C-RAN, vRAN, O-RAN and Cell-free Massive MIMO

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Motivation – why do we need 6G?

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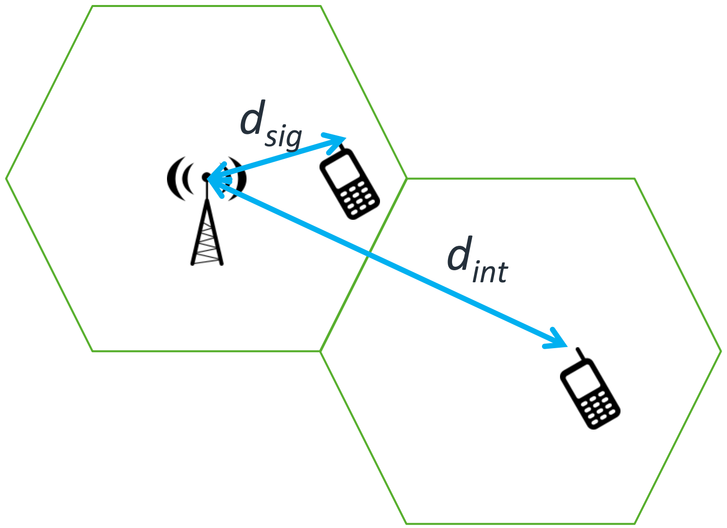
- 5G has – conceptually at least – opened up a vast range of applications for wireless networks, with a corresponding range of service requirements
- Many of these require greatly increased **network density** to provide increased reliability, reduced latency, increased capacity/capacity density – or all of these
- Up to this point increased capacity-density in cellular networks has been achieved primarily by ***network densification***
  - i.e. by reducing cell sizes and providing more base stations/access points
- However there is evidence that we are reaching a limit on network densification within the current cellular paradigm
  - hence we need a "paradigm shift"
- The object of this talk is to present some new concepts towards this
  - and show how they also fit with existing concepts like C-RAN and vRAN

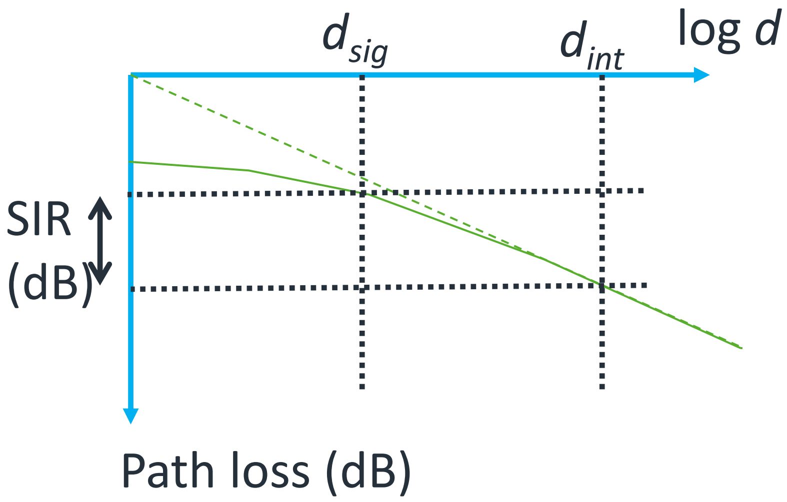
Outline

- *Motivation*
- Limits on densification
- Part of the solution: massive MIMO
- Beyond the cellular paradigm: “cell-free” massive MIMO
- Relationship with C-RAN, vRAN, O-RAN…
- Scalability: “Fog massive MIMO”
- Challenges for vRAN architectures

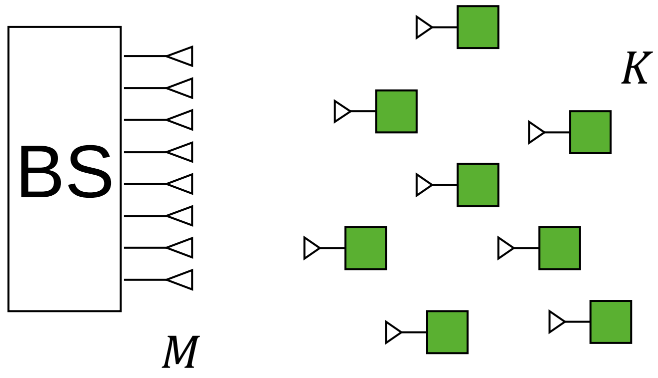
Fundamental limits on densification

- We usually assume that path loss is inversely proportional to some power of distance
  - this means that when we reduce cell sizes signal distance and interfere distances reduce in the same proportion
  - hence signal to interference ratio (SIR) remains constant
- However we are now reaching densities such that this may no longer be true, and the distance-power curve flattens
  - this will cause SIR to drop, and limit densification
- ***When distances between APs decrease to order of 10s of metres or less, inter-user interference tends to become unmanageable***





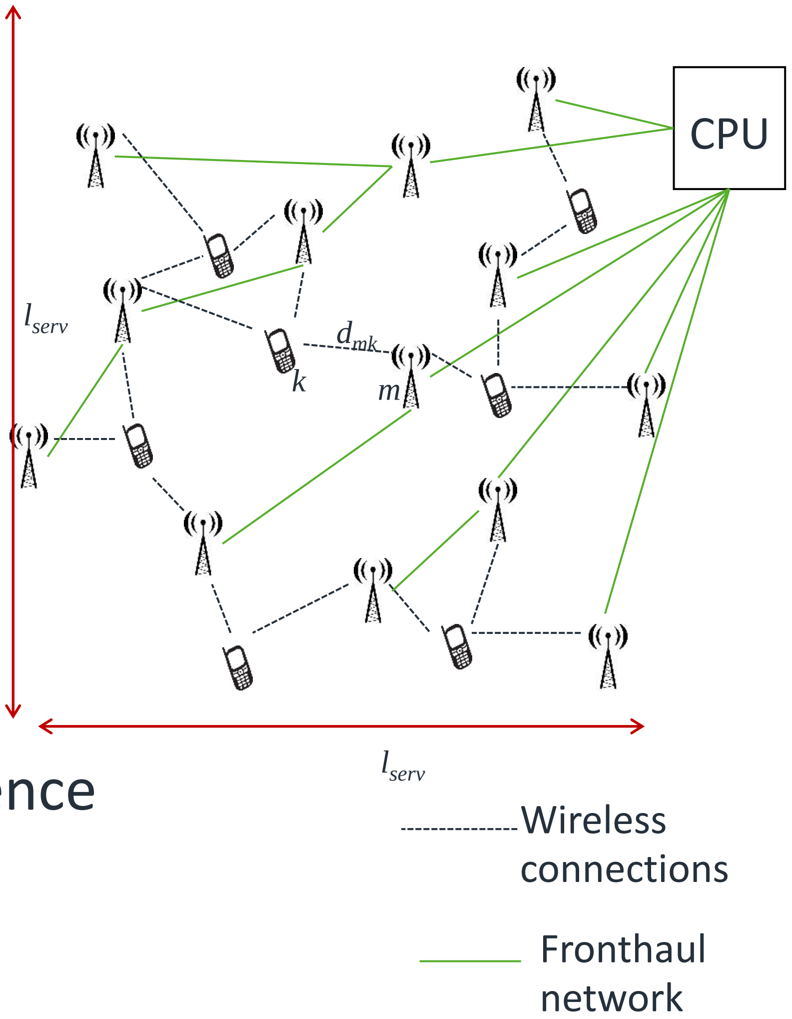
Massive MIMO



- An important new technology for 5G is ***Massive MIMO***, using large antenna arrays at base stations
- Originally derived from the theoretical insight that if the number of antennas in the base station array is much greater than the number of users,
  - then entire system behaves as a single large ***multi-user MIMO*** system
  - and **all users in the cell can be served in the same spectrum** using simple processing
  - clearly this can greatly increase capacity per cell
- However this still operates within the cellular paradigm
  - and leaves "cell edge" users subject to larger path loss and greater ***inter-cell interference***
- An alternative approach is to distribute the antennas from the base station array across the cell in a ***distributed antenna system*** (DAS)
  - while still combining signals at the base station as in a collocated antenna array

“Cell-free” massive MIMO

- “Cell-free” massive MIMO (CF-MaMIMO) goes further
  - distributing the antennas at access points (APs) over a much larger service area
  - and bringing signals to a single central processing unit (CPU) via ***fronthaul*** links
- This brings network infrastructure much closer to all users
  - thus providing a much more uniform service to all
- It in effect abolishes the concept of the cell
  - and hence also inter-cell interference
  - now all APs combine to serve all users, leaving no interference source
- The similarity to the ***C-RAN*** (“Cloud” radio access network; Centralized RAN) architecture is obvious



Relationship with vRAN, O-RAN...

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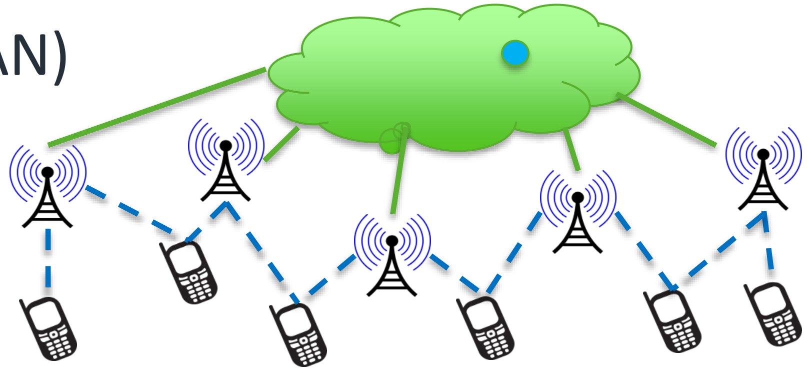
- In general we can consider ***virtualized RAN architectures*** (vRAN)
  - network functions no longer carried out in a specific location by specialised hardware
  - but may be implemented flexibly in processors located throughout the network



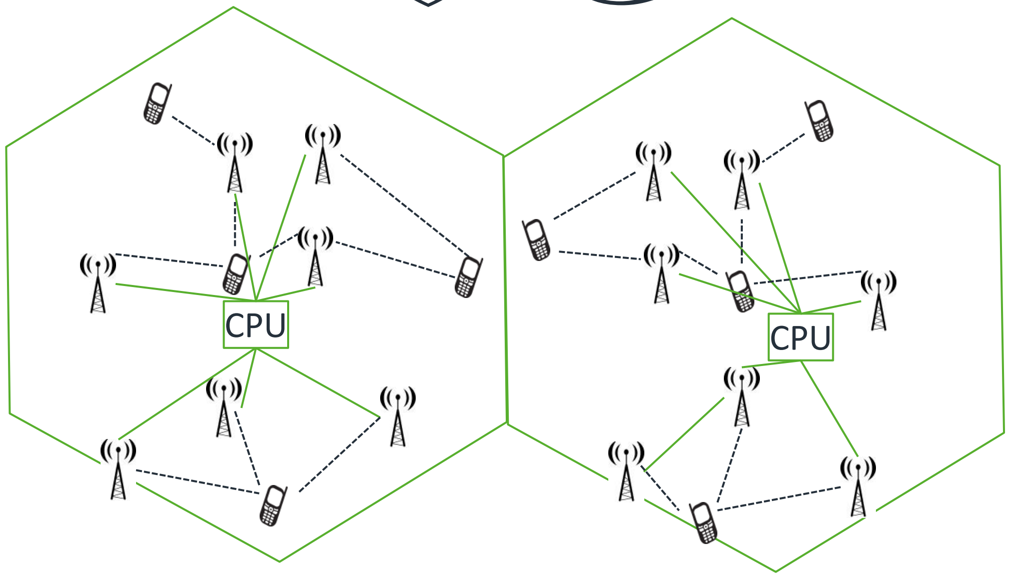
- Known as ***network function virtualization*** (NFV)
  - applies also to modulation/demodulation, beamforming, FFT processing, FEC decoding
- ***Open RAN*** (as promoted by ***O-RAN Alliance***) provides standards for an open multi-vendor radio access network on these principles

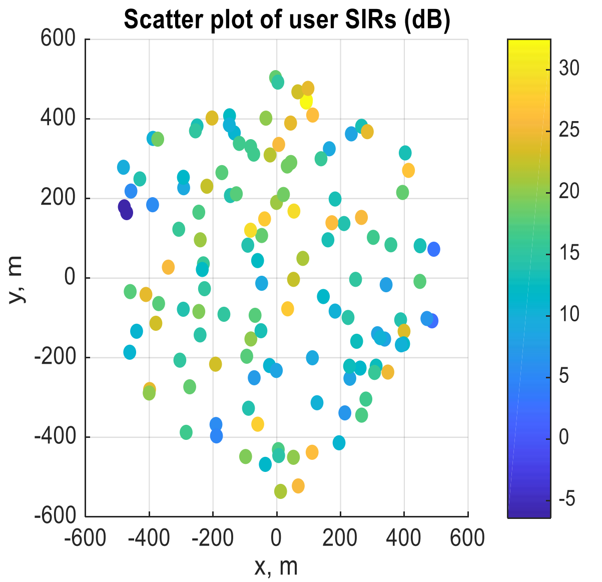
O-RAN ALLIANCE

- **But CF-MaMIMO is not the same as C-RAN, vRAN, etc**
  - C-RAN is focussed on implementation of conventional processing
  - CF-MaMIMO focusses on joint processing to eliminate interference, though could readily be implemented on C-RAN, vRAN, O-RAN platform

Scalability

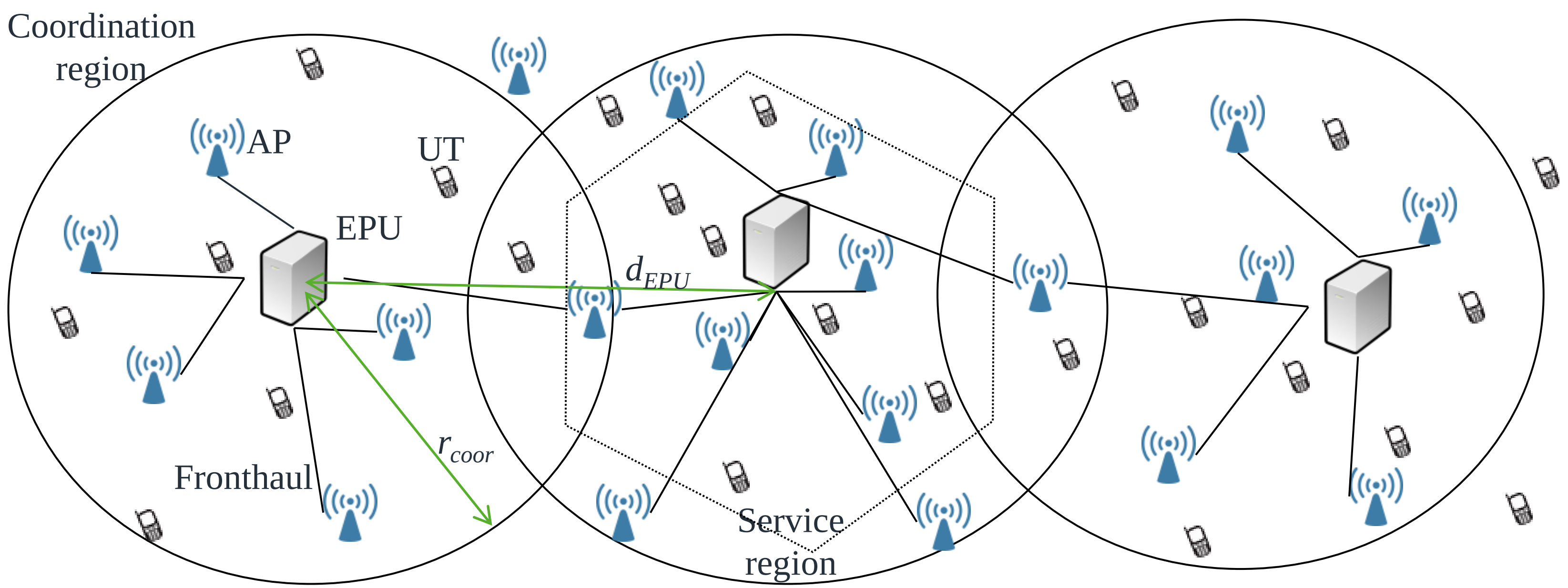
- CF-MaMIMO is not the end of the story
  - its major challenge is **scalability**
- Demands on CPU, delay limitations etc mean service area cannot be increased indefinitely
  - and if service area is split between multiple CPUs, then interference will reappear at edges of regions
  - scatter plot shows that signal to interference ratio (SIR) within region is quite uniform, but edge users may have poor SIR
  - there are still some disadvantaged users
- This has caused us to propose ***"Fog" massive MIMO*** (F-MaMIMO)





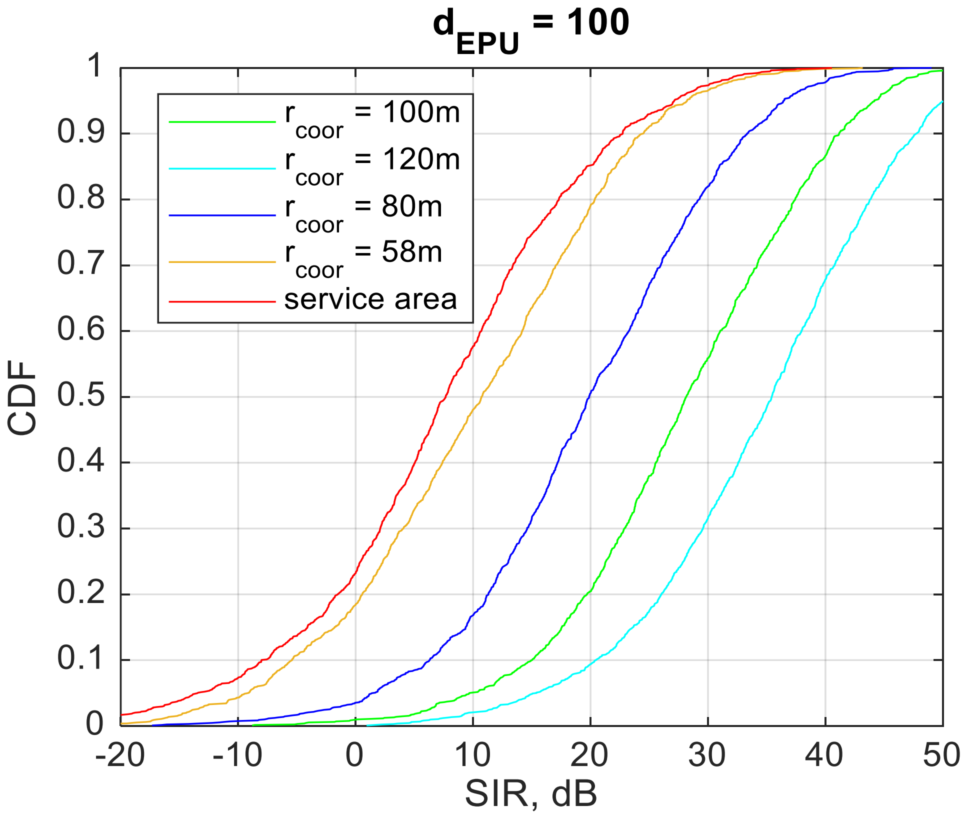
"Fog" massive MIMO

- Move baseband processing back from the "cloud" nearer to the network edge (or "fog")
  - into ***edge processing units*** (EPUs), much smaller and closer than the CPU
- To avoid disadvantaging any users due to edge effects, define:
  - overlapping ***coordination regions*** for each EPU
  - also contiguous ***service regions*** in which all users' signals are processed at given EPU
- APs in coordination region of an EPU are connected to that EPU
  - APs in the overlap of coordination regions may be connected to multiple EPUs



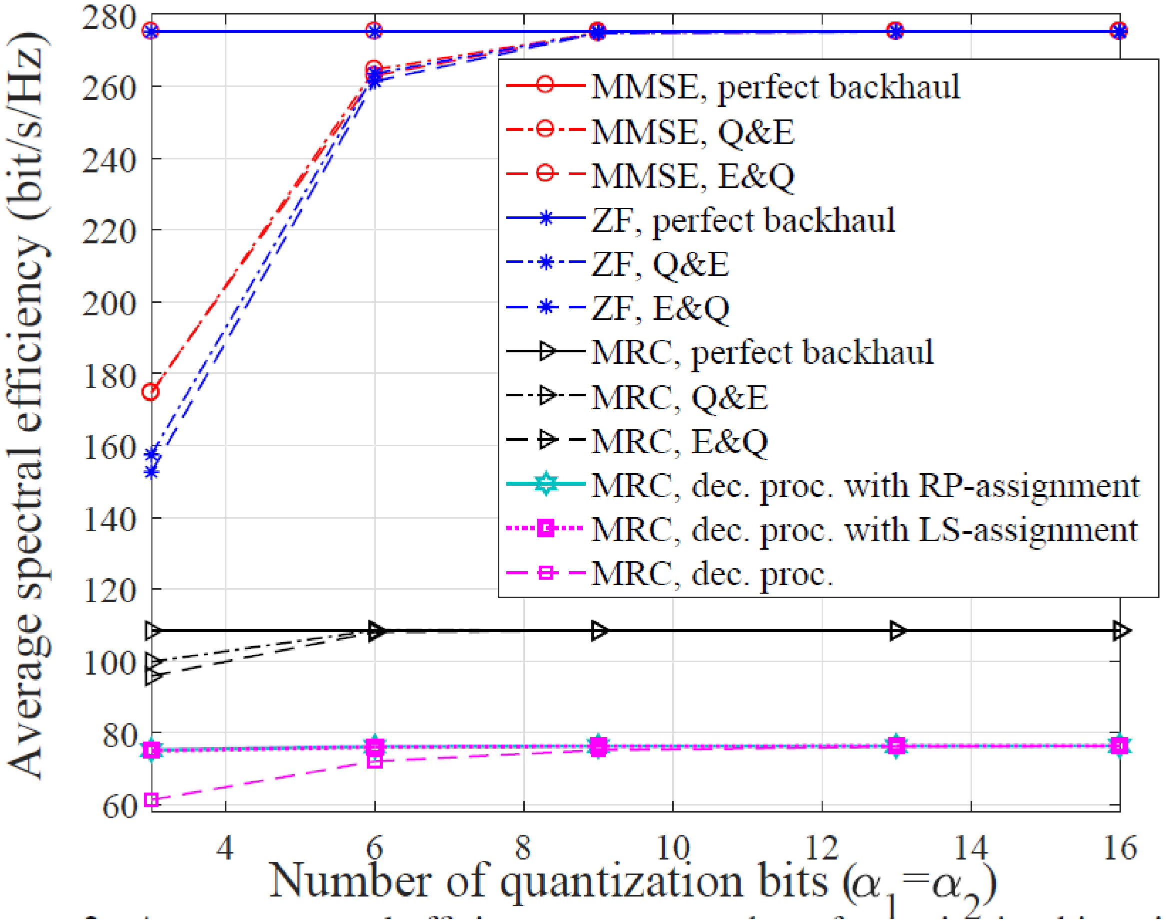
SIR in F-MaMIMO

- The coordination region radius then controls interference from uncoordinated users
  - can significantly increase signal to interference ratio by increasing r_{coor}
- Note that while in CF-MaMIMO CPU regions must be large (many hundreds of users) to limit interference,
  - in F-MaMIMO EPU service regions may cover 10s of users or fewer



Other challenges

- A major challenge in C-RAN – and also in CF-MaMIMO – is fronthaul loads
- Fronthaul transports signals in digital form
  - hence requires quantization of signals
  - this may result in total fronthaul load many times greater than total user throughput
- The CF-MaMIMO approach allows trade-off between precision of digitisation and network performance
  - effect of quantization can be analysed to determine how many quantization bits are required to avoid spectrum efficiency loss
- We can also examine effect of detection algorithms (MRC versus ZF versus MMSE)



Conclusions

- We may be reaching the limits of the network densification which has so far enabled huge increases in cellular network capacity, area spectrum efficiency and availability
  - a new approach is required to avoid excess interference as networks become denser
- Massive MIMO helps to increase capacity per cell
  - but remains within the cellular paradigm, and hence does not overcome intercell interference (ICI)
- We describe “cell-free” massive MIMO
  - effectively abolishes the concept of the cell, and with it ICI
- This has a clear relationship with network architectures like C-RAN, vRAN etc
  - but CF-MaMIMO provides algorithms that ensure elimination of ICI
- CF-MaMIMO has remaining challenges, especially scalability – hence F-MaMIMO
- Also allows theoretical analysis of quantization – hence trade-off with fronthaul load