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Relaxing CDN Energy: Considering Peer-Assisted

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Abstract:
This paper presents an analysis of a peer-assisted CDN system, where an ISP manages its own CDN and its users participate in a P2P network to assist content delivery. The system consists of a two level of peer where first level can be considered as direct client from CDN (seeders) and second level is peer that get data from first level (leechers). We show that depend on number of peers, upload rate of peer in first level, and capacity of CDN, CDN energy can be reduced when peer in first level contribute to second level. Moreover bigger upload rate of peers in first level, then bigger peers in second level can be served by peers in first level thus reducing CDN work load.

Keywords: CDN, Data Center, Energy, Peer Assisted, P2P

1. 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. Some news broadcasters also rely on P2P technology to deliver popular live events. For example, CNN uses the Octoshape 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.

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, FTTH will be massively deployed by network opera-

tors throughout the world. As access bandwidth increases, P2P systems may become more efficient since a peer can contribute much more.

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

On the other hand, data center where CDN server placed faces costs for powering the data center. The Uptime Institute, a global data center authority, surveyed 1100 data center owners and operators on 2012, reported that 55% organizations must increase budget 10% than 2011 [1]. 30% of organizations will run out of data center capacity (power, cooling, space, and network) in the end of 2012 [1]. More than 50% organizations surveyed reported that saving energy is major priority [1]. Even in the data centers using the state of art cooling technologies heat dissipation accounts for at least 20% until 50% of the total power consumption [2]. The increases in energy cost and the demand due to growth of traffic urges the data center operators and owners to look for ways to reduce energy usage in the years to come. Although reducing energy consumption can effectively reduce overall cost, this will limit the capacity growth and scalability of the service provisioning. For example: routers and servers spend most of their energy on the baseline activities such as running the fans, spinning hardisks, powering backplane, and powering the memory. Even in an idle state, modern systems can be consuming anything from 50% until 80% of the power consumed under maximum load [3], [4]. Alternatively, the data center and be revamped by relocating some services to end-host computers or peers. Peers contribute their communication, storage, and computation resources to exchange data and provide services while the data center performs central administration and authentication as well as backend processing. P2P network, formed by peers offer flexibility and scalability in service delivery. It is not our aim to advocate

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Fig. 1: In Complex relationship of entities in Internet, CDN mostly placed in data center near to eyeball ISP. If CDN can not reach eyeball ISP due to business or economic reason, CDN can be placed near to IXP or even inside IXP, and CDN will reach eyeball ISP from peering point inside IXP.

one system architecture over another. Many issue such as manageability, reliability, and ease of deployment must be taken into account when making high level architectural decisions.

In this paper, we study the energy consumption of hybrid CDN-P2P. It has been known that CDN energy consumption is better than P2P architecture [5], [6], unfortunately that model only think small part of problem energy consumption (devices/hardwares). To be fair, we also need to see how combination of some architectures can help to reduce energy footprint, for example: combination of CDN and P2P.

The rest of this paper is organized as follows. Section 2 present motivation of this paper. Section 3 provides an overview of system model, data center model and energy model. In section 3, we will present result and analysis. Section 4 will conclude this paper.

2.   Motivation

In the economic supply chain of video traffic, most ISPs get a little revenue from video traffic thus ISP wants to monetize that traffic. the future of CDN business is likely to live deeper into ISP networks, more integrated into and interleaved with ISP infrastructures thus users can get good quality of video. The idea of ISP managed CDN has been proposed in recent years. The complexity of the CDN business encourage ISP to manage their own CDN rather than allow others to run CDNs on their networks.

CDN architectures are host-oriented: content is delivered to end users through host servers that are centrally managed in a few data centers fig.1. The growing of Internet traffic dominated by video, the energy consumption of a host oriented architecture becomes problematic due to over provisioning factor. The idea of utilizing the user's computation power to support ISP operation is not new. The figaro project proposed residential gateway as an integrator of different networks and services, becoming an Internet wide distributed content management for a proposed future Internet architecture. The important key in this architecture

is both user home gateway and access bandwidth controlled and managed by ISP. In this case, ISP can offload part of workload on their CDN to user's home gateway. By offloading workload, their CDN can relax energy demand thus relaxing data center power budget or relaxing capacity planning for power. This architecture depends largely on the number of devices which can be found online at a point in time. While some users keep their home gateway online at all times, there are small number of users might turn off or their home gateway can not be reached. Based on study from Dischinger et al., [7] and Valancius et al., [8], the average availability of the residential gateways in 12 major ISPs over one month is up 85% with 5% until 8% uptime variations thought out a day.
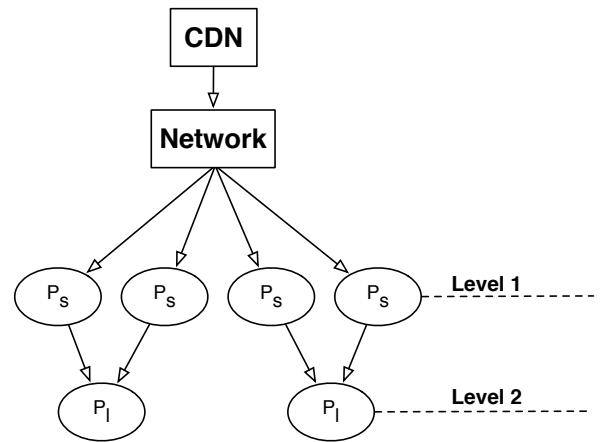
3.   System Description

Fig. 2: Model of content delivery architecture with peer assisted.

Figure 2 shows model of CDN with peer assisted. P_s in fig.2 is peers in level 1 or seeders. Seeders get content directly from CDN. P_l in fig.2 is peers in level 2 or leechers. Leechers get content from seeders.

Maximum number of seeders is bounded by maximum CDN's capacity, while maximum number of leechers in level 2 is bounded by number of seeders can support the bitrate. Denote number of seeders is n_s, number of leechers is n_l, ρ is maximum bitrate that supplied by seeders to leechers, and $r = 1$ is video bitrate, therefore we have number of leechers that can be supported by seeders is:

$$\lfloor n_l \rfloor = n_s . \rho \tag{1}$$

Number of seeders that support or upload content to leecher is:

$$n_s^u = n_l . \frac{r}{\rho} \tag{2}$$

The illustration as follows, suppose we have video bitrate $r = 1$, seeder upload rate $\rho = 0.25$, and maximum CDN capacity is $643 Mbps$. Maximum number of seeders supported by CDN is $n_s = 643$. Maximum number leechers supported by seeders is $n_l = 160$. Number of seeders that upload content to leechers is $n_s^u = 640$. Therefore we have three seeders that do not need to upload content to leecher.

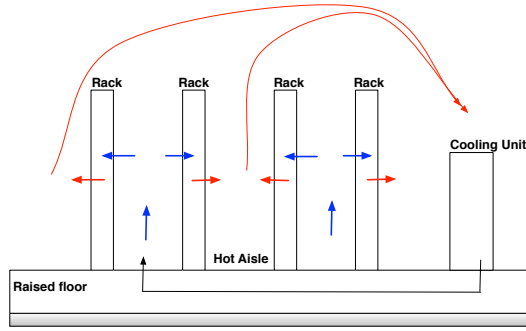## 3.1   Abstracting Data Center Power

Fig. 3: A typical data center schematic. The cooling infrastructure comprises industry standard racks on a raised floor, through which multiple compressor-driven computer room air conditioning unit circulate cool air through a share plenum.

Many aspects involved in power management in data center and interactions among power management strategies across subsystems grow more complex. Five distinct subsystems account for most of a data center's power draw: server and storage systems, power conditioning equipment, cooling and humidification systems, networking equipment, and lighting/physical security. In this section, we only focus on relationship between cooling power and hardware temperature.

Data center seek to provision the cooling adequately to extract the heat produce by servers, switches, routers, and other devices. Practically, cooling provisioning are done at facilities level. Data center operator operate cooling facilities based on power ratings of servers, switches, routers, and other devices often with some additional headroom for risk tolerance. The compounded over provisioning of computing and cooling infrastructures can drive up initial and recurring costs.

The cooling cycle of a typical data center operates in the following way: Cooling units operate by extracting heat from the data center and pumping cold air into the room, usually through a pressurized floor plenum. The pressure forces the cold air upward through vented tiles, entering the room in front the hardware Fans draw the cold air inward and through the server; hot air exits through the rear of the server. The hot air rises sometimes with the aid of fans and a ceiling plenum , and is sucked back to the cooling units. The cooling units force the hot air past pipes containing cold air or water. The heat from the returning air transfer through the pipes to the cold substance. The heated substance leaves the room and goes to a chiller and cooling unit fans force the cold air back into the floor plenum. Above process is shown in fig.3

The efficiency of this cycle depends on several factors, including the conductive substance and the air flow velocity, but it is quantified by coefficient of performance (COP). The COP is the ratio of heat removed (Q) to the amount of work necessary (W) to remove that heat:

$$COP = \frac{Q}{W} \qquad (3)$$

Therefore, the work necessary to remove heat is inversely proportional to the COP. A higher COP indicates a more efficient

process, requiring less work to remove a constant amount of heat.

However, the COP for a cooling cycling is not constant, increasing with the temperature of the air the cooling unit pushes into the plenum. COP value empirically can be computed using [9]:

$$COP(T) = 0.0068.T^2 + 0.0008.T + 0.458 \qquad (4)$$

where $T = T_{sup} + T_{adj}$ and $T_{adj} = T_{safe}^{in} - T_{max}^{in}$.
T_{sup} is temperature supply by cooling unit and T_{adj} is temperature difference between maximum safe hardware inlet temperature (T_{safe}^{in}) and the maximum observed hardware inlet temperature (T_{max}^{in}). If T_{adj} is negative, it indicates that a hardware inlet exceeds maximum safe temperature thus we need to lower T_{sup} to bring the hardwares back below the system redline level.
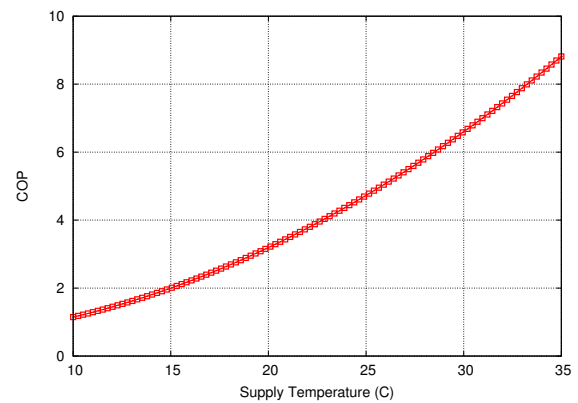

Fig. 4: COP curve for the chilled water cooling units from HP Lab utility data center. As the target temperature of the air the cooling unit pumps into the floor plenum increases, the COP increases.

Cooling cost can be calculated as [9] :

$$C = \frac{Q}{COP(T)} \qquad (5)$$

Where Q is amount of power the servers and hardwares consume. COP(T) is our COP at $T = T_{sup} + T_{adj}$. Currently we assume a uniform T_{sup} from each cooling units due to the complications introduced by non-uniform cold air supply.

3.2   Energy Model

In this paper, our goal is to provide a general view and a fair comparison of the energy consume by a CDN and hybrid CDN-P2P architecture. To do so, we designed a series of model and perform an analysis. Our energy model is similar to the models used in [10]. Network model for energy is assumed to be flat network as shown in fig.2.

For each component, we consider two energy measurement: baseline energy consumption and energy consumed per work unit δ. The baseline energy is the energy consumed to keep the device on. Even when there is no traffic, the device still consume energy. The energy consumption for a single request in CDN server as:

$$E_d = E_s \qquad (6)$$

while the energy consumption for a single request in network as:

$$E_r = d_s . E_r \qquad (7)$$

and energy of peer or client is E_p.

where d_s is number of hops or the path length. We define δ_s and δ_r work-induced energy consumed per additional bit transferred by a server and router. We can express these per-bit work induced consumptions as follows:

$$\delta_s = \frac{(S_{max} - S_{base})}{M_s} \qquad (8)$$

S_{base} is a server's baseline power consumption. S_{max} is a server's power when operating at maximum capacity. M_s is the maximum capacity in bit per second for a server. Same formulation also applied for network component.

$$\delta_r = \frac{(R_{max} - R_{base})}{M_R} \qquad (9)$$

R_{max} is a router power when operating at maximum capacity. R_{base} is a router's baseline power consumption. M_R is maximum capacity in bit per second for a router.

Substituting eq.8, and eq.9 to eq.6 and eq.7, we can rewrite eq.6 and eq.7 as follows:

$$E_d = \delta_s . B + E_{s-baseline}$$
$$E_r = d_s . \delta_r . B + E_{r-baseline} \qquad (10)$$
$$E_p = \delta . B + E_{p-baseline}$$

Finaly total energy is:

$$E_t = E_d + E_r + E_p$$
$$E_t = \delta_s . B + E_{s-baseline} + d_s . \delta_r . B + E_{r-baseline} + \delta_p . B + E_{p-baseline} \qquad (11)$$

where B is size of file to be transferred.

Considering cooling energy, we can substitute eq.5 to eq.11, therefore total energy consumed:

$$\hat{E}_t = E_t . \left(1 + \frac{1}{COP(T)}\right) \qquad (12)$$

4. Result and Discussion

4.1 Live Streaming

For numerical simulation, we use work induced energy consumed per second from [10]. For CDN server baseline, we use server idle power $E_{s-baseline} = 290$ watt and router baseline power $E_{r-baseline} = 750$ watt [10]. For peer baseline, we use peer base power $E_{p-baseline} = 13.5$ watt [8]. The peer has 256MB flash storage. The dummy network model used in this numerical simulation is shown in fig.5. The data flows from CDN to network in this case router then arrive in seeders. If seeders need to upload data to leechers then, it will flows through router then arrive in leechers. Parameters values used in this numerical simulation is shown in table 1.

Figure 6 shows energy usage for CDN server, router, total energy consumption for CDN scenario (without peer assisted). We plot energy consumption for CDN server, router, clients, and total energy for every T or COP coefficient value. In CDN only scenario, the energy consumption is increase as number of client

Table 1: Numerical Simulation Parameters.

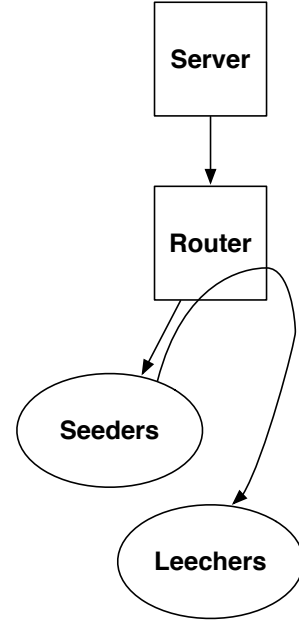| Symbol	Value
δ_s	$5.2.10^{-8}$ (J/b)
δ_r	$8.0.10^{-9}$ (J/b)
δ_p	$16.10^{-}9$ (J.b)
$E_{r-baseline}$	750 watt
$E_{s-baseline}$	290 watt
$E_{p-baseline}$	13.5 watt
d_s	1
N_s^u	[0.25, 0.5, 0.75, 1] Mbps
N	[100, .., 1000]
T	[20, 25] correspond to COP value [3.194, 4.728]

Fig. 5: Dummy network

increase. This is natural because increasing of clients imply to increasing of traffic from CDN server through router to clients. The effect of different T to total energy is small. It is between 1% until 7.7%.

Figure 7 shows energy consumption for CDN, router, and total energy consumption for CDN-P2P scenario. We use upload rate of seeders to leechers $\rho = 0.25$. We assume that CDN server always utilize under 50%. For CDN server energy E_d, the usage of energy increase until number of seeders $n_s = 500$. On $n_s = 500$ the CDN server right on 50% utilization. When CDN server on 50% utilization, maximum number of seeders are $n_s = 500$ and number of leechers can be served by seeders is 125 peers. Therefore in this situation, CDN server can save energy, because with just 50% utilization, additional 125 peers are served from seeders. We can see this situation as flat line in fig.7. Next, to be able to server more peers, we allow CDN server to increase the 62.5% utilization. With 62.5% utilization, 625 peers served by CDN server. Number of leechers can be supported by seeders are 156 peers. In this situation CDN server can save energy, because with just 62.5% utilization and number additional 156 peers are served from seeders. We can see this situation as flat line in fig.7 from $N = 625$ until $N = 781$ In router case, we do not see router can get energy saving because number of traffic increase as increasing number of peers. For example, when CDN server
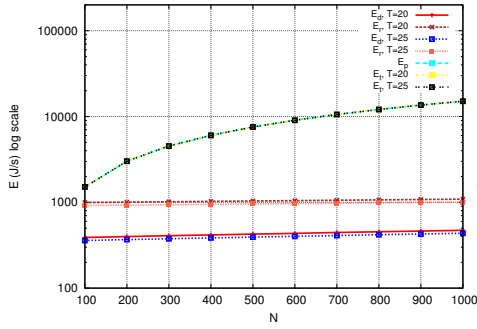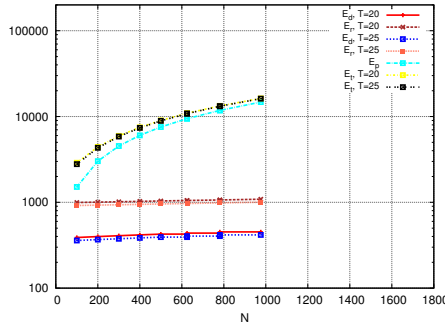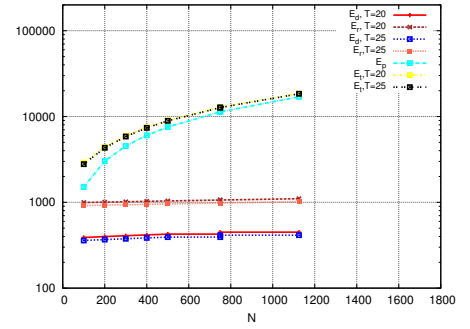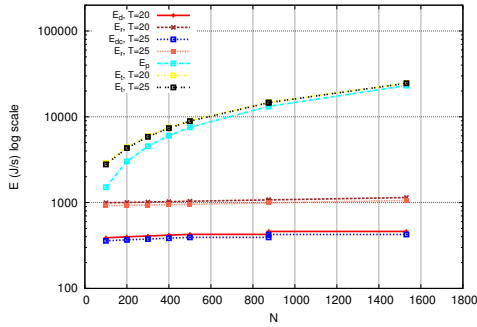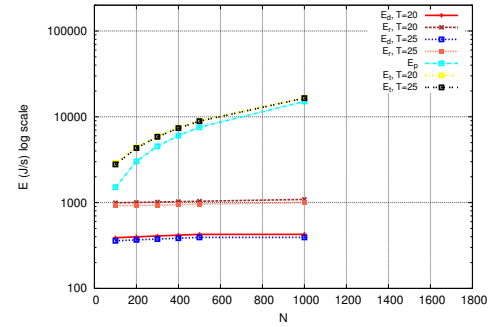
Fig. 6: CDN.

Fig. 7: CDN-P2P $\rho = 0.25$.

Fig. 8: CDN-P2P $\rho = 0.5$.

Fig. 9: CDN-P2P $\rho = 0.75$.

Fig. 10: CDN-P2P $\rho = 1$.

on 50% utilization, maximum number seeders are $n_s = 500$ and number of leechers can be served by seeders is 125 peers. Traffic traverse through router is 500Mbps plus additional 125Mbps. We get 125Mbps from 500 multiply to upload rate of seeders 0.25Mbps Different air temperature supply, make different power consumption. With $T = 25$ or $COP = 3.194$, we can see the power consumption for all components decrease. That's because energy needed to supply air cooling with temperature $T = 25$ is less than energy needed to supply air cooling with temperature $T = 20$.

Next, Figure 8 shows energy consumption for CDN, router, and total energy consumption for CDN-P2P scenario. We use upload rate of seeders to leechers $\rho = 0.5$. We assume that CDN server utilization under 50%. For CDN server energy, the usage of energy increase until number of seeders $n_s = 500$. On $n_s = 500$ the CDN server right on 50% utilization. When CDN server on 50% utilization, maximum number of seeders are $n_s = 500$ and number of leechers can be served by seeders are 250 peers. In this situation, CDN server can save energy, because with just 50% utilization, additional 250 peers are served from seeders. We can see this situation as flat line in fig.7 from $N = 500$ until $N = 750$. In order to allow more peers, then CDN server must allow to increase its utilization from 50% to 75%. Again we will see flat line in fig.7 from $N = 750$ until $N = 1125$. That's because with CDN server utilization 75%, with number of seeders $n_s = 750$ can also serve leechers $n_l = 325$ leechers. On the other hand, energy consumption of router increasing with the increasing number of peers because router needs to accommodate traffic from all peers.

Figure 9 shows energy consumption for CDN, router, and total energy consumption for CDN-P2P scenario. We use upload rate of seeders to leechers $\rho = 0.75$. We assume that CDN server utilization under 50%. The result almost same with previous. CDN

server energy increase until number of seeders $n_s = 500$. When CDN server hit 50% utilization, maximum number of seeders are $n_s = 500$ and number of leechers can be served by seeders are 325 peers. Therefore with same energy level on 50% utilization the system can server additional 325 peers. Again, for router energy consumption is increasing.

Figure 10 shows energy consumption for CDN, router, and total energy consumption for CDN-P2P scenario. We use upload rate of seeders to leechers $\rho = 1$. We assume that CDN server utilization under 50%. The result almost same with previous. CDN server energy increase until number of seeders $n_s = 500$. When CDN server hit 50% utilization, maximum number of seeders are $n_s = 500$ and number of leechers can be served by seeders are 500 peers. Therefore with same energy consumption level on 50% utilization the system can server additional 500 peers. Once again, router energy consumption is increasing.

Figure 11 shows percentage difference of energy consumption between CDN and CDN-P2P for CDN server component with $\rho = [0.25, 0.5, 0.75, 1]$. The power saving that CDN server get is from 3.8% to 11%. More clear figure is shown in fig.13 for $\rho = 0.75$ where CDN server can save energy because the utilization of CDN server is same when the system has number of peers from 500 to 875 and from 875 peers to 1531 are handle with same CDN utilization. Figure 12 shows percentage difference of energy consumption between CDN and CDN-P2P for total system with $\rho = [0.25, 0.5, 0.75, 1]$. The power saving that total system get is from 0.1% to 0.9%. Figure 14 reports percentage difference of energy consumption between CDN and CDN-P2P for total system with $\rho = 0.75$. While CDN server part can save more energy, due to peers high energy consumption then total energy saving in the system that we can get is small, from 0.2% to 0.9%.
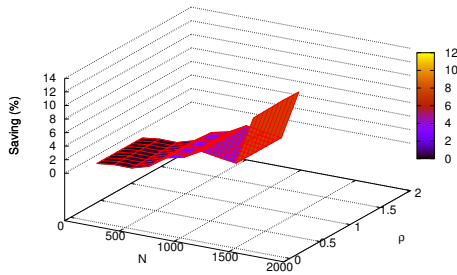
Fig. 11: Different power consumption between CDN and CDN-P2P for CDN server component with ρ = 0.25, 0.5, 0.75, 1.
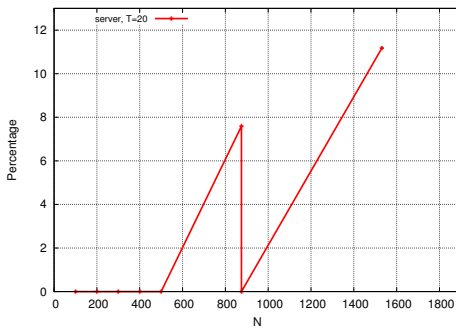

Fig. 12: Different power consumption between CDN and CDN-P2P for total system with ρ = 0.25, 0.5, 0.75, 1.

Fig. 13: Different power consumption between CDN and CDN-P2P for CDN server component with ρ = 0.75.

Fig. 14: Different power consumption between CDN and CDN-P2P for total system with ρ = 0.75.

4.2   Online Storage

In peer-assisted online storage, user contribute their upload bandwidth to redistribute of a file that they are downloading or that they have cached locally. We follow peer-assisted online storage model in [11] as basis of our work. In peer-assisted online storage, users can browse a catalog of available files and asynchronously issue request to download a given file, which are ideally immediately satisfied by the system. In order to reduce startup latency, first block of file must be downloaded from server [12]. In peer-assisted online storage, users interested to a specific file can retrieve it from servers (CDN) and from users storing copy of it in their computer or dedicated set top boxes/home gateway remotely. Peer-assisted online storage model in [11], the arrival process of request for considered file follow Poisson process, it takes into account multiple files of different popularity and server bandwidth provisioning. For detail, we refer the readers to [11], [12], [13].

5.   Related Work

Content Distribution Networks with peer assist have been successfully deployed on the Internet, such as Akamai [14] and LiveSky [15]. The authors of [14] 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. [15] described LiveSkye as 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
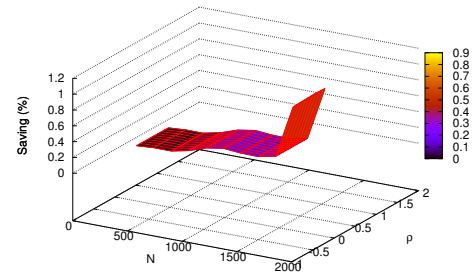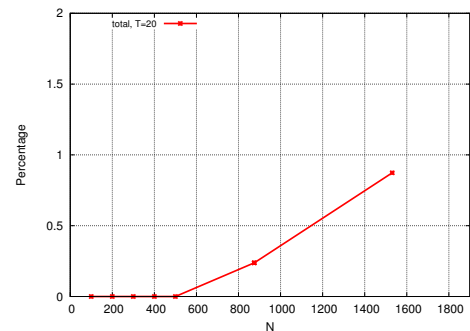
of P2P integration with the existing CDN infrastructure, and network friendliness and upload fairness in the P2P operation. Measurement from LiveSky showed that LiveSky can save bandwidth around 40% [15]. The author in [16] and [17] proposed mechanisms to minimize CDN server bandwidth to make the content distribution cheap. They designed different peer prefetching policies of video on demand system in surplus mode while ensuring user quality of experience. A similar analysis has been done in [18] for live video streaming system where the authors proposed different limited peer contribution policies to reduce CDN bandwidth requirement and eventually off the distribution process from CDN to P2P system. An ISP friendly rate allocation schemes for a hybrid CDN-P2P video on demand system in [19]. These technique try to minimize CDN server bandwidth while reducing ISP unfriendly traffic and maximizing peer prefetching. Load on CDN server has been shown to be reduced using this approach while reducing cross ISP traffic. Above studies were performed for video on demand or live video streaming. While video is the most popular content, the systems can be also for other type contents. Moreover while content based services are growing, energy consumption of a content distribution system has not been analyzed.

Related to CDN and energy usage, in a seminal work [20], the authors show that if costs are based on electricity usage and if the power prices vary in real-time, global load balancing decision can be made such that users are routed to locations with the cheapest power without significantly impacting user performance or bandwidth cost. In [21], the author proposed utilizing batteries

for CDN for reducing total supplied power and total power costs. The authors in [21] also proposed battery provisioning algorithms based on workload of CDN server. The result shows that batteries can provide up to 14% power savings.

The idea that utilize ISP controlled home gateway to provide computing and storage services and adopts managed peer-to-peer model is presented in [8]. Valancius et al. [8] show that distributing computing platform in NaDa (Nano Data Center) save at least 20-30% energy compare to traditional data centers. The saving in NaDa comes from underutilizing home gateway, avoidance of cooling costs, and the reduction of network energy consumption as a result of demand and service co-localization.

The comparison between CDN architecture and peer-to-peer architecture are discussed in [6] and [5]. Both authors in [6] and [5] agree that CDN architecture is more energy saving compare to peer-to-peer architecture. Another interesting study of energy efficient in content delivery architectures is presented by Guan et al. [22]. by Guan et al. [22] comparing energy efficient of CDN architecture and CCN architecture. The authors in [22] conclude that CCN is more energy efficient in delivering popular content while the approach with optical bypass is more energy efficient in delivering infrequent accessed content.

To the best of our knowledge, the study of energy in that considering peer-to-peer in CDN architecture is presented in [23]. Mandal et al. [23] mentioned that hybrid CDN-P2P systems can reduce a significant amount energy in the optical core network around 20-40% less energy. The authors only considered energy consumption of hardware especially optical devices and does not include overhead inside data center, CDN server energy comsumption, and consumed power by peers. Our work is quite different, we take number of peers with static content and add overhead of data center which is power of cooling cause by temperature of hardware for different purpose which are live streaming and video on demand.

6.   Conclusion and Future Work

In this paper, we have introduced the comparison of energy consumption between the peer-assisted CDN architecture and CDN architecture for live streaming and video on demand service. Integrating peer to peer capability to assist the existing CDN has a potential to save energy consumption. In this study, we show that event without explicitly considering energy consumption while assigning content, the peer assisted CDN can save energy consumption. Although the energy savings depend on number of request (number of clients), number of router and its configuration, for total system energy saving is around 0.5 to 1.2. If we break per component, the CDN server is the part that can be push to save energy up to 11% and can be more if new generation of power proportional server is used [24]. We agree with [4], Router component in the other side is quite difficult for energy saving, because different chassis size, different network interface type slot, and different configuration has different energy consumption. Several areas that we have been identified for future work are:

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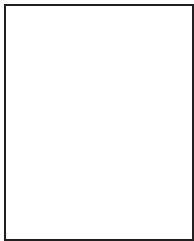
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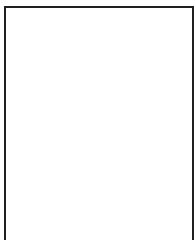
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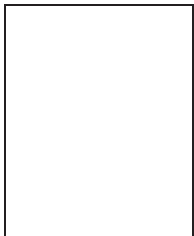
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