The Role of Computational Outage in Dense Cloud-Based Centralized Radio Access Networks

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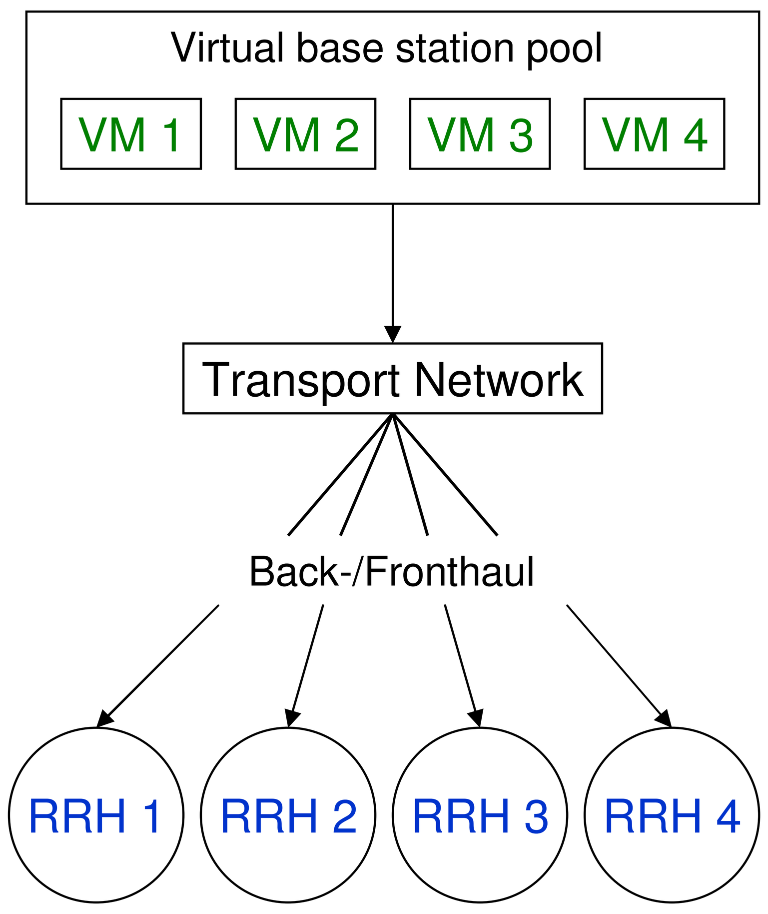
Introduction

- In a centralized radio-access network (C-RAN), all the baseband processing for a group of cells (cloud group) is performed centrally at a computing cloud.
  - A scalable number of virtual machines (VMs) centrally process the signals for a group of base stations (BSs).
  - The transport network connects the cloud group through fiber-optic or possibly mmWave.
  - Each cell is served by a remote-radio head (RRH), which performs minimal processing: typically downconversion and A/D.



Computational Outage

- A computational outage occurs when the amount of computation required to decode the signal in a cloud group exceeds the available resources.
- The probability of computational outage is:

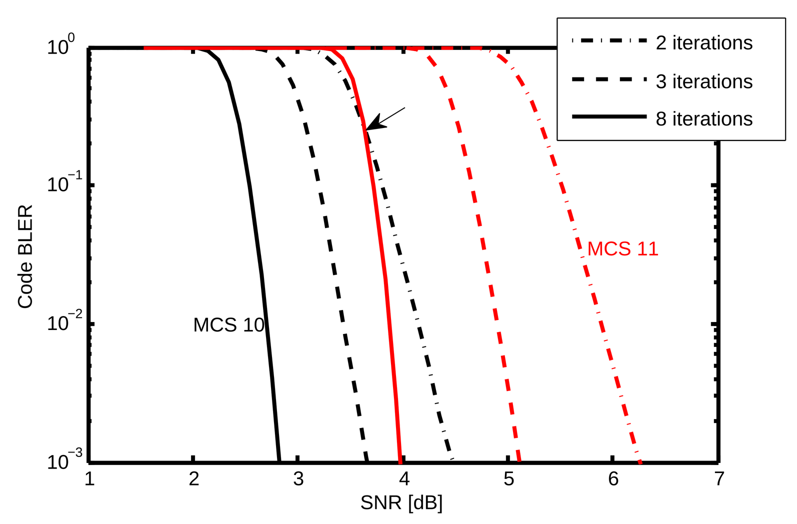
$$\epsilon_{comp} = \mathbb{P}\left[\sum_{i=1}^{N_{cloud}} \mathcal{C}(\gamma_i) > N_{cloud} \cdot \mathcal{C}_{max} \right]$$

Number jointly processed cells; Complexity of i^{th} uplink; Available per-cell computing resources

- From the system perspective, a computational outage is just as harmful as an outage due to fading, noise, and interference (i.e., channel outages).
- The channel and computational outage are not mutually exclusive.

Case Study: Decoding a Single LTE Transport Block

- LTE defines 27 modulation-and-coding schemes (MCSs).
  - ▷ Modulation: 4-QAM, 16-QAM, or 64-QAM.
  - ▷ Variable-rate turbo code through rate matching.

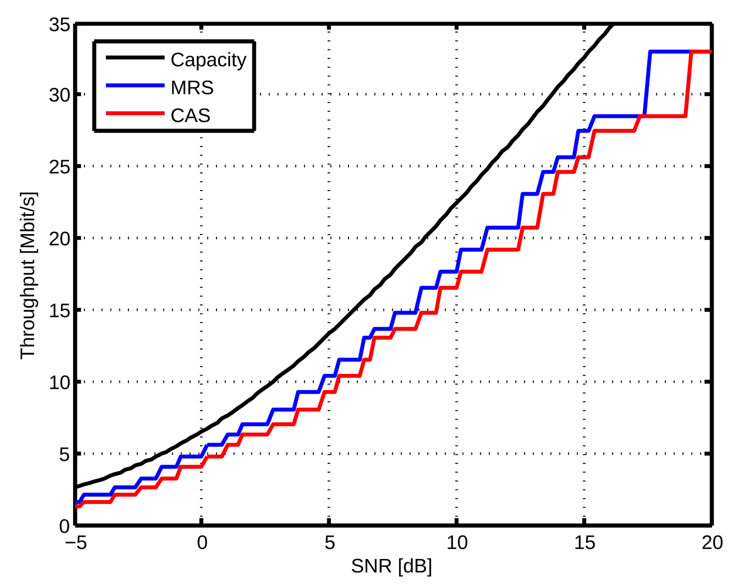


- At ≈ 4 dB:
  - ▷ MCS 10 requires 4x less iterations.
  - ▷ MCS 11 has a 14% higher throughput.

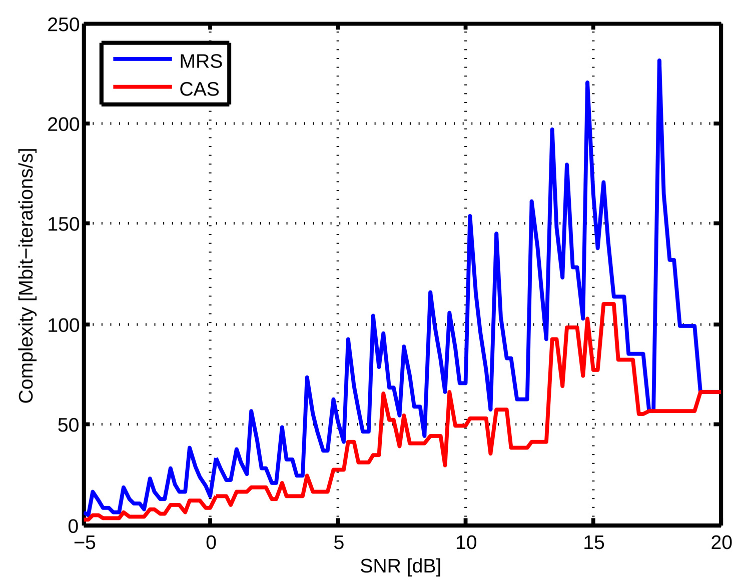
- It is assumed 45 resource blocks (RBS) are allocated to each UE.
  - ▷ Maximum allocation in a 10 MHz deployment, when between three and five RBS are reserved for the physical uplink control channel.

Resource Allocation Options

- Two resource allocation policies are considered:
  - ▷ Max-rate selection (MRS):
    - Pick the MCS that achieves target error rate after 8 iterations of decoding.
    - Tries to maximize rate with little regard to computation.
  - ▷ Computationally-aware selection (CAS):
    - Pick the MCS that achieves target error rate after 2 iterations of decoding.
    - Tries to reduce the number of computations.



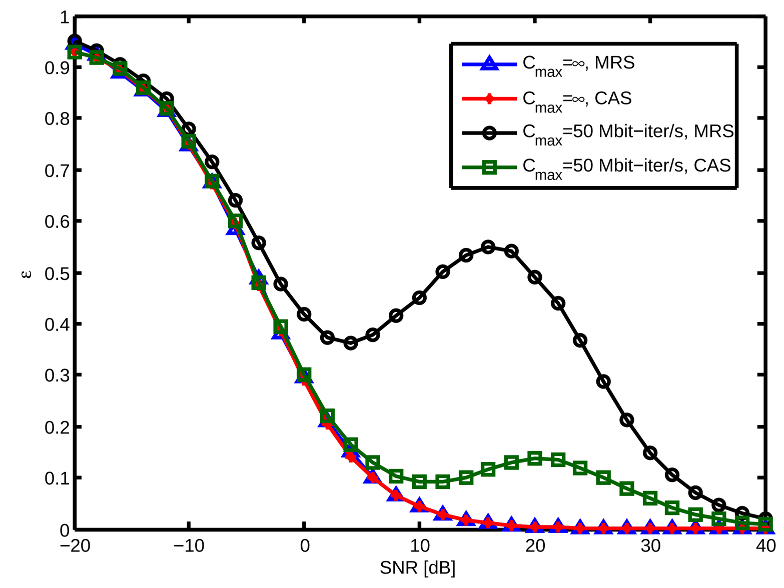
(a) Raw throughput.



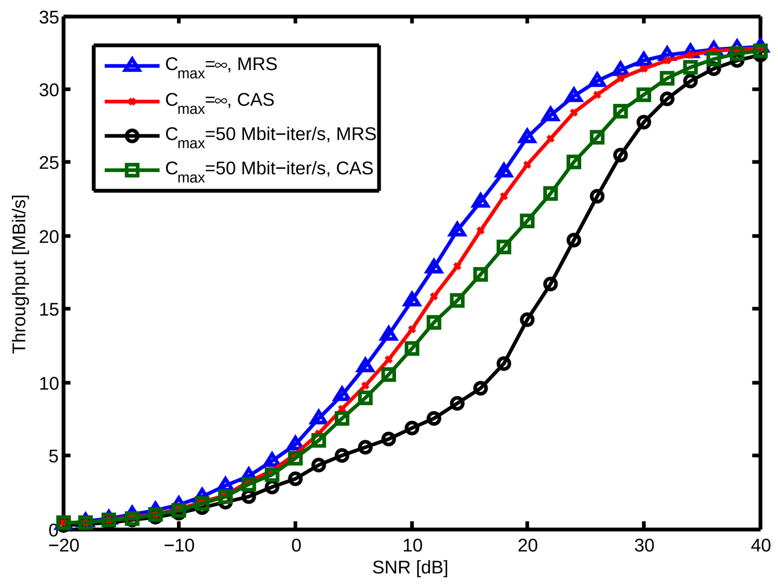
(b) Computational effort.

Results: Impact of Block Rayleigh Fading in an Isolated Cell

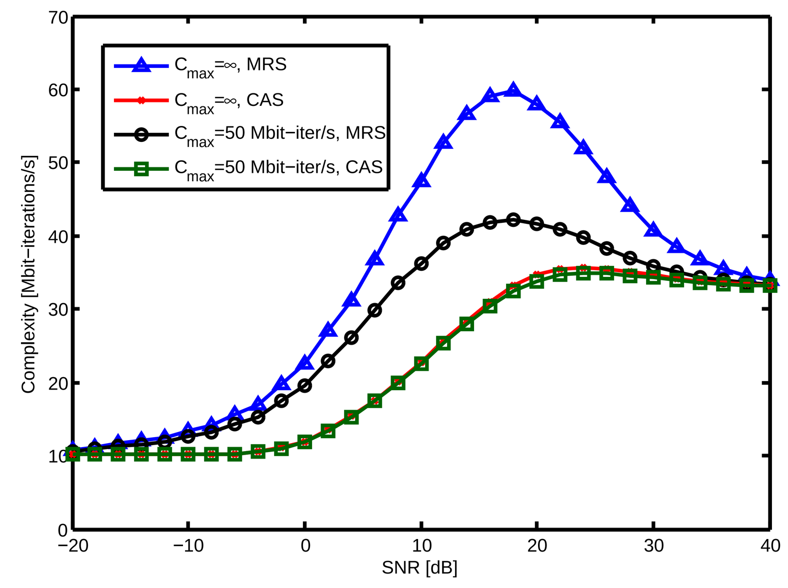
- The outage probability is the probability that a transport block is lost due to either channel or computational outage.
- The effective throughput is the rate of successful transmission.



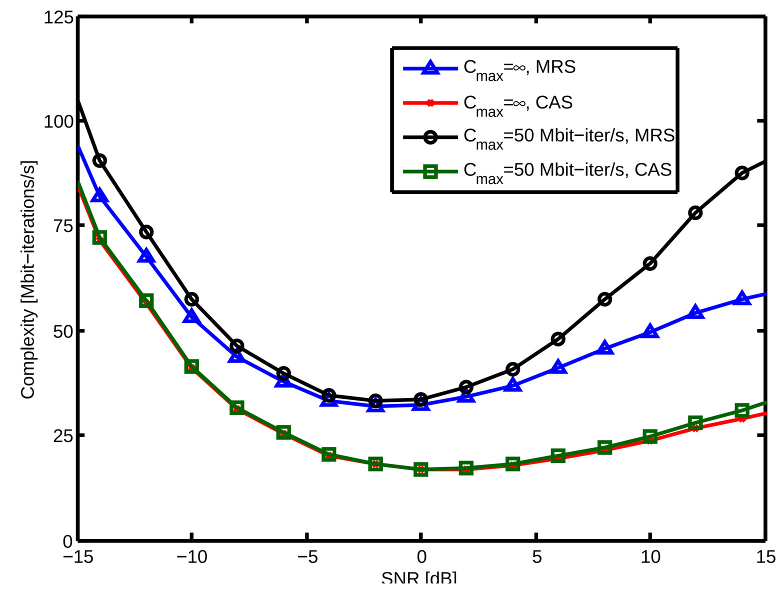
(c) Outage probability.



(d) Effective throughput.



(e) Average complexity.



(f) Complexity required for successfully decoding.

Results: Impact of Co-Channel Interference in the Uplink

- By adopting a distance-dependent path loss, and fractional power control, the SINR for the uplink at the j^{th} BS is:

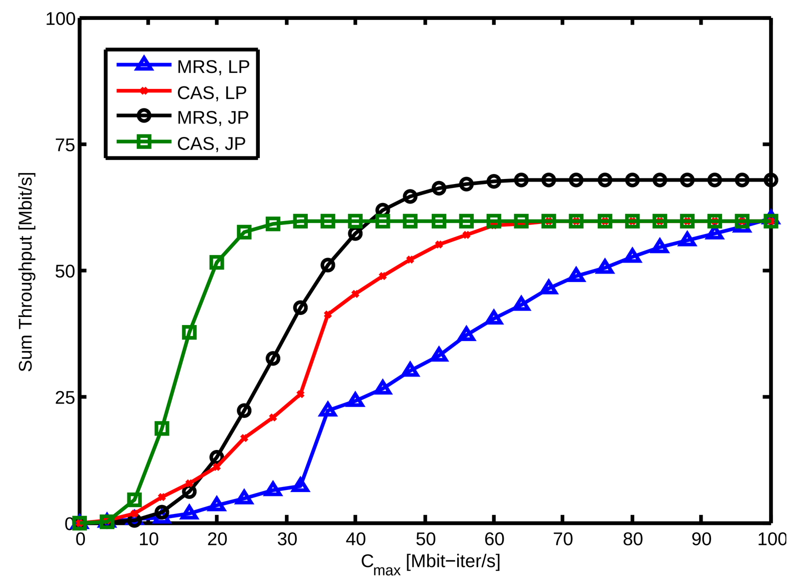
$$\gamma_j = \frac{g_{j,j}\, d_{j,j}^{(s-1)\alpha}}{\Gamma^{-1} + \sum_{i \neq j} g_{i,j} d_{i,j}^{-\alpha} d_{i,i}^{\alpha s}}$$

Power gain due to fading; Path-loss exponent; SNR; Compensation factor; Distance between the i^{th} mobile and the j^{th} BS

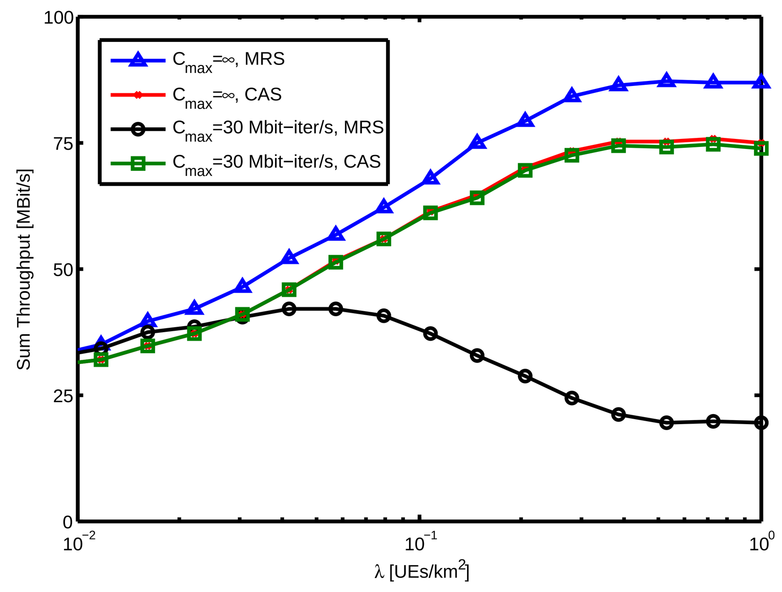
- The following settings are used:

Fading	Rayleigh
Allocated resources	1 UE/cell
Number of BSs	N_{bs} = 129
Location of the BSs	From database of major UK provider
Spatial distribution for the UEs	PPP with intensity λ [UEs/km^2]
Size of cloud group	N_{cloud} = 8
Path loss exponent	α =3.7
SNR	Γ = 20 dB
Compensation factor	s=0.1

- Comparison of:
  - ▷ Central processing (CP): cells are processed centrally.
  - ▷ Local processing (LP): cells are processed separately.



(g) Sum throughput vs complexity constraint with λ =0.1 UEs/Km^2.



(h) Sum throughput vs mobile density.

Conclusions

- Centralized RAN is a viable alternative to local RAN processing.
- The newly introduced concept of computational outage helps to quantify the complexity-throughput tradeoff in centralized RAN platforms.
- A computational-aware resource allocation policy can provide higher throughput when computational resources are constrained.