

An Analysis and Comparison of CDN-P2P-hybrid Content Delivery System and Model

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Abstract- In order to fully utilize the stable edge transmission capability of CDN and the scalable last-mile transmission capability of P2P, while at the same time avoiding ISP-unfriendly policies and unlimited usage of P2P delivery, some researches have begun focusing on CDN-P2P-hybrid architecture and ISP-friendly P2P content delivery technology in recent years. In this paper, we first survey CDN-P2P-hybrid architecture technology, including current industry efforts and academic efforts in this field. Second, we make comparisons between CDN and P2P. And then we explore and analyze main issues, including overlay route hybrid issues, and playing buffer hybrid issues. After that we focus on CDN-P2P-hybrid model analysis and design, we compare the tightly-coupled hybrid model with the loosely-coupled hybrid model, and we propose that there are some main common models which need further study. At last, we analyze the prospective research direction and propose our future work.

Keywords- CDN, P2P, P2P Streaming, CDN-P2P-hybrid Architecture, Live Streaming, VoD Streaming

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I. INTRODUCTION

The ongoing growth of broadband technology in the worldwide market has been driven by the hunger of customers for new multimedia services as well as Web content. In particular, audio and video streaming has become popular for delivery of rich information to the public - both residential and business. In recent years, PC-based Internet streaming, IP network television (IPTV), large-size file downloading, and high-definition video have become mainstream broadband streaming applications. The high-bandwidth, high-traffic and high QoS demands, inherent in these applications, have brought huge challenges to the current best-effort Internet. How to implement large-scale, low cost, QoS guaranteed content delivery has become one core problem. In the next-generation Internet, various types of wired and wireless networks will coexist, such as broadband Internet, wireless wide area network (WWAN, 3G and post-3G), wireless

metropolitan area network (WMAN), wireless LAN, wireless personal area network, and so on. At the same time, a variety of wired / wireless terminals are emerging, including mobile PC, TV set-top box, 3G mobile phone, netbook, iPad and so on. All these different terminals will obtain streaming content and service through a variety of heterogeneous access networks, such as ADSL, the cable network, Wi-Fi, 3G, and Wimax, et al.

Therefore, the question of how to build a number of low-cost expandable, controllable and manageable, fast and efficient, safe and reliable content service networks on top of the Internet IP layer, is a key issue.

In current content service platforms, Content Delivery Networks (CDN) is a representative technique. CDN is based on large-scale distributed cache servers located closer to the edges of the Internet for efficient delivery of digital content including various forms of multimedia content. There are many commercial CDN companies [2], including Akamai, AT&T, NTT Communication, Limelight, Mirror Image, Level 3, Verisign and Internap. Akamai is the largest among these CDN companies [26]. Akamai's EdgePlatform comprises 56,000 servers deployed in 70 countries and 1000 networks that continually monitor the Internet, including traffic, trouble spots and overall conditions.

Although CDN is an effective means of streaming content access and delivery, there are two barriers to making CDN a more common service: expensive construction cost and administration complexity. Deploying a CDN for publicly available content is very expensive. It requires administrative control over cache nodes with large storage capacity at geographically dispersed locations with adequate connectivity [12]. Each cache node must be configured to participate in the replication scheme and to automatically update its directory structure. The administrative system for a CDN must be concerned with both node hardware and content availability. Failed hardware components must be reported as well as failed or corrupted data replication. CDN can be scalable, but due to this administrative overhead and expensive cost, not rapidly so.

Popularity of Peer to Peer (P2P) streaming has been shown to greatly reduce the dependence on CDN, as well as accelerate the distribution process between content providers and consumers. Many research works have been undertaken in P2P live streaming and P2P VoD streaming [3-10]. There are several large-scale P2P streaming applications that serve millions of users, such as PPLive, UUSee, PPStream, SopCast, et al. Indeed, streaming media content delivery using various peer-to-peer or peer-assisted frameworks allows the sharing of client resources, such as CPU, memory, storage, bandwidth, etc, and has greatly reduced the dependence on central content servers or CDN servers [34]. The P2P approach is more scalable and needs less investment, and each client not only gets service but also provides service as well. The con is that it is not easy to manage and the QoS is also a problem due to dynamic churn. Peers usually perform selfishly, and will ignore the global benefit, for example the backbone consumption etc [34]. P2P has also fundamentally altered the relationship among content owners, network providers (ISPs) and consumers. Popularity of P2P streaming applications has resulted in increased traffic on ISP networks. Being largely network-oblivious, many P2P applications may lead to substantial network inefficiency. For the benefits of backbone network carriers and ISPs, it is desirable to combine the features of P2P and CDN systems, that will best protect the previous investment and improve the service capability at the same time. P2P technology is not a replacement for CDN, while it's a complement to CDN. This is because there are instances where both sets of technologies have their own strengths and weaknesses [30]. A natural question is whether they can be combined to obtain the scalability advantage of P2P, as well as the reliability and manageability advantages of CDN. Indeed, with recent rapid growth of P2P applications and CDNs, many industrial and academic initiatives have been taken to combine the two technologies to get the "best of both worlds". The most challenging problem of current content delivery network is to realize controllable, manageable, credible, network-friendly content distribution architecture through the integration of CDN and P2P.

In recent years, some researches have begun focusing on ISP-friendly P2P content delivery technology (e.g., [4, 7, 9]) and CDN-P2P-hybrid architectures (e.g., [11,12,14-22,25,32-35,39]). In this paper, we first make a survey of CDN-P2P-hybrid architecture technology, including current industry efforts and academic efforts. Second, we make comparisons between CDN and P2P. Then we explore and analyze main issues, including overlay route hybrid issues, and playing buffer hybrid issues. After that we focus on CDN-P2P-hybrid model analysis and design, and we compare the tightly-coupled hybrid model with the loosely-coupled hybrid model, finally we point out that there are some main common CDN-P2P-hybrid models which need further study.

To the best of our knowledge, our work represents the first extensive and in-depth analysis and comparison of CDN-P2P-hybrid systems and models. To summarize, the key contributions and key findings of this paper are the following:

- We present a comprehensive survey of CDN-P2P-hybrid technology, including current industrial efforts and academic efforts in this field. Specifically, we conduct a thorough analysis of the academic achievements of this new field in recent years.
- Furthermore, we explore and discuss major issues and problems arising in the CDN and P2P integration process, including overlay route hybrid issues, and playing buffer hybrid issues. Then we make a detailed comparison of how existing hybrid schemes dealing with these issues.
- We propose that there are two kinds of CDN-P2P hybrid models: the tightly-coupled hybrid 1+1 model and the loosely-coupled 1+N hybrid model. And we further analyze their applicability based on their strengths and weaknesses.
- Finally we assess that there are some main common CDN-P2P-hybrid models that need in-depth study, including (1)the hybrid-scheduling model between CDN global scheduling and P2P distributed routing,(2)the total hybrid-delivery services capacity dynamic allocation model,(3) the P2P-ISP friendly delivery model under the guidance of CDN,(4) the controllable management model, and (5) the secure and trustable delivery model, et al.

The remainder of this paper is organized as follows: in Sec. II, we make a detailed survey on current CDN-P2P-hybrid delivery technologies. In Sec. III, we compare CDN and P2P streaming architecture's strengths and weaknesses. We explore and analyze the main issues of CDN-P2P-hybrid delivery and some existing solutions for these issues in Sec IV. In Sec V, we propose two kinds of CDN-P2P hybrid models: the tightly-coupled hybrid model and the loosely-coupled hybrid model and we also analyze the common CDN-P2P-hybrid delivery models. We conclude the paper and propose our future work in Sec.VI.

II. CDN-P2P-HYBRID ARCHITECTURE TECHNOLOGY SURVEY

A. Industrial Efforts on CDN-P2P Hybrid Architecture

The hybrid CDN-P2P delivery model is becoming increasingly popular largely due to the rapid growth in the demand for online video and due to industrial efforts.

Akamai is making a big push into the P2P-CDN business. Akamai, with its acquisition of Red Swoosh P2P technology, is expected to combine P2P file distribution software with its back-end control system and global network of edge servers [18]. Akamai applied for an open patent in 2008: "Hybrid content

delivery network (CDN) and peer-to-peer (P2P) network” [22]. In this patent, they described the following mechanisms: a content delivery network (CDN) typically includes a mapping system for directing requests to CDN servers. One or more peer machines become associated with the CDN, and the CDN mapping system is then used to enable a given peer to locate another peer in the P2P network, and/or a CDN server. Using this hybrid approach, CDN customer content may be delivered from the CDN edge network, from the P2P network, or from both networks. In one embodiment, customer content is uploaded to the CDN and stored in the edge network, or in a storage network associated therewith. The CDN edge network is then used to prime the P2P network, which may be used to take over some of the content delivery requirements for the customer content. The decision of whether to use the edge network or peer network resources for delivery may be based on load and traffic conditions.

VeriSign, CacheLogic, Grid Networks, Internap, and Joost have all announced their own CDN-P2P services as well [18]. VeriSign (VRSN) is launching CDN-P2P combination project. And Cachelogic, has been working with carriers and are already hawking their P2P-CDN offerings. For instance, they announced that they are working with Babelgum, to deliver video over its Velocix Network, a P2P-CDN service that Cachelogic claims will radically change the economics of content delivery. Even pure-play P2P companies like Pando have started dabbling with P2P CDNs [28]. Pando Networks announced they are putting the world’s largest Hybrid P2P content delivery service in the hands of media companies so they can accelerate and optimize their HD media streams, downloads and RSS channels [30]. The inherent properties of hybrid P2P networking represents a fundamental evolution of the physics of content delivery — supply is directly proportional to demand and inversely proportional to cost.

GridNetworks wants to provide the underlying technology that streams high quality television content over the internet and into homes. Its architecture is part traditional CDN, part peer-to-peer network. In simple terms, the content delivered by GridCasting is initially buffered by a handful of data centers. Then after about 10-30 seconds of video playback, the data centers hand over delivery responsibilities to around 16 peers (other consumers of online video content who have cached it already and can serve as mini data centers themselves) [27]. Cisco will include Grid Networks’ peer-to-peer software in its home networking products, “They’re going to embed the GridCasting client into edge devices in millions of households in the coming year-plus,” Grid Networks CEO Tony Naughtin told a reporter in 2008 [29].

ChinaCache, the largest CDN company in China, has developed and deployed a hybrid CDN-P2P live streaming system-LiveSky [17][35]. LiveSky works

well even when the client upload bandwidth is restricted and ineffective. LiveSky provides good performance even with churn—the fraction of peers that join or leave in a specific interval. In later chapters, we continue to analyze LiveSky.

B. Academic Efforts on CDN-P2P Hybrid Architecture

Therefore, in order to fully make use of the stable backbone-to-edge transmission capability of a CDN and the scalable last-mile transmission capability of P2P, while at the same time avoiding ISP-unfriendly policies and unlimited usage of P2P delivery, some researches have been focusing on CDN-P2P-hybrid architecture and ISP-friendly P2P content delivery since 2006.

Dongyan Xu et al. published one earliest papers focusing on this issue [11]. This paper proposed and analyzed a novel hybrid architecture that integrates both CDN- and P2P-based streaming media distribution. The architecture is highly cost-effective: it significantly lowers the cost of CDN capacity reservation, without compromising the media quality delivered. In particular, they proposed and compared different limited contribution policies for peers that request media data, so that the streaming capacity of each peer can be exploited on a fair and limited basis [11]. Their analytical and simulated results formed a rigorous basis for the planning and dimensioning of the hybrid architecture. Through analysis of this paper, we think their hybrid architecture design is relatively simple; just one CDN server link to P2P network. In practice, the hybrid architecture of CDN and P2P is a multiple-to-multiple relationship. The author stated that the stages of a media data distribution process are from CDN-only at beginning, transferring to CDN-P2P coexistence, to P2P only at last. This is an idealistic situation. In practice, CDN and P2P coexist most of the time, with different shares of the workload over time.

Our previous work proposed a novel hybrid architecture [12]-PeerCDN, which combines the two approaches seamlessly with their inherent strengths. PeerCDN is a two-layer streaming architecture. The upper layer is a server layer which is composed of original CDN servers including origin servers and replica servers. The lower layer consists of groups of clients who request the streaming services, with each client acting as a peer node in the group. Each group of client peers is led by the nearby replica server-strong node. Client peers contribute their resources through the coordination of the strong node. The scheme uses a revised Kademlia-like protocol to construct a topology-aware overlay network.

Specifically, there are some academic papers focusing on this issue in some famous conferences, such as SIGCOMM2007/2008 and INFOCOM 2007/2008. In SIGCOMM2007, Cheng Huang et al.[9] showed that peer-assistance can dramatically reduce server bandwidth costs, particularly if peers prefetch content when there is spare upload capacity in the

system. They consider the impact of peer-assisted VoD on the cross-traffic among ISPs. Although this traffic is significant, if care is taken to localize the P2P traffic within the ISPs, they can eliminate the ISP cross traffic while still achieving important reductions in server bandwidth. We have proposed the P4P project in SIGCOMM2008, [13]. The P4P framework is a flexible and light-weight framework that allows network providers (ISP) to explicitly provide more information, guidelines and capabilities to emerging applications, such as P2P content distribution. P4P stands for provider portal for applications. P4P provides multiple interfaces for networks to communicate with P2P applications. The interfaces preserve network provider privacy and allow network providers and applications to jointly optimize their respective performance. The evaluations demonstrate that this can be a promising approach to improve both application performance and provider efficiency. But P4P requires ISPs to expose the necessary interface, which may result in ISPs operation burden and some security problems and need relatively close cooperation between ISPs and P2P application.

In SIGCOMM2008, David R. Choffnes et al. [14] presented Ono: the design, deployment and evaluation of an approach to reducing this costly cross-ISP traffic without sacrificing system performance. Their approach recycles network views gathered at low cost from content distribution networks (CDN) to drive biased P2P neighbor selection without any path monitoring or probing. The results show that their lightweight approach significantly reduces cross-ISP traffic and, over 33% of the time, it selects peers along paths that are within a single autonomous system (AS). This method is one kind of loosely-coupled hybrid structure between CDN and P2P. P2P cleverly uses some external public information about the CDN to make the decision of choosing neighbors with ISP-friendly consideration. Currently there are some closely-coupled hybrid CDN-P2P systems, and in this paper, we comparatively study their respective characteristics.

Combining the advantages of CDN and P2P networks has been considered a feasible orientation for large-scale video stream deliver. To guarantee QoS and facilitate management in large scale high-performance media streaming, Zhijia Chen et al. [15] extended the current P2P model towards a novel Peer-Server-Peer (PSP) architecture for media streaming. In their Peer-Server-Peer (PSP) structure, media content is first distributed among trusted servers and eventually reaches different clusters of peers for their P2P distribution. All the carefully-deployed servers (some may belong to CDN), which are formed by dedicated proxy servers for content distribution) form a trustworthy and controllable overlay network, through which servers provide initial content, guide streaming traffic to achieve overall traffic optimization, and conduct key distribution. Their research is ongoing.

Xuening Liu et al. [16] proposed a peer-assisted content distribution network, i.e. PACDN, which blends the mesh-based P2P ideas into the traditional CDN to enhance performance and scalability. The basic features of PACDN include: 1) The placement of edge servers and source streaming servers, which build a hierarchical multi-tree based on an in-hierarchy peer-assisted overlay, which is optimized according to the knowledge of underlying physical topology. This scheme in the design is called "server side peer-assisted". 2) To enhance the system scalability and reduce the deployment costs, clients and edge servers construct a Client/Server based and P2P network assisted overlay with the increase of viewers, which is called "client side peer-assisted" in this design.

Based on the above two paper's research, in the latest ACM Multimedia2009 and ACM Transaction2010, Hao Yin et al. presented design and deployment experiences of LiveSky[17] [35], a commercially deployed hybrid CDN-P2P live streaming system. CDNs and P2P systems are the common techniques used for live streaming, each having its own set of advantages and disadvantages. LiveSky inherits the best of both worlds: the quality control and reliability of a CDN and the inherent scalability of a P2P system. They addressed several key challenges in the system design and implementation including (a) dynamic resource scaling while guaranteeing stream quality, (b) providing low startup latency, (c) ease of integration with existing CDN infrastructure, and (d) ensuring network-friendliness and upload fairness in the P2P operation. To summarize the three papers, we find the integration of CDN and P2P forms a relatively tightly-coupled relationship. In their CDN-P2P hybrid topology, they described that every CDN node lead a group of peer nodes, therefore, all the nodes have been split into different groups. The existing P2P systems have to change their own overlay structure to accept the leadership of the dominant CDN. This hybrid method is efficient, but it is not suitable for one CDN to integrate with multiple heterogeneous P2P, which needs one kind of loosely-coupled relationship. Later we will discuss these two kinds of relationship in detail.

Cheng Huang et al.[18] quantified the potential gains of hybrid CDN-P2P for two of the leading CDN companies, Akamai and Limelight. They first developed a novel measurement methodology for mapping the topologies of CDN networks. They then considered ISP-friendly P2P distribution schemes which work in conjunction with the CDNs to localize traffic within regions of ISPs. To evaluate these schemes, they used two recent real-world traces: a video-on-demand trace and a large-scale software update trace. They found that hybrid CDN-P2P can significantly reduce the cost of content distribution, even when peer sharing is localized within ISPs and further localized within regions of ISPs. This paper focuses on measurement techniques of CDN-P2P

hybrid architecture; they do not include a detailed description for the design of a CDN-P2P hybrid mechanism.

Hai Jiang et al. [19] presented a hybrid content distribution network (HCDN) integrating complementary advantages of CDN and P2P technology, which is used to improve efficiency of large scale content distribution. Their hybrid model is simplistic, but they carried out a detailed performance evaluation based on a deterministic fluid model. And they provided numeric results of HCDN, a conventional CDN and pure P2P. As shown in their analysis and numerical results, they draw the conclusion that the HCDN has many advantages on average downloading time, service capacity and system scalability.

Duyen Hoa HA et al. [20] introduced a new hybrid CDN-P2P solution for real time streaming. Different from others, their solution is based on the effective management of the playing buffer at the peer-side to best equilibrate the bandwidth used between the CDN side and the P2P side. The main idea is to divide the playing buffer into two parts: the CDN priority part and the P2P priority part. During the playback time, lacking packets in the CDN priority part will be received from CDN servers, and lacking packets in the P2P priority part will be received from other peers. By divide the playing buffer into 2 parts, they can profit from all the advantages of CDN servers and P2P network: the performance of CDN servers and the cheap cost of using peers to distribute media content. Their paper is not concerned with how CDN is integrated with P2P, and their focus is, after integration, on how to utilize the buffer division mechanism to get the respective contents of CDN and P2P resources to work in parallel.

A new concept of integrating both CDN and P2P technologies into a replication-aware CDN-P2P architecture has been proposed by Hung-Chang Yang et al.[21]. They proposed a two-step selection approach on landmark-based selection algorithm to find the nearest replica-cache server and peer-caches to download content in this architecture. Furthermore, recent studies have supported the claim that network coding technology is beneficial for large-scale P2P content distribution. Herein, they showed how to apply network coding technology to distribute content so that the content provider's rights can be protected.

Jimmy Jernberg et al. [32] presented a new approach to building a scalable Web Hosting environment as a CDN on top of a structured peer-to-peer system of collaborative web-servers integrated to share the load and to improve the overall system performance, scalability, availability and robustness. Unlike cluster-based solutions, it can run on heterogeneous hardware, over geographically dispersed areas. Manal El Dick et al. [33] have developed Flower-CDN, a locality-aware P2P based content-distribution network (CDN) in which the users that are interested in a website support the distribution of its

content. The idea is that peers keep the content they retrieve and later serve it to other peers that are close to them in locality. Their architecture is a hybrid between structured and unstructured networks. When a new client requests some content from a website, a locality-aware DHT quickly finds a peer in its neighborhood that has the content available. Additionally, all peers in a given locality that maintain content of a particular website build an unstructured content overlay.

III. CDN AND P2P ARCHITECTURE TECHNOLOGY COMPARISON

Through the analysis of these above related papers, we make a detailed comparison between CDN and P2P in the following table. We can observe both of them have their own advantages and fundamental shortcomings. The two techniques have great complementary characteristics, so their integration will provide a big opportunity to build a manageable, reliable, QoS-guaranteed, and scalable content service platform.

TABLE I. COMPARISON BETWEEN CDN AND P2P

Comparison Item between CDN and P2P	CDN	P2P
Service Capability and Scalability	Service capability is limited and expansion cost is higher	Service capability can grow up with peer node increases and expansion cost is lower
Reliability and Stability	High reliability, good stability	Low reliability, dynamic, and poor stability
Network-friendly and orderly flow	Network(ISP)-friendly, flow is controlled in different regions	Network(ISP)-unfriendly, traffic disorder, cross-ISP expansion in the whole network
Content Source Monitor	Can be monitored	It is difficult to monitor
User Management	Centralized user management	Loose or less user management
QoS Guarantee	Can be guaranteed within the maximum service capacity	Best-effort, can't be controlled
Content Copyright and Security	Controllable and manageable	Uncontrollable, non-management, content pollution may arise
Service Node Authentication	Center certification	Distributed certification or non-certification
Service Node	CDN node is service node, and client nodes just	Client nodes can provide P2P content delivery service to other

	access to CDN services, service node is homogeneous	client nodes, service node is heterogeneous
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IV. CDN AND P2P HYBRID ISSUES DISCUSSION

A. Overlay Route Hybrid Issues

Using a CDN-P2P hybrid approach, client users can fetch contents from the CDN edge network, from the P2P network, or from both networks. The decision of whether to use the edge network or the peer network resources for delivery is based on overlay route technology [39]. There are two kinds of CDN and P2P hybrid overlay: PAC (Peer-aided CDN) [12,16,17,20,21,22] and CAP (CDN-aided P2P) [3,36,37]. Most CDN providers, such as Akamai[21], ChinaCache[17], integrate their CDN with P2P in PAC manner. Most overlay route technologies in CDN are using DNS redirection technology, such as Akamai. In PAC method, users are mainly redirected and served by CDN. P2P overlay is applied to improve user performance and to alleviate the stress of CDN. However, in CAP method, most streaming contents are distributed to users through P2P network. CDN serves as a rescuer for some starving P2P peers. Most P2P application providers, such as PPLive, UUSEE, integrate their P2P network with CDN in CAP manner. The overlay route technology of most P2P streaming application is using tracker-based redirection technology, such as PPLive, PPStream, and many P2P file sharing applications are using DHT technology, such as BT, E-mule, et al. We introduce related work of PAC and CAP, respectively.

(1) PAC Method

In [22], Akamai PAC hybrid delivery scheme's overlay route mechanism mainly relies on the CDN DNS redirection mechanism. Figure1 describes the main mechanisms as the following. Every step number corresponds to the number of Figure1. Note Step (3) and Step (3') is an alternative step; if Step (3) is selected, and then the next step is Step (4), otherwise Step (3') and (4').

(1) One peer node's request is directed to the CDN, which in one embodiment then returns to the peer node a file, sometimes referred to as a metafile. In one embodiment, this metafile includes one or more CDN or hybrid CDN-P2P domains or sub-domains that can then be used by the peer node to obtain the desired content.

(2) Thus, for example, assume the metafile includes a set of domains such as peer.ake.net, peer.cdn.net, and the like, each of which is resolved by the CDN DNS query mechanisms, which is authoritative for all domains returned in the metafiles.

(3) In this example, the first domain is designed to be resolved to another peer in the P2P network, and the

second domain is designed to be resolved to an edge server in the CDN network (thus acting as failover in this example). This ordering is merely representative, as the order may be switched so that the peer is the backup. In either case, the peer node client then makes a DNS query to the first domain or sub-domain in the list, and that DNS query is resolved through the CDN DNS query mechanism to identify a nearby peer in the P2P network from which the content can be fetched.

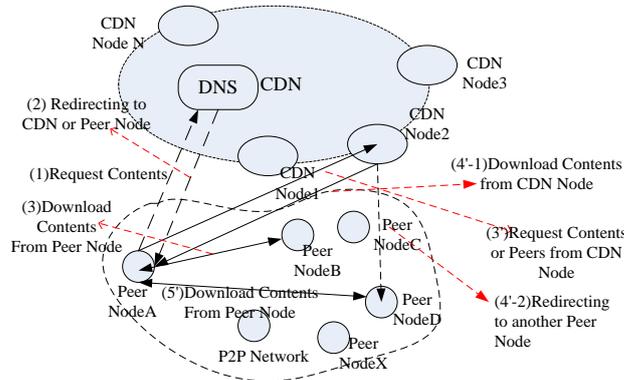


Figure1. Akamai hybrid delivery scheme

(3') If this operation fails, if the peer cannot contact the identified peer, or if the identified peer does not have the content, the second domain is tried, this time returning an edge server in the CDN. This will be an edge server that is nearby, that is likely to have the content and that is not overloaded. But if the client's request has been redirected to an edge server, the edge server can then choose how to handle this request, i.e., (4'-1) by delivering the content objects itself, or (4'-2) by redirecting the request to a peer network resource. (5') Downloading the contents from a peer node, the next step of (4'-2).

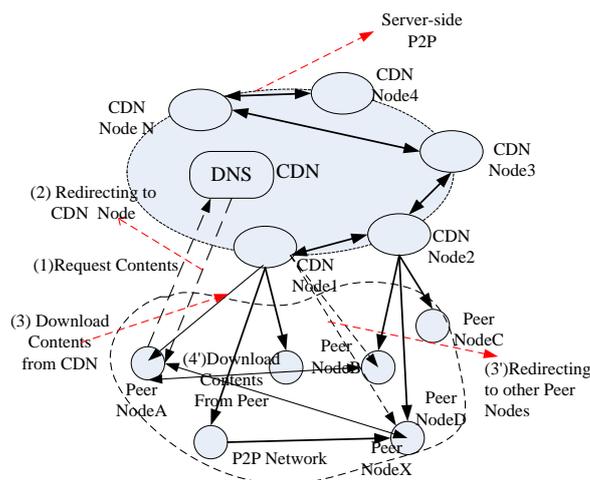


Figure2. LiveSky hybrid delivery scheme

Livesky[17] also used the PAC hybrid delivery scheme's overlay route mechanism. It first relies on the CDN DNS redirection mechanism to reach an edge server, and the edge server can act as the tracker of P2P

overlay to help the requested peer find neighbors. They described the main mechanisms in Figure2.

(1) A client first obtains the URL for the live stream from the content source (e.g., livesky://domainname/live1).

(2) The GSLB component of the CDN takes into account the client location, the edge SN (Service Node-CDN Node in Figure2) location, and the edge SN loads to find a suitable edge SN for this client. The client is then redirected to these edge SNs using traditional DNS-based redirection techniques.

(3)The edge SN serves a new LiveSky-enabled client in CDN-mode.

(3') The edge SN serves as a tracker for the P2P operation to bootstrap new clients with candidate peers.

(4') And then the peer node will request and download content from other peer nodes.

In [21], Hung-Chang Yang et al. proposed a two step selection PAC approach on landmark-based selection algorithm to find the nearest replica-cache server (CDN Node) and peer-caches to download content in this architecture. Figure3 describes the main mechanisms.

(1) The first step also depends on domain name server (DNS) to find the nearest replica-cache server. When the end user wants to get the content distribution service site via querying the local domain name server, the content provider server issues the measure messages to the CDN-DNS which act as landmarks. The local domain name server starts up the querying process to the CDN-DNS, and the CDN-DNS will measure the round-trip time between the CDN-DNS and the local domain name server. Note Figure3 merges the interaction between local DNS and CDN-DNS.

(2) When the local DNS server receives responses from all CDN-DNS, it replies to the end user which is the nearest replica-cache server of the local domain name server of that end user. If there are many replica-cache servers belonging to the same region, they can further use the Euclidean-Distance equation to compute which is the nearest replica-cache server.

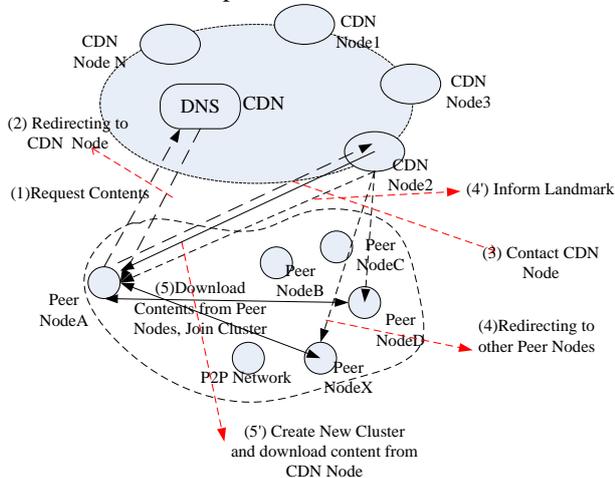


Figure3. Landmark-based two step selection approach

(3) At the second step, when the end users contact the nearest replica-cache server, the replica-cache server issues the measure messages to other peer-caches which act as landmarks. The landmark will measure the round-trip time between the landmark and the end user.

(4) When the replica-cache server receives responses from all landmarks, it replies to the end user which is the nearest peer-cache. (5) The end user will send join message to the nearest peer-cache and the nearest peer-cache will add the end user to the cluster member list. The end user downloads contents from the peer-cache.

(4') Otherwise, if the end user is out scope of the nearest peer-cache, the end user will create a cluster for itself and inform the nearest replica-cache server.

(5')Further, the end user will act as a cluster leader to inspire new peers, and download contents from the replica-cache.

Our previous work [12] proposed a PAC based PeerCDN architecture. Just as Figure4 described, PeerCDN is a two-layer streaming architecture. The upper layer is a CDN framework layer which is composed of original CDN servers, including origin servers and replica servers. The lower layer is called Peer node layer, which consists of multiple groups of clients who request the streaming services, each client is considered a peer node in the group. The connecting point between the CDN framework layer and the Peer node layer is located in the nearest replica server, we call it the Strong Node. It is the Strong Node's duty to coordinate the content direction for each request. In order to prevent the fail-over of that server, other nearby strong nodes can also be candidate leaders, if the nearest strong node fails, one of the candidate leaders will be selected to become the new leader of that group.

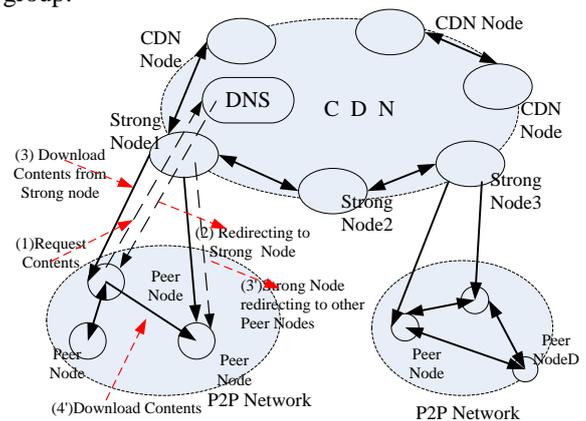


Figure4. PeerCDN hybrid overlay architecture

Figure 4 illustrates content request flow; strong node 2 is the candidate of strong node 1 and strong node 3.

(1) One peer node requests content from DNS (here merging the interaction between local DNS and CDN-DNS).

(2) DNS Redirects to Strong Node.

- (3) Download content from Strong node.
- (3')Optionally, Strong Node redirects to other Peer Nodes.
- (4')Download Contents from selected Peer Nodes.

(2) CAP Method

Currently, in order to improve service quality, many P2P application providers (e.g. PPLive[3], UUSee[36], Zattoo[37], CoolStreaming[38]), either use their own servers or use third-party CDN to reinforce their P2P system. We summarize this method as CDN-aided P2P system (CAP). In this method, CDN is served as a backup system for rescuing. When a peer joins the overlay network, it will be redirected to the common P2P network first by a P2P tracker. If the peer cannot obtain enough content from the P2P network, it will ask the tracker for help and be redirected to a CDN to fetch required data.

(3) Other Methods

In [19], the architecture of HCDN can be further abstracted to a two-level hierarchical hybrid model. The process of content delivery includes two stages: the CDN-level and the P2P-level. In a backbone network, the CDN system is deployed and the content is strategically disseminated on surrogate servers. In an access network, the centralized P2P system is introduced, and the user nodes can exchange content between each other. So, user nodes can concurrently get content from both surrogate servers and other user nodes. In a CDN-level backbone network, the surrogate server is a logical entity and may consist of multiple physical servers or clusters. The P2P-level access network is an overlay network. The peers may be geographically separate and the access networks may be overlapped.

Figure 5 illustrates the architecture of HCDN. They didn't point out the order of CDN and P2P request routing. They pointed out that the request routing in traditional CDN, such as the iterative or recursive scheme, can be also adopted in HCDN. In P2P system implementations, the range of indexing service can be decided by request routing (e.g. an intelligent DNS scheme) or selected manually by user nodes.

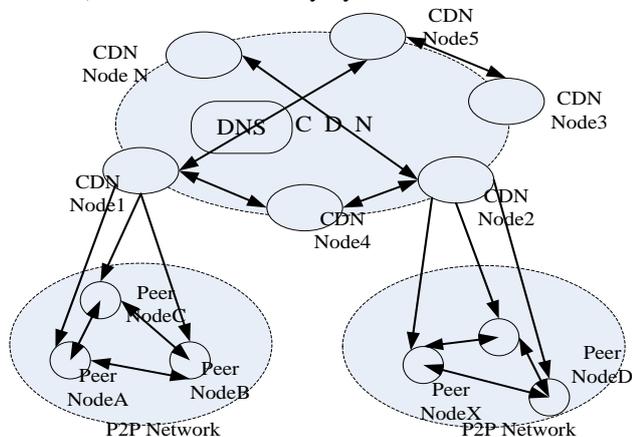


Figure5. The architecture of HCDN

In [18], they do not describe the overlay route hybrid mechanisms in detail, but they assume that the peers only share with others in the same CDN service region. In this way, the peers assist the CDN, but do not create any additional cross region traffic compared with a pure-CDN solution. Therefore, their architecture is similar to the architecture of HCDN.

When we study the hybrid relationship between CDN and P2P technologies, we need to consider the mainstream delivery mechanisms of current P2P streaming systems. Existing approaches for live P2P streaming can be generally divided into two classes: tree-based approaches and mesh-based approaches [24]. Tree-based approaches use push-based content delivery over multiple tree-shaped overlays, and mesh-based approaches use pull-based content fetching method from a randomly connected mesh. A tree is probably the most natural structure for a multicast overlay, but is vulnerable in the presence of dynamic end-hosts [23]. Data-driven approaches form a mesh out of overlay nodes to exchange data, which greatly enhances their resilience. It however suffers from an efficiency-latency tradeoff, given that the data have to be pulled from mesh neighbors with periodical notifications. In general, CDN is more suitable to support the tree and push based content delivery method.

Both methods have advantages and disadvantages, and neither can completely solve the P2P delivery task. This motivates recent research for a tree-mesh hybrid delivery method. Feng Wang et al. [23] suggested a novel hybrid tree/mesh design - mTreebone that leverages both overlays.

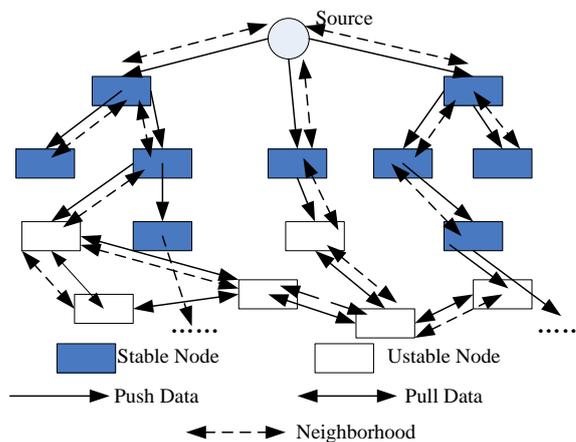


Figure6. mTreebone framework [23]

Just as shown in Figure6, the key idea of mTreebone is to identify a set of stable nodes to construct a tree-based backbone, called treebone, with most of the data being pushed over this backbone. The source of the treebone can be a CDN node. These stable nodes, together with other non-stable nodes, are further organized through an auxiliary mesh overlay, which facilitates the treebone to accommodate node dynamics and fully exploit the available bandwidth between overlay nodes. To realize such a hybrid overlay for live streaming, the author described that the

following unique and important issues have to be addressed [23]. First, they have to identify the stable nodes in the overlay; second, they have to position the stable nodes to form the treebone, which should also evolve to optimize its data delivery; third, they have to reconcile the treebone and the mesh overlays, so as to fully explore their potentials.

In some cases, CDN and P2P integration need to reconcile tree-based and mesh-based overlays. The most typical example is that LiveSky adopts a similar hybrid approach combining the multintree and mesh schemes to achieve both efficient delivery and robustness to churn [17]. Peers are organized in a tree-based overlay on a per-substream basis. This ensures that all nodes contribute some upload bandwidth. Additionally, in order to be robust to network or node failures, peers also use a mesh-style pull mechanism to retrieve missing frames for continuous playback [17].

B. Playing Buffer Hybrid Issues

(1) Introduction of Buffer Mechanism

The buffer at each peer represents a sliding window of the media channel, containing blocks to be played in the immediate future.

In the tree-based approach, an overlay construction mechanism organizes participating peers into a single tree or multiple trees. Each peer determines a proper number of trees to join based on its access link bandwidth [24]. The content delivery is a simple push mechanism from the tree's upper layer to the tree's lower layer node's playing buffer.

In the mesh-based approach, participating peers form a randomly connected overlay, or a mesh. Each peer tries to maintain a certain number of parents (i.e., incoming degree) and also serves a specific number of child peers (i.e., outgoing degree) [24]. Upon arrival, a peer contacts a bootstrapping node to receive a set of peers that can potentially serve as parents, and then the peer will pull contents from some selected parents into its playing buffer.

(2) Buffer Design Mechanism Comparison between Live Streaming and Vod Streaming

Another important issue to consider is, applying CDN-P2P hybrid techniques into live streaming and VoD streaming is different due to the following fundamental differences between the two types of streaming [6]. First, end-to-end delay is more important for live streaming than VoD streaming. In live streaming, the shorter the end-to-end delay is, the more lively the stream is perceived by the users (defined as liveness in). In VoD streaming, liveness is simply irrelevant because the video stream is already pre-recorded. Second, a user joining an on-going live streaming session is only interested in the stream starting from his/her joining time, while in the VoD streaming case the whole video must be delivered to the new user, and VOD streaming allows users to execute VCR-like commands such as "dragging the progress bar back and forth", "forward", "rewind". If a user

drags the progress bar to a new position, he is interested in the stream starting from this new position. Therefore, in live streaming, we can determine the period from the user joining time by adding 20 or 30 seconds as an emergency zone, and the emergency zone data can depend on the CDN. However, in VoD streaming, when one user drags the progress bar to a new position, we should consider how to adjust the beginning position of emergency zone to this new position as soon as possible, this will increase the risk of re-buffering delay.

(3) Buffer Design Comparison

In the CDN-P2P hybrid scenario, the client's playing buffer may be filled via the push-pull hybrid mode. The following compares such kinds of hybrid modes.

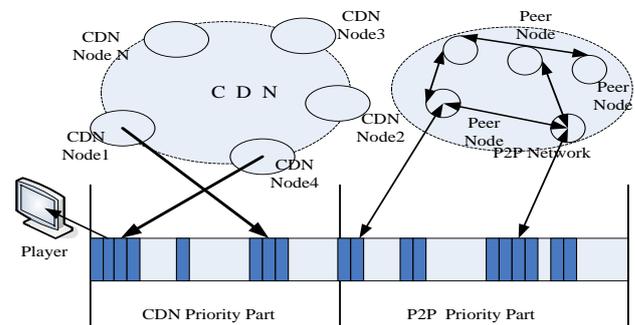


Figure 7. Application layer hybrid buffer design

In [20], different from other hybrid CDN-P2P systems, their mechanism works not on hybrid overlay layer but on application level so it is easier to deploy and does not need any modification at the ISP's side. Just as Figure 7 illustrates, they proposed a new hybrid CDN P2P mechanism which acts on the effective management of the playing buffer at the client-side. This solution is motivated by: data slots in the buffer which are near the play side must be ready before the scheduled playing times and data slots in the rest of the buffer can be filled later. Therefore, the part which is near the play side has higher priority for filling data and the others have less priority. From that, they simply treat the playing buffer as two parts: the CDN server's priority part and the priority part for peers in the P2P network. The CDN server priority part is the part of the buffer whose data slot must be received as soon as possible to assure the media playback begins in time. On the other hand, the P2P network priority is a part of the buffer whose data slot can be received later. The client will pull contents from the CDN node into its CDN priority part buffer, and then it will pull contents from peer nodes into its P2P priority part buffer. By contrast, mTreebone adopted a different hybrid buffer management method.

In mTreebone, the data blocks are delivered by two means. In general, they are pushed over the treebone. And if a gap appears in the stream received by a node, due to either temporal capacity fluctuation in the treebone or node dynamics as discussed later, the node

may pull the missed blocks through the mesh overlay. They introduce a seamless push/pull buffer that coordinates the treebone and the mesh to make data delivery efficient yet resilient against failure [23].

Figure8 illustrates push/pull switching, where a tree-push pointer is used to indicate the latest data block delivered by the push method, and a mesh-pull window facilitates the pull delivery [23]. When a node is temporarily disconnected from the treebone, its tree-push pointer will be disabled and only the mesh-pull window works to fetch data from its mesh neighbors. When it connects to the treebone again, the tree-push pointer will be re-activated. The mesh-pull window is always kept behind the tree-push pointer so as not to request data currently being delivered by the treebone. Therefore, no duplicated data blocks are received from both the treebone and the mesh. By comparing these two methods above, we find mTreebone is more flexible than the above Application Layer Hybrid method, which adopts a more static method to divide the buffer. But mTreebone’s buffer is more dependent on the tree, while Application Layer Hybrid method only depends on the CDN node in the playing start-up phase, which can reduce pressure on the CDN.

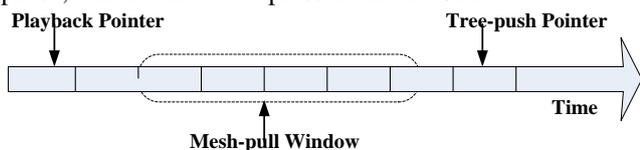


Figure8. mTreebone push/pull switch buffer design [23]

(4) Buffer Data Block Size Comparison between CDN and P2P

In the CDN-P2P hybrid scenario, an important issue to consider is the size of data blocks. In general, the data block size of CDN and P2P delivery is different. For example, UUSee Inc. is one of the leading P2P multimedia solution providers in mainland China, it simultaneously broadcasts over 800 live streaming channels to millions of peers, mostly encoded to high quality streams around 500 Kbps. The peer buffer size in UUSee is 500 media blocks, and each block represents 1/3 second of media playback [5][36]. So we can calculate that the size of each block is approximately 20.8KB. But in each transmission, CDN is capable of providing larger size blocks, such as 1MB- 16 seconds data for each request. If so, we need to consider CDN and P2P distributing different sizes of blocks to fill the buffer. Now most of the hybrid schemes do not yet consider this issue.

V. CDN-P2P-HYBRID MODEL ANALYSIS AND DESIGN

A. Tightly-coupled Hybrid Model vs Loosely-coupled Hybrid Model

In the current multimedia technology field, it is a key problem to establish a new-generation content

delivery solution, which supports large-scale accessing, and can be cost-effectively extended, effectively monitored, QoS guaranteed, network-friendly, regional controllable, and safe and reliable. CDN and P2P are two mainstream content delivery technologies in the current Internet, but constrained by the computing model, both of them have their own advantages, while there are some fundamental shortcomings. The two models have great complementation, so their integration is an important trend. We need to research CDN and P2P hybrid delivery model for realizing controllable, manageable, credible, network-friendly content distribution technology, exploring difficult problems of CDN-P2P hybrid distribution technology. We find there are two kinds of CDN-P2P hybrid models: the tightly-coupled hybrid model vs. the loosely-coupled hybrid model.

B. Tightly-coupled Hybrid 1+1 Model

We think the tightly-coupled hybrid model is 1+1 model. It means one CDN system can only integrate with one P2P system. Just as Figure 9 shows, CDN and P2P have an overlap area, where CDN nodes and P2P nodes closely collaborate to execute content delivery function, including the CDN nodes acting as a tracker to involve in the construction process of the P2P overlay network; CDN nodes manage and guide P2P nodes to realize ISP-friendly P2P delivery, CDN nodes and P2P nodes collaborate on content delivery [34].

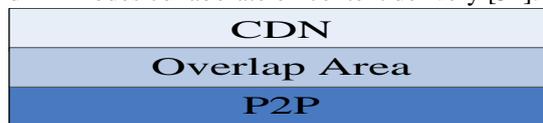


Figure 9. Tightly-coupled hybrid 1+1 model [34]

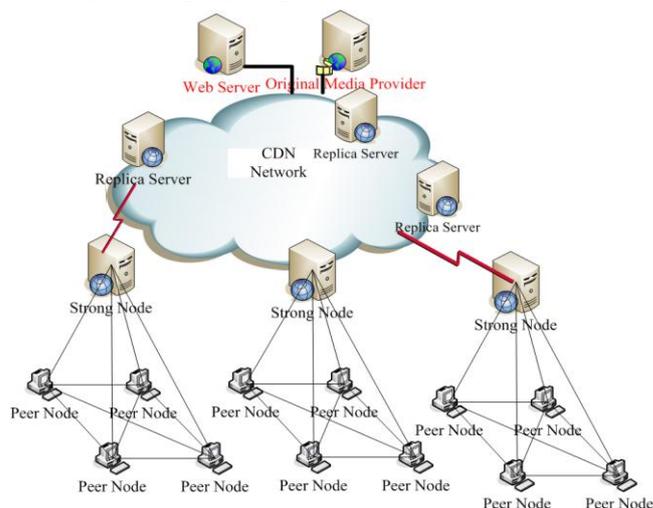


Figure 10. PeerCDN CDN-P2P hybrid architecture [12]

As Figure 10 shown, our PeerCDN [12] is one kind of typical 1+1 tightly-coupled hybrid model. PeerCDN realizes the management of regional autonomy when constructing the overlay network. The overlay network is constructed geographically to become a topology-aware overlay network through redirecting of strong

nodes. In our PeerCDN architecture, each group of client peers is led by the nearest Strong Node.

In this model, the P2P system is attached to the CDN system. In other words, CDN nodes lead to build P2P systems. This model is efficient for one CDN integrating with one P2P, but it is not suitable for one CDN integrating with multiple P2P. For example, PPLive and PPStream are two of the largest P2P streaming media operators, if PPLive and PPStream want to integrate with a CDN through such method, PPLive and PPStream have to break their current overlay construction and data transmission mechanisms to adapt to the CDN, which will increase the integration difficulty.

C. Loosely-coupled Hybrid 1+N Model

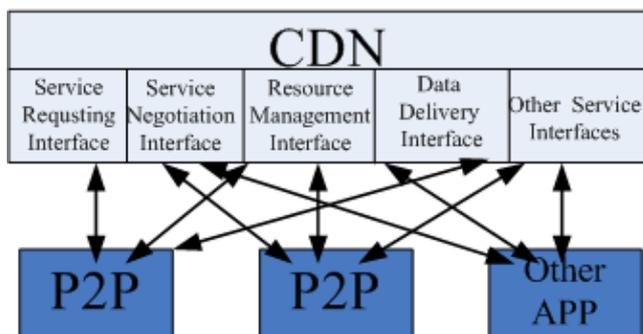


Figure 11. Loosely-coupled hybrid 1+N model

The popularity of Cloud Computing technology calls for Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Therefore, cloud computing era requires content services available on-demand and be utilized in an open and loosely-coupled fashion. If a CDN operator wants to integrate with a number of heterogeneous P2P operators, it needs to expose a series of public service interfaces to serve multiple P2P operators [34], including the service requesting, service negotiation interface, data delivery service interface, resource management interface and other interfaces. This kind of integration is a loosely-coupled 1+N hybrid model. Loosely-coupled hybrid model means that one CDN can provide services for multiple P2P systems with public service interfaces, rather than being tightly integrated with only one P2P system, just as Figure 11 shows. CDN is not directly involved in the construction of P2P overlay network, and CDN does not directly lead P2P systems, but when one P2P system request service from CDN, it can send request to CDN interface, and negotiate SLA with CDN. And finally P2P can use some CDN nodes' data delivery service when an emergency or flash crowd happens.

For example, China Telecom, as China's largest network operators, is building a large-scale CDN system, they want to make their CDN able to provide services for more P2P or other streaming operators (PPLive, PPStream, UUSee et al.) in parallel, such as content accelerating services. Therefore, they need such a loosely-coupled 1+N hybrid model. At the same

time, 1+N hybrid model can be easily extended into N+N hybrid model.

Web Services interfaces are neutral for platform and technology, so application business objects can integrate easily through Web Services. Web Services technology has been verified to well support enterprise application integration (EAI) and B2B integration (B2Bi) solution. In order to improve our PeerCDN architecture, we proposed WS-CDSP [25]: a novel Web Services-based Content Delivery Service Peering Scheme, which can support loosely-coupled multimedia content peering delivery service architecture. WS-CDSP belongs to such loosely-coupled 1+N hybrid models. The main function is to enable explicit cooperation and integration among P2P, CDN and VoD. The main components in the novel architecture are described in the Figure 12. Note that the curve circle of every P2P system in the figure represents different organization's P2P, not different autonomous regions of the same P2P system, which is different with PeerCDN.

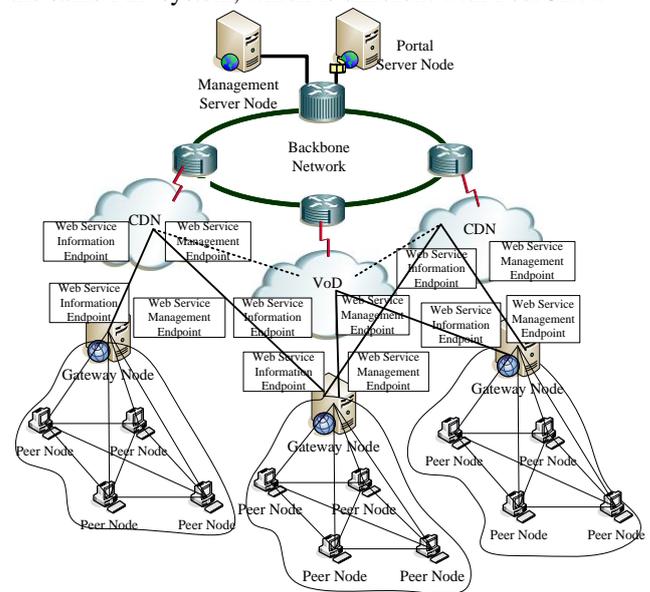


Figure 12. WS-CDSP: web services-based content delivery service peering architecture [25]

In order to support explicit cooperation between P2P, CDN and VoD, every P2P, CDN and VoD system should provide two endpoints: one is the Web Service Information Endpoint; the other is the Web Service Management Endpoint [25]. The Web Service Information Endpoint can act as black box interface to expose the system information of CDN, VoD, or P2P. CDN and VoD system can provide cache or VoD server node information, topology structure information, and media content item information through Web Service Information Endpoint and all these information can be described with XML and exposed by WSDL [25]. The Web Service Management Endpoint provides a manageable interface, and the platform manager can request the running load status of CDN, VoD, or P2P, or subscribe to the events [25]. CDN and P2P

technologies can be loosely integrated through these interfaces.

In order to construct open service relationship, we have proposed SNEGO: CDN-P2P loosely-coupled SLA negotiation model in [34]. As Figure13 described, CDN firstly provides an open and standard-based agreement interface for the P2P and other applications to negotiate with it. We use WS-Agreement for establishing service agreement between two CDN and P2P. This scheme also allows CDN easily integrated with other application.

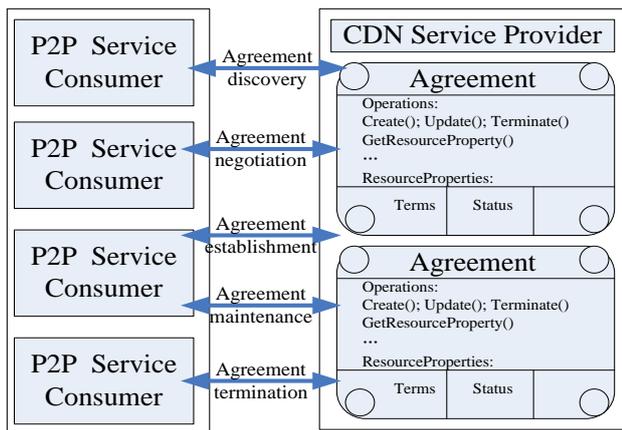


Figure 13. CDN-P2P loosely-coupled SLA negotiation model [34]

D. Comparison of Current CDN-P2P-hybrid Schemes

Furthermore, we compare the abovementioned current CDN-P2P-hybrid schemes in term of tightly coupled model and loosely coupled model in Table II.

TABLE II. COMPARISON OF CURRENT CDN-P2P-HYBRID SCHEMES

Current CDN-P2P-hybrid Scheme	Hybrid Mode	Whether CDN nodes are involved in P2P content delivery	Whether CDN nodes are involved in P2P Overlay Construction
Dongyan Xu's Scheme	Tightly Coupled	Yes	No
PeerCDN	Tightly Coupled	Yes	Yes
Ono	Loosely Coupled	No	Yes, but passively
PSP	Tightly Coupled	Yes	No
PACDN	Tightly Coupled	Yes	Yes
LiveSky	Tightly Coupled	Yes	Yes
Akamai CDN-P2P	Tightly Coupled	Yes	Yes
HCDN	Tightly Coupled	Yes	No
WS-CDSP	Loosely Coupled	Yes	No
SNEGO	Loosely Coupled	Yes	No

E. Common CDN-P2P-Hybrid Delivery Models

In both the tightly-coupled and loosely-coupled models, we think that there are some common models that need to be further studied in the future work:

(1)The hybrid-scheduling model between CDN global scheduling and P2P distributed scheduling: CDN utilizes GSLB to realize global scheduling, and P2P streaming utilizes Tracker and local decision to realize distributed scheduling. CDN and P2P both have content service capabilities, but their capabilities have different characteristics, therefore what we need to solve is how to integrate the CDN GSLB scheduling mechanism with the P2P distributed scheduling mechanism to achieve mixed scheduling and united service. And this kind of mixed service can achieve scalability through P2P services, while at the same time, ensuring service reliability through CDN. In the CDN-P2P hybrid architecture, we need to study the controllable scheduling model, specifically study how to integrate the CDN's strengths of global scheduling and centralized management with P2P's characteristics of distributed scheduling and flexible extension.

(2) Total hybrid-delivery services capacity dynamic allocation model: CDN node service capacity is different in the traditional CDN scenario and the CDN-P2P hybrid scenario. In traditional CDN scenario, CDN node service capacity is fixed, for example, if one CDN node is bound to concurrently serving 500 users with 300kbps for every user, the maximum capacity is 500 as client nodes consecutively request the CDN Node more than tens of minutes. But in the CDN-P2P hybrid scenario, peer nodes only occasionally utilize the CDN Node for tens of seconds, so the CDN node can serve more than 500 users. So we can dynamically extend the CDN node service capacity through using some wise scheduling algorithms. At the same time, the P2P streaming system service capacity can be extended easily, but it lacks the stability of service, and it can not assure the quality of service. Therefore, in the CDN-P2P hybrid scenario, we can optimize the allocation mechanism to do a seamless hand over process to balance the load of two content service systems (CDN node and P2P node). By dynamically and flexibly allocating the amount of CDN and P2P services, we can achieve "1 +1 > 2" results, which means the intelligent CDN-P2P hybrid service capacity is larger than the simple sum of CDN and P2P's respective capacities.

(3) P2P-ISP friendly delivery model under the guidance of CDN: CDN has realized the network-friendly feature by optimizing cache node deployment and redirecting users in accordance with the nearby principle. For the ISP and the backbone network operators, a significant drawback of P2P is cross-ISP traffic and unlimited, greedy consumption of network bandwidth. This produces a significant impact on the ISP network. How to design a Network-friendly P2P distribution model with the participation of CDN node is a key problem, which the CDN-P2P hybrid model

needs to solve. CDN and P2P can cooperate to make peer node locality-aware to fast find nearby stored copies of the requested content.

(4) Controllable management model: the decentralized feature of a P2P network makes it lack management capacity, for the management of end-users, churn management, and content availability management. The CDN system typically has complete management capabilities, including cache node management, content management, AAA (Authentication, Authorization, and Accounting), business and network management, etc. How to make the entire CDN-P2P hybrid system manageable through integration is a key problem. Specifically, controllable management model should focus on making CDN help manage peer node's churn behavior (i.e., failure, leave, join) and increase total robustness in the highly dynamic P2P environment.

(5) Secure and trustable delivery model: some issues such as identity authentication and content protection are also key problem that need to be considered. How to integrate CDN centralized authentication and P2P decentralized authentication, how to combine CDN secure and controllable content distribution and P2P flexible and free content distribution and overcome their shortcomings. This needs to study a secure and reliable CDN-P2P hybrid distribution model.

VI. CONCLUSION AND FUTURE WORK

CDN and P2P are two mainstream content delivery technologies in the current Internet, but constrained by the computing and service model, both of them have advantages and fundamental disadvantages. The two technologies have much complementary features; therefore their integration is very necessary and helpful to build a new-generation efficient, QoS-guaranteed, and large-scale content service system. However, their integration is not simple. A common streaming content distribution platform is not a simple combination of CDN and P2P, rather the integration of CDN and P2P needs to solve many problems. At present, research and development work has been started; in particular, we need to study CDN and P2P integration mechanisms from the key issues, basic models, and key algorithms.

CDN and P2P integration research is still in developing stage. In this paper, we reviewed the related research work of this field in recent years, and then we analyze the key issues that need to be solved, such as overlay route hybrid issues, playing buffer hybrid issues, and so on. In order to realize the mixed mode of P2P extending CDN and CDN guaranteeing P2P, we point out there are some reliable, secure and friendly hybrid delivery models that need to be researched in depth.

In our future work, we will focus on designing these key hybrid models and related algorithms, and developing some prototype systems to experimentally verify the advanced features of these models and

algorithms. Finally, we plan to carry out larger scale experiments with our prototype and make a real deployment in our ongoing CNGI (China Next Generation Internet) project- National Higher Education Conference Video Resources Sharing Project.

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