Cost-aware caching: optimizing cache provisioning and object placement in ICN

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IEEE Globecom, 8-12 December 2014, Austin, Texas

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Outline

- Context
- Scenario
- Our contribution
  - Design of a cache system with the aim to reduce inter-domain traffic cost of ISPs
  - Optimization models: CLASSIC vs. COST-AWARE
    - Forwarding, object placement, cache sizing
  - Greedy algorithms
- Results & findings
  - Classic caching is cost-ineffective
  - Cost-aware caching can bring sizable cost savings
- Conclusion

Context

- Work on **cache design** focuses on classic metrics:
  - hit ratio, hop distance, traffic load

- Some works on **economic implications** of caching
  - Only interaction between ISPs is considered
  - No consideration on cache design inside ISPs network

Orthogonal aspects

We study how an ISP can reduce costs by properly designing its cache system

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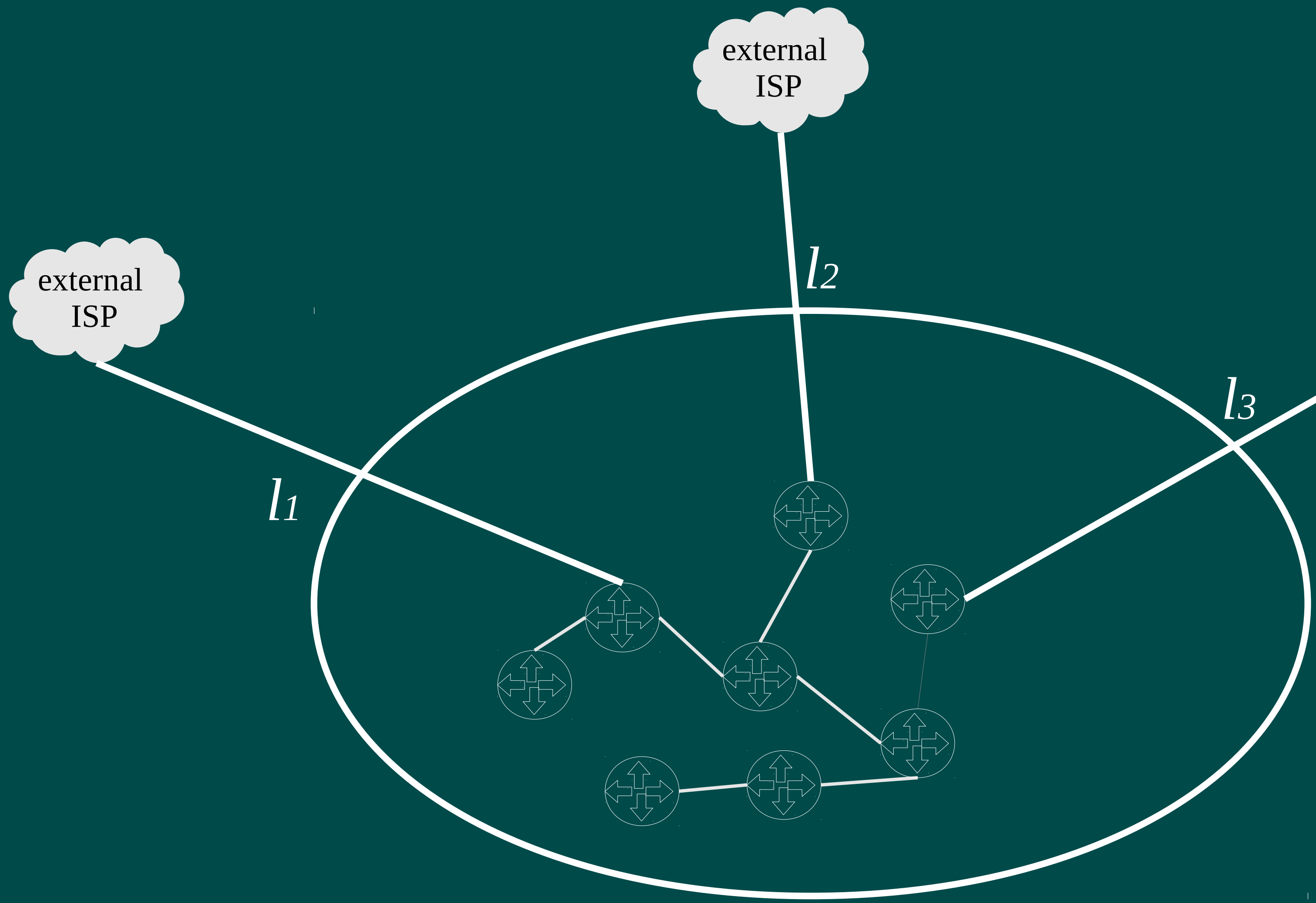
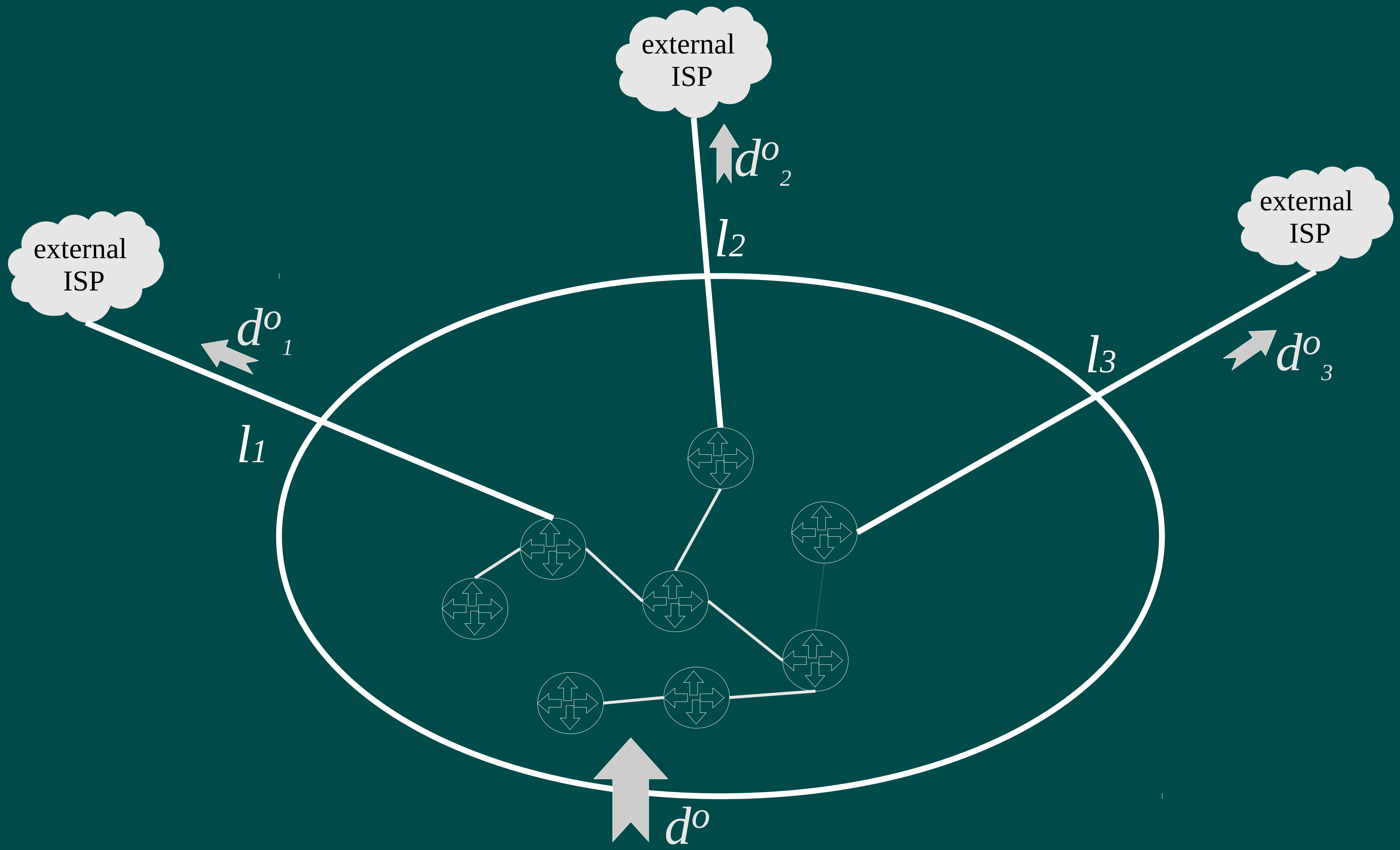
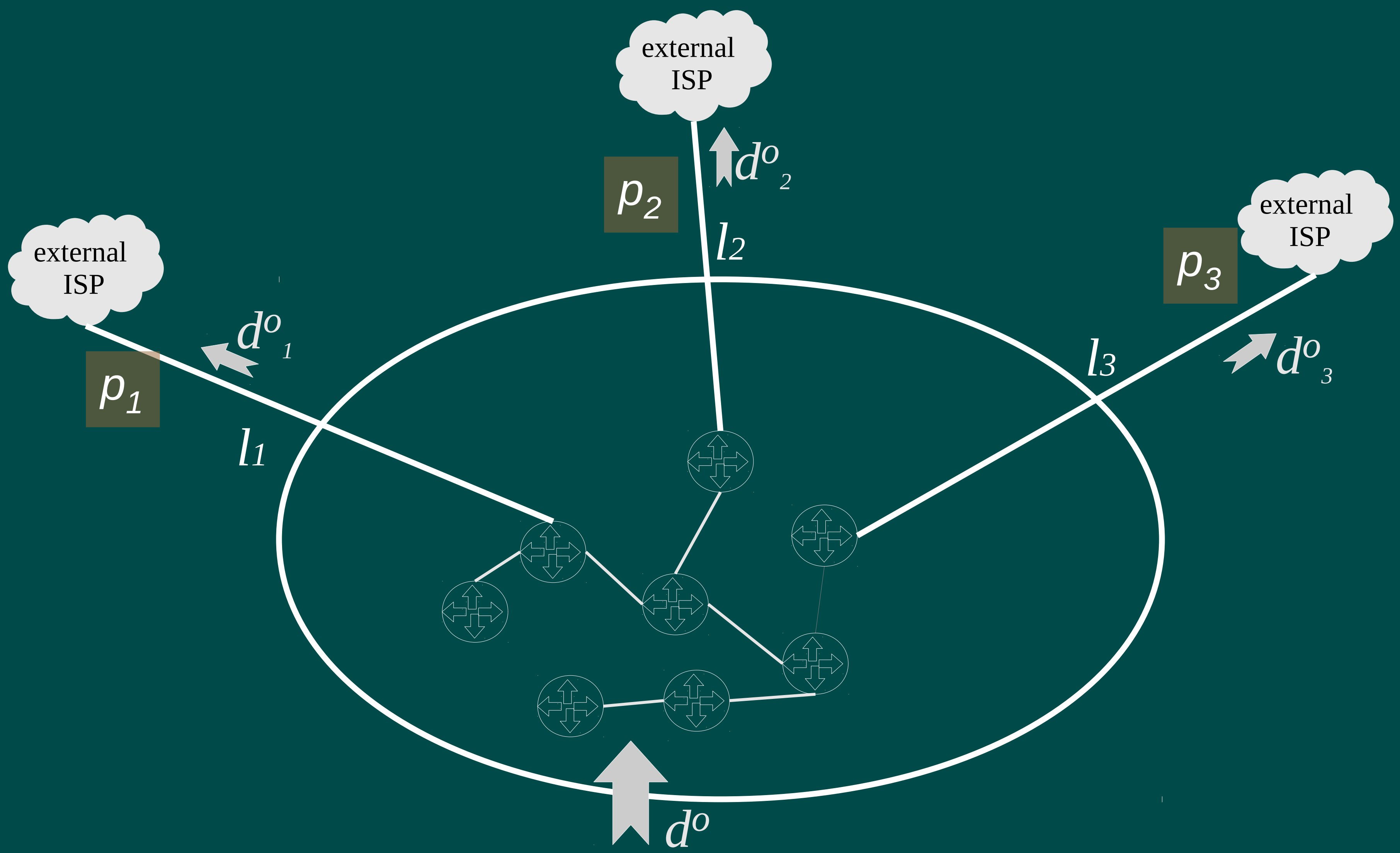
Scenario



Scenario

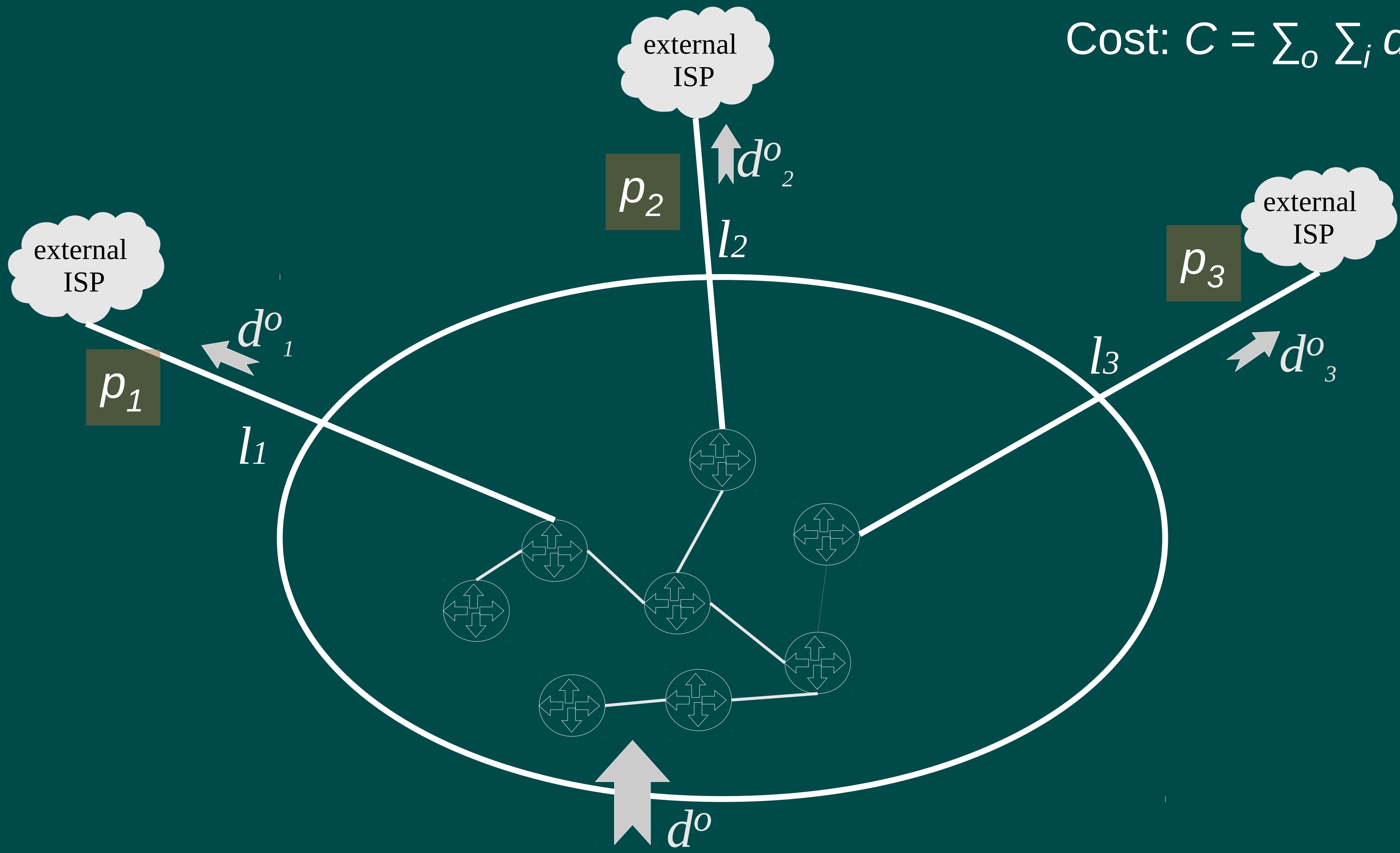

external ISP
external ISP
external ISP
d^o_2
l_2
d^o_1
l_1
l_3
d^o_3
d^o

Scenario


external ISP
external ISP
external ISP
$d^o{}_2$
p_2
l_2
p_3
$d^o{}_1$
l_3
$d^o{}_3$
p_1
l_1
d^o

Scenario

Cost: $C = \sum_o \sum_i d^o{}_i \, p_i$



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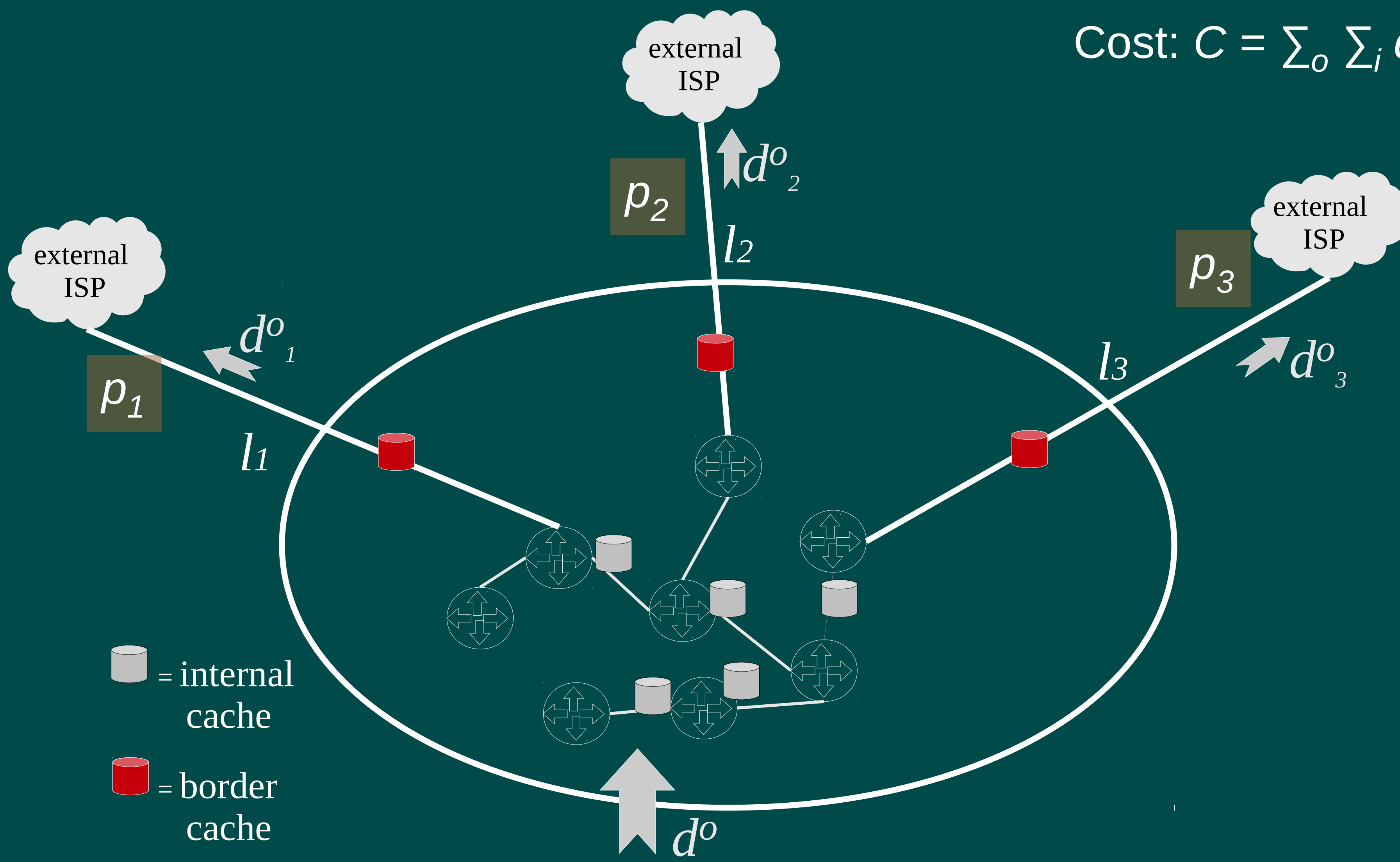
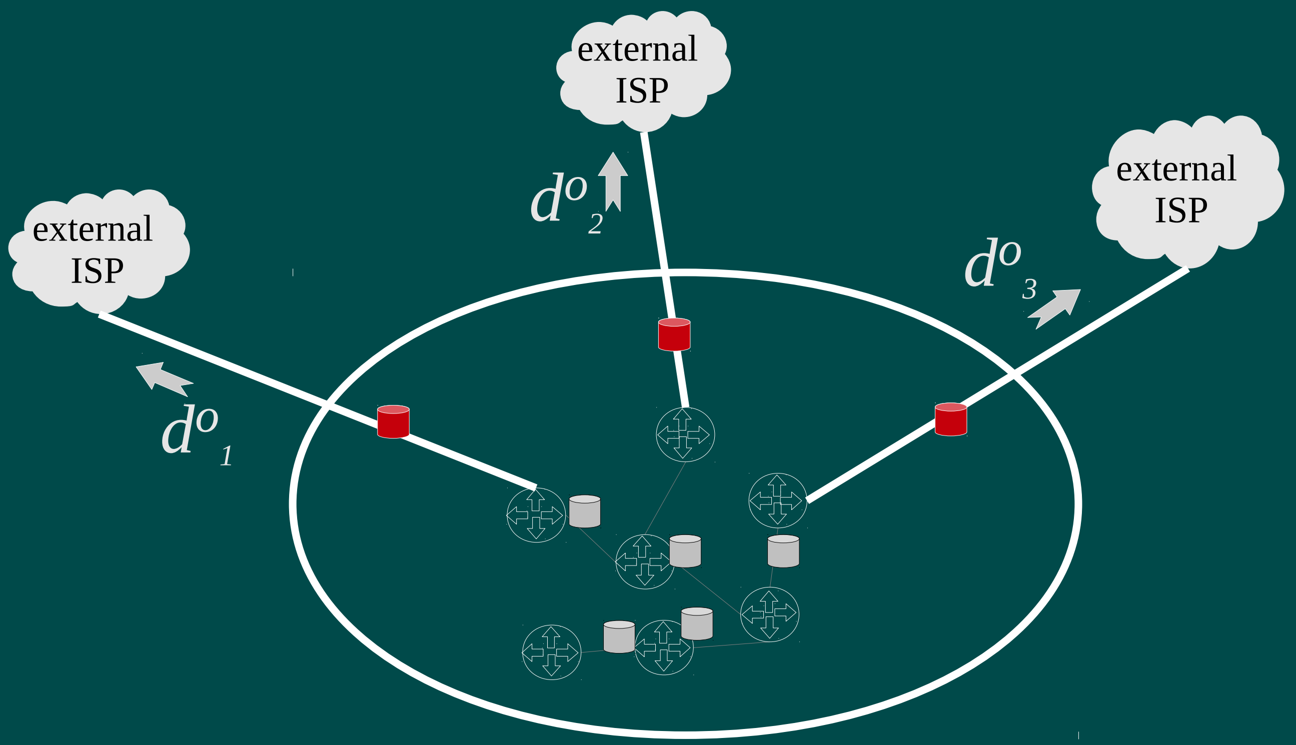


Optimization goals

At first glance: hit-ratio ↗ ➡ inter-domain traffic ↘ ➡ cost ↘



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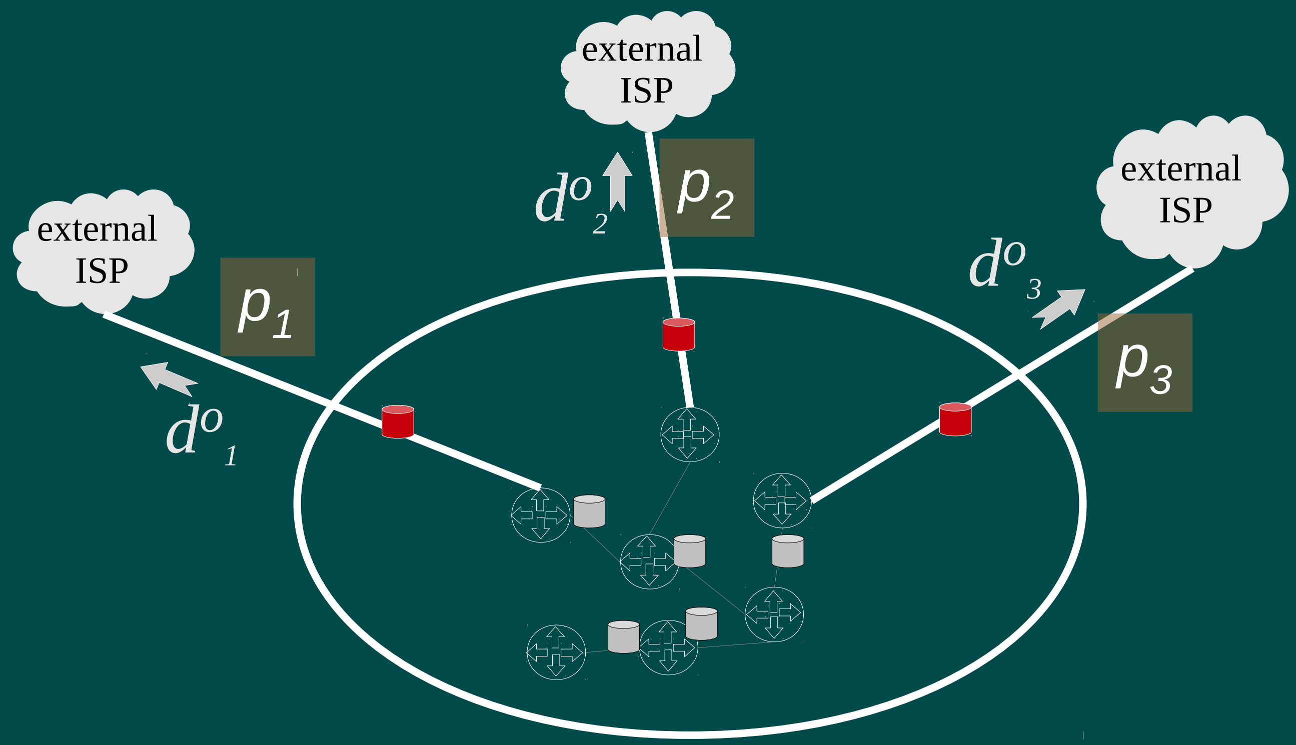

Price heterogeneity

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Optimization goals

At first glance: hit-ratio ↗ ⇒ inter-domain traffic ↘ ⇒ cost ↘

- *CLASSIC opt model*

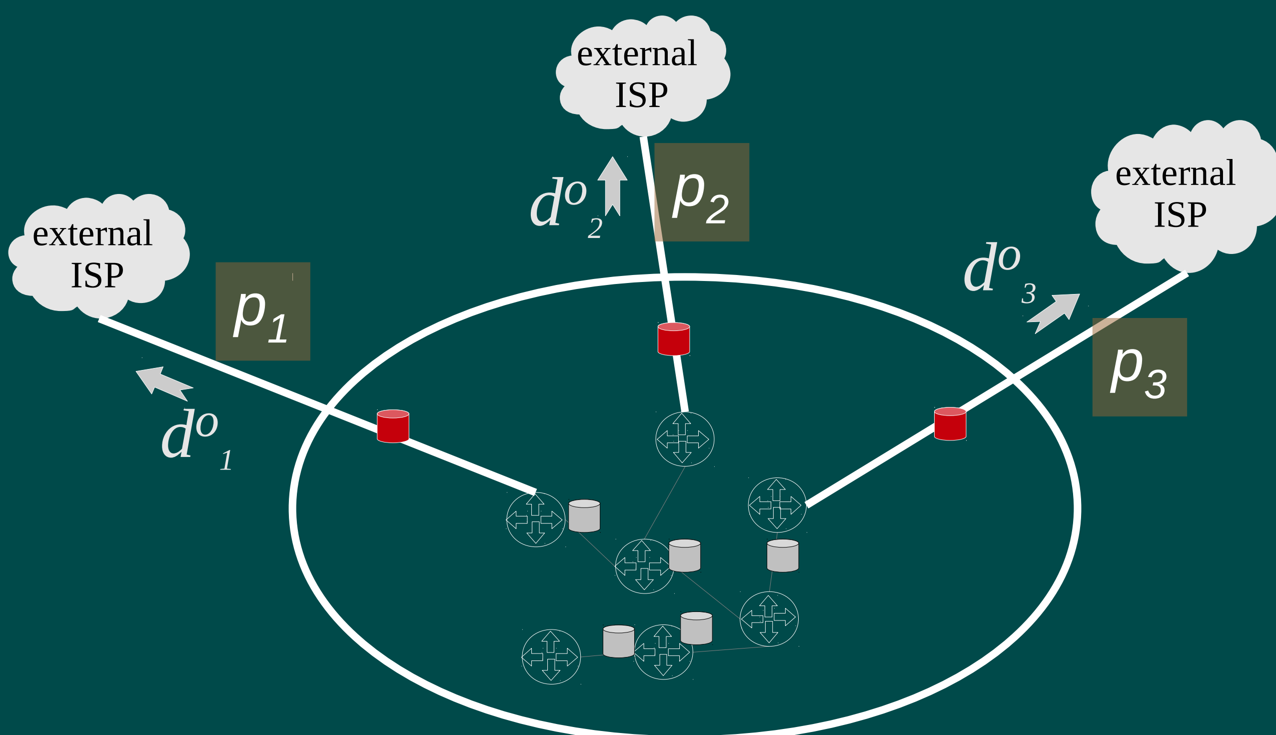
  Hit-ratio: $H = \dfrac{d^o - \sum_o \sum_i d^o_i}{d^o}$

  max H

- *COST-AWARE opt model*

  Cost: $C = \sum_o \sum_i d^o_i \, p_i$

  min C



Price heterogeneity

Constraints

$$\rho_o = F\left(\mathcal{Q}, P, \{x_{n,o} | n \in \mathcal{N}\}\right) \tag{1}$$

$$d^{out}_{core,o} = (1 - \rho_o) d_o \tag{2}$$

$$d^{out}_{core,o} = \sum_{l \in \mathcal{L}} d^{in}_{l,o} \tag{3}$$

$$d^{in}_{l,o} = 0, \forall l \in \mathcal{L} \setminus \mathcal{L}_o \tag{4}$$

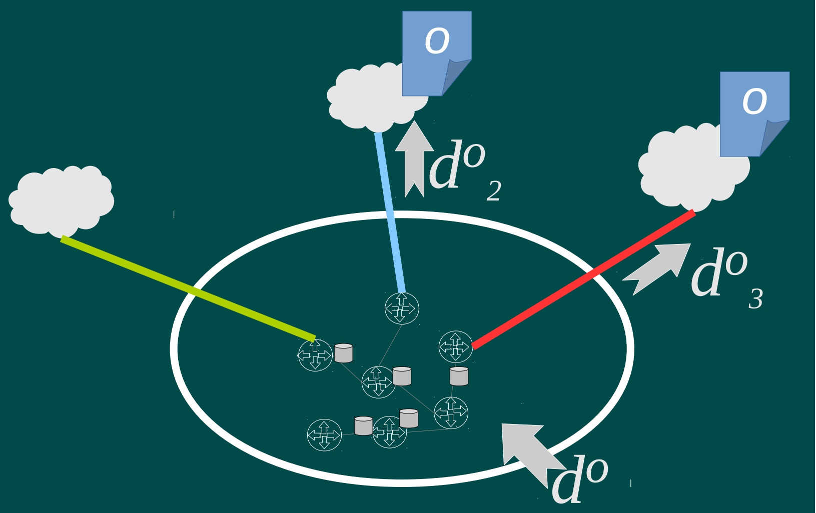
$$d^{out}_{l,o} = (1 - x_{l,o}) \cdot d^{in}_{l,o} \tag{5}$$

$$\sum_{o \in \mathcal{O}} x_{l,o} = cs_l, \forall l \in \mathcal{L} \tag{6}$$

$$\sum_{o \in \mathcal{O}} x_{n,o} = cs_n, \forall n \in \mathcal{N} \tag{7}$$

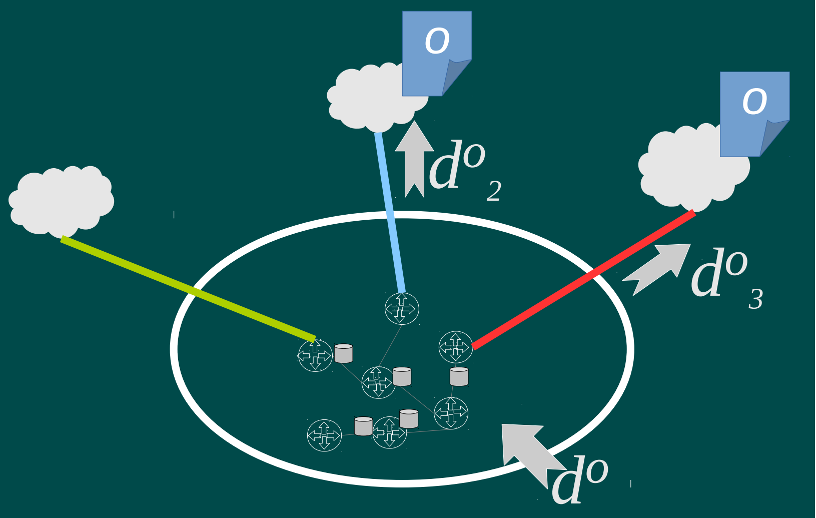
$$\sum_{l \in \mathcal{L}} cs_l + \sum_{n \in \mathcal{N}} cs_{n,o} \leq C_{tot}. \tag{8}$$

Greedy algorithms



Greedy algorithms

1. Where should we forward each request for object *o*?



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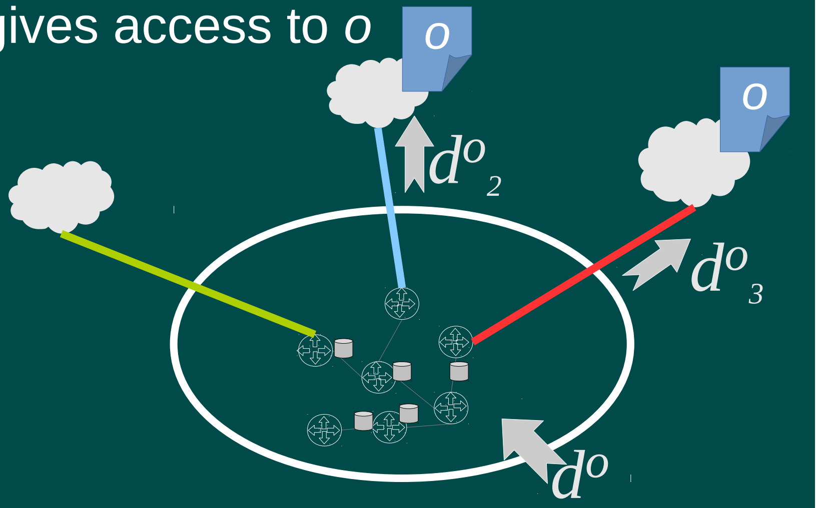

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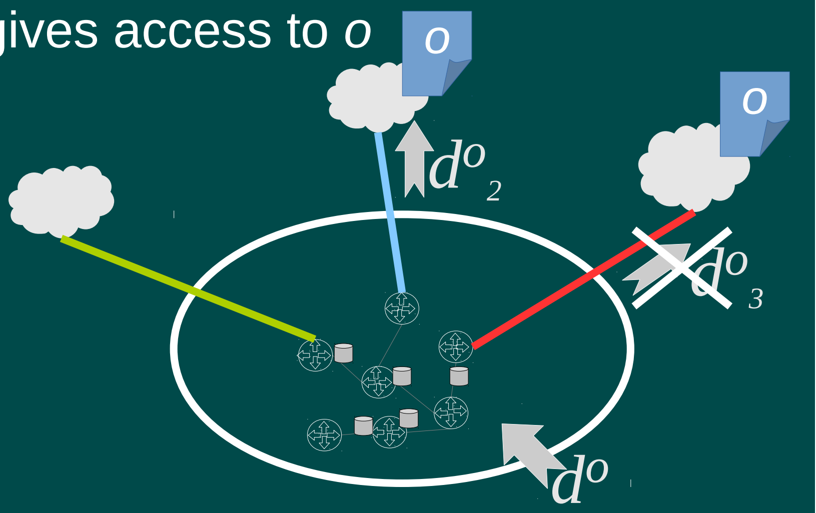

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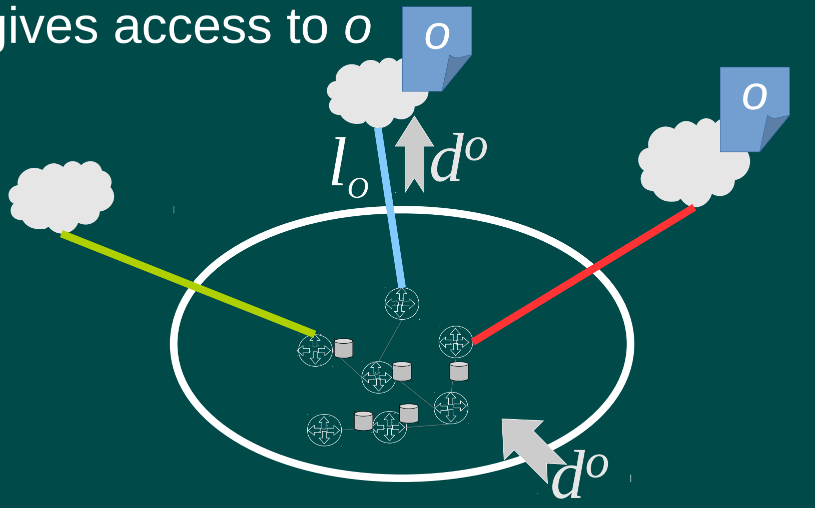
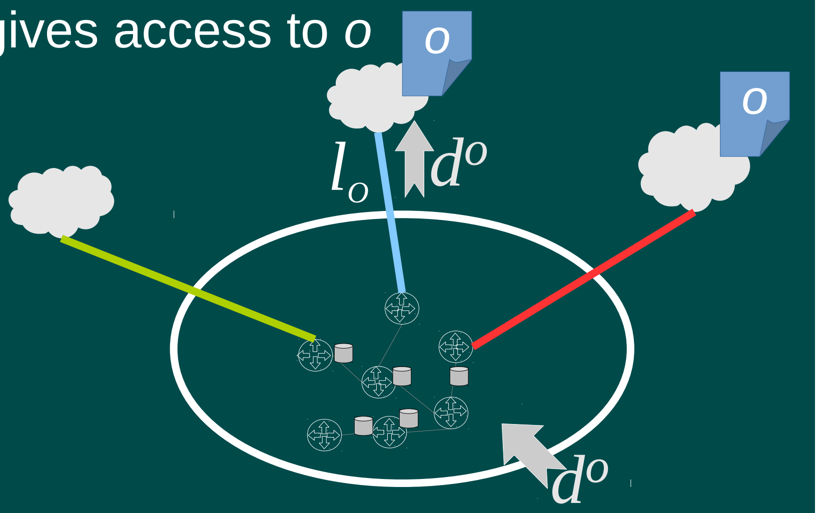


Greedy algorithms

1. Where should we forward each request for object *o*?

- Forward them only to the cheapest link l_o that gives access to *o*
- Compute the cost of each object

  $c_o \triangleq d^o \cdot p_{l_o}$



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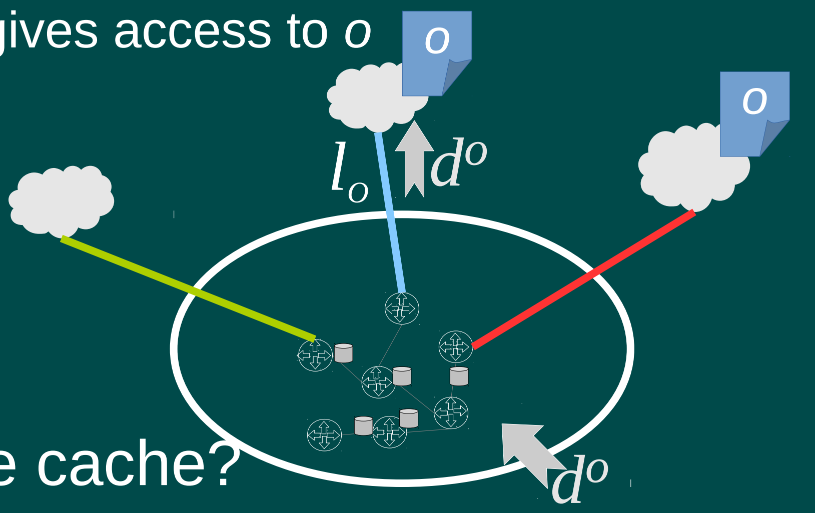

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- If your cache budget is C_{tot}, cache the C_{tot} objects with highest cost $c_o = d_o \cdot p_{lo}$

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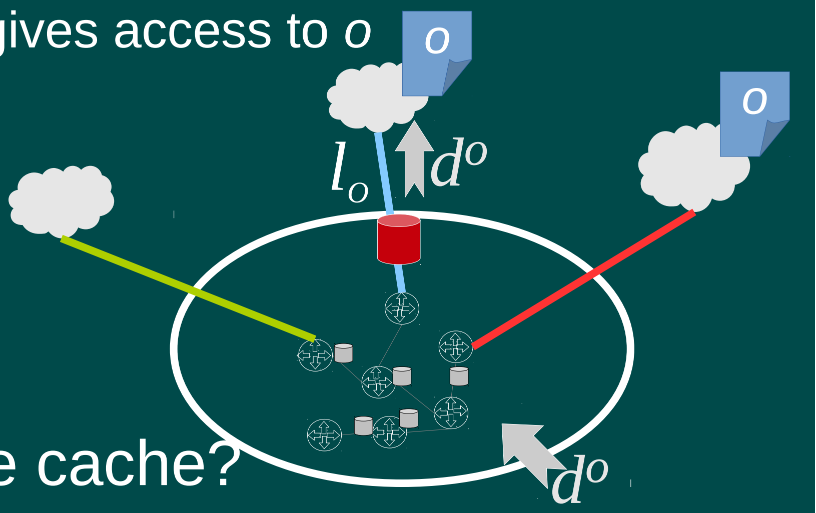

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Greedy algorithms

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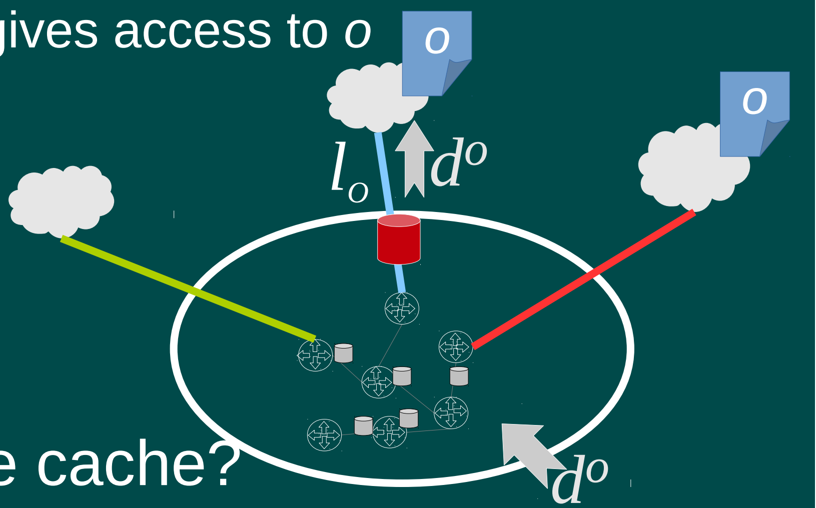

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COST-AWARE solution

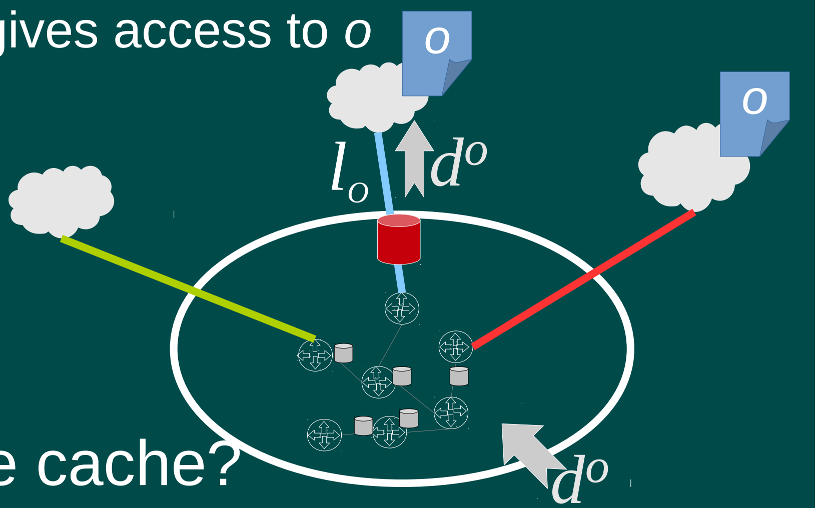
Greedy algorithms

Forwarding:

1. Where should we forward each request for object *o*?

- Forward them only to the cheapest link l_o that gives access to *o*
- Compute the cost of each object

$$c_o \triangleq d^o \cdot p_{l_o}$$



Object placement:

2. Which objects should we cache?

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Cache sizing:

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COST-AWARE solution

Greedy algorithms

Forwarding:

1. Where should we forward each request for object *o*?

- Forward them only to the cheapest link l_o that gives access to *o*
- Compute the cost of each object
  $c_o \triangleq d^o \cdot p_{l_o}$

Object placement:

2. Which objects should we cache?

- If your cache budget is C_{tot}, cache the C_{tot} objects with highest cost $\boxed{c_o = d_o \cdot p_{lo}}$
- Cache the C_{tot} most popular objects, i.e. the ones with highest $\boxed{d^o}$

Cache sizing:

3. Where should we cache o?

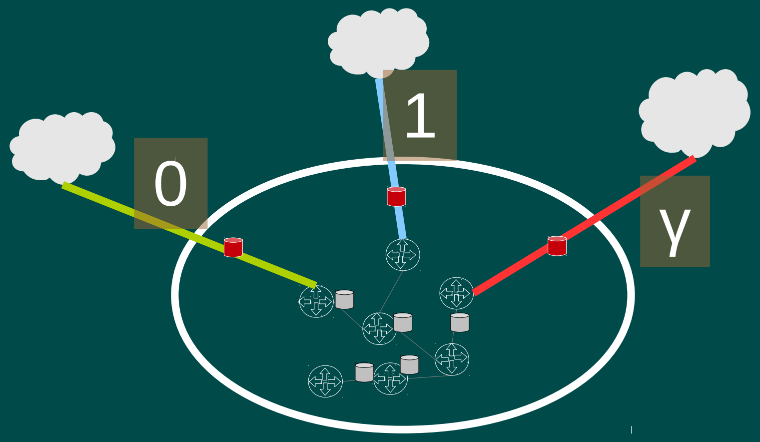
- Cache *o* in the border cache of the associated link l_o

COST-AWARE solution

CLASSIC solution

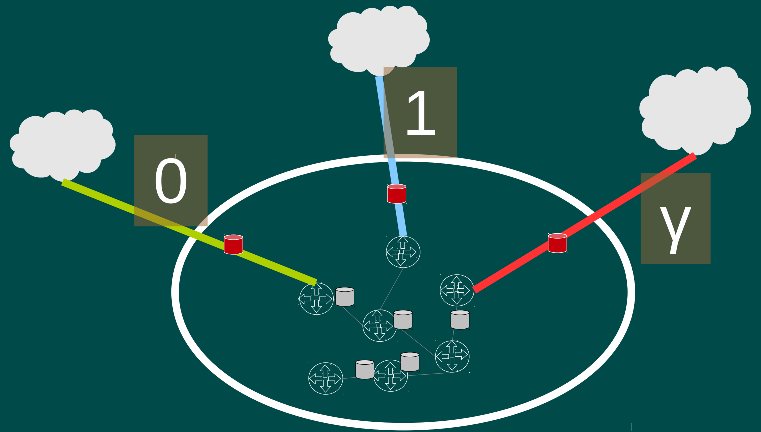
Parameters

- Realistic catalog: 10^7 objects
- Zipf popularity
- 3 external links



- Objects are randomly distributed on external links (40 seeds)
- For each configuration, we compute:
  - $H_{CLASSIC}$, $C_{CLASSIC}$, $H_{COST\text{-}AWARE}$, $C_{COST\text{-}AWARE}$

Cost savings

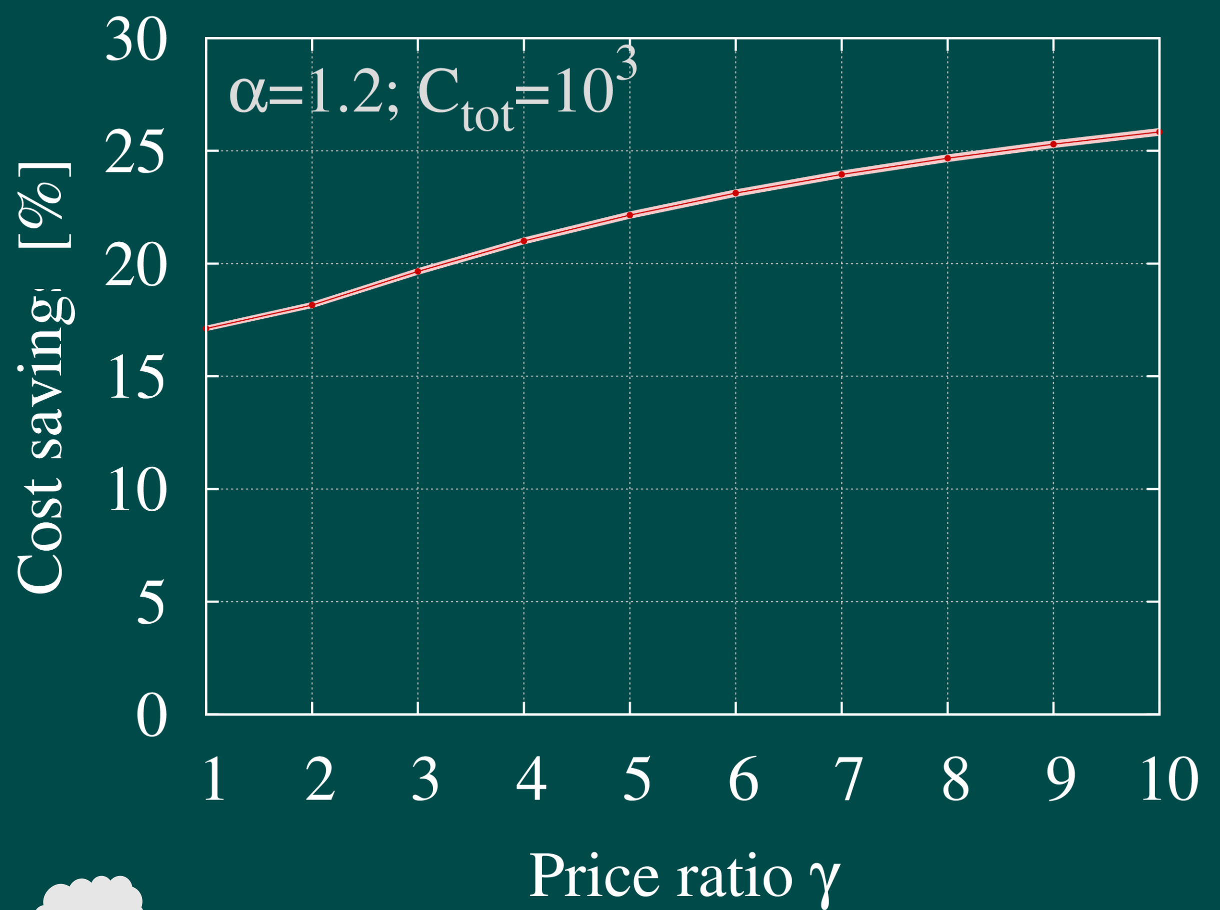


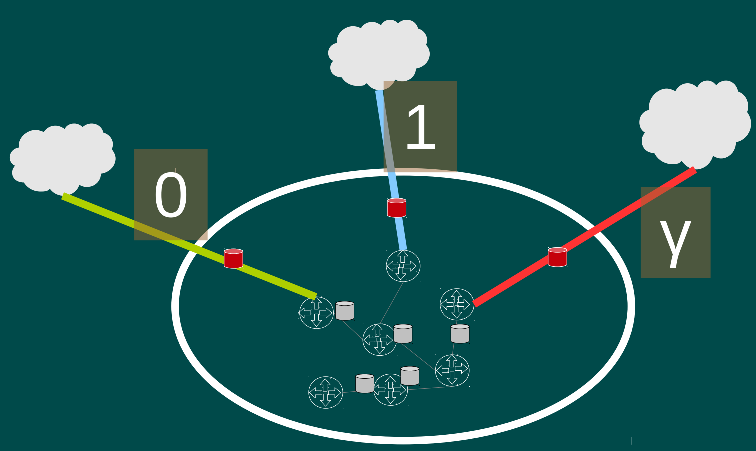
$$\text{Cost saving} = \frac{C_{CLASSIC} - C_{COST\text{-}AWARE}}{C_{CLASSIC}}$$

Cost savings

Price diversity ↗

⇒ Savings ↗



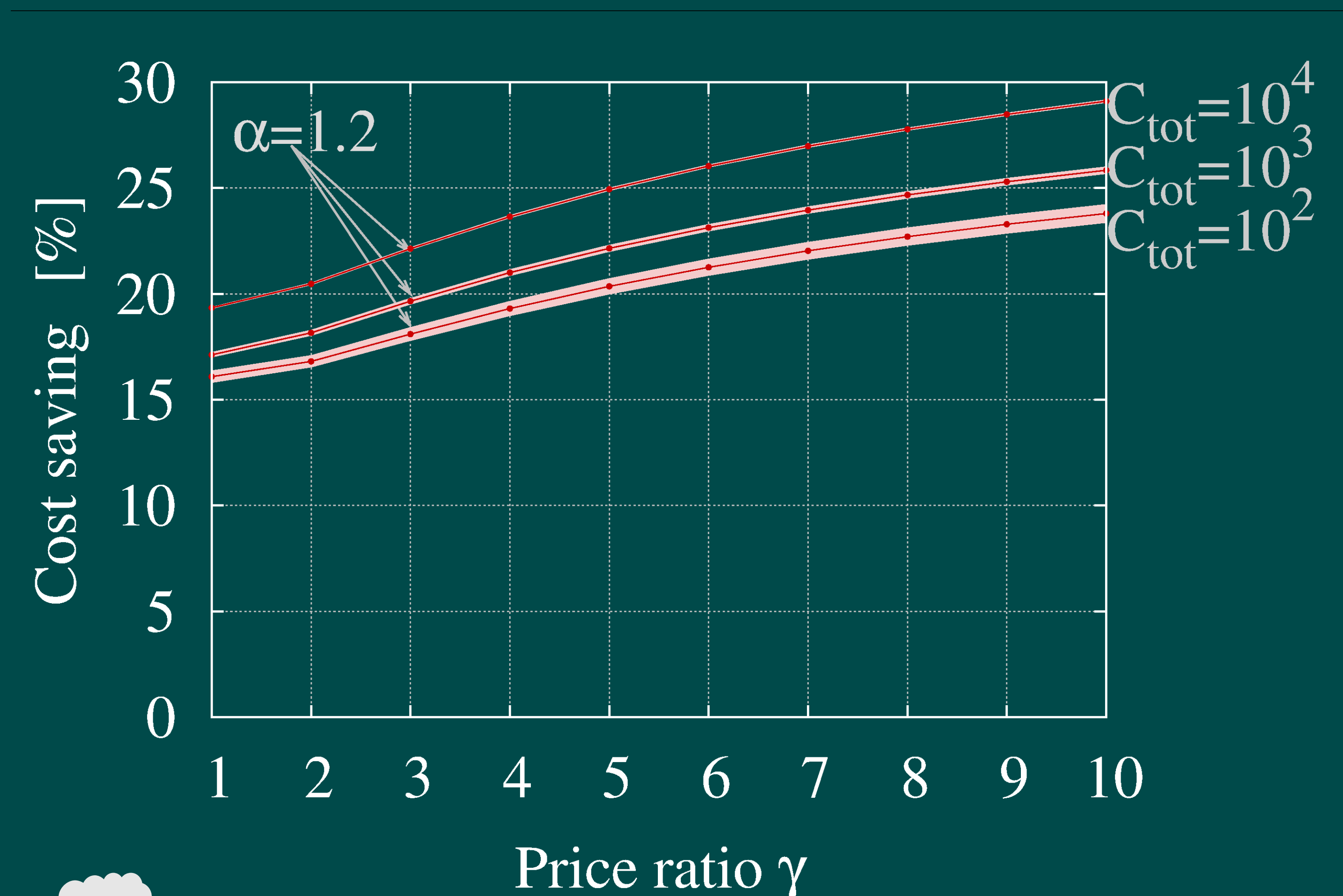


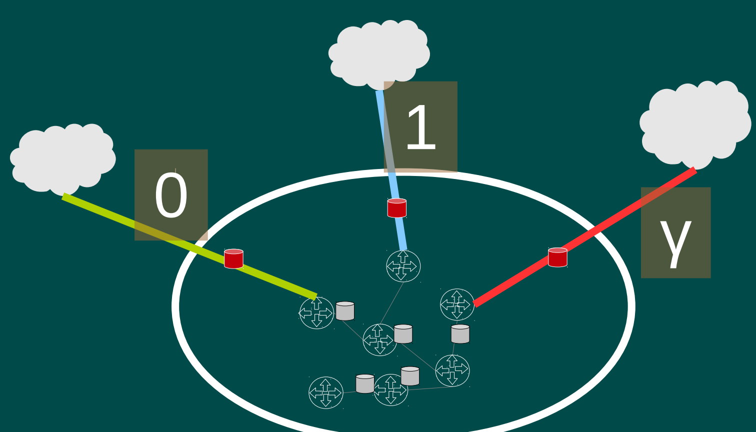
$$\text{Cost saving} = \frac{C_{CLASSIC} - C_{COST\text{-}AWARE}}{C_{CLASSIC}}$$

Cost savings

Price diversity ↗
➡ Savings ↗

Cache Budget ↗
➡ Savings ↗





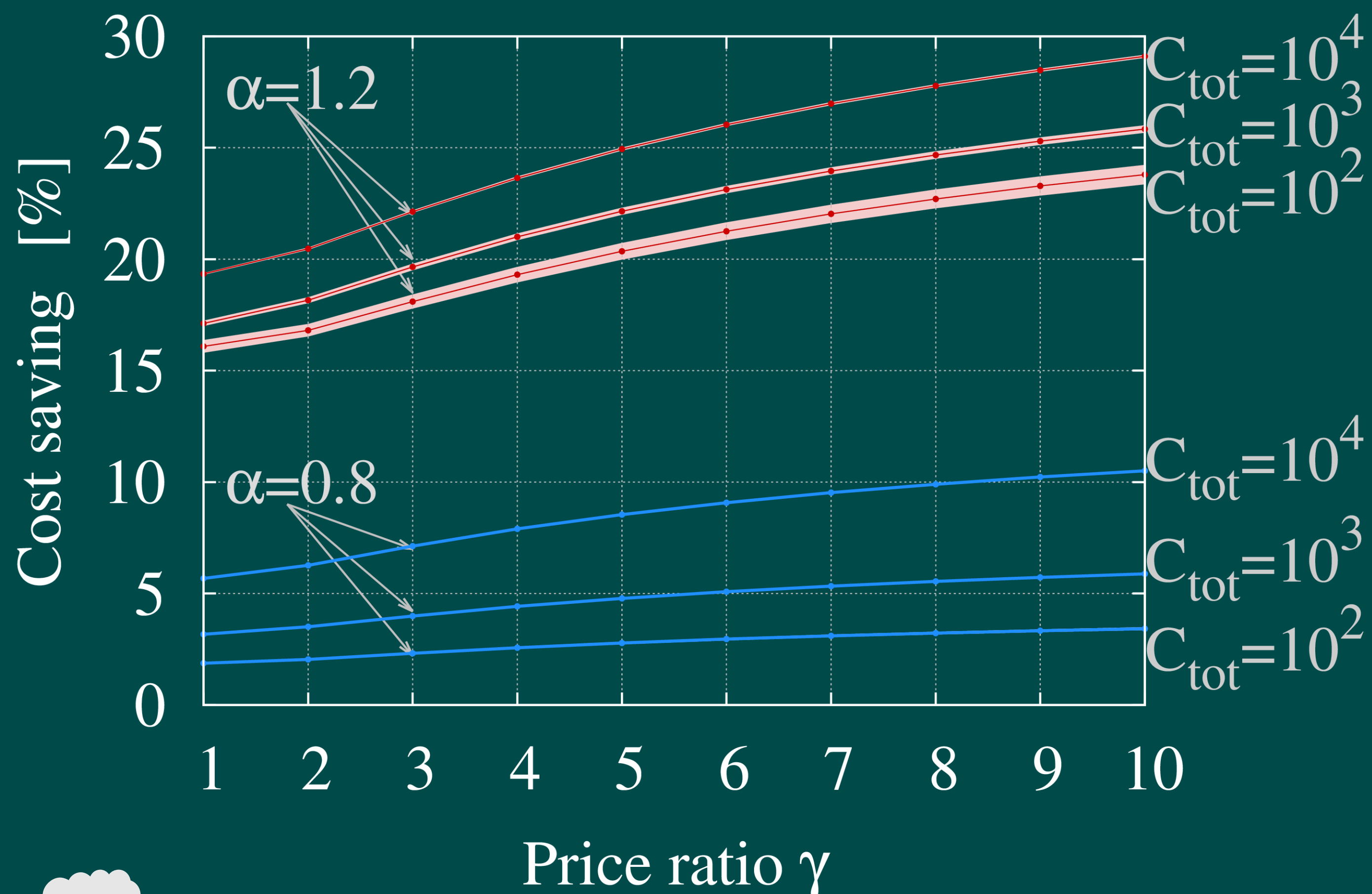
$$\text{Cost saving} = \frac{C_{CLASSIC} - C_{COST\text{-}AWARE}}{C_{CLASSIC}}$$

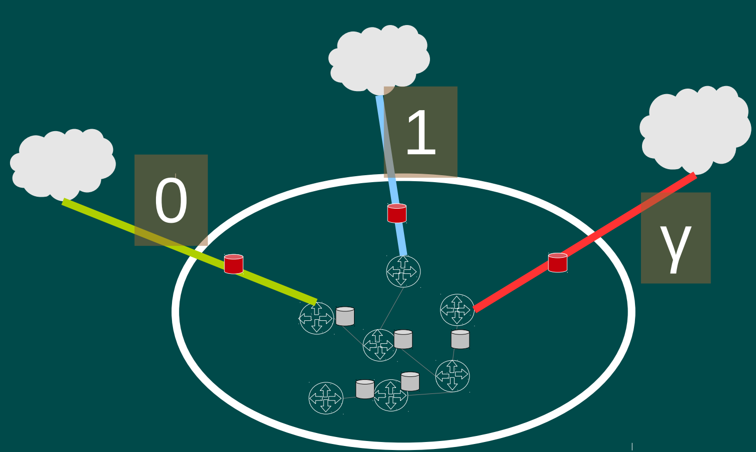
Cost savings

Price diversity ↗
⇨ Savings ↗

Cache Budget ↗
⇨ Savings ↗

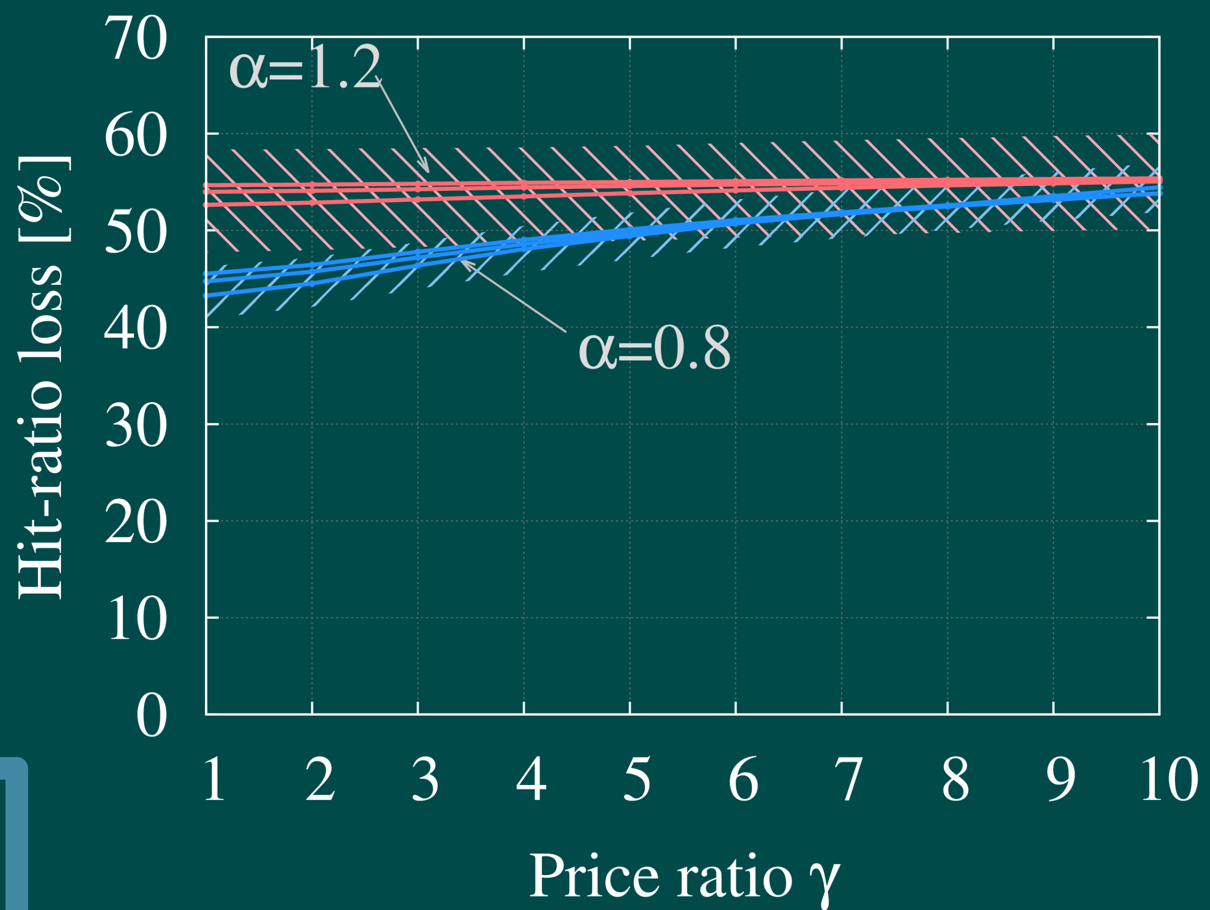
Skew ↗
⇨ Savings ↗





$$\text{Cost saving} = \frac{C_{CLASSIC} - C_{COST\text{-}AWARE}}{C_{CLASSIC}}$$

Hit-ratio loss

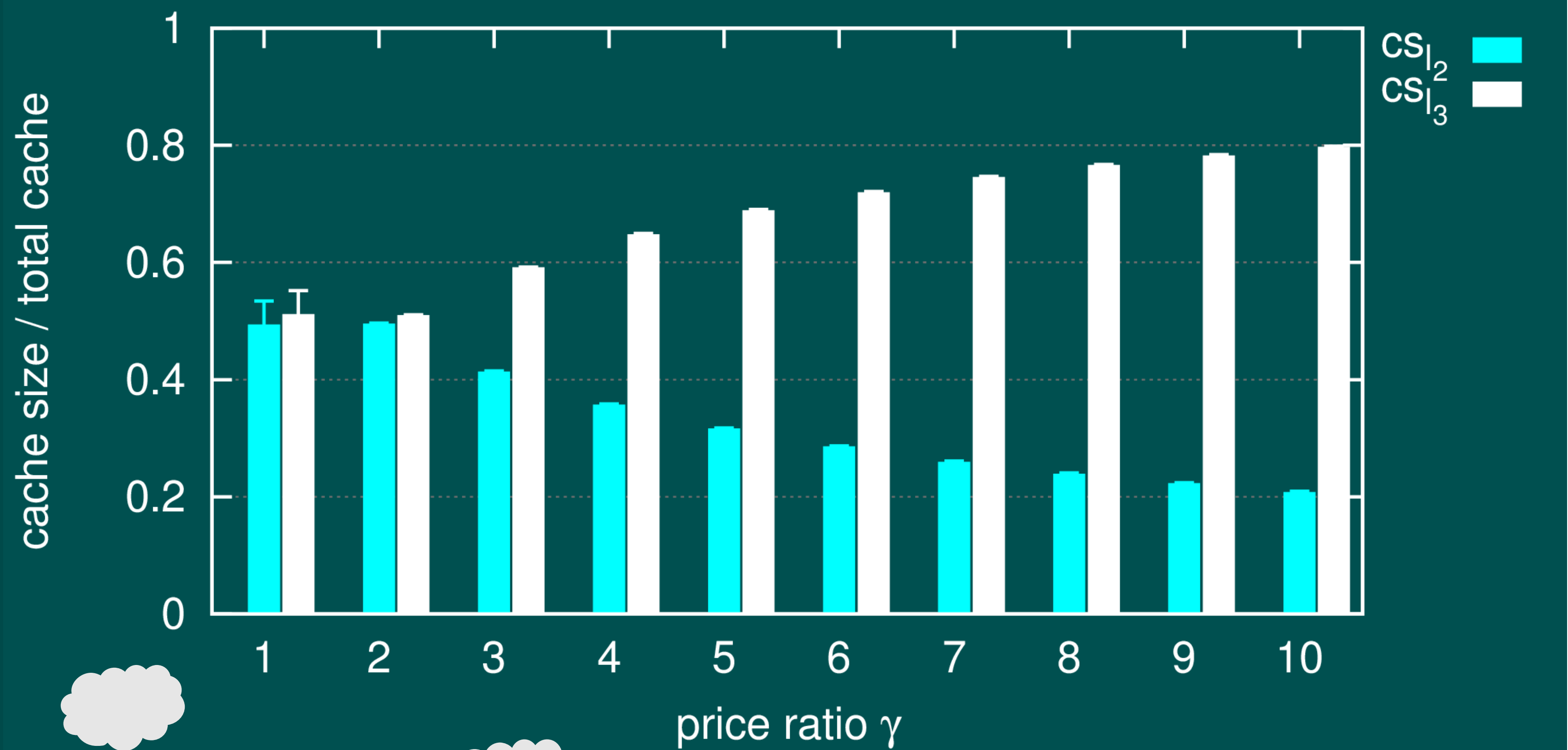


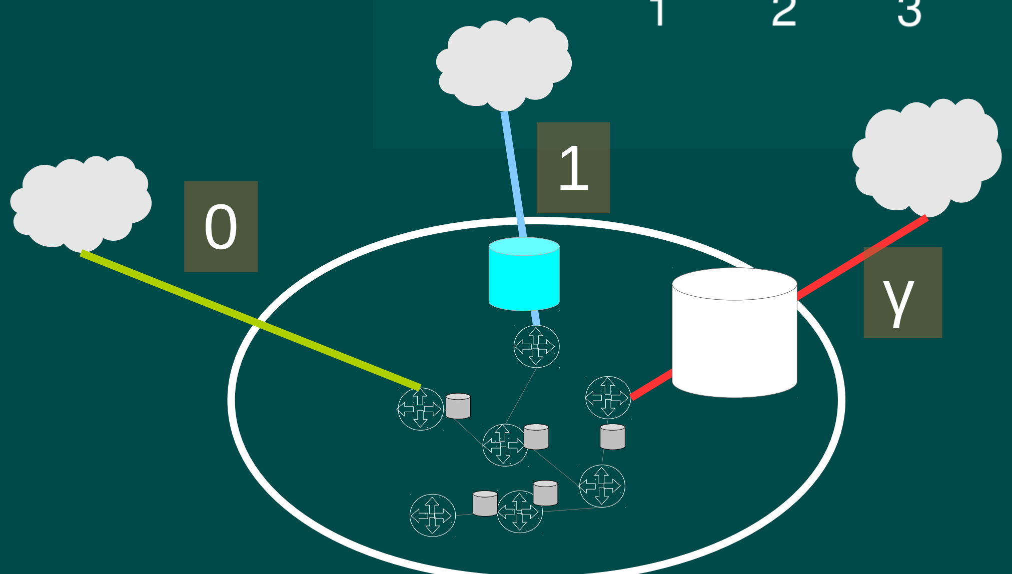
To attain cost savings, an ISP should sacrifice cache efficiency

$$\text{Hit-ratio loss} = \frac{H_{CLASSIC} - H_{COST\text{-}AWARE}}{H_{CLASSIC}}$$

Cache sizing

$\alpha = 1.2;$
$C_{tot} = 10^3$





Cost-aware decision policy

Is cost-awareness implementable in a cache?

Yes!

A. Araldo, D. Rossi, F. Martignon,
"***Design and Evaluation of Cost-aware Information Centric Routers***",
in ACM SIGCOMM Conference on Information-Centric Networking (ICN), Paris, 2014

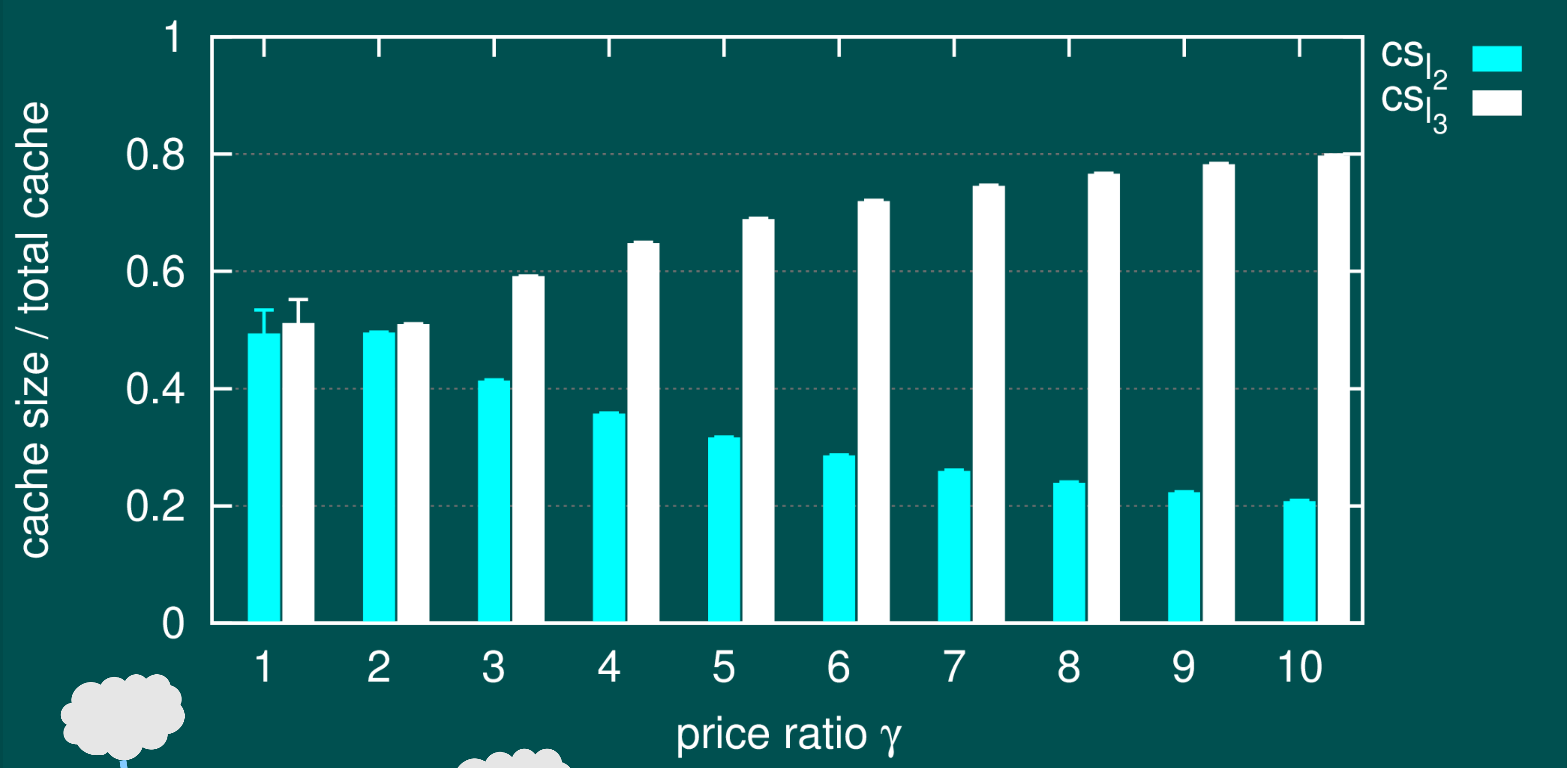
Conclusion

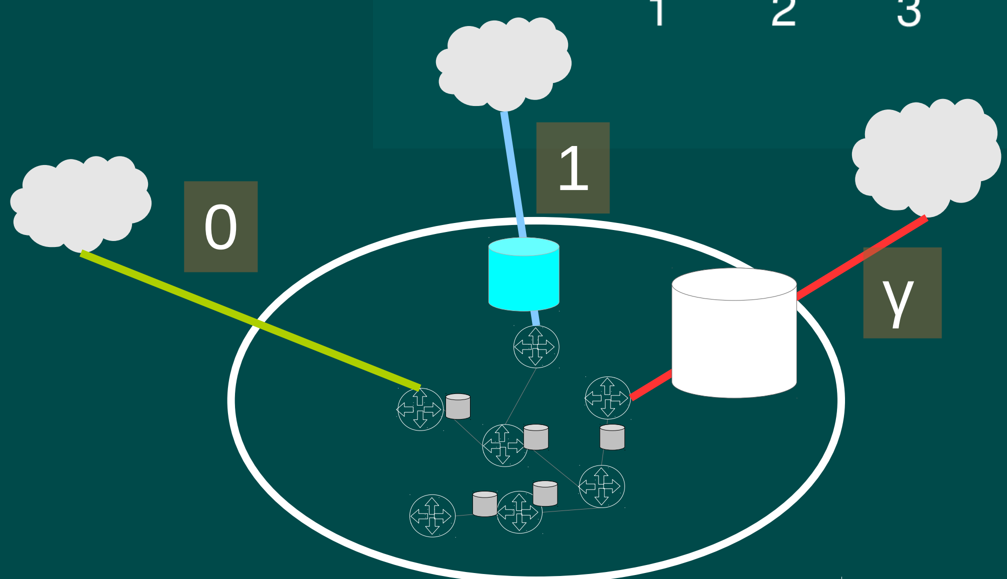
- We proposed two optimization models: CLASSIC vs. COST-AWARE
  - Forwarding, object placement, cache sizing
- We proposed two greedy algorithms
  - We analytically prove their optimality
- Key findings
  - Classic caching is cost-ineffective
  - We need Cost-Aware caching to take into account price heterogeneity
  - It brings sizable savings (~25%)

Backup

Cache sizing details

α = 1.2;
$C_{tot} = 10^3$





- Why with γ=2, the caches on the cheap and expensive links are almost the same?
  - Cache sizing does not depend only on the link prices but also on how many objects we retrieve through each link.
  - In case an object is reachable through l_2 and l_3, the greedy algorithm imposes to use l_2
  - Therefore, more objects are retrieved through l_2 and the cache of l_2 is quite big, even if the price is half the price of l_3
- Why is the variability of the cache size is so high for γ=1?
  - For γ=1 the price has no influence, only the object distribution (which link gives access to each object) matters. Since it changes from a run to another, it brings a large variability to cache sizing results
  - For higher values of γ, also the link price (that does not change from a run to another) impacts the solution and attenuates the variability of the object distribution

Greedy algorithm time complexity

- Polynomial time algorithm
  - Forwarding
    - Find the cheapest link for all the objects
      $O(|L|\cdot|O|)$
      - $|L|$: number of links
      - $|O|$: number of objects
    - Compute the price of each object
      $O(|O|)$
  - Object placement
    - Find the C_{tot} most expensive objects It is a
      $O(|O| \cdot \log |O|)$
  - Cache sizing
    - For each link, count how many selected objects are behind it
      - $O(|L| \cdot |O|)$