Investigating Structure of Modern Web Traffic

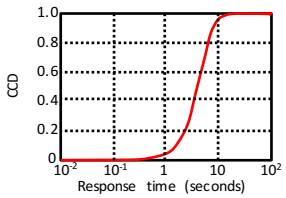
Noriaki Kamiyama[1,2] Yuusuke Nakano[1,2]
Kohei Shiomoto[1] Go Hasegawa[2]
Masayuki Murata[2] Hideo Miyahara[2]

[1]NTT Network Technology Laboratories
[2]Osaka University

2015. 7. 3

Increase of Web Response Time

Complementary cumulative distribution (CCD) of response time of most popular 1,200 websites when accessing from Tokyo, Japan

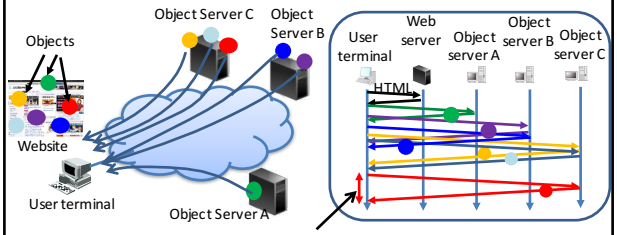


- Response time of 50% websites: longer than 4 seconds
- Response time of 10% websites: longer than 9 seconds
- Need to reducing web response time

 1

Need to Reduce HTTP Response Time

- One website consists of multiple data objects which are delivered from various object servers using HTTP sessions.
- Reducing HTTP response time is one of most effective approach for reducing web response time.



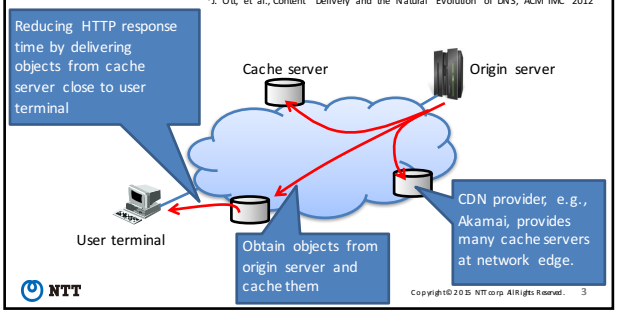
HTTP response time:
RTT plus server response time

 2

CDN: Platform Delivering Web Objects

- 74% of 1,000 most popular websites use CDN*, and CDN is most common technique for reducing HTTP response time.

*J. Ott, et al., Content Delivery and the Natural Evolution of DNS, ACM IMC 2012



 3

Contribution of This Presentation

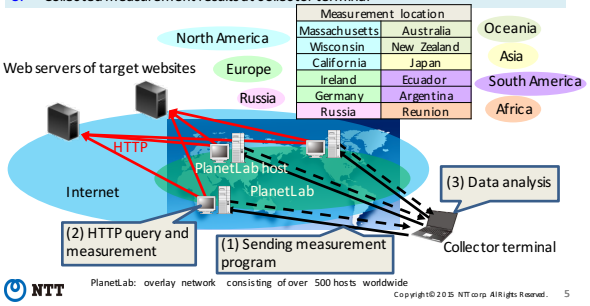
- Has not clarified actual effect of CDNs on reducing HTTP response time
- Important to clarify structure of modern web traffic to maximize effect of CDN

- Developed and implemented active-based framework for measuring communication structure of web traffic
- Measured distance and RTT to origin or cache servers from client terminals as well as HTTP response time of web objects
- Based on experimental results, clarified various tendencies of geographical distribution of original objects and CDN caches

 4

Measurement Procedure

1. Selected 12 PlanetLab hosts as measurement terminals accessing various websites
2. Measured various properties, e.g., HTTP response time and RTT, by executing program at each PlanetLab host to access various websites sequentially
3. Collected measurement results at collector terminal

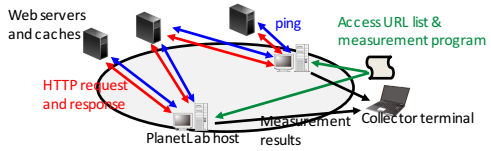


PlanetLab: overlay network consisting of over 500 hosts worldwide

 5

Measurement Program

- Generated URL list and sent it to each PlanetLab host
- Starting from 0:00 (midnight) or 12:00 (noon), each PlanetLab host executed following procedures:
  1. Accessed websites according to URL list and obtained HAR (HTTP Archive) files
  2. Extracted information of HTTP response time from obtained HAR files
  3. Measured RTT to each object server by sending *ping*
  4. Obtained domain name of each object server using *dig* command
  5. Sent measurement results to collector terminal

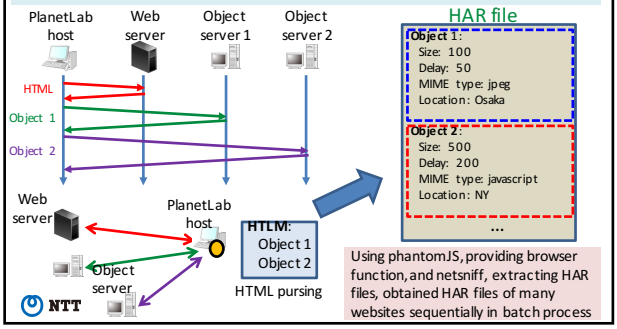


NTT

 6

Obtaining HAR Files

- Obtained HTML file initially, and obtained each object embedded in HTML file
- HAR (HTTP Archive) file: outputs various properties of each object in JSON (JavaScript Object Notation) format



Using phantomJS, providing browser function, and netsniff, extracting HAR files, obtained HAR files of many websites sequentially in batch process

NTT

 7

URL List of Measurement Target

- Selected 300 most popular websites in each of 16 categories based on public information of Alexa*
- Totally Selected 927 websites from which HAR files were successfully obtained at all 12 measurement locations

*http://www.alexa.com/topsites

Category	#sites	Category	#sites
Business	40	Home	47
Computer	91	Shopping	68
News	27	Adult	102
Reference	109	Arts	60
Regional	73	Games	58
Science	86	Kids & teens	64
Society	83	Recreation	52
Health	52	Sports	53

NTT

 8

Classifying Objects Based on CDN Use

- Classified objects into CDN objects delivered using CDN or non-CDN objects delivered without using CDN
  - Listed 44 second-level domains of various CDN providers by manually checking websites of various CDN providers
  - Obtained domain names of hosts actually delivering objects, e.g., www.akamai.com/qqq/rrr, by using dig command from URL names, e.g., www.google.com/xxx/yyy.jpg, of objects extracted from HAR files
  - Identified CDN objects by comparing second-level domain obtained by dig command with entries of generated list

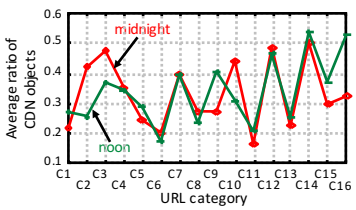
List of second-level domains of CDN objects

profile.ak.fbcdn.net	cloudfront.net	akamaihd.net	edgesuite.net
static.ak.fbcdn.net	vo.msecnd.net	edgesuite.net	cloudfront.net
r.ddmcdn.com	edgecastcdn.net	edgekey.net	vo.msecnd.net
s.cdn-care.com	cdngc.net	srip.net	edgecastcdn.net
cmscdn.staticcache.org	bootstrapcdn.com	akamaitechnologies.com	cdngc.net
g-ecx.images-amazon.com	example.com	akamaitechnologies.fr	push-11.cdnsun.com
max.blurtitcdn.com	akadns.net	akamaitech.net	ve14.fr3.atl1.llnw.net
a.espncdn.com	akam.net	akadns.net	hs-9.cdn77.com
ecx.images-amazon.com	akamaiedge.net	akam.net	nyud.net
edgekey.net	akamai.net	akamaistream.net	CloudFlare
edgesuite.net	akamaiedge.net	edgekey.net	Incapsula

NTT

9

Ratio of CDN Objects



ID	Category	ID	Category
C1	Business	C5	Regional
C2	Computers	C6	Science
C3	News	C7	Society
C4	Reference	C8	Health

ID	Category	ID	Category
C9	Home	C13	Games
C10	Shopping	C14	Kids & teens
C11	Adult	C15	Recreation
C12	Arts	C16	Sports

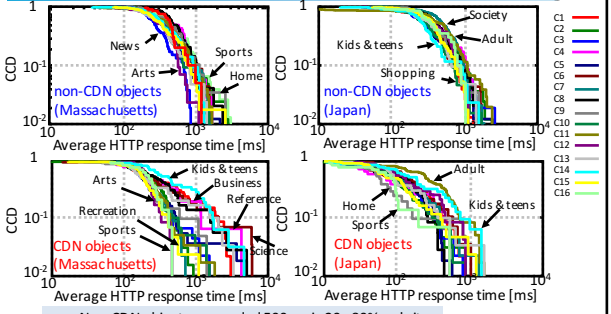
- Having more CDN objects in websites of Computers, News, Society, Shopping, Arts, and Kids & teens
- Having fewer CDN objects in websites of Business, Regional, Science, Adult, and Games

Ratio of CDN objects differed among categories, between 0.2 and 0.5

NTT

 10

Average HTTP Response Time at Noon



- Non-CDN objects: exceeded 500 ms in 20 - 80% websites
- CDN objects: exceeded 500 ms in just 2 to 40% websites

NTT

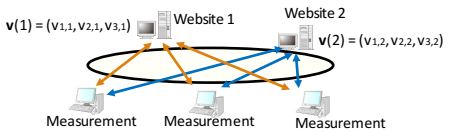
Confirmed effect of CDN in reducing HTTP response time

11

Clustering Analysis of Websites based on RTT

- Geographical pattern of original objects, i.e., non-CDN objects, and CDN caches delivering CDN objects will differ among access locations even when accessing same website.
- Analyzed geographical tendencies by clustering websites based on average RTT at 12 access locations
  - Applied k-means method based on vectors $\mathbf{v}(y)$ with elements v_{xy}, average RTT b/w access location x and objects of website y.
  - Optimally set cluster count k using JD method*
  - Set initial cluster using k-means++ method**

*A. L. Jain and R. C. Dubes, Algorithms for Clustering Data, Englewood Cliffs, NJ Prentice-Hall, 198
**D. Arthur and S. Vassilvitskii, kmeans++:the advantages of careful seeding,ACM SODA 2007



NTT 12

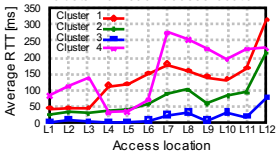
Geographical Distribution of Original Objects

L1	Massachusetts	L7	Australia
L2	Wisconsin	L8	New Zealand
L3	California	L9	Japan
L4	Ireland	L10	Ecuador
L5	Germany	L11	Argentina
L6	Russia	L12	Reunion

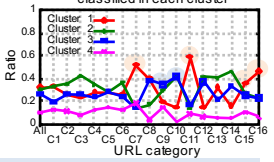
Clustering websites based on RTT of non-CDN objects at midnight

C1	Business	C5	Regional	C9	Home	C13	Games
C2	Computers	C6	Science	C10	Shopping	C14	Kids & teens
C3	News	C7	Society	C11	Adult	C15	Recreation
C4	Reference	C8	Health	C12	Arts	C16	Sports

Av. RTT of non-CDN objects of each cluster from each access location



Ratio of websites of each category classified in each cluster



- Cluster 1: RTT was small only in North America, and more websites of Society, Adult, Recreation, and Sports were classified. ⇒ Geographical locality is weak, and identical content are viewed from various regions.
- Cluster 3: RTT was small in all areas except Africa, and more websites of Home and Shopping were classified. ⇒ Geographical locality is strong, and unique content are viewed in each region.

13

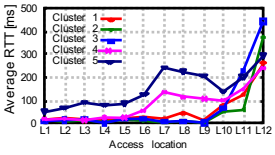
Geographical Distribution of Cache Servers

L1	Massachusetts	L7	Australia
L2	Wisconsin	L8	New Zealand
L3	California	L9	Japan
L4	Ireland	L10	Ecuador
L5	Germany	L11	Argentina
L6	Russia	L12	Reunion

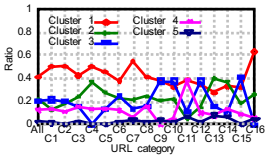
Clustering websites based on RTT of CDN objects at midnight

C1	Business	C5	Regional	C9	Home	C13	Games
C2	Computers	C6	Science	C10	Shopping	C14	Kids & teens
C3	News	C7	Society	C11	Adult	C15	Recreation
C4	Reference	C8	Health	C12	Arts	C16	Sports

Av. RTT of CDN objects of each cluster from each access location



Ratio of websites of each category classified in each cluster



- Cluster 1 & 2 & 3: RTT was small in all regions except South America and Africa, and more than 80 % of websites of all categories except Adult were classified. ⇒ Using CDN deploying cache servers worldwide
- Cluster 4 & 5: RTT was small in North America and Europe, and more Adult websites were classified. ⇒ Using CDN deploying cache servers in specific areas

14

Conclusion

- Actively measured structure of web traffic from 12 locations in world
  - Classified web objects into non-CDN and CDN objects
  - Measured HTTP response time and RTT of each object
- Ratio of CDN objects differed among categories, between 0.2 and 0.5
- Confirmed effect of CDN in reducing HTTP response time
  - Non-CDN objects: exceeded 500 ms in 20 - 80% websites
  - CDN objects: exceeded 500 ms in just 2 to 40% websites
- Revealed various geographical pattern of original objects
  - Websites with weak locality: identical objects from North America
  - Websites with strong locality: unique objects in each region
- Revealed various geographical pattern of CDN caches
  - Most websites used CDN deploying cache servers worldwide

NTT 15

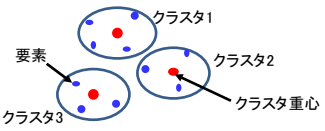
Example of HAR File

HAR file of www.google.com

NTT 16

クラスタリング手法

- k-means法: 非階層型クラスタリング手法の一つで，クラスタの重心を用いて，各要素を k 個のクラスタに分類
  - 各要素を重心の距離が最も近いクラスタに分類する処理をクラスタが収束するまで反復

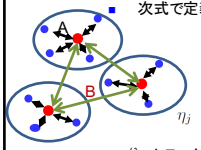


- k-means++法: 距離の離れた要素を初期クラスタの重心に設定することで，分類精度を向上
  - ランダムに一つの要素を選び，クラスタ重心に設定
  - 各要素 x に関して，その最近傍重心との距離D(x)を計算
  - $D(x)^2$に比例する確率に従い，新しいクラスタ重心としてランダムに一つ要素を選択
  - k 個のクラスタ重心が選択されるまで上記処理を反復
  - 以後はk-means法を用いてクラスタを生成

NTT 17

クラスタ数 k の最適選定

- Jain-Dubes法*を用いて最適なクラスタ数　k を設定
  - 要素数が n のときに，$2 \le k \le 1+\log_2 n$ の範囲で各クラスタ数 k のクラスタリングを実施
  - 次式で定義されるコストp(m)が最小となるkを選択



$$p(k) = \frac{1}{k}\sum_{i=1}^{k} \max_{1 \le j \le k} \left\{ \frac{\eta_i + \eta_j}{\xi_{ij}} \right\}$$

$$\eta_j = \frac{1}{n_j}\sum_{i=1}^{n_j} D\left(\boldsymbol{x}_i^{(j)}, \boldsymbol{m}_j\right) \qquad \xi_{ij} = D(\boldsymbol{m}_i, \boldsymbol{m}_j)$$

$x_i^{(j)}$: クラスタ j 内の i 番目の要素, n_j: クラスタ j の要素数
m_j: クラスタ j の重心, D(**a**,**b**): ベクトル**a**と**b**間の距離

- 各クラスタに属する要素のクラスタ重心に対する距離Aの平均値の，二つのクラスタの重心間の距離Bに対する比率を，最小化することに相当

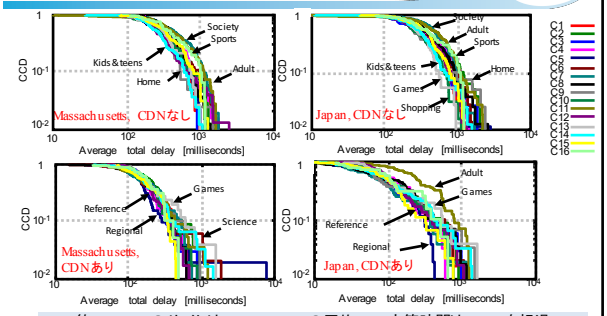
*A. K. Jain and R. C. Dubes, Algorithms for clustering data, Prentice-Hall, 1988

Basic Properties

ID	Category	Website count 0:00	Website count 12:00	Object size (kbytes)	Object count	Total size (Mbytes)
C1	Business	59	40	14.70	55.14	0.810
C2	Computers	112	91	16.26	43.63	0.709
C3	News	39	27	13.55	72.45	0.982
C4	Reference	112	109	13.09	43.42	0.568
C5	Regional	80	73	17.77	50.59	0.899
C6	Science	95	86	14.04	52.86	0.742
C7	Society	79	83	15.01	66.86	1.003
C8	Health	86	52	14.27	54.30	0.775
C9	Home	85	47	15.66	55.39	0.867
C10	Shopping	69	68	15.67	70.77	1.109
C11	Adult	112	102	10.49	53.04	0.557
C12	Arts	55	60	15.43	68.18	1.052
C13	Games	87	58	15.28	54.12	0.827
C14	Kids & teens	106	64	13.23	54.59	0.722
C15	Recreation	86	52	13.55	57.30	0.776
C16	Sports	38	53	16.62	86.67	1.440

- Entertainment websites, e.g., Arts, Shopping, and Sport, tend to have more objects and larger total data size.
- Information websites, e.g., Business, Computers, Health, and Reference, tend to have fewer objects and smaller total data size.

平均WaitのCCDを比較(midnight)



- 約20～80%のサイトはNon-CDN-Objの平均HTTP応答時間は500msを超過
- CDN-Objの平均HTTP応答時間が500msを超過するサイトは約5%～20%

CDN使用によるHTTP応答時間削減 効果を 確認

HTTP応答時間改善の施策

I. **CP(content provider)がCDN使用オブジェクト(CDN-Obj)の比率を増加**
現状，CDNを用いずに配信しているObj(non-CDN-Obj)をCDNで配信し，CDN-Objの比率を増加させることでHTTP応答時間を低減

II. **CPが使用CDNを変更**
CDN事業者のキャッシュの地理的な配置，キャッシュサーバ能力，NWスループット，キャッシュ制御ポリシィ，等が異なることから，よりHTTP応答時間の低減効果が見込めるCDN事業者にCPが契約先を切替

III. **CDN事業者がObjのキャッシュ位置や配信サーバ選択を適正化**
CDN事業者がキャッシュサーバ配置場所，キャッシュサーバ制御ポリシィ(置換方式，キャッシュ判断方式)，配信キャッシュサーバ選択を適正化し，ユーザに近いキャッシュサーバから配信することでHTTP応答時間を低減

本発表：広域アクティブ測定により，CDN-Objとnon-CDN-Objの地理的な配置傾向を分析し，施策I&IIIのHTTP応答時間改善のポテンシャルを評価

取得データ

- 各受信オブジェクトに対して，HARファイルから以下の情報を抽出(GeoIPのAPIを用いてホスト名から都市名と座標を取得)

データ項目名	Key
HTTP 送信先ホスト名	“request”-“url”
ホストの存在する国名	GeoIP: “country_name”
ホストの存在する都市名	GeoIP: “city”
ホストの緯度	GeoIP: “latitude”
ホストの経度	GeoIP: “longitude”
サイズ (byte)	“response”-“content” -“size”
総遅延時間 (ms)	“time”
コネクション接続時間 (ms)	“timings”-“blocked”
DNS 名前解決時間 (ms)	“timings”-“dns”
TCP コネクション確立時間 (ms)	“timings”-“connect”
HTTP リクエスト転送時間 (ms)	“timings”-“send”
サーバ応答待ち時間 (ms)	“timings”-“wait”
レスポンス転送時間 (ms)	“timings”-“receive”
SSL/TLS 時間 (ms)	“timings”-“ssl”
MIME Type	“response”-“content” -“mimeType”

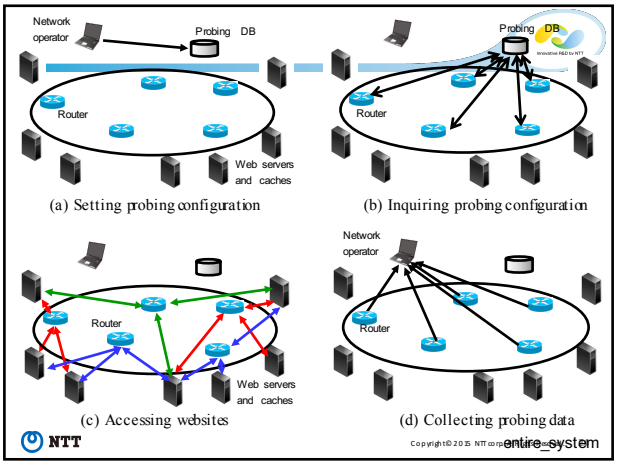
- digコマンドを用いて，実際に各オブジェクトを配信した サーバのドメイン名を取得し，さらにpingを送付してRTTを計測

Overview of Measurement and Analysis

I. 世界の12の地点から約1,000のWebサイトにアクセスした際の，配信サーバ距離，RTT，HTTP応答時間等の各種通信特性を測定

II. 測定データを，CDN-Objとnon-CDN-Objとに分離して，さらにWebサイトのジャンルごとに，平均値や累積分布を算出

I. 12の各測定地点における各特性値に基づきWebサイトをクラスタ分析することで，各WebサイトジャンルのCDN-Objとnon-CDN-Objの地理的な配置傾向を分析


Network operator
Probing DB
Router
Web servers and caches
(a) Setting probing configuration
Probing DB
Router
(b) Inquiring probing configuration
Router
Web servers and caches
(c) Accessing websites
Network operator
Router
(d) Collecting probing data
NTT
entire system