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HCDN Network Model based on CDN Technologies

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Abstract: To use the complementary strengths of CDN and P2P networks for the large-scale digital content distribution, this thesis proposes a hybrid content distribution network model, which deploys the CDN system in the backbone networks and builds the P2P regionalization network in the access network, so the end users can simultaneously access data through the CDN and P2P networks. Experimental results show that compared with the traditional CDN network the proposed model can reduce the edge server load and save the cost of deployment; compared with the P2P network, it can enhance the QOS guarantee and reduce the backbone traffic; compared with HP2P, it has greater download rate, which can reduce the network transmission overhead.

Keywords: Network model; Deployment costs; Traffic load; Rout mechanism

1. Introduction

Nowadays, CDN network is mainly used in Web and streaming media content distribution, and the related research works mainly focus on the replica placement policy, content routing algorithms, load balancing and redirect requests etc. Gadde S et al study integration issues of the CDN network and the Web in-depth, in which the results have been widely used. Accessing to the copy of the Web on edge servers by users can improve the efficiency [1]. Tim Wauters et al make improvement on the replica placement strategies, propose the dynamic mechanism of distribution and propose the load balancing algorithm [2-4]. Shaikh A et al describe the request redirection mechanism based on intelligent DNS, and the users orient the user requests to the "nearest" edge servers [5-7]. Fei Zong-Ming et al propose the large file distribution technology based on fragmentation; its characteristic is that the by memory on the copy storied on the edge server is not a complete file, but the file fragmentation according to strategy division. Cahill Adrian J et al describe a Video-CDN system, which uses the high quality of TV content with CDN distribution technology. Day M and Cain B et al make research on the Content Distribution Internet (CDI), which offers interoperability to a plurality of independent CDN networks [8].

On the other hand, in recent years, P2P file has been widely used in sharing networks field, and people conduct a lot of research work on P2P technology at the same time. According to structure P2P network can be divided into centralized, decentralized and hybrid type. In the center structure, there is an index server to provide resources location information for all peer nodes. The typical applications is shown as BitTorrent proposed by Johan Pouwelse, where its structure is simple and positioning queries is fast, but its scalability is limited to the index server capacity [9-10]. In the completely decentralized structure, there is no server and the resource location is realized through the collaboration of the peer. The typical method is as Chord proposed by Ion Stoic. In the hybrid structure, some of the peer node is selected as a "super-node", which provides positioning in

By deploying multiple distributed CDN replica servers at the network edge CDN optimize the distribution of content on the Internet end users. Since the emergence of CDN in the late 1990s, CDN has experienced ten years of development. The value orientation of traditional CDN service changed over time: Initially, CDN focus on improving the response time to reduce the perception experience of the end user; and now, for content providers CDN can share the infrastructure of their content distribution services, and by improving the effectiveness of the system, the content providers' needs of service capacity in the network traffic peak can be met, thereby the content providers' cost input on Web infrastructure can be reduced. Besides, some recent trends indicate that CDN pattern is begin to be transferred as a utility computing model, but the construction cost of CDN is high and the scalability is poor [11].

2. Network Integration of Traditional P2P and CDN Technology

2.1. CDN is as the center and the P2P autonomous region is as the edge

The management mechanism and service capacity of CDN are introduction to the P2P networks and formed the structure with CDN as the center and the P2P autonomous region as the edge that is the PCDN technology shown in Figure 1. The structure is currently used in R & D projects related to IPTV. Since the introduction of P2P technology, compared to the IPTV system of C / S mode, it greatly saves the bandwidth overhead. This kind of structure improves the controllability of the content and enhances the stability of P2P, but it uses only the merits of both technologies, but not effectively achieves the complementary of the advantages and disadvantages of the two technologies.

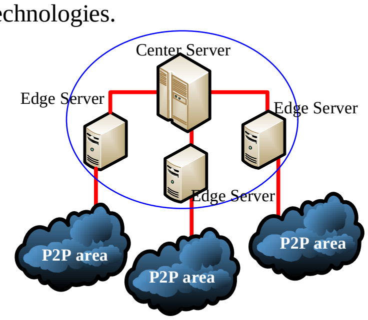

Figure 1. Structure with CDN as the center and the P2P autonomous region as the edge

2.2. Establishing P2P network between the edge servers

The storage device of CDN is organized as the way of P2P; the directory services and multi-point transmission capacity P2P are used to achieve content exchange between CDN storage devices to enhance the ability of content distribution of CDN (shown in Figure 2). This kind of structure reduces the pressure on the central server caused by content distribution. Wherein, P2P nodes are servers, that is, Server to Server. Distance between the edge servers is far and the network environment is quite different, so transmission between servers must have some bottlenecks.

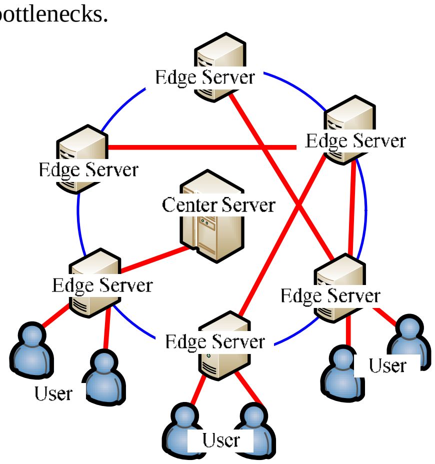

Figure 2. Structure of establishing P2P network between the edge servers

The existing structures have the entirely different performance in terms of scalability, content, copyright, effectiveness of user management, QoS, traffic ordering, client deployment and so on, while the performances of complementary are the specific characteristics of P2P system and CDN system. That is to say, the structure 1 is an improved P2P system, and structure 2 is an improved CDN systems. Although both of the two systems are combined the advantages of P2P and CDN, it do not fully integrated with the CDN technology and P2P technology.

3. HCDN Network Model

3.1. Hybrid content distribution network model

The structure of traditional CDN network is shown in Figure 4(a). The contents are strategically distributed from the source server to the Edge servers; the user node can obtain data from the edge server. Compared with the traditional C / S structure CDN networks can reduce data latency, increase the transmission rate and reduce the source server load. A Hybrid Content Distribution Network (HCDN) is proposed. The network architecture structure of HCDN is shown in Figure 3.

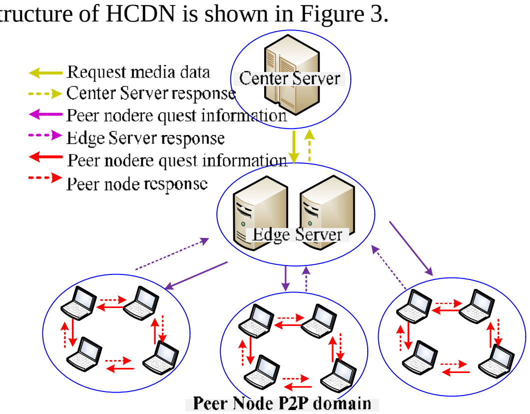

Figure 3. Network architecture structure of HCDN

The centralized P2P network structure can be expressed as the index model shown in Figure 4 (b); the user nodes can obtain the other peer information of the same file by exchanging the index servers and the file data can be exchanged between the user nodes. Since the server only maintains the index information but do not involved in the transmission of the file data, the load is reduced and it has good scalability.

It is worth mentioning that, HCDN is the overlay network formed by the server and the user nodes. The edge server is a logical entity, which is constituted by the cluster or multiple physical servers. P2P network in HCDN uses the central structure, so: 1) the query speed of centralized index is fast, which can reduce the response time of the user request; 2) it is simple to achieve and control; 3) the index server can be integrated with the edge server, and also it can be deployed.

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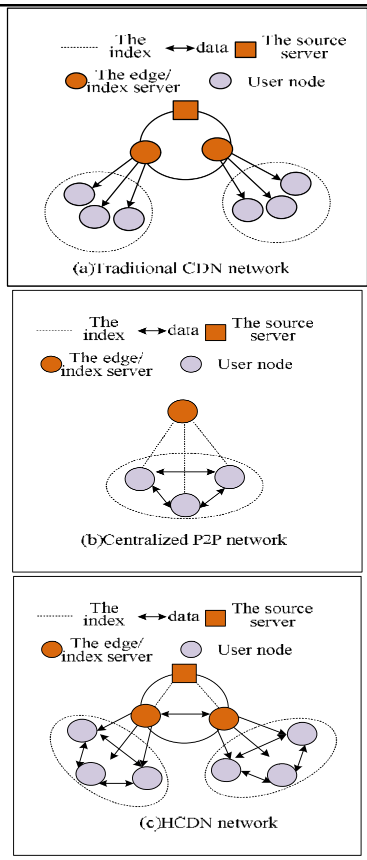

Figure 4. Network models of CDN, centralized P2P and HCDN

3.2. Model description

Assuming that each user node has the same upload bandwidth and download bandwidth u_1, the request arrival rate is parameter obeyed the Poisson distribution of parameter λ; download nodes can be interrupted before becoming the seed nodes, and the interrupt rate is obeyed the with the with exponential distribution with the mean as $1/\partial$; seed node can leave the system after a period of time, and the leaving rate is obeyed the exponential distribution with the mean as $1/\beta$. Factor $\eta\left(0\le\eta\le1\right)$ is used to represent the upload efficiency of the download nodes, namely utilization of uploading bandwidth; when $\mu=0$, it means that the download node does not upload data; when $\mu=1$, it means that the upload rate of the download nodes is the maximum bandwidth. In order to avoid losing the generality, file size is set as $f_i=0$.

In HCDN network, if the download bandwidth is the bottleneck, the overall upload speed of the system is u_1; if the it is not limited to the download bandwidth, the overall upload speed of the system is $u_1\left(x(t)+\eta y(t)\right)+u_1$, in which $u_1\left(x(t)+\eta y(t)\right)$ comes from the P2P network; μ_i comes from the edge server of CDN network.

Therefore, flow model of HCDN network is shown in Figure 5. The number of changes of seed nodes and download nodes in the system can be expressed as follows:

$$\begin{cases}\dfrac{cx(t)}{ct}=\min\left\{cy(t),\mu_p(x(t)+\eta_y(t))+\mu_s\right\}-\beta_x(t)\\ \dfrac{cy(t)}{ct}=\lambda-\min\left\{uy(t),\mu_1(x(t)+\eta_y(t))+\mu_s\right\}-\alpha_y(t)\end{cases}\tag{1}$$

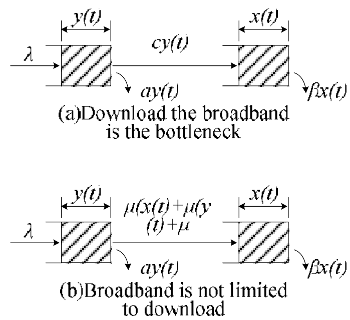

Figure 5. Flow model of HCDN network

3.3. Seed nodes and the number of download nodes with the steady state

The steady state is considered, so

$$\frac{cx(t)}{ct}=\frac{cy(t)}{ct}=0\tag{2}$$

According to formula (1), it can be obtained

$$\begin{cases}0=\min\left\{c\bar{y},\mu_p(\bar{x}+\eta\bar{y})+\mu_s\right\}-\beta\bar{x}\\ 0=\lambda-\min\left\{c\bar{y},\mu_p(\bar{x}+\eta\bar{y})+\mu_s\right\}-\alpha\bar{y}\end{cases}\tag{3}$$

Wherein, $\bar{x}$ and $\bar{y}$ are the equilibrium values of $x(t)$ and $y(t)$. Solving the equations (4) to get:

$$\begin{cases}\bar{x}=\dfrac{c\lambda}{\beta(c+\alpha)}\\ \bar{y}=\dfrac{\lambda}{c+\alpha}\end{cases}\tag{4}$$

Wherein, $d\bar{x}\ \mathbf{p}\ u_t\left(\bar{x}+\eta\bar{y}\right)$ means that in HCDN download bandwidth is the bottleneck;

$$\begin{cases}\bar{x}=\dfrac{\eta\lambda\mu_p+\alpha\mu_s}{\eta\beta\mu_p-\alpha\mu_p+\alpha\beta}\\ \bar{y}=\dfrac{\beta\lambda-\lambda\mu_p-\beta\mu_s}{\eta\beta\mu_p+\alpha\beta-\alpha\mu_p}\end{cases}\tag{5}$$

Similarly, to the traditional pure P2P network, let $u_i = 1$, using the flow model it can be derived the expression of seed nodes and download nodes under the steady state:

$$\begin{cases} \bar{x} = \dfrac{d\lambda}{\beta(b+\alpha)} \\ \bar{y} = \dfrac{\lambda}{b+\alpha} \end{cases} \tag{6}$$

$$\begin{cases} \bar{x} = \dfrac{\eta\lambda\mu_p}{\eta\beta\mu_p - \alpha\mu_p + \alpha\beta} \\ \bar{y} = \dfrac{\beta\lambda - \lambda\mu_p}{\eta\beta\mu_p + \alpha\beta - \alpha\mu_p} \end{cases} \tag{7}$$

3.4. Average download time

Using the Little rule, the average download time of the user nodes in a steady state is obtained as:

$$D = \frac{\dfrac{\lambda - \alpha\bar{y}}{\lambda}\bar{y}}{\lambda - \alpha\bar{y}} = \frac{1}{\lambda} \bullet \bar{y} \tag{8}$$

Wherein, D is the average download time; $\lambda - \alpha\bar{y}$ is average ratio of download nodes after downloading; $\lambda - \alpha\bar{y}$ is the average number of download nodes turning into seed nodes.

Thus, for HCDN network, according to formula (7), (8) and (9) it can be obtained as follows:

$$D_{HCDN} = \begin{cases} \dfrac{1}{b+\alpha'} & \mathrm{b}\bar{y} < \mu_p(\bar{x} + \eta\bar{y}) + \mu_i \\ \dfrac{1}{\lambda} \bullet \dfrac{\beta\lambda - \lambda\mu_p - \beta\mu_s}{\eta\beta\mu_p + \alpha\beta - \alpha\mu_p} & cb \geq \mu_p(\bar{x} + \eta\bar{y}) + \mu_i \end{cases} \tag{9}$$

Similarly, for the P2P network, according to formula (7) to (9) it can be obtained as follows:

$$D_{P2P} = \begin{cases} \dfrac{1}{b+\alpha'} & \mathrm{b}\bar{y} < \mu_1(\bar{x} + \eta\bar{y}) \\ \dfrac{1}{\lambda} \bullet \dfrac{\beta - \mu_p}{\eta\beta\mu_p + \alpha\beta - \alpha\mu_p} & \mathrm{b}\bar{y} \geq \mu_1(\bar{x} + \eta\bar{y}) \end{cases} \tag{10}$$

For traditional CDN network, it conform to the queuing model characteristics of the typical M/M/1, and its reach rate and service are as followings:

$$\begin{cases} \lambda_s = \lambda \\ \mu_s = \begin{cases} i \bullet c, 1 \leq i \leq m, m = \dfrac{\mu_s}{c} \\ \mu_s, i > m \end{cases} \end{cases} \tag{11}$$

Thus, the probability when the length of the queue is i can be obtained:

$$y_i = \begin{cases} \left[\dfrac{1}{i!}\right]\left[\dfrac{\lambda}{b}\right]^i y_0 & 1 \leq i \leq m \\ \left[\dfrac{1}{m!}\right]\left[\dfrac{\lambda}{b}\right]^m \left[\dfrac{\lambda}{\mu_s}\right]^{i-m} y_0, i > m \end{cases} \tag{12}$$

Therefore, the average download time of CDN network can be expressed as following:

$$D_{CDN} = \frac{\sum iyi}{\lambda} \tag{13}$$

4. Simulation and Analysis

4.1. Experimental environment and setup

The theoretical numerical analysis and simulation experiment combined to make performance evaluation and comparison. For the theoretical numerical analysis, based on the formula derivation of the model described in Section 4, MATLAB software tools are used to from the HCDN performance characteristics as well as the comparison among the other programs (CDN, P2P and HP2P). In the simulation experiments, based on discrete event simulation mechanism, by using the General Peer-to-Peer Simulator (GPS) (a JAVA-based general P2P simulation framework) simulation of HCDN network is completed.

In the simulation experiment, this paper mainly focuses on the tendency of the number of nodes. By comparing with the theoretical, the validity of the performance analysis model is verified. Wherein, simulation scenario is as follows: each user node P and the edge server S are respectively connected with the forwarding node T; the source server R are connected with the four forwarding nodes; the topology is shown in Figure 6. The round-trip delay of P and T is 6ms; the round-trip delay of S and T is 17ms; the round-trip delay of R and T is 26ms; the bandwidth of edge server S and the source server R is u_1; the download of each user node and upload bandwidth are respectively b and u_i; the Poisson distribution probability with the parameter λ is joined the network; the exit rate of download nodes and seed nodes are respectively subject to the exponential distribution of parameter α and β; the congestion control strategy of transport layer is ignored in the experiments, that is, the nodes can use its maximum transmission bandwidth.

The following data is used as the basic parameters of theoretical analysis and numerical simulation: $u_i = 0.0016$, $u_1 = 0.05$, $b = 0.005$, $\eta = 0.002$ α=0·001, $\eta = 1$, $u = 1$, $t_i = 3$, $t_p = 5$, $t_r = 7$. By changing the parameter values, the influence of the performance by respective factors is analyzed.

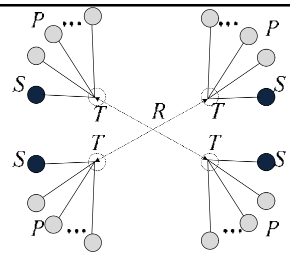

Figure 6. Network topology of Simulation

4.2. Tendency of the Number of Nodes

The given basic parameters satisfy the condition $b\bar{y}\,\mathbf{p}\,u_i\left(x+\eta\bar{y}\right)$, that is, the download bandwidth of download nodes is the bottleneck; Figure 7 (a) shows the trend changing of the download node and seed node in P2P level network of HCDN over time. In order to test the situation unlimited to the download bandwidth, let β=0·005, so $b\bar{y}\,\mathbf{p}\,u_i\left(x+\eta\bar{y}\right)$. Figure 7 (b) shows the corresponding trend. As can be seen, the trend includes two phases: the exponential growth phase and the steady phase. At the same time, it can be seen that the experimental results are very close to the theoretical value, which verifies the effective of the HCDN network performance based on Fluid Model. The subsequent performance evaluation and comparison will be based on the numerical analysis of the performance model in section 4.

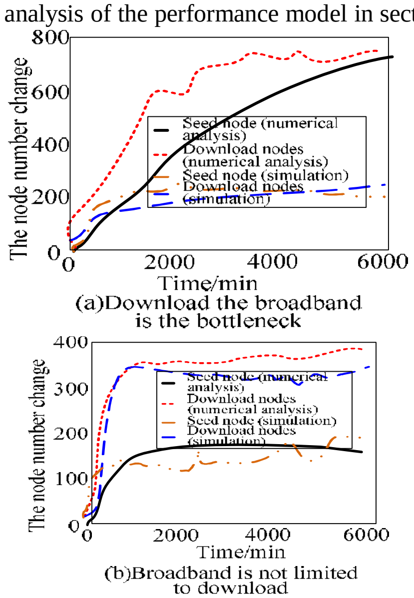

Figure 7. Tendency of the number of nodes

4.3. Factors of the Number of Nodes

To analyze the impact of the exit rate of the seed nodes to the number of nodes on the steady state, the value of α is varies between 0·004~0·013, and Figure 8 shows the corresponding numerical results. With the increase of the α value, the number of seed nodes is reducing, and then the number of download nodes is increasing.

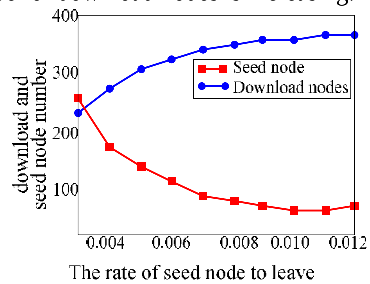

Figure 8. Impact of the exit rate of seed nodes to the number of nodes

In order to analysis the impact of the upload bandwidth of user nodes to the number of nodes on steady state, the value of u_i varies between 0·004~0.013. Figure 9 shows the corresponding results of numerical analysis. With the increasing of the value of u_i, the number of seed nodes is increasing, while the number of download nodes is decreasing; when $u_i\,\mathbf{p}\,bu_i\,\mathbf{p}\,b$, the size of u_i has s a significant influence on the number of nodes on the steady state.

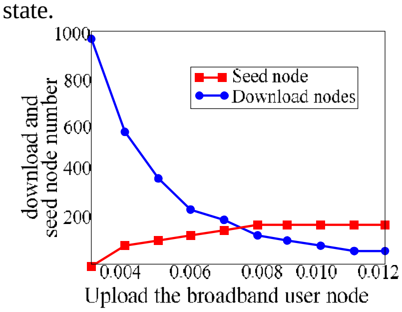

Figure 9. Impact of the upload bandwidth (u_i) of user node to the number of nodes

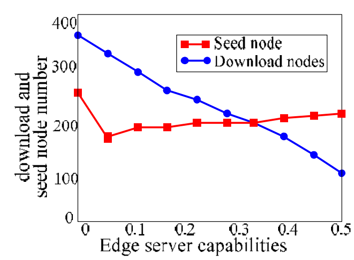

Figure 10. Impact of the edge Server capability (u_i) to the number of nodes

In order to analysis the impact of the up edge server bandwidth to the number of nodes on steady state, the value of u_i varies between 0~0·6. Figure 10 is the corresponding results of numerical analysis. It can be seen that with the increase of the edge server service's capability, the number of seed nodes in stable state is increasing, while the number of download nodes is decreasing.

4.4. System Service Capacity

As shown in Figure 11, in the serve service capabilities HCDN has obvious advantages. the service capabilities of P2P, HP2P and HCDN networks are increasing with the increase of the number of user nodes; while the service capability if CDN network is the fixed value, that is, the service rate of the edge server. When the number of user node is small, CDN is superior to P2P network; when the number of user nodes is large, P2P networks is superior to CDN. Meanwhile, the service capabilities of HCDN network are superior to HP2P.

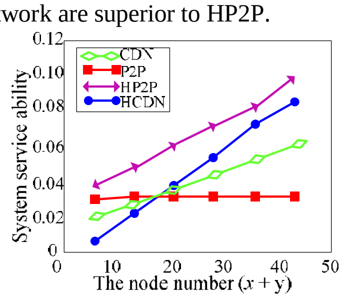

Figure 11. System service capacities

4.5. Load of the Servers

To analyze the impact of the download nodes to the server load, let $u_i = 0.06$, the number of seed nodes is 5. Figure 14 is the corresponding result curve. From the figure, with the increasing of the number of nodes, for the load increase of edge servers CDN and HP2P networks are significantly higher than HCDN network. When the number of nodes is big (like y> 52), the edge servers can work at full capacity.

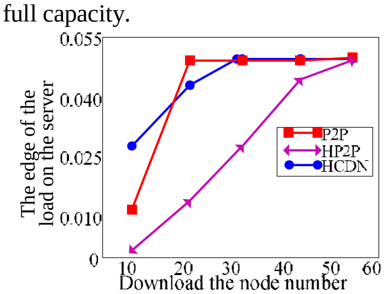

Figure 12. Edge server load in CDN, HP2P and HCDN networks

4.6. Network Transport Overhead

Let $u_i = 0.06$, the number of seed nodes is 15; Figure 15 shows the experimental results of the network transport overhead. Due to t_i **f** t_p (HCDN) and it has the control of P2P zone, the distance between peer nodes is typically less than the distance between the peer and the edge server). From the figure, network transmission overhead of HP2P and HCDN is between the CDN and P2P; when the number of nodes is small, it is close to the P2P network; when the number of nodes is large, it is close to the CDN network. Since t_i **f** t_p, network transmission overhead of HP2P is larger than HCDN.

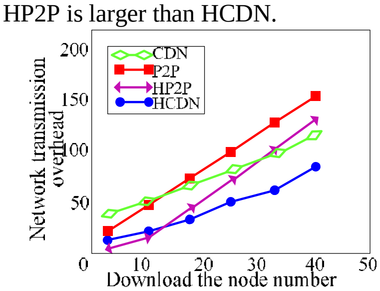

Figure 13. Network transmission overhead in CDN, P2P, HP2P and HCDN

5. Conclusion

This paper proposes a hybrid content delivery network based on CDN and P2P technologies, which comprehensive utilizes the complementary advantages of CDN and P2P networks and makes detailed exposition of the key processes for HCDN network. Compared with the traditional CDN network, HCDN can reduce the edge server load to save the cost of deployment; compared with P2P network, HCDN can enhance the QOS guarantee to reduce the backbone traffic; compared with the HP2P, HCDN has greater download speeds to reduce the network traffic overhead.

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