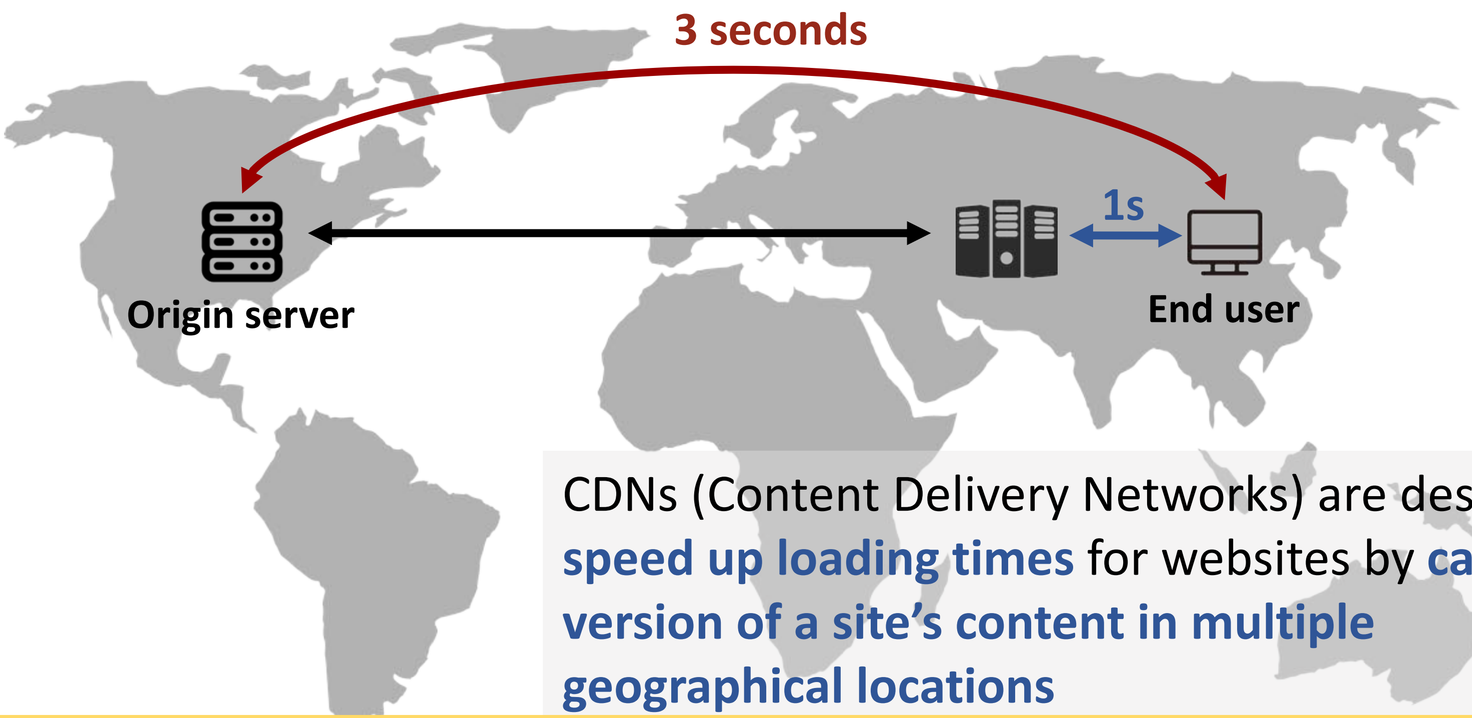
22nd ACM/IFIP International Middleware Conference, Industrial Track (Middleware Industry'21)

POLYGON:

A QUIC-Based CDN Server Selection System Supporting Multiple Resource Demands

Mengying Zhou, Tiancheng Guo, Yang Chen, Junjie Wan, Xin Wang

Everybody Uses CDNs

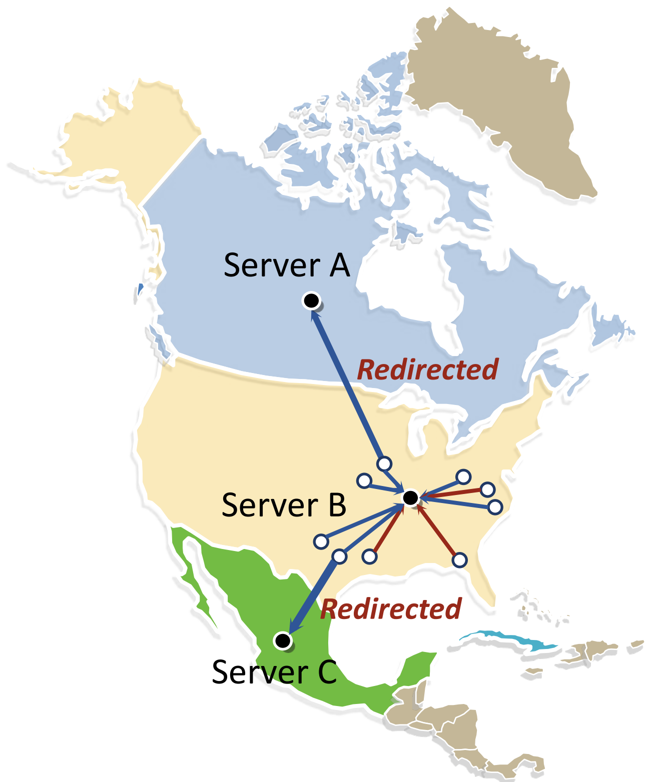


CDNs (Content Delivery Networks) are designed to **speed up loading times** for websites by **caching a version of a site's content in multiple geographical locations**

Is the smallest geographic distance enough?

CLOUDFLARE Akamai fastly

The Usefulness of Bandwidth



● CDN server ○ Client

- A: 100Mbps, 150ms - 1000 requests/s
- B: 1Gbp
- C: 100

- Two content types in the CDN requests:
  - A epic NBA moment video:
    - large size (15M), in the end of the browsing queue
  - A widely used JavaScript library:
    - small size (200K), in the front of the browsing queue

- According to the geographic distance, the CDN requests from **North America** will be **ALL** direct to **Server B**

Avg. Job Completion Time:
- Video: 273.3 s
- JS: 2.2 s

Exceed Load especially bandwidth

- Video requests are **prioritized for bandwidth**, not latency. If we redirect **20% of video requests** to **Server A / Server C**:

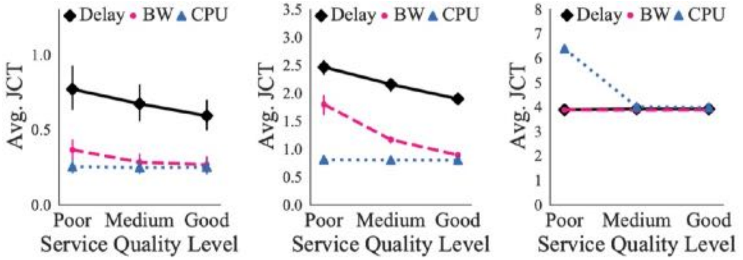
Avg. Job Completion Time:
- Video:
  - **Server A: 256.7 s**
  - **Server B: 265.2 s ↓**
  - **Server C: 242.8 s**

Bandwidth also matters for CDN selection

Delay, Bandwidth, and CPU All Matter

Types of requests sensitive to three common resource types

- Delay-sensitive (e.g. JavaScript file)
- Bandwidth-sensitive (e.g. video)
- CPU-sensitive (e.g. database query)



(a) Delay-sensitive (b) Bandwidth-sensitive (c) CPU-sensitive

Finding: each resource shows the most significant influence on its corresponding type of requests.

Priorities of Request	1st	2nd	3rd
Delay-sensitive	Delay	Bandwidth	CPU
Bandwidth-sensitive	Bandwidth	Delay	CPU
CPU-sensitive	CPU	Delay	Bandwidth

Considering resource priorities of different requests is necessary when selecting CDN servers

How Previous Solutions?

1. Centralized router manager considering the concurrent request load [Alzoubi et al., TWEB'11]
2. FastRoute [Flavel et al., NSDI'15]
   - Offloading traffic to other nodes by editing the DNS resolvers
   - Applied in Bing search engine [Calder et al., IMC'15]

Shortcomings

- ***They treat the resource priority of different types of requests as the same***
- ***They are based on Anycast routing, which loses precise control over CDN server selection***

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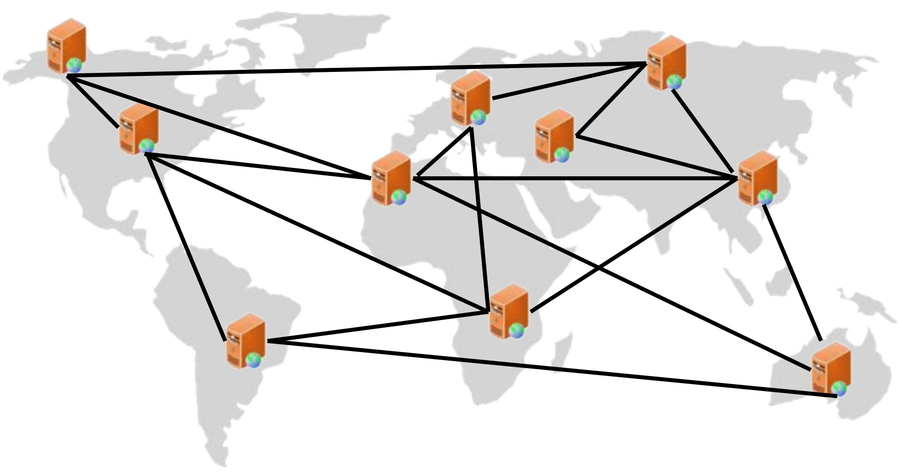
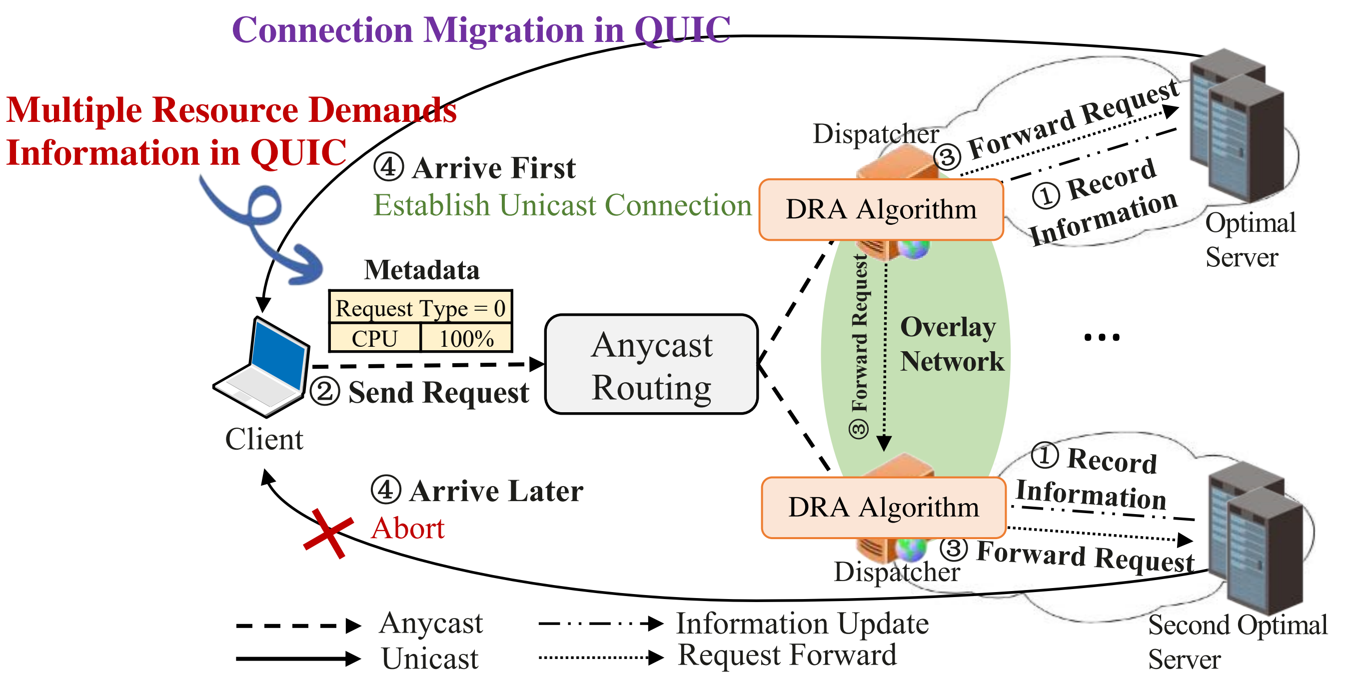
A set of dispatchers at strategic network locations:



1. Resource status collection
2. Server assignment with multiple resource demands
3. Forwarding requests to suitable CDN servers at a small cost

Polygon Workflow



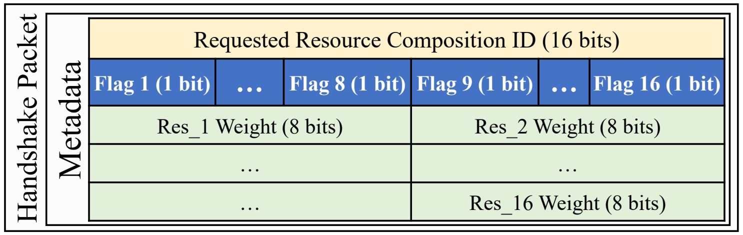
- Step 1: Collecting real-time resource status
- Step 2: Sending request and selecting server { Appending Resource Demand Info; Demand Restriction Allocation (DRA) Alg.
- Step 3: Forwarding request to suitable server { Redundant Forwarding; Fast Forwarding via Overlay Network
- Step 4: Establishing unicast connection and content transmission

QUIC Brings More Benefits

- *QUIC is proposed by Google to reduce the latency and enhance the ability in mobility*

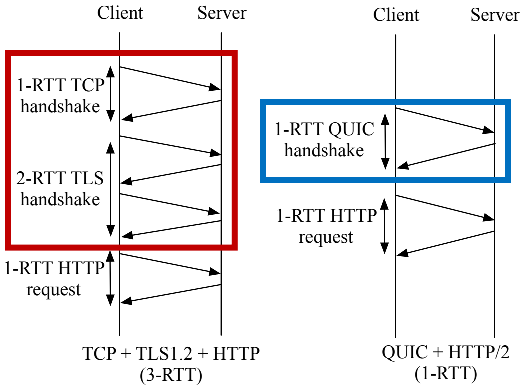
1. Metadata in QUIC

- Metadata block in handshake packet
- Both supporting the pre-defined classic resource compositions and customizable demand weights



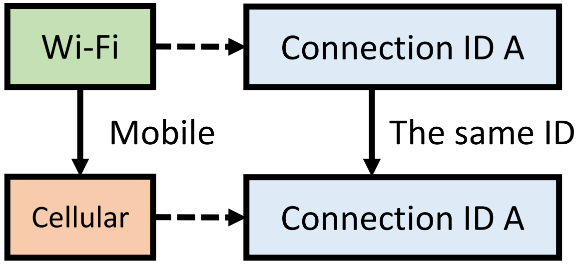
2. Zero-Latency Connection Establishment to Dispatchers

- QUIC reduces the handshake delay with 1-RTT/0-RTT rather than 3-RTT of TCP



3. Eliminating Re-Connection between Client and Server

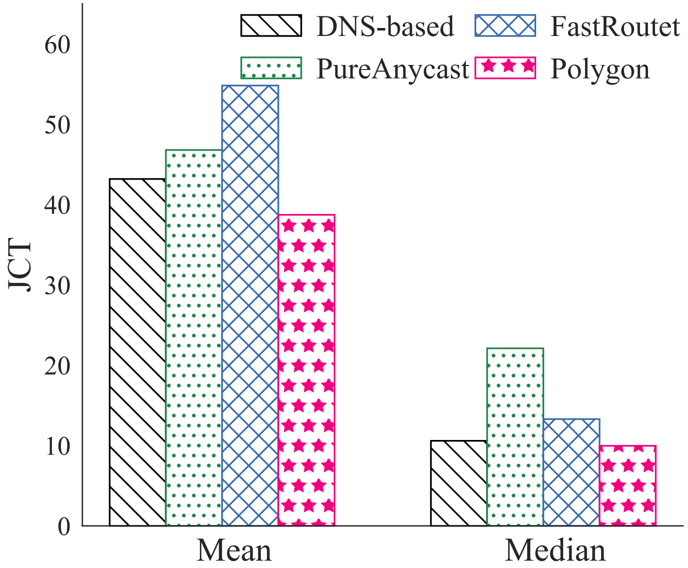
- Connection migration in QUIC guarantees the feasibility of the continuous connection even when the IP address changes
- One QUIC connection can accomplish sending, forwarding, and transmitting



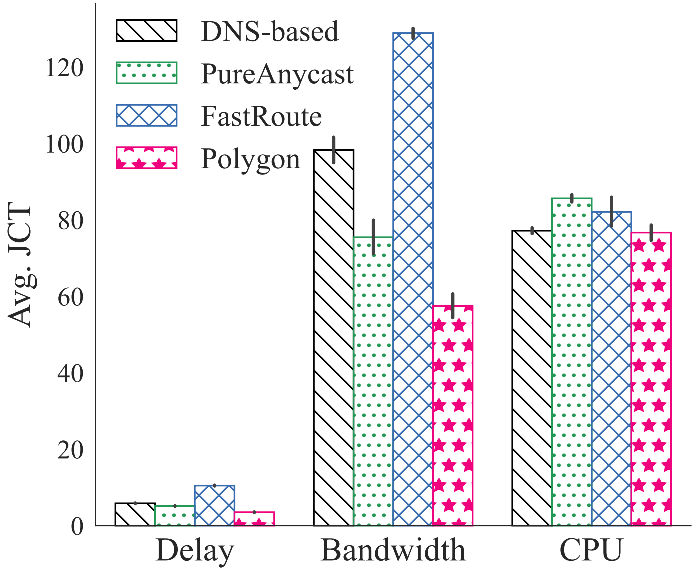
Migration without awareness

Less Job Completion Time

- **Comparison of job completion time performance among DNS-based, PureAnycast-based, FastRoute, and Polygon**



(a) The mean and median values of job completion time



(b) The average job completion time of requests sensitive to different resource types

1. Polygon **achieves less job completion time** in terms of either the mean or median value
2. Overall improvement benefits from each type of requests, especially **bandwidth-sensitive requests**

Higher Resource Utilization Efficiency

- **The number of requests completed in the same 2 hours and the average resource cost to complete per request**

Method	# BW Req.	BW Cost / # BW Req.	# CPU Req.	CPU Cost / # CPU Req.
DNS-based	1570	7.04	421	0.74
PureAnycast	1915	6.31	576	0.60
FastRoute	497	12.56	380	0.90
Polygon	***2166***	***4.71***	***619***	***0.49***
Max improvement	*↑13%*	*↓25%*	*↑7%*	*↓18%*

1. Polygon makes better use of the unoccupied servers and **alleviates the resource preemption** in crowded regions
2. **64%** of CPU-sensitive requests and **34%** of bandwidth-sensitive requests are redirected to **other regions**

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1. Requests in different application scenarios would have different resource type priorities
2. Polygon is a QUIC-based CDN server selection system that supports multiple types of resource demands
3. A real-world evaluation demonstrates the significant improvement in job completion time and resource utilization efficiency

Thanks for your listening!

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(Technical Details)

1. Requests in different application scenarios would have different resource type priorities

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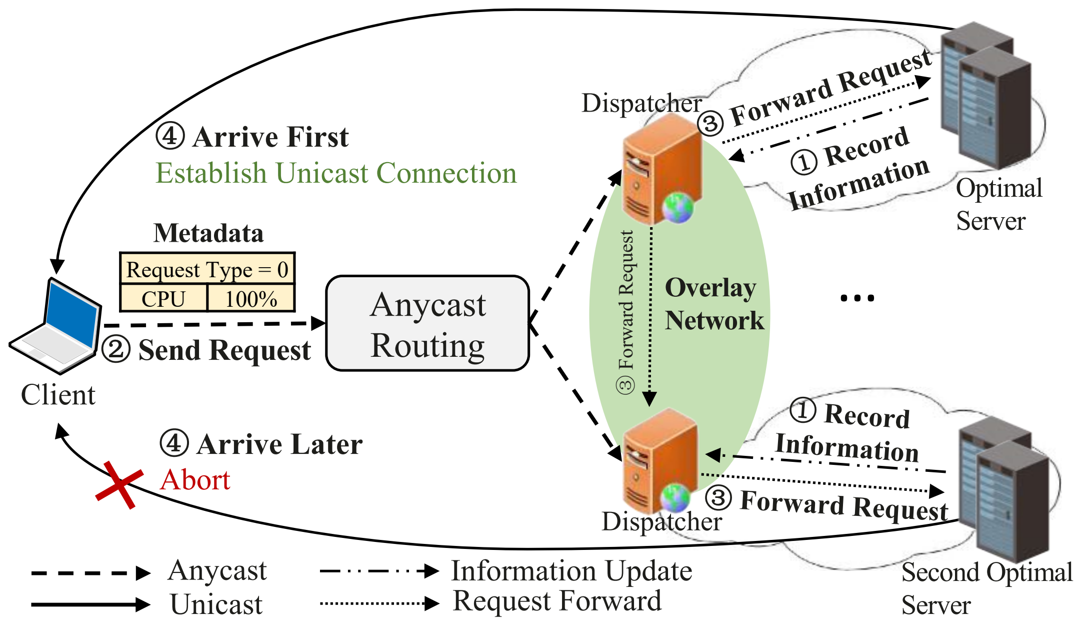
3. A real-world evaluation demonstrates the significant improvement in job completion time and resource utilization efficiency

Design Overview



- Step 1: Collecting real-time resource status
- Step 2: Sending request and selecting server
- Step 3: Forwarding request to suitable server
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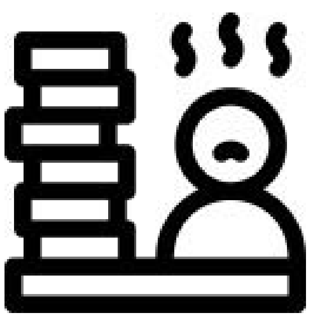
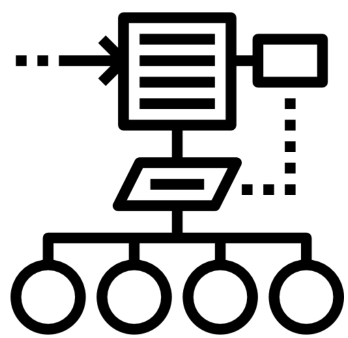
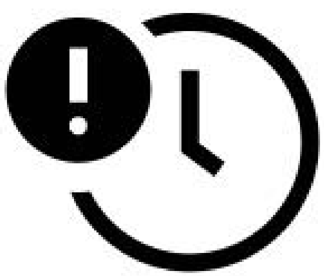
Practical Challenges

- Diversity of resource status
- Effective demand delivery and robust selection
- Extra delay for connecting and forwarding



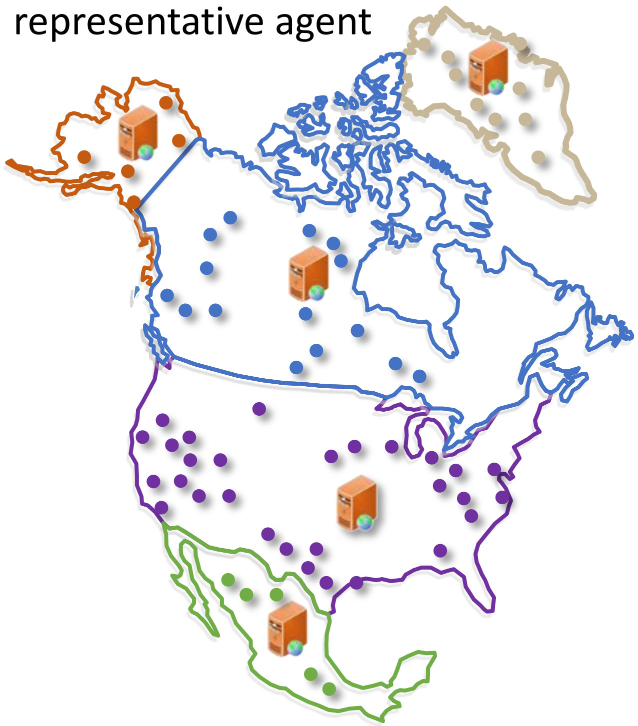




Collection of Resource Status

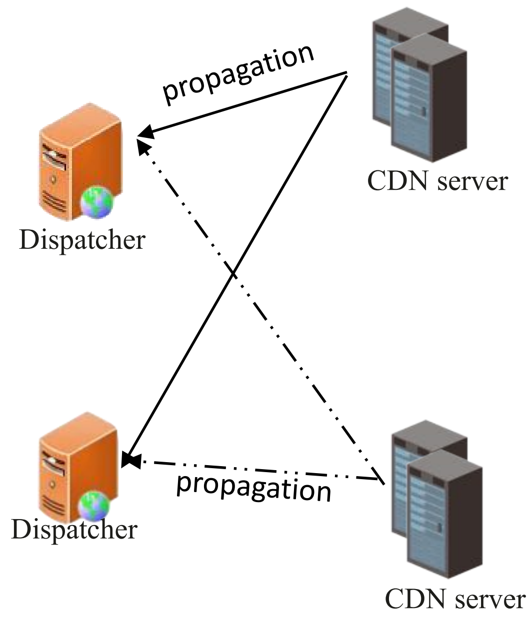
Delay & Bandwidth:

- Provided by the representative agent in each area
- One dispatcher in each region acts as a representative agent



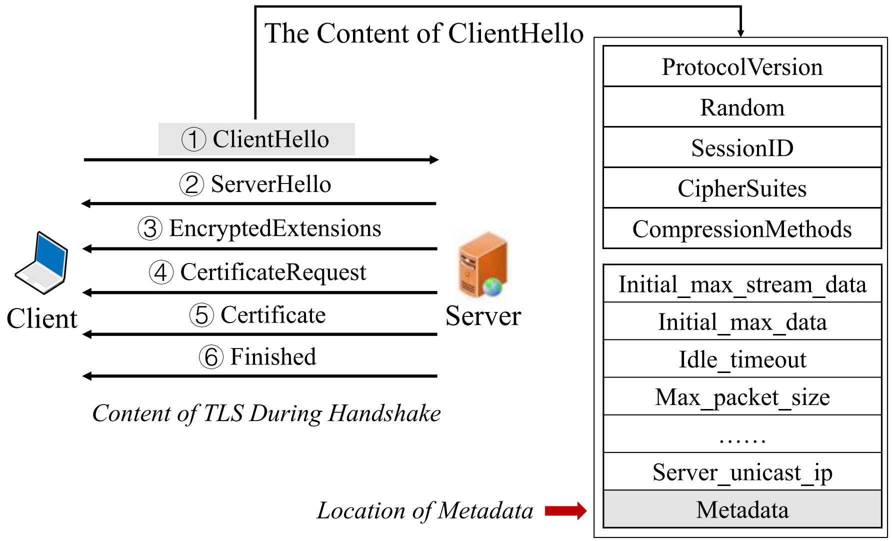
CPU:

- Collected by each server
- CPU capability: *idle rate* × *number of CPU cores* × *CPU clock frequency*

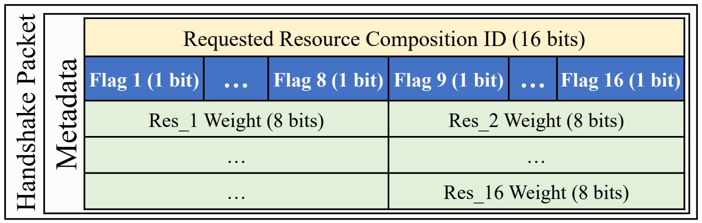


- Collection interval: Delay: 1h, Bandwidth: 1.5s, CPU: 1.5s

Diagram of Metadata Implementation



The design of metadata



- Polygon uses a metadata block within the *ClientHello* packet to specify resource demands

Sending Request with Resource Demands

1. Pre-defined classic resource compositions

e.g. Requested Resource Composition
① ID=1: only sensitive to delay
② ID=2: only sensitive to bandwidth
③ ID=3: only sensitive to CPU
…

Handshake Packet — Metadata

Requested Resource Composition ID (16 bits)					
Flag 1 (1 bit)	**…**	**Flag 8 (1 bit)**	**Flag 9 (1 bit)**	**…**	**Flag 16 (1 bit)**
Res_1 Weight (8 bits)			Res_2 Weight (8 bits)		
…			…		
…			Res_16 Weight (8 bits)		

2. Customizable demand weights

Requested Resource Composition ID = **0**															
1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
11110 (Decimal 30, parsed for flag 1)								10100 (Decimal 20, parsed for flag 3)							
1010 (Decimal 10, parsed for flag 15)								101000 (Decimal 40, parsed for flag 16)							

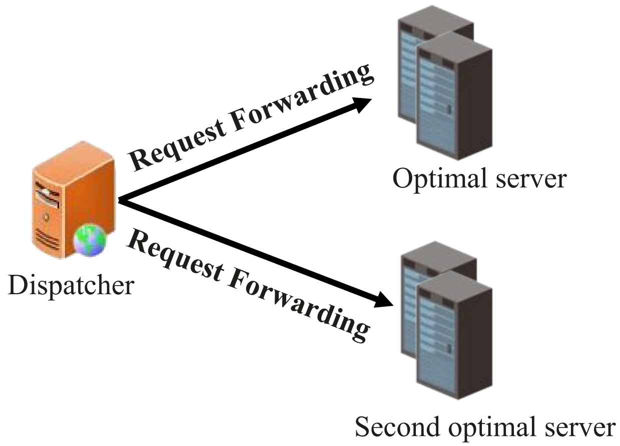
e.g. ID=0, and 30% for delay, 20% for bandwidth, 10% for CPU, 40% for loss

Demand Restriction Allocation (DRA) Algorithm

Two aspects determine the server score:

1. Amount of currently available resources
2. Maximum capability of resources

Calculate servers' scores and pick up the optimal and the second optimal servers

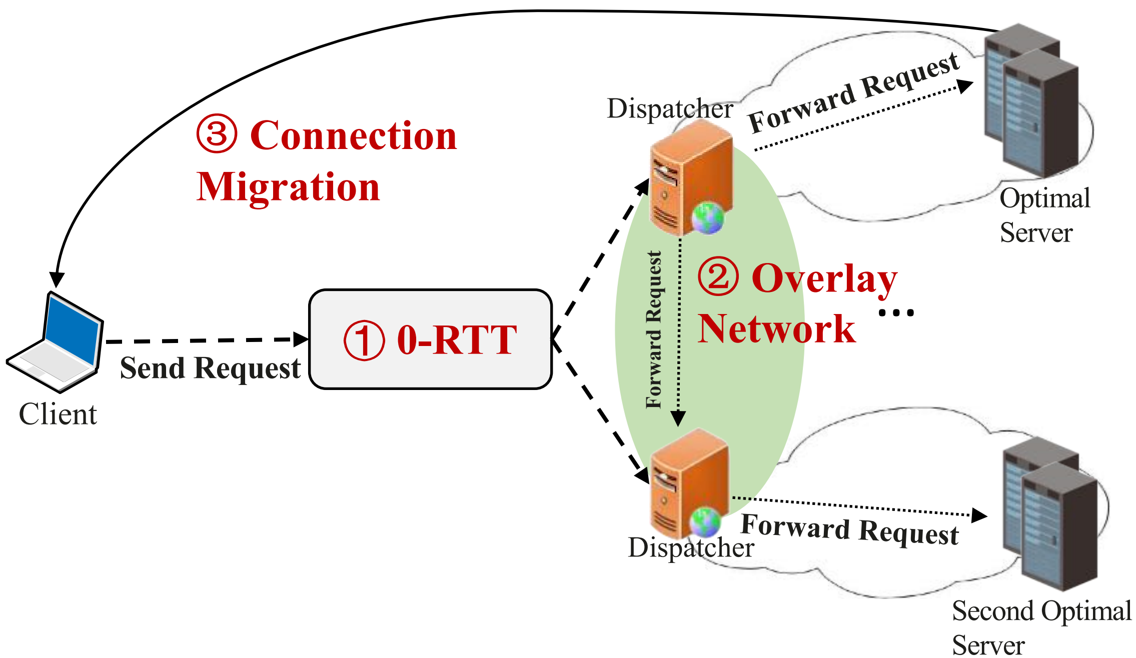


Redundant Forwarding

- Avoiding the potential sharp capacity degradation of the optimal node
- Being triggered when there is no much difference between the two nodes

Request Forwarding by Dispatchers

- **Reducing the extra delay** by the introduction of dispatchers
  ① Zero-latency connection establishment to dispatchers
  ② Fast forwarding via overlay network
  ③ Eliminating re-connection between client and server



Experiment Configuration

- Testbed deployment
  - 5 dispatchers and 5 CDN servers located in five continents
  - 10 clients: Asia (3), North America (3), Europe (2), Australia (1), and South America (1)
- Virtual machine setting
  - Conducted on Google Cloud Platform
  - Ubuntu 18.04 LTS, one standard vCPU and 3.75 GB memory
- Simulated requests
  - Delay-sensitive: frontpages of Alexa Top 500 Sites
  - Bandwidth-sensitive: video file (5MB), visiting 10 times
  - CPU-sensitive: 100 random queries in a database with 1 million entries
  - The ratio of each type of requests: 4:4:1

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Thanks for your listening!

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