Peer-Assisted Content Distribution Aided by Video Popularity Evolution Model.

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***Abstract*—Generally content distribution network (CDN) have adopted two different architectures: client-server model that's is the most common architecture model and peer-assisted CDN. In client-server model, clients download content dedicated and geographically managed servers while in peer-assisted model, clients download content from each other client.**

I. Introduction

Streaming content, especially video, represents a significant fraction of the traffic volume on the Internet, and it has become a standard practice to deliver this type of content using Content Delivery Networks (CDNs) such as Akamai and Limelight for better scaling and quality of experience for the end users. For example, YouTube uses Google cache and MTV uses Akamai in their operations.

With the spread of broadband Internet access at a reasonable flat monthly rate, users are connected to the Internet 24 hours a day and they can download and share multimedia content. P2P (peer to peer) applications are also widely deployed. In China, P2P is very popular; we see many P2P applications from China such as PPLive, PPStream, UUSe, Xunlei, etc. [1]. Some news broadcasters also rely on P2P technology to deliver popular live events. For example, CNN uses the Octoshape [2] solution that enables their broadcast to scale and offer good video quality as the number of users increases.

From the Internet provider point of view, the presence of so many always-on users suggests that it is possible to delegate a portion of computing, storage and networking tasks to the users, thus creating P2P networks where users can share files and multimedia content. Starting from file sharing protocols, P2P architectures have evolved toward video on demand and support for live events.

A P2P based architecture usually requires a sufficient number of nodes supplying the data (seeders) to start the distribution process among the joining peers. A peer usually offers a low outbound streaming rate due to the traditional asymmetrical DSL home connectivity and hence multiple peers must jointly stream contents to a requesting peer (leecher). The decentralized, uncoordinated operation implies that scaling to high number of peers comes with side effects. Typical problems of a P2P streaming architecture are low stream quality with undesirable disruptions, resource unfairness due to heterogeneous peer resources, and high startup delay. Moreover, current P2P applications are not aware of the underlying network and may conflict with the ISP routing policies and business model.

A number of P2P streaming applications have been designed, analyzed and deployed, attracting a significant number of users. Research studies and deployment experiences have both demonstrated that P2P is a promising solution in terms of scalability and deployment costs. On the other hand, the heterogeneous nature and unstable behavior of the peers contributing bandwidth and computational resources, along with the networking issues, affect the user experience and limit the commercial success of P2P video streaming applications. Alternatively, video contents can be efficiently distributed on services offered by managed network architectures and CDN companies. The major issues of CDN are high deployment cost and good but not unlimited scalability in the long term. Given the complementary features of P2P and CDN, in recent years some hybrid solutions have been proposed [3]–[5] to take the best of both approaches.

Broadband network access helps P2P applications to perform better. xDSL networks are deployed worldwide, and in some countries, such as Japan, even higher bandwidth fiber to the home (FTTH) already exceeds DSL in market penetration. In the coming years, network operators throughout the world will massively deploy FTTH. As access bandwidth increases, P2P systems may become more efficient since a peer can contribute much more.

Typically, each end user device is involved directly in the P2P swarm, both to receive the benefits of P2P and to serve others. In such cases, the installation of P2P software in every end device is necessary and the user is directly involved in the content's swarm. Under such conditions, the disposition of peers may result in unstable behavior and the swarm can be affected by the rapid and frequent disconnections that are common for mobile devices. Furthermore, users' devices usually can contribute to the swarm only with limited upload bandwidth. In addition, techniques developed to select P2P neighboring peers are often unfriendly toward the ISP's routing policies.

Different topologies have been proposed in the literature, such as those where the collaborative mechanism for content distribution is created among more stable devices such as residential gateways. The residential gateway (i.e., a home gateway placed in at the user's premises, serving several terminals within the home network but directly managed by ISP) is considered the central entity for a managed P2P infrastructure [6], [7]. Running on more stable and powerful devices, each gateway peer can contribute more bandwidth to the content swarm compared to the traditional end-user P2P systems. Peer selection procedures can be managed directly by the ISP, with the goal of avoiding the traversal of multiple nodes across ISP boundaries. Since P2P traffic is now decreasing and moving to the cloud [8], there is plenty of headroom for the ISP to use the gateway in a peer-assisted CDN, and the always-on nature of the gateway makes it the perfect device to run peer-assisted applications. ISPs may even be willing to give rebates to users who allow their gateways to be used, since the ISP benefits from incorporating the gateway into their CDN. With the growing interest to interconnect CDNs [9], [10], this architecture can benefit the ISP.

In Peer assisted CDN, users can download content from CDN nodes from or other users or peers. A user may cache the content after download to serve requests from other users. Due to the complexity of the behavior of peers, the process should be done in the home gateway user where the ISP can control it.

While in P2P assisted CDN for video on demand (VoD), most of reseacher assume the catalog of video is already established following zipf distribution for popularity thus the video rank is static. In our work, our catalog is dynamic, every video has its own popularity evolution following beta distribution thus we are not realy on the popularity rank. It's very natural that we can not rely on static the popularity rank, since in VoD popularity can change every week moreover Internet wide scale VoD like Youtube serves many regions and users in each region has different preference to watch the video thus every region has different popularity rank of videos. In Youtube, Popularity evolution of a video has three phase which is before-peak, at-peak, and after-peak. This aspect will be explained in sect.III. In this paper, we present how the model of video popularity evolution can help P2P assisted CDN ecosystem.

Our paper presentation as follows: (1) we describe related work in sect.II; (2) we explain detail of Youtube popularity evolution model in sect.III; (3) we explain the caching strategy for CDN and peer in sect.IV; (4) we explain our simulation design, simulator, and its evalution in sect.V. Finally, we present our conclusions in section VI.

II. Related Work

Content Distribution Networks with peer assist have been successfully deployed on the Internet, such as Akamai [11], [3] and LiveSky [12]. The authors of [11] examine the risks and benefits of peer-assisted content distribution in Akamai and measure the effectiveness of its peer-assisted. The authors of [3] conclude from two real world traces that hybrid CDN-P2P can significantly reduce the cost of content distribution and can scale to cope with the exponential growth of Internet video content. Yin et al. [12] described commercial operation of a peer-assisted CDN in China. LiveSky solved several challenges in the system design, such as dynamic resource scaling of P2P, low startup latency, ease of P2P integration with the existing CDN infrastructure, and network friendliness and upload fairness in the P2P operation. Xu et al. [13] using game theory, showed that the right cooperative profit distribution of P2P can help the ISP to maximize the utility. Their model can easily be implemented in the context of current Internet economic settlements. Misra et al. [6] also mentioned the importance of P2P architecture to support content delivery networks. The authors use cooperative game theory to formulate simple compensation rules for users who run P2P to support content delivery networks.

The idea of telco- or ISP-managed CDN has been proposed in recent years. The complexity of the CDN business encourage telcos and ISPs to manage their own CDN, rather than allow others to run CDNs on their networks. It has been shown that it is cost effective [14] [15]. Kamiyama et al. [16] proposed optimally ISP operated CDN. Kamiyama et al. mentioned that, in order to deliver large and rich Internet content to users, ISPs need to put their CDNs in data centers. The locations are limited while the storage is large, making this solution effective, using optimum placement algorithm based on real ISP network topologies. The authors found that inserting a CDN into an ISP's ladder-type network is effective in reducing the hop count, thus reduce total link cost. Cisco has initiated an effort to connect telco- or ISP-managed CDNs to each other, to form a CDN federation [14] using open standards [9]. They argue that the current CDN architecture is not close enough to the users and ISPs can fill this position.

The idea of utilizing the user's computation power to support ISP operation is not new. The Figaro project [17] proposed residential gateway as an integrator of different networks and services, becoming an Internet-wide distributed content management for a proposed future Internet architecture [17]. Cha et al., [7] performed trace analysis and found that an IPTV architecture powered by P2P can handle a much larger number of channels, with limited demand for infrastructure compare to IP multicast. Jiang et al. [18] proposed scalable and adaptive content replication and request routing for CDN servers located in users' home gateways. Maki et al. [19] propose traffic engineering for peer-assisted CDN to control the behavior of clients, and present a solution for optimizing the selection of content files. Mathieu et al., [20] are using data gathered from France telecom network to calculate reduction of network load if customers are employed as peer-assisted content delivery.

Guo et al., [23] is closest with our work because we use that work as comparison. The author proposed local system (local counter) to calculate the segment popularity in peer-assisted proxy system.

III. Characterizing Internet VoD Popularity

Before analyzing the system description and video caching, we first examine the popularity characteristics of Internet VoD services. We use YouTube as example of VoD service. The studies of content popularity evolution are mostly considered in short time periods. Borghol et al., [21] measure the evolution of content popularity in long periods (36 weeks) in which view count statistics of Youtube. Complement with Borghol et al., [21] work, we also did same measurement as Borghol et al., [21] for eight weeks from October-November 2013. We collected number of views, upload time YouTube videos on a weekly basis. We use YouTube's API to sampling popular videos. The API provides a call that returns details on 20 popular videos. Finally, we combine our datasets with Borghol et al., datasets.

In datasets, we have one-week spacing between consecutive snapshots. We can get how many times the video was view during the one-week period since last week or since snapshot $(i-1)$. As same Borghol et al., [21] work, we define time-to-peak for a video as its age (time since upload) at which its weekly viewing rate is the highest during measurement (from the first week until end of measurement). The time-to-peak distributions is shown in fig.1. Figure 1 shows that around three-quarters of a large fraction videos peak within the first six weeks since their upload and beyond six weeks we have uniform distribution thus the time-to-peak is exponentially distributed mixture with uniform distribution. Our finding coherence with Borghol et al., [21]. To estimate the the rata parameter of exponential part of time-to-peak distribution, we use Maximum Likelihood Estimation (MLE) [22]. Using MLE method, we can get exponential parameter $\lambda = 0.61$. For video popularity evolution which is weekly view distribution, we follow Borghol et al., [21] which use beta distribution. For weekly views distribution, Borghol et al., [21] found that beta distribution as good model to explain views evolution.

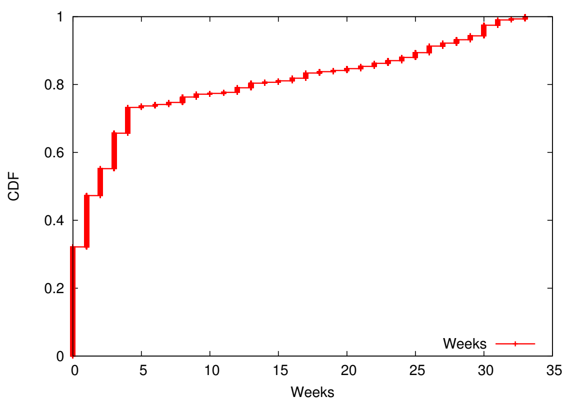

Fig. 1: Time to peak empirical distribution.

IV. System Description

In this paper, we consider a peer-assisted CDN system. There are two main components: (1) the CDN servers which at a minimum consist content delivery platform and control plane platform. (2) Clients which request and downloads the videos. In addition, clients form a self-organized P2P overlay network.

The CDN servers are maintained by a CDN company or a content provider company (e.q Netflix) or an Internet service provider (ISP). In peer-asssisted CDN, a peer caches the videos that it has downloaded. Peers independently manage their cache localy. When a peer join the system video replica is cached. When a peer leaves the systen video replicaed is evicted. In both process, a peer always reports to CDN thus CDN knows the status of a peer.

Figure **??** shows example of Akamai's peer-assisted CDN system that in operation since 2010. In this architecture, Akamai expect that subtantial fraction of content should be delivered by the peers. The peer-assisted QoS should be comparable to that traditional CDN system and the system should offer reliable accounting for services provided. This is important because in commercial setting CDN company must be able to calculate customer's usage.

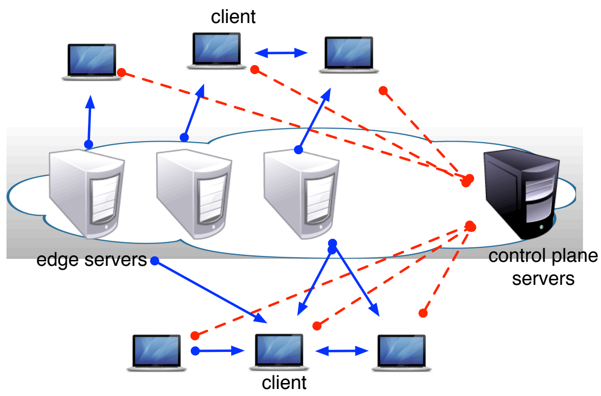

Fig. 2: Peer Assisted CDN Overview.

A. *CDN caching strategy*

As we mentioned in previous sect.IV, the CDN collects metadata. The metadata will be used for assisting P2P clients for caching decision. CDN collects the following parameters:

- n_j^r: total number of the times video j has been requested.
- t_j^r: the last time video j was requested.
- n_j^s: total number of the time that video j is served by CDN.
- t_j^s: the last time that video j was served by CDN.
- a_j: the time that video j was added to video server's catalog.
- n_j^c: total number of the times that video j is served by CDN.
- t_j^p: the time that video is added into peer's cache.
- t: the current time.

We use the method proposed in [23] to estimate the popularity video as follows:

$$P_j = min\left\{\frac{n_j^r}{t_j^r - a_j}, \frac{1}{t - t_j^r}\right\} \quad (1)$$

The expression of $\frac{n_j^r}{t_j^r - a_j}$ reflects the long-term request rate of the video or probability of future access rate and the expression of $\frac{1}{t - t_j^r}$ reflects the approximation of the video's recent request rate. The video with the smallest popularity is chosen as the candidate to be replaced when the CDN cache is full. Since above eq.1 considering both recent access and pass access information, the CDN can cache the most requested video for clients.

B. Peer caching strategy

In a peer side, we follow Guo et al., [23] for cache replacement strategy. We define the utility function for peer replacement as follows:

$$u = \frac{(f(p) - f(p_{min})) \times (f(p_{max}) - f(p))}{r^{\alpha+\beta}} \tag{2}$$

p represents popularity of the video, p_{min} represents estimation of minimum popularity in P2P system, p_{max} represents estimation of maximum popularity in P2P system, r represents the number of replicas of the video in the system, and $f(p)$ is monotonic non-decreasing function. α and β are the adjustment factor.

The CDN can calculate p_{min} and p_{max} then propagate to the P2P system. We choose the video with the smallest u value as the candidate to be replaced when a peer's cache capacity is full. In the next section (sect.V), we will show how popularity evolution knowledge is used to simplified our calculation for utility function.

V. Evaluation

In order to evaluate the proposed cache strategy using before-peak, at-peak, and after-peak information from VoD model, we have to compare our model to PROP model [23].

A. Simulation Design

An event driven simulator is developed using Python for this purpose and we use Youtube VoD model as video catalog of the simulated Internet VoD system in our experiment.

B. Peer and CDN server interaction

In fig.2, we describe the process of a peer that requests a video in simulator. peer and cdn are implemented in object oriented model. When a peer requests a video, it always goes to a CDN server (step 1). The CDN provides the videos to the peer (step 2). If there is another peer request same video, that request will go to CDN (step 3). CDN will check its record to see if there are some peers cache that requested video. If there are some peers cache that requested video, CDN will reply with redirect message that asking a peer to download requested video from other peer (step 4). If there are no peers have requested video, CDN will serve the video. A peer then can request the video to other peer and get the video (step 5 and step 6). From this description, we can see that deploying peer-assisted CDN can save some traffic since the clients which form P2P network can sharing the contents or videos.

1) Catalog Generator: In catalog generator, we assume peer request a video to CDN following poisson process with a mean rate $\lambda = 1.1$ [24] and we made it 3600 videos per hour, finally we generate video request for 360 days of simulation thus we have 31104000 request by peers. In our simulator, time is divided into rounds. During a round, a peer request video according to popularity. How a peer choice a video, we will explain in next paragraph.

First of all, we calculate the number of videos at-peak time as follows: sample N value from the time-to-peak distribution and determine the number of videos n_j^{at} that peak at week j. Total number of video $N = n_j^{before} + n_j^{at} + n_j^{after}$.
Next, we determine view count terminus which the number of final view count of video. In view count terminus, we assume that a video will not get big additional view after at-peak phase. We assign view count terminus randomly from datasets. After determining view count terminus, we assign beta distribution parameter for every video.

Since we can estimate the time of at-peak phase for each video, we know the mode of beta distribution value and we can calculate α and β value using the mode of distribution formula: $m = \frac{\alpha-1}{\alpha+\beta-2}$. We assign α value randomly between 1 and 2 thus we can calculate β value. With the knowledge of beta distribution of every video and its view count terminus, we can know the view count and view rate of every video as function from time. The knowledge of view count and view rate, will be used top generate a video choice.

For video choice, we estimate that a peer will choose video proportionally considering view count and view rate of the video. We can get view count and view rate from probability distribution function (pdf) and cumulative distribution function (cdf) of beta distribution above multiply by video's view count terminus. In last step, we assign file size of video randomly between 1MB and 200MB. Finally, we have a catalog that consists of: video to be choosen, time when uploaded, view count terminus, at-peak week, and video size.

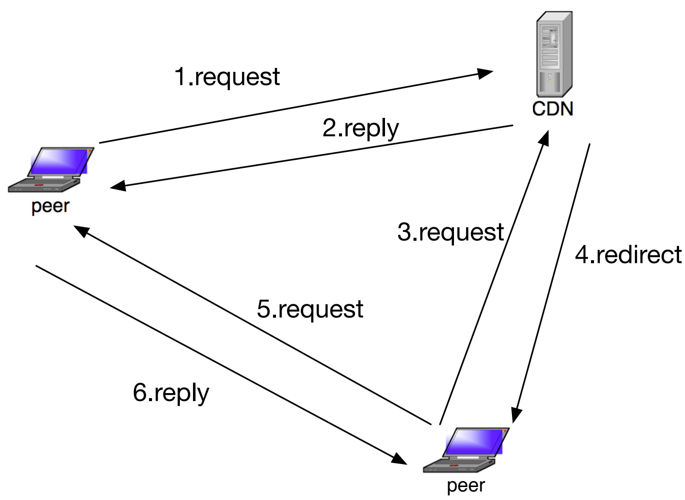

Fig. 3: Peer interaction in simulator.

2) Utility Function: Equation 2 express the utility function used by peer for cache replacement. Since we can estimate before-peak week, at-peak week, and after-peak week of video, we modified the utility function as follows: (1) for before-peak and after-peak, we assume that requests to video are low thus we define utility function as: $u = \frac{f(p) - f(p_{min})}{r^{\alpha+\beta}}$.
(2) for at-peak, we assume that request to video are high thus we define utility function as: $u = \frac{f(p_{max}) - f(p)}{r^{\alpha+\beta}}$.

3) Simulation Parameters: The simulation parameters are follows:

- Length: 360 days.
- Video size: random between 1MB and 200MB.
- Peer capacity: [500MB,1000MB].
- CDN capacity: 10000MB.
- Number of peers: 100000.
- Number of videos: 10000.

We compare our proposed improvement of PROP to original PROP [23] implementation.

C. Result and Discussion

Figure 4 shows peer contribution for our model compare to PROP. Moreover fig. 4a shows the comparison of CDF of peer contribution between our model and PROP for peer capacity 500MB. Figure 4b shows the comparison of CDF of peer contribution between our model and PROP for peer capacity 1000MB. Our model gain higher peer contribution than PROP. Figure 4c we compare our model between peer capacity 500MB and peer capacity 1000MB. Peer capacity 1000MB gives higher peer contribution because additional space makes a peer can cache more videos. From fig. 4b and fig. 4c, We can see that in our model peer contributions are higher than PROP. We do significance statistical testing if our model has significantly different from PROP. We use Kolmogorov-Smirnov (KS) test for this purpose. KS-test tries to determine if two datasets differ significantly. It has the advantage of making no asumption about the distribution of data. Reject the null hypothesis of no difference between datasets if p-value is small. For peer capacity 500MB when we compare our model and PROP, we get K-S statistic value 0.5 and p-value is 0.5e-005, while peer capacity 1000MB we get 63.34 and p-value is 0.46e-005. Since the the p-value is below 1% we can reject null hypothesis that both data are the same.

Figure 7 shows distribution of the number of replicas with different popularities at snapshot $t = 10$day. Figure 7a shows distribution of the number of replicas comparison for peer capacity 500MB and 1000MB with different popularities rank at snapshot $t = 10$day. Figure 7b shows distribution of the number of replicas comparison for peer capacity 500MB and 1000MB with different popularities at snapshot $t = 6$week. Figure 7c shows distribution of the number of replicas comparison for peer capacity 500MB and 1000MB with different popularities at snapshot $t = 6$week.

VI. Conclusion and Future Work

This paper presents a scheme for a ISP managed peer-assisted CDN model that Some areas of improvement that we have identified for future are: We are also very interested to include energy trade off this peer-assisted CDN architecture in order to know how much energy saving by ISP and how much increase of energy at users home gateway side in this architecture.

Acknowledgment

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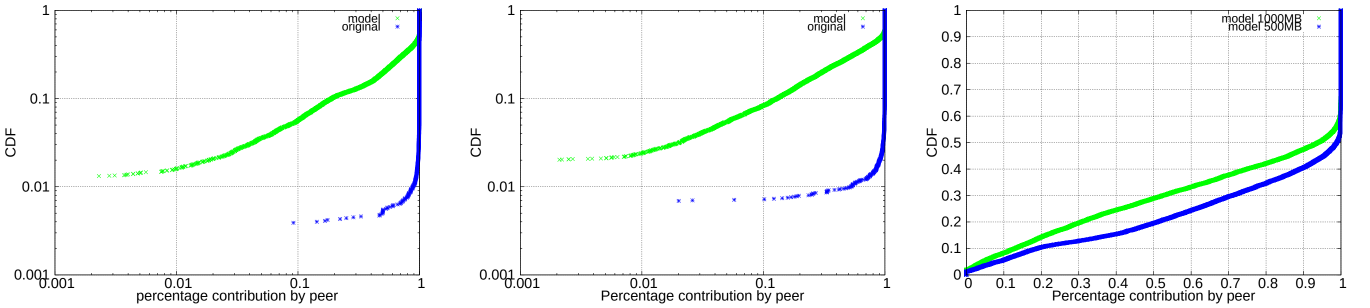
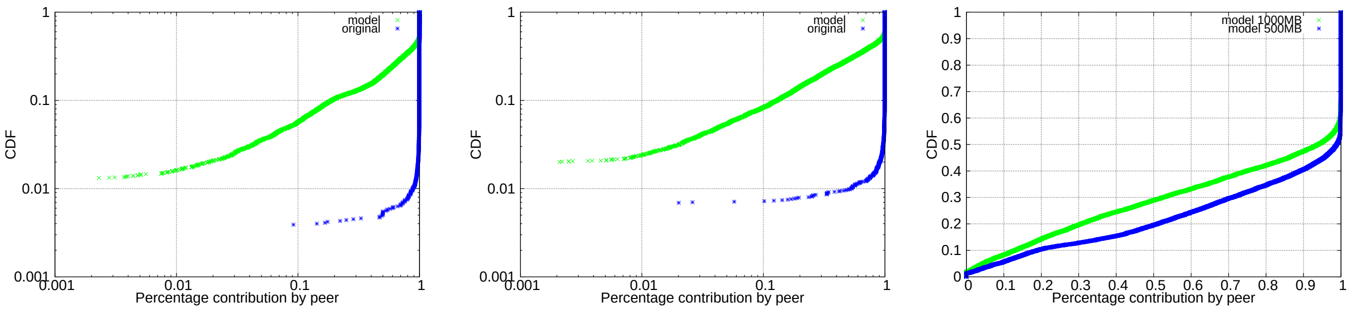


(a) CDF percentage of contribution of peers where peer capacity 500MB and CDN capacity 10GB. x and y axis in logscale.

(b) CDF percentage of contribution of peers where peer capacity 1000MB and CDN capacity 10GB. x and y axis in logscale.

(c) CDF peer contribution percentage between peer with 500MB capacity and 1000MB capacity and CDN capacity 10GB.

Fig. 4: CDF peer contribution for peer capacity 500MB and 1000MB, CDN capacity 10000MB. Model refers to our work and original refer to PROP [23].



(a) CDF percentage of contribution of peers where peer capacity 500MB and CDN capacity 20GB. x and y axis in logscale.

(b) CDF percentage of contribution of peers where peer capacity 1000MB and CDN capcity 20GB. x and y axis in logscale.

(c) CDF peer contribution percentage between peer with 500MB capacity and 1000MB capacity and CDN capacity 20GB.

Fig. 5: CDF peer contribution for peer capacity 500MB and 1000MB, CDN capacity 20000MB. Model refers to our work and original refer to PROP [23].

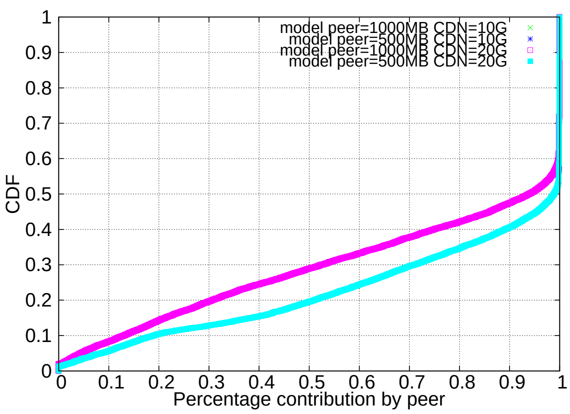


Fig. 6: Comparisan the model of CDN capacity 10GB vs. 20GB.

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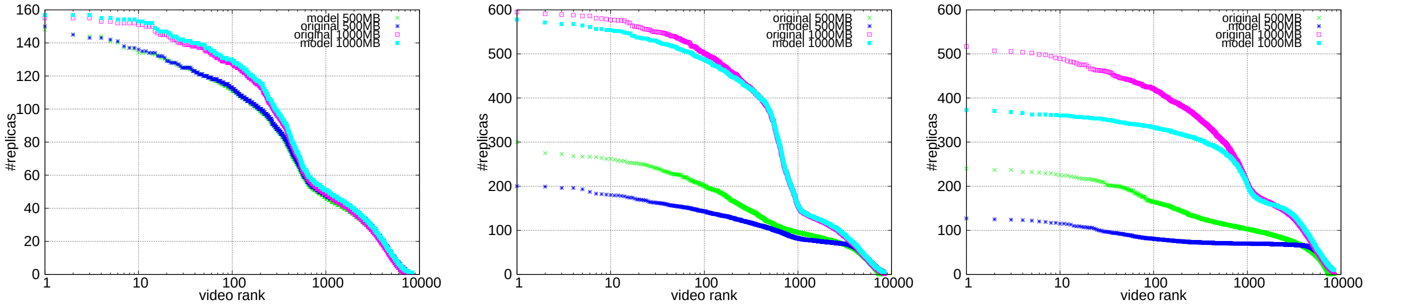
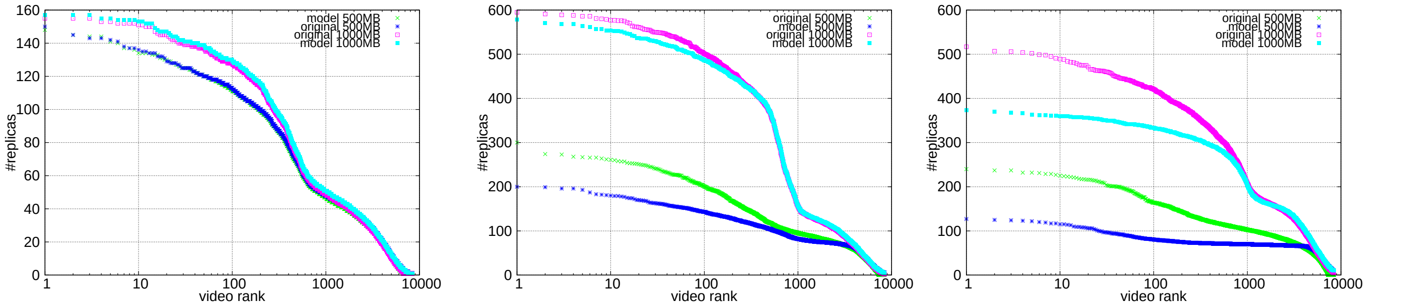


(a) Replica by popularity at t=10day for peer capacity 500MB.

(b) Replica by popularity at t=10day for peer capacity 1000MB.

(c) Replica by popularity at t=10day for peer capacity 1000MB.

Fig. 7: Peer replica at $t = 10$day, $t = 6$week, and $t = 10$week for peer capacity 500MB and 1000MB.



(a) Replica by popularity at t=10day for peer capacity 500MB and 1000MB, CDN capacity 20GB.

(b) Replica by popularity at t=10day for peer capacity 500MB and 1000MB, CDN capacity 20GB.

(c) Replica by popularity at t=10day for peer capacity 500MB and 1000MB., CDN capacity 20GB.

Fig. 8: Peer replica at $t = 10$day, $t = 6$week, and $t = 10$week for peer capacity 500MB and 1000MB, CDN capacity 20GB.

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