Computational Outage:
A New KPI for C-RAN

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A VERY SHORT presentation for the University of Southampton, UK

Joint work with
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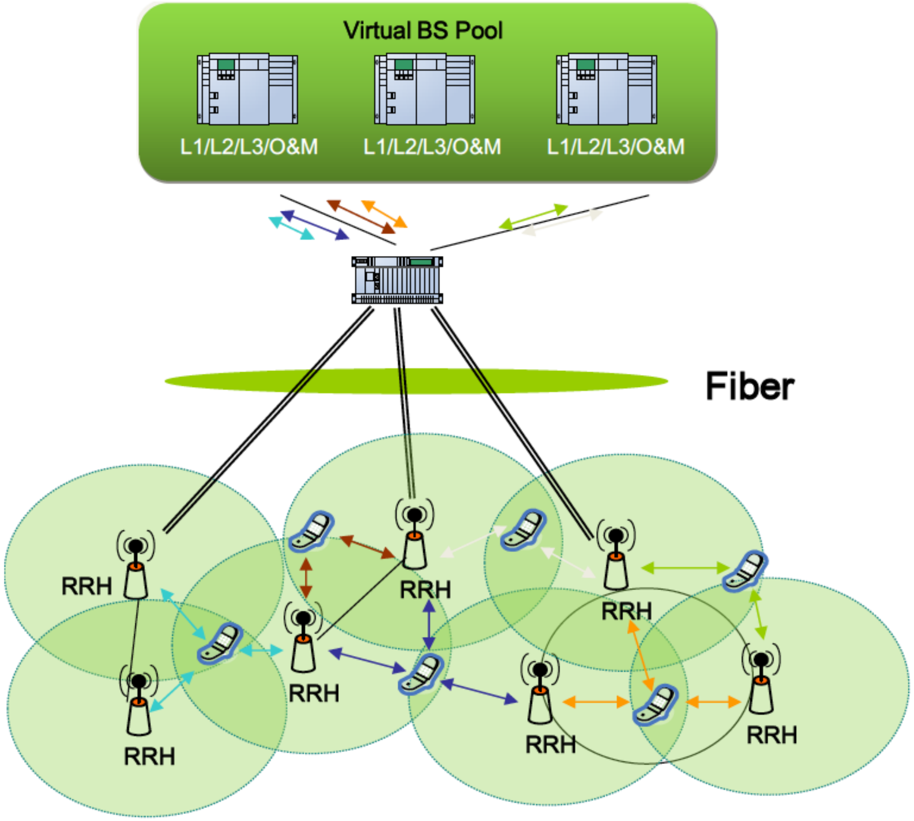
Conclusions Up Front

- C-RAN is coming
  - It can be implemented with current technology
  - Trials are underway, products to follow
- C-RAN is beneficial
  - Creates opportunities for enhanced collaboration
- C-RAN is green
  - Reduces the computational load
  - Opportunities to selectively turn off sites
- C-RAN is challenging
  - Trades benefit on the wireless side for increased demands on the wired fronthaul

C-RAN

- Aggressive use of virtual BBU pools is known as C-RAN
- RAN = Radio Access Network
- C = ?
  - Cloud
  - Central
  - Collaborative
  - Cooperative
  - Clean (i.e., Green)



cloud group

[1]. China Mobile Research Institute, “C-RAN: The Road Towards Green RAN,” White Paper, 2010.

Computational Outage

- If a transport block is not decoded before the deadline, then a computational outage occurs
- From a systems perspective, a computational outage is no different than any other kind of outage (e.g., due to fading or interference)
- For a conventional (locally processed / non-pooled) system, a computational outage occurs when the following condition occurs

$$C(\gamma) > C_{max}$$

  where C_{max} is the maximum number of bit-iterations that can be supported within the deadline
- The computational outage probability is the probability of this event

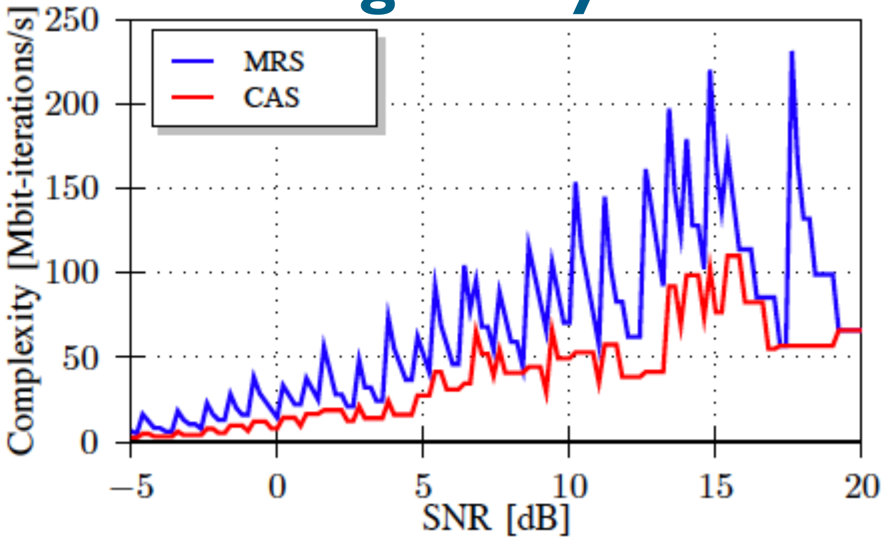
Computational Load for Turbo Decoding

- The load to decode a given transport block is:

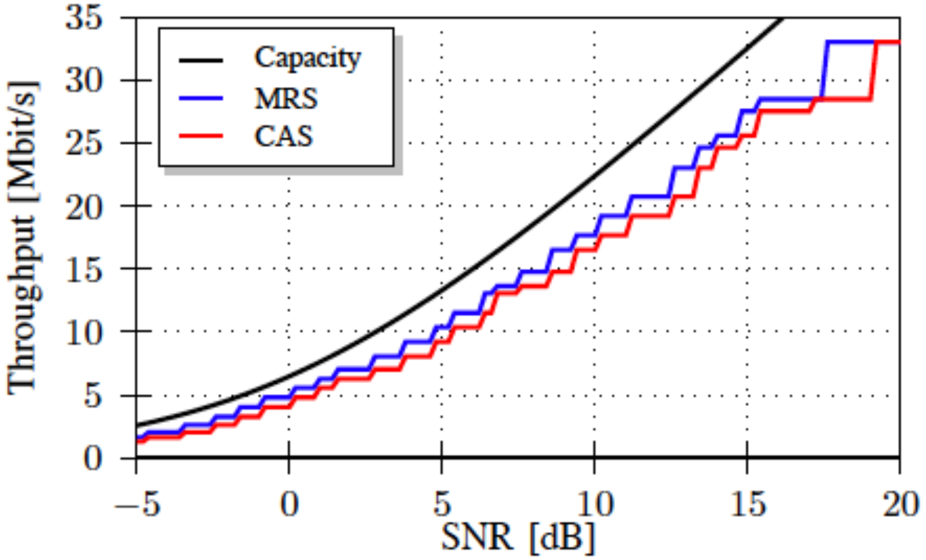
$$\mathcal{C}(\gamma) \quad = \quad \sum_{r=1}^{C} K_r I_r$$

- Where:
  - Load depends on SINR γ and the selected MCS
  - C is the number of code blocks after segmentation
  - K_r is the number of information bits in the rth code block
  - I_r is the number of decoding iterations for the rth code block
- Load is in units of bit-iterations
  - Relation between bit-iterations and CPU cycles is implementation dependent, but fixed for a given architecture

Scheduling Policy Influences the Load



(b) Computational effort



(a) Raw throughput

- MRS = max-rate scheduling
  - Target 10^{-1} BLER after 8 iterations
- CAS = computationally aware scheduling
  - Target 10^{-1} BLER after just 2 iterations

[2]. M.C. Valenti, S. Talarico, and P. Rost, “The role of computational outage in dense cloud-based centralized radio access networks,” in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, (Austin, TX), Dec. 2014.

Effect of Mobile Density

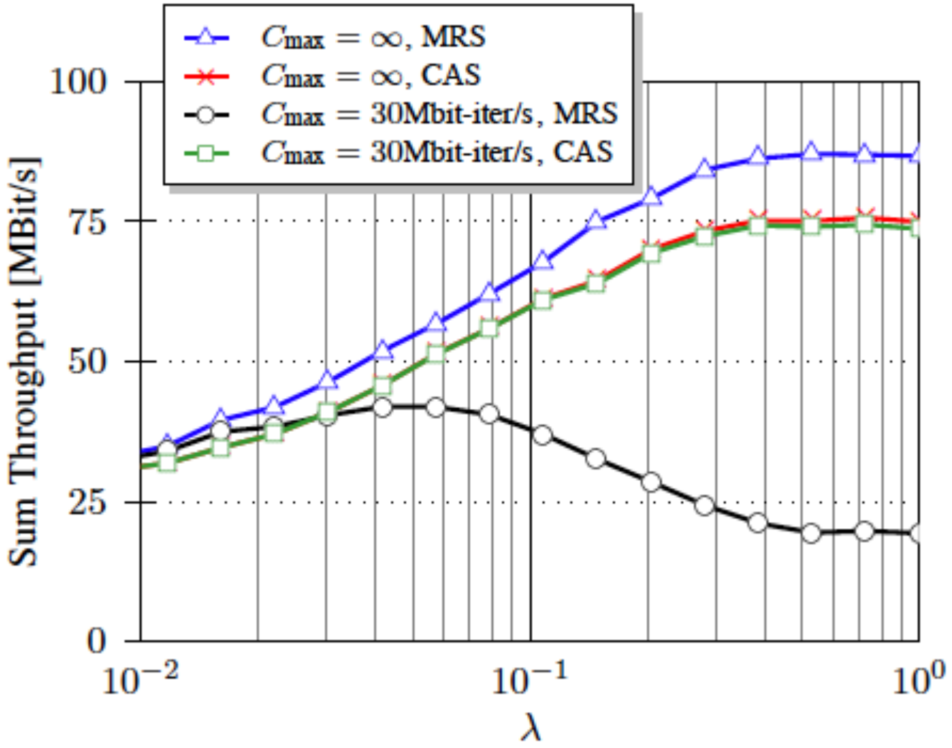
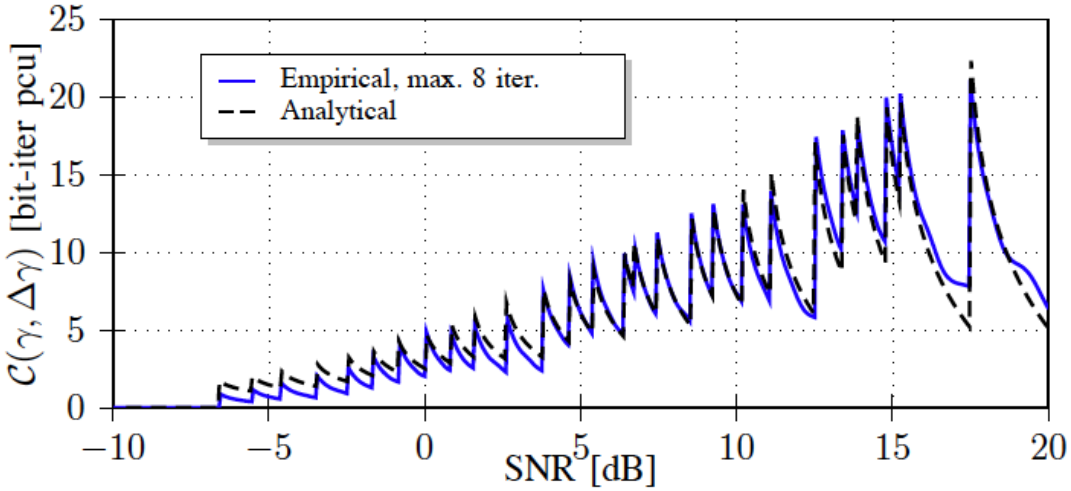


Fig. 9. Sum throughput with cloud processing as function of the density of UEs when $N_{\text{cloud}} = 8$. Two MCS-selection schemes are considered: computationally aware selection (CAS) and max-rate selection (MRS).

- Centrally processed
- Variable density of mobile devices
- When constrained, MRS degrades with increasing user density

[2]. M.C. Valenti, S. Talarico, and P. Rost, "The role of computational outage in dense cloud-based centralized radio access networks," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, (Austin, TX), Dec. 2014.

Towards a Theory for Computational Outage



- The complexity of decoding can be modeled statistically
- Similar to modeling the channel statistically
- By using the statistical model, analytical insight can be obtained without resorting to simulation

[3]. P. Rost, S. Talarico, and M.C. Valenti , "The complexity-rate tradeoff of centralized radio access networks," *IEEE Transactions on Wireless Communications,* vol. 14, no. 11, pp. 6164-6176, Nov. 2015.

Outage Complexity

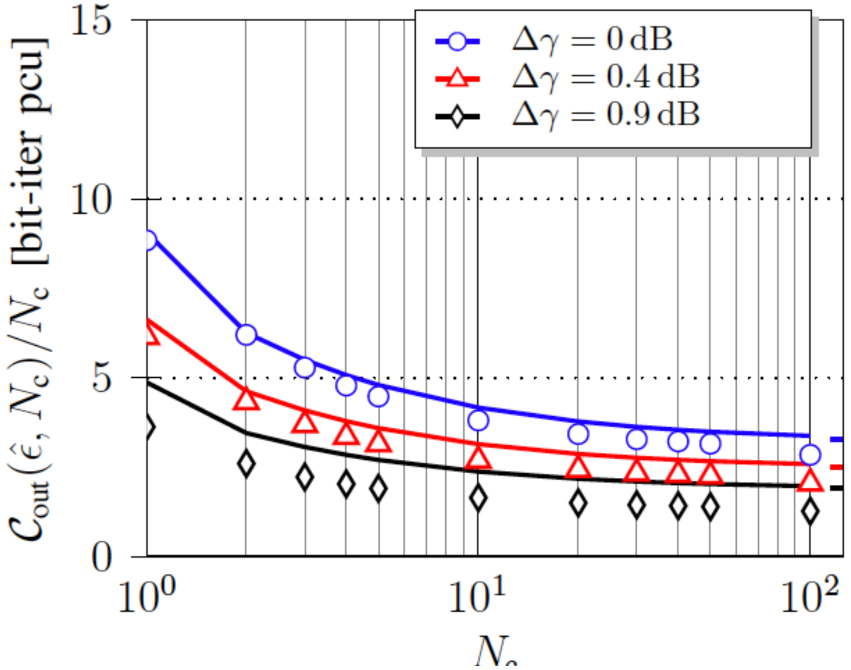


Fig. 5. Outage complexity to ensure per-cell outage constraint $\hat{\epsilon} = 0.1$ as function of the number of RAPs, whose signals are centrally processed. Solid lines are evaluated analytically, while dots are obtained through simulations using one million trials. The notches on the right side of each sub-figure show the behavior as $N_\mathrm{c} \to \infty$.

- Outage complexity is the amount of computing power required to achieve a desired computational outage probability
- Analogous to outage capacity
- Useful to plot as a function of the cloud group size N_{cloud}
- Can be used to rapidly determine compute power needed

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Optimal Scheduling

- The scheduling problem can be formulated as

$$\mathcal{R}_{\text{opt}} = \arg\max_{\mathcal{R} \in \mathcal{R}'} \sum_{r_k \in \mathcal{R}} r_k, \quad \text{s.t.} \sum_{r_k \in \mathcal{R}} \mathcal{C}_k \leq \mathcal{C}_{\text{server}}.$$

where r_k is the rate of the k^{th} user, C_k is its offered computational load, and C_{server} is the total available computing power

- Optimal solution results in a water-filling algorithm
- A heuristic alternative solution is to simply pick the user with highest complexity and back off its rate until the complexity constraint is satisfied

[4] P. Rost, A. Maeder, M.C. Valenti, and S. Talarico, “Computationally aware sum-rate optimal scheduling for centralized radio access networks,” in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, (San Diego, CA), Dec. 2015.

Benefits of Optimal Scheduling

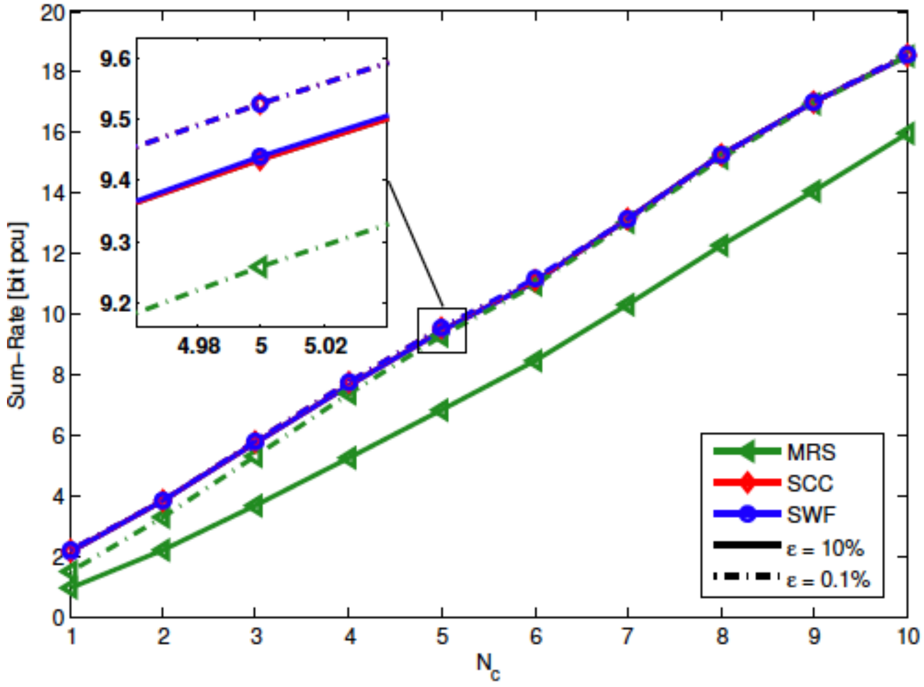
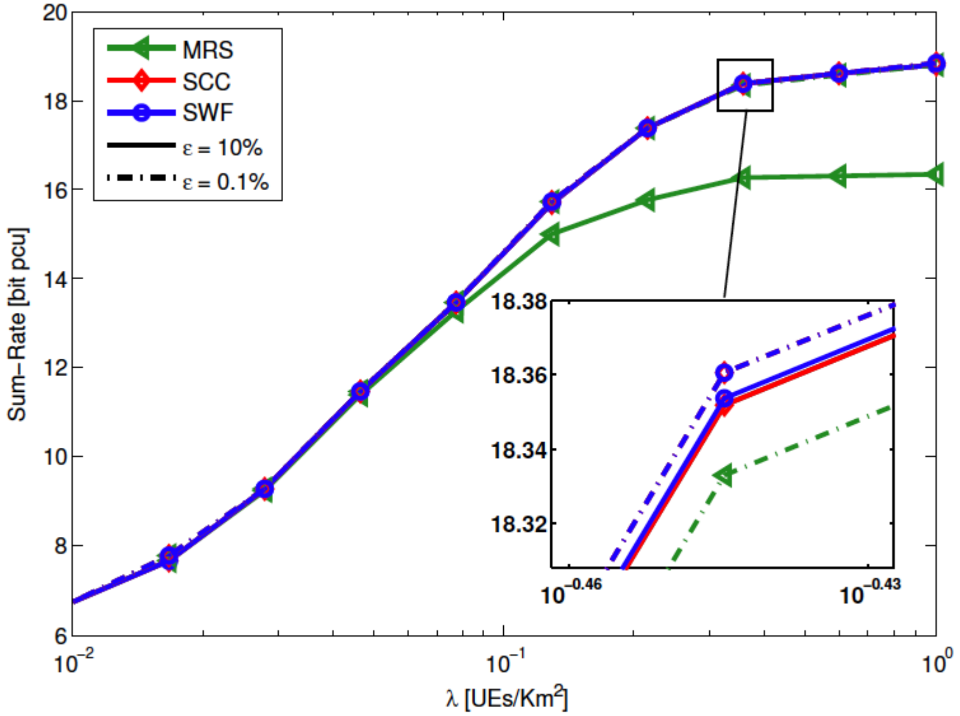


Fig. 4. Sum-rate as a function of N_c.

- Three approaches
  - max-rate scheduling (MRS)
  - scheduling with complexity cutoff (SCC)
  - scheduling with water filling (SWF)
- Cellular network
  - 129 actual base stations
  - λ = 1 device per km^2
- Variable N_{cloud}

[4] P. Rost, A. Maeder, M.C. Valenti, and S. Talarico, “Computationally aware sum-rate optimal scheduling for centralized radio access networks,” in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, (San Diego, CA), Dec. 2015.

Scheduling More Important As Network Densifies



- Fix N_{cloud} = 10
- Vary the user density
- Optimal scheduling provides 20% higher throughput for highly dense networks

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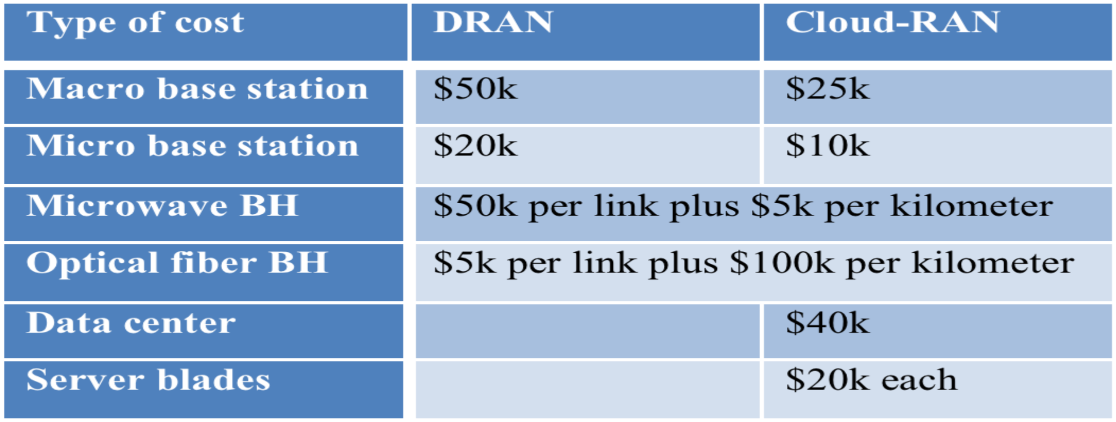
C-RAN vs. Decentralized RAN --- Economic Perspective

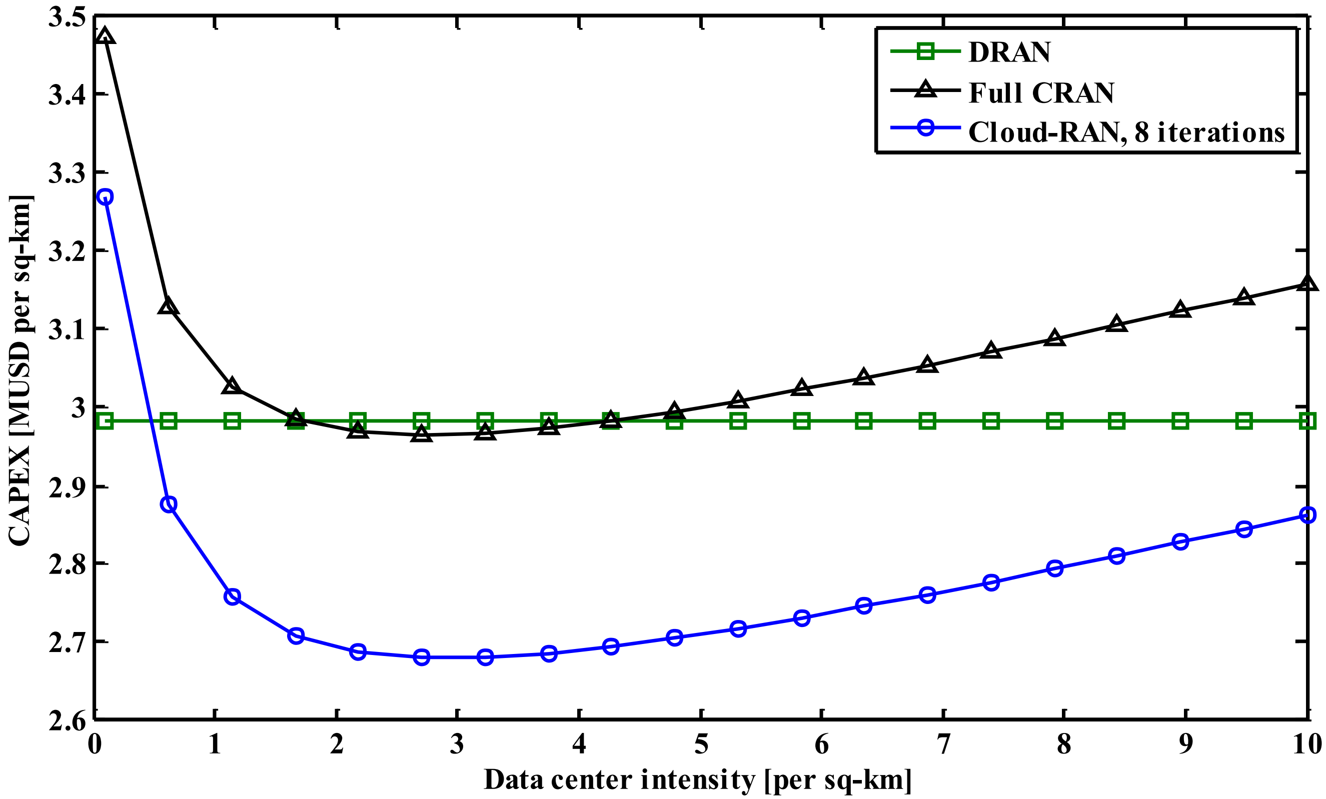
- The costs of C-RAN are determined by
  - Cost per RRH
  - Cost per BBU server
  - Cost for fronthaul / backhaul (per km)



Type of cost	DRAN	Cloud-RAN
Macro base station	$50k	$25k
Micro base station	$20k	$10k
Microwave BH	$50k per link plus $5k per kilometer	
Optical fiber BH	$5k per link plus $100k per kilometer	
Data center		$40k
Server blades		$20k each

[5] P. Rost, I. Berberana, A. Maeder, H. Paul, V. Suryaprakash, M.C. Valenti, D. Wubben, A. Dekorsy, and G. Fettweis, “Benefits and challenges of virtualization in 5G radio access networks,” *IEEE Communications Magazine*, vol. 53, no. 12, Communications Standards Supplement, pp. 75-82, Dec. 2015.

Economic Analysis: An Example



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QUESTIONS?

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