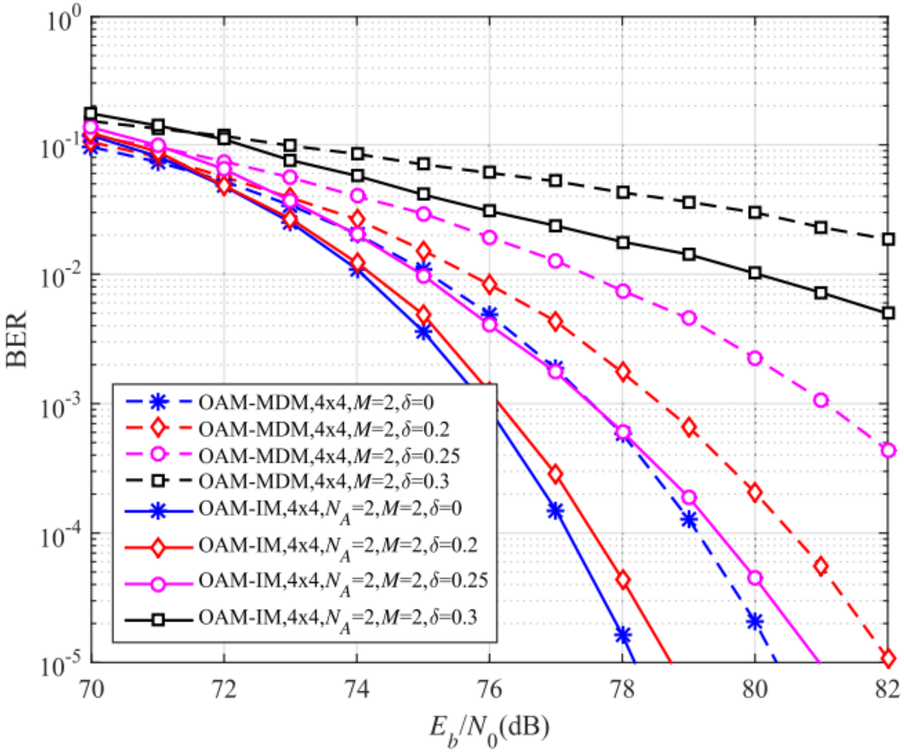


Fig. 6. OAM-IM and OAM-MDM comparison for imperfect alignment.

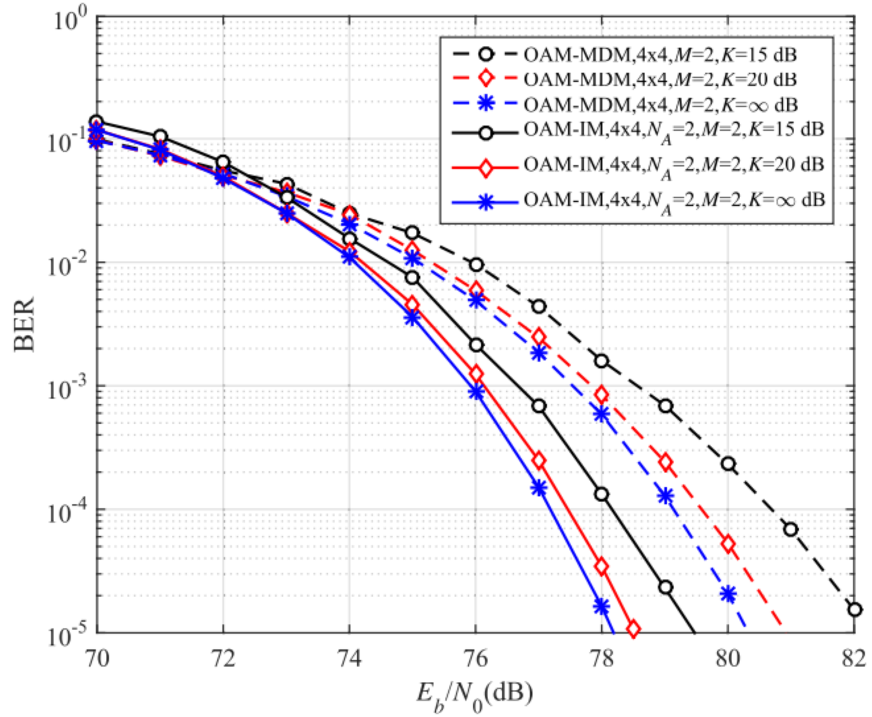
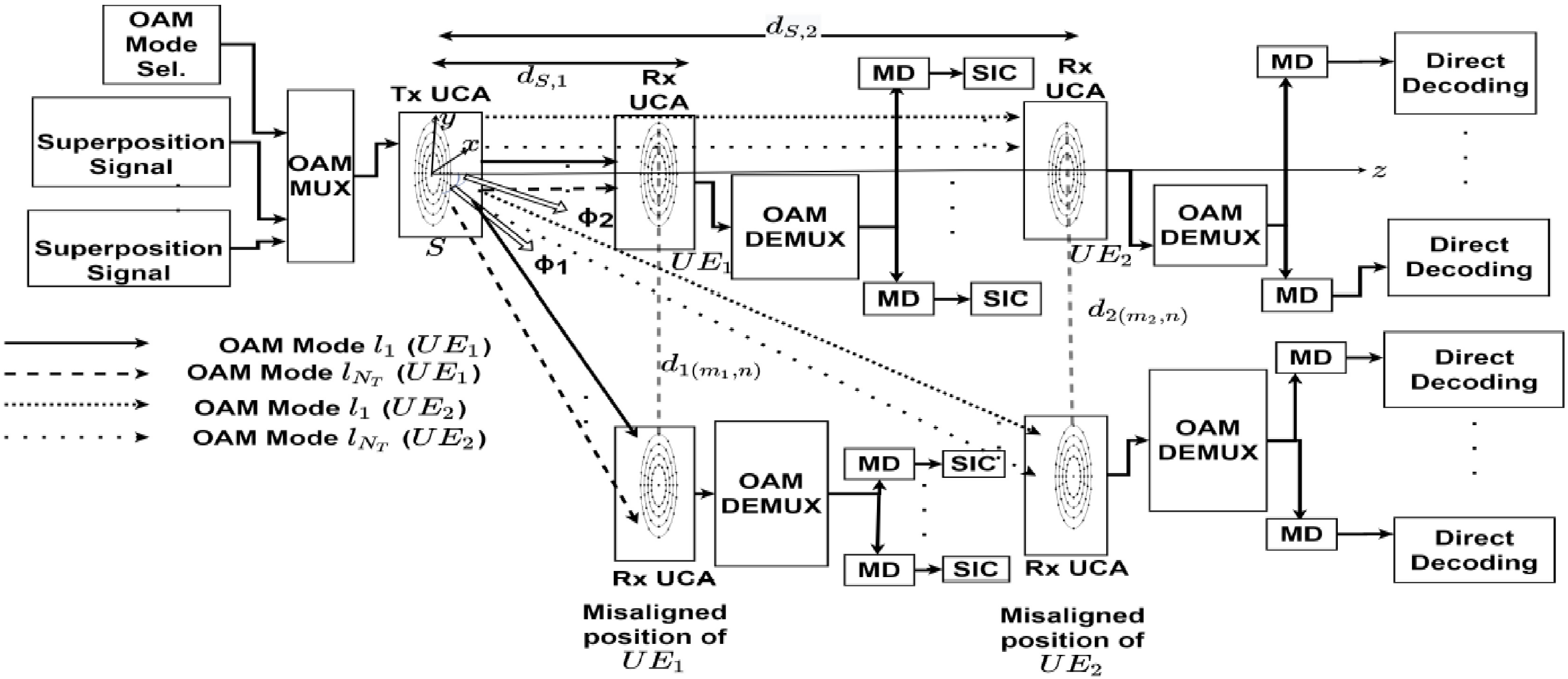


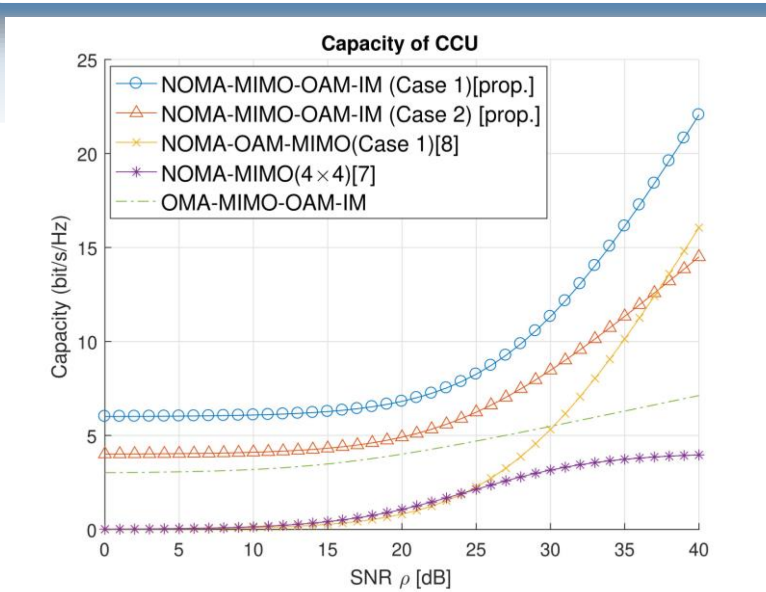
Fig. 7. OAM-IM and OAM-MDM comparison for Rician fading channels.

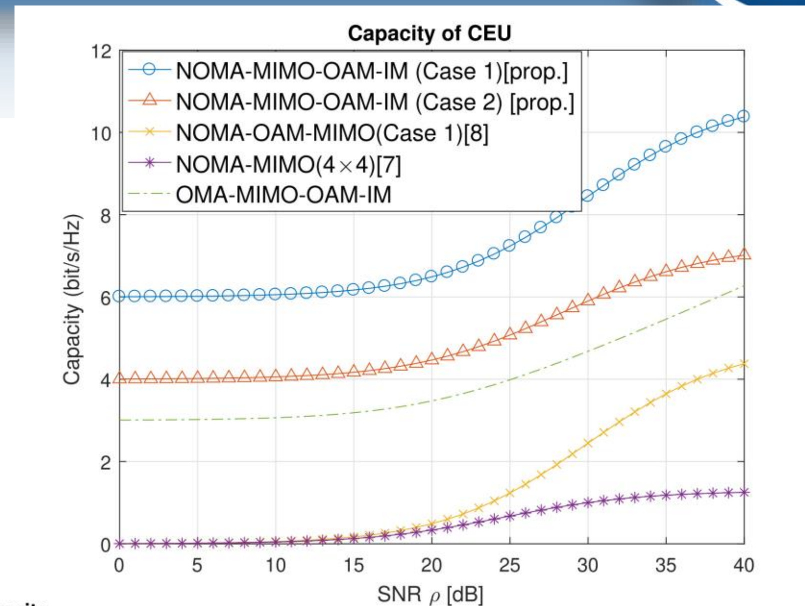
MIMO-NOMA with OAM-IM

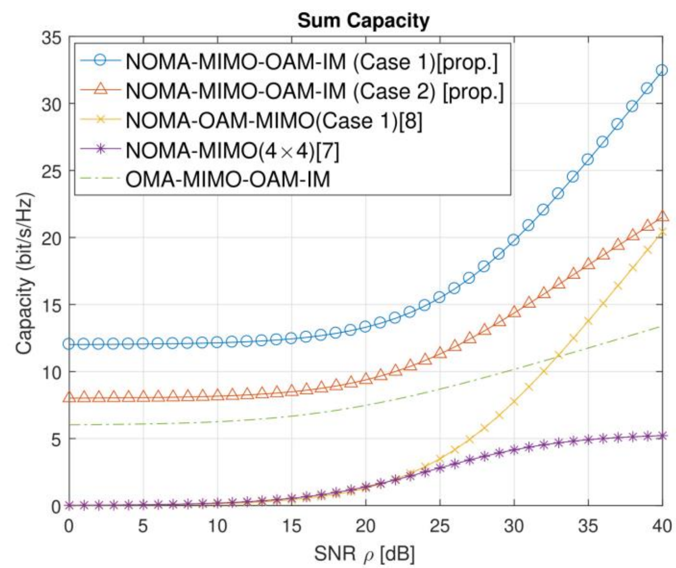


A. A. Amin and S. Y. Shin, "Channel Capacity Analysis of Non-Orthogonal Multiple Access With OAM-MIMO System," in *IEEE Wireless Communications Letters*, vol. 9, no. 9, pp. 1481-1485, Sept. 2020, doi: 10.1109/LWC.2020.2994355.

MIMO-NOMA with OAM-IM







Impedance Matching : Novel IM

Impedance Matching

Impedance matching : designing source and load impedances to minimize signal reflection or maximize power transfer

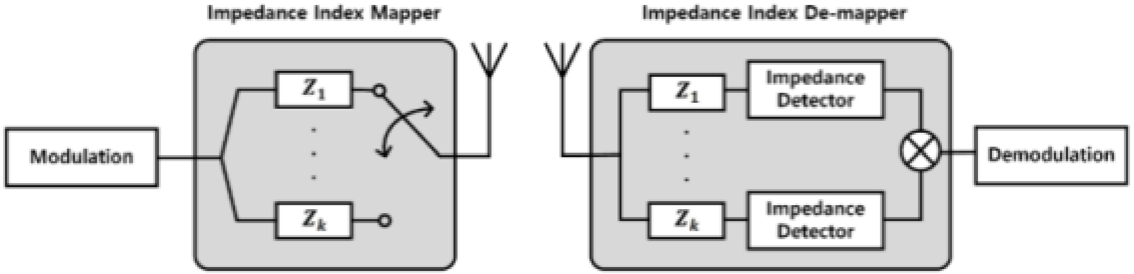
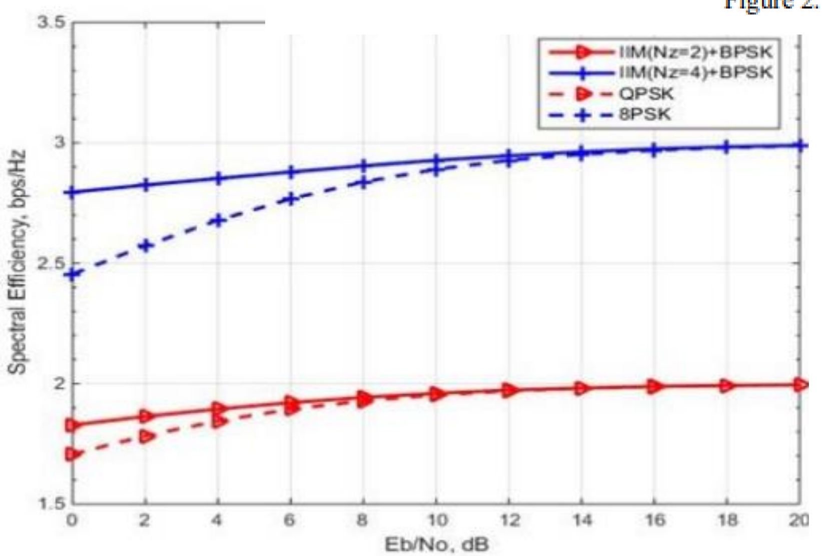
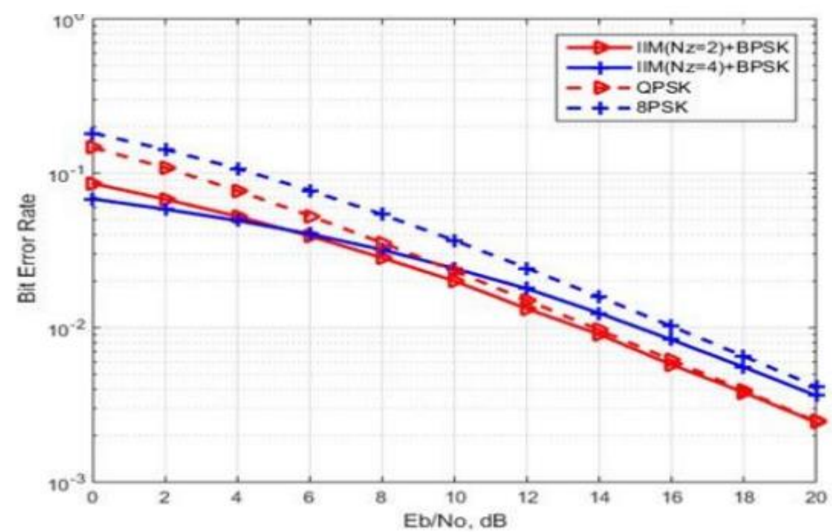


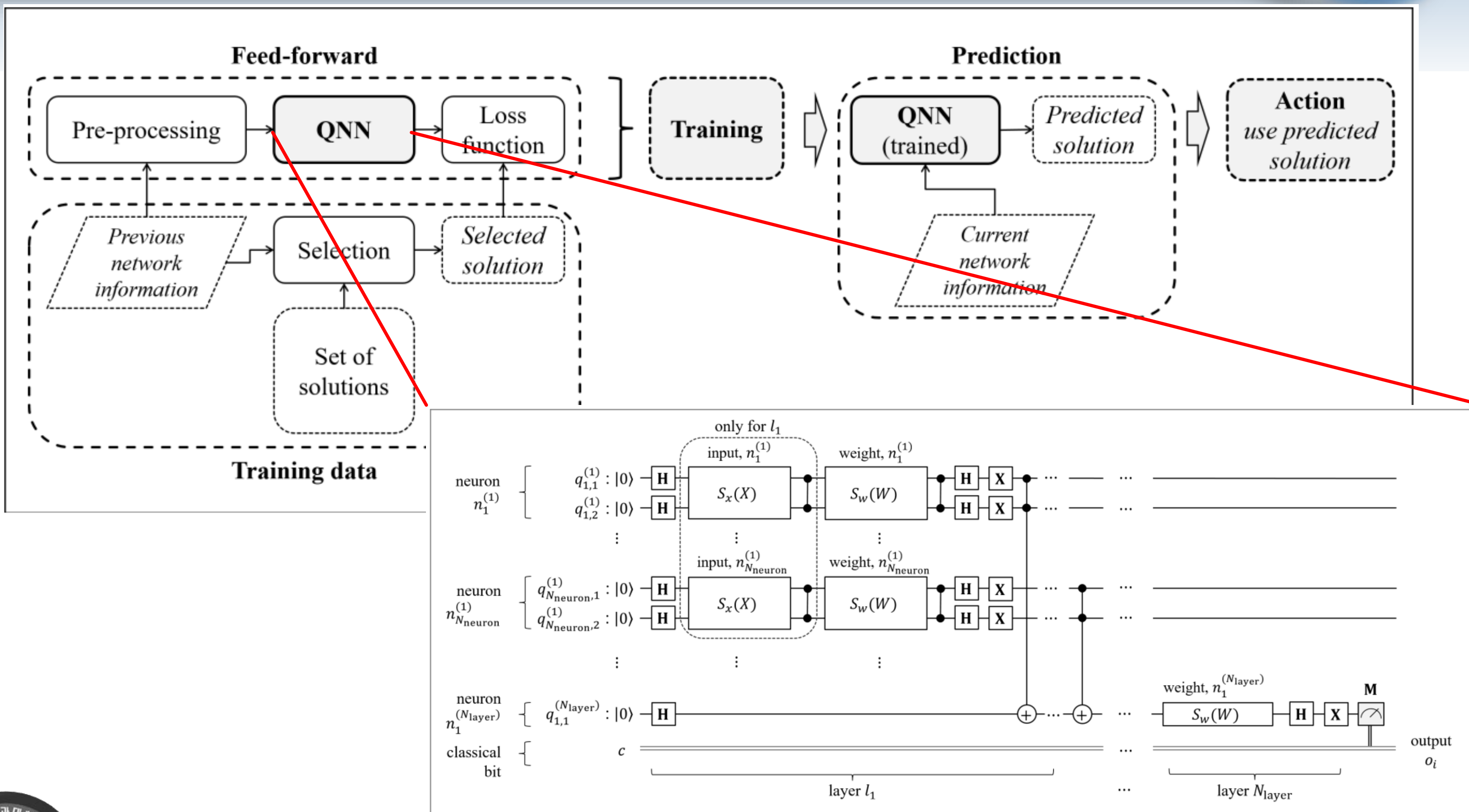
Figure 2. System model





Hye Yeong Lee, Soo Young Shin. "**A Novel Index Modulation Scheme With Impedance Matching**", Indonesian Journal of Electrical Engineering and Computer Science, Volume 14, No. 3, pp 1203-1209 June 2019

RAT Resource Optimization with Quantum Computing

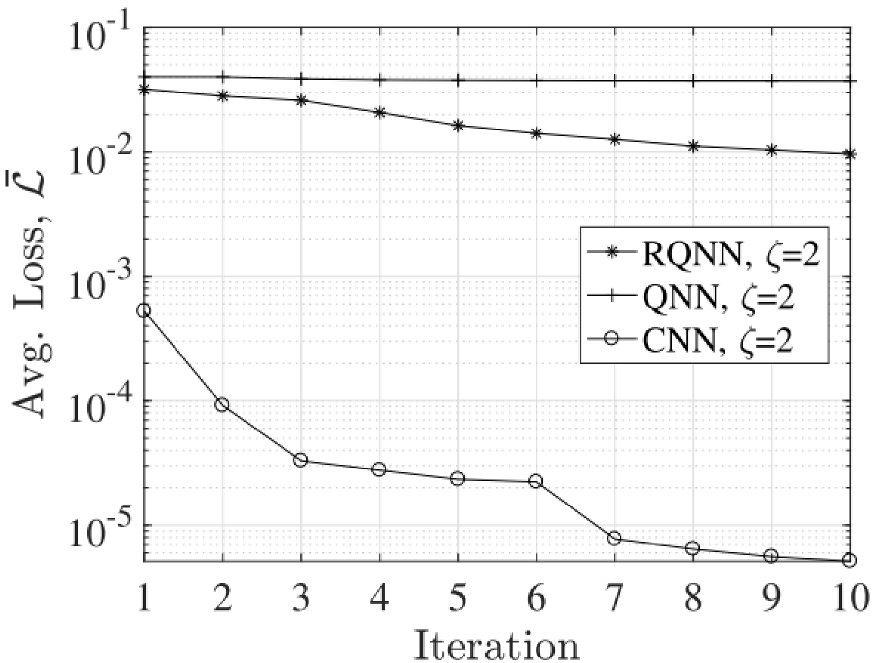


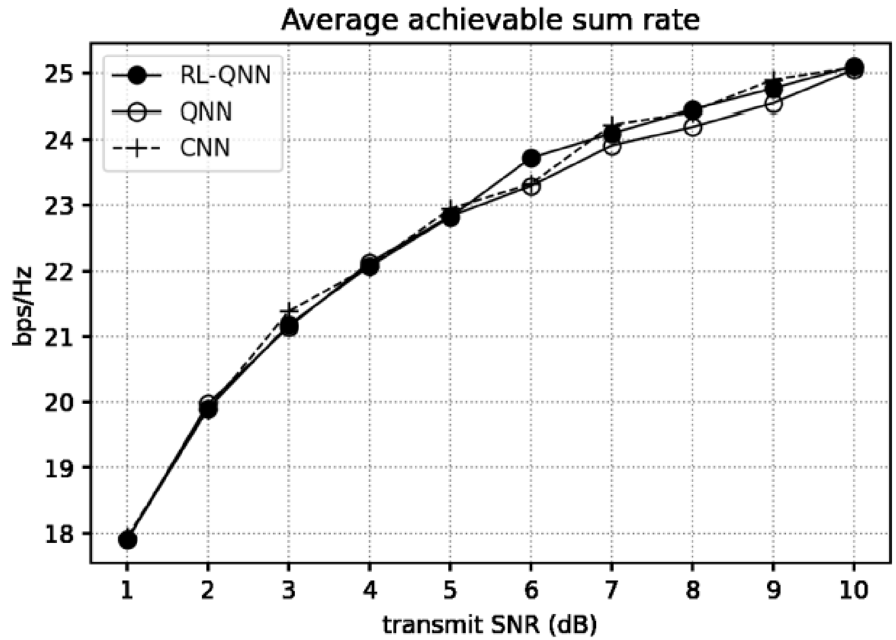
B. Narottama and S. Y. Shin, "Quantum Neural Networks for Resource Allocation in Wireless Communications," in IEEE Transactions on Wireless Communications, vol. 21, no. 2, pp. 1103-1116, Feb. 2022, doi: 10.1109/TWC.2021.3102139.

RAT Resource Optimization with Quantum Computing

COMPLEXITY COMPARISON

Method	Time Complexity
QNN	$U_{\text{QNN}} \in \mathcal{O}\left(N_{\text{layer}} N_{\text{neuron}}\right)$
RL-QNN	$U_{\text{RL-QNN}} \in \mathcal{O}\left(N_{\text{layer}} N_{\text{neuron}}\right)$
CNN	$U_{\text{CNN}} \in \mathcal{O}\left(N_{\text{layer}} \left(N_{\text{neuron}}\right)^2\right)$





Conclusion and Future Works

Conclusion:

Addressed RAT research challenges for B5G/6G

Integration of diverse RATs for B5G/6G

Future Works :

Develop novel RAT for 6G

Optimize the system using deep learning (AI) and other optimization tools (quantum neutral network)

Thank You

Terima kasih

wdragon@kumoh.ac.kr

Wireless Emerging Network System Lab