

# Improving non-coherent communications with AI

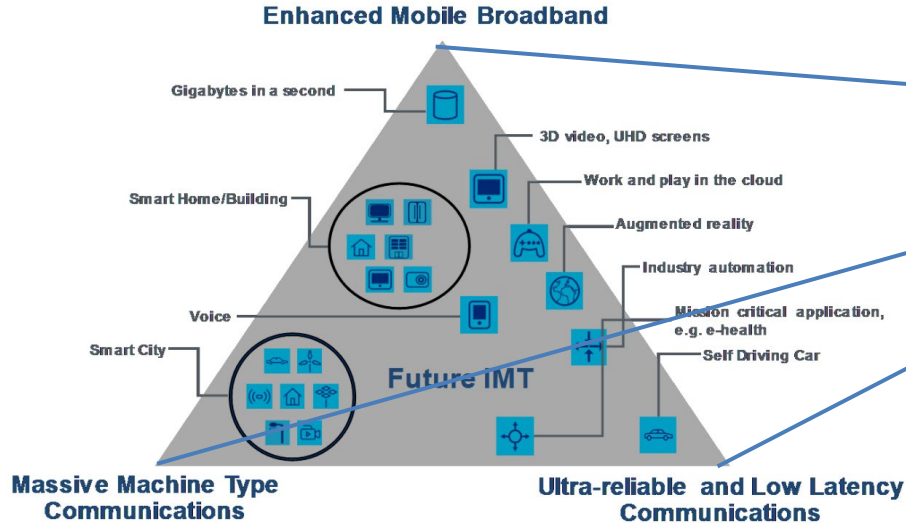
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**Universidad Carlos III de Madrid, Spain**



# Towards 6G

Digital  
World

## 5G Usage scenarios



Physical  
World

Human  
World

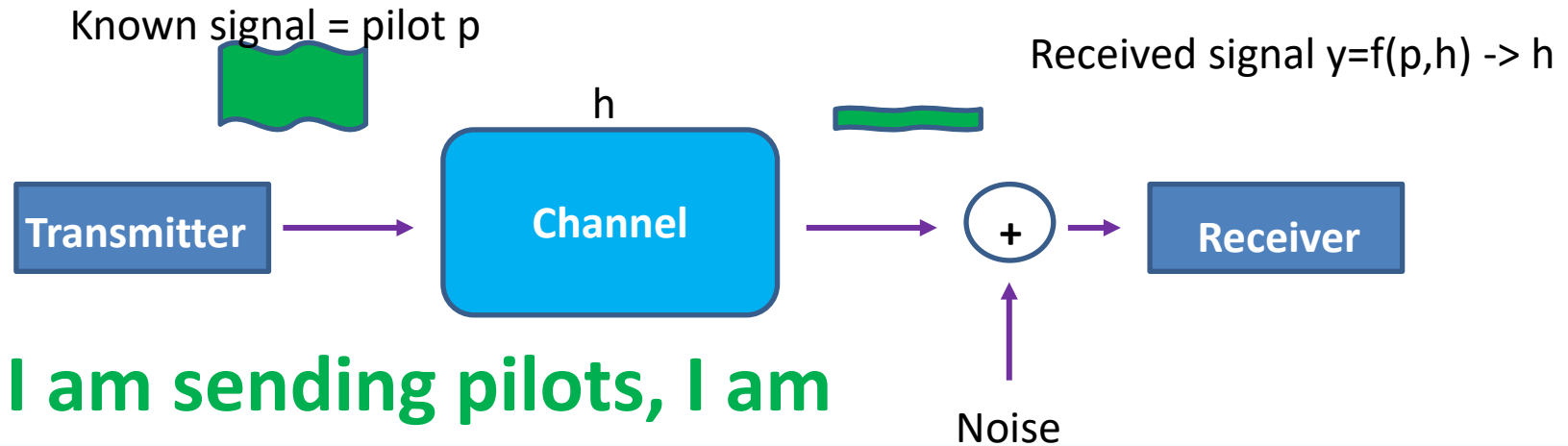
- **Sustainability**
- **Global coverage**

Image from rawpixel.com - [www.freepik.es](http://www.freepik.es)

# What are non coherent (NC) communications?

- Coherent detection:
  - Requires a replica of the carrier at the receiver with frequency and phase synchronized with the transmitted one
  - An estimation of the channel attenuation and phase needs to be recovered: **channel state information (CSI)**
  - The received signal and replica of the possible transmitted signals can be cross-correlated
- Non coherent detection:
  - No reference wave is used
  - The carrier phase is not recovered in the receiver
  - No CSI at the receiver side
  - Possible with ASK, FSK, DPSK, with a performance penalty

**Coherent communications lead to improved performance with respect to NC but at the expense of acquiring CSI**



**If I am sending pilots, I am not sending information ...**

# Non coherent communications – why now?

- When we consider the needs of CSI obtaining and sharing, the theoretical loss of NC processing may become negligible
- Channel estimation is wasteful in some circumstances (channels with low coherence time, low SNR)
- CSI estimation and sharing can be complex for the new techniques and the new standards, e.g. **massive MIMO**
- NC may solve some of these problems for massive MIMO
- The “magic” of massive MIMO (self interference cancellation) may improve NC performance

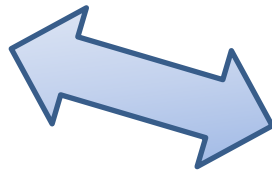


# Massive MIMO

- Benefits of increasing (a lot) the number of antennas
  - Improve data rates and reliability (multiplexing and diversity gains)
  - Decrease required transmit power
  - Simple precoders/decoders



$R$  antennas at BS,  $R \gg$

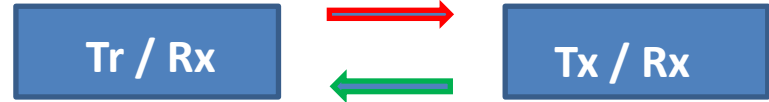


$K$  single antenna users,  $K \ll R$

# CSI in massive MIMO

- Channel State Information (CSI) - Need to estimate many channels!

- TDD is a must (+ calibration)

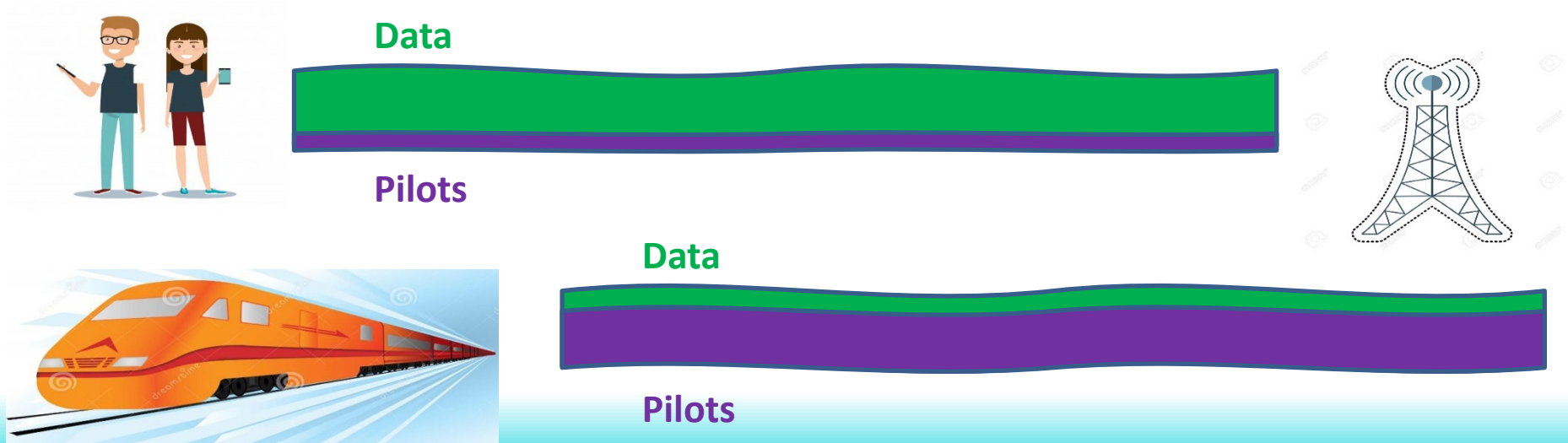


- Pilot contamination: Uplink pilot sequences from different cells interfere with each other.
  - Solutions are proposed in the literature ...

**Obtaining CSI in massive MIMO is problematic**

# High mobility worsens the problem

- If the channel changes fast, we need more pilots
- High pilot density means high overhead and low efficiency -> low data rate or throughput



# Non-coherent massive MIMO



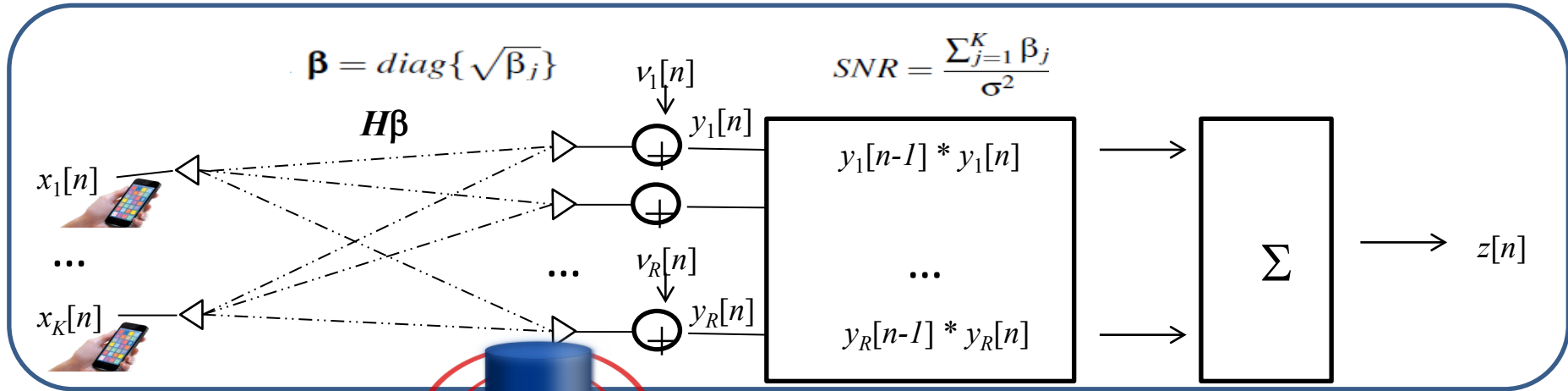
- ASK (amplitude shift keying) energy-detector schemes
  - They achieve rates which are not different from coherent schemes in a scaling law sense
  - Too many antennas are required for reasonable performance with actual constellation designs
- Differential PSK schemes
  - Single user with improved performance (wrt req. number of antennas)
  - Multi-user through constellation design

M. Chowdhury, A. Manolakos, A.J. Goldsmith, "Design and Performance of Noncoherent Massive SIMO Systems," Proc. of 48th Annual Conference on Information Sciences and Systems, Princeton, 2014.

A. G. Armada and L. Hanzo, "A Non-Coherent Multi-User Large Scale SIMO System Relying on M-ary DPSK," IEEE ICC, Jun. 2015 pp 2517-2522.

# Multi-user uplink with M-DPSK

- Data symbol sequences M-PSK
- Tx signal comes from differentially encoding the data symbols: D-MPSK



$K$  users

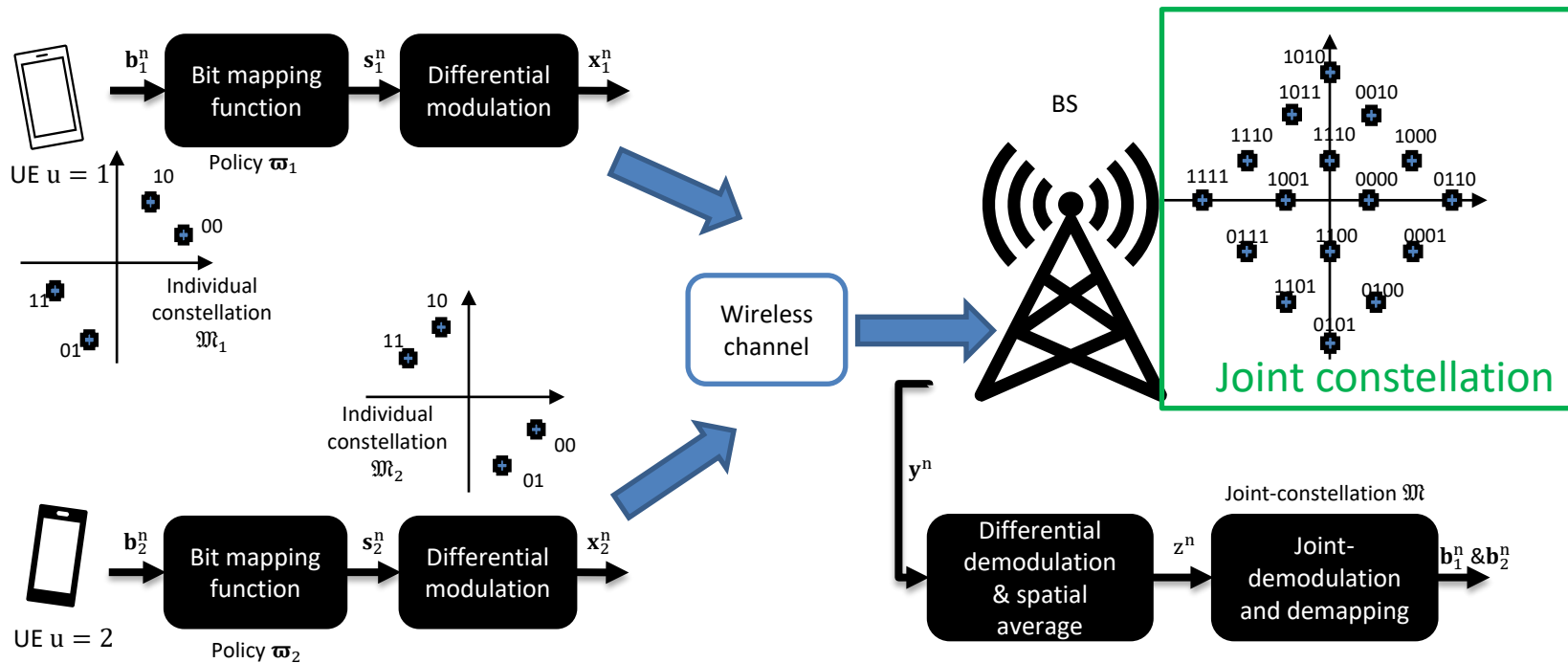
$R$  antennas at BS

Frequency-fat fading

$$z[n] = \frac{1}{R} \sum_{i=1}^R y_i[n-1]^* y_i[n]$$

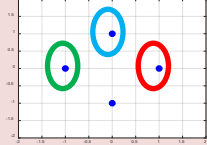
The phase difference of two consecutive symbols received at each antenna is non-coherently detected and they are all added to give the decision variable  $z[n]$

# How to multiplex several users without CSI?

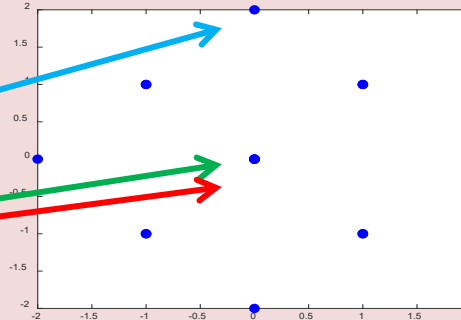


# Joint constellation

User 1:



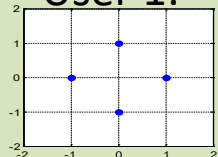
User 2:



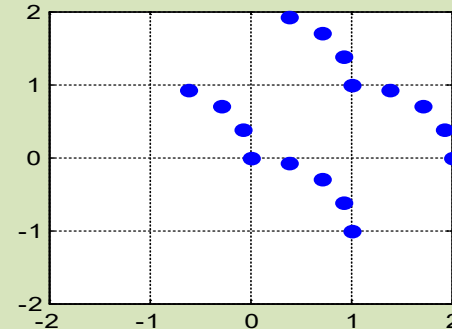
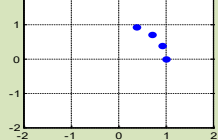
**Not a good choice ..  
Cannot decode  
unambiguously all  
points of individual  
users**



User 1:



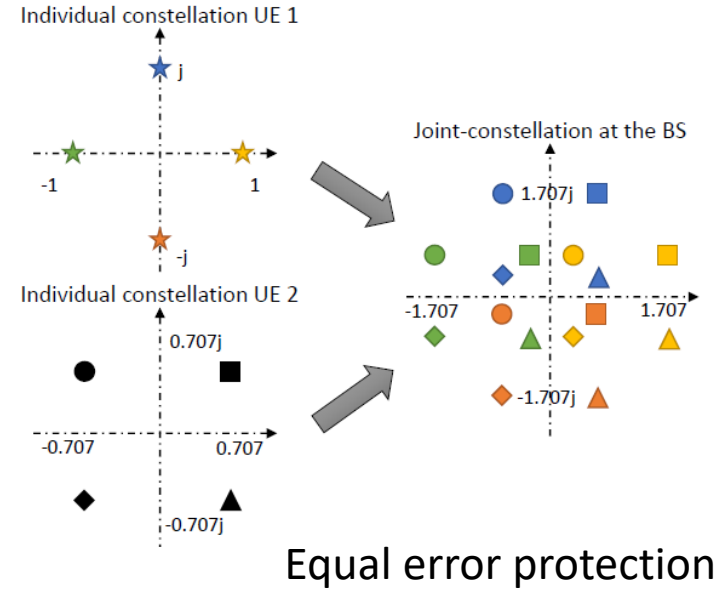
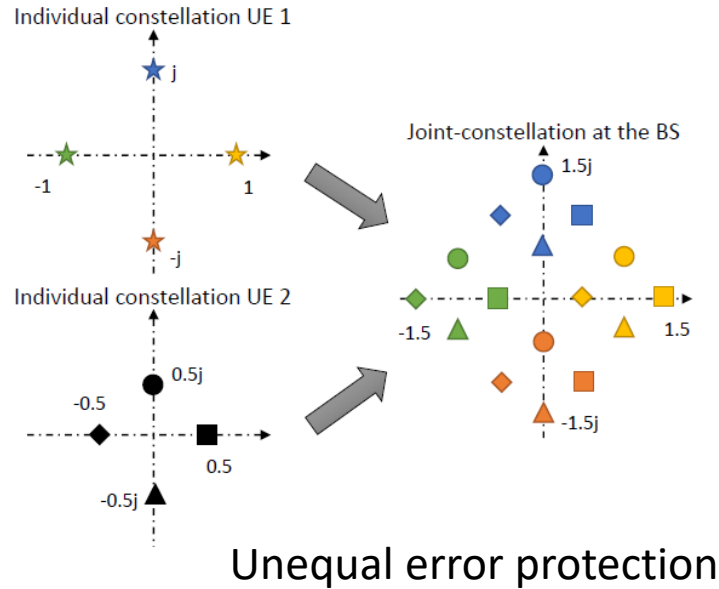
User 2:



**16 distinct points  
Good choice!**

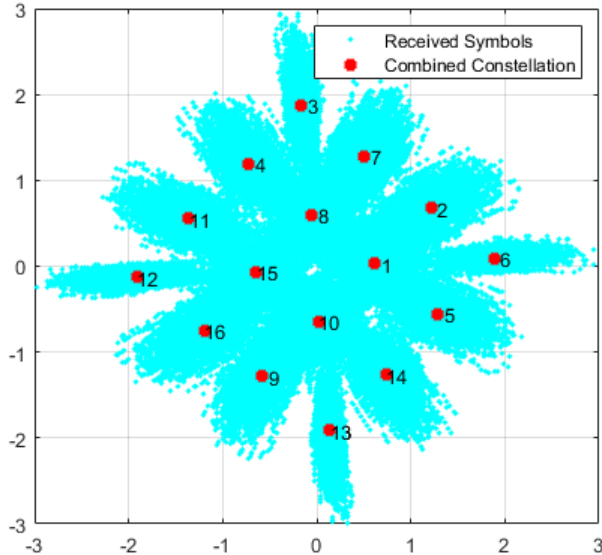


# Some initial joint constellations



# How to find better constellations?

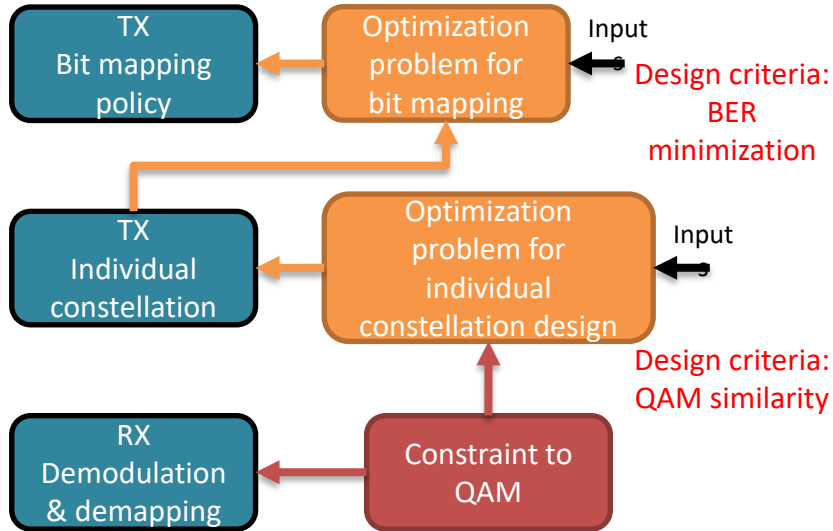
# Evolutionary computation



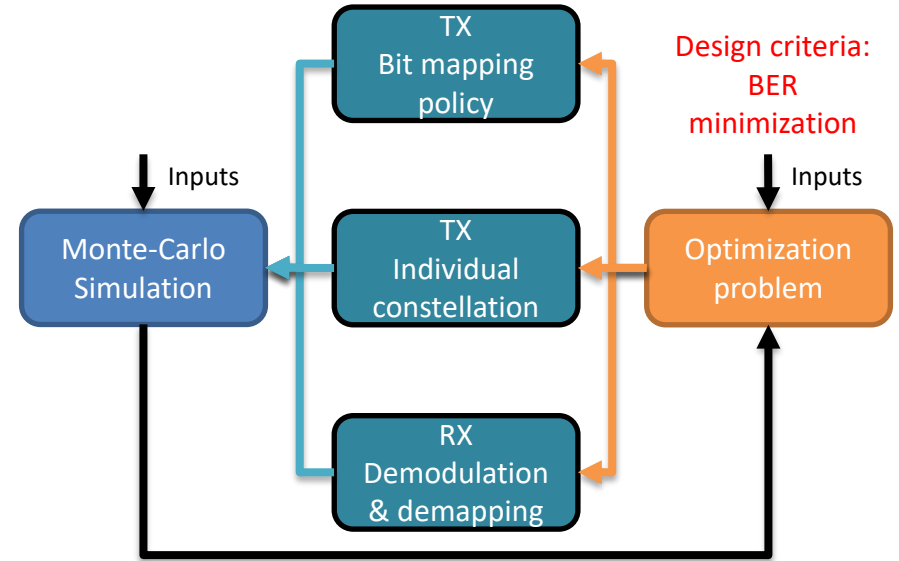
- The self-interference and noise are not Gaussian, and it depends on the individual constellation!!!
- Two methods:
  - Gaussian Approximation Optimization (GAO)
  - Monte-Carlo based Optimization (MCO)
- Evolutionary Computation (subfield of AI)
  - Solve Non-Convex Opt. Problems
  - Genetic Algorithm

# Optimization methods

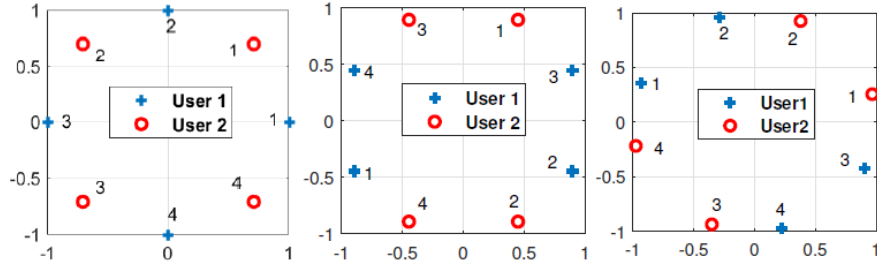
NC - GAO



NC - MCO



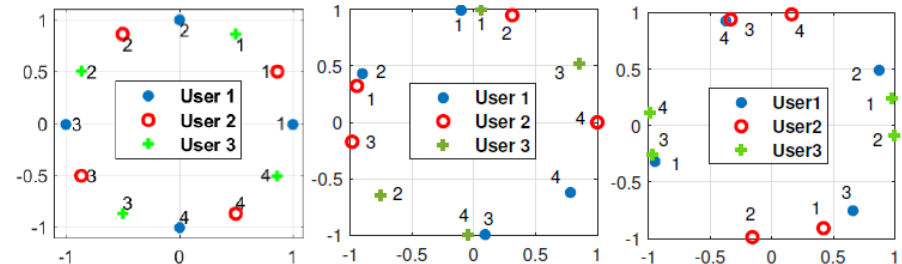
# Some results



(a) Individual EEP.

(b) Individual GAO.

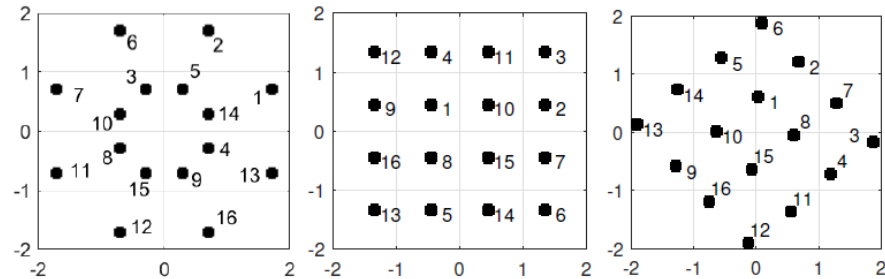
(c) Individual MCO.



(a) Individual EEP.

(b) Individual GAO.

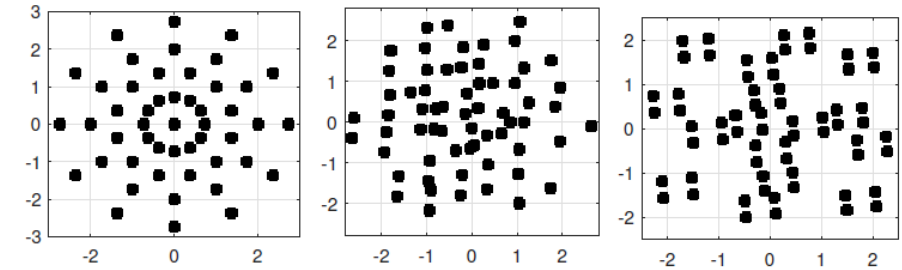
(c) Individual MCO.



(d) Joint EEP.

(e) Joint GAO.

(f) Joint MCO.

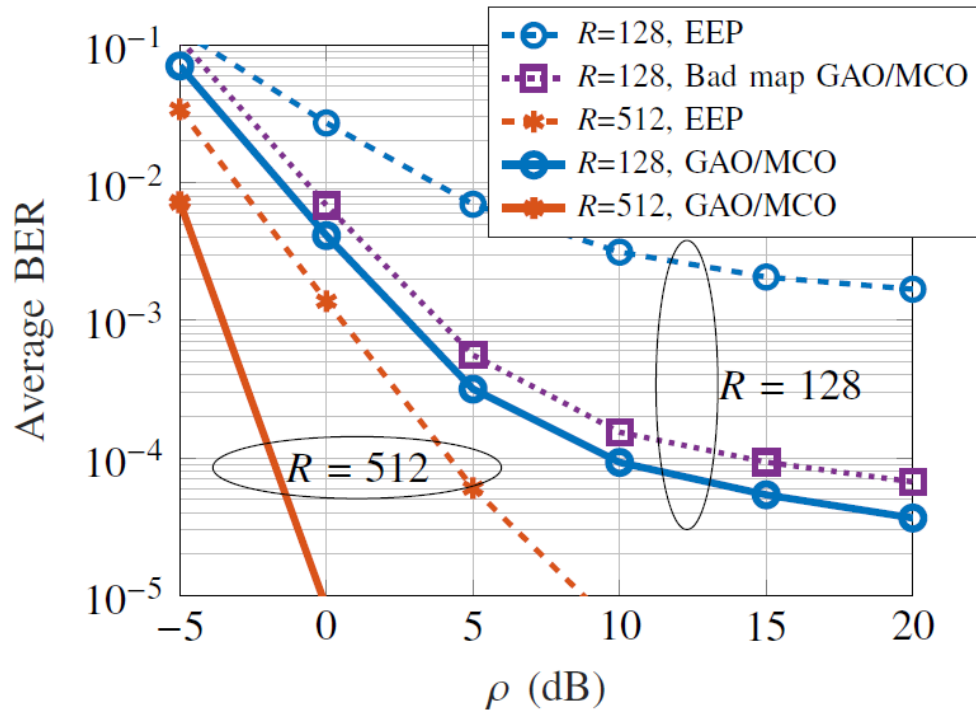


(d) Joint EEP.

(e) Joint GAO.

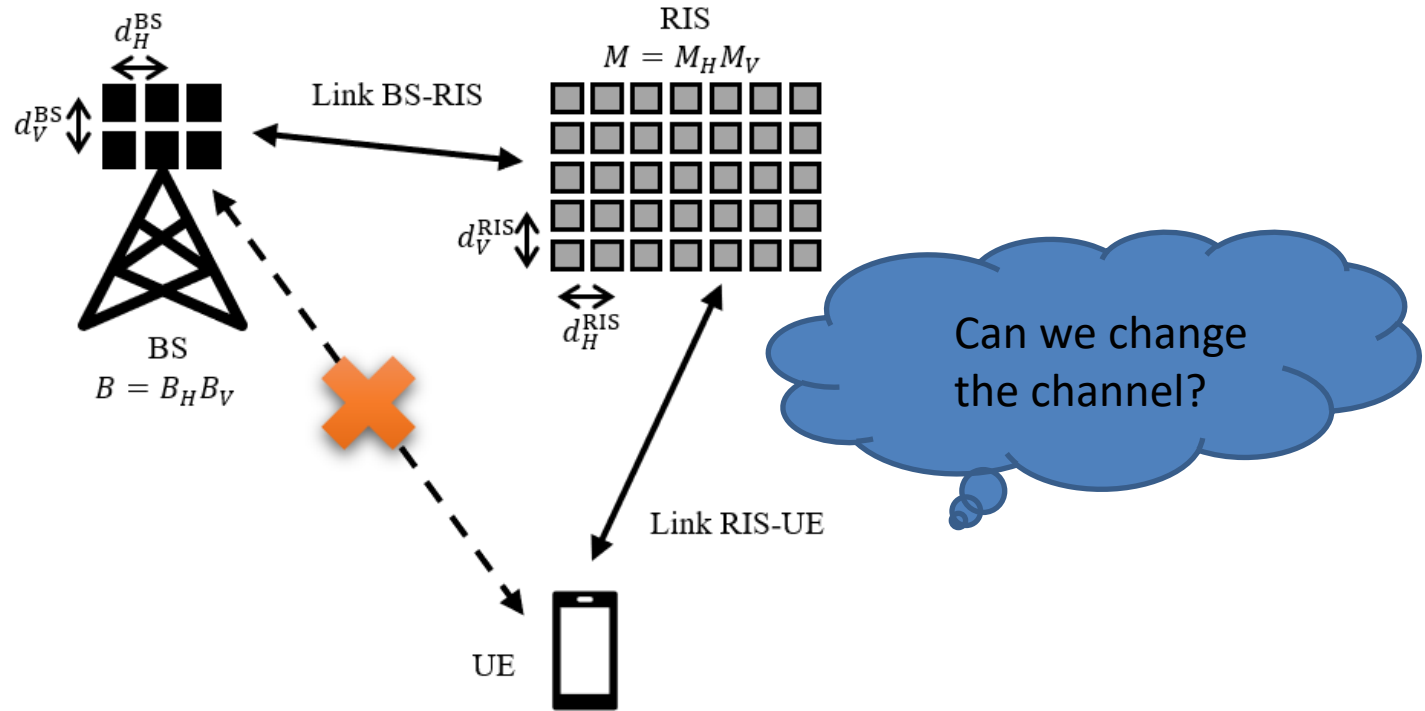
(f) Joint MCO.

# BER vs SNR for 2 users and DQPSK

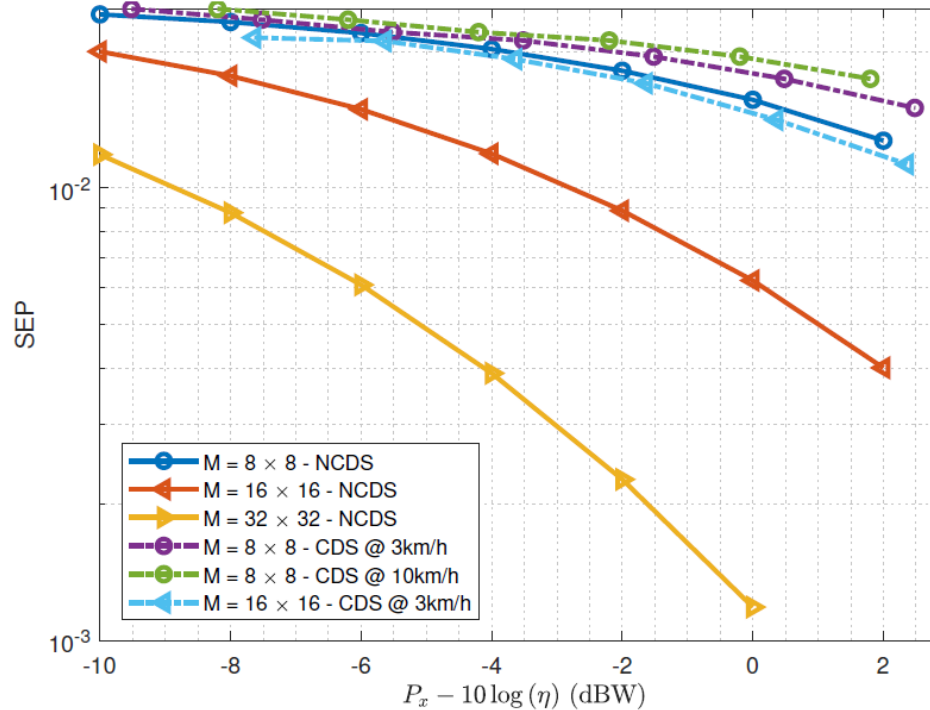


**Now, they can be combined with other trends in communications**

# Reconfigurable Intelligent Surfaces (RIS)



# NC vs coherent RIS (DQPSK, QPSK)

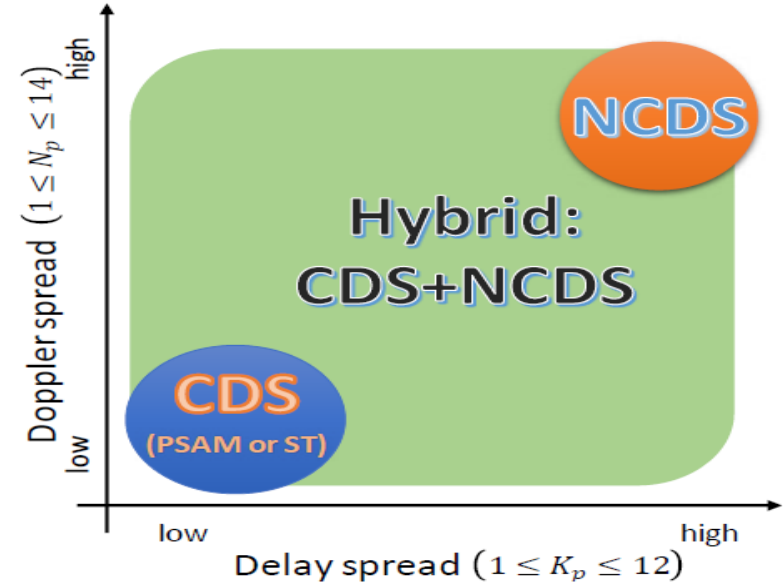
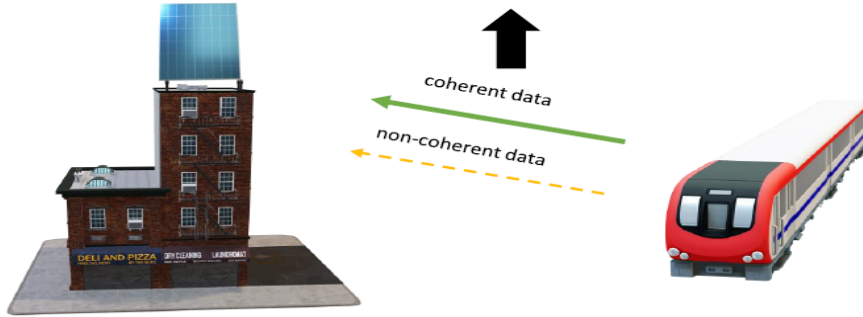


Coherent for low mobility and small RIS

NC allows large RIS and does not care about mobility

# Combination of coherent and non coherent schemes

|      | n=1 | n=2 | n=3 | n=4 | n=5 | n=6 | n=7 | n=8 | n=9 | n=10 | n=11 | n=12 | n=13 | n=14 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|
| k=1  |     |     | P   |     |     | P   |     |     | P   |      |      | P    |      |      |
| k=2  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=3  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=4  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=5  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=6  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=7  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=8  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=9  |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=10 |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=11 |     |     |     |     |     |     |     |     |     |      |      |      |      |      |
| k=12 |     |     |     |     |     |     |     |     |     |      |      |      |      |      |



Most of the pilots can be replaced by NC data

# It is time for non coherent massive MIMO!

- Solve the CSI bottleneck
- Applicable to high mobility
- Low complexity, low power consumption
- Can be combined with OFDM, BF, RIS and other features for beyond 5G
- Several challenges yet to be solved ... AI can help!



*Thank  
you !*

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