Reducing Web Latency through Dynamically Setting TCP Initial Window with Reinforcement Learning

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Microsoft Research 微软亚洲研究院 [¶]
Baidu 百度 [‡]

Motivation and background

- **Web latency matters!**

Google latency increases 100ms ~400ms, query number decrease 0.2%~0.6%[1]

bing latency increases 50ms, revenue decrease 1.2% [2]

amazon every 100ms of latency cost them 1% in sales [3]

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[1] J.Brutlag. (June, 2009). Speed matters for Google web search.

[2] E.Schurman,J.Brutlag.(June,2009).The User and Business Impact of Server Delays, Additional Bytes and Http Chunking in Web Search.

[3] Latency Is Everywhere And It Costs You Sales. https://goo.gl/bRi5Xs

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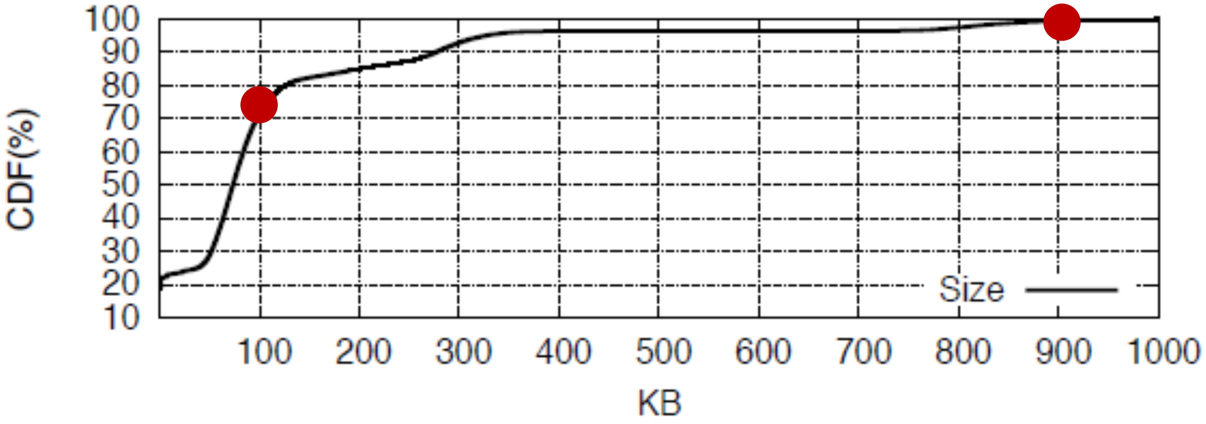
Motivation and Background

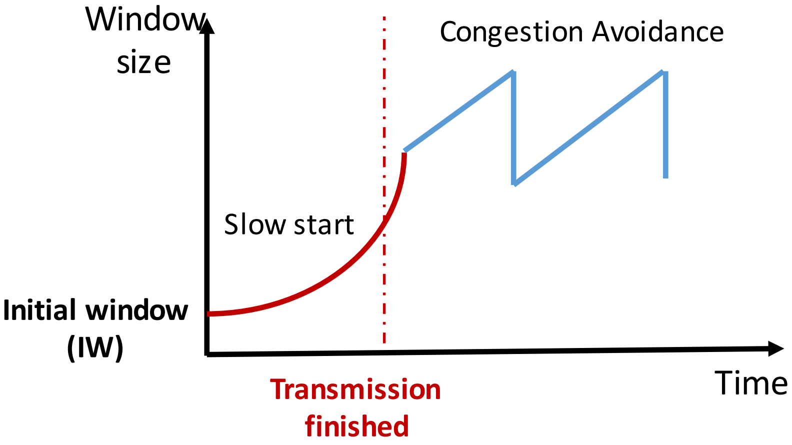
- **Currently, data transmission of most web services are based on TCP.**

- **Most flows of web service are short.**
  - 99% flows are smaller than 100KB [Greenberg SIGCOMM'09]
  - 70% flows of Baidu mobile search service are smaller than 100KB.

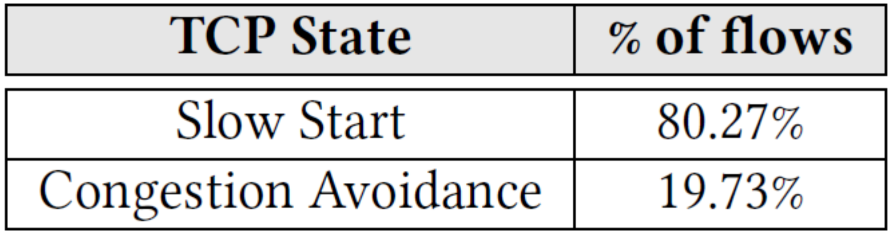


Motivation and Background

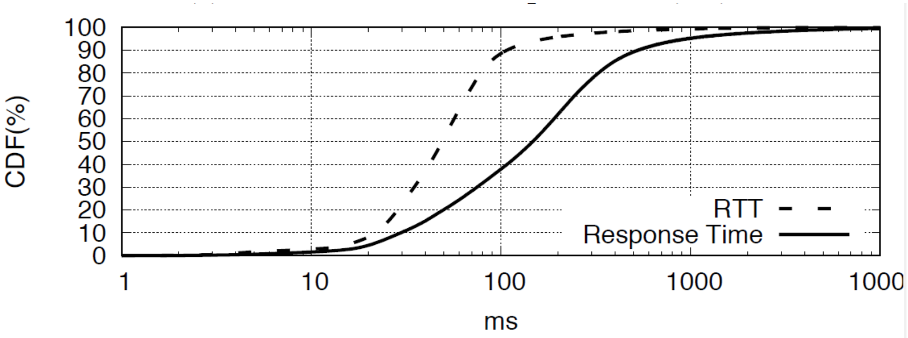
- **Short flow's transmission is slow because of TCP's *flow startup problem* [RFC6077]**
  - Slow-start mechanism with a conservative initial window (IW) to probe the bandwidth during the transmission.



- **Inefficient bandwidth utilization**
- **Multiple RTTs for short flow**



TCP State	% of flows
Slow Start	80.27%
Congestion Avoidance	19.73%



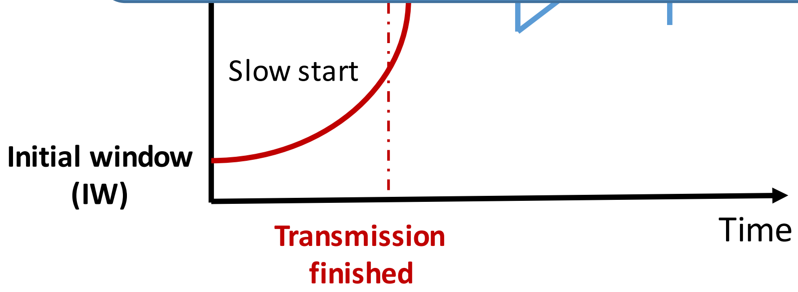
(b) The distribution of RTT and response time (ms). The x-axis logscale.

Motivation and Background

- **Short flow's transmission is slow because of TCP's *flow startup problem* [RFC6077]**
  - Slow-start mechanism with a conservative initial window (IW) to probe the bandwidth during the transmission.

TCP State	% of flows

The reason is the sender doesn't know how to set the IW.



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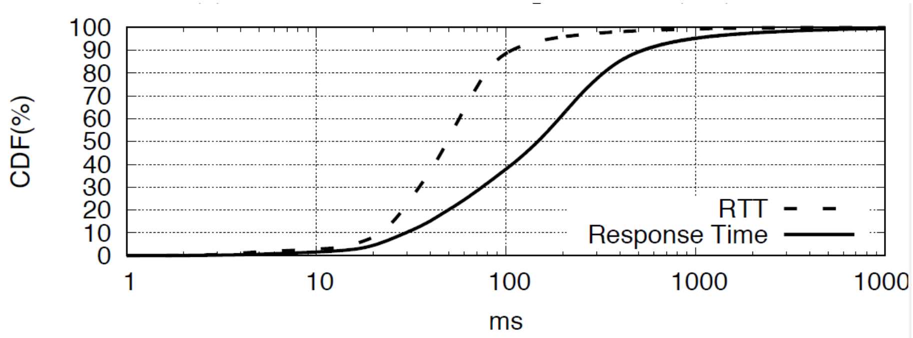


(b) The distribution of RTT and response time (ms). The x-axis logscale.

Motivation and Background

- **Why IW is hard to set?**
  - Large IW -> network congestion; Small IW -> long latency
  - No knowledge to learn.
    - When connection established, the sender does not know current network condition.
    - Only one kind of IW has been used in history.

- **One static IW is suboptimal.**
  - Different users have different network conditions.
  - For one user, its network condition could changes over time.

Network	2G	3G	4G	Wi-Fi
RTT	300~1000ms	100~500ms	10~100ms	10ms ~100ms
Bandwidth	100–400 Kbit/s	0.5–5 Mbit/s	1–50 Mbit/s	25 Mbit/s
Ideal Cwnd	3~16	5~223	1~446	2~223

Ideal Cwnd = Bandwidth * RTT

Related Works

- **Many prior works have been done to improve TCP performance.**

1. **New congestion control algorithm (e.g. TCP Tahoe, Reno, Bic, Cubic, BBR, PCC, Remy, PCC Vivace, Copa, Indigo)**
    - Pros: Quickly converge to the right available bandwidth after transmission begins.
    - Cons: Flow startup problem exists.

2. **Increasing IW (IW = 2~4 in 2002**[RFC3390]**, IW = 10 in 2013**[RFC6928])
    - Pros: simple and easily deployed.
    - Cons: one standard value is suboptimal.

3. **Aggressive startup (e.g. Jump start** [FLDnet07], **Halfback** [Conext15]**):**
    - Pros: fast transmission.
    - Cons: hardly seen deployed; may cause damage to the other co-existing flows.

Related Works

- **Many prior works have been done to improve TCP performance.**

1. **New congestion control algorithm (e.g. TCP Tahoe, Reno, Bic, Cubic, BBR, PCC, Remy, PCC Vivace, Copa, Indigo)**
    - Pros: Quickly converge to the right available bandwidth after transmission begins.
    - Cons: Flow startup problem exists.

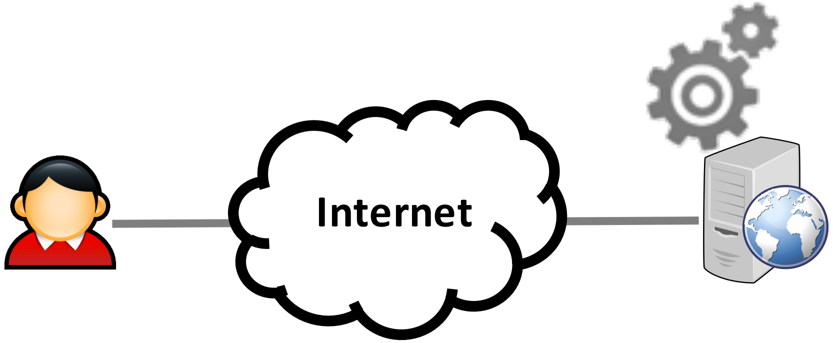
The flow startup problem is only mitigated but not directly solved

    - Cons: one standard value is suboptimal.

3. **Aggressive startup (e.g. Jump start** [FLDnet07], **Halfback** [Conext15]**):**
    - Pros: fast transmission.
    - Cons: hardly seen deployed; may cause damage to the other co-existing flows.

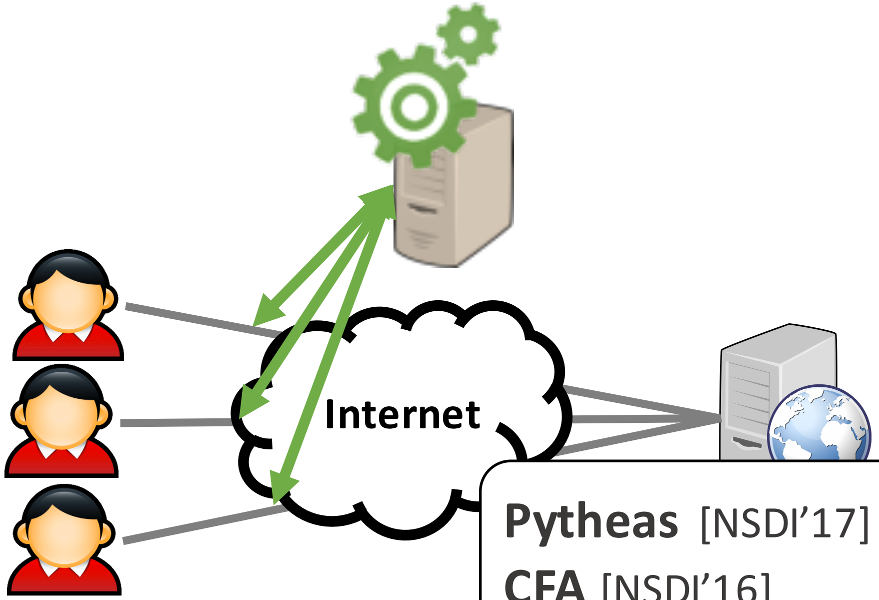
Data-driven approach is promising

Local data of single flow



Classic approaches

Global data of many flows

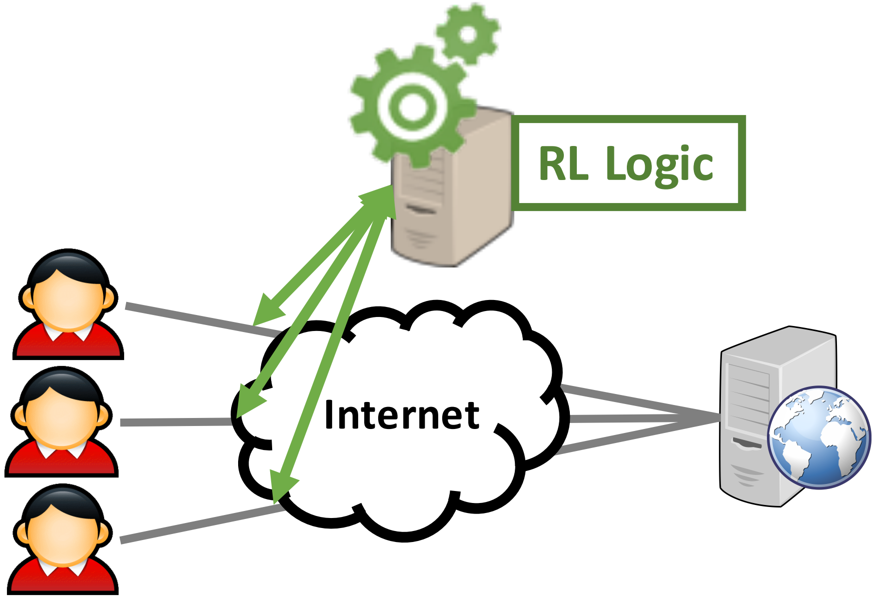


Pytheas [NSDI'17]
CFA [NSDI'16]
VIA [SIGCOMM'16]
CS2P [SIGCOMM'16]

Data-driven approach

Our Idea

Model IW setting as a Reinforcement Learning problem (Real-time Exploration and Exploitation).

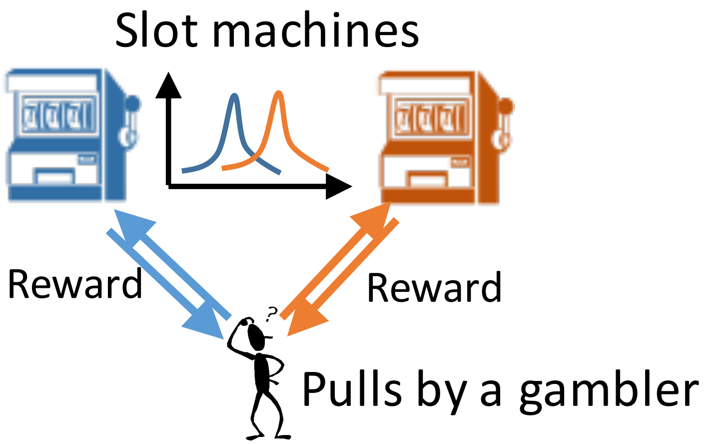


A classic problem in RL

Multi-armed bandit problem

Goal: Maximize mean rewards given a limited amount of pulls

Goal: Optimize mean TCP performance for a limited amount of flows

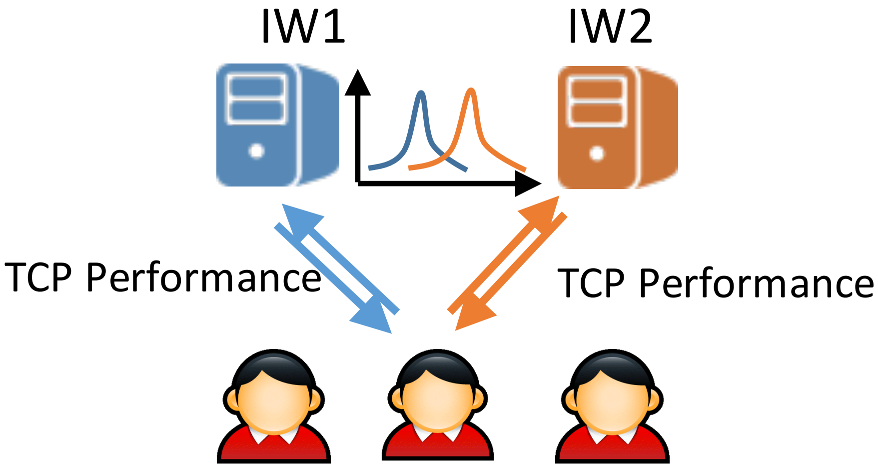


Slot machines

Reward

Reward

Pulls by a gambler



IW1

IW2

TCP Performance

TCP Performance

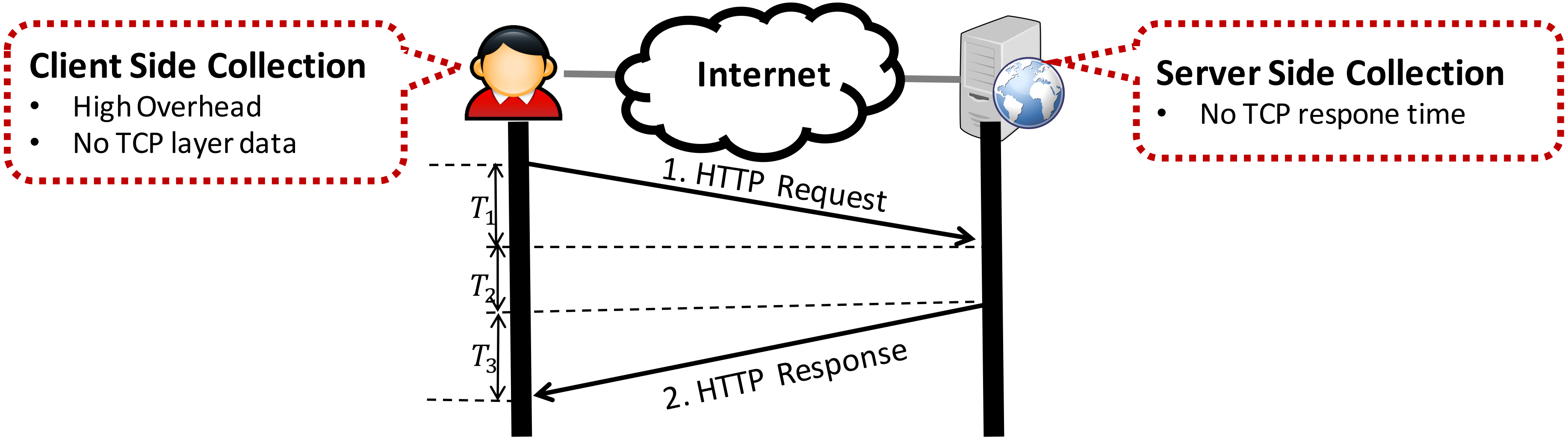
The challenges in practice

- **Challenge #1:** How to measure TCP performance data on the server side?

- **Challenge #2:** How to apply RL methods on highly variable and non-continuous network conditions of the Internet?

Challenge #1: How to measure TCP performance data on the server side

- **RL needs global fresh data**



Client Side Collection

- High Overhead
- No TCP layer data

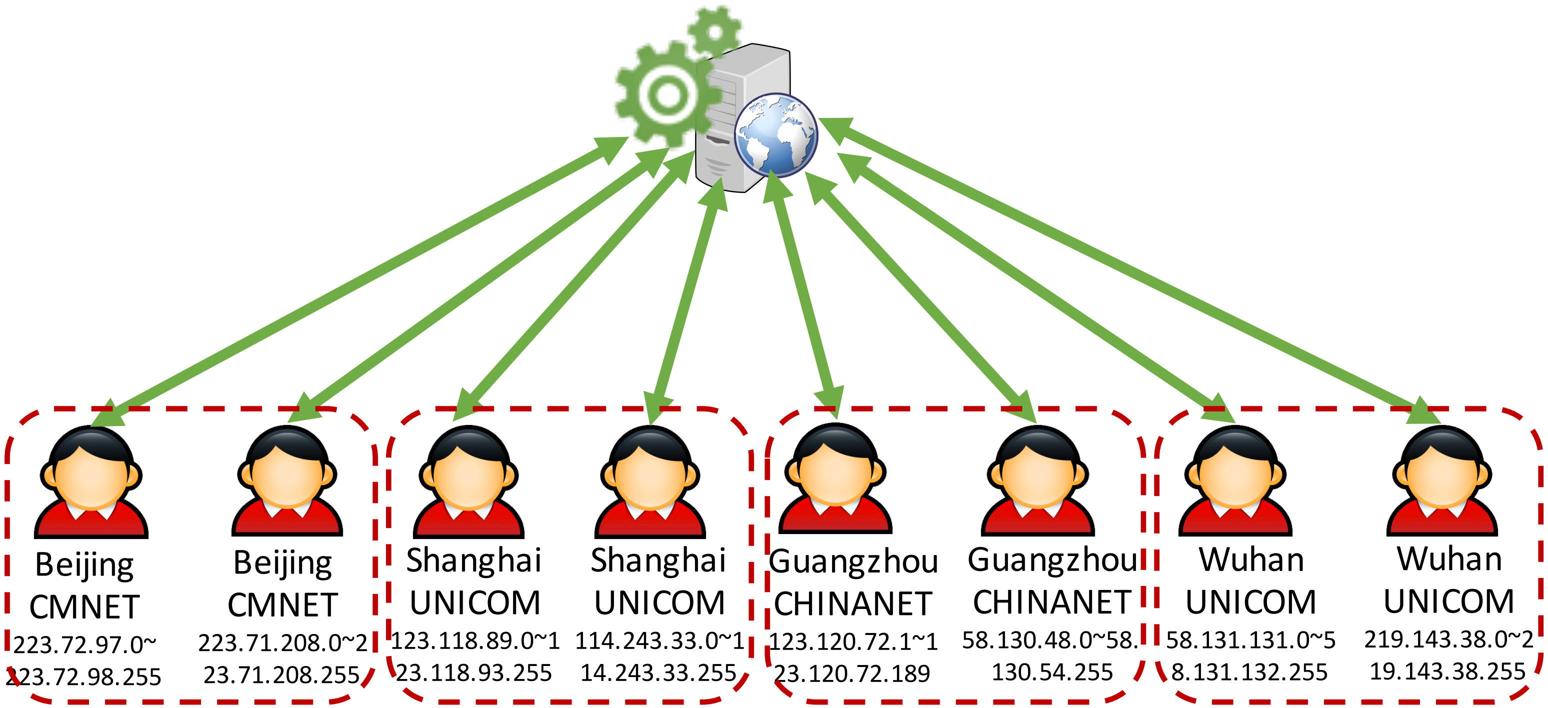
Server Side Collection

- No TCP respone time

Web latency = TCP response time = T_1 + T_3

Challenge #2: How to apply RL methods on highly variable and non-continuous network conditions of the Internet?

- **Users network condition are variable**



Beijing CMNET 223.72.97.0~223.72.98.255

Beijing CMNET 223.71.208.0~223.71.208.255

Shanghai UNICOM 123.118.89.0~123.118.93.255

Shanghai UNICOM 114.243.33.0~114.243.33.255

Guangzhou CHINANET 123.120.72.1~123.120.72.189

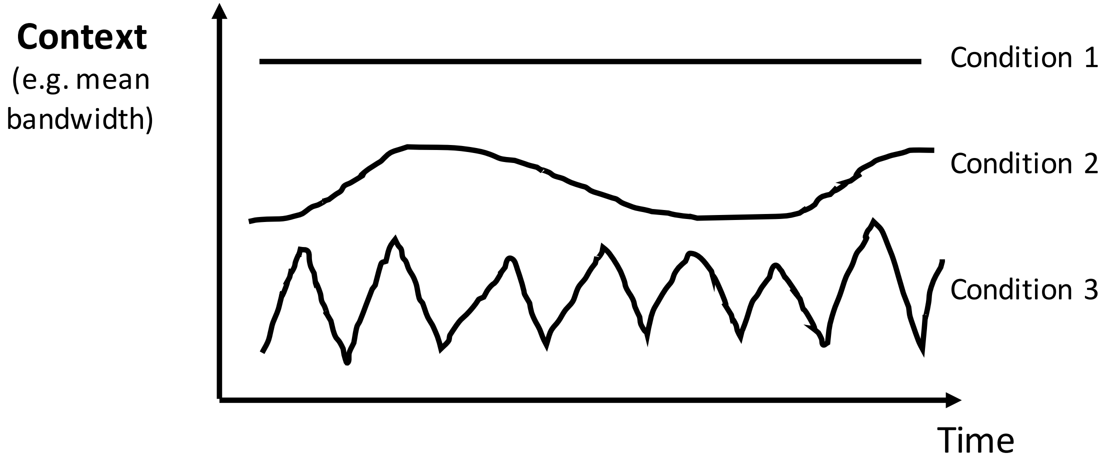
Guangzhou CHINANET 58.130.48.0~58.130.54.255

Wuhan UNICOM 58.131.131.0~58.131.132.255

Wuhan UNICOM 219.143.38.0~219.143.38.255

Challenge #2: How to apply RL methods on highly variable and non-continuous network conditions of the Internet?

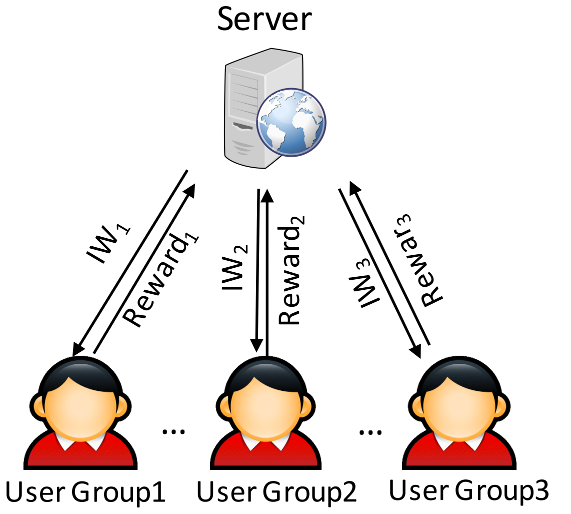
- **RL requires continuity of the context that affects the reward of the decision**



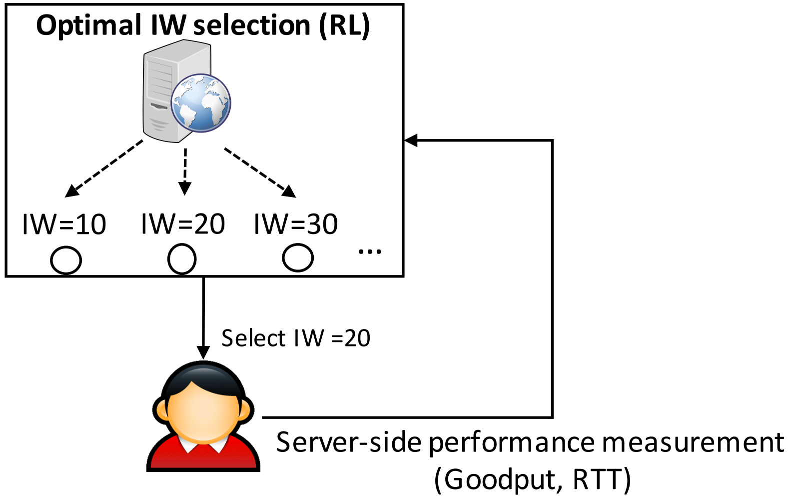
- **Not every user group can satisfy this RL's requirement**
  - Fine-grained -> not enough data samples
  - Coarse-grained -> suboptimal performance

SmartIW: Group-based RL

- **The key ideas:**
  1. Using **different IWs** for **different user groups** who can satisfy the RL's requirements
  2. For one user group, **wisely learning** the optimal IW by **RL**
  3. Server-side data collection.



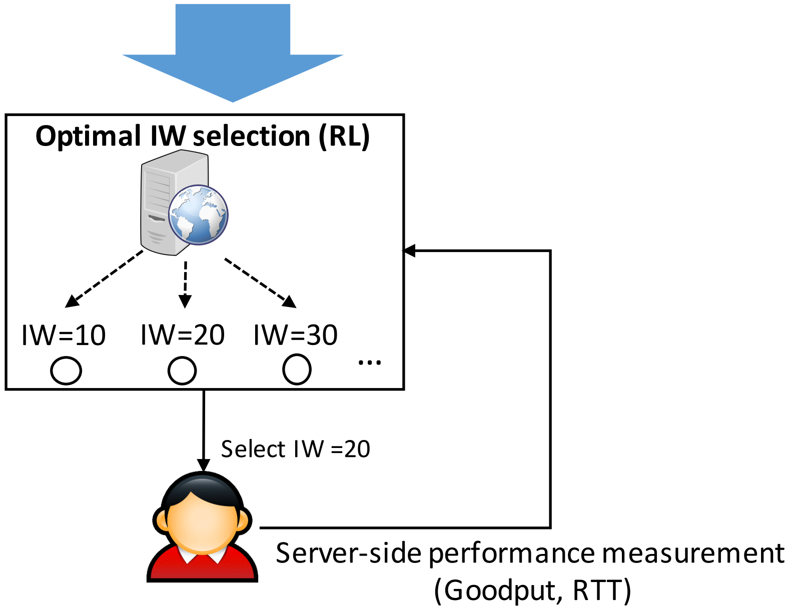
(a) Using different IWs for different user groups



(b) The logic of IW selection for one user group

RL Algorithm

Discounted Upper Confidence Bound


Optimal IW selection (RL)

IW=10 IW=20 IW=30 …

Select IW =20

Server-side performance measurement (Goodput, RTT)

- **Reward:**
  - Goodput & RTT

$$X_s(i) = \alpha * \frac{Goodput_s(i)}{Goodput_{max}} + (1-\alpha) * \frac{RTT_{min}}{RTT_s(i)}$$

- **Decision Space:**

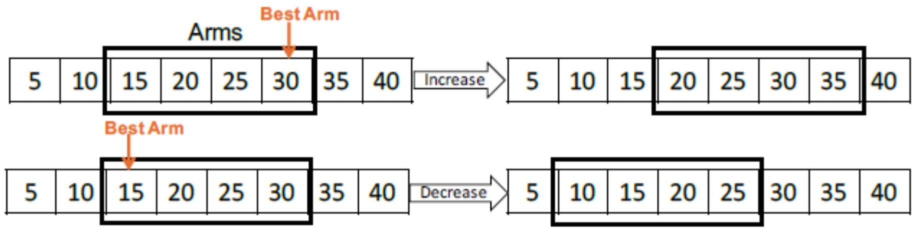


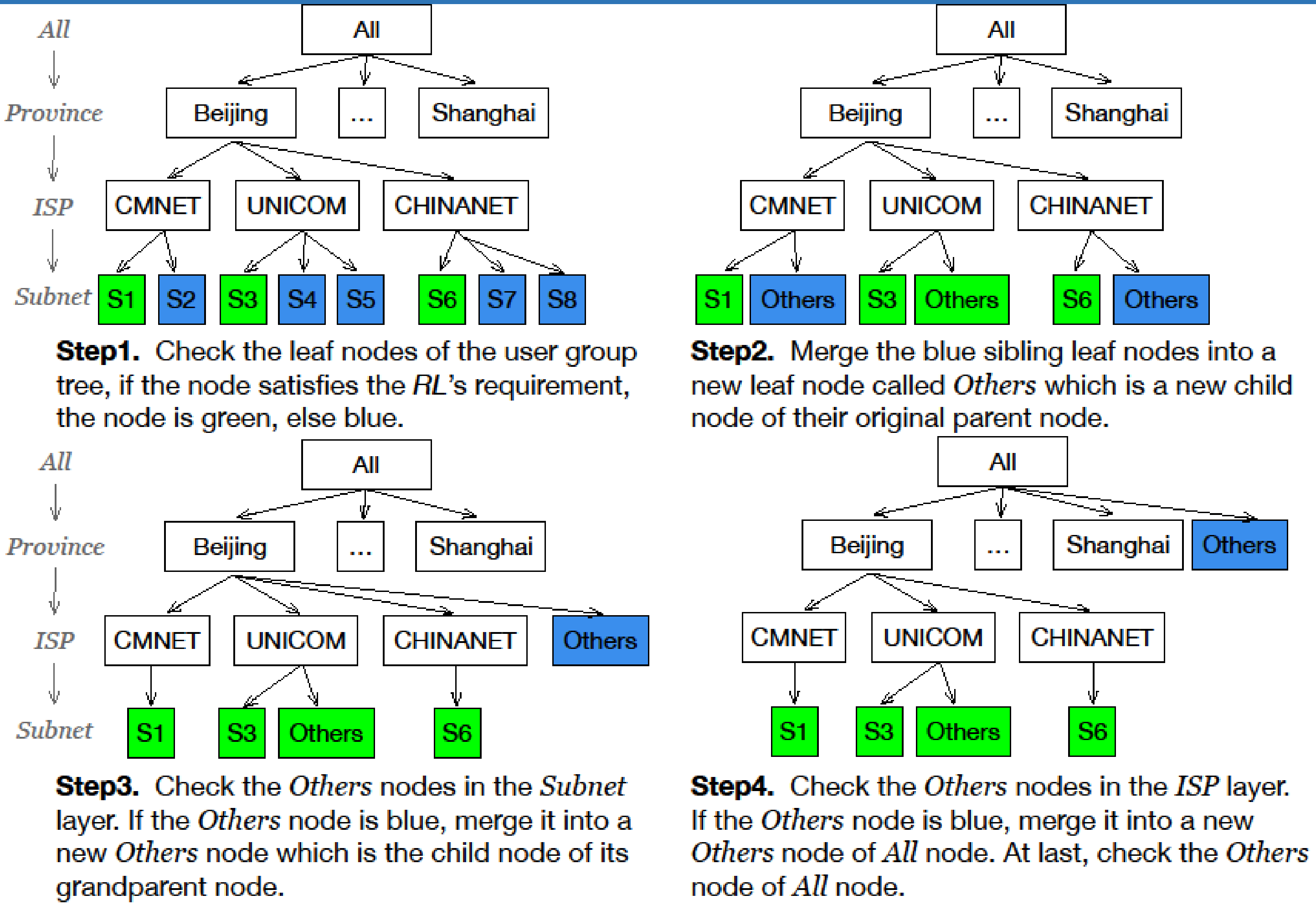
Fig. 4: The procedure of the sliding-decision-space method.

User grouping Algorithm

- **User group**
    - Bottle-
    - Find the
- **RL's requir**
    - Continui
    - Network

$J = \sum_{s=2}^{n}$

$J \leq T$



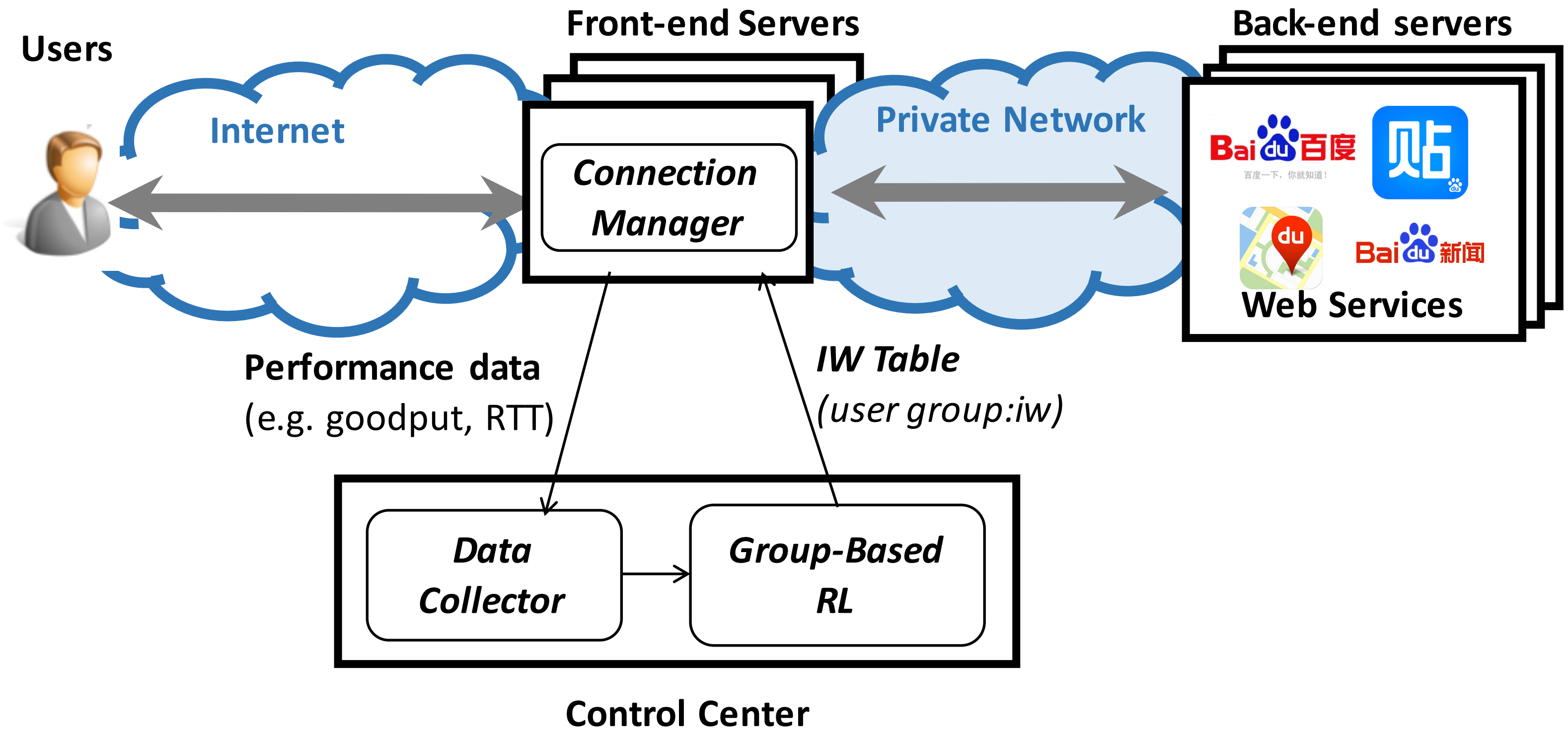
Step1. Check the leaf nodes of the user group tree, if the node satisfies the *RL*'s requirement, the node is green, else blue.

Step2. Merge the blue sibling leaf nodes into a new leaf node called *Others* which is a new child node of their original parent node.

Step3. Check the *Others* nodes in the *Subnet* layer. If the *Others* node is blue, merge it into a new *Others* node which is the child node of its grandparent node.

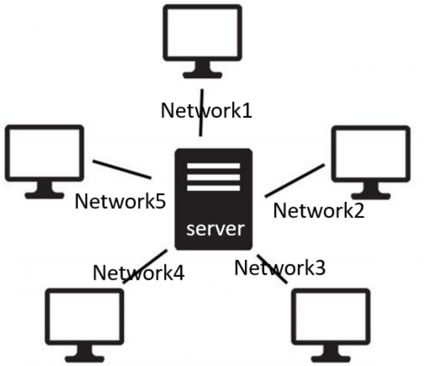
Step4. Check the *Others* nodes in the *ISP* layer. If the *Others* node is blue, merge it into a new *Others* node of *All* node. At last, check the *Others* node of *All* node.

System Implementation



Evaluation

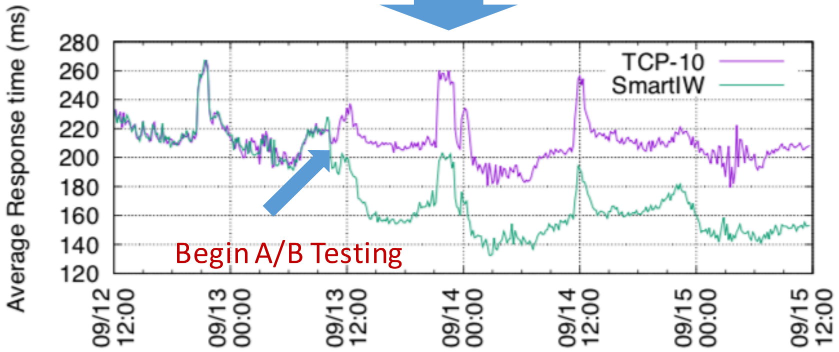
- **Online experiment:**
  - SmartIW can continuously bring about **23% improvement** of the average response time.



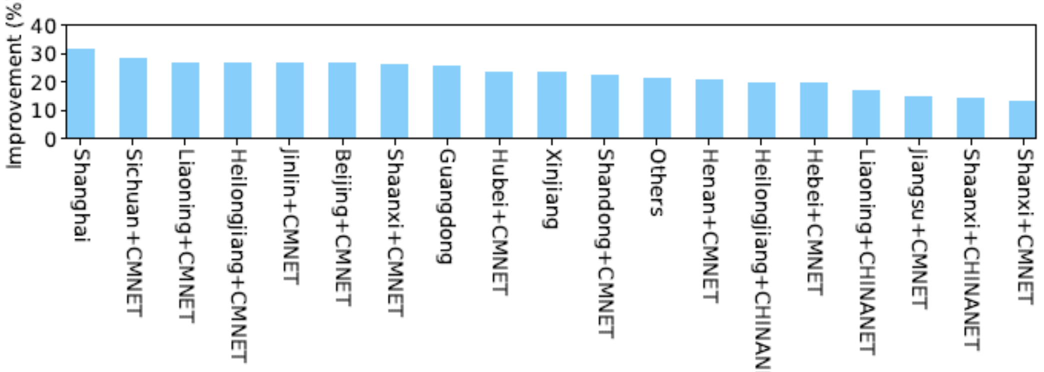
- **Testbed experiment:**
  - Both user grouping and reinforcement learning can help improve the network performance by **29%**.
  - Directly using a aggressive IW is a bad choice.

Online experiment

Continuously improve overall performance by 23%



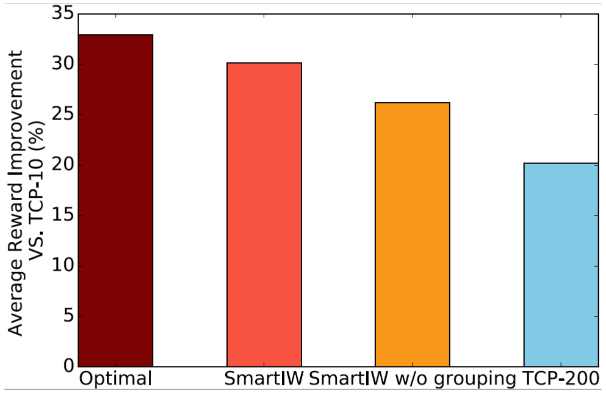
Each group has 15%~32% performance improvement.



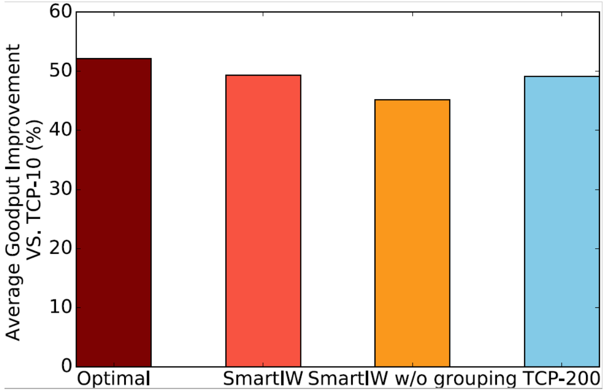
19 user groups (3 Provinces, 15 Province+ISP, 1 Others)

Testbed Experiment

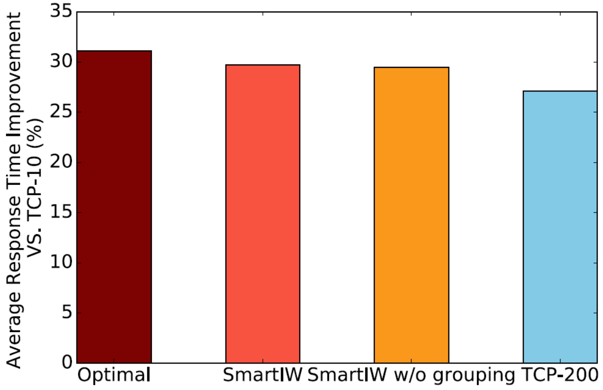
- **Replay user groups' 24*hour network condition.**
- **5 Schemes:**
  - TCP-10
  - TCP-200
  - *SmartIW*
  - *SmartIW w/o grouping*
  - Optimal



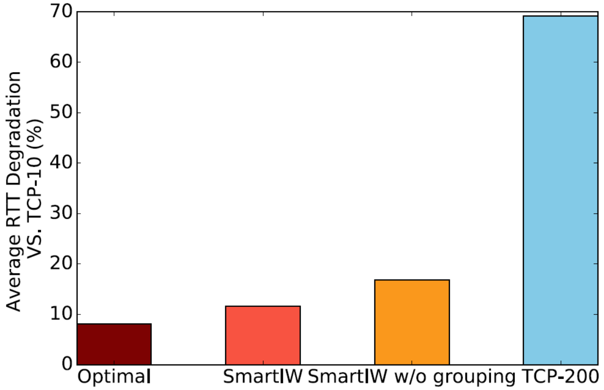
Reward = 0.8*Goodput + 0.2/RTT



Goodput



Response Time



RTT

Testbed Experiment

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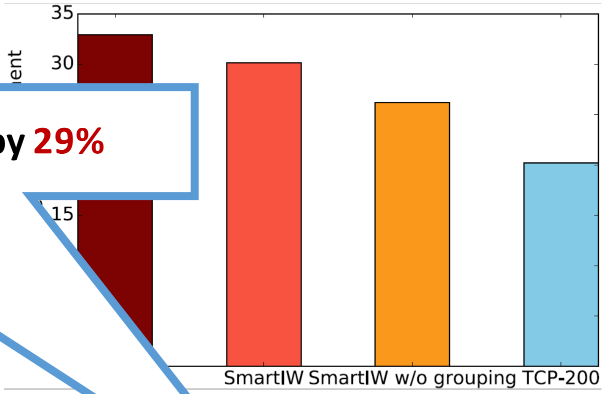
1. SmartIW improves average response time by 29%



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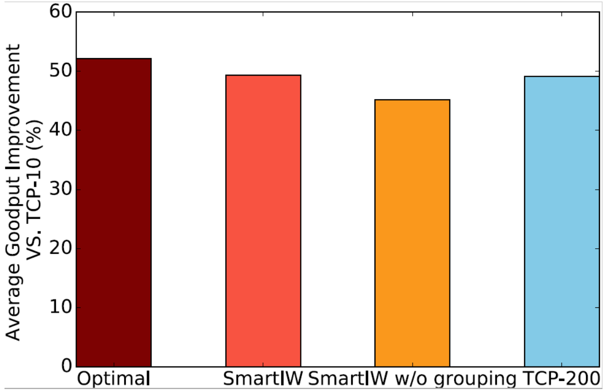
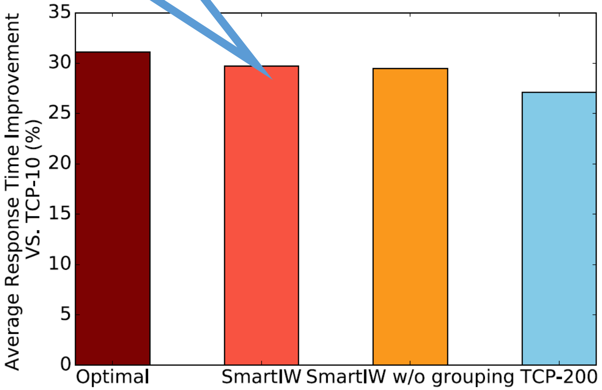


Goodput



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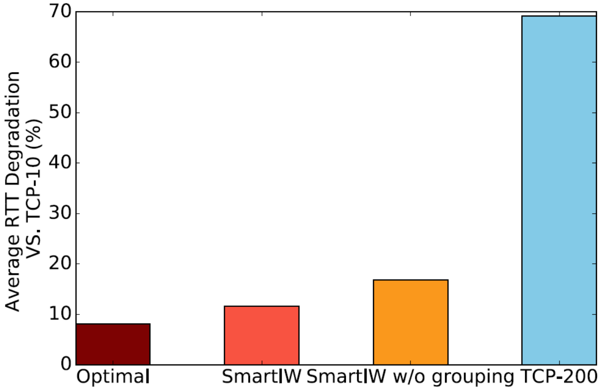


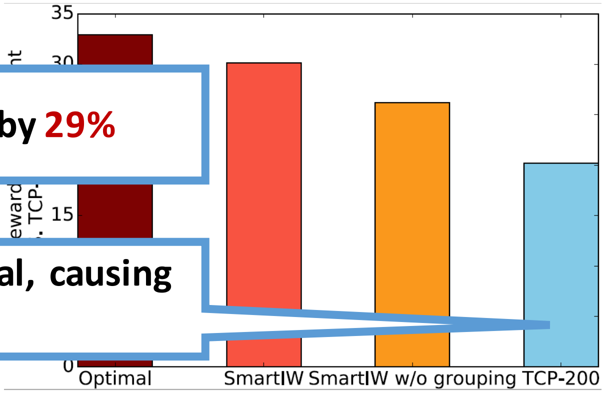
RTT

Testbed Experiment

- **Replay user groups' 24*hour network condition.**

1. SmartIW improves average response time by 29%

2. Directly using an aggressive IW is suboptimal, causing critical congestion.



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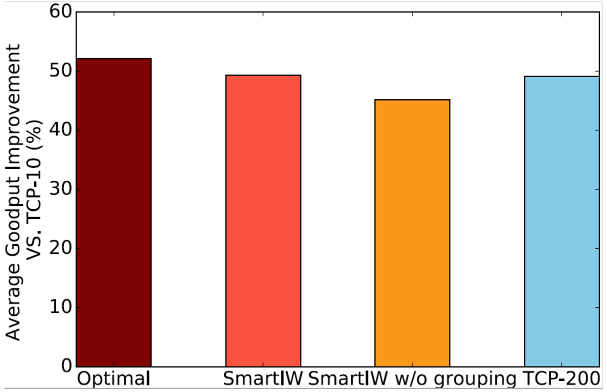
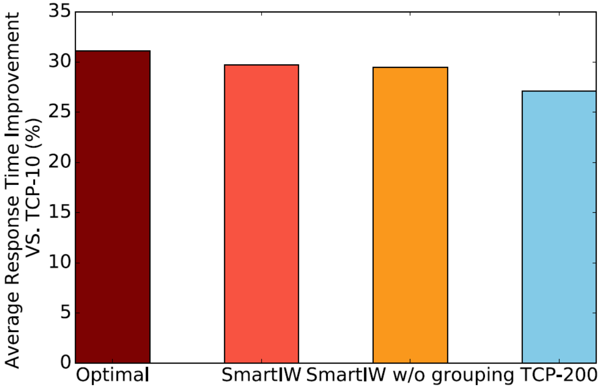
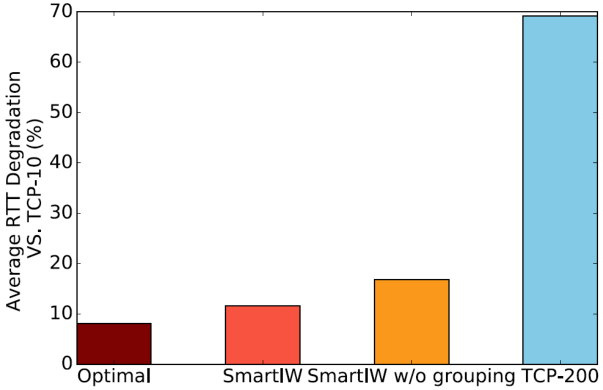


Goodput



Response Time



RTT

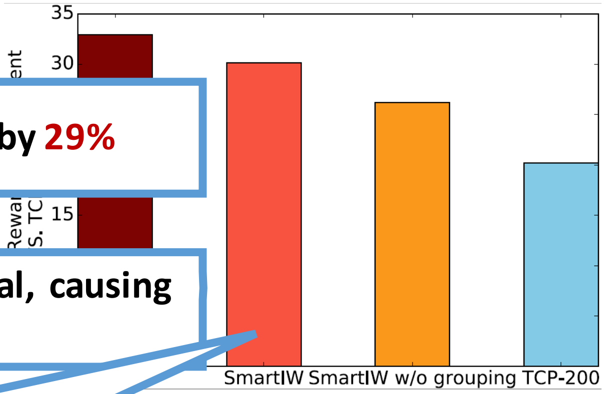
Testbed Experiment

- **Replay user groups’ 24*hour network condition.**

1. SmartIW improves average response time by 29%

2. Directly using an aggressive IW is suboptimal, causing critical congestion.

3. Both grouping and RL can improve the performance.



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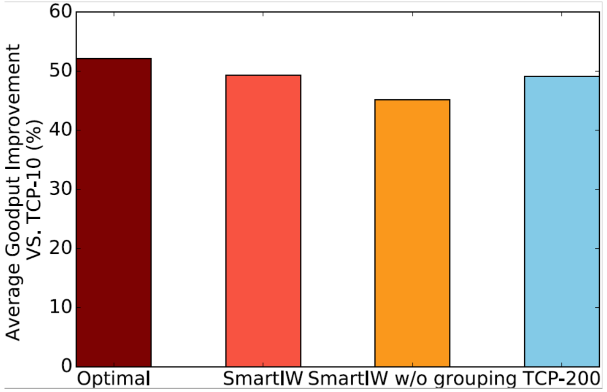

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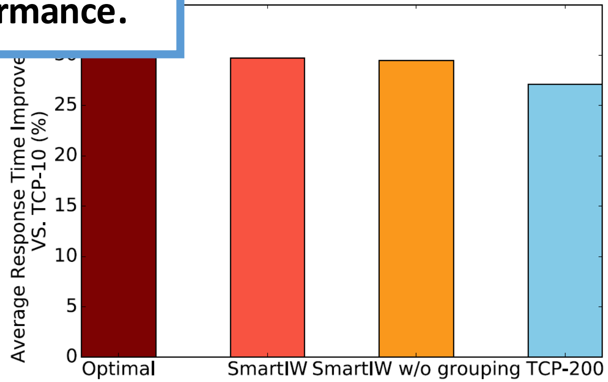

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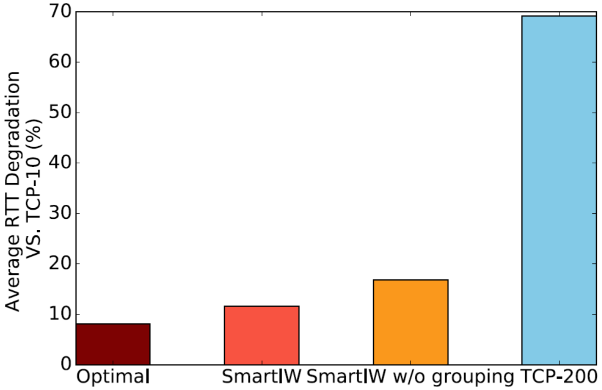

RTT

Conclusion

- **TCP flow startup problem is very obvious in the real world.**
- **We propose a system called *SmartIW* that can set TCP *IW* at server side smartly using group-based reinforcement learning to improve the web performance.**
- **Testbed and Online experiment prove our system works well.**
  - Online: 23% performance improvement
  - Testbed: 29% performance improvement

Thanks

Q&A?