Resource Allocation for Non-Orthogonal Multiple Access with and without Joint Transmission

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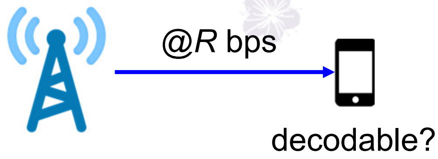
Outline

- Background and preliminary
  - Achievable rate (Shannon capacity)
  - Non-orthogonal multiple access (NOMA)
  - CoMP
- System models
  - The NOMA scenario
  - The JT scenario
- Proposed methods
  - Utility-based power allocation
  - Matching-based user pairing
- Simulation results
- Conclusion

Introduction: Achievable rate

- Retrievable/decodable at any rate?
  - At faster rate
  - At slower rate



Introduction: Achievable rate

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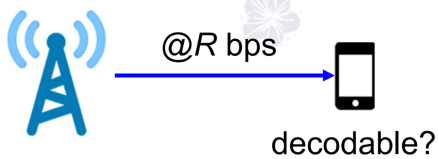
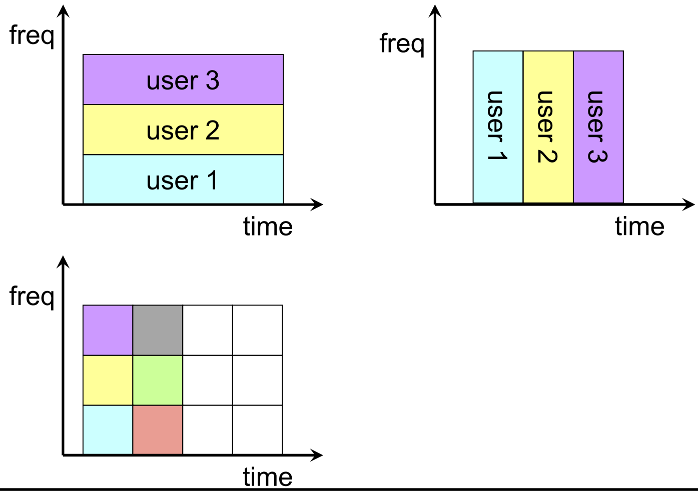


- Shannon-Hartley Theorem

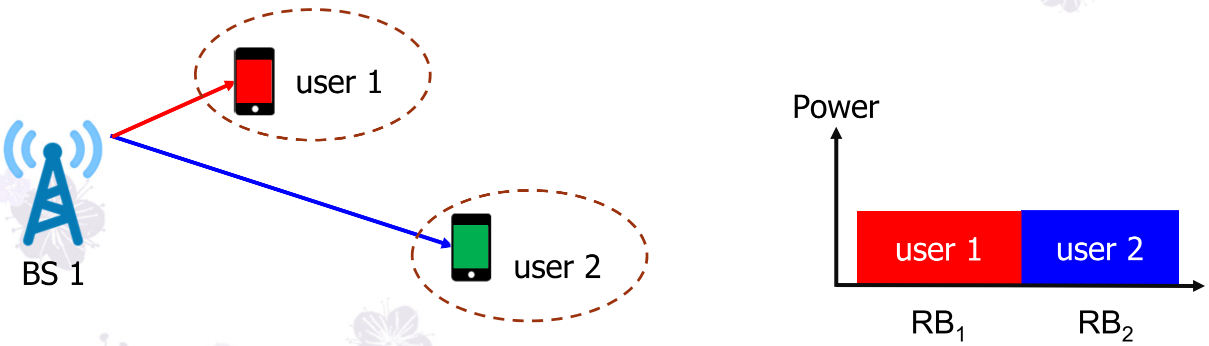
$$R \leq B \cdot \log_2 \left(1 + \frac{S}{I + N} \right)$$

Introduction: Resource block (RB)

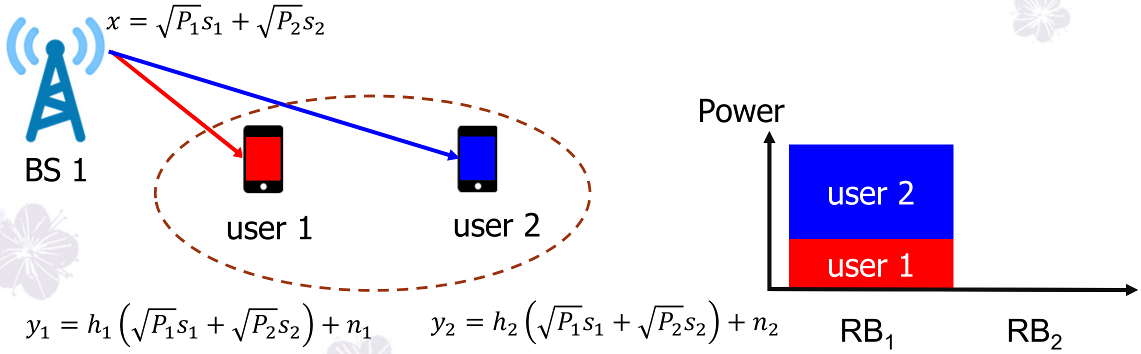
- Radio resource is often partitioned and managed in
  - Frequency domain
    - Sub-bands
  - Time domain
    - Time slots
  - Or both
    - Resource blocks (RBs)



Introduction: Orthogonal Multiple Access (OMA)



Introduction: Non-Orthogonal Multiple Access (NOMA)

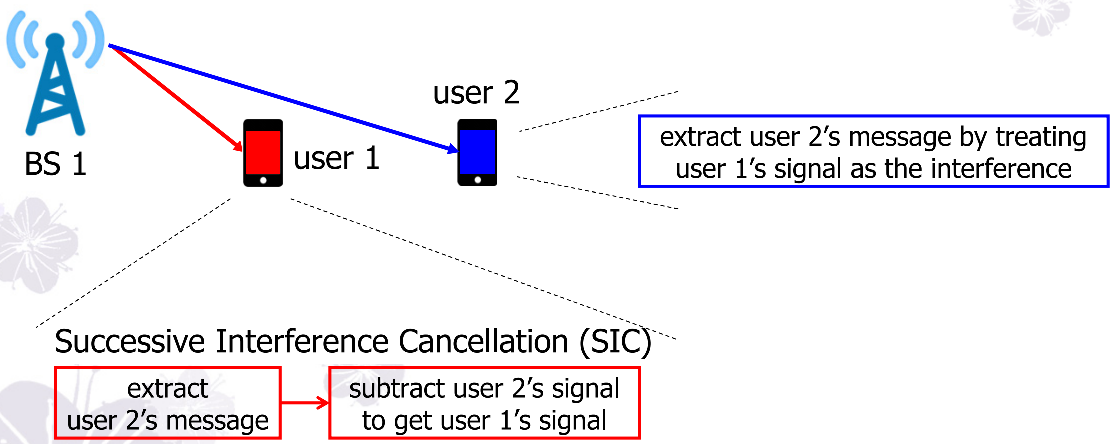


$$x = \sqrt{P_1}s_1 + \sqrt{P_2}s_2$$

$$y_1 = h_1\left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2\right) + n_1 \qquad y_2 = h_2\left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2\right) + n_2$$

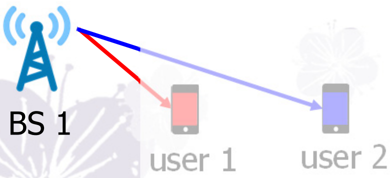
Q: How do you extract user 1's data and user'2 data, respectively?
A: Successive interference cancellation (SIC).

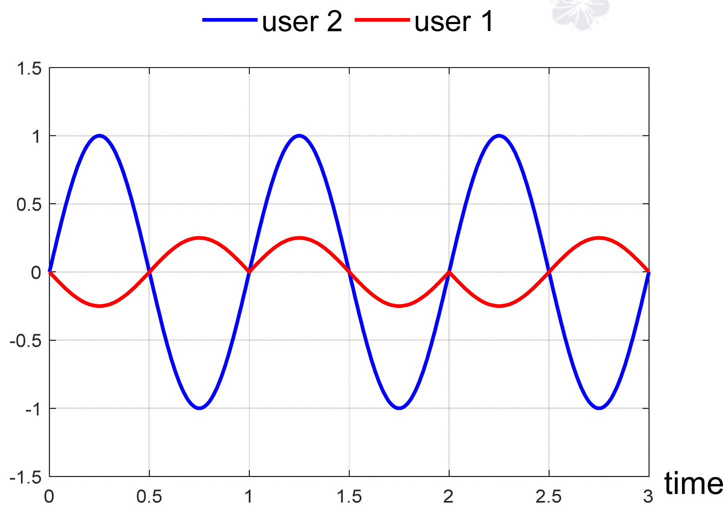
Introduction: Successive Interference Cancellation (SIC)



Introduction: Successive Interference Cancellation (SIC)

- For example,
  - Carrier signal: $\sin 2\pi t$
  - User 2's data: $(000)_2$
  - User 1's data: $(101)_2$
  - Noise is not drawn here!





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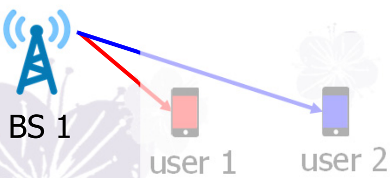

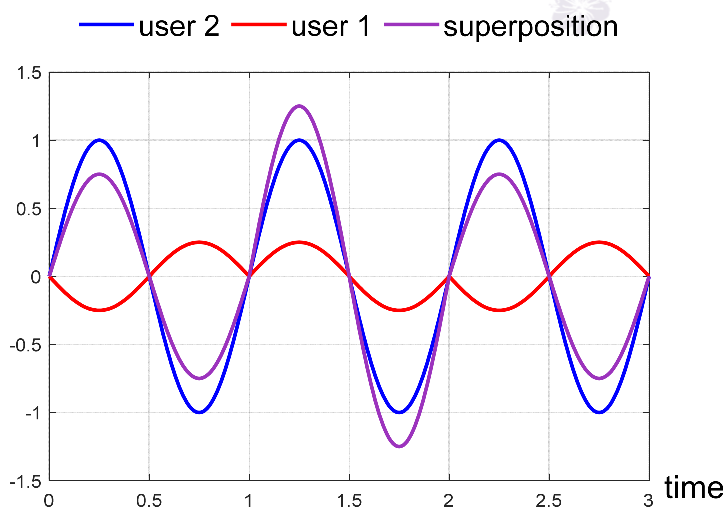

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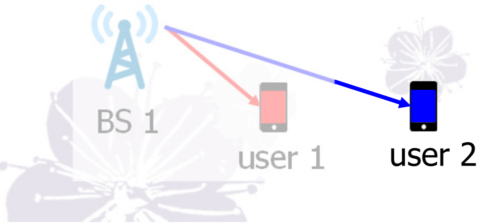

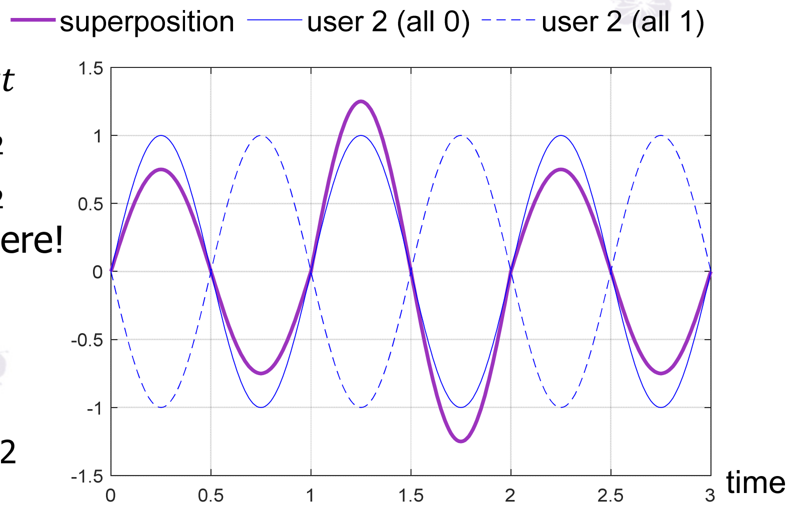

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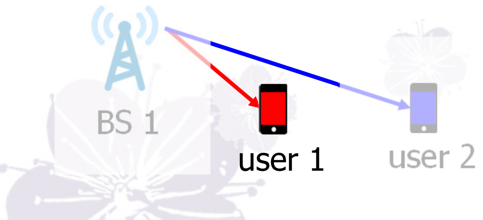

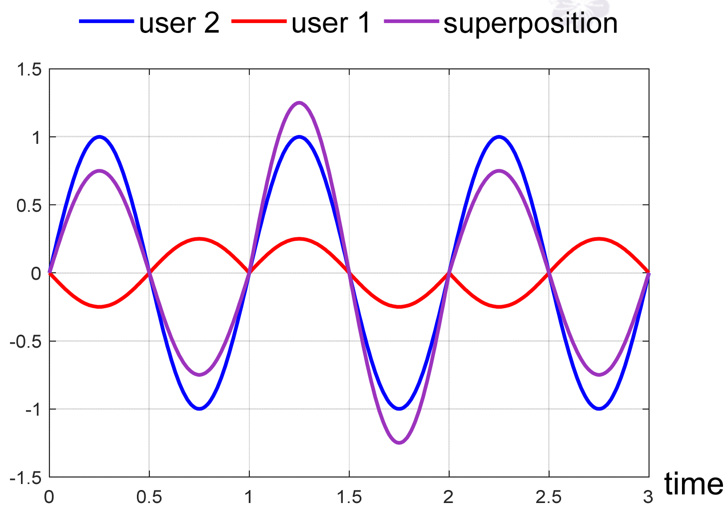

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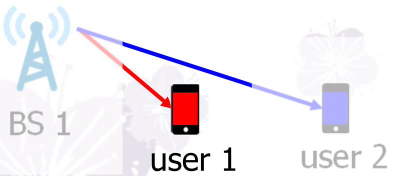
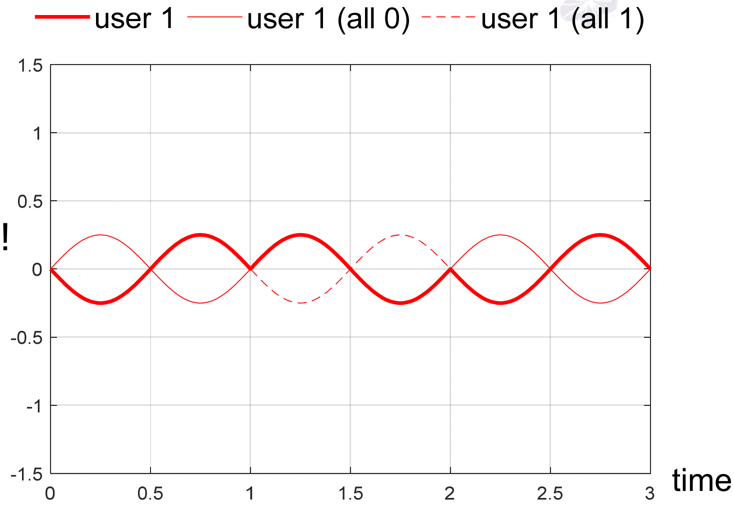
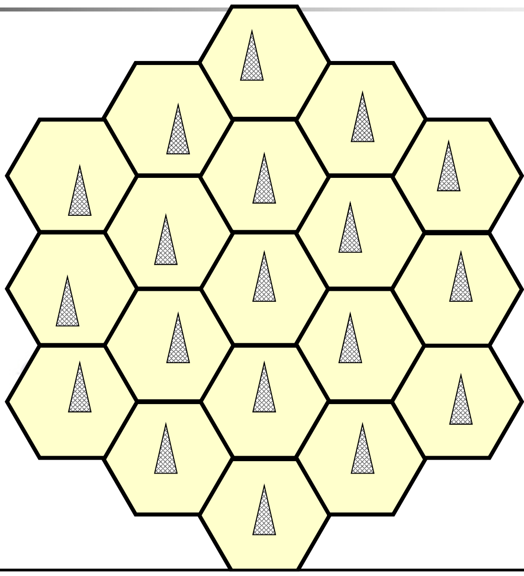




Introduction: Frequency reuse

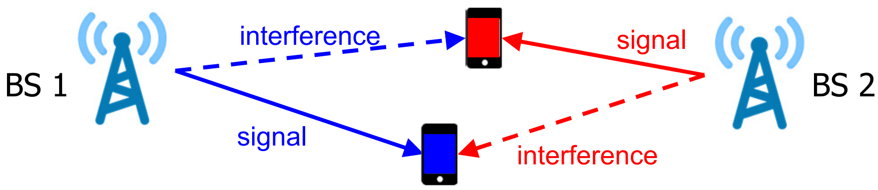
- Take GSM-900 as an example
  - 25MHz bandwidth (downlink)
  - 3.1KHz per call
  - Can only accommodate $25M / 3.1K \approx 8000$ concurrent calls
  - There are more than 9M / 8 active users in peak hours in Taiwan (2014)
  - Internet access typically consumes higher bandwidth than a call
- How can engineers make it possible?

Introduction: Frequency reuse

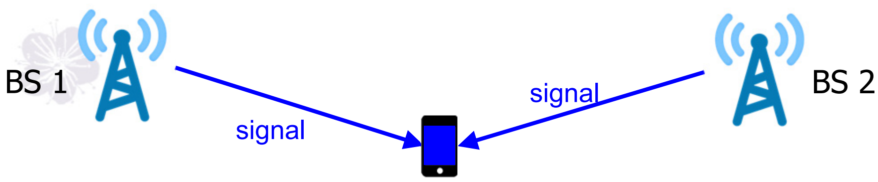


Introduction: CoMP (Coordinated Multipoint)

- Beneficial, especially for users at cell edge, whose signal is weak.
- Without CoMP

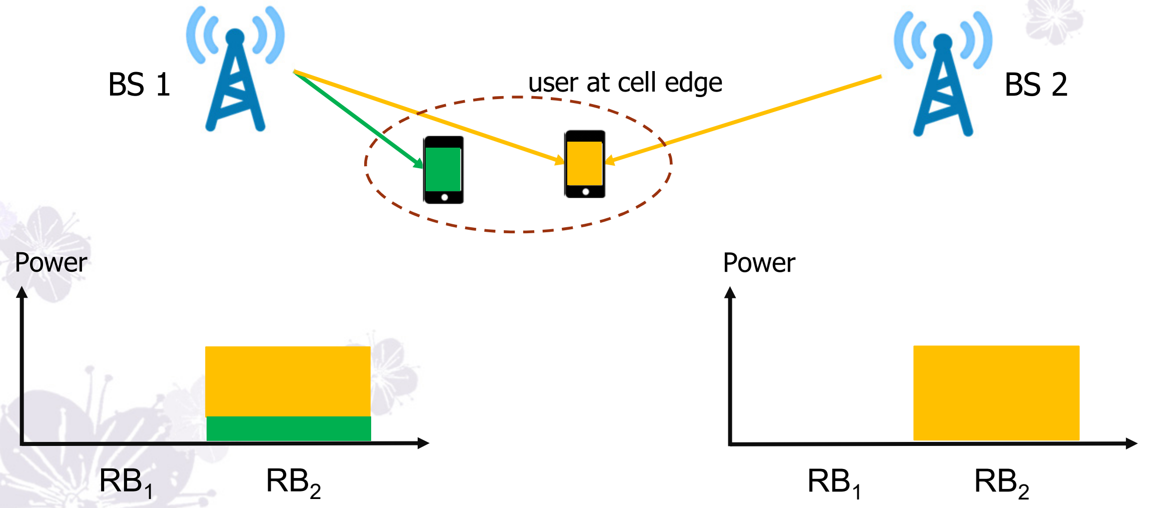


- With JT-CoMP



But spectrum efficiency degrades!

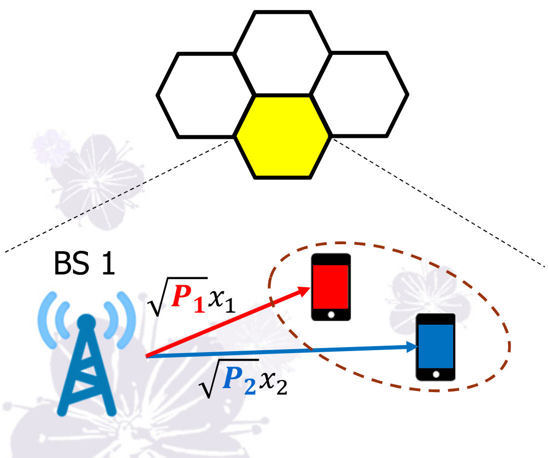
Introduction: NOMA + JT-CoMP

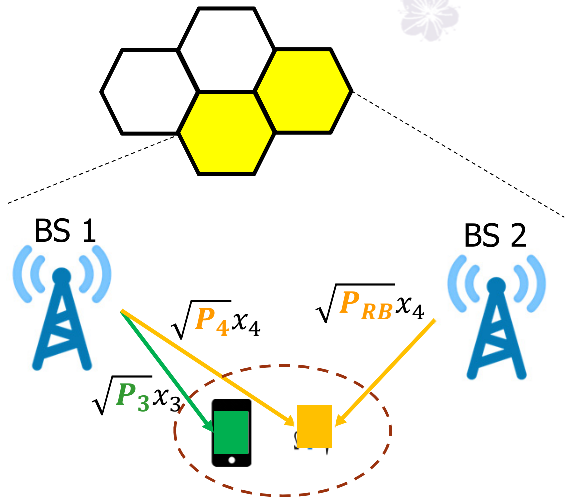


Overview of two scenarios

The JT scenario
(the joint transmission scenario)

The NOMA scenario





Primary and secondary goals

- Primary goal
  - Maximizing the number of users that attain their rate requirements
  - If there exist multiple optimal solutions for the primary goal, then we consider the secondary goal

  We propose an **efficient user pairing** method

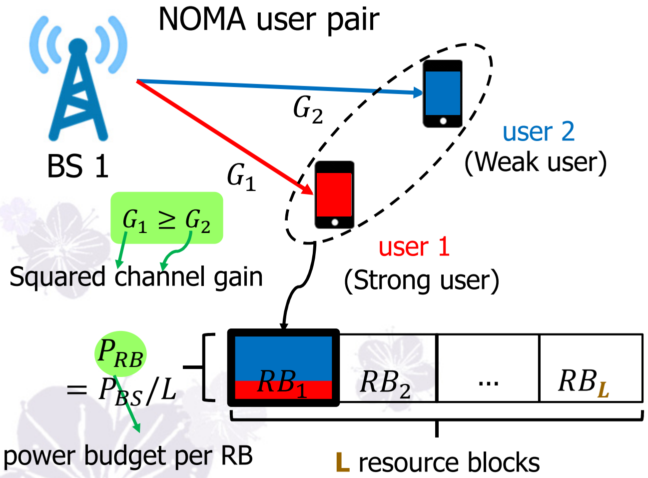
- Secondary goal
  - Maximizing total **utility**

  We devise an **optimal power allocation** method

System Model: The NOMA scenario

Downlink

Multiple users in the cell



The achievable rates:

SINR for user 2

$$R_2 = \log_2\left(1 + \frac{p_2 G_2}{N_2 + p_1 G_2}\right) \quad \because p_1 + p_2 = P_{RB}$$

$$= \log_2\left(1 + \frac{(P_{RB} - p_1) G_2}{N_2 + p_1 G_2}\right)$$

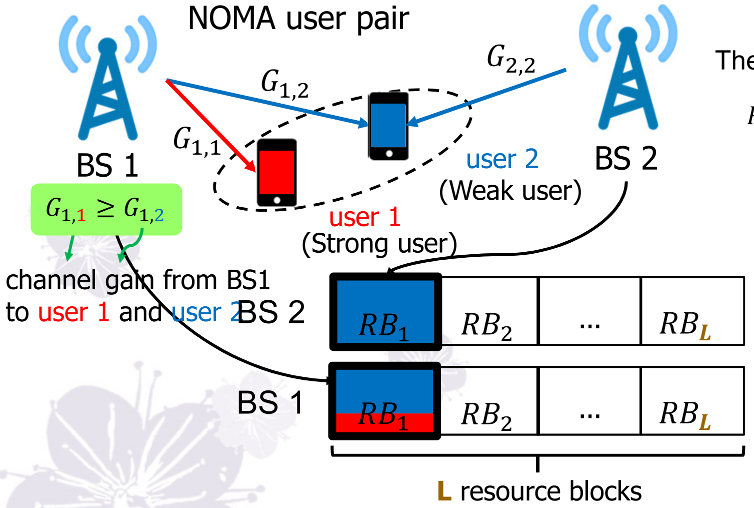
$$R_1 = \log_2\left(1 + \frac{p_1 G_1}{N_1}\right)$$

SINR for user 1 after SIC

System Model: The JT Scenario

Downlink

Multiple users in a cell



The achievable rates:

Transmission power to user 2

SINR for user 2

$$R_2 = \log_2\left(1 + \frac{p_2 G_{1,2} + P_{RB} G_{2,2}}{N_2 + p_1 G_{1,2}}\right)$$

$$= \log_2\left(1 + \frac{(P_{RB} - p_1) G_{1,2} + P_{RB} G_{2,2}}{N_2 + p_1 G_2}\right)$$

$\because p_1 + p_2 = P_{RB}$

$$R_1 = \log_2\left(1 + \frac{p_1 G_{1,1}}{N_1}\right)$$

SINR for user 1 after SIC

System Model: Pairwise utility

- The **pairwise utility** of a NOMA/user pair is defined as a weighted sum of the achievable rates:

$$u = w \cdot R_1 + 1 \cdot R_2$$

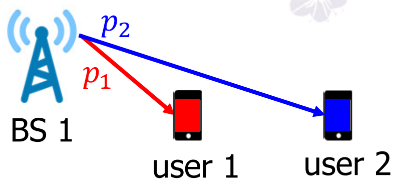
  - where $0 < w < 1$
- Unequal weights are used to
  - Encourage strong users to pair with weak users
  - Take error propagation in SIC into account
- In the NOMA scenario, w is set to $\alpha = e^{-\sigma_1/\sigma_2}$
  - where $\sigma_m = \frac{N_m}{G_m}$ $for\ m \in \{1,2\}$
- In the JT scenario, w is set to $\beta = \frac{\sigma_{2,1}}{\sigma_{2,1} - \sigma_{1,1}} e^{-\frac{\sigma_{1,1}}{\sigma_2^C}}$
  - where $\sigma_{1,1} = \frac{N_1}{G_{1,1}}$, $\sigma_{2,1} = \frac{N_1}{G_{2,1}}$, $\sigma_2^C = \frac{N_2}{G_{1,2} + G_{2,2}}$

System Model: Pairwise utility

- Given a pair of users, the pairwise utility is
  - $u(p_1) = \alpha \log_2\left(1 + \frac{p_1}{\sigma_1}\right) + \log_2\left(1 + \frac{P_{RB} - p_1}{\sigma_2 + p_1}\right)$ in the NOMA scenario
  - $u(p_1) = \beta \log_2\left(1 + \frac{p_1 G_{1,1}}{N_1}\right) + \log_2\left(1 + \frac{(P_{RB} - p_1)G_{1,2} + P_{RB} G_{2,2}}{N_2 + p_1 G_2}\right)$ in the JT scenario
- Given a set of user pairs, the total utility is the sum of their pairwise utilities

System model: Constraints for each (possible) NOMA pair

- Constraints due to power budget
  - $0 \le p_1 \le P_{\mathrm{RB}}$
  - $0 \le p_2 \le P_{\mathrm{RB}}$
  - $0 \le p_1 + p_2 \le P_{\mathrm{RB}}$
- Constraint due to rate requirements
  - $R_1 \ge r_1$
    - Or equivalently, $\frac{p_1}{\sigma_1} \ge \eta_1$
      - where η_1 is the corresponding SINR threshold.
  - $R_2 \ge r_2$
    - Or equivalently, $\frac{p_2}{\sigma_2 + p_1} \ge \eta_2$
      - where η_2 is the corresponding SINR threshold.



Primary and secondary goals

Efficient user pairing method

- Primary goal
  - Maximizing the number of users that attain their rate requirements

Optimal power allocation method

- Secondary goal
  - Maximizing total **utility**

Utility-based power allocation in the NOMA scenario

Allocate p_1 to maximize the utility, $u(p_1) = \alpha \cdot \log_2\left(1 + \frac{p_1}{\sigma_1}\right) + \log_2\left(1 + \frac{P_{RB} - p_1}{\sigma_2 + p_1}\right)$

If p_1 had a **unconstrained domain**:

$$g(p_1) = u(p_1)\ln 2 = \alpha \cdot \ln(1 + \frac{p_1}{\sigma_1}) + \ln(1 + \frac{P_{RB} - p_1}{\sigma_2 + p_1})$$

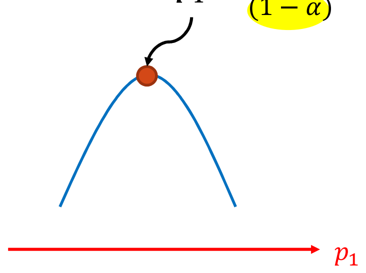
Constant value

maximizes g is equivalent to maximizes u

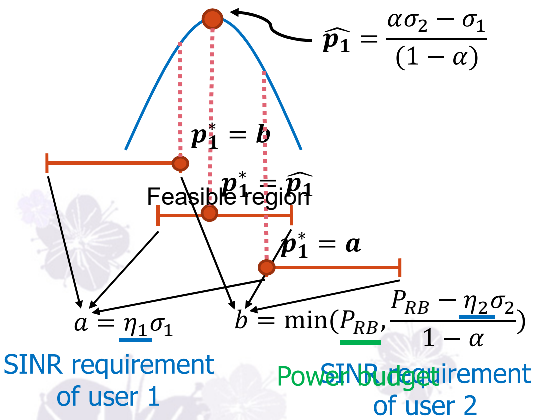
$$\frac{dg}{dp_1} = \frac{(\alpha\sigma_2 - \sigma_1) - (1 - \alpha)p_1}{(\sigma_1 + p_1)(\sigma_2 + p_1)} \quad (\sigma_1 + p_1)(\sigma_2 + p_1) > 0$$

Linear function of p_1 with negative slope

$$\widehat{p_1} = \frac{\alpha\sigma_2 - \sigma_1}{(1 - \alpha)}$$



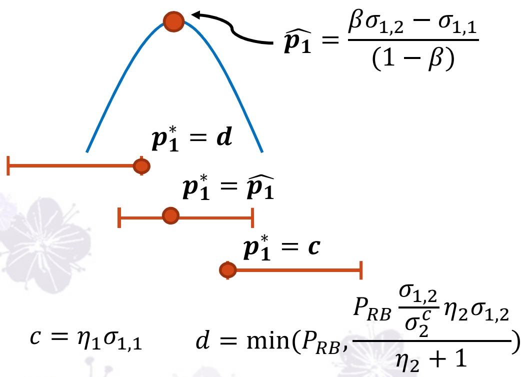
Utility-based power allocation: The NOMA scenario



$$p_1^* = \begin{cases} \frac{\alpha\sigma_2 - \sigma_1}{(1-\alpha)} & \text{, if } a \le \frac{\alpha\sigma_2-\sigma_1}{(1-\alpha)} \le b \\ b & \text{, if } a \le b > \frac{\alpha\sigma_2-\sigma_1}{(1-\alpha)} \\ a & \text{, if } b \ge a > \frac{\alpha\sigma_2-\sigma_1}{(1-\alpha)} \end{cases}$$

If $a > b$, then p_1 has no feasible solution.

Utility-based power allocation: The JT scenario



$$p_1^* = \begin{cases} \frac{\beta\sigma_{1,2} - \sigma_{1,1}}{(1-\beta)} & \text{,if } c \le \frac{\beta\sigma_{1,2}-\sigma_{1,1}}{(1-\beta)} \le d \\ d & \text{,if } c \le d < \frac{\beta\sigma_{1,2}-\sigma_{1,1}}{(1-\beta)} \\ c & \text{,if } d \ge c > \frac{\beta\sigma_{1,2}-\sigma_{1,1}}{(1-\beta)} \end{cases}$$

If $c > d$, then p_1 has no feasible solution.

Primary and secondary goals

Efficient user pairing method

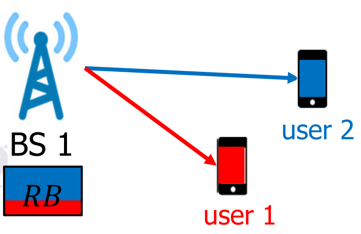
- Primary goal
  - Maximizing the number of users that attain their rate requirements
    - These users are called well-served users.
    - A user pair whose users are both well-served is called a well-served user pair.

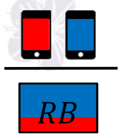
Optimal power allocation method

- Secondary goal
  - Maximizing total **utility**

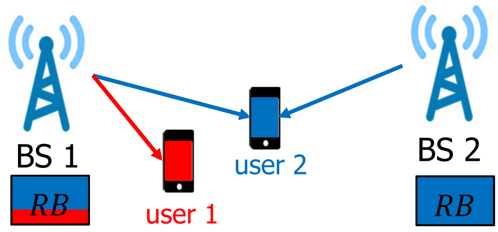
Which scenario should have higher priority?

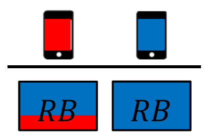
The NOMA Scenario



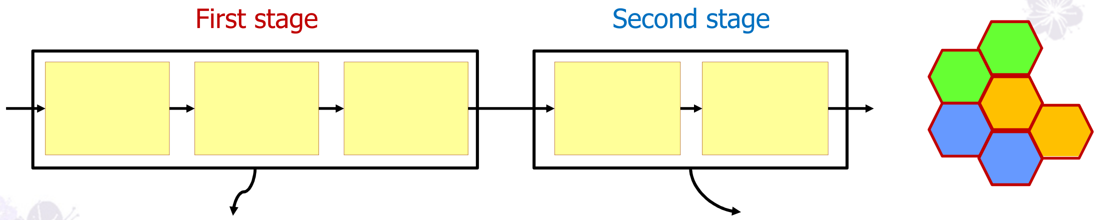
RB usage efficiency =  = 2

The JT Scenario



RB usage efficiency =  = 1

Matching-based user pairing



First dealing with the NOMA scenario Then dealing with the JT scenario

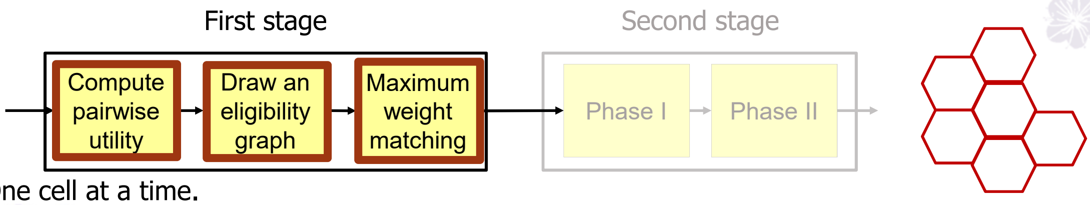
The NOMA scenario has better RB usage efficiency

Maximize the number of well-served users and total utility for each cell → then help unserved users on cell-pair basis

Matching-based user pairing

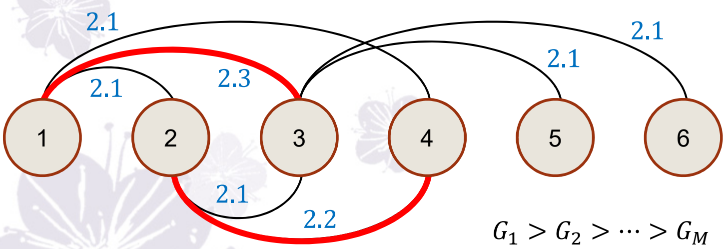
Set of users $\mathcal{M} = \{1, 2, \dots, M\}$

Set of RBs $\mathcal{L} = \{1, 2, \dots, L\}$



One cell at a time.

Find optimal pairwise utilities of all possible **user pairs** by the method aforementioned (NOMA scenario).



$$W_e = 2 + \frac{\text{pairwise utility of } e}{\sum_{e' \in E} \text{pairwise utility of } e'}$$

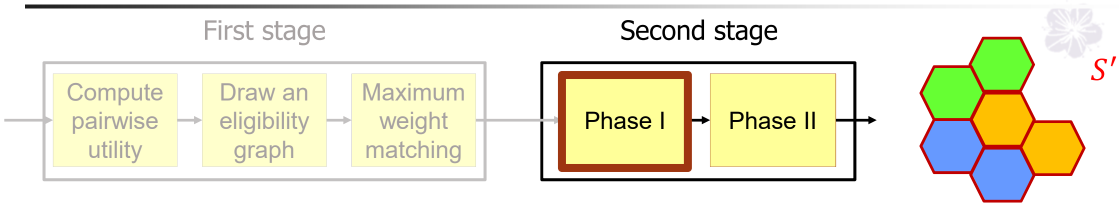
Primary goal / 2 users

Normalized goal / Secondary goal 2

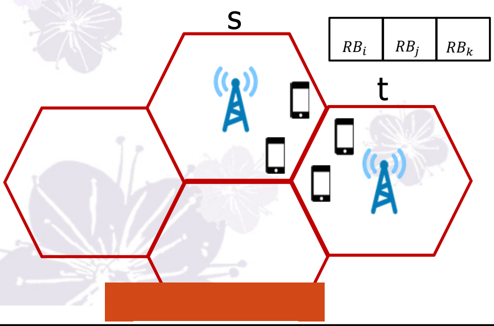
$G_1 > G_2 > \cdots > G_M$

$S = \{(1,3), (2,4)\}$ $\mathcal{M} = \{(5,6)\}$

Matching-Based User Pairing



Find **cell pairs** that have highest potential.



For each possible **cell pair,** we compute the potential:

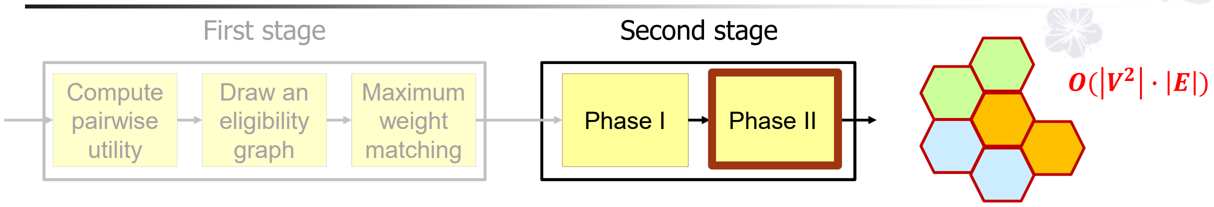
$$\phi_{st} = \min(M_s + M_t, 2L_{s,t})$$

Numbers of unserved users in cell s and cell t

Unoccupied RBs the two cells have **in common**

Use similar steps to find out a MWM, S' → cell pairs

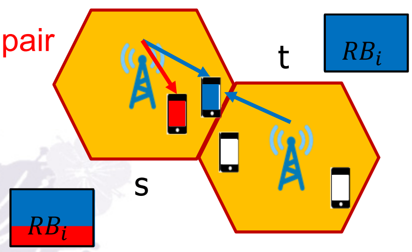
Matching-Based User Pairing



Find optimal pairwise utilities of all possible **user pairs** by aforementioned method (JT),

for cell s and cell t respectively.

Each cell pair in S'



Use similar steps to find out a MWM, S'',

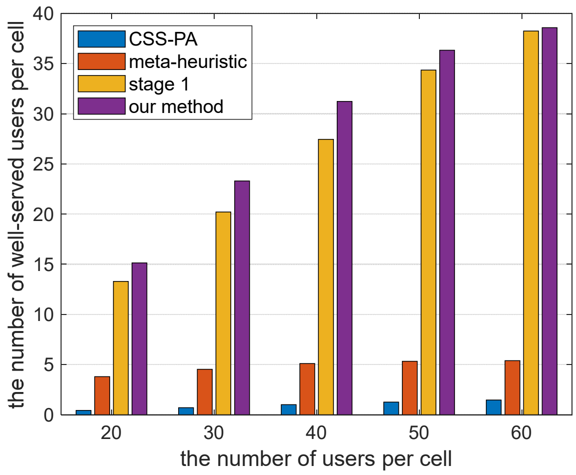
S'' is users pairs well-served in the JT scenario

Simulation results

- Simulation parameters

Parameter	Value
Radius of cell	500 m
Power budget per BS	40 dBm
The number of BS antenna	1
The number of user antenna	1
The rate requirements of users	1,2,4,8 bps/Hz
The number of RBs	20
Path loss model	$133.6 + 35log_{10}$(d[km])
Bandwidth per resource block	180 kHz
Noise spectral density	-174 dBm/Hz

Simulation results



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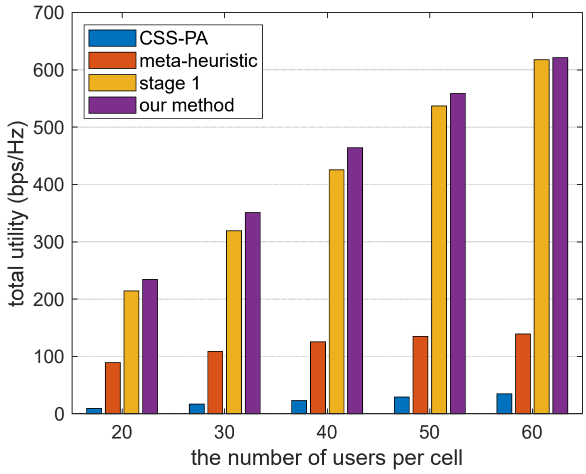

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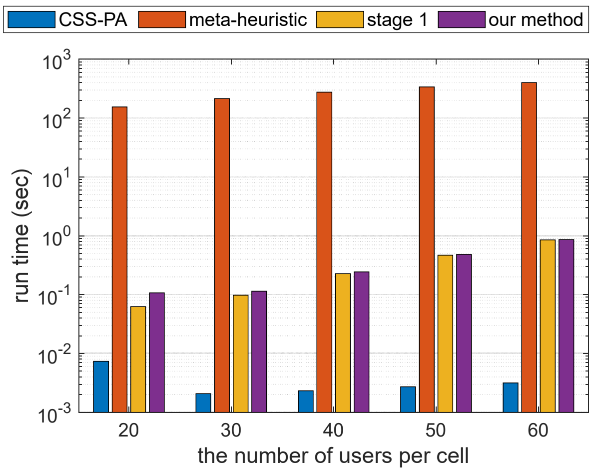

Conclusion

- We consider both user pairing and power allocation jointly for NOMA with CoMP support
  - Primary goal: Maximization of the number of well-served users
  - Secondary goal: Maximization of total utility
- Our proposed method
  - Closed-form formulas for optimal utility-based power allocation
  - Matching-based user pairing method
- Simulation results
  - Our method outperforms the other schemes in terms of
    - The number of well-served users
    - Total utility
  - The performance gap becomes larger as the number of users increases