Rate Splitting Multiple Access for 6G Communications and Sensing

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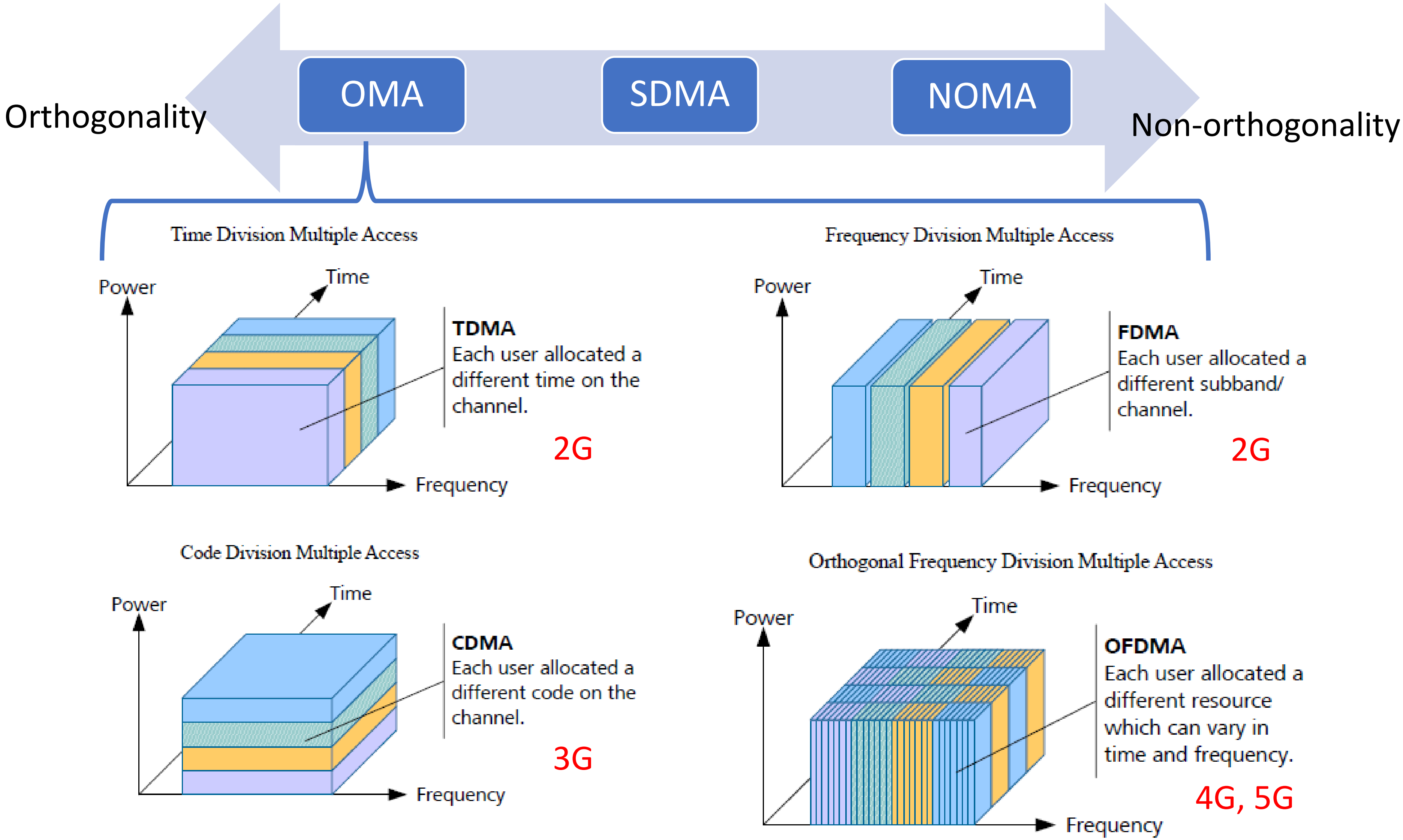
Interference and Multiple Access

Interference Physical scarcity

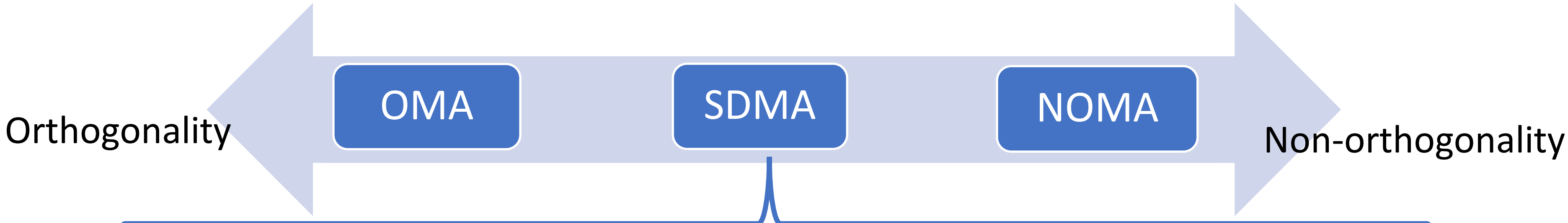
How to efficiently serve multiple wireless users, devices, services ?

Multiple Access Techniques



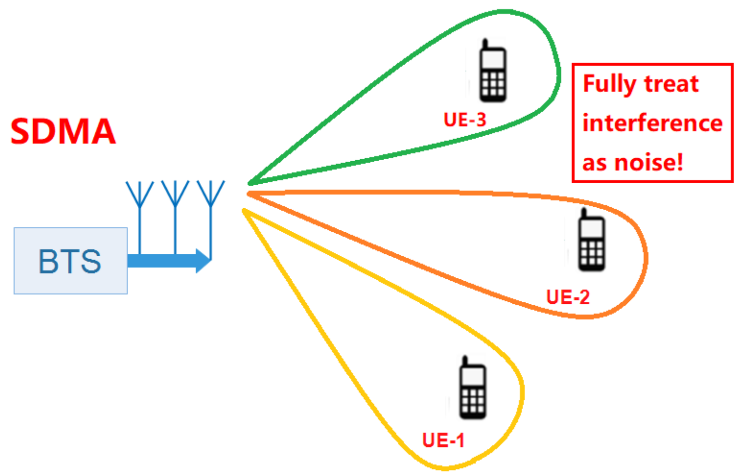
OMA: eliminate multi-user interference by allocating orthogonal radio resources.

Multiple Access Techniques



Space division multiple access (SDMA):

- Multiplex users in spatial domain using multi-user linear precoding (MU-LP)
- Used in multiuser / massive / millimeter-wave / network-MIMO



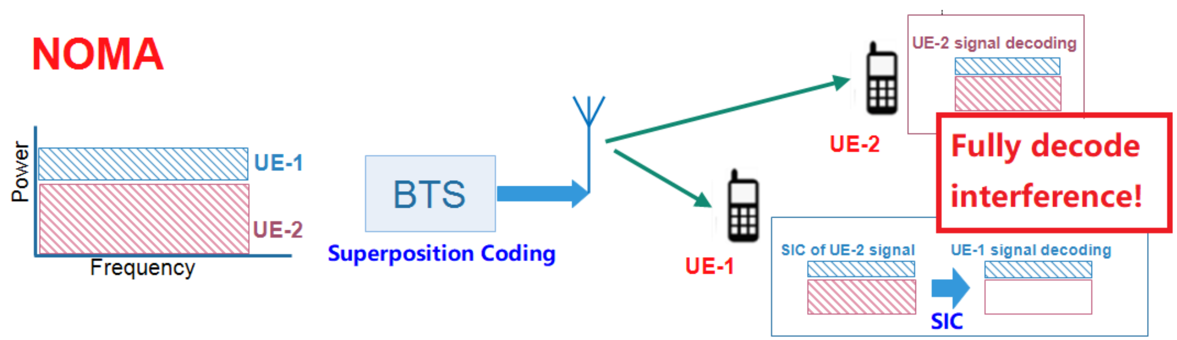
4G, 5G

SDMA: manage multi-user interference by spatial precoding at the transmitter and <u>fully treating interference as noise</u> at receivers.

Multiple Access Techniques

Power-domain non-orthogonal multiple access (NOMA):

- Use power domain to break the orthogonality
- Apply superposition coding (SC) at the transmitter and successive interference cancellation (SIC) at each receiver



Study item, no work item in 5G

NOMA: manage multi-user interference by <u>fully decoding interference</u> at receivers.

Multiple Access Techniques

Orthogonal vs. Non-Orthogonal: not the problem!

- SDMA (4G/5G) is non-orthogonal: users interfere

The real problem: how is interference managed

- OMA: no interference
- SDMA: treat interference as noise
- NOMA: fully decode interference

Lessons from Information Theory: [Etkin, Tse, Wang, IEEE TIT 2008]

treat as noise — partially treat as noise, partially decode — fully decode

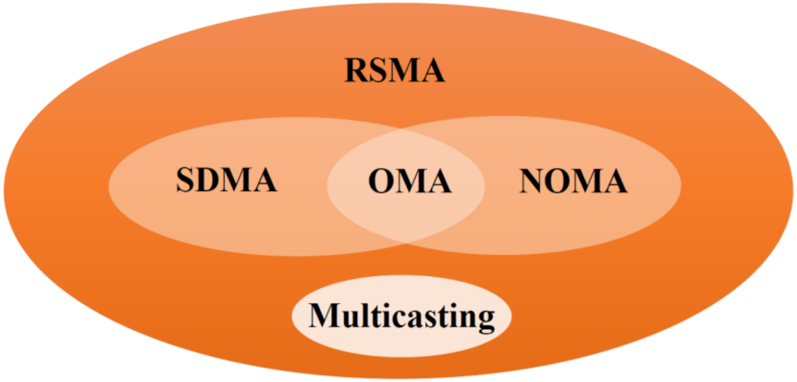
weak ⟷ **strong**

	Weak	Medium	Strong
SDMA	✓	✗	✗
NOMA	✗	✗	✓
?	✓	✓	✓

Rate Splitting Multiple Access

Rate Splitting Multiple Access (RSMA) a **general, flexible** and **robust** multiple access [1]

General with existing multiple access
OMA, SDMA, NOMA subsets of RSMA



Flexible to various levels of interference

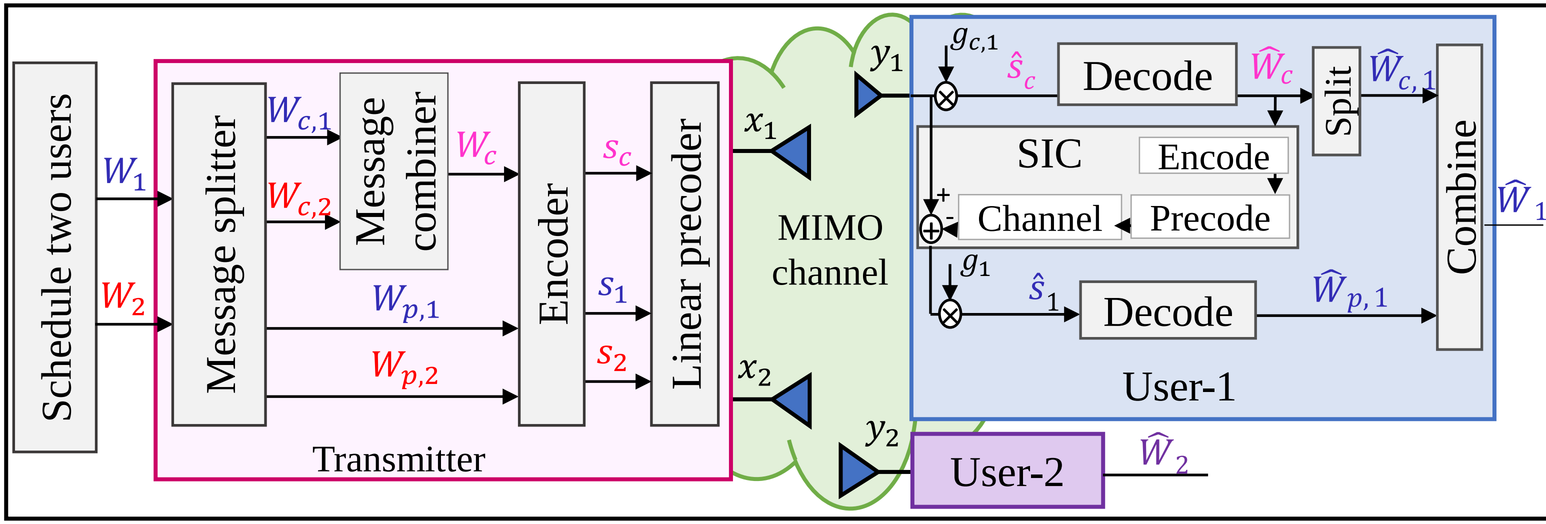
	Weak	Medium	Strong
RSMA	✓	✓	✓

Robust to channel state information (CSI) uncertainty: information theoretic optimal!

treat as noise — partially treat as noise, partially decode — fully decode

SDMA ⟷ RSMA ⟷ NOMA

RSMA: Two-User Example



Transmitter

- Message splitting:

$$W_1 \xrightarrow{\text{split}} \{W_{c,1}, W_{p,1}\} \text{ and } W_2 \xrightarrow{\text{split}} \{W_{c,2}, W_{p,2}\}$$

- Creating the **common message**:

$$\{W_{c,1}, W_{c,2}\} \xrightarrow{\text{combine}} W_c$$

- Independent encoding:

$$W_c \xrightarrow{\text{encode}} s_c,\ W_{p,1} \xrightarrow{\text{encode}} s_1,\ W_{p,2} \xrightarrow{\text{encode}} s_2$$

- Transmit signal:

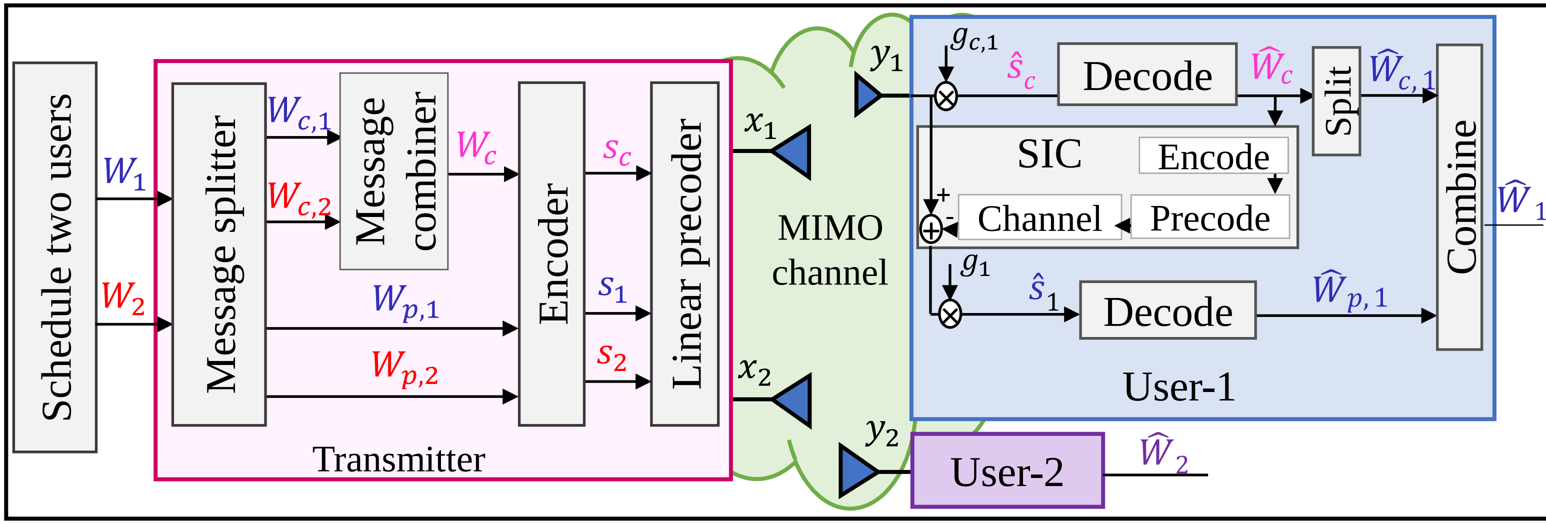
$$\mathbf{x} = \mathbf{p}_c s_c + \mathbf{p}_1 s_1 + \mathbf{p}_2 s_2$$

- **From 2 messages, we generate 3 streams!**

Receiver

- Both users first decode s_c by treating s_1 and s_2 as noise.
- Both users perform **SIC** and then decode s_1 and s_2 , respectively.
- Rate of user-k is split: rate of s_k+part of the rate of s_c

Mapping of Messages to Streams



	s_1	s_2	s_c
SDMA	W_1	W_2	-
NOMA	W_1	-	W_2
OMA	W_1	-	-
Multicasting	-	-	W_1 , W_2
RS	$W_{p,1}$	$W_{p,2}$	$W_{c,1}$, $W_{c,2}$

decoded by its intended user and treated as noise by the other user

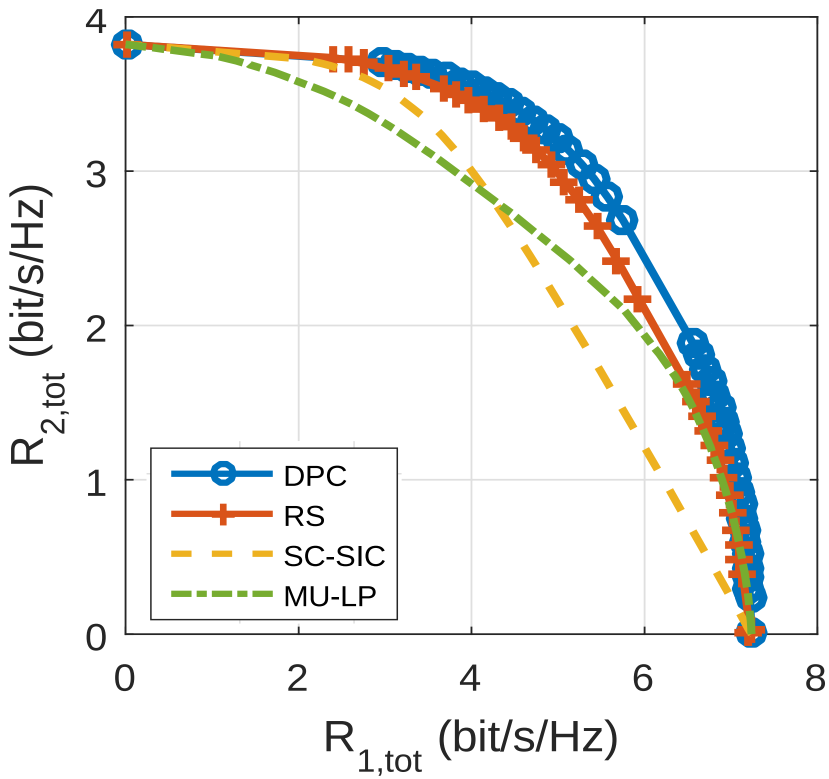
decoded by both users

RS is a more general framework: RS ⊃ SDMA/OMA/NOMA/Multicast

Spectral Efficiency: Rate Region – perfect CSI

Optimization results with perfect CSIT: $max \sum_k u_k R_k$

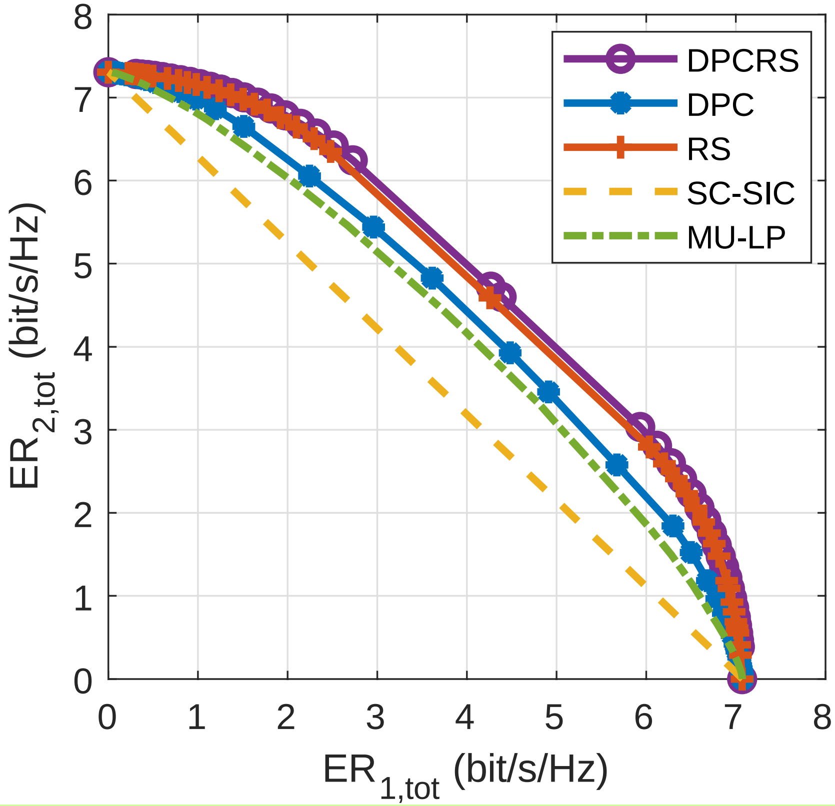
$M = K = 2$, $\mathrm{SNR} = 20$ dB, 10 dB average channel gain difference.



RSMA generalizes and outperforms SC-SIC (NOMA) and MU-LP (SDMA).
RSMA achieves a rate region closer to the capacity region.

Spectral Efficiency: Rate Region – imperfect CSI

Two-user ergodic rate regions with $M = K = 2$, imperfect CSIT ($\alpha = 0.6$), SNR = 20 dB:



$$max \sum_k u_k R_k$$

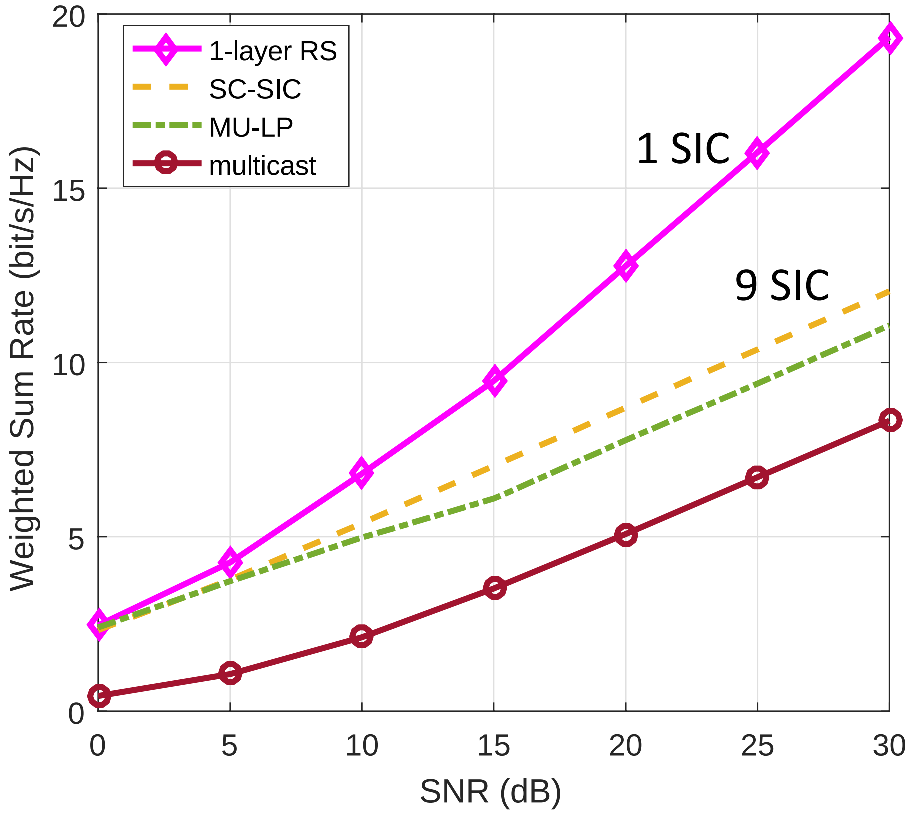
RS schemes outperform conventional NoRS, i.e., SDMA/MU-LP/MU-MIMO, NOMA and DPC!

Spectral Efficiency: QoS constraints

Optimization results: 10-user weighted sum rate with QoS, $M = 2$

$$max \sum_k u_k R_k$$

s.t. $R_k > R_k^{th}, \forall k$



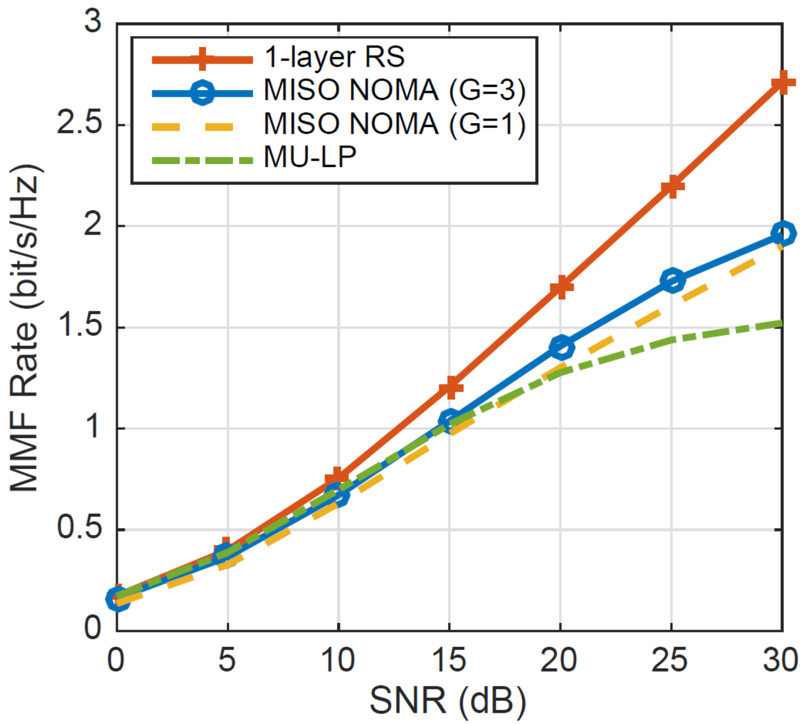
Huge gains with RS (1 SIC layer) vs. NOMA (9 SIC layers!)

Spectral Efficiency: Max-Min Fairness

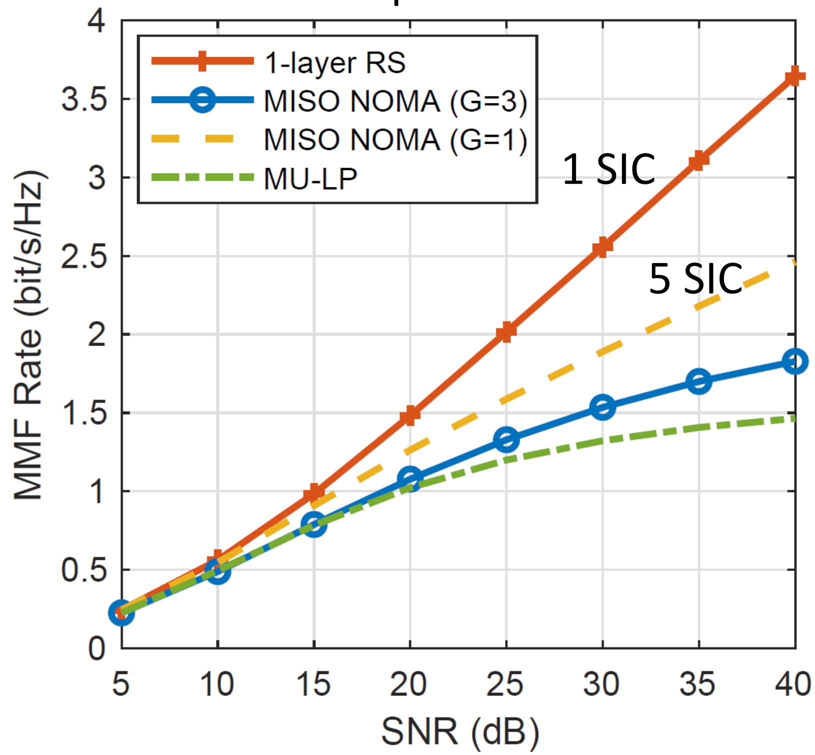
Optimization results: $\max \min R_k$

- $M = 4, K = 6$, SNR $= 20$ dB, 10dB path loss difference.

Perfect CSIT



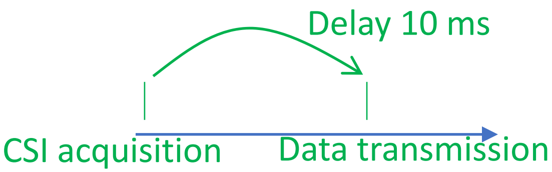
Imperfect CSIT



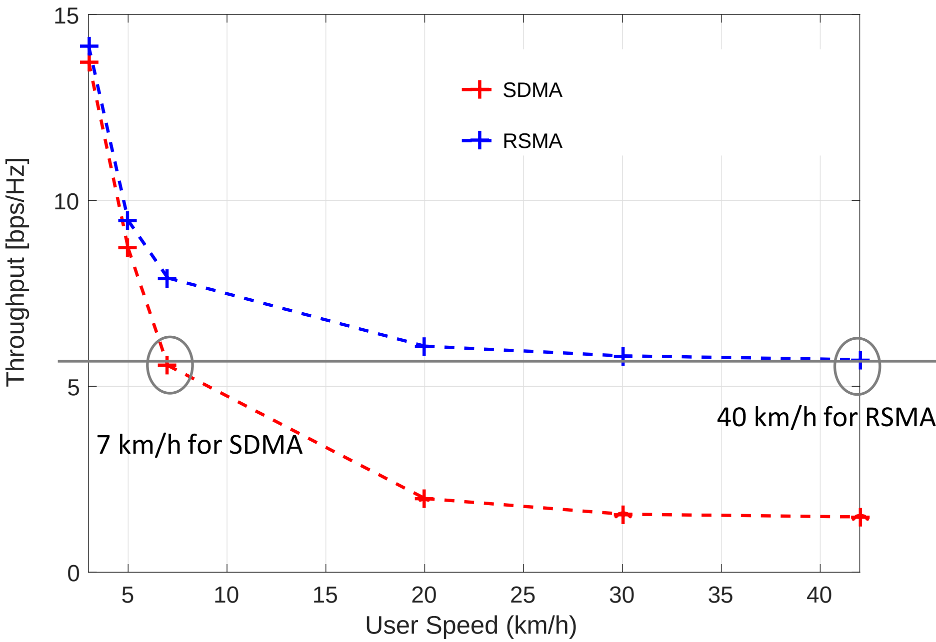
Huge gains with 1-layer RS: rate, fairness and robustness enhancements with only 1 SIC!

Spectral Efficiency: TDD Massive MIMO

Link-level simulation with OFDM waveform and 3GPP channel model ($M = 32, K = 8$, 10ms feedback delay):



$$max \sum_k R_k$$



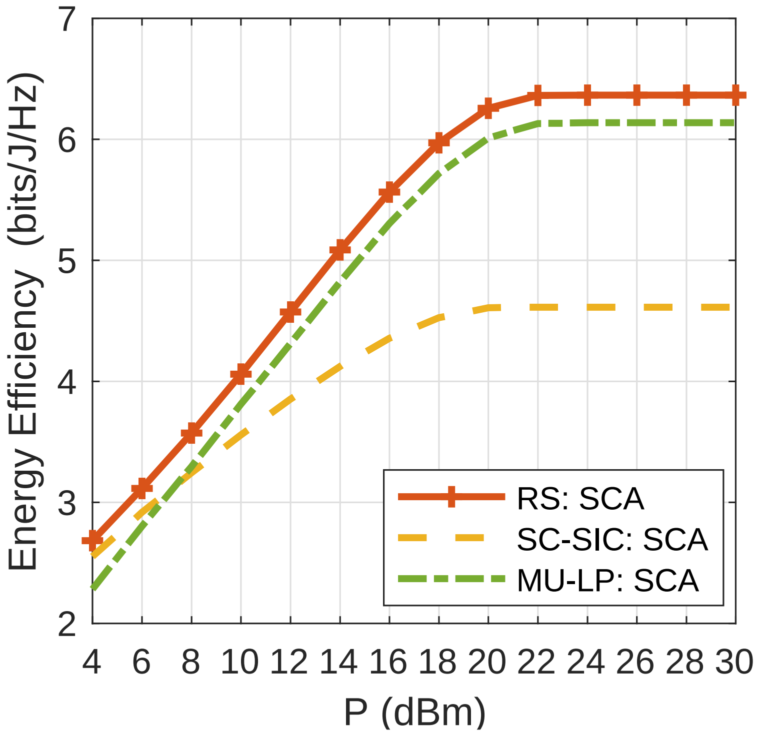
With the same QoS rate constraint, RSMA supports a much higher user speed.

RSMA maintains multiuser connectivity in mobility conditions.

Energy Efficiency

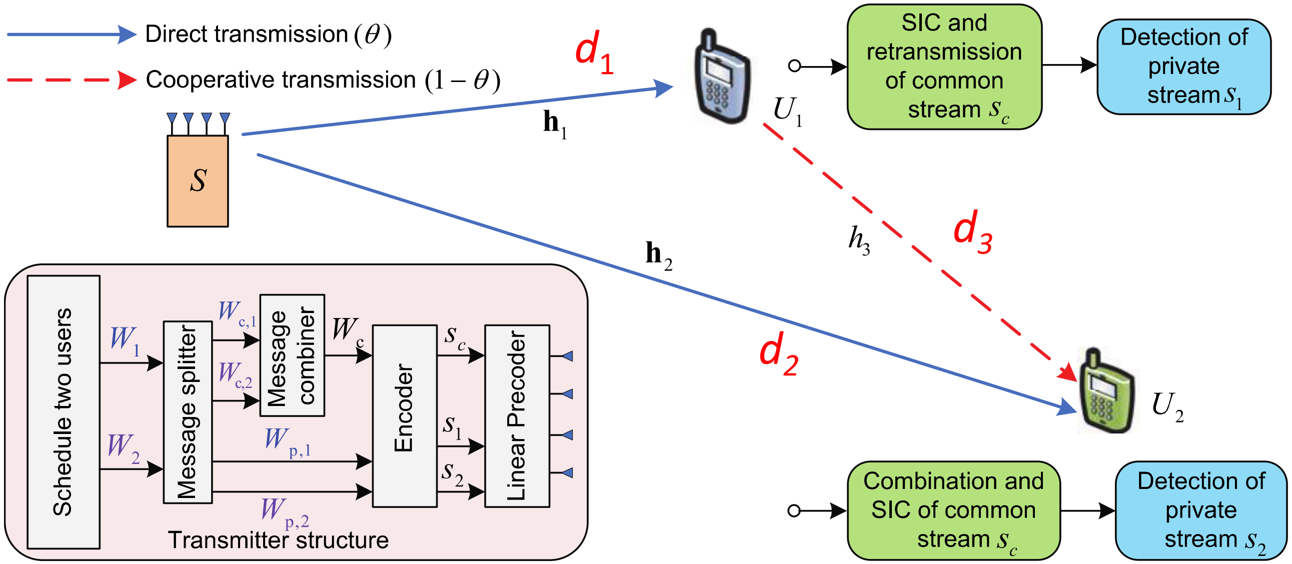
Optimization results: $max \frac{\sum_k R_k}{P + P_c}$

- $M = K = 2, P_c = 33$ dBm, 10 dB average channel gain difference.
- Achievable energy efficiency averaged over 100 random channel realizations:

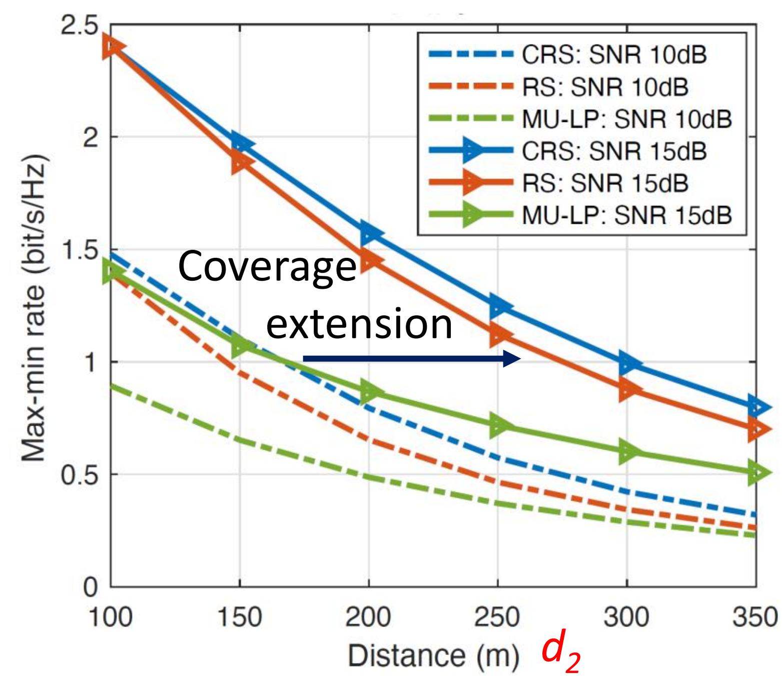


RS schemes offers higher energy efficiency than SDMA and NOMA

Coverage



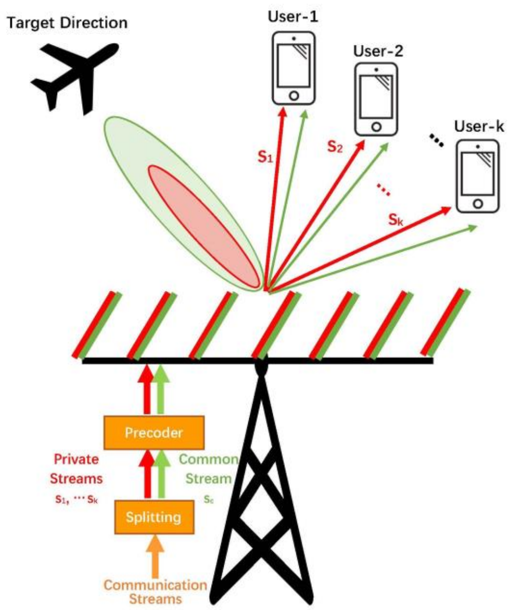
RSMA boosts the coverage compared to MU-LP/SDMA

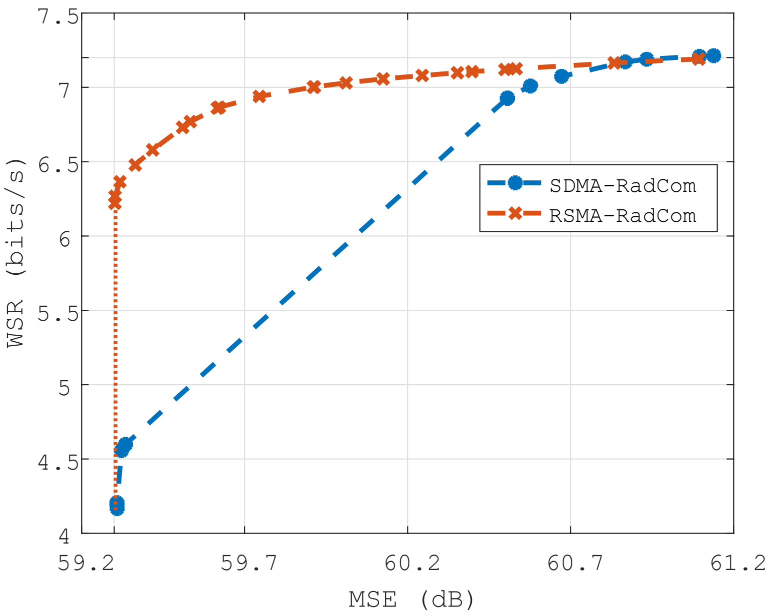


Joint Communication and Radar

How to make the **best use of the spectrum** for the dual purpose of radar and communication?

Find the multiple access strategy that achieves the best trade-off between communication and radar performance.

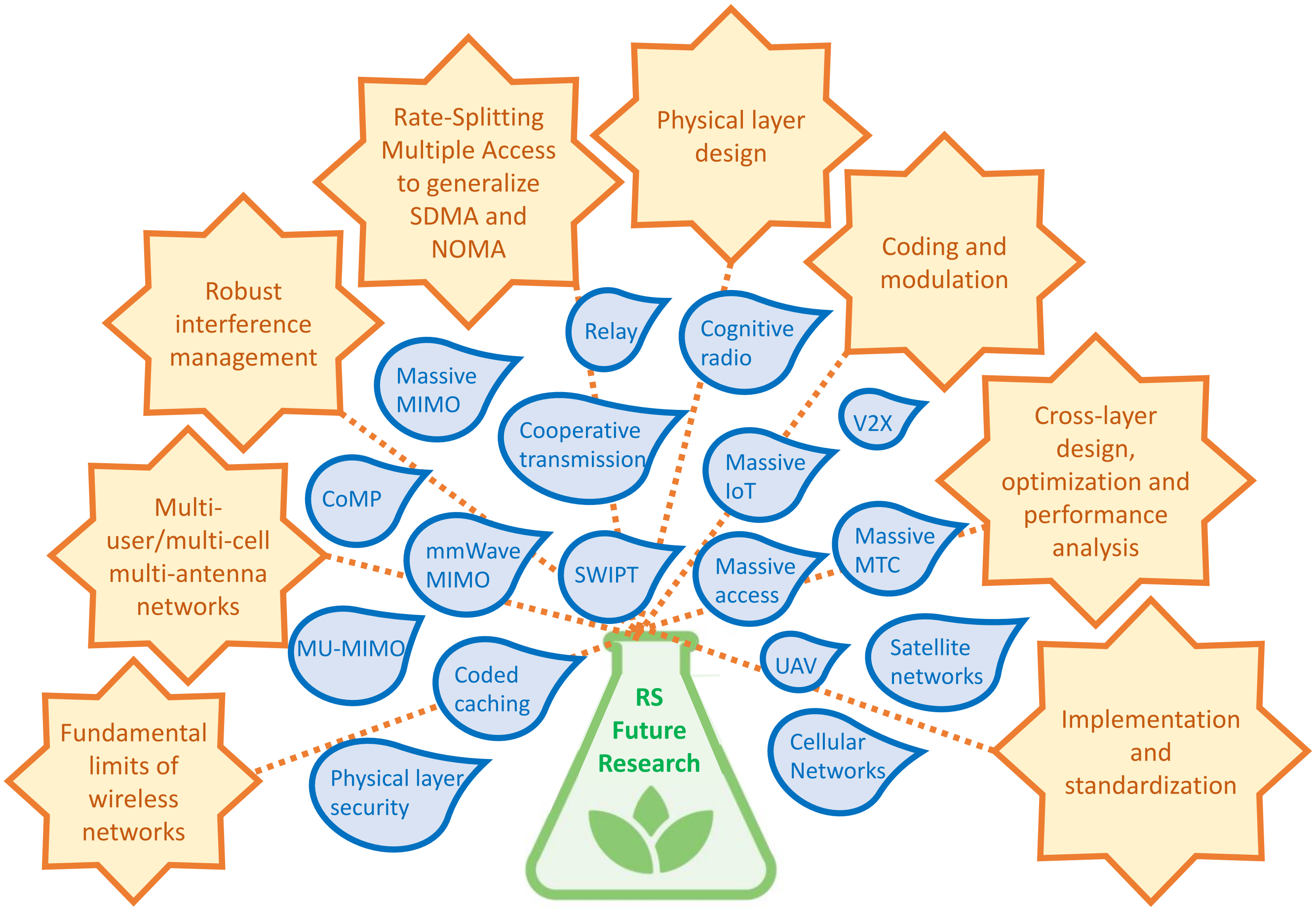




RSMA efficiently manages radar-communication interference and achieves better tradeoff.

Future Challenges

A **gold mine of research problems** for academia and industry:

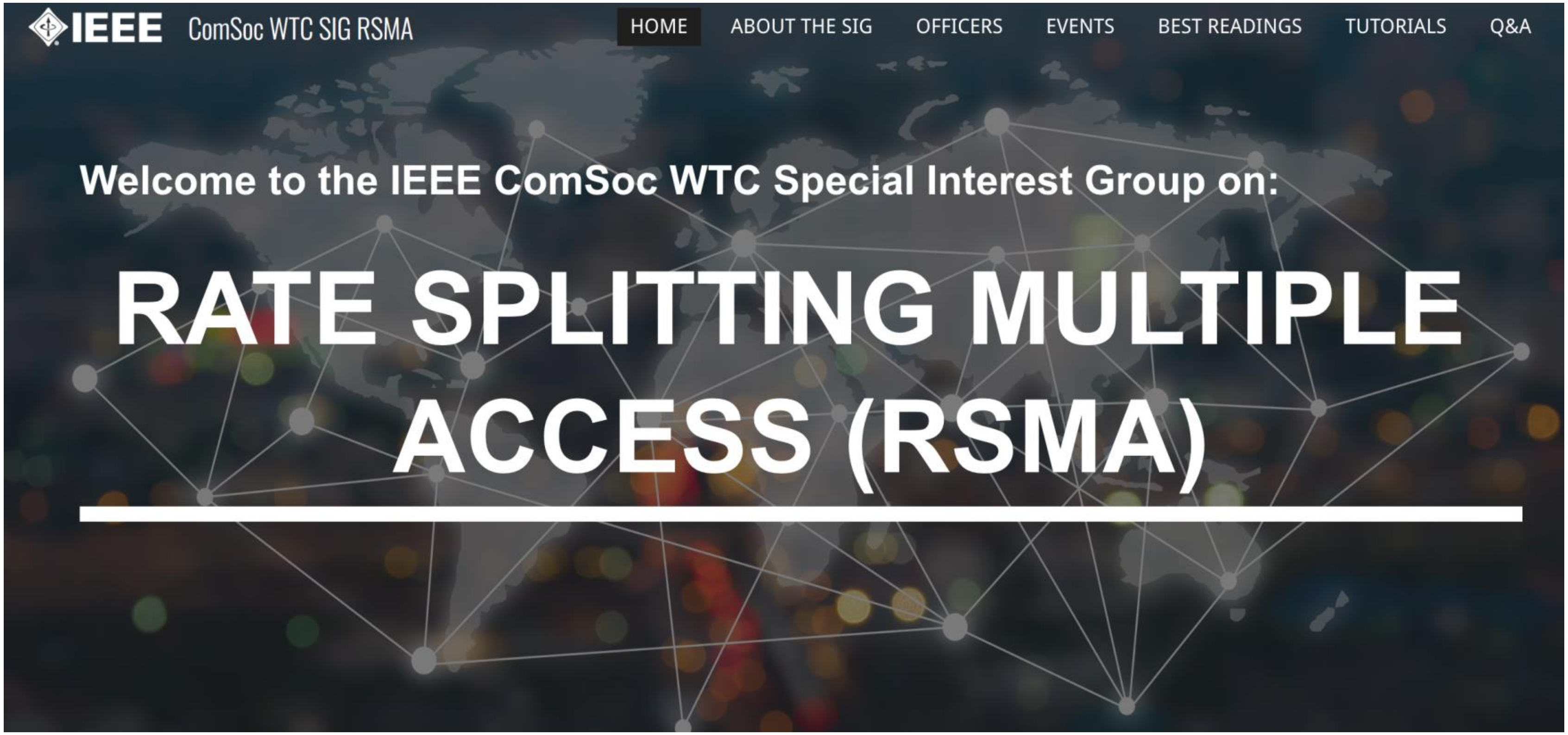


Conclusions

General Observations of RSMA:

- Partially decode interference, partially treat interference as noise
- Robust interference management strategy
- Flexible non-orthogonal transmission strategy
- General and unified multiple access
- Significant performance benefits
  - SE, EE, coverage, QoS, fairness, robustness, feedback overhead reduction, complexity reduction, lower latency
- Numerous applications: eMBB, URLLC, mMTC, and new services
  - joint sensing/radar and communications, integrated cellular and satellite communications

IEEE ComSoc Special Interest Group on RSMA



Link: https://sites.google.com/view/ieee-comsoc-wtc-sig-rsma/home