INVAR: Inversion Aware Resource Provisioning and Workload Scheduling for Edge Computing

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作者团队背景

Research Interests

- Cloud Computing & Cloud Platform
- Data Center & Edge Server
- Queueing System & Response Time
- Resource Allocation
- Amazon Web Services

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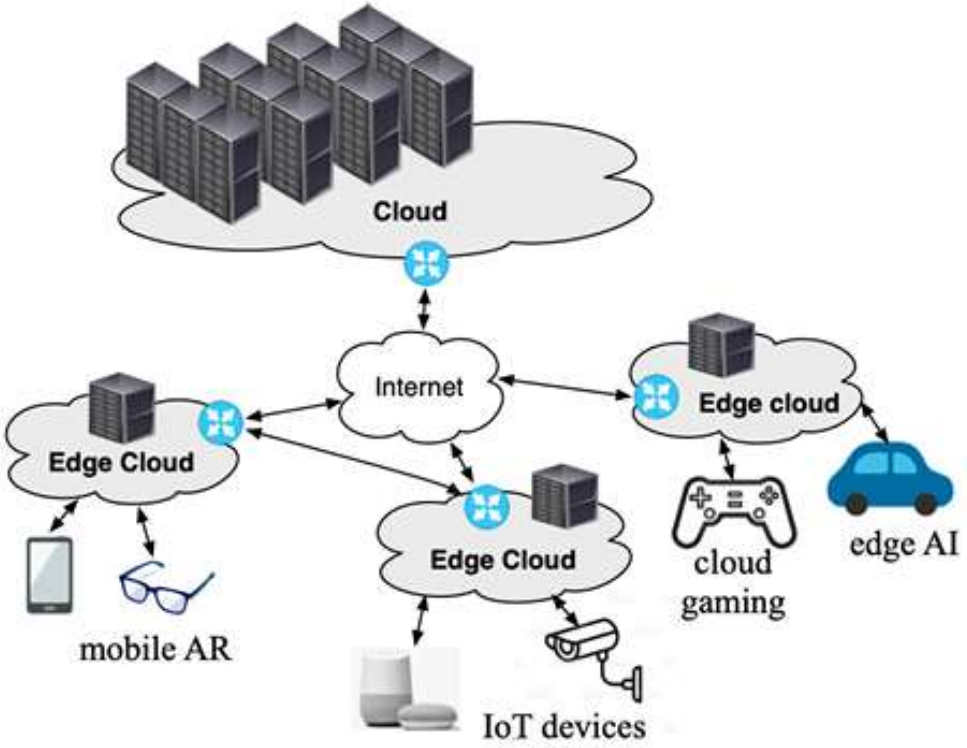
目录

Introduction

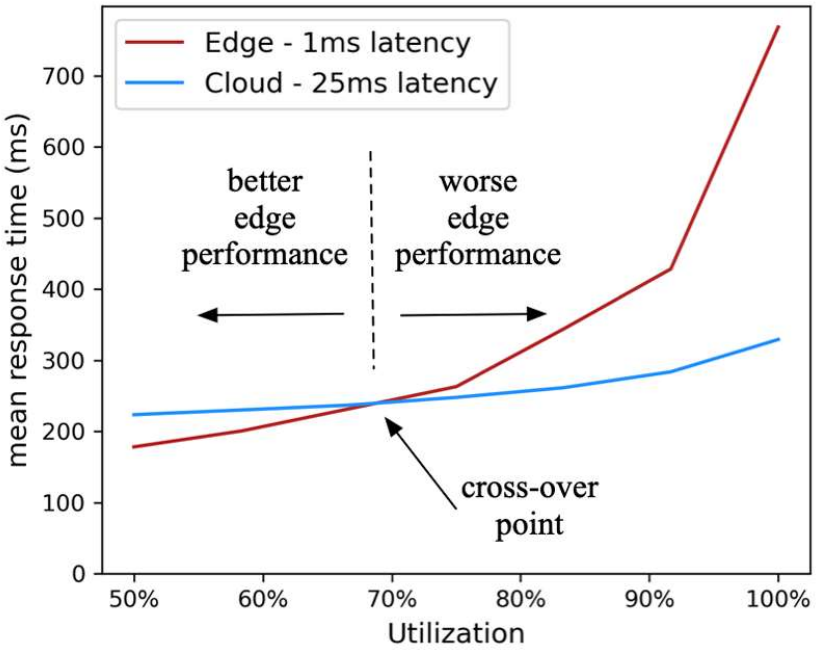


边缘计算 => 云计算：

高实时性高并发的应用场景

更低的传输延时

Introduction

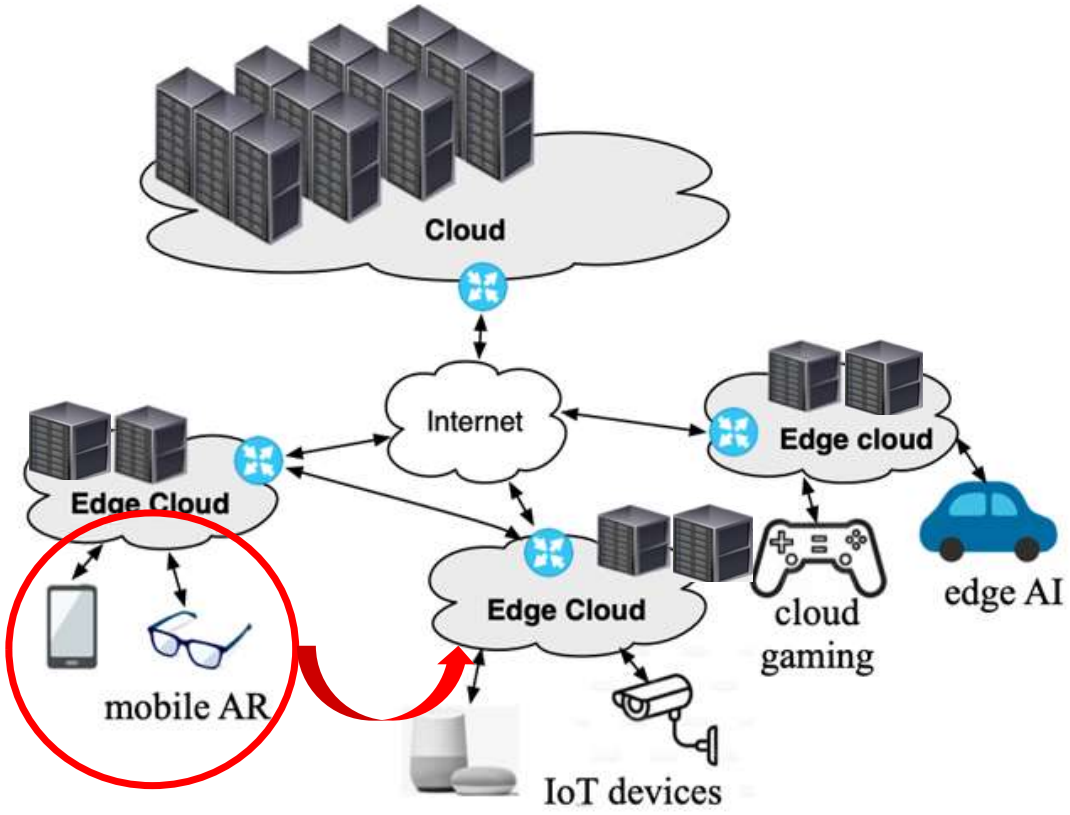


边缘性能倒置现象：

边缘优先响应时间 > 云计算响应时间

响应时间 = 传输延迟 + 排队延迟 +服务时间

Introduction

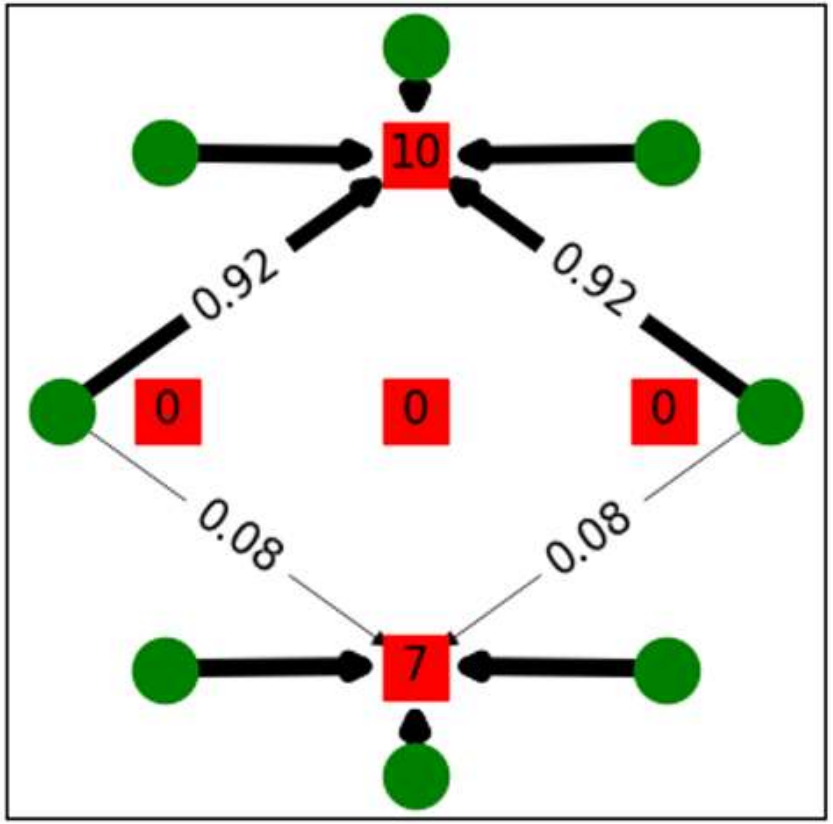


常见的解决方法：

1. 增加服务器资源

2. 重定向至其他数据中心

Introduction



概率调度方法：

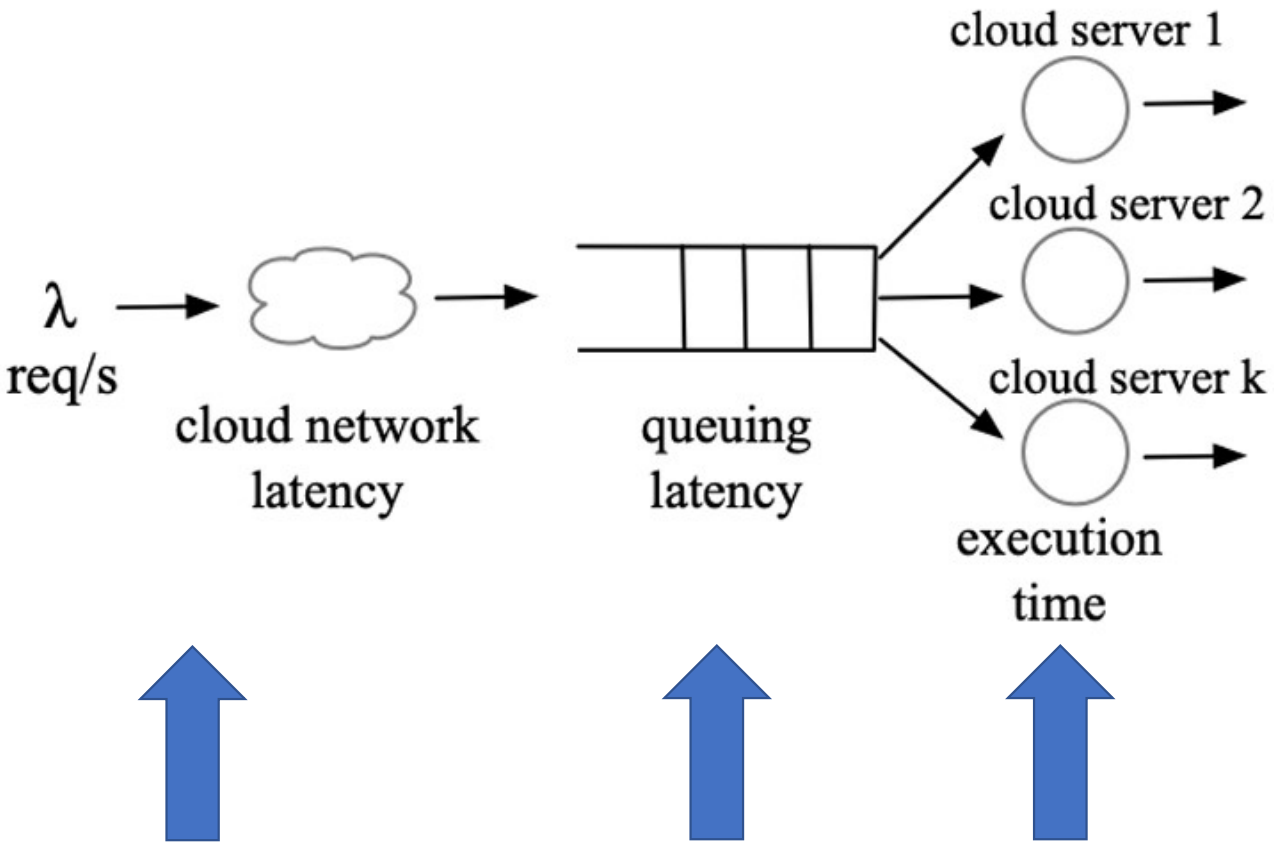
用户请求概率地指向某个数据中心

绿色：用户地址

红色：数据中心（中间为云，四周为边缘）

有向线段：请求发送给某个数据中心的概率

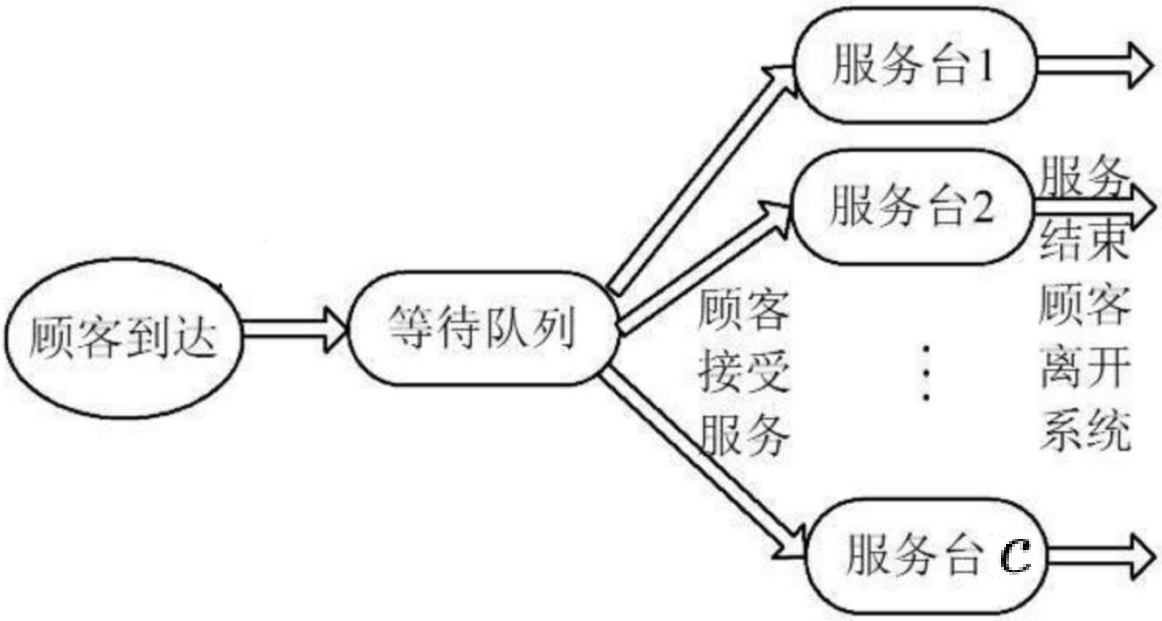
Background



云/边缘端处理请求：

1. 传输延迟
2. 排队延迟
3. 服务时间

Design



单个数据中心的M/M/c队列

L个用户位置（顾客）

K个数据中心

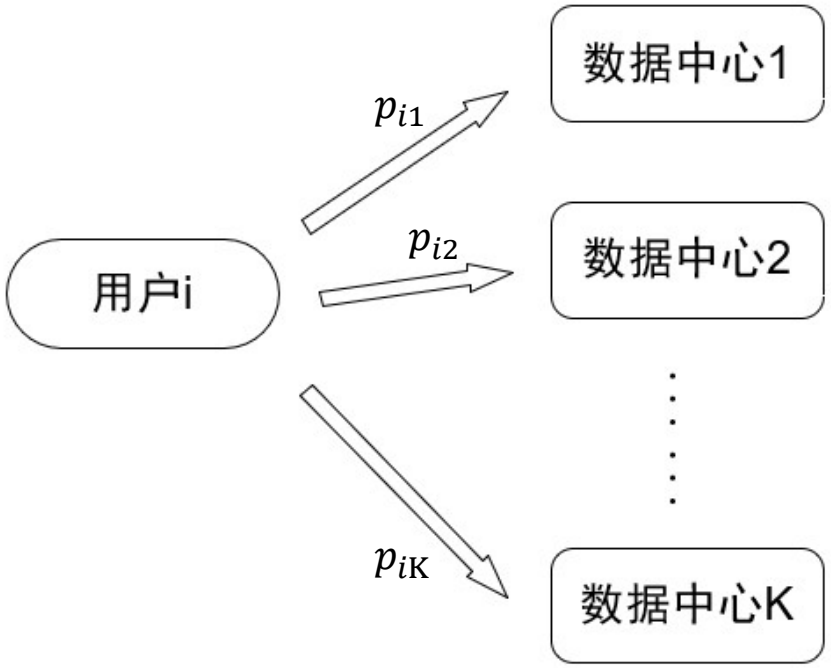
每个数据中心j有c_j个服务器（服务台）

用户i平均请求达到率为γ_{i}

数据中心j平均服务率为μ_{j}

数据中心j开销为$c_j\omega_{\mathrm{j}}$

Design



概率调度M/M/c队列

数据中心j的有效到达率：

$$\lambda_{\mathrm{j}} = \sum_{i=1}^{L} \gamma_i * p_{ij}$$

Design

在数据中心的平均花费时间 = 等待时间 + 服务时间：

$$T_j^D = \frac{C(c_j, \lambda_j/\mu_j)}{c_j\mu_j - \lambda_j} + \frac{1}{\mu_j}$$

其中：

$$C(c, \lambda/\mu) = \frac{(\frac{(c\rho)^c}{c!})(\frac{1}{1-\rho})}{\sum_{k=0}^{c-1}\frac{(c\rho)^k}{k!} + \frac{(c\rho)^c}{c!}\frac{1}{(1-\rho)}} \qquad \rho = \frac{\lambda}{c\mu}$$

所有用户的平均响应时间：

$$T(c, p) = \sum_{i=1}^{L}\frac{\gamma_i}{||\gamma||_1}\sum_{j=1}^{K}p_{ij}(T_{ij}^N + T_j^D)$$

Design

$$
\begin{aligned}
\min_{c,P} \quad & T(c,P) \\
\text{s.t.} \quad & 0 \le p_{i,j} \le 1 \quad \forall i \in 1 \dots L, \forall j \in 1 \dots K \\
& 0 \le c_j \le C_j \quad \forall j \in 1 \dots K \\
& \sum_{j=1}^{K} p_{i,j} = 1 \quad \forall i \in 1 \dots L \\
& \lambda_j < c_j \mu_j \quad \forall j \in 1 \dots K \\
& \sum_{j=1}^{K} c_j w_j \le W
\end{aligned}
$$

NP难！

Design

$$C(c,\lambda/\mu) \le [\frac{\lambda}{c\mu} + \eta(\frac{\Phi(\alpha)}{\phi(\alpha)} + \frac{2}{3}\frac{1}{\sqrt{c}})]$$ [1]

$$\phi(\alpha) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\alpha^2} \qquad \Phi(\alpha) = \frac{1}{2}[1 + erf(\frac{\alpha}{\sqrt{2}})]$$

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

$$\alpha = \sqrt{-2c(1-\rho+ln\rho)} \qquad \eta = (c-\lambda/\mu)/\sqrt{c} \qquad \rho = \frac{\lambda}{c\mu}$$

[1] Refining square-root safety staffing by expanding Erlang C

Design

$$\min_{c,P} \quad T'(c,P) + \tau \left(\sum_{j=1}^{K} c_j w_j - W \right)^2$$

$$\begin{aligned}
\text{s.t.} \quad & 0 \leq p_{i,j} \leq 1 && \forall i \in 1 \ldots L, \forall j \in 1 \ldots K \\
& 0 \leq c_j \leq C_j && \forall j \in 1 \ldots K \\
& \sum_{j=1}^{K} p_{i,j} = 1 && \forall i \in 1 \ldots L \\
& \lambda_j < c_j \mu_j && \forall j \in 1 \ldots K
\end{aligned}$$

PERT-OPT

Design

$$\begin{aligned}
\min_{P} \quad & T(c, P) \\
\text{s.t.} \quad & 0 \leq p_{i,j} \leq 1 \quad \forall i \in 1 \ldots L, \forall j \in 1 \ldots K \\
& \sum_{j=1}^{K} p_{i,j} = 1 \qquad \forall i \in 1 \ldots L \\
& \lambda_j < c_j \mu_j \qquad \forall j \in 1 \ldots K
\end{aligned}$$

FLOW-OPT

Design

Algorithm 1 Inversion Aware Deployment Plan Search Algorithm

Input: L, γ, K, C, μ, w, T^N, T^{cloud}, δ, W, ϵ
Output: c, P

$T^{target} \leftarrow T^{cloud} - \delta$
$W^l \leftarrow 0$
$W^u \leftarrow W$
while $W^u - W^l > \epsilon$ **do**
  $W^m \leftarrow \frac{W^l + W^u}{2}$
  status, $c, P \leftarrow$ PERF_OPT$(L, \gamma, K, C, \mu, w, W^m)$
  if status = solved **and** $T'(c, P) \leq T^{target}$ **then**
    $W^u \leftarrow W^m$
  else
    $W^l \leftarrow W^m$
  end if
end while
status, $c, P \leftarrow$ PERF_OPT$(L, \gamma, K, C, \mu, w, W^u)$
if $T'(c, P) \leq T^{target}$ **then**
  $c \leftarrow$ round(c)
  $P \leftarrow$ FLOW_OPT(L, γ, μ, c)
  return c, P
else
  return "NO SOLUTION FOUND"
end if

STEP1：二分查找得出最小成本

利用PERT-OPT得出分配向量

STEP2：分数解转为整数解

STEP3：通过FLOW-OPT得出分配概率

Evaluation

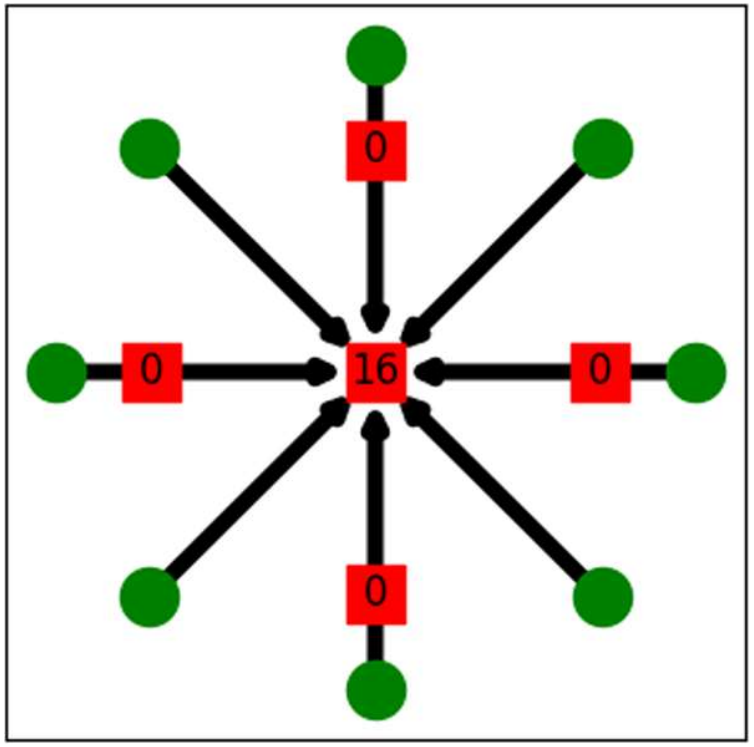
Julia + JuMP

PERT-OPT：Artelys Knitro + 多起点

FLOW-OPT：Ipopt + 内点法

数值模拟：离散事件模拟器DES

Evaluation



模拟场景

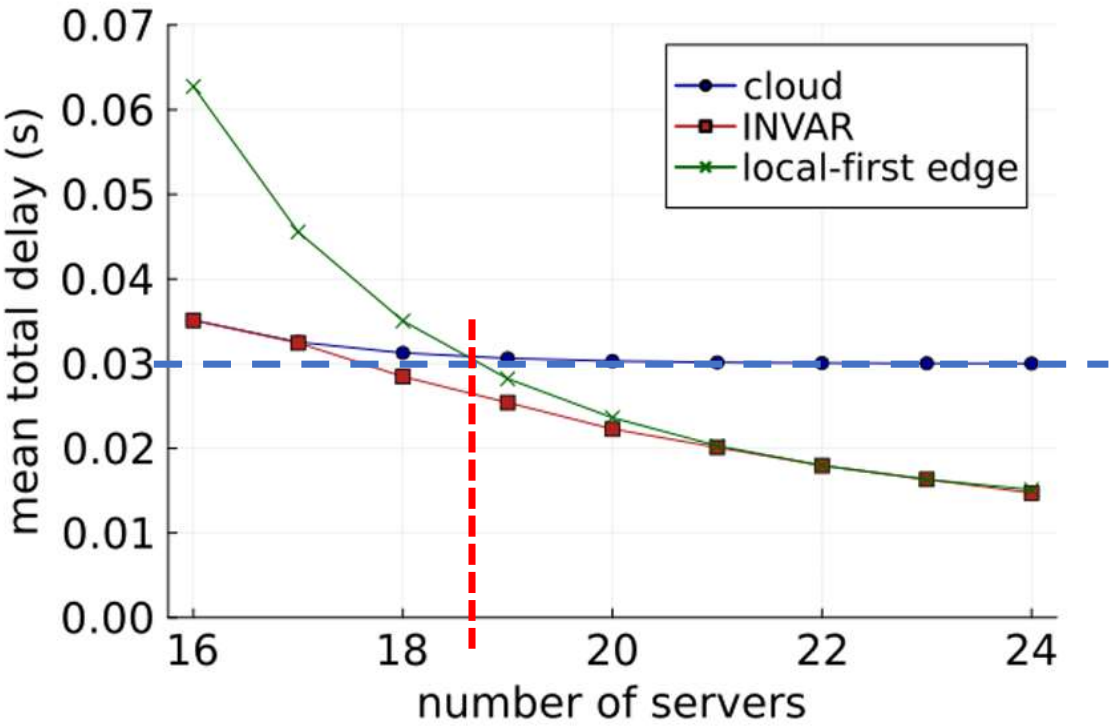
绿色：用户地址$[\gamma_i = 15]$

红色：数据中心（中间为云，四周为边缘）

$[\mu_j = 10, \omega_j = 1]$

云数据中心容量上限为50，边缘数据中心为10

Evaluation



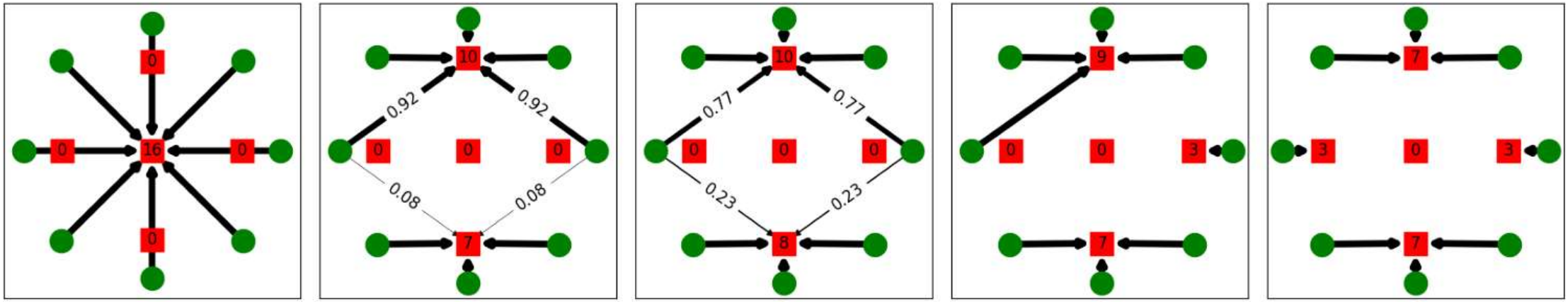
服务器总数由16 => 24

云部署逐渐趋近30ms极限

边缘性能倒置：< 19台

INVAR 一直保持最优

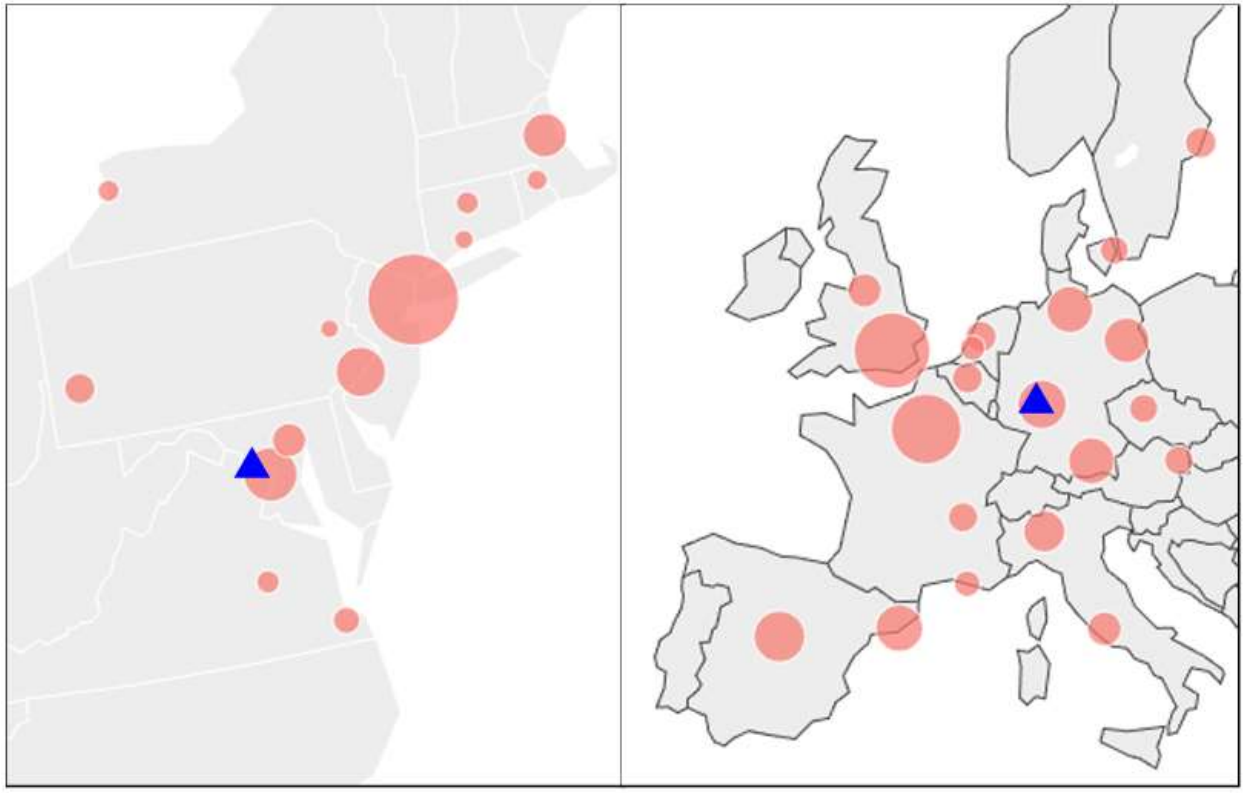
Evaluation



(a) budget=16 (b) budget=17 (c) budget=18 (d) budget=19 (e) budget=20

概率调度部署计划 (服务器数量 16 => 24)

Evaluation



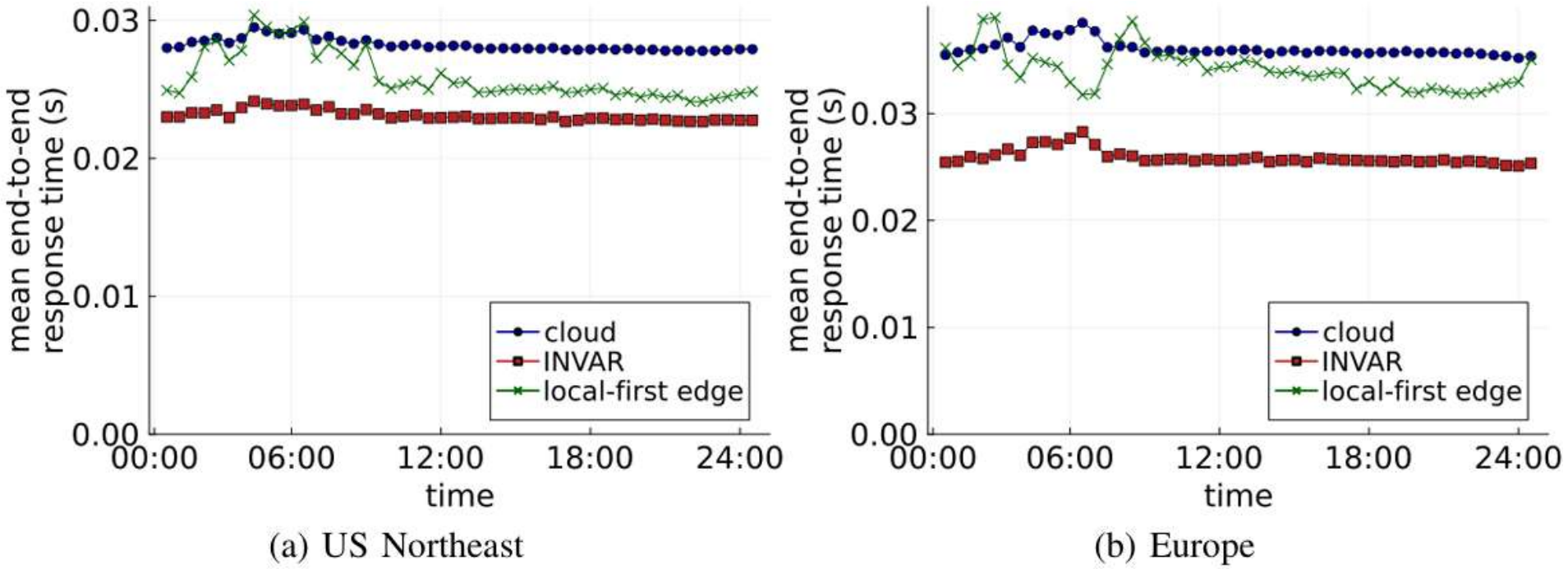
(a) US Northeast (b) Europe

2013 年 8 月 Akamai

美国东北部 (请求主要分布四大城)

欧洲地区 (请求分布更为均匀)

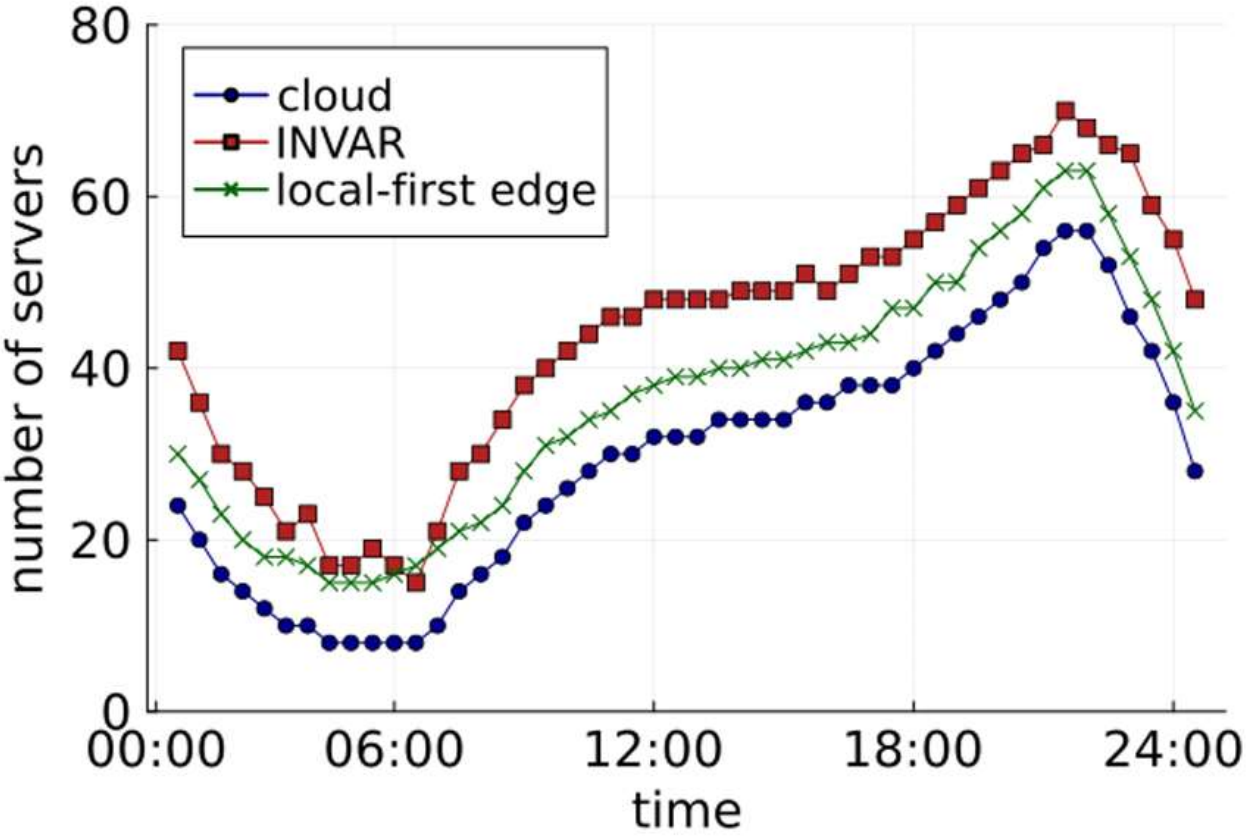
Evaluation



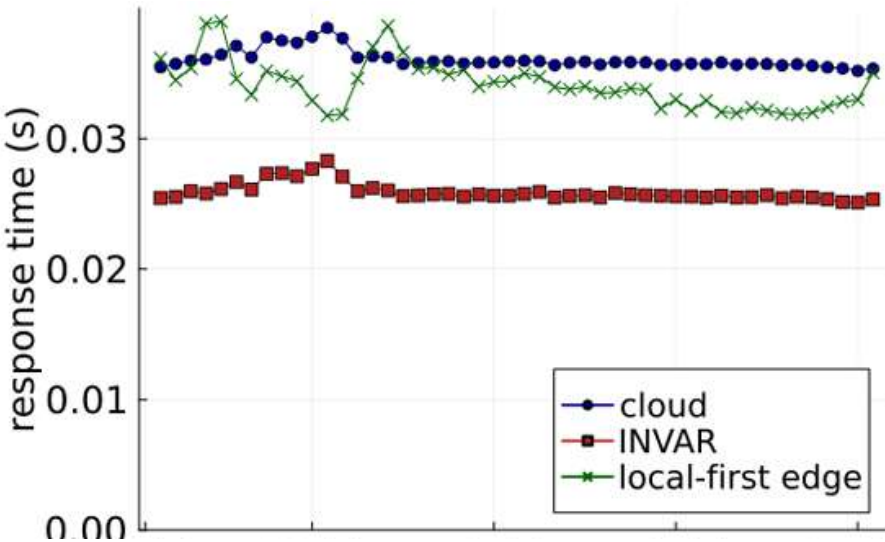
(a) US Northeast (b) Europe

出现了边缘性能倒置

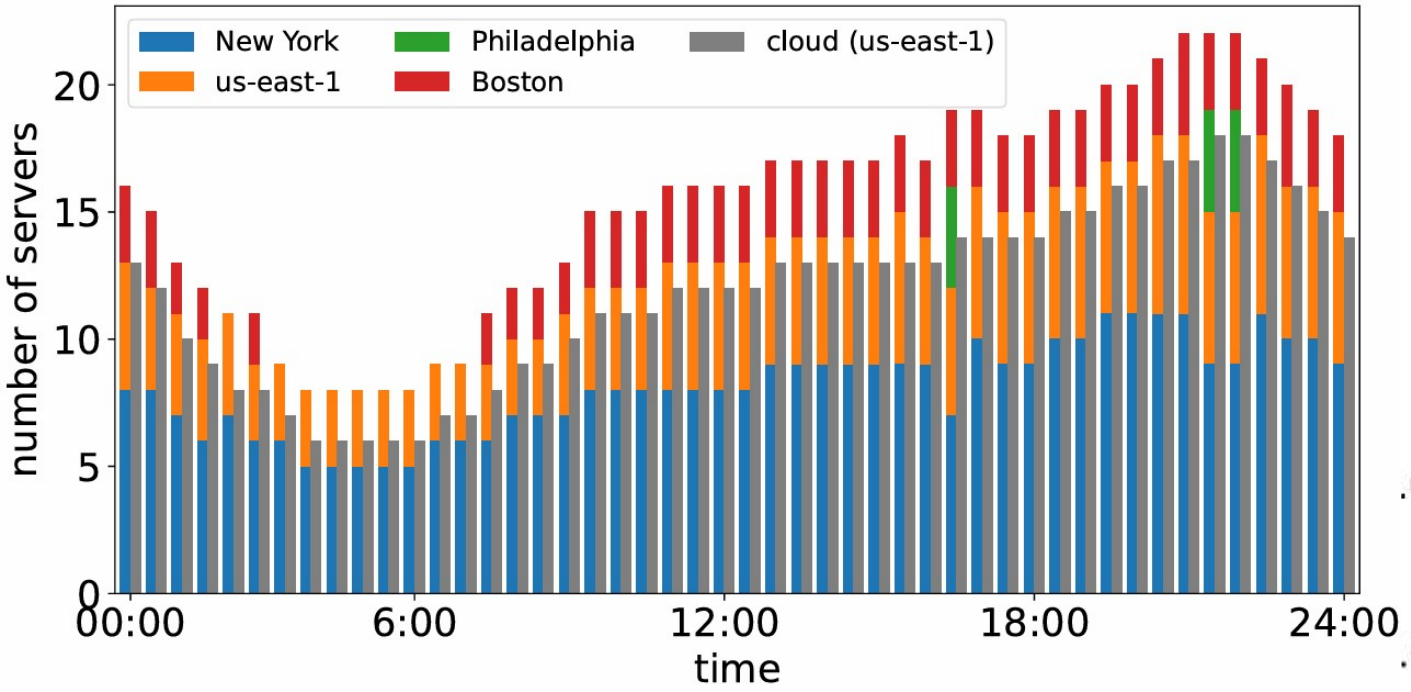
Evaluation



欧洲地区服务器部署数量

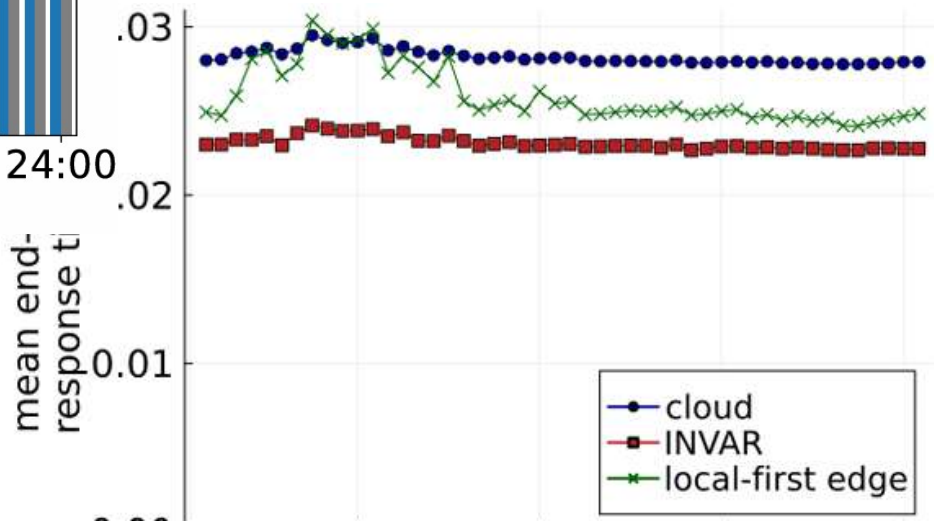


Evaluation



美国东北部服务器部署数量

不严谨！



Evaluation

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  status, $c, P \leftarrow$ PERF_OPT$(L, \gamma, K, C, \mu, w, W^m)$
  if status = solved **and** $T'(c, P) \leq T^{target}$ **then**
    $W^u \leftarrow W^m$
  else
    $W^l \leftarrow W^m$
  end if
end while
status, $c, P \leftarrow$ PERF_OPT$(L, \gamma, K, C, \mu, w, W^u)$
if $T'(c, P) \leq T^{Target}$ **then**
  $c \leftarrow$ round(c)
  $P \leftarrow$ FLOW_OPT(L, γ, μ, c)
  return c, P
else
  return "NO SOLUTION FOUND"
end if

必然的延时降低

Evaluation

Method — Distribution	mean	95% CI
Numerical Analysis — $E(\gamma)$	0.0229955	–
Simulation — $E(\gamma)$	0.0230106	(0.0229797, 0.0230415)
Simulation — $U(0, 2/\gamma)$	0.0227394	(0.0227214, 0.0227574)
Simulation — $\Gamma(3, 3\gamma)$	0.0226909	(0.022672, 0.0227097)
Simulation — $\Gamma(5, 5\gamma)$	0.0226576	(0.0226449, 0.0226702)

到达时间

Method — Distribution	mean	95% CI
Numerical Analysis — $E(\mu)$	0.0229955	–
Simulation — $E(\mu)$	0.0230106	(0.0229797, 0.0230415)
Simulation — $U(0, 2/\mu)$	0.0228921	(0.0228825, 0.0229017)
Simulation — $\Gamma(3, 3\mu)$	0.0228781	(0.022865, 0.0228911)
Simulation — $\Gamma(5, 5\mu)$	0.0228574	(0.0228469, 0.0228679)

服务时间

Conclusion

边缘性能倒置问题：

引入概率调度方法降低高请求边缘数据中心排队延迟

存在逻辑问题，可以改进！

IDEAS

1.在同一个成本下进行INVAR相关实验

2. 云数据中心 + 边缘数据中心协同调度

3. 一个请求可能需要n个服务器共同处理

4. 分配概率动态调整

Thanks for listening
请老师同学们批评指正

汇报人：黄　　凯
2024 年 11 月 10 日