On the Importance of Container Image Placement for Service Provisioning in the Edge

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Outline

1. Introduction
2. Formal Models and algorithms
3. Experimental Evaluation
4. Conclusion

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1. Introduction
   - Context
   - Goal and Challenges
2. Formal Models and algorithms
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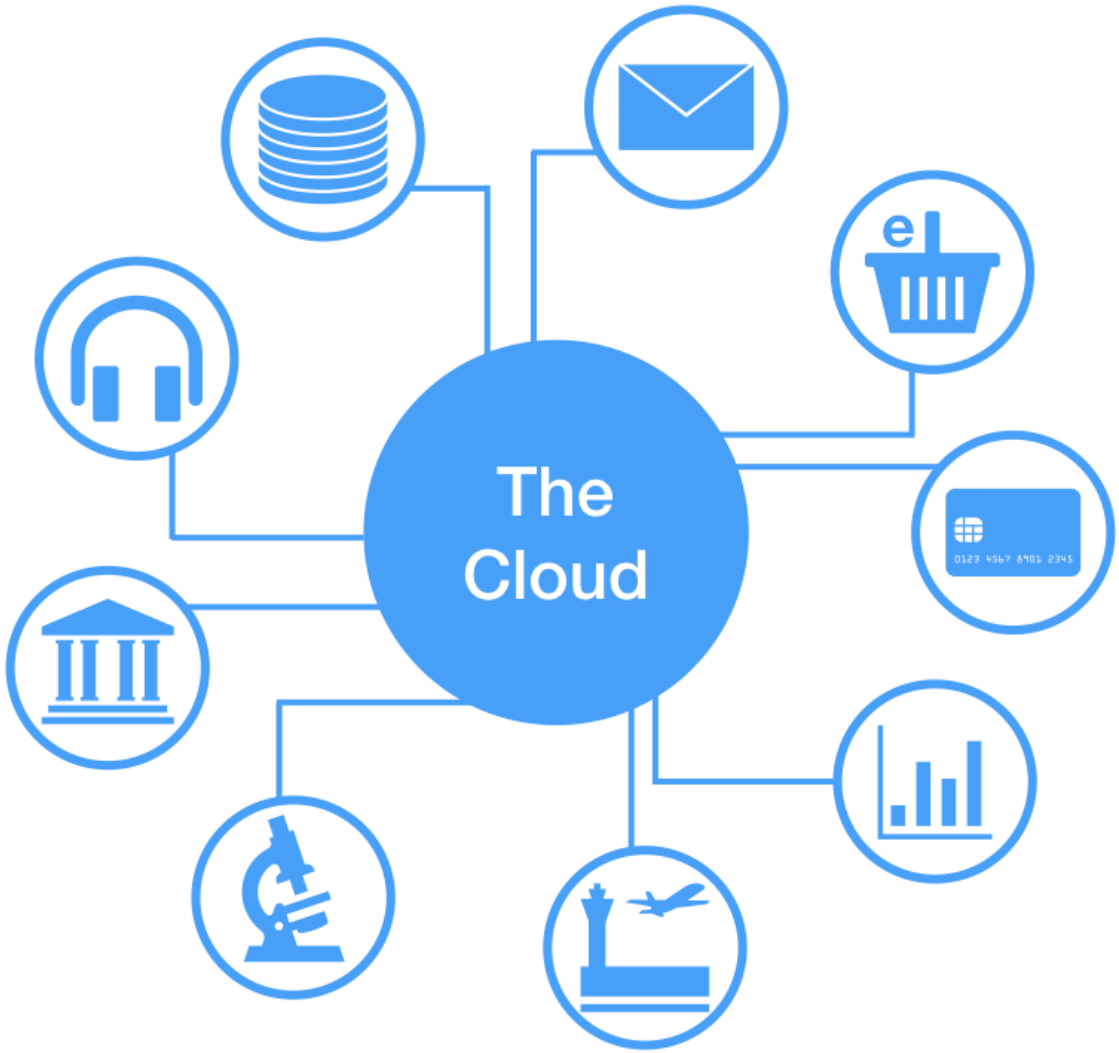
Context



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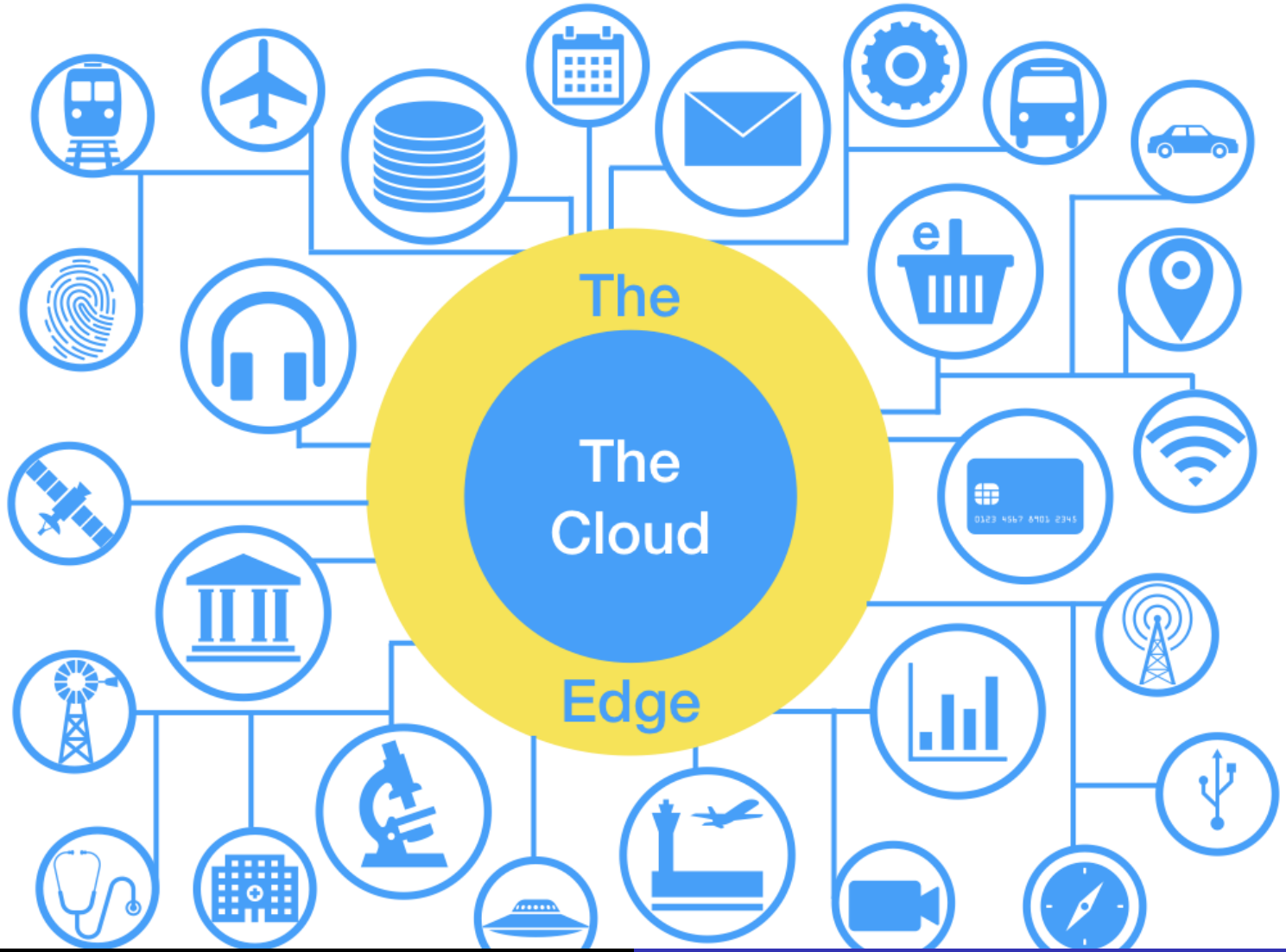

Containers in Edge

- Containers are extensively used in cloud data centers
  – Google launches more than 2 billion containers a week[1]

[1] www.theregister.co.uk/2014/05/23/google_containerization_two_billion

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  – Downloading a 500 MB image over 5 MB/s link takes 100s

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What we propose

Placing container images across Edge servers!

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Service provisioning

- **Goal**: providing *fast* and *predictable* retrieving times for a set of images on the entire network

- **Challenges**:
  - **Heterogeneity of the network (bandwidth)**
  - **Ensure data availability**
  - **Limited storage capacities**

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  - **Limited storage capacities**
    ↪ Not too much replications!

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1 Introduction

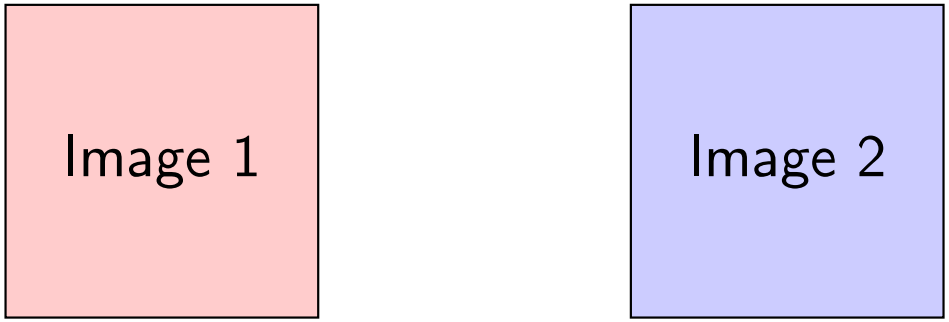
2 Formal Models and algorithms
- Definitions
- MaxLayerRetrievalTime
- KCBP
- MaxImageRetrievalTime
- KCBP-WC

3 Experimental Evaluation

4 Conclusion

Docker Images and Layers

- We base our model on the Docker structure of images.
- An images is composed of a collection of layers.
- A layer can be shared between several images.



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  $\hookrightarrow$ Gain in terms of storage cost.

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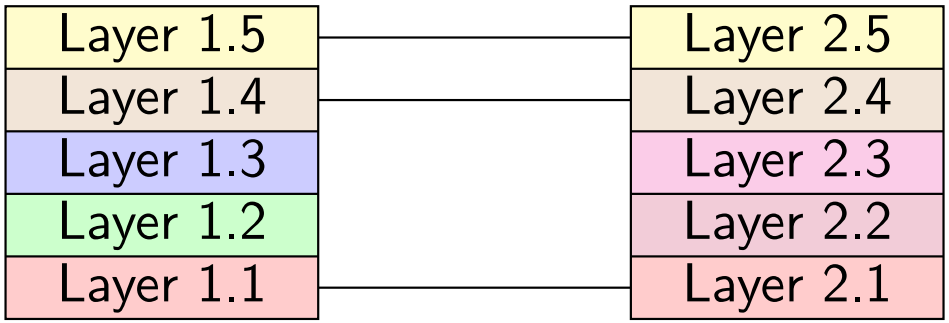

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Retrieving assumptions

- We focus on placement here but we need to define the retrieving policy.
- **Policy**: If an image is requested on one node, each layer is individually retrieved from the node that owns a replica that has the *largest* bandwidth.
- **The retrieving time of an image is determined by the longest retrieving time among the ones of its layers.**

MaxLayerRetrievalTime

Problem (*MaxLayerRetrievalTime*)

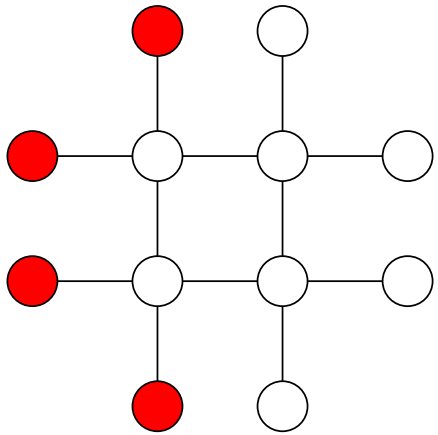
Let V be a set of nodes with storage capacity c and $\mathcal{L}$ be a set of layers. Return a valid placement that minimizes: $\max_{u \in V,\ l_i \in \mathcal{L}} T_i^u$.

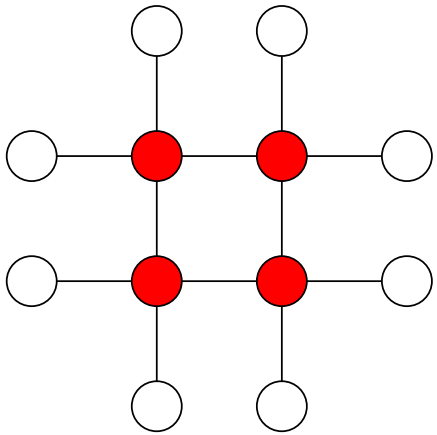
- V: set of nodes of the network (seen as a complete graph).
- c: storage capacity of a node (equal for all nodes).
  $\hookrightarrow$ The sum of the sizes of layers stored on each node has to be lower than c.
- T_i^u: retrieving time of layer l_i on node u.
  $\hookrightarrow$ Depends on the size of l_i and on the bandwidth between u and the chosen node.

k-Center

Problem (k-Center)

Placing k facilities on a graph such that the maximum distance from any node to any facility is minimized.





- Popular model for Content Delivery Networks (CDNs)[2]

[2] Qiu, Lili, Venkata N. Padmanabhan, and Geoffrey M. Voelker. "On the placement of web server replicas." In Proceedings IEEE INFOCOM 2001

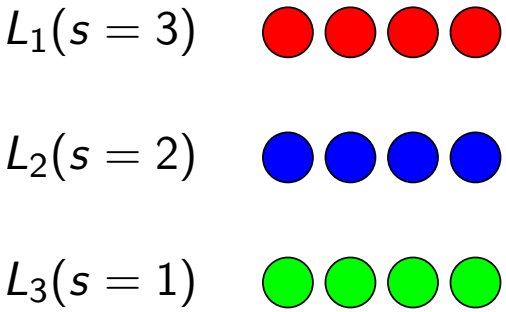
k-Center

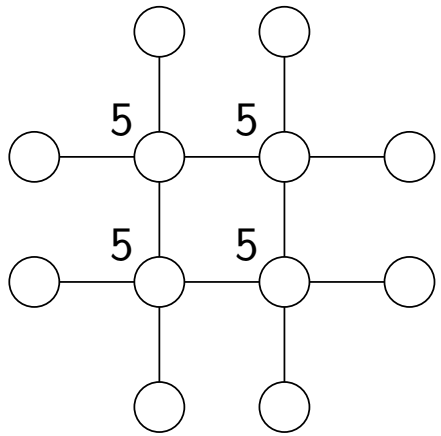
- With only one layer, replicated k times, *MaxLayerRetrievalTime* is equivalent to *K-center*.
- Because of limited storage capacities, all layers cannot be placed on the k most central nodes.
- **Solution:** iterative k-Center algorithm.

k-Center Based Placement

Algorithm:

- Sort the layers by decreasing sizes
- For each layer L_i with size s_i:
  - Use a k-Center solver (k number of replicas) on the subgraph with all nodes with remaining storage capacities $c_j \geq s_i$





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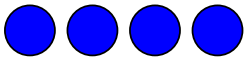
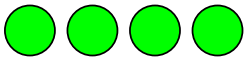
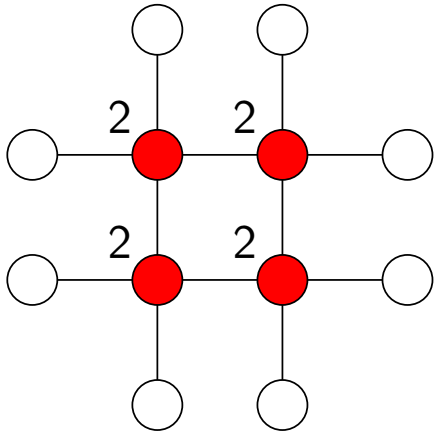
$L_2(s = 2)$ 

$L_3(s = 1)$ 



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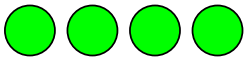
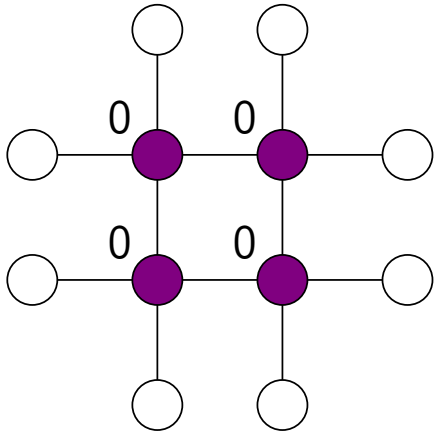
$L_3(s = 1)$ 



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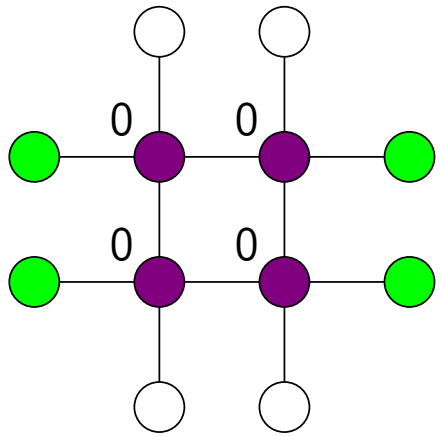

MaxImageRetrievalTime

- KCBP tends to gather many layers on same nodes
- If several layers are retrieved from the same node, these downloads are done *sequentially*.
- **Solution:** Place the image's layers on distinct nodes.

Problem (*MaxImageRetrievalTime*)

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k-Center Based Placement-Without Conflict

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- Sort the layers by decreasing sizes
- For each layer L_i with size s_i:
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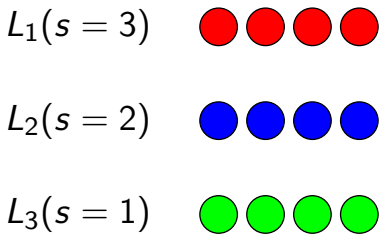

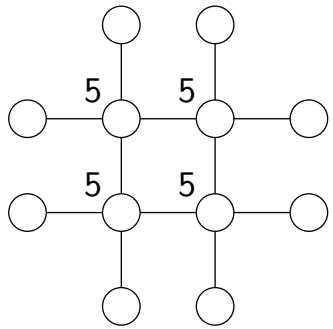

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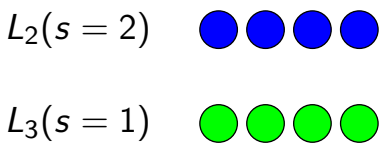

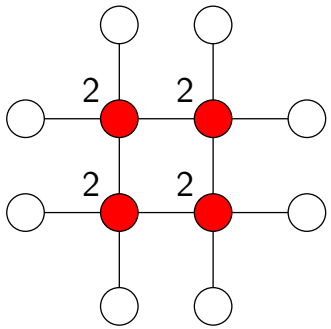

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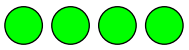
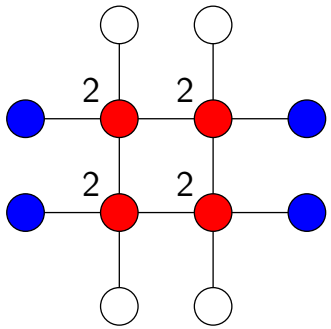
$L_3(s = 1)$ 



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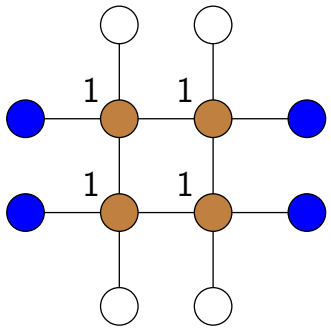
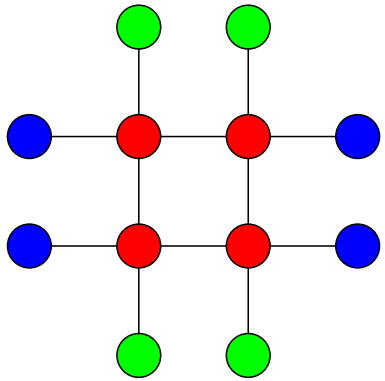


k-Center Based Placement-Without Conflict

- We do not want to spread too much!



- What if another layer share an image with the three previous ones?
- We only apply the criterion "not sharing an image" on the α% *largest* layers ($\alpha = 10$ here).

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2 Formal Models and algorithms

3 Experimental Evaluation
- Simulation Methodology
- Experimental Results

4 Conclusion

Simulation Methodology

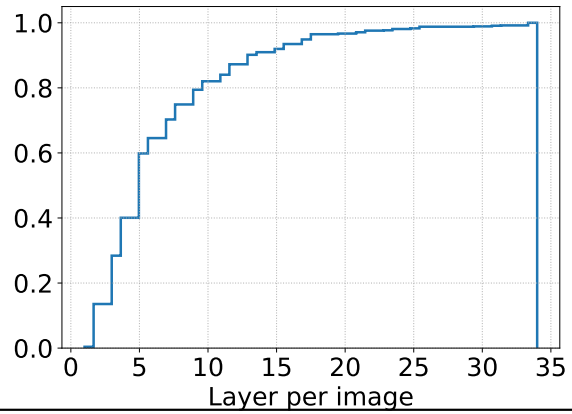
Simulation Methodology

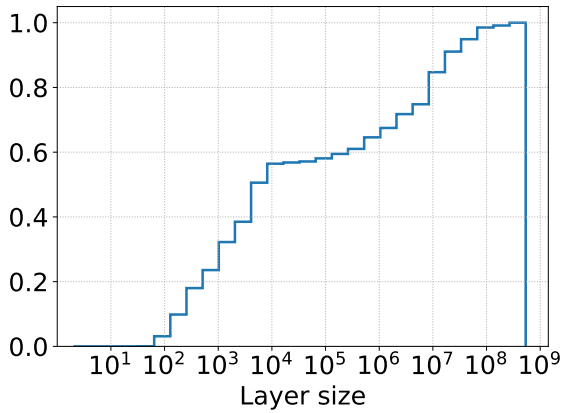
- **Simulator:** written in Python and publicly available at `gitlab.inria.fr/jdarrous/image-placement-edge`
- **Dataset:** cloud container images dataset
- **Networks:** synthetic and real network topologies

Container Image Dataset

- IBM cloud traces from Frankfort data center[3].

Total #images	996
Total size of images	93.76 GB
Total #layers	5672
Total size of unique layers	74.25 GB





[3]Anwar, Ali, et al. "Improving docker registry design based on production workload analysis." In USENIX FAST'18. 2018.

Synthetic Networks

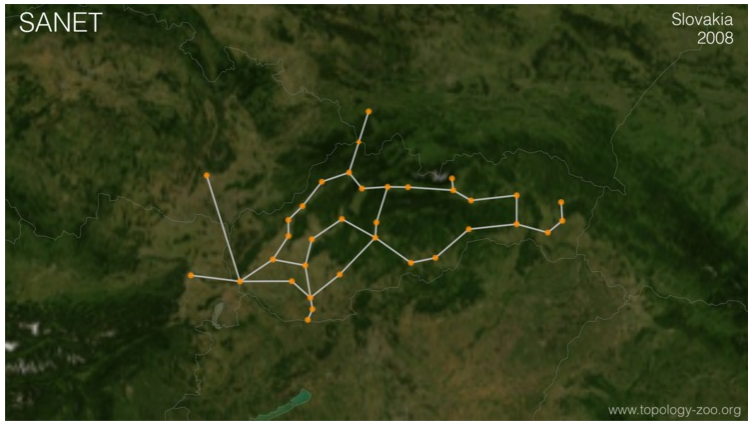
- Complete graphs with random bandwidths on edges.
- **Homogeneous**: same bandwidth for all.
- **Low**: most of the edges have low bandwidth.
- **High**: most of the edges have high bandwidth.
- **Uniform**: edges bandwidths follow a uniform distribution.

Network	Number of nodes	Links bandwidths (bps)				
		min	25th	median	75th	max
Homogeneous	50	4G	4G	4G	4G	4G
Low	50	8M	763M	1G	2G	8G
High	50	478M	5G	6G	7G	8G
Uniform	50	8M	2G	4G	6G	8G

Real Networks

- France and Slovakia national networks[4].

Network	Number of nodes	Links bandwidths (bps)				
		min	25th	median	75th	max
Renater	38	102M	126M	132M	139M	155M
Sanet	35	63M	6G	8G	8G	10G



[4] retrieved from `http://www.topology-zoo.org`

Strategies

- Our placement strategies:
  - KCBP
  - KCBP-WC
- Comparison strategies:
  - Best-Fit (round-robin distribution of layers)
  - Random
  - 50 runs for each.
- All layers are replicated 3 times.
- Storage capacity: $f \times \frac{\text{size of total dataset}}{\text{number of nodes}}$, $f \in \{1.1, 2, INF\}$.

Impact of Conflicts

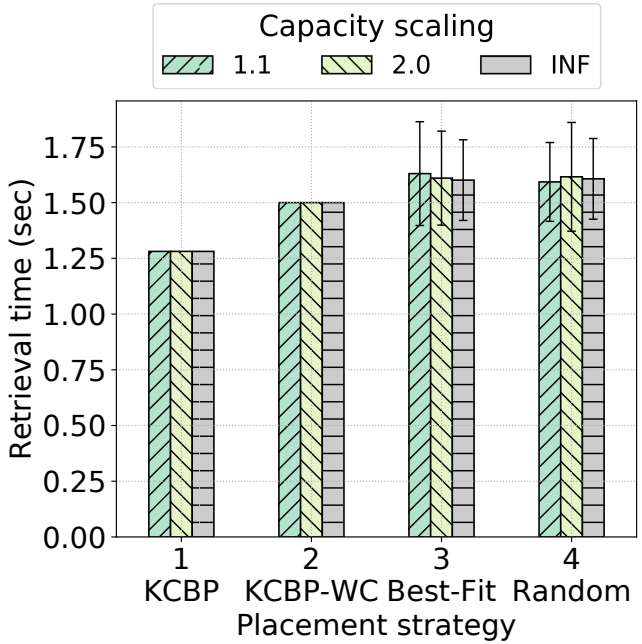


Figure: Layers Retrieval Times (High Network)

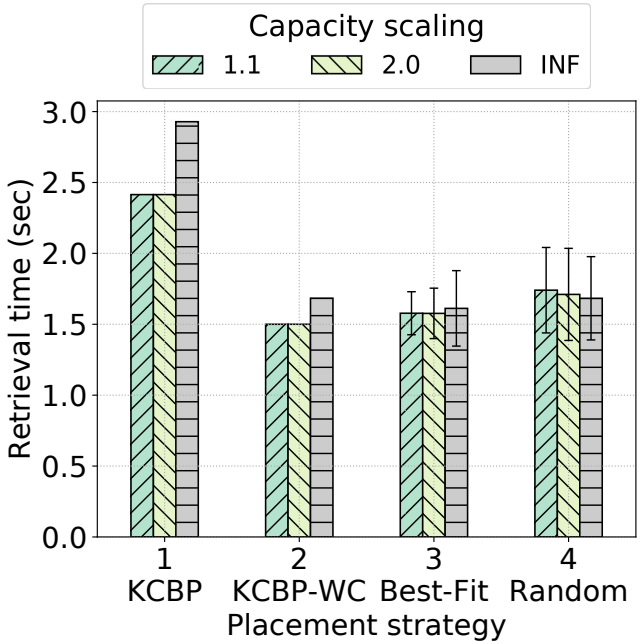


Figure: Images Retrieval Times (High Network)

- Conflicts have significant impact.

Impact of Heterogeneity of Bandwidths

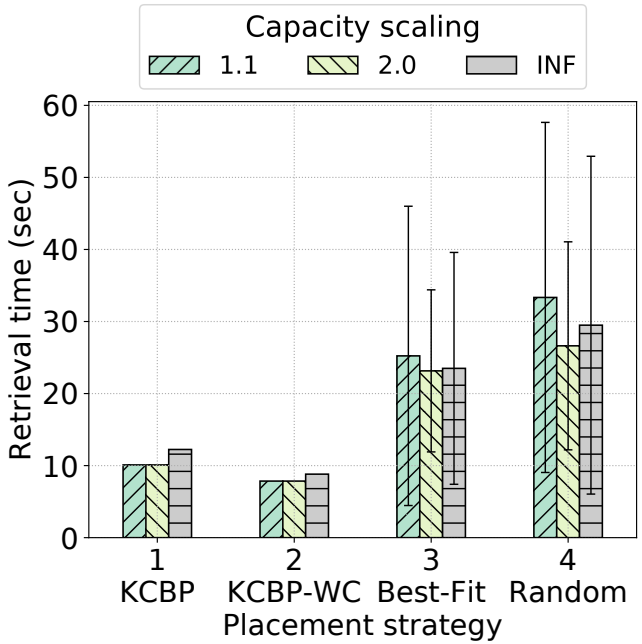


Figure: Low Network

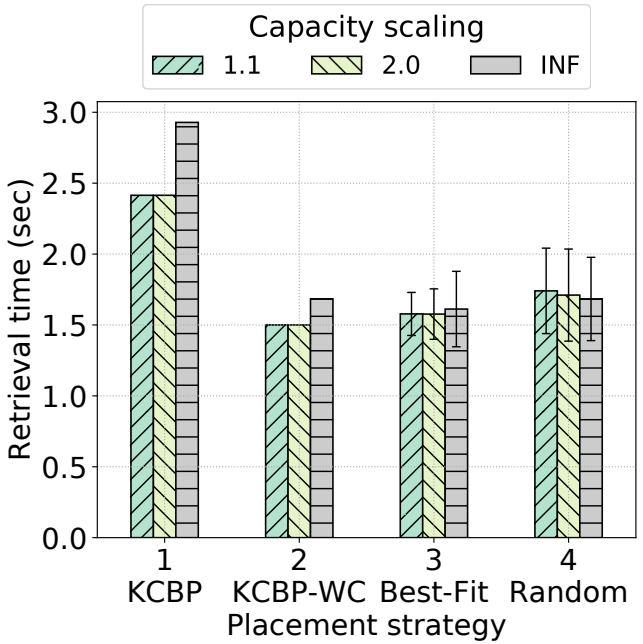
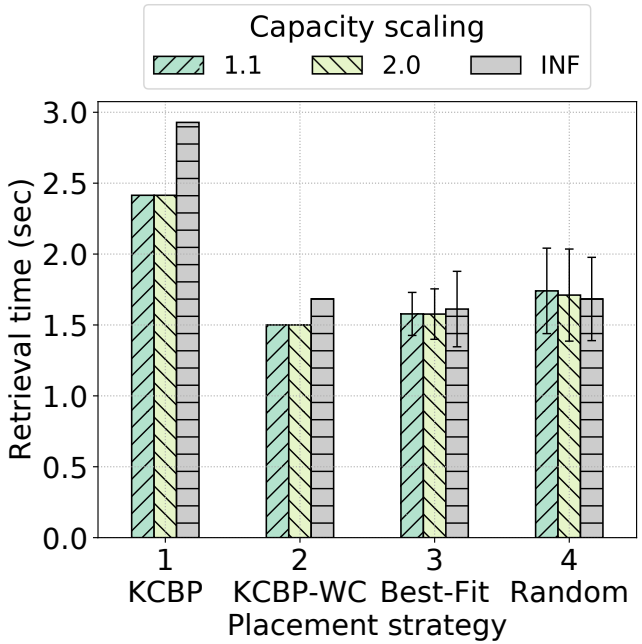


Figure: High Network

- Low Network: many "low connectivity nodes"
  $\rightarrow$ centrality of layers placement is important.
- High Network: few "low connectivity nodes".

Network size and the KCBP-WC large layer factor



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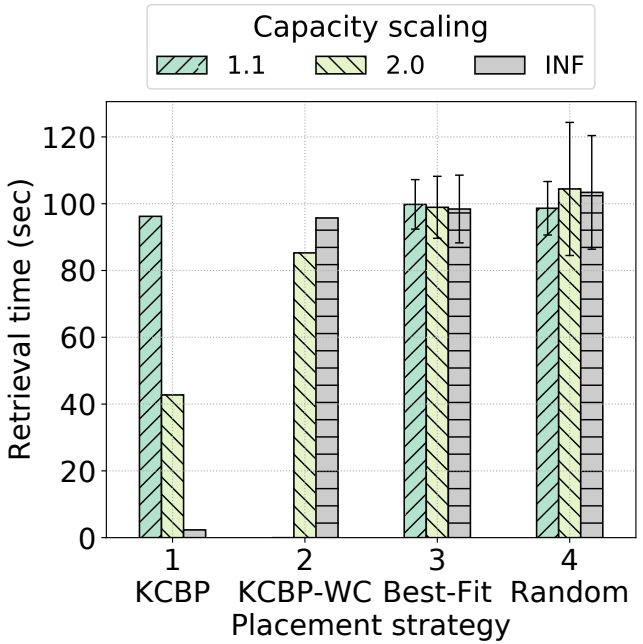
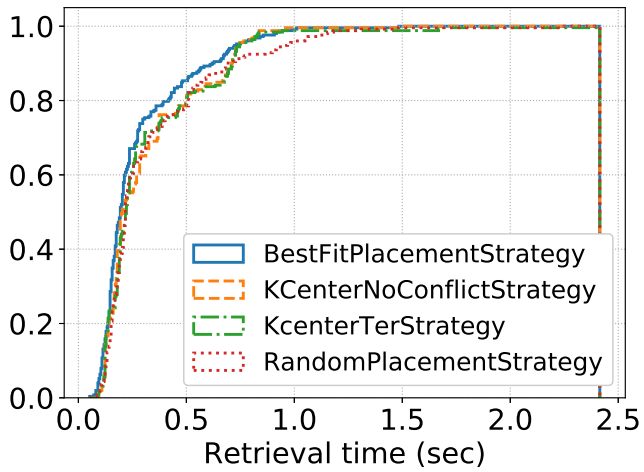


Figure: Sanet Network

- Retrieving multiple layers sequentially from a highly connected node could sometimes outperforms parallel retrieval from faraway nodes.

Distribution of image retrieval times



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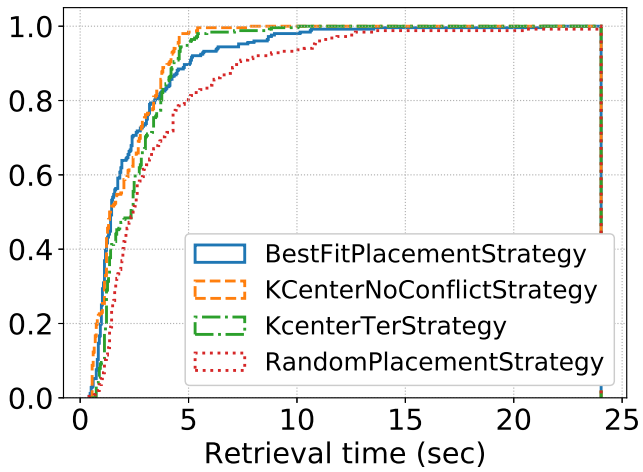

Figure: Low Network

- Best-Fit has the best retrieval time for 20% of the largest images on High Network.
- For Low Network, KCBP-WC has the lead on these images.

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  - A formal model for container image placement.
  - Two placement strategies (i.e., KCBP and KCBP-WC).
  - A simulation-based evaluation with two state-of-the-art techniques.

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Simulator code is publicly available at `https://gitlab.inria.fr/jdarrous/image-placement-edge`.