# Channel Disparity in Non-Orthogonal Multiple Access (NOMA)

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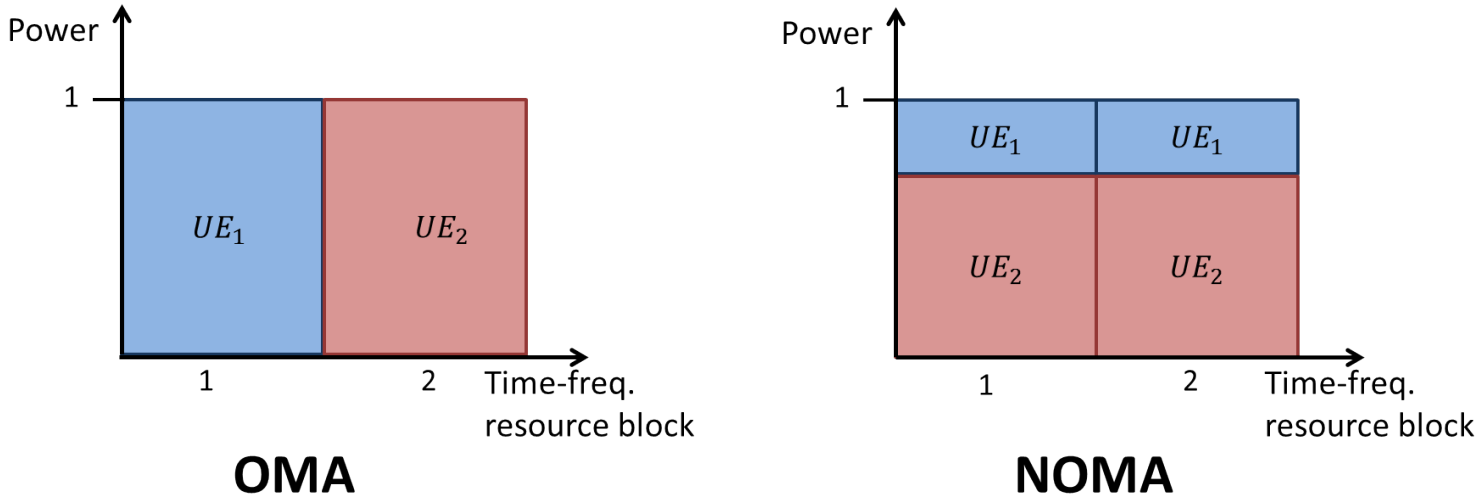
# Outline

# NOMA Basics

- Superposition coding in the power domain

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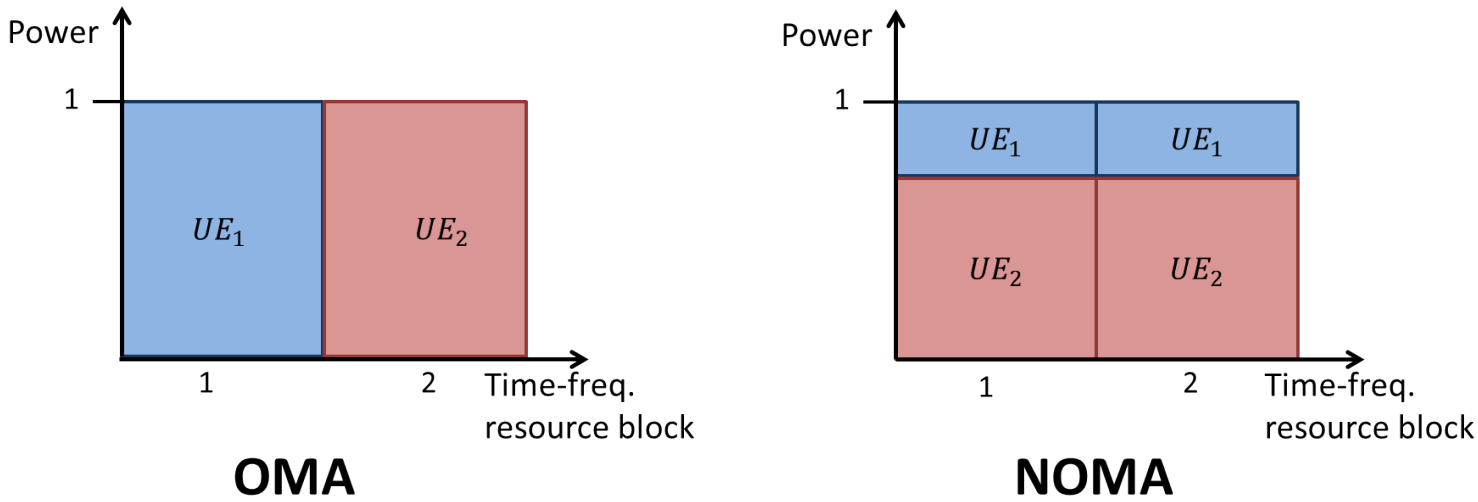
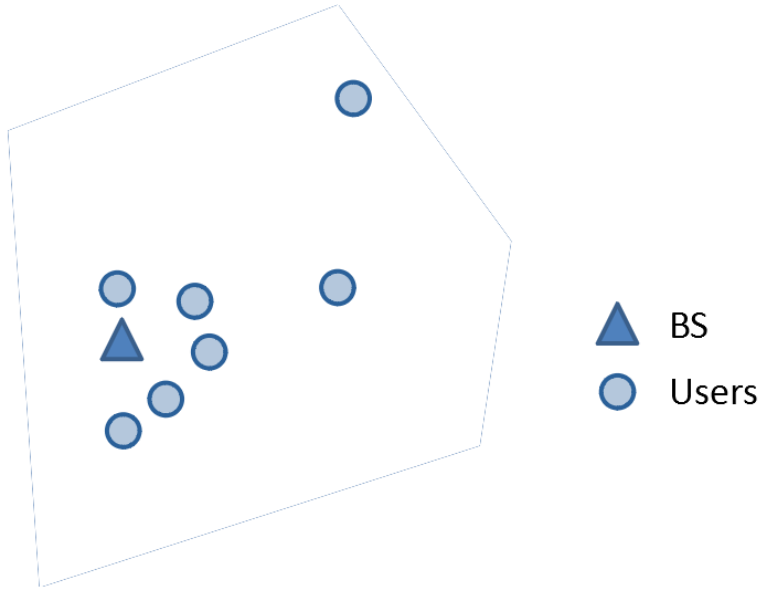



  Multiple users share a resource-block – referred to as a cluster
- NOMA requires ordering users in the cluster based on some measure of channel strength
- Successive Interference Cancellation (SIC) is used for NOMA decoding

  In the downlink:
  - Requires a user to decode the messages for all weaker UEs
  - Treat messages of all stronger users as noise

# NOMA Clustering

- Clustering: the process of selecting which users belong to a cluster and therefore share a resource-block



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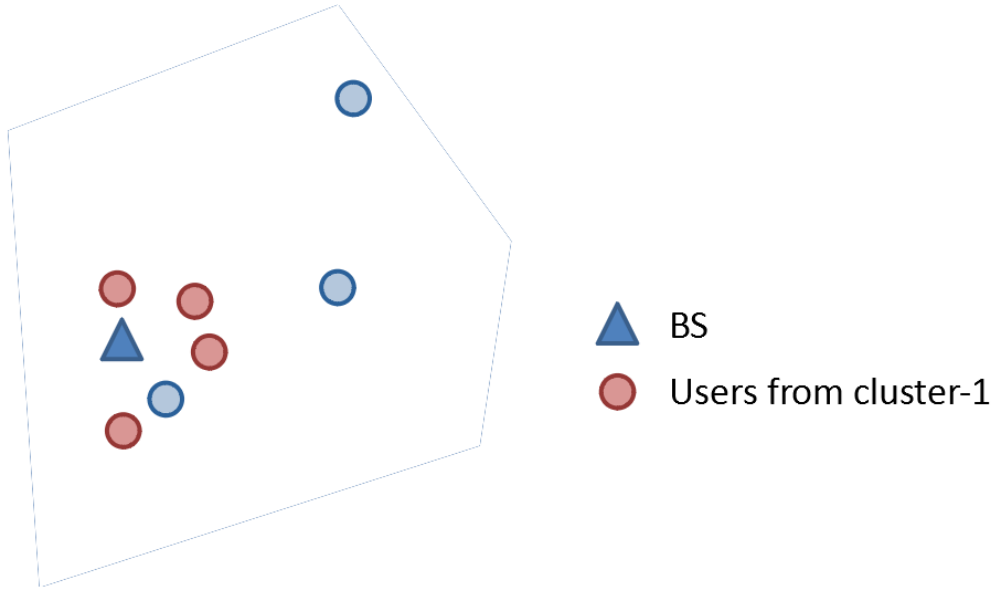

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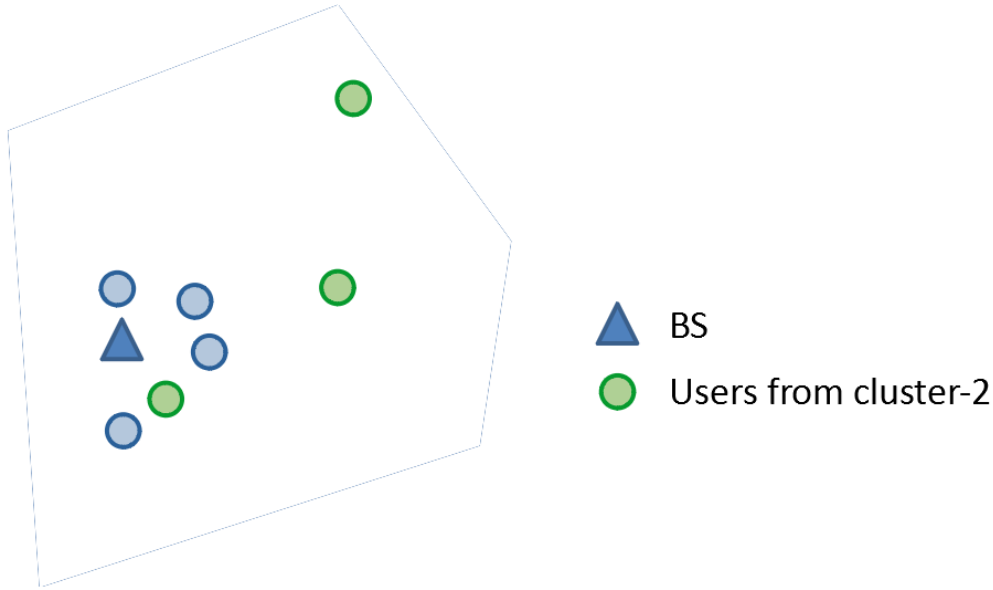

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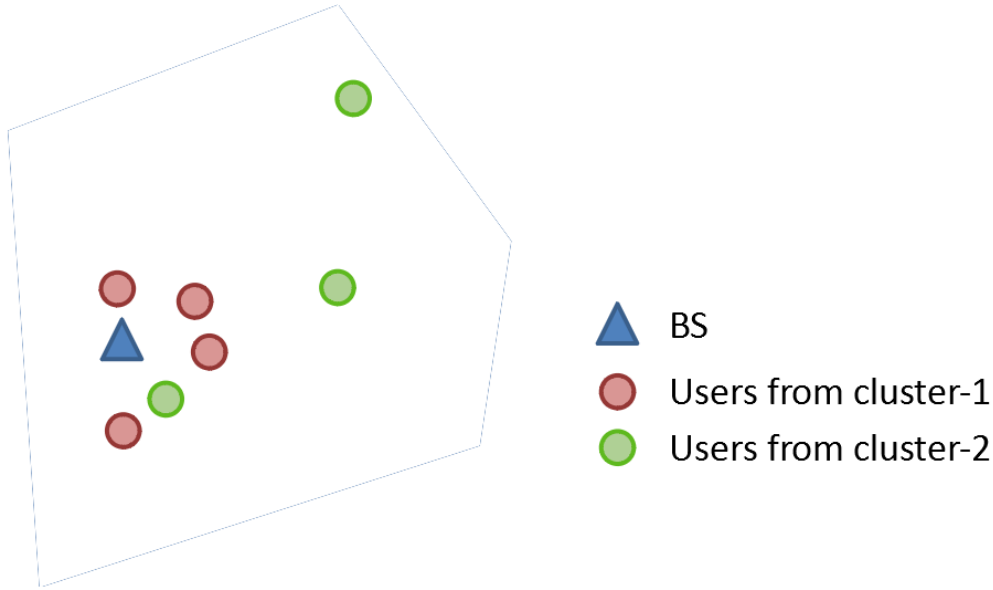

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   - Voronoi cell is an intrinsic spatial restriction [1]
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   - Disk surrounding a BS:
     - With fixed radius - risks users being outside Voronoi cell [3]
     - With variable radii so that users are always inside Voronoi cell [4],[5]
   - Sectors of disks based on interference conditions [4]
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2. Channel disparity restrictions between users in a cluster
   - Defining and quantifying channel disparity is difficult - some difference or ratio of link distances/some measure of channel strength etc. of users
   - Disk with annulus model guarantees some minimum channel disparity in terms of link distance
   - Strong user has $\mathrm{SINR} > \mathrm{T}_1$, weak user has $\mathrm{SINR} < \mathrm{T}_2$, where $T_1 > T_2$ guaranteeing minimum difference of $T_1 - T_2$ between users in cluster [6]

- Impact of channel disparity and spatial restrictions on clustering is intertwined making the problem even more complex
- Based on real-time variables clustering becomes more difficult
- Open area of research and still not very well defined

# Common Misunderstandings in NOMA

M1 Pairing a strong user with a weak user improves performance

M2 Allowing users with similar channel strengths to share a resource-block is dangerously detrimental for performance

M3 When users with similar channel strengths employ NOMA, power allocation will be similar – makes decoding weak user's message hard for both strong and weak user as interference from strong user's message is too high

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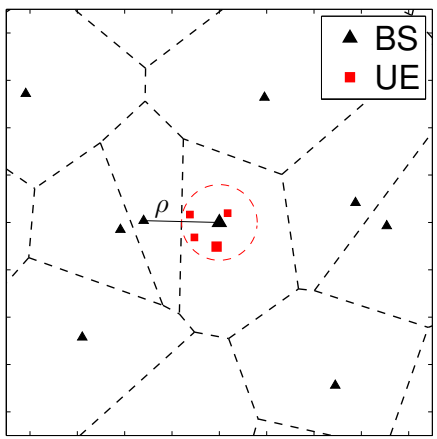
- NOMA - and any communication really - should be intended for users with various channel qualities
- Unlike OMA, NOMA involves *sharing* a resource-block between multiple users
- Increasing channel disparity beyond a point leads to the weak user becoming too weak
  - Such a user cannot afford sharing
  - Needs its own resource-block, maybe even extra help via techniques such as CoMP
- A strong user can always do more with any resource than a weak user

# Setup

Two-user downlink NOMA: The system maximizes sum rate subject to a QoS constraint.

- $\rho$: the distance between the BS and nearest interfering BS
  - Fix strong user at link dist. $\rho/4$. Random orientation.
  - Increase weak user's link dist. from $\rho/4$. Random orientation.
  - Users up to link dist. $\rho/2$ always guaranteed to be inside cell
  - Channel disp. measured as $\frac{\text{weak user's link dist.}}{\text{strong user's link dist.}}$



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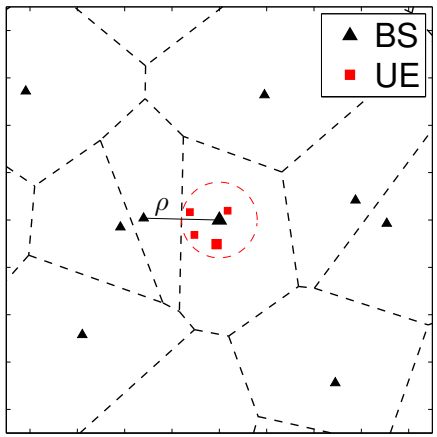



- Weak user given least amount of power to attain QoS
  - Increases with channel disparity
- Remaining power goes to strong user

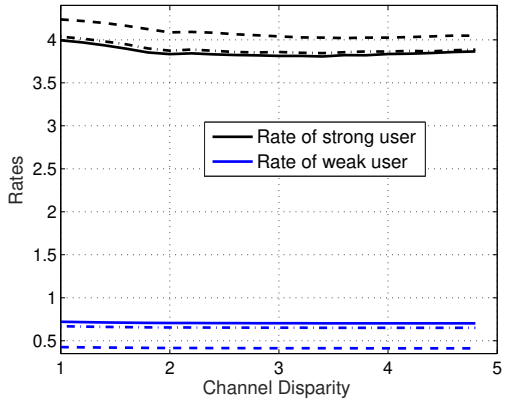



Fig. 1: Rates against increasing channel disparity.

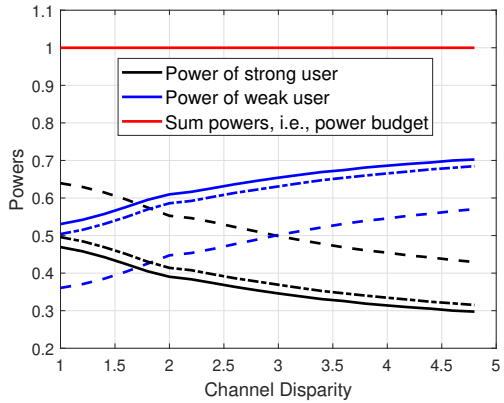



Fig. 2: Powers against increasing channel disparity.

QoS constraint: $\log(1+\theta)$. Dashed, dash-dotted, and solid lines represent $\theta = 0.5$, 0.9, and 1, respectively.

- At first, rate of strong user decreases with channel disparity
  - As less power is left for the strong user
  - Negates the proposition that increasing disparity always improves NOMA performance
- Maximum rate is at lowest channel disparity, i.e., the users have very similar channel conditions.
- With $\theta = 0.9$: power allocation is equivalent at lowest channel disparity and performance is still maximum
  - Equal power allocation is not necessarily detrimental for performance

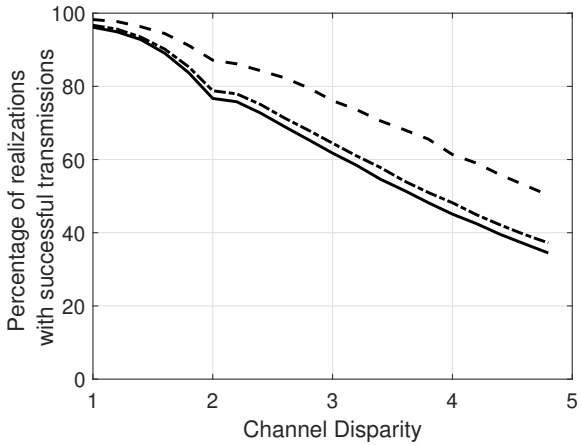
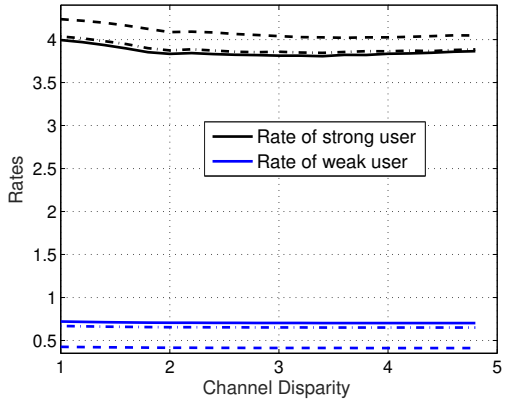



Fig. 3: Percentage of successful cells.

- The percentage of successful realizations decreases significantly with disparity
  - Disparity in the considered setups is conditioned on link distances
  - Low disparity: link distances are good (i.e., short) so outage occurs only when very poor fading conditions – not that frequent
  - High disparity: link distances are large so successful transmissions occur only when fading conditions are very good – not that frequent

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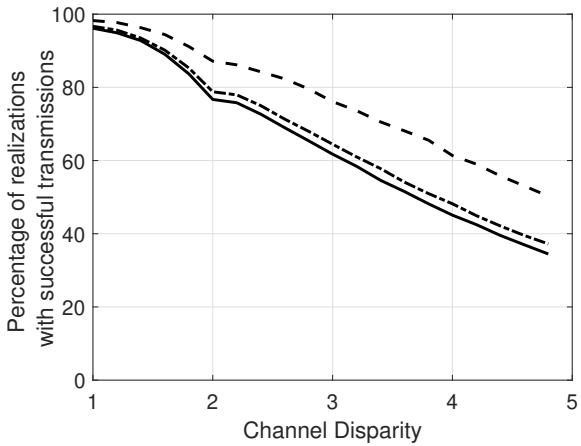


Fig. 3: Percentage of successful cells.

- Performance does not decrease monotonically with disparity – at very high disparity, rate of the strong user increases again
  - High disparity corresponds to the fewer realizations with very good fading conditions
- Although high disparity does not result in the worst rates, the percentage of successful transmissions is very low – effective rates may be very low

# Literature on Comparing the Impact of Channel Disparity

- [6], [7] compare impact of users distributed uniformly at random all over the cell with more 'selective' clustering techniques
  - [6] ensures minimum channel disparity $T_1 - T_2$ between the strong and weak user – i.e., promotes higher channel disparity between users
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- Both [6] and [7] show that their selective clustering outperforms no-restriction clustering – contradictory!
- [6] uses fixed power allocation, [7] uses optimum
  - System model in [6] does clustering post-resource allocation
  - Selecting users with more channel disparity may thus be superior in this setup
  - Conclusion cannot be generalized to setups with other fixed resource allocation values, or when clustering is done prior to resource allocation

- In [8], two-user downlink NOMA, single-cell setup. Results show:
  - (1) Fixed power allocation: pairing users with higher channel disparity is superior
  - (2) CR-NOMA: pairing users with lower channel disparity is superior
- In (1), the power allocation is not optimum given channel conditions of users (similar to [6])
- What if the power in (1) was chosen equivalent to the values in (2)?
  - There would be a contradiction in the conclusion of which users to pair

# Remarks

- Increasing traffic in 5G and beyond $\Longrightarrow$ high intercell interference
  - Dominant component of SINR and channel quality even in techniques such as NOMA that introduce intracell interference
  - Channel disparity between users decreases
- Significant impact of intercell interference makes SuIC decoding more immune to very similar power allocation
- Pairing weak users with strong users can still be desirable if the goal is to help weaker users achieve better rates via transmissions, albeit shared, over *multiple* resource blocks
  - This is to improve a goal such as the sum rate of very weak users over *multiple* resource blocks

# Flexibility Associated with NOMA

- In OMA, performance is limited by the strength of the user – it can only perform so much in the allotted resource block
- As such, NOMA is well known and promoted for improving user fairness
- Less highlighted: NOMA allows immense flexibility in utilizing available resources

- Next generation networks will have a plethora of devices with varying requirements – URLLC to low QoS devices such as those in IoT
  - With flexible QoS, NOMA can be employed for users with high channel disparity
  - Target rates for weak users can be chosen accordingly so that they do not become the bottleneck for power consumption
  - Upper limit on channel disparity - varies with the network conditions and QoS requirements
- Require a combination of smart clustering and resource allocation
  - Efficient strategies would vary with goals, network conditions, and available devices
  - No fear of clustering users with low channel disparity – improves our understanding of better strategies to adopt

# Conclusion

- A lot of work still needs to be done on efficient clustering strategies
- Common misconceptions about clustering in NOMA such as pairing users with similar channel strengths being detrimental are simply not true
- NOMA introduces a lot of flexibility in meeting various very specific goals of next generation networks – through not just efficient resource allocation, but also efficient clustering

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# Submitted for Publication

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# QUESTIONS