# Internet streaming and network neutrality: comparing the performance of video hosting services

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Abstract: Network neutrality is a hot topic since a few years and involves different aspects of interest (e.g. economic, regulatory, and privacy) for a wide range of stakeholders, including policy makers, researchers, economists, and service providers. When referring to video streaming, a killer web service of the Internet, much has been discussed regarding if and how video providers violate or may violate neutrality principles, in order to give users a "better" service compared to other services or to other providers. In this paper we provide a contribution to this discussion analyzing the performance of three main video hosting providers (i.e. YouTube, Vimeo, and Dailymotion) from a user viewpoint. We measure the throughput and RTT experienced by users watching real videos of different popularities, at different day hours, and at several locations from around the world. We uncover the performance differences of these providers as a function of the different variables under control and move a step forward to understand what causes such differences. Our results allow to understand what are the real performance users currently get from these providers and if the performance differences observed can be due or considered as a violation of network neutrality principles, providing a ground for people interested in legal and regulatory issues of web applications and services.

## 1 INTRODUCTION

There is a long ongoing debate on network neutrality, for which several definitions exist which share the common idea that data on the Internet should be treated in the same way despite several its characteristics such as technology, device, application, service, user, provider, and country they come from or go to. A first debate about network neutrality in terms of Internet traffic management policies appeared in 2003 (Wu, 2003), but concerns about possible threats to the end-to-end nature of the Internet raised already in the late 1990s (Lemley and Lessig, 2000). Nowadays the debate has gained momentum also because of recent events such as the one involving the provider Comcast, which was slowing down uploads from peer-to-peer file sharing applications (Svensson, 2007). The discussion on whether the Internet should be fully neutral, or rather providers should be allowed to use techniques to differentiate traffic does not concern only economic aspects, but also and increasingly both legal and regulatory ones. A work regarding legal aspects was presented in (Koops and Sluijs). In our paper we do not want to advocate a position pro or against network neutrality. We rather aim at providing a contribution to understand the current situation from a user viewpoint, which is of interest for people concerned with legal and regulatory issues of web applications and services. Our work focuses on three Video Hosting Services, YouTube, Vimeo, and Dailymotion, for which we studied the performance achievable by end users depending on video popularity and user location (i.e. country). We analyze the traffic related to video streaming because this service accounts a very high share of Internet traffic (about 60% according to CISCO (Cisco, 2015)). The highlights of our work could be summarized as follow:

- We introduce a methodology that, regardless of the providers considered in this work, allows acquiring, analyzing, and comparing performance statistics of video hosting services.
- We measure, analyze, and compare these statistics for YouTube, Vimeo, and Dailymotion, from several locations around the world.
- We provide insights on geographical location of the infrastructures and routing policies used by the video hosting services to deliver their content.

The reminder of the paper is structured as follows. Related Work is reviewed in the next section, which also highlights the novel aspects of this work. Knowledge on infrastructures of video hosting services is given in Section 3. In Section 4, we present our methodology and the way we collected the dataset. Section 5 describes in detail the results and it is followed by a discussion about geographical location in Section 6. We conclude the paper in Section 7.

# 2 RELATED WORK

Several interesting works on the analysis of video hosting services are focused on YouTube only, since it generates a large share of Internet traffic. The first extensive data-driven analysis about video popularity and users behavior of YouTube was presented in 2007, (Cha et al., 2007). Data collection involves a very long time period (tens of years) and furthermore compares YouTube with classic on demand video providers such as Netflix and Yahoo! Movies. A tool to measure QoS and QoE of YouTube is designed in 2012, (Plissonneau et al., 2012). Metrics collected by a hundred of volunteers have been analyzed by authors to infer the main delivery policies of YouTube videos, to understand the impact of the ISP on these policies, and finally YouTube policies are compared in the US and Europe. One of the earliest analysis of HTTP video streaming with a comparison between YouTube and one of its competitors Dailymotion was presented in 2012, (Plissonneau and Biersack, 2012). The authors use packet traces from a residential ISP network to infer for each streaming flow the video characteristics, such as duration and encoding rate, as well as TCP flow characteristics, such as RTT and packet loss rate. More focused on geographical location of infrastructure, (Padmanabhan and Subramanian, 2001) has built a service to translate the IP addresses of Internet hosts into their geographical location. They have proposed three techniques to infer the location of target host: *GeoTrack*, based on information provided by DNS, *GeoPing*, using delay measurements between target host and geographically known location, and *GeoCluster*, that combines partial host-to-location mapping information and BGP prefix. A recent work, (Calder et al., 2013), tries to clustering all servers of Google infrastructure in serving-site and then localize them using a technique called Client-Centric Geolocation or CCG. The CCG is based on the hypothesis that clients that are directed to the server are likely to be topologically, and probably geographically, close to the server.

Summarizing, studies more relevant to our work investigated either the CDN infrastructure and performance measures, or the geographic location of such infrastructure. Our work moves a step forward with respect to existing literature. To the best of our knowledge, we are the first to provide a comparative analysis of the performance of three most popular video hosting services, YouTube, Vimeo, and Dailymotion. We uncover the different performance they provide to real users from around the world and investigate on the causes of such differences, providing insights on the infrastructure each of them uses for video delivery. Unlike works based on residential ISPs measurements, that involve a large number of volunteers, we perform active measurements using a globally distributed research infrastructure (i.e. (Chun et al., 2003)). Performance indicators collected may be different from the ones of residential users. However, our main aim of comparing the different services (to understand if and how they violate or may violate network neutrality principles) is not affected by this choice.

# 3 INFRASTRUCTURES OF PROVIDERS

The following section describes the infrastructure of the video hosting services analyzed. Although there are several studies focused on YouTube (Google) infrastructure (e.g. (Calder et al., 2013)), that try to identify the number, structure, and location of caches and servers, less information is available on the other providers. In general, information about these infrastructures is not publicly disclosed. We crossed several sources of information for obtaining the views on the infrastructures that follow. Then we verify and confirm the accuracy of such views with the experiments in Section 6.

## 3.1 Dailymotion

Dailymotion was launched in France in 2005. Originally it consisted of one homemade Linux cluster and limited connectivity via a classical Internet connection able to serve only a few thousand users (Pelaprat, 2007), (EMC2, 2010). Afterwards, it moved to a more scalable architecture based on a network file system where input/output bandwidth, caching, and latency are shared throughout the system and performance scales linearly with the numbers of nodes. Dailymotion has not officially declared agreements with third party CDNs but, starting 2014, it has chosen Orange as partner for the optimization of worldwide distribution of video content, as part of its launch of premium live streaming "channels" (Orange, 2014). A solution, called "Media Delivery", was implemented by Orange and Akamai Technologies and is said to use an extensive network of servers to accelerate the distribution of video content over the Internet (Akamai, 2014a). At present Dailymotion provides an "only for premium services platform" while standard users are connected to the origin data center, with a data discrimination based on content.

## 3.2 Vimeo

Vimeo, founded in 2004, uses the Akamai CDN (Vimeo, 2013) to distribute its content. Akamai has a very broadly deployed network of edge servers, with 20 to over 100 times more Points of Presence (POPs) than other global CDN providers (Akamai, 2014c). Its edge servers are located within thousands of ISPs networks, as close as possible to the users, through the partnership with the Internet service providers. They claim to providing lowest latency, high throughput, and low risk of network congestion. Akamai provides a CDN dedicated to the streaming media content deployment, named Adaptive Media Delivery (Akamai, 2014a). It allows the transmission of video streams with Adaptive Bit Rate and back up in Akamai NetStorage, for later viewing (Akamai, 2014b). Akamai has also developed a modified version of TCP/IP to optimize the transmission speed. A protocol called Fast TCP uses the delay as a measure to control network congestion and improve the throughput. The beneficial use of this protocol are exploited by the CDN in the acceleration of both video distribution and download (Akamai, 2012).

## 3.3 YouTube

YouTube, born in 2005, was acquired by Google in 2006. It is the most popular service on which users can share and watch video content. The infrastructure can be organized in the following components:

- *Data Center*: a set of high-efficiency backend servers used for computation and storage.
- *Edge Points of Presence (POPs)*: cache servers distributed worldwide,(Google, 2015). PoPs represent the terminal nodes of Google network and are connected via peering with ISPs to deliver Google services traffic to users. The caches are identified by Google in four *logical namespace* and PoPs are classified based on a three-level hierarchy. *Primary cache cluster*: `a_c.v[1-24].lscache[1-8].c.youtube.com`, where "a_c" matches the IATA airport code (IATA, 2010). *Secondary cache cluster*: `tc.v[1-24].cache[1-8].c.youtube.com`. *Tertiary cache cluster* few number of cluster named as *cache* or *altcache*.
- *Backbone*: a global fiber network to interconnect data centers and deliver traffic to Edge PoPs.
- *Google's edge caching* the whole cache infrastructure including nodes inside the ISPs. These nodes (PoP) are calling *Google Global Cache (GGC)* (Calder et al., 2013) and allow ISPs to deliver Google contents to the users, increasing performance and reducing transportation costs being closer to each other.

# 4 METHODOLOGY AND TOOLS

Scope of our work is to evaluate the performance of video hosting services to understand whether performance differences are noticed and could impact network neutrality. We evaluate the performance of video hosting service provider for different kinds of content and different geographical locations to discover if: providers have their own infrastructure in the country; there are *cache-servers* deployed inside ISP infrastructures; special routing policies exist and how/when they are applied.

The web service under test are YouTube, Vimeo, and Dailymotion. We have defined four categories of videos depending on popularity: less than 500 views, between 10k and 120k views, between 120k and 1M views, and over a million views. We have chosen a video with a 720p resolution for each category. Every experimental campaign is performed over a period of one day (24 hours), and downloads are carried out at intervals of two hours. The data acquisition phase of our analysis lasted 15 of weeks in a period of time that covers several months between 2014 and 2015. Data reported in the following section refers to one of these campaigns. Results of the other campaigns showed similar results. As set of geographically well know clients we used a distributed network of 200 PlanetLab nodes, deployed on a total of 36 countries. PlanetLab uses high speed networks inside Research Centers and Universities therefore the analysis cannot strictly describe behavior of residential users. However, our aim is to compare the performance of different providers and we use PlanetLab as a reference. More in depth, for each PlanetLab node we perform a set of simple operations in batch to acquire the data, as described in the following:

- Running *netstat* in background. This command is used to detect the IPv4 address of server that physically contains the video to which the client has been directed through DNS or other means.

- Using *youtube-dl* to download the video. This command is used to estimate the throughput.
- Given the IPv4 address of server that physically contains the video, running a *ping* to evaluate RTT and TTL.
- Using *traceroute* tool to discover the path from client to server and mapping the name of routers in the path.

We assume that the measures of RTT and TTL, as well as the path shown by *traceroute*, could be in a good approximation representative of the network status during the video downloads. Video providers can adopt various approaches to cope the fragmentation of terminals and network connection issues. Adaptive bitrate streaming (ABS) is one of the widespread technique that adapt the bitrate in response to changing bandwidth conditions. Among the providers under test, only Vimeo does not use a web player that supports *ABS* for video delivery. Therefore, even if *youtube-dl* support DASH (Lederer et al., 2012) and HLS (Pantos and May, 2015), two spread ABS standard implementation, we have performed video download without taking advantage of these techniques in order to compare the providers at conditions that are as similar as possible to each other.

# 5 EVALUATION

In the following section we analyze the performance of the three video hosting services, evaluating indicators such as throughput, RTT, and distance in hops, related to users downloading videos of different popularity from several locations all around the world.

Table 1: Throughput (KiB/s) - Statistical Indicators

| Provider-Class | Min | I Quart. | Median | Average | III Quart. | Max |
|---|---|---|---|---|---|---|
| dm-1M | 21.36 | 353.8 | 415.1 | 487.1 | 502.4 | 11570 |
| dm-120K | 21.18 | 351.9 | 401.9 | 467.4 | 475.0 | 12690 |
| dm-10K | 24.10 | 344.1 | 378.5 | 421.8 | 419.9 | 8354 |
| dm-500 | 6.752 | 354.6 | 402.7 | 474.2 | 471.6 | 9368 |
| vi-1M | 24.44 | 1788 | 5367 | 6944 | 9802 | 35010 |
| vi-120K | 18.63 | 1770 | 4992 | 6619 | 9000 | 34790 |
| vi-10K | 17.45 | 1976 | 6110 | 7806 | 10310 | 39000 |
| vi-500 | 29.05 | 2144 | 6226 | 7894 | 10300 | 38830 |
| yt-1M | 11.79 | 1228 | 4408 | 5698 | 8235 | 23300 |
| yt-120K | 33.83 | 1153 | 4156 | 5930 | 8465 | 34690 |
| yt-10K | 32.3 | 1124 | 4014 | 5801 | 8617 | 34900 |
| yt-500 | 14.06 | 1565 | 5025 | 6793 | 9034 | 31760 |

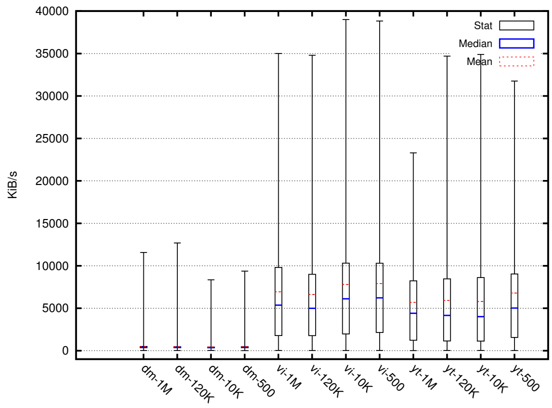



Figure 1: Throughput - Comparison among Dailymotion, Vimeo, and YouTube

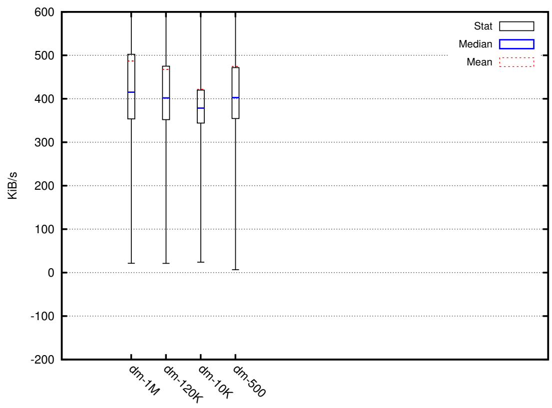



Figure 2: Throughput - Dailymotion Zoom

### 5.0.1 Throughput

Figure 1 depicts the values of throughput recorded by clients for each provider and each video category. Dailymotion (dm-*) has the smallest values while Vimeo (vi-*) and YouTube (yt-*) have similar throughput. The statistical indicators of throughput (i.e. minimum, first quartile, median, average, third quartile, and maximum) are reported in Table 1. Dailymotion has a median throughput value of about 400 KiB/s while most of clients do not reach more than 500 KiB/s. Spikes affect the average value of the throughput and these spikes are related to an "anomaly" that we will discuss more in depth in the following. Vimeo and YouTube have similar trends, although Vimeo has larger values of throughput for each video category, as shown in table 1. Also in these cases, the average values are affected by spikes which significantly differ from the median. Regarding Vimeo, throughput values of about 320 Mbps and RTT values of about of 0.140 ms have been recorded.

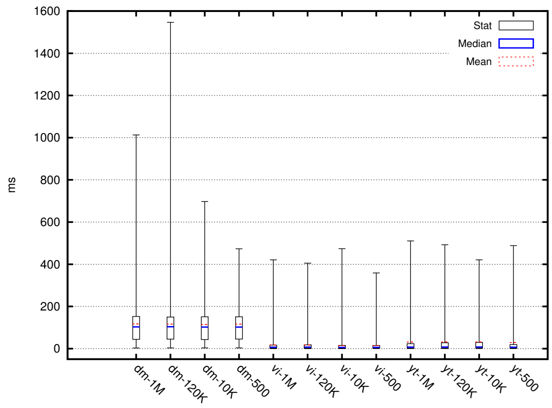



Figure 3: RTT

This very good performance is related to PlanetLab nodes who are only one “hop” away from Vimeo servers. A brief discussion about these values will be provided in the following.

### 5.0.2 Round Trip Time

The performance values related to the delay (i.e. RTT) are shown in Figure 3. RTT values regarding Dailymotion vary from 40 ms to 150 ms, with a median value of about 100 ms. These values are always higher in comparison to its competitors. This could be related to the centralized nature of Dailymotion infrastructure, Section 3.1. Regarding Vimeo, there is a small range of variation, from 2 ms to 18 ms, and the minimum values are very small independently of the video category. An extremely low RTT value, about 0.14 ms, has been recorded by a PlanetLab node *planetlab1.arizona-gigapop.net*, located in the United States. A distributed infrastructure, like Akamai CDN (see Section 3) allows to obtain better performance both in terms of Throughput and RTT, regardless the country from which the client requests the content. YouTube has a similar behavior, whose servers show RTT values similar to those of Vimeo although on a wider range (from 2 ms to 30 ms).

Table 2: RTT(ms) - Statistical Indicators

| Provider-Class | Min | I Quart. | Median | Average | III Quart. | Max |
|---|---|---|---|---|---|---|
| dm-1M | 3.375 | 44.29 | 103.1 | 117.4 | 152.4 | 1013.0 |
| dm-120K | 3.568 | 44.95 | 103.7 | 116.2 | 149.8 | 1547.0 |
| dm-10K | 3.516 | 43.12 | 102.4 | 114.6 | 150.8 | 697.5 |
| dm-500 | 3.42 | 45.35 | 102.1 | 116.0 | 150.9 | 473.4 |
| vi-1M | 0.135 | 2.378 | 6.738 | 16.91 | 16.72 | 421.1 |
| vi-120K | 0.141 | 2.500 | 7.183 | 17.45 | 18.33 | 405.1 |
| vi-10K | 0.139 | 1.887 | 5.698 | 14.28 | 15.21 | 473.7 |
| vi-500 | 0.142 | 1.914 | 5.839 | 14.54 | 15.00 | 358.9 |
| yt-1M | 0.223 | 2.550 | 7.312 | 31.17 | 23.53 | 510.8 |
| yt-120K | 0.208 | 2.869 | 7.623 | 32.08 | 27.90 | 492.3 |
| yt-10K | 0.241 | 3.214 | 7.751 | 32.09 | 29.59 | 420.9 |
| yt-500 | 0.205 | 2.405 | 6.935 | 28.92 | 19.58 | 488.5 |

## 5.1 Temporal Behaviour

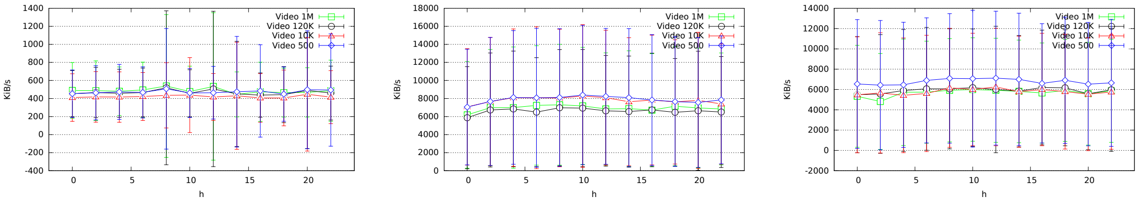
In the following sections, we will point out how performance evolve in time. This kind of analysis is aimed at identifying differences of performance or of treatment for the different hours of day.

Figure 4 shows a whole day comparison between the throughput of the providers. Regarding Dailymotion, see Figure 4(a), there seems to be no particular treatment related to the different video categories. Moreover the average value of the throughput evolves in a nearly constant way. Standard deviation values highlight spikes at 8h and 12h. They refer to servers deployed in Korea and Singapore. They let us suppose the presence of servers in these countries, as opposed to the assumptions made in the in Section 3. A further investigation to understand the performance of PlanetLab nodes in these countries is left as future work. The temporal evolution of the mean and standard deviation values of throughput is shown in Figure 4(b) for Vimeo and in Figure 4(c) for YouTube. The mean values are constantly above 5000 KB/s, an order of magnitude higher than Dailymotion. Moreover, all providers have better performance for videos with lower number of views.

## 5.2 Performance by country

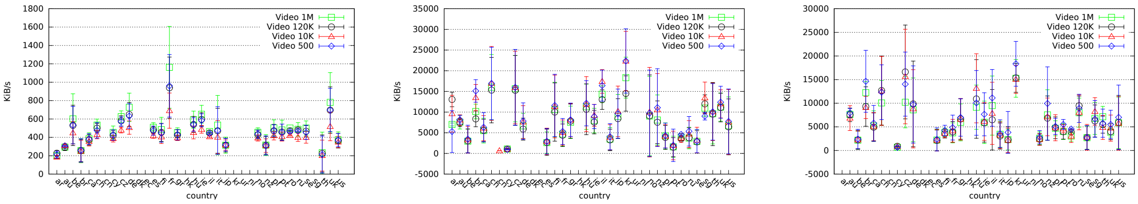
In this section we present the values of the performance parameters as a function of the country of the client. Data acquisition is performed over a period of one day (24 hours) with tests carried out at intervals of two hours.

Figure 5(a) shows the average throughput of each video category in each country for Dailymotion. This supports our hypothesis about the centralized location of the all Dailymotion servers: the performance is better in France than in the other countries, and all European countries have better performance than non-European ones. We excluded the values of Singapore and Korea (for Singapore the maximum throughput is about 12000 KiB/s) otherwise they would have made the graph unreadable. For Vimeo, as we can see in Figure 5(b), the throughput is variable in each country. Unlike Dailymotion, these differences are not related to the distance between client and server, but to the quality of the network in each country. Regarding the analysis of different video categories, there is an overlap of the values of the average throughput in almost every country, with higher values for the videos having less than 500 views, denoting the presence of different treatments according to the video category. Finally, Figure 5(c) shows mean and standard deviation values of the throughput of YouTube



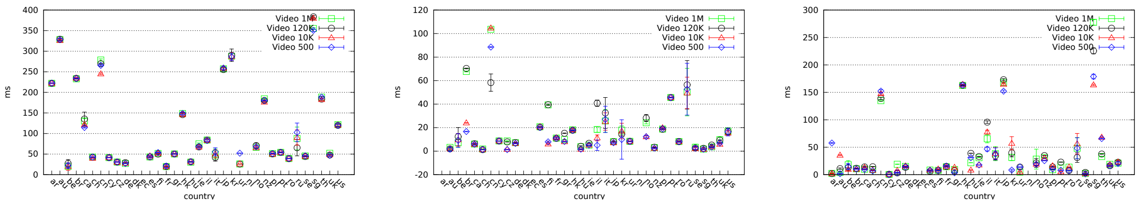

(a) Dailymotion (b) Vimeo (c) YouTube

Figure 4: Average Throughput over 24h




(a) Dailymotion (b) Vimeo (c) YouTube

Figure 5: Average throughput in each country




(a) Dailymotion (b) Vimeo (c) YouTube

Figure 6: Average RTT in each country

servers. As anticipated in Section 3, Google distribution network is based on *peering*. This figure shows that its performance is strongly influenced by the network infrastructure of the certain country. The management through *peering* has led the CDN to define supply agreements with third-party companies, in order to obtain the widest possible capillarity. The comparison of mean values of different countries denotes variability related to the country. As with other providers, video with fewer views have performance slightly better than others categories.

### 5.2.1 Round Trip Time

The average and standard deviation values of RTT, regarding Dailymotion, are shown in Figure 6(a). The overlap of the average values of RTT means that no treatments to different category of video is applied. The European countries have lower RTT than others countries. In particular the average value is in most cases below 50 ms while extra-European countries have values always higher than 100 ms. Specifically, RTT values in Korea and Singapore are respectively 300 ms and 350 ms. Using traceroute, we made an analysis of the paths followed by packets traveling from the clients in Korea towards the servers. Firstly, packets pass through hops inside the network of the Kookmin University (where the PlanetLab node are deployed), then they travel towards Lever 3 US and Level 3 Paris and finally they arrive at the Dailymotion server. The same analysis was repeated for the clients in Singapore and results confirm the hypothesis of a centralized infrastructure for Dailymotion, as anticipated in Section 3. Concerning the RTT values of Vimeo, shown in Figure 6(b), the values are similar for each video category in almost all countries. We can therefore assume that every client is routed to the same servers that contains all videos. The RTT for the majority of countries is smaller than 20 ms, which indicates that the infrastructure of Akamai is effectively distributed. Observing the average values of the RTTs shown in Figure 6(c), we can assert that YouTube, thanks to the CDN created by Google, is really globally distributed, bringing the contents as close as possible to the client. However a high RTT value for Asian countries can be spotted. The results from China can probably be related to the censorship operations implemented by the Government.

# 6 DISCUSSION

## 6.1 Geolocation IPv4 servers

In this section we report the results obtained applying the techniques described in Section 2 to geographically locate the servers of video hosting services. In particular, we have compared the results obtained using two different techniques: *Geoping*, based on the values of RTT measured in every country during each video download, and *Geotrack*, which uses *traceroute*, and provides the names and addresses of the routers through which the data flow travels from client to server. Notice that *traceroute* does not always correctly provide all the hops for the entire path. The whole operation is affected by issues well known in literature, for example: load balancing (Augustin et al., 2011), anonymous routers (Gunes and Sarac, 2008), hidden routers (Marchetta and Pescape, 2013), misleading intermediate delay (Marchetta et al., 2014), and third-party addresses (Marchetta et al., 2013). For space constraints we cannot provide all the results obtained. However, it is possible to summarize the following results for each providers:

- Dailymotion deploys its entire infrastructure in France (i.e. in Paris), no other caches are distributed elsewhere in the world. However, there are abnormal activities by some nodes as we described in the previous section.
- Vimeo has distributed cache-servers, uses the Akamai infrastructure, and every time a video is requested, the user is redirected to the "closer" server. This is highlighted by the lower values of the RTT and by the names of the servers containing the video (owned by Akamai). The clients are always re-directed to the same server, without considering the day time or the network overload. Clients are re-directed to the back-end servers only in case the content is not present in the cache-server.
- YouTube presents its own cache-servers in almost all the countries in which there are the PlanetLab nodes we used for testing. The infrastructure fell within the *Internet Exchange Point*, in which they connect to networks via *peering* to local ISPs. Unlike Akamai, there are evidences of a delivery strategy that assesses both the "distance" between client and server, and the "load" of the network.

## 6.2 IPv4 Identification and name-server of the providers

We used the reverse DNS in order to determine the *name-servers* associated to the IPv4 of all the servers contacted. From the list of name-servers consequently obtained, we can say that:

- For Dailymotion, there are only 8 servers from which clients, from all over the world, download videos.
- For Vimeo, the servers from which the downloads are predominantly made are part of the network of Akamai[1].
- For YouTube, the servers are globally distributed, but not always they belong to Google. Sometimes *name-server* identified them as part of telecommunication or hosting companies, such as Tiscali, Asianet Web, or Oneandone.

Referring to the discussions on the Network Neutrality and to the study of addresses and name-servers, there are no evidences of preferential treatments related to the video categories. The different performance observed are instead due to different infrastructures used by providers. An interesting case is the Russia where no CDN or third party servers are present and all videos are coming from Sweden.

# 7 CONCLUSION

The aim of our study was to compare the performance indicators of video hosting services, to understand whether the performance differences could impact network neutrality and users privacy. It is worth noting that we did not want to determine whether neutrality is good or bad, but we rather wanted to evaluate the performance differences from the user point of view, which is of interest for people concerned with legal and regulatory issues of web applications and services. We proposed a methodology that, regardless of the provider, allows to acquire and analyze performance data and topology information about the infrastructure of the providers. To validate the methodology, a comparison of the three video hosting services (Dailymotion, Vimeo, and YouTube) was performed on basis of: performance indicators (i.e. throughput, RTT, and TTL), geographical location of the infrastructures, and routing policies used by the video hosting services. Results show that Dailymotion has a centralized infrastructure. Moreover, its performance decays with the clients' distance

[1]Server not part of Akamai have also been noticed.

from infrastructure location. Vimeo and YouTube use CDNs to deliver their contents, where the first showed the best performance indicators compared to its competitors. Both infrastructures are in some cases connected to the PlanetLab nodes, used as client, through only two intermediate hops. We clearly showed that providers using distributed infrastructure are actually able to reach better performance. Regarding network neutrality, no evidences of special treatment based on video category have been collected. The highlighted performance differences may still be regarded as lack of neutrality because all providers should be able to benefit from the same conditions of distribution and spread of their contents. However, such differences are not due to different treatments of traffic, but rather to different technology infrastructures. Deciding on whether this is or not a neutrality violation is out of the scope of this paper. We rather aimed at providing people concerned with regulatory or legal issues with information about the current situation and performance of video hosting services over the Internet.

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