Graph-based Framework for Flexible Baseband Function Splitting and Placement in C-RAN

Group Meeting Presentation (Paper Review)

J. Liu, “Graph-based framework for flexible baseband function splitting and placement in C-RAN,” *Proc. IEEE ICC*, 2015.

Speaker: Yu Wu
04/13/2018

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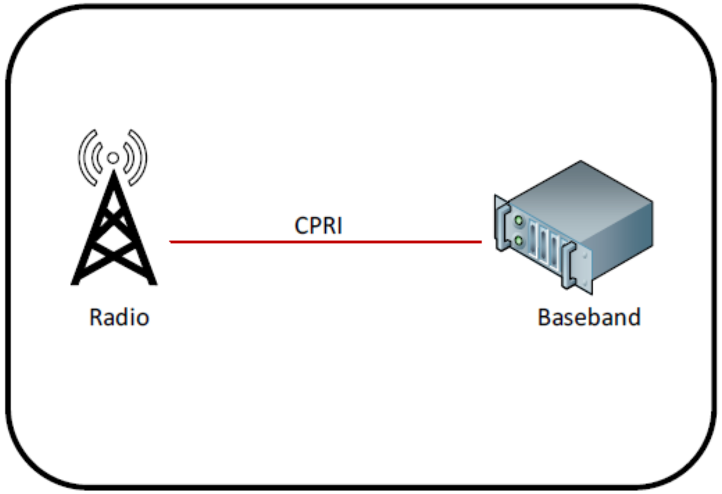
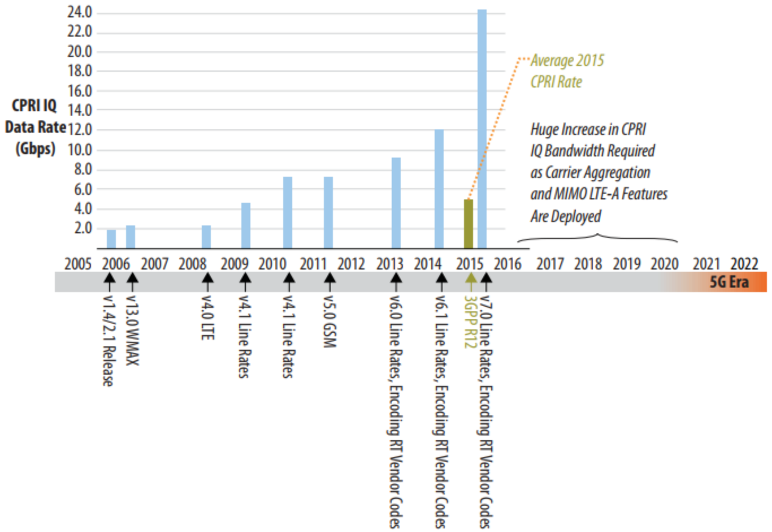
Motivations

- In C-RAN, radio signals are first digitized at the antenna sites by **remote radio heads (RRHs),** and then transported via **fronthaul network** to centralized **baseband processing units (BBUs)** for signal processing.
- However, the major challenge is the **huge bandwidth requirement** for fronthaul network. For a typical long-term evolution (LTE) cell configuration of 20 MHz wireless bandwidth and 8 antennas, 10 Gbps fronthaul bandwidth is required in downlink (DL) or uplink (UL) to transport baseband samples.





X. Liu, *et al.*, "Evolution of mobile fronthaul towards 5G wireless and its impact on time-sensitive optical networking," *Proc. OFC*, 2017.

Altera, "The Emerging Need for Fronthaul Compression," *White Paper*, 2016.

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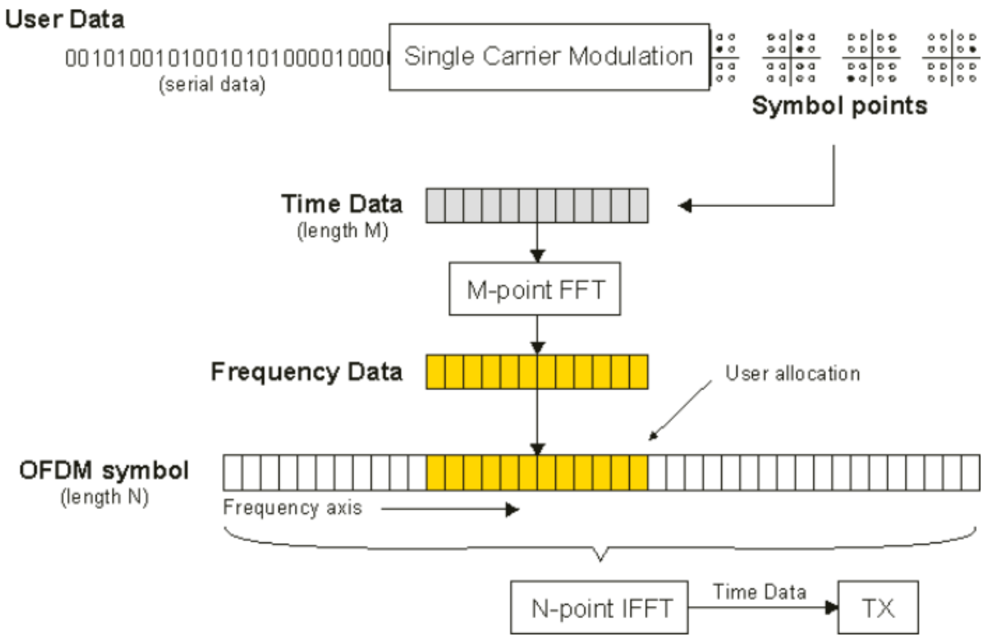
Motivations

❑ Why radio samples demand huge bandwidth?



What happens in your smart phone

❖ For example, modulation turns constellation codewords, which can be represented with only a few bits (4 bits for 16 QAM), into complex constellation samples, which is usually digitized with tens of bits (30 bits for LTE).

❖ Other functions like channel encoding and beamforming, also introduce redundancies.

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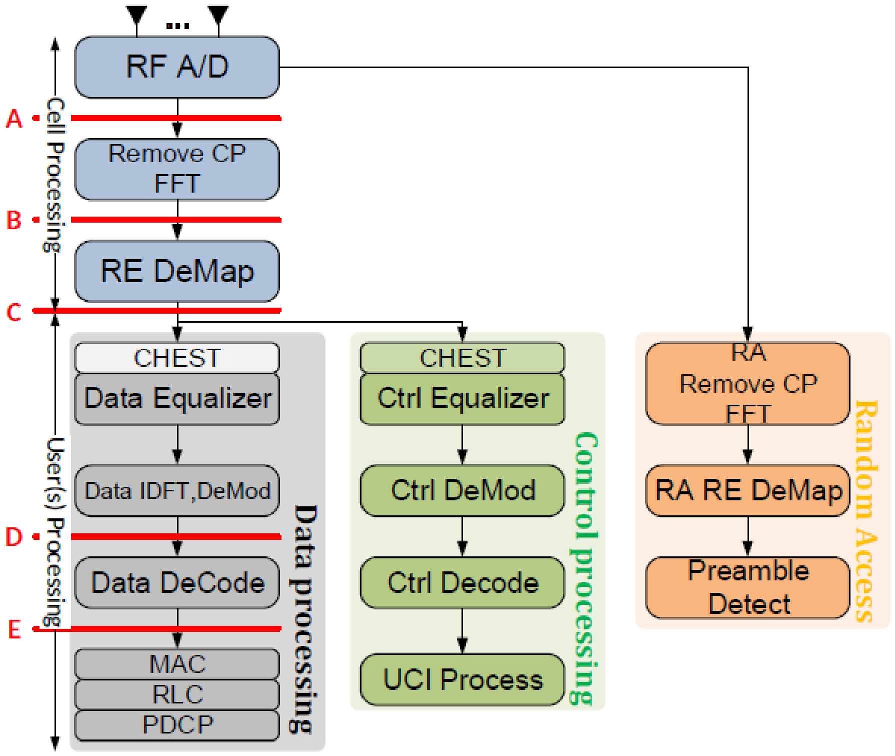
Keysight Technologies, "LTE Physical Layer Overview," http://rfmw.em.keysight.com/wireless/helpfiles/89600b/webhelp/subsystems/lte/content/lte_overview.htm.

Motivations

- How does functional split help?



Entire BBU stack

- **Split A**: The RRH includes only time-domain RF and A/D while the BBU includes all other functions. This is the standard split considered in C-RAN.
- **Split B**: The RRH further removes the cyclic prefix (CP) in the time domain. It then applies FFT, transforming samples from time domain to frequency domain, and finally removes guard band sub-carriers.

Keysight Technologies, "LTE Physical Layer Overview," http://rfmw.em.keysight.com/wireless/helpfiles/89600b/webhelp/subsystems/lte/content/lte_overview.htm.

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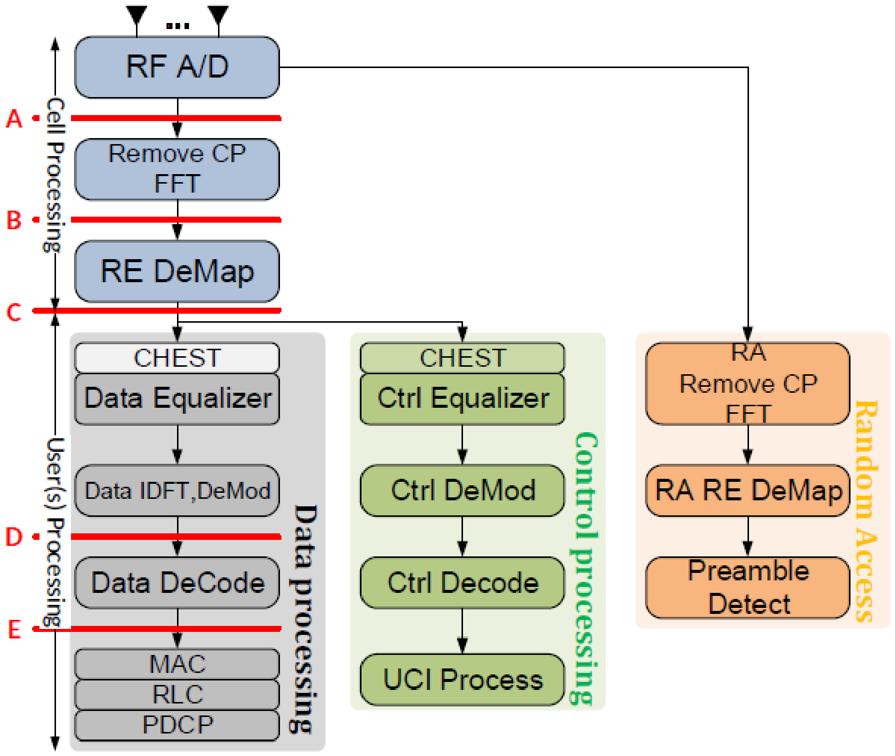

Entire BBU stack

- **Split C**: Includes also the resource element demapper in the RRH, which categorizes used resources based on pre-allocated information of each served UE. In this split, essentially per-cell processing takes place inside the RRH, and per-UE processing in the BBU.
- **Split D**: The RRHs now also do some per-user processing. Channel estimation based on control and data reference signal (RS) symbols is performed and the estimation result is then applied for equalization. Afterwards, it applies IDFT and demodulation outputs the log-likelihood ratio (LLR) of each bit to BBU.
- **Split E**: The RRHs further perform bit-rate processing, including de-scrambling, de-rate matching, channel decoding and CRC check. The BBU will receive whole transport block in bits for higher layer processing.

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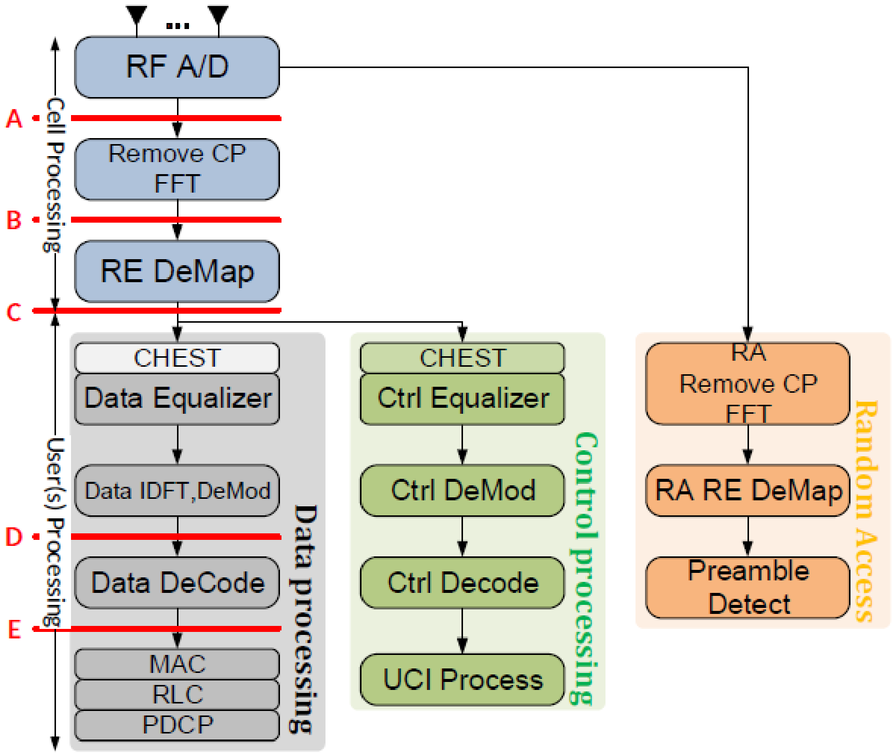

Entire BBU stack

- Observations
  - Bandwidth requirement decreases from split A to split E.
  - Traffic after splits A/B requires constant transmission rate while traffic after splits C/D/E depends on end users in terms of:
    - How many users are transmitting at current OFDM symbol.
    - How often do users transmit.

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Keysight Technologies, "LTE Physical Layer Overview," http://rfmw.em.keysight.com/wireless/helpfiles/89600b/webhelp/subsystems/lte/content/lte_overview.htm.

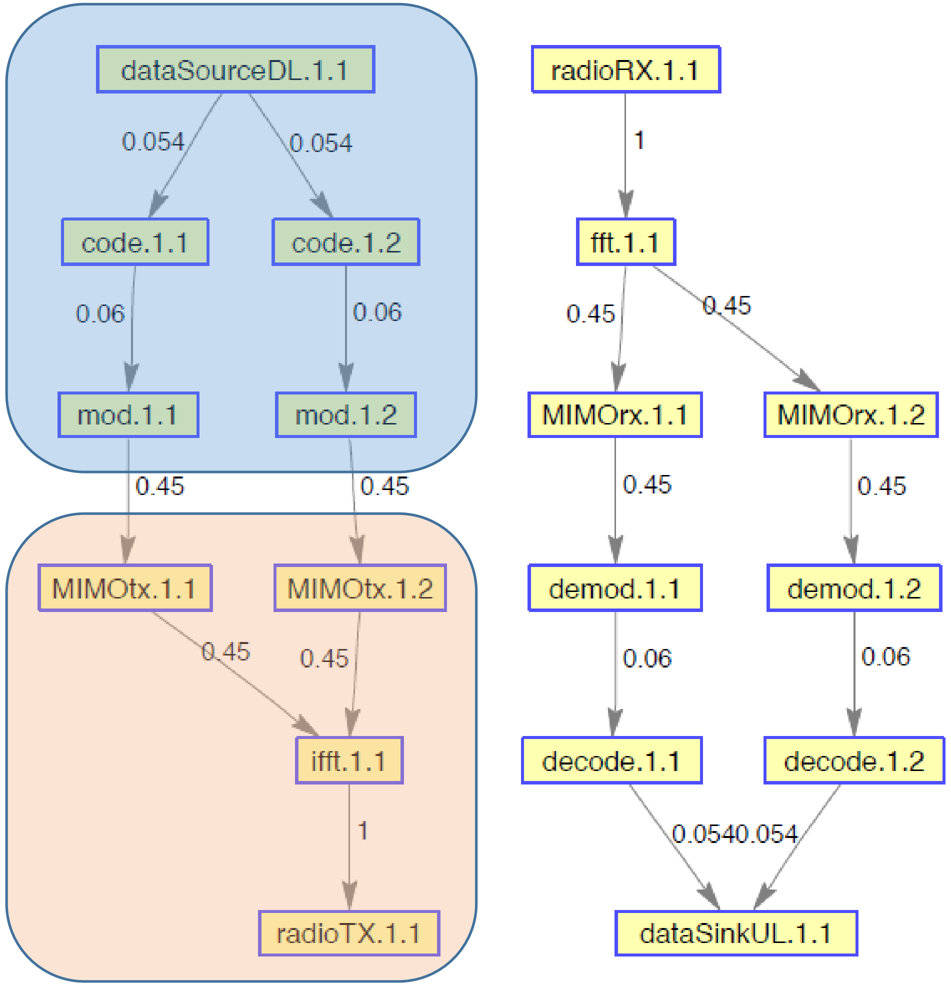
Contributions

- Tradeoff between computational cost and fronthauling cost.
  - **Computational cost:** the cost to place baseband processing functions. It differs from locations (BBU or RRH).
  - **Fronthauling cost:** the cost to transmit signals over fronthaul network. It is proportional to required transmission bandwidth.

- In this paper, the authors present a graph-based framework for baseband function splitting and placement.
  - Translate baseband processing functions into directed graphs so that the splitting and placement problems can be formulated as graph clustering problems.
  - Propose a genetic algorithm with customized fitness function and mutation module for the graph-clustering problem.
  - Perform simulations to study the tradeoff.

Graph-based Clustering Scheme

- Link weight $\omega(e)$ to represent amount of information it carries



- Overhead of cyclic prefix and control signaling is 10%
- During modulation/demodulation, 30 bit complex baseband sample is transformed from/into a 4 bit constellation codework (16 QAM).
- In case of CoMP, mutual links between neighbouring MIMO modules are added in a cyclic fashion.

Graph-based Clustering Scheme

- Node weight $\gamma(v)$ to represent its computational complexity

Index	1	2	3	4	5	6
Type	radioTX	radioRX	fft	ifft	MIMOtx	MIMOrx
Weight	0	0	1	1	0.5	0.5
Index	7	8	9	10	11	12
Type	mod	demod	code	decode	sourceDL	sinkUL
Weight	0.1	0.1	0.1	2	0	0

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S. Bhaumik, et al., "CloudIQ: a framework for processing base stations in a data center," *Proc. ACM MobiCom*, 2012.

Graph-based Clustering Scheme

- Computational cost function for a cluster *i*

COMPUTATIONAL COST FUNCTION $c_c(i, \xi)$ USED IN SIMULATION.

Cell site	Central office
$2^{\sum_{\xi(v)=i} \gamma(i)}$	0

ξ: a mapping from node to cluster

- Fronthauling cost function between cluster *i* and cluster *j*

FRONTHAULING COST FUNCTION $c_f(i, j, \xi)$ USED IN SIMULATION.

Clusters	Cost
within cell site	0
within central office	0
between cell sites i and j	$4^{\sum_{\xi(e)=(i,j)} \omega(e)}$
between cell site and central office	$2^{\sum_{\xi(e)=(i,j)} \omega(e)}$

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Graph-based Clustering Scheme

- Latency constraint on a path *p*

DELAY FUNCTION $d(p;\xi)$.

cell site	central office
$\sum_{v\in p}\left(\gamma(v)\sum_{\xi(w)=\xi(v)}\gamma(v)\right)$	0

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Genetic Algorithm

- Objective (fitness function)

$$
\begin{aligned}
F(\boldsymbol{\xi};\alpha,\beta) =& \alpha \sum_i c_c(i;\xi) + (1-\alpha) \sum_i \sum_j c_f(i,j;\xi)) \\
&+ \beta \sum_p (d(p;\xi) - D(p))^+,
\end{aligned}
$$

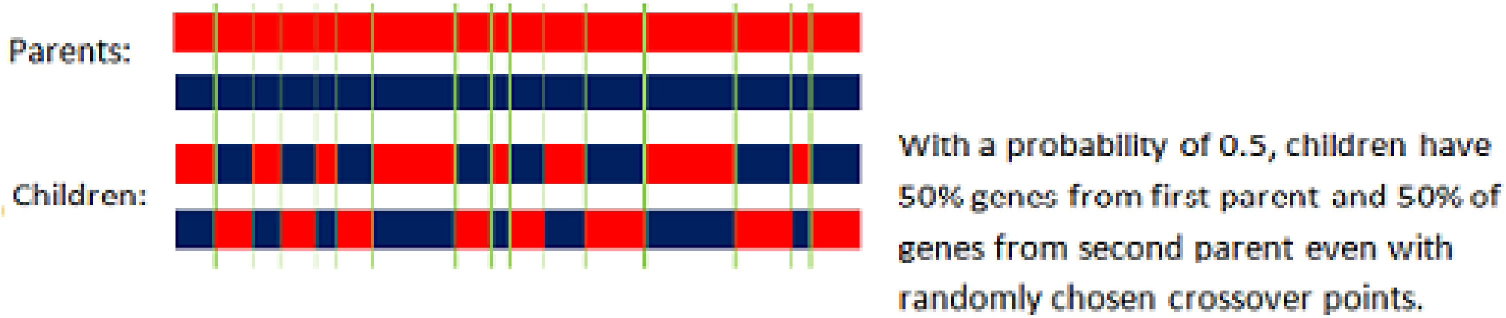
Genetic Algorithm

- **Natural encoding and cluster seeding**
  - The clustering scheme can be represented with a discrete valued vector $\xi \in Z^N$, where N is the total number of baseband processing functions. The k-th entry is the cluster index for the k-th function/node.

  - Some functions/nodes (seed nodes) can only be place at specific cluster. For example, radio transmitter or receiver have to be placed at distributed cell sites.

Genetic Algorithm

- **Crossover:**
  - This crossover function selects the genes of an offspring from its parents with equal probability.



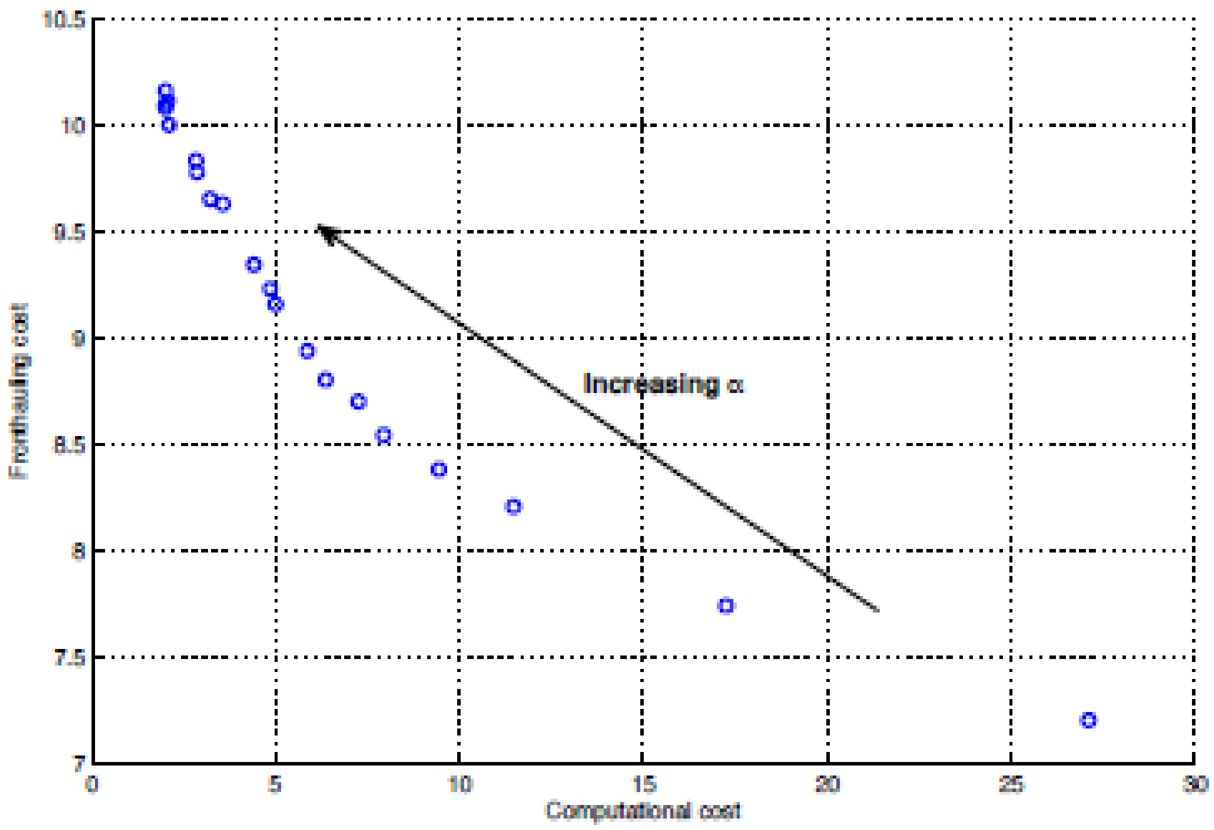
Wikipedia, “Genetic algorithm,” https://en.wikipedia.org/wiki/Crossover_(genetic_algorithm)#/media/File:UniformCrossover.png.

Genetic Algorithm

- **Graph-based mutation**
  - Allowed Mutation Set, $A(i) = \{\xi(j) \mid C(i, j) = 1, j \text{ is seed}\}$, includes the clusters that a node i is currently connected with.
  - Randomly change the value of an individual's chromosome at position i to a value selected from A(i).
  - Mutation function helps the population's chromosomes escape from local minimum.

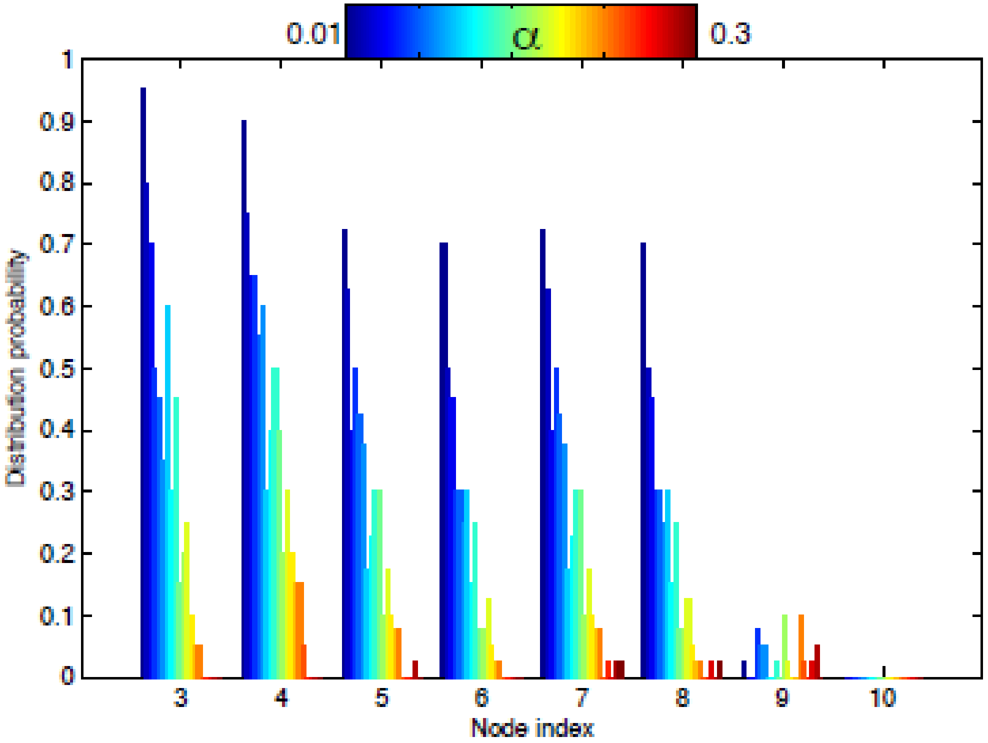
Simulation Results

- ❑ Tradeoff between computation and fronthauling costs by varying α, D(p) = 30.



Simulation Results

- Clustering schemes under different α, D(p) = 30



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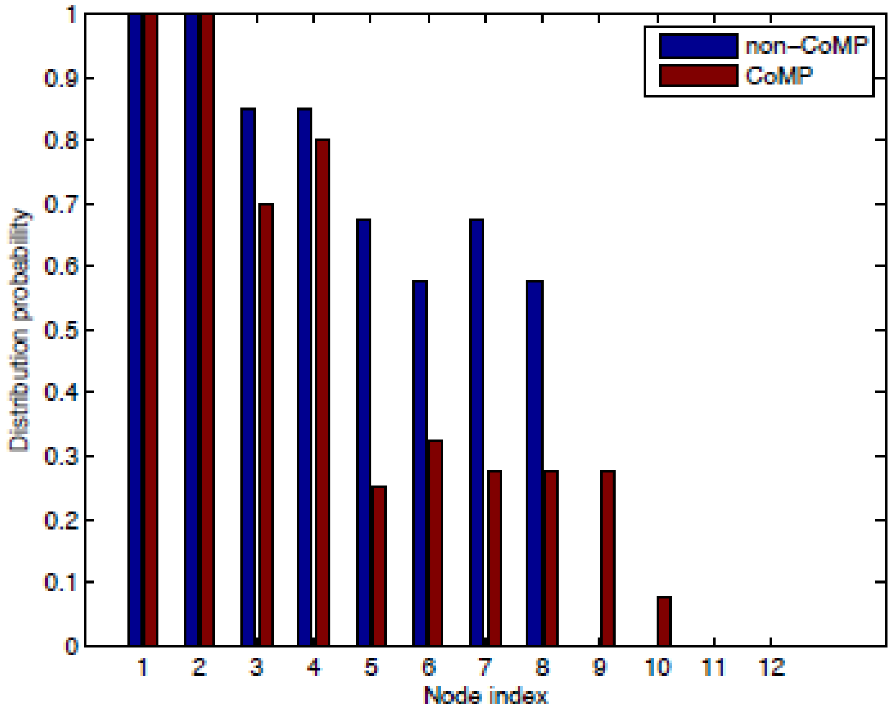
Simulation Results

- Clustering statistics with and without CoMP, $\alpha = 0.05$, $D(p) = 30$.



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Thank you!