RIS-assisted NOMA communication under Phase and SIC Imperfections

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Outline

1. Introduction and Motivation
2. NOMA with imperfect SIC
3. Generalization, Fairness, UL/DL, Use case
4. RIS-Assisted NOMA with IPC
5. About Us

Introduction

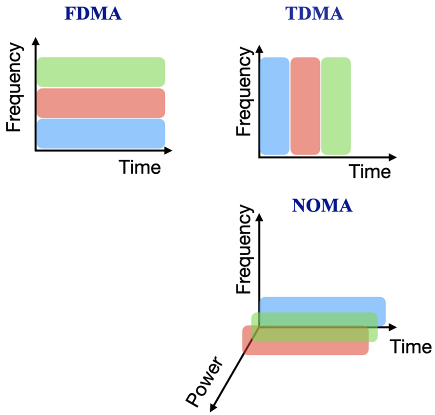


Figure: Evolution towards Non-Orthogonal Multiple Access (NOMA).

Introduction

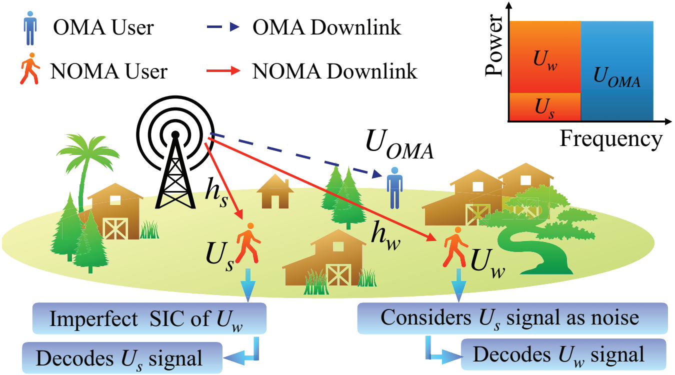


Figure: Illustration of a hybrid OMA-NOMA system.

Introduction

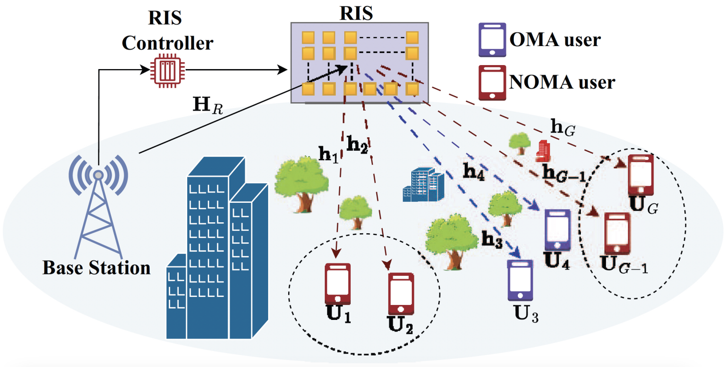


Figure: Reconfigurable Intelligent Surfaces (RIS) and NOMA.

Introduction

- Issue 1: Imperfect SIC can deteriorate NOMA performance
- Issue 2: IPC degrades the RIS performance
- Concerns: Below OMA performance, Fairness?
- Observation: Existing user clustering, power allocation schemes exhibit poor performance with imperfect SIC and IPC
- Solution: Enhanced user clustering & power allocation

Motivation

- Bound performance of NOMA with imperfect SIC and IPC
- Utilise these bounds to enhance NOMA user pairing
- Ensure greater than equal to OMA performance
- Generalise for larger number of users in a NOMA cluster
- Attain fairness among paired NOMA user

OMA rates

- Downlink OMA SINR for user u on a subchannel is

$$\gamma_u^O = P_b \frac{|h_u|^2}{N_0 + I_u}.$$

- Corresponding normalized downlink rate can be expressed as

$$R_u^O = \frac{1}{2}\log_2\left(1 + \gamma_u^O\right).$$

- Consider NOMA users U_s & U_w with $|h_s|^2 > |h_w|^2$.
- Let δ_s and $(1 - \delta_s)$ be fractions of power to U_s & U_w.

NOMA rates

- Corresponding NOMA SINRs are

$$\gamma_s^N = \frac{\delta_s P_b |h_s|^2}{N_0 + I_s + \beta(1-\delta_s) P_b |h_s|^2} \text{ and } \gamma_w^N = \frac{(1-\delta_s) P_b |h_w|^2}{N_0 + I_w + \delta_s P_b |h_w|^2},$$

- Equivalently written as

$$\gamma_s^N = \frac{\delta_s \gamma_s^O}{1 + \beta(1-\delta_s)\gamma_s^O} \text{ and } \gamma_w^N = \frac{(1-\delta_s)\gamma_w^O}{1 + \delta_s \gamma_w^O},$$

- The respective NOMA normalized downlink rates are

$$R_s^N = \log_2\left(1 + \gamma_s^N\right) \text{ and } R_w^N = \log_2\left(1 + \gamma_w^N\right),$$

Derived Bounds

- To obtain an upper bound on δ_s, we consider

$$R_w^N > R_w^O$$

$$\log_2\left(1+\frac{(1-\delta_s)\gamma_w^O}{1+\delta_s\gamma_w^O}\right) > \frac{1}{2}\log_2\left(1+\gamma_w^O\right)$$

$$\delta_s < \frac{1}{\gamma_w^O}\left(\sqrt{1+\gamma_w^O}-1\right) \triangleq \delta_s^{UB}\,.$$

- Similarly, we impose a constraint on the strong user rate,

$$\log_2\left(1+\frac{\delta_s\gamma_s^O}{1+\beta(1-\delta_s)\gamma_s^O}\right) > \frac{1}{2}\log_2\left(1+\gamma_s^O\right)$$

$$\delta_s > \frac{(1+\beta\gamma_s^O)(\sqrt{1+\gamma_s^O}-1)}{\gamma_s^O(1+\beta\sqrt{1+\gamma_s^O}-\beta)}\,.$$

Derived Bounds

- Let Average Sum Rate (ASR) for OMA and NOMA be respectively defined as

$$ASR^O = R_s^O + R_w^O \text{ and } ASR^N = R_s^N + R_w^N,$$

- We solve $ASR^N > ASR^O$ to obtain

$$\beta < \frac{(1+\delta_s\gamma_s^O)\sqrt{1+\gamma_w^O} - (1+\delta_s\gamma_w^O)\sqrt{1+\gamma_s^O}}{\gamma_s^O(1-\delta_s)(\sqrt{1+\gamma_s^O}(1+\delta_s\gamma_w^O) - \sqrt{1+\gamma_w^O})}$$

Substituting upper bound of δ_s, we get

$$\beta < \frac{\gamma_w^O - \gamma_s^O + \gamma_s^O\sqrt{1+\gamma_w^O} - \gamma_w^O\sqrt{1+\gamma_s^O}}{\gamma_s^O(\sqrt{1+\gamma_s^O} - 1)(\gamma_w^O - \sqrt{1+\gamma_w^O} + 1)}$$

Derived Bounds

- Applying positivity constraint on the numerator

$$\delta_s > \frac{1}{\sqrt{1+\gamma_s^O} + \frac{1}{\sqrt{1+\gamma_w^O}}} \triangleq \delta_s^{LB}$$

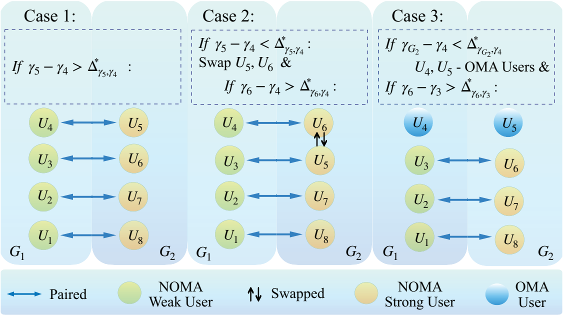
- The upper bound of δ_s should be always greater than its lower bound

$$\gamma_w^O < \frac{(\sqrt{1+\gamma_w^O}-1)(\sqrt{1+\gamma_s^O}\sqrt{1+\gamma_w^O}+1)}{\sqrt{1+\gamma_w^O}}.$$

- Subtracting γ_w^O from both sides

$$\Delta^{MSD}_{\gamma_s^O,\gamma_w^O} = \gamma_s^O - \frac{(\sqrt{1+\gamma_w^O}-1)(\sqrt{1+\gamma_s^O}\sqrt{1+\gamma_w^O}+1)}{\sqrt{1+\gamma_w^O}},$$

Proposed Adaptive User Pairing (AUP) Algorithm



[1] N. S. Mouni, A. Kumar and P. K. Upadhyay, "Adaptive User Pairing for NOMA Systems With Imperfect SIC," *IEEE Wireless Communications Letters*, vol. 10, no. 7, pp. 1547–1551, July 2021, doi: 10.1109/LWC.2021.3074036.

Proposed Adaptive User Pairing (AUP) Algorithm

Algorithm 1 AUP Algorithm

INPUTS : G_1, G_2, P_t, N_o

VARIABLES : $k1$ and $k2$ are variables representing user indices in groups G_1 and G_2, respectively. i and j are intermediary variables, used to keep track of user indices paired.

1. Initialize the variables: $i = 1,\ j = 0$
2. **for** ($k1 = N/2; k1 > 0; k1 - -$)
3.   **for** ($k2 = N/2 + 1 + j; k2 \leq N; k2 + +$)
4.   Select γ_{k1} from G_1 and γ_{k2} from G_2
5.   **if** ($\gamma_{k2} - \gamma_{k1} > \Delta_{\mathrm{DL}}^{\mathrm{MSD}}$)
6. U_{k1}, U_{k2} will be paired;
7.   **if** ($k1 + k2\ != N + 1$)
8.   Swap U_{k2} and $U_{N/2+1+j}$
9.   Sort users after $U_{N/2+1+j}$ in ascending order
10. $j = j + 1, i = i + 1$, Break;
11.   **if** ($k2 == N$)
12. $k2 = N/2 + i, j = i, i = i + 1$;
13. U_{k1}, U_{k2} will be OMA users, Break;
14.   **end**
15. **end**

Proposed Adaptive User Pairing (AUP) Algorithm

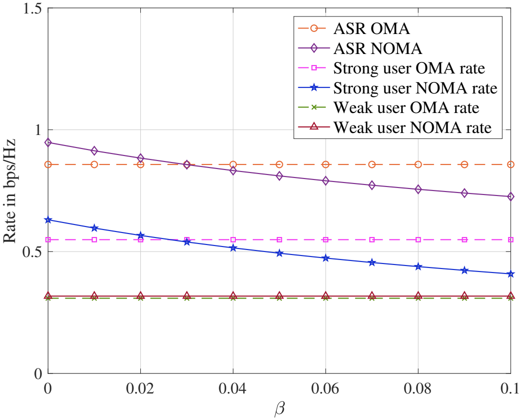


Figure: Variation w.r.t. β for a fixed value of $\delta_s = 0.23$ with LR model.

Proposed Adaptive User Pairing (AUP) Algorithm

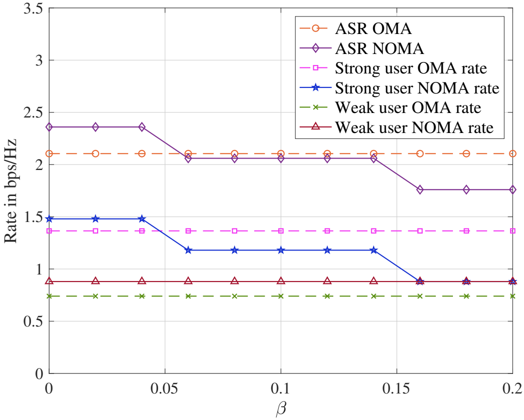


Figure: Variation w.r.t. β for a fixed value of $\delta_s = 0.23$ with DR model.

Proposed Adaptive User Pairing (AUP) Algorithm

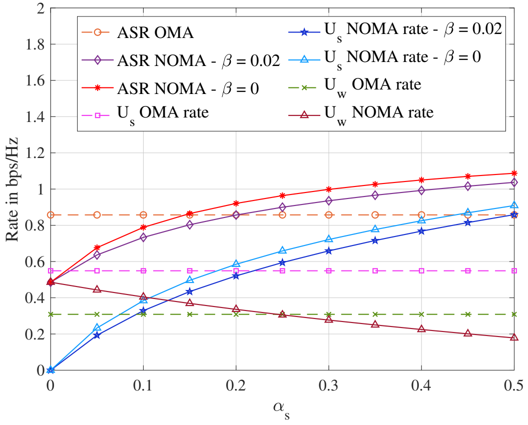


Figure: Variation w.r.t. δ_s for a fixed value of $\beta = 0.02$ with LR model.

Proposed Adaptive User Pairing (AUP) Algorithm

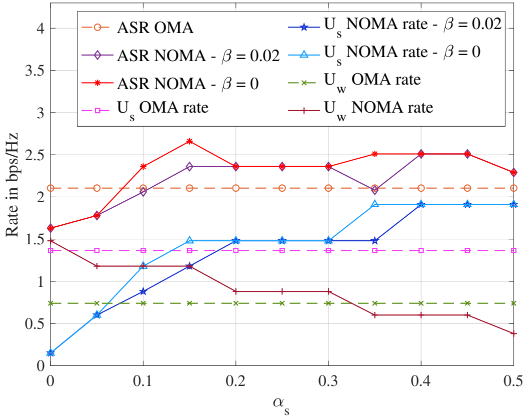


Figure: Variation w.r.t. δ_s for a fixed value of $\beta = 0.02$ with DR model.

Proposed Adaptive User Pairing (AUP) Algorithm

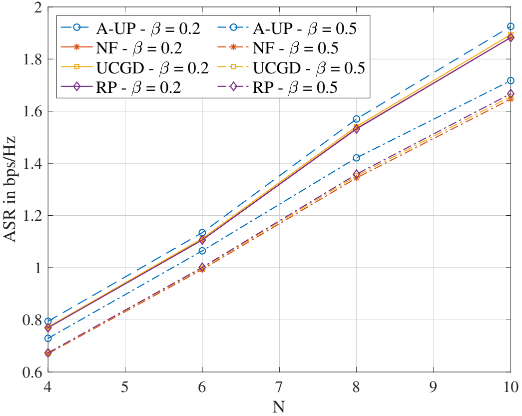
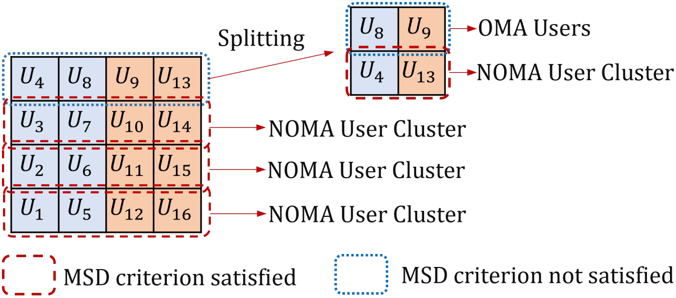


Figure: Comparative ASR performance between AUP, NF, RP and UCGD given N = [4, 6, 8, 10] and β = [0.2, 0.5].

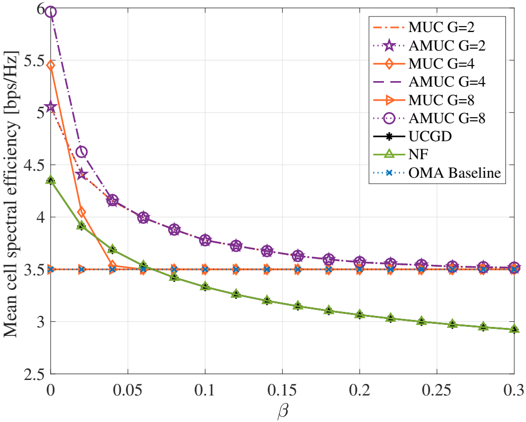
Generalisation to N users



[2] Dr. Abhinav Kumar, N Siva Mouni, Pavan Reddy, "A method for adaptive multi-user clustering in Non-Orthogonal Multiple Access systems with Imperfect," 202241018280, published in 2023.

[3] N. S. Mouni, P. R. Manne, A. Kumar, P. K. Upadhyay and M. Magarini, "Adaptive Multi-User Clustering and Power Allocation for Hybrid OMA-NOMA System with Imperfect SIC," in *Proc. COMSNETS*, Bengaluru, India, 2024, pp. 747–751.

Generalisation to N users



[3] N. S. Mouni, P. R. Manne, A. Kumar, P. K. Upadhyay and M. Magarini, "Adaptive Multi-User Clustering and Power Allocation for Hybrid OMA-NOMA System with Imperfect SIC," in *Proc. COMSNETS*, Bengaluru, India, 2024, pp. 747–751.

Fairness

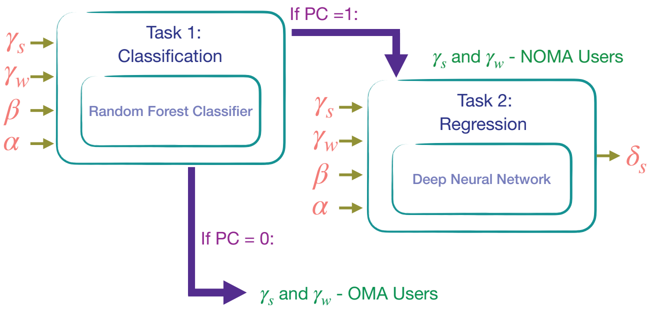
The utility function for an α-Fair scheduler, given a user with rate x is expressed as

$$U_\alpha = \begin{cases} \frac{x^{1-\alpha}}{1-\alpha} & \text{if } \alpha > 0, \alpha \neq 1, \\ \log(x) & \text{if } \alpha = 1. \end{cases}$$

$$T_\alpha = \begin{cases} \left(\frac{1}{2}((R_s^N)^{1-\alpha} + (R_w^N)^{1-\alpha})\right)^{\left(\frac{1}{1-\alpha}\right)} & \\ & \text{if } \alpha > 0, \alpha \neq 1, \\ (R_s^N R_w^N)^{\frac{1}{2}} & \text{if } \alpha = 1. \end{cases} \quad (1)$$

[4] N. S. Mouni, P. M. Reddy, A. Kumar and P. K. Upadhyay, "α-Fairness based User Pairing for Downlink NOMA Systems with Imperfect SIC," in *Proc. IEEE GLOBECOM*, Rio de Janeiro, Brazil, 2022, pp. 1679-1684.

A Machine Learning based approach to Resource Allocation



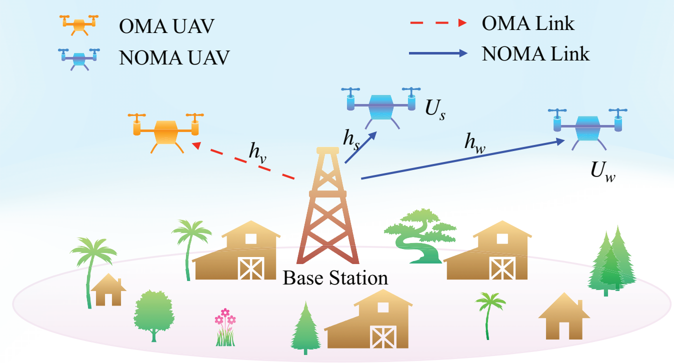
[5] N. S. Mouni, M. P. Reddy, A. Kumar and P. K. Upadhyay, "DNN based Adaptive User Pairing and Power Allocation to achieve α-Fairness in NOMA Systems with Imperfections in SIC," in *Proc. AIMLSystems '22*, ACM, New York, NY, USA, Article 17, 1–5.

Enhanced User Pairing and Power Allocation for UL/DL

Strategy	Uplink NOMA			Downlink NOMA		
	Pairing Criterion	δ_s^{DL}	δ_w^{DL}	Pairing Criterion	δ_s^{DL}	δ_w^{DL}
Biased	$\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{UL}}^{\text{BAUP}}$	1	1	$\beta < \beta^*$, & $\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{DL}}^{\text{MSD}}$	1	0
Fair	$\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{UL}}^{\text{FAUP}}$	1	1	$\beta < \beta^*$, & $\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{DL}}^{\text{MSD}}$	$\alpha_s^* + \phi/2$	$\alpha_w^* + \phi/2$
Greedy	$\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{UL}}^{\text{FAUP}}$, $\beta < \beta^*_{\text{UL,G}}$	1	$\alpha_s^{\text{G,UL}}$	$\beta < \beta^*$, & $\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{DL}}^{\text{MSD}}$	$\alpha_s^* + \phi$	α_w^*
Max-min	$\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{UL}}^{\text{FAUP}}$, $\beta < \beta^*_{\text{UL,M}}$	$\alpha_s^{\text{M,UL}}$	1	$\beta < \beta^*$, & $\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{DL}}^{\text{MSD}}$	α_s^*	$\alpha_w^* + \phi$
Sub-optimal	$\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{UL}}^{\text{FAUP}}$	$\alpha_s^{\text{SO,UL}}$	$\alpha_w^{\text{SO,UL}}$	$\beta < \beta^*$, & $\gamma_s^{\text{O,UL}} - \gamma_w^{\text{O,UL}} \geq \Delta_{\text{DL}}^{\text{MSD}}$	$\alpha_s^{\text{SO,DL}}$	$\alpha_w^{\text{SO,DL}}$

[6] N. S. Mouni, M. P. Reddy, A. Kumar and P. K. Upadhyay, "Enhanced User Pairing and Power Allocation Strategies for Downlink NOMA Systems with Imperfections in SIC," in *Proc. COMSNETS*, Bangalore, India, 2023, pp. 457-461. *Won Best Poster Award

Application to UAV communication



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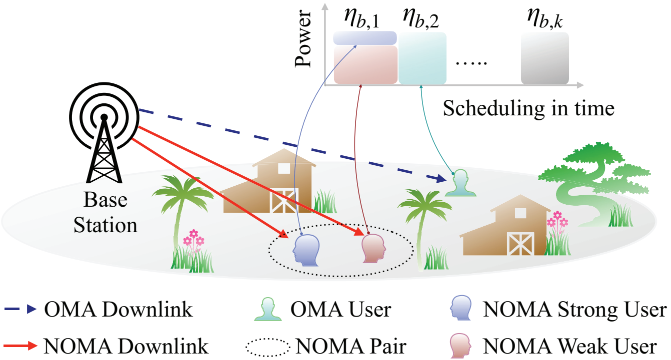
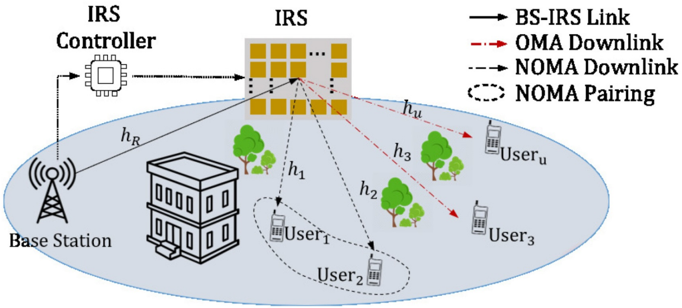
Optimizing time based scheduling for hybrid OMA-NOMA



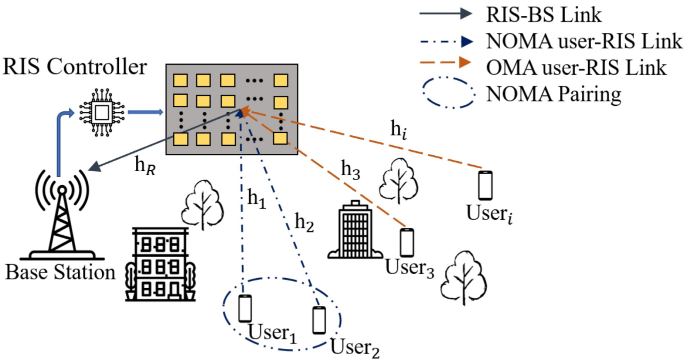
[8] N. S. Mouni, P. Agarwal, Y. Ramamoorthi and A. Kumar, "Optimizing Time Scheduling for Hybrid OMA-NOMA Systems under Imperfect SIC: An α-fair Utility Approach," in *Proc. IEEE VTC 2024.*

User Pairing for RIS-Assisted Donwlink NOMA with IPC



[9] P. Reddy M and A. Kumar, "User Pairing and Power Allocation for IRS-Assisted NOMA Systems with Imperfect Phase Compensation," *IEEE Wireless Communications Letters*, vol. 11, no. 12, pp. 2492–2496, Dec. 2022.

User Pairing for RIS-Assisted Uplink NOMA with IPC



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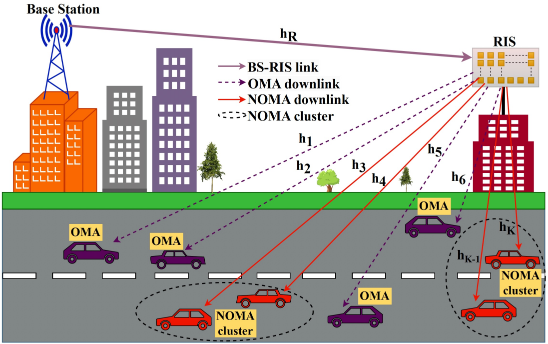
RIS-Assisted NOMA V2X Systems with IPC



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Other Contributions in NOMA and SIC

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- T. Uday, A. Kumar, and L. Natarajan, "NOMA for Multiple Access Channel and Broadcast Channel in Indoor VLC," *IEEE Wireless Communications Letters*, vol. 10, no. 3, pp. 609-613, March 2021.
- A. K. Shukla, V. Singh, P. K. Upadhyay, A. Kumar, and J. M. Moualeu, "Performance Analysis of Energy Harvesting-Assisted Overlay Cognitive NOMA Systems with Incremental Relaying," *IEEE Open Journal of the Communications Society*, vol. 2, pp. 1558-1576, 2021.
- Y. S. Reddy, A. Dubey, A. Kumar, and T. Panigrahi, "A Probabilistic Approach to Model SIC based RACH mechanism for Machine Type Communications in Cellular Networks," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 2, pp. 1878-1893, Feb. 2021.
- Y. S. Reddy, A. Dubey, A. Kumar, and T. Panigrahi, "A Successive Interference Cancellation based Random Access Channel Mechanism for Machine-to-Machine Communications in Cellular Internet-of-Things," *IEEE Access*, vol. 9, pp. 8367-8380, 2021.

Ongoing works in our Lab.

- NOMA and RIS with imperfect phase and SIC
- OTFS and ISAC
- ML/DL and Communications
- Domain Adaptation and Domain Generalization
- Industry partners: SMC Japan, NTT Japan, ZF India

About IITH

- 17 year old with 330+ faculty, 5500 students (60%+ PG)
- 4 incubation centers, 260+ startups (1.5 billion INR revenue)
- 28 CoEs with 1.35 billion INR research funding
- 5G Testbed
- TiHAN Testbed
- Bachelor in AI and Bachelor in IC Design and Technology.

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