Multi-path Routing Policy for Content Distribution in Content Network

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Abstract

Content distribution technology, which routes content to the cache servers, is considered as an effective method to reduce the response time of the user requests. However, due to the exponential increases of content traffic, traditional content routing methods suffer from high delay and consequent inefficient delivery. In this paper, a content selection policy is proposed, which combines the histories of cache hit and cache hit rate to collaboratively determine the content popularity. Specifically, the CGM policy promotes the probability of possible superior paths considering the storage cost and transmission cost of content network. Then, the content routing table is updated with the proportion of the distribution on the paths. Extensive simulation results show that our proposed scheme improves the content routing and outperforms existing routing schemes in terms of Internet traffic and access latency.

Keywords: Content routing, multi-path routing, game theory, cache server

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1. Introduction

Over the last decade, the Internet has dramatically increased in complexity, due not only to the boom of mobile Internet and computer networks, but also the massive growth of User Generated Content (UGC) [1]. The fast growing UGC traffic has imposed heavy burden on backbone networks because most of the UGC dissemination do not concern the actual physical network topologies and incline to generate cross-autonomous system (AS) traffic. Though IP networking has overcome the performance bottleneck, content-based networks, such as content delivery networks (CDN) [2], have flourished the enormous content volume. The dominating development trend is that networks no longer facilitate simple data spreading, but rather generate more sophisticated content access and dissemination.

The most popular cache system is fairly simplistic, and it is neither sufficient nor compatible for content delivery which requires popular content dissemination or pre-distribution. Such as utility-driven caching [3] and telecommunications system network server[34], which improved the algorithm efficiency of Least Recently Used (LRU) or First Input First Output (FIFO), but did not take into account the content's popularity and forecast. In these systems, traditional cache technology can store recently accessed contents and activate the cache copy if local users request the same contents again, but it cannot prepare replica placement for the requests which may come.

Researchers around the world are currently searching for methods which optimize content routing quality and efficiency, but the following shortcomings exist:

- Default best-effort Internet routing may cause more congestion which would result in the absence of end-to-end Quality of Service[4].
- Existing mainstream routing algorithms focus primarily on router and link factors on single path, but they are not effective for the use of network resources [5] and can not predict and optimize content delivery.
- Routing policy focuses primarily on local features in individual AS, but it hasn't a network-wide view of topology or traffic [6], so cross-AS traffic is hard to be optimized.

To overcome these disadvantages and enable the distributed content routing policy to work more efficiently, properties which are inherent to content networks must be considered. Link states and client preferences should be utilized to predict the routing cost and traffic demand by distributed computing and distributed policy generation [7]. When content is cached and distributed in the network, the corresponding storage cost and transmission cost will be generated, the transmission cost of content scheduling from content servers and cache servers are affected by the transmission link states. So the content routing can be described as a game problem which reduces the cost of routing by reasonably allocating link bandwidth resources.

This paper focuses on issues associated with multi-path content routing and proposes a method which utilizes the most efficient use of limited network resources to achieve QoS content routing. Further, this paper also proposes a game theory policy as an optimal multi-path transmission that considers both storage cost and transmission cost of content network. The main contributions of this work are:

- Router, link factors and histories of cache hit are simultaneously used to predict desirable content, so that the most popular content will be successfully predicted and distributed in the cache server.

- With the Multi-path Routing Policy, multiple sources are pre-computed, so that traffic can be routed from the content servers and cache servers to significantly improve QoS for clients.
- Deployment of game theory algorithm in the network is not necessary to change the existing network structure. Through judging and weighing of game and cost theory, the most effective routing policy is used to obtain maximum profit.

The remainder of this paper is organized as follows. Section II provides a summary of related works and their relevant limitations. In Section III, the content model and the Coordination Game Model(CGM) are described, in addition to the content policy. Section IV presents simulation scenarios and their results. Finally, Section V concludes the paper and points out future research directions.

2. Related Work

In this section, we begin with a brief review of the existing relevant works on routing technologies of routing system and follow with a discussion of the current content routing optimization technologies.

2.1 Routing System

QoS routing system, as a critical design issue for both fixed and mobile networks, has been extensively studied by researchers.

Lee B S et al. researched the data center traffic and found that the big flows are few in numbers while large in data volume[8]. The limited size of switch flows results in that the big flows are easily evicted. The authors proposed a flow cache framework to enhance the fairness for big flows and to use dynamic-index hashing for placing the flow records onto various buckets. In [9], the system that enhanced the utilization of network among the Inter-Data Center (IDC) was presented. In order to match the current traffic demand, the control method was used to determine how much traffic would be sent in per service, but the traffic price was not considered. To deal with the expensive price limitations in current routing hardware and network devices, Heise P et al. [10] used Openflow in the avionics environment to make use of commercial off the shelf devices and configured them in a way that gave similar performance. Bosshart P et al [11] advocated Routing Control Platform (RCP), which was a backwards compatible system, to give the operators of transit networks more control to Border Gateway Protocol (BGP) routing decisions in their AS, but it lacked overall analysis. Vissicchio S et al. [12],[13] proposed a system in which both flexibility and robustness was achieved through central control over distributed routing. Karthikeyan V et al. [14] proposed multicast routing paths to manage routing paths in content network. This method determined the first path by the unicast routing protocol and determined the second path by the multicast tree of routers. In this method, the adjustment factor was determined according to content delivery network's information. To evaluate the routing path stretch, Ming Z et al. [15] analyzed the relationship between path stretches and the collaboration cost under different collaboration strategies. Hammoudeh M et al. [16] analyzed a new protocol of load balancing and cluster-based route optimisation which adopted various Quality of Service (QoS) metrics to meet Quality of Experience (QoE) of different users.

These current researches on routing systems focus on routing in normal Internet, but do not consider the routing between content servers or cache servers, which will bring less benefit for cache systems than content routing.

2.2 Content Routing Optimization

Even since Internet technology has a prosperous future, high performance content routing has been a long term researched in the field of networking science. Unstable content routing QoS results in the need of routing optimization.

A lot of researches have been conducted for using routers and caches to be aware of the content which should be distributed for an efficient content routing. To solve the problem which users can only exploit the nearby CDN content, some scholars [17],[18] researched the scalable content routing which enables data to be stored, shared and searched. Compared with traditional IP routing, scalable content routing can exploit multiple sources for efficient distribution by using both IP routing and content routing. However, lacking of full network management, scalable content routing only achieves local optimization instead of global optimization. Based on Content-Centric Network(CCN) content routing, Liu T et al. [19] proposed short-cut routing which enables routers to observe neighbor’s caching information and perform optimal routing decision, and analyze the performance of the short-cut routing by using the average delay which a node acquired a content. Some researchers [20],[21] proposed Content Aware Routing (CAR), a novel content oriented traffic engineering, which was designed for content and egress router pair. With this method, content could be obtained from anywhere, but multi-source routing was not introduced in this paper. Flavel A and Panda A [22],[23] proposed a high scalable and operational anycast-based system in which the performances of numerous popular online services can be significantly improved. Yichao Jin et al. [24] described a content-delivery-as-a-service (CoDaaS) to distribute UGC and reduce the delay for better user experiences. In order to leverage multipath transmission for multi-homed devices, Jonas Eymann et al. [25] proposed a probabilistic ant-routing mechanism. However, the additional parameter α, which depends on the network topology and load, was not the optimal value. Yamashita S et al. [26] proposed a novel approach to content-oriented Traffic Engineering (TE), called content aware routing (CAR). Andrzej Bęben et al. [27] proposed a multi-criteria decision algorithm which computed the better source and path for serving content by combining the content request invoking and path characteristics. This technology needed a routing policy system for the efficient utilization of network and server resources. Hemmati E et al. [28] compared the link-states and distance vectors and then proposed the name-based content routing protocol, which was the first name-based and distance vectors based content routing protocol. To deal with the highly dynamic nature of P2P networks, Shivshankar S et al. [29] developed a dissemination framework which combined publishing/subscribing semantics with multicast routing.

With these algorithms, the client is more inclined to retrieve the content by only one link, so it will cause more cost. In addition, these algorithms only concern content routing performance and do not concern content popularity.

In this paper, we introduce a novel QoS routing policy which is different from all the above mentioned. First, not only router and link factors between network users are used to detect the shortest path among them, but also histories of the cache hit and content requirements are exploited to predict desirable content. Secondly, with the proposed QoS routing policy, partial shortest path are pre-computed to reduce the response time of nodes’ routing queries. Thirdly, deploying the proposed QoS routing policy in the whole networks is not necessary to change the existing network structure.

3. Policy Design and Implementation

Content network stores the network content with the distributed cache server, which is the peer-peer equivalence relation. The content stored in cache servers is complementary, which effectively reduces the redundancy in the cache server. When the content is distributed, local cache server gets the content from the adjacent multiple cache servers. Then, through content transmission, the overall goal of the content network is reached: reduce the bandwidth of backbone network and decrease the pressure of the original server.

However, the contents cached in the cache servers are not exactly the same and the links between the cache servers contain complex link information. The transmission efficiency of the content routing is affected by the other cache servers' storage and the link information between the cache servers. Content distribution between cache servers using multiple alternative paths through a network can yield a variety of benefits such as fault tolerance, increasing bandwidth, and improving security. So, content routing between the cache servers can be described as a game theoretic problem where transmission costs can be reduced significantly between multiple cache servers by allocating the link bandwidth resources.

In this section, the game theory method is used to analyze the cooperation mechanism between the cache servers and the link state. Then Coordination Game Model (CGM) is constructed to coordinate the resource allocation between the cache servers to reach the game equilibrium.

3.1 Content Model

Hot contents in the network are frequently accessed, the other contents are rarely requested. Because hot contents containing high relevant material are more likely to be popular among users, and the hot characteristic of the content in the network conforms to the Zipf's Laws[30]. To improve the efficiency of caching and optimize the most content requests, high hot content should be stored in the cache server.

In order to meet dynamic and variable user interests, content popularity measurement must not only perceive the dynamic transfer of content, but also be insensitive to the temporary flow changes. In this paper, a content model is proposed to describe the real-time status of content popularity. Content popularity involves its historical popularity and its current popularity. Notably, the history of content popularity may decline although it remains currently to be popular with high probability. Moreover, current popularity is expressed by the up-to-date hit rate, which describes the influence of the newest content.

Content popularity prediction is a multi-variable statistical analysis method. As detailed below, the main principle is prediction of the value of k+1 at time k to ensure minimum prediction error.

$$\boldsymbol{P}(k)=\boldsymbol{A}\cdot\boldsymbol{P}(k-1)+\boldsymbol{B}\cdot\boldsymbol{H}(k-1) \tag{1}$$

where $P(k)$ is the content popularity vector which describes popularity at time k, $H(k\text{-}1)$ is cache content hit vector which consists of number of content cache hit times in [k-1, k] time interval. A and $\boldsymbol{B}$ are variable matrix respectively:

$$\begin{cases} \boldsymbol{A} = \begin{vmatrix} x_1 & 0 & ... & 0 \\ 0 & x_1 & ... & 0 \\ ... & .. & ... & ... \\ 0 & 0 & ... & x_1 \end{vmatrix} \\ \\ \boldsymbol{B} = \begin{vmatrix} 1-x_1 & 0 & ... & 0 \\ 0 & 1-x_1 & ... & 0 \\ ... & .. & ... & ... \\ 0 & 0 & ... & 1-x_1 \end{vmatrix} \\ \\ 0 < x_1 < 1 \end{cases} \tag{2}$$

where x_1 is the adjustment factor of content popularity.

For m contents in the network, there are matrix $\boldsymbol{P}(k)$ and $\boldsymbol{H}(k)$. $\boldsymbol{P}(k) = [p_1(k), p_2(k), ..., p_d(k), ..., p_m(k)]^T$, and $\boldsymbol{H}(k) = [h_1(k), h_2(k), ..., h_d(k), ..., h_m(k)]^T$. Where $p_d(k)$ is the popularity of content d at time k. $h_d(k-1)$ is number of times to be visited for content d in [k-1, k] time interval. Combined with Eq. (1) and Eq. (2), the content popularity of content d is:

$$\begin{aligned} p_d(k) &= x_1 \cdot p_d(k\text{-}1) + (1\text{-}x_1) \cdot h_d(k\text{-}1) \\ &= x_1^{\,k} \cdot p_d(0) + \sum_{j=1}^{k} [(1\text{-}x_1) \cdot x_1^{\,j\text{-}1} \cdot h_d(k\text{-}j)] \end{aligned} \tag{3}$$

Real-time updates can be described accurately by using this content popularity model, as the influence of past popularity of cached content is not only considered, but also the influence of burst traffic is considered. In addition, the earlier the content to be accessed, the lower its influence.

3.2 Network Cost

The content network can be represented as a scalar graph, **G**=(**V**,**E**), **V** is the set of network nodes, **E** is the set of communication links.

$$\begin{cases} \mathbf{S} = (s_1, s_2, ..., s_k) \subset \mathbf{V} \\ \mathbf{R} = (r_1, r_2, ..., r_l) \subset \mathbf{V} \\ \mathbf{C} = (c_1, c_2, ..., c_m) \subset \mathbf{V} \\ \mathbf{U} = (u_1, u_2, ..., u_n) \subset \mathbf{V} \end{cases} \tag{4}$$

Where S is the source set of content in the network, s_1 is the 1st content, s_2 is the 2nd content, and s_k is the kth content. R is the router set that network content transmission through by, r_1 is the 1st router, r_2 is the 2nd router, and r_l is the lth router. C is the cache server set which distributed in network edge that close to the user. c_1 is the 1st cache server, c_2 is the 2nd cache server, and c_m is the mth cache server. U is the users set to which content service provided, u_1 is the 1st user, u_2 is the 2nd user, and u_n is th nth user.

Edge set **E** is consisted of paths $e(v_i, v_j)$, which locates between node v_i and v_j. For edge $e(v_i, v_j)$, v_i is the starting point of the link, and v_j is the termination point of the link.

$$\begin{cases} e(v_i, v_j) \in \mathbf{E} \\ v_i \in \mathbf{V} \\ v_j \in \mathbf{V} \\ i \neq j \end{cases} \tag{5}$$

Definition 1. Transmission cost. Content routing between any two nodes in the network, should generate the content transmission cost. The transmission cost $T_C(e,d)$, or the cost of content *d* transmitted in path *e*, can be described as:

$$T_C(e,d) = s_i(d) \cdot u(e) \cdot D(e) \tag{6}$$

$s_i(d)$ is the size of content *d*, $u(e)$ is the cost of path *e* to transmit unit information. $D(e)$ is the path congestion weight. Because $u(e)$ is only associated with operator's maintenance cost, for comparison, the value of $u(e)$ is set to 1 in this paper.

Definition 2. Path congestion weight. Content transmission occupies part of path bandwidth and it results in the path congestion weight, which can be described as:

$$D(e) = \frac{1}{B(e) - B(e)_{used}} \tag{7}$$

where $B(e)$ is the total bandwidth of the path *e* and $B(e)_{used}$ is the used bandwidth.

Definition 3. Storage cost. Content stored in any cache servers in the network should generate the content storage cost. The content stored cost $S_C(c,d)$, which is the cost of content *d* stored in cache server *c*, depending on the storage space occupied by the content *d* in the cache server:

$$S_C(c,d) = q(c) \cdot w(c,d) \tag{8}$$

$q(c)$ is the cost of cache server *c* to store unit size content. $w(c,d)$ is storage space weight.

Definition 4. Storage space weight. Content is converted into a format which is supported by the cache server, and it takes up a certain storage space. The storage space weight of the content *d* is:

$$w(c,d) = s_a(c,d) - s_b(c,d) \tag{9}$$

$s_a(c,d)$ is the remaining storage space of cache serer *c* before content *d* is stored, $s_b(c,d)$ is the remaining storage space of cache serer *c* after content *d* is stored.

When the user requests content, the request will be redirected to local cache server. If there is no user required content in the cache server, users will then get content from the remote source server. The sum of the storage cost and the transmission cost of users getting content from cache server should be greater than the transmission cost of users getting content from original server, otherwise, the cache will lose its meaning. Therefore, in content network, cache server stores content *d* with popularity $p_d(k)$, and provides content services for users, should meet :

$$S_C(c,d) + p_d(k) \cdot T_C(e(c,u),d) < p_d(k) \cdot T_C(e(s,u),d) \tag{10}$$

From the Eq. (6), Eq. (8) and Eq. (10), Eq. (11) can be obtained:

$$\begin{aligned} q(c)\cdot(s_a(c,d)-s_b(c,d))+p(d)\cdot s(d)\cdot u(e(c,u))\cdot D(\mathrm{e}(\mathrm{c},u)) \\ < p(d)\cdot s(d)\cdot u(e(s,u))\cdot D(\mathrm{e}(s,u)) \end{aligned} \quad (11)$$

3.3 Game Model

Content scheduling between the cache servers can be described by CGM as five aspects:

$$\mathbf{G}=\left\{\,\mathbf{C},\mathbf{S},\,A,\,I,\,U\,\right\} \quad (12)$$

where $\mathbf{C}$ is the set of game participants which are cache servers, which provide users with content services. In the network with *m* cache servers, $\mathbf{C}=(c_1,\,c_2,\dots,c_m)$.

$$\mathbf{S}=\left\{\,s_0,s_1\,,\,s_2,\,\dots,\,s_m\,\right\} \quad (13)$$

where $\mathbf{S}$ is the set of all possible policies, s_0 is the policy which schedules content from source server, s_1 is the policy which schedules content from the 1st cache server, s_2 is the policy that scheduling content from the 2nd cache server, s_m is the policy that scheduling content from the *m*th cache server.

A is the dynamic game process. *I* is the game information which influences storage condition of the cache servers and the path condition between cache servers.

U is the utility function of content routing. Utility function of users in AS where the cache server is located acquiring content is.

$$U_i=U_{i,1}+U_{i,2}+\dots+U_{i,j}+\dots+U_{i,m} \quad (14)$$

where $U_{i,j}$ represents the transmission cost of the *i*th cache server for obtaining content *j* from original server or other cache servers.

$$U_{i,j}=\sum_{x=0}^{m}p_{re}(e_x)\cdot T_C(e_x,j) \quad (15)$$

If *x*= 0, e_0 is the path between the *i*th cache server and original server. If *x*≠0, e_x is the path between users and cache server *i*. $p_{re}(e_x)$ is the percentage of transmission content which is assigned on path e_x.

Game of *N* cache servers in network can be expressed as $\mathbf{G}=\left\{\,\mathbf{C},\mathbf{S},\,A,\,I,\,U\,\right\}$. In this model, if $\mathbf{S}^*=\{s_1^*,s_2^*,\dots,s_n^*\}$ satisfies the Nash equilibrium, Eq. (16) should be met:

$$\begin{cases} U_i(s_i^*,s_{-i}^*)\le U_i(s_i,s_{-i}^*) \\ \qquad\forall s_i\in\mathbf{S}_i \end{cases} \quad (16)$$

where S_i is the set of the executable policies of the *i*th cache server, s_i can be any policy in set $\mathbf{S}_i$. s_i^* is the policy that the *i*th cache server chooses, while s_{-i}^* is the policies which the other cache servers choose. Eq. (16) informs that when the system reaches the Nash equilibrium, the transmission cost of users in AS to get content *j* can be minimized.

In order to achieve global equilibrium, cache servers should send their policies to each other cache servers. This determines that the coordination process between cache servers is completely an information based game process.

Each cache server is based on its information *I* (including information of cache server storage and path between cache servers). Then, the appropriate policies are chosen in $\mathbf{S}$, through continuous content scheduling, so that content servers' profit achieves a Nash equilibrium. According to the conservation of flow, the problem can be described as:

$$\begin{aligned}
&U_i(s_i^*, s_{-i}^*) \le U_i(s_i, s_{-i}^*) \\
&subject\ to \\
&\sum_{s\in E', t\in E'} P_{st}^m - \sum_{s\in E', t\in E'} P_{ts}^m = 0 \ (s \ne c_m, t \notin S_m) \\
&\sum_{s\in E', t\in E'} P_{ts}^m = \sum_{s\in s_m} \sum_{s\in E', t\in E'} P_{st}^m = 1 \ (s = c_m) \\
&\sum_{m\in M} d_m P_{st}^m \le b_{st} u \\
&\forall s_i \in \mathbf{S}_i
\end{aligned} \tag{17}$$

E' is the set of the directed link in network, P_{st}^m is the percentage of content *m* in the directed *link*(*s*,*t*), P_{ts}^m is the percentage of content m in the directed *link*(*t*,*s*). c_m is the user who requested for content *m*. s_m is the original server and content servers that provide content services. d_m is the content m's demand for network bandwidth resources. b_{st} is the unidirectional bandwidth of directed *link*(*s*,*t*).

Content routing is divided into two cases:

1) Cache servers need to get content from a cache server, and the two cache servers are connected through the *K* (*K*=1) links.

2) Cache servers need to get content from the other serial cache servers by using different paths. Then, multiple cache servers can be abstracted as a logical set of content sources. For cache server request for content scheduling, the content of the content source can be received from two content servers in unison. Therefore, in this paper, the above two cases are abstracted as the multi-path routing between cache server and content source.

In order to cope with this situation, traditional content scheduling uses the best effort transmission method. Transmission is achieved by finding the shortest path between the source and the destination cache server. However, best effort transmission method has shown two drawbacks:

1) The limitation of bandwidth resource in the path may lead to path congestion.

2) Only one path is used for content scheduling, resource constraints may occur on the transmission path, while other path resources remain idle.

The bandwidth, transmission delay and transmission cost of each path between the cache servers are not the same, sometimes with large differences.

In this instance, the CGM is used to solve the content routing problem on each path. In the content scheduling, if the link transmission state is good, it is allowed to transmit a large proportion of the content, and if the link transmission state is not good, it is just allowed to transmit a smaller proportion of the content or not to transmit content. For multiple states of good link, the transmission proportion of each link is determined by the resources of each link.

When the content scheduling achieves the Nash equilibrium, the proportion of the distribution on the path e_l is:

$$p_{re}(e_l) = \frac{\frac{1}{D(e_l)}}{\sum_{x=1}^{K} \frac{1}{D(e_x)}} \times 100\% \tag{18}$$

At this point, the bandwidth utilization of each link and the content distribution of links achieve the Nash equilibrium, which leads to the transmission cost to be minimized when the content is scheduled.

The optimization effect of multi path routing on the content scheduling increases with the number of paths. However, when the path number is more than five it will only slightly improve transmission effectiveness and the size of the routing table increases significantly [27]. Therefore, the path number of the cooperative cache server is restricted as the following:

$$K = \begin{cases} k & k \le 5 \\ 5 & k > 5 \end{cases} \tag{19}$$

k is the number of available content scheduling paths. When k is less than 5, all the paths are used for content transmission. While k is greater or equal to 5, 5 paths with the best performance is chosen.

3.4 Application examples

In this section, a simple content network model is proposed to explain how Coordination Game Model works. Suppose that congestion weight $D(e)$ is unit 1, contents are stored in four cache servers and user's requirements are shown in **Fig. 1**.

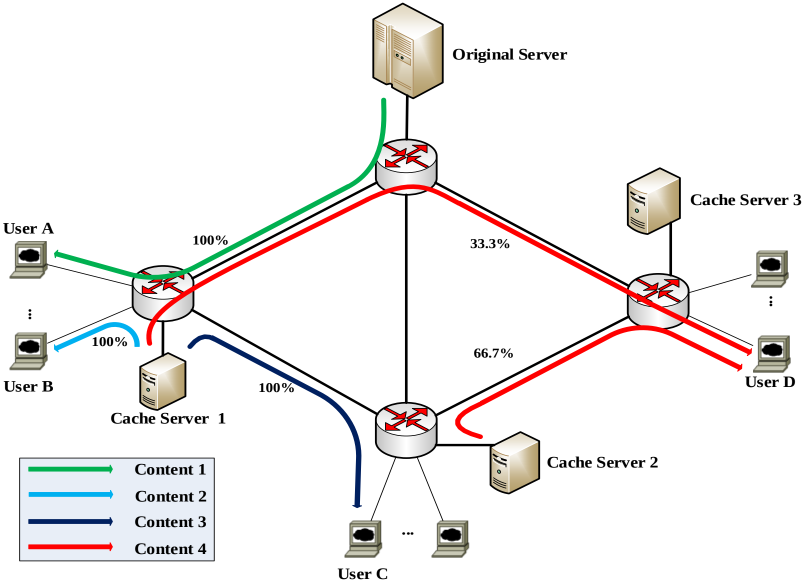


Fig. 1. A simple content network model

Fig. 1 shows an example of multi-path routing. Different distributions of network content may result in several available access methods.

Suppose that user A requests for Content 1, if all the Cache Servers do not have the corresponding content, then User A receives the content from the original server. The proportion of the content allocation in the path is 100%.

Cache Server 1 stores the content 2 that User B requested for, When User B requests

Content 2, the proportion of the content allocation in the path is 100%.

As opposed to Content 2, Content 3 is cached by Cache Server 1, which is not the local cache server. User C obtains content from Cache server 1. When the Nash equilibrium is reached, the shortest path is used to carry out the content. The proportion of the content allocation in the path is 100%.

The request for Content 4 shows a simple overview of multi-source routing. User D then demands Content 4, which is cached at both Cache Server 1 and Cache Server 2. According to the paths' state, the Nash equilibrium is directly employed to obtain the contents from the cache server 1 and the cache server 2. The path congestion weight $D(e)$ of the two paths are 2 and 1, respectively. According to Eq. (17) and Eq. (18), K=2, and the proportion of the allocation of the two paths are 33.3% and 66.7% respectively.

4. Experimental Classification Results and Analysis

As described above, the content distribution efficiency is maximized when popular content delivery and distribution with multi-path routing are presented. The following sections discuss simulation scenarios, detail the settings being used, and present conclusive findings derived from these experiments.

4.1 Application examples

To test the efficiency and effectiveness of the proposed cache distribution policy of multi-path routing for popular content, we build a simulation environment using OPNET on Windows i386 and process the results with MATLAB R2010a. Three simulation scenarios are utilized in the experiment.

Scenario A corresponds to a setting where OSPF is used to distribute content through user requests. If the local cache hits, it is sent directly to the client; otherwise, users get content from other cache servers, Open Shortest Path First (OSPF) policy [32],[33] is used as the content routing policy. The reason why OSPF is used in the experiment is that OSPF is the most widely used algorithm in content distribution's practical application. By contrasting with OSPF, the substantial increase in other methods can be reflected.

In Scenario B, when user requests for the content. If local cache hits, it is sent to the client directly; otherwise, users get content from other cache servers, Equal-Cost Multi-path Routing (ECMP) proposed in [31] is used as the content routing policy.

The method proposed in this paper is used in Scenario C. In this scenario, the CGM proposed in this paper is used to decide path selection of content routing from the cache server.

Seventeen nodes (*N1*-*N17*) with similar storage capacity are deployed on the network topology during the experiment to analyze the content routing capacity and attribute values of link are shown in **Fig. 2**. A subnet with user is deployed at the network edge and a server node is deployed on the network topology to supply the content in order to represent user experience. The server node and subnet are connected by Node 1 and Node 17 respectively.

Simulation parameters are summarized in Table 1. Bandwidth and delay are measured in *ms* and *Mbps*.

Scenario A uses OSPF routing algorithm, which uses Classical Dijkstra algorithm for paths selection. Scenario B uses ECMP, in which content is forwarded to a single destination by multiple paths with equal congestion weight $D(e_l)$. Scenario C use CGM based content routing algorithm, in which congestion weight $D(e_l)$ and users' demand is used to find the game equilibrium point. Then, traffic flow on each path is determined by Eq. (18).

Furthermore, content with high popularity is distributed from the original server to cache servers in Scenario B and Scenario C. During the transmission process, CGM routing delivers the content on each path with different proportion.

Table 1. Simulation Parameters

Parameter name	Parameter Value
Number of Content servers	7
Number of users in Subnet	100
Number of Routers	17
Subnet start time(s)	*uniform* (990, 1010)
Simulation time(s)	3600s

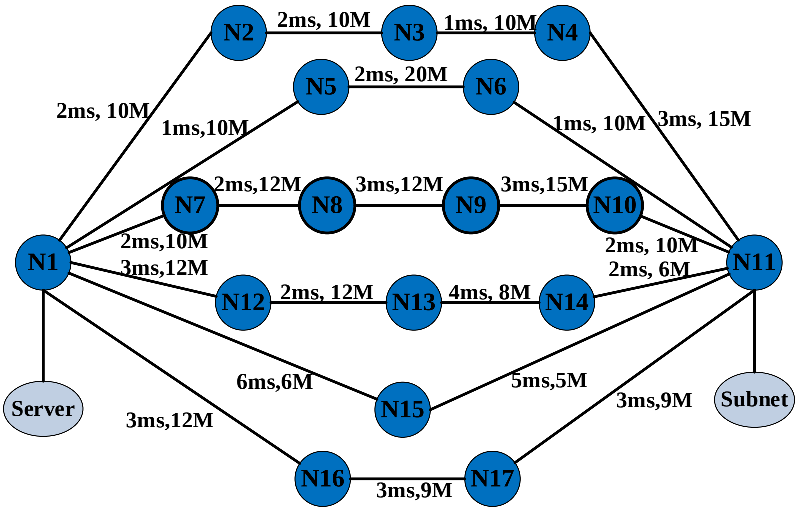


Fig. 2. Simulation Topology

This content routing optimization algorithm presented in this paper not only recognizes the network load, but also uses other redundant paths to complete the forwarding process. Using of the redundant paths achieves the path backup function.

According to the input parameters in **Fig. 2**, the problem of path selection for content routing can be solved.

1) In Scenario A, OSPF algorithm is used to get the optimal path N1，N15，N11 with the minimum number of hops.

2) In Scenario B, ECMP is used to evenly distribute traffic on 6 paths. The traffic flow distributed on each path is 16.7%.

3) In Scenario C, CGM proposed in this paper is used to optimize the content routing. When a game reaches equilibrium, the proportion of traffic flow in each path is convergent. When the 5 optimal paths present the content assigned on each path is: path1(N1, N2, N3, N4, N11) is 18.9%, path2(N1, N5, N6, N11) is 44.1%, path3 (N1, N7, N8, N9, N10, N11) is 13%，path4(N1, N12, N13, N14, N11) is 10.6%, path5 (N1, N16, N17, N11) is 13.4%.

Results of paths selection of different algorithms are shown in Table 2.

Table 2. Path Selection Results

Algorithm/policy	Path Selection	Hops	Transmission ratio
OSPF	Path1:N1,N15,N11	2	100%
ECMP	Path1:N1,N2,N3,N4,N11	4	16.7%
	Path2:N1,N5,N6 ,N11	3	16.7%
	Path3:N1,N7,N8,N9,N10,N11	5	16.7%
	Path4:N1,N12,N13,N14,N11	4	16.7%
	Path5:N1.N15,N11	2	16.7%
	Path6:N1,N16,N17,N11	3	16.7%
CGM	Path1:N1,N2,N3,N4,N11	4	18.9%
	Path2:N1,N5,N6 ,N11	3	44.1%
	Path3:N1,N7,N8,N9,N10,N11	5	13%
	Path4:N1,N12,N13,N14,N11	4	10.6%
	Path5:N1,N16,N17,N11	3	13.4%

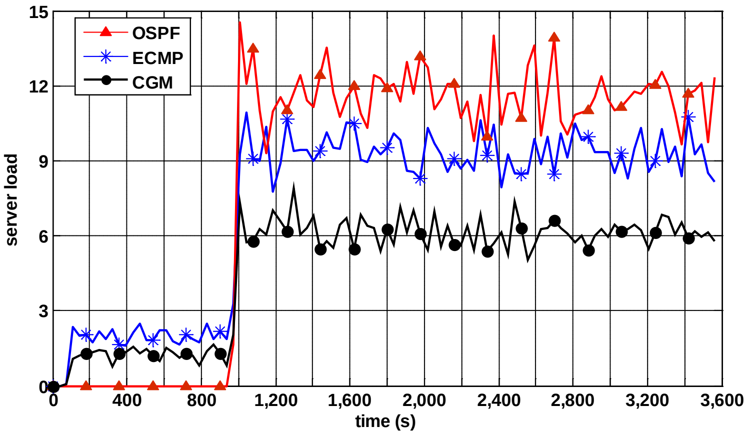
4.2 Simulation Results

To determine whether pressure on the content server is alleviated under the proposed method, the simulation results for the server load of the original server is analyzed.

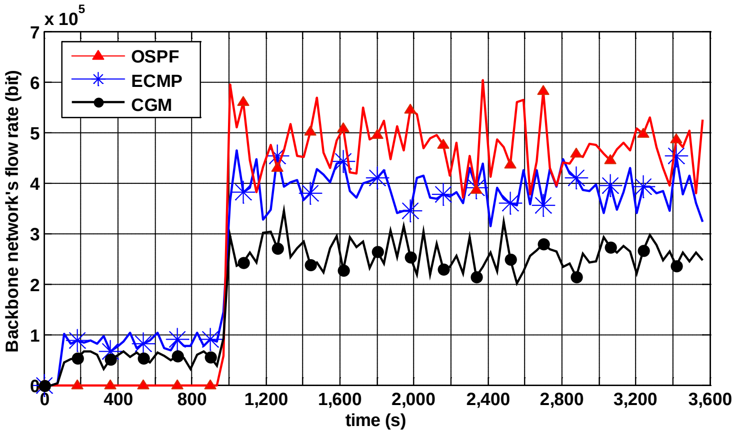
In this paper, OPNET is used for simulation, and server load represents the number of request in OPNET. Parameter description has been added for server load and throughput:

In OPNET, server load notes the numbers of requests that belong to different sessions maintained at the server. Also note that requests for the same session are queued until the first request is completed. Throughput represents the average number of bits which is successfully received or transmitted by the receiver or transmitter channel per unit time.

This measured value reflects the optimal routing system for the content provider. The smaller these values are, the better the system performances are.



(a) Server load



(b) Throughput

Fig. 3. Server load and throughput

Curves for load of the content server in all three scenarios proves a positive correlation with the number of processing requests. **Fig. 3(a)** shows the overlaid statistics of the server load for the three scenarios.

Fig. 3(b) depicts the throughput overlaid statistics of the three scenarios, which indicates backbone network's flow rate, flow rate decreases with increasing of cache hit ratio. The smaller this value is, the smaller server load is. Comparing **Fig. 3(a)** and **Fig. 3(b)**, it becomes clear that sharpness of the curves for server load and throughput are quite similar. Once the users start requesting content, the content generated from the content server passes through the backbone network, and curves of server load and throughput reach saturation soon.

For Scenarios A and B, in which content is not distinguished or pre-distributed, the hit rate of the cache server is lower. Because an unacceptable amount of storage is occupied to introduce a considerable bandwidth cost, it in practice would worsen the traffic situation. On the contrary, in Scenario C, content popularity is used to evaluate the storage costs. In Scenario C, popular content is predicted and distributed to cache servers, where the content pre-distribution mechanism is employed.

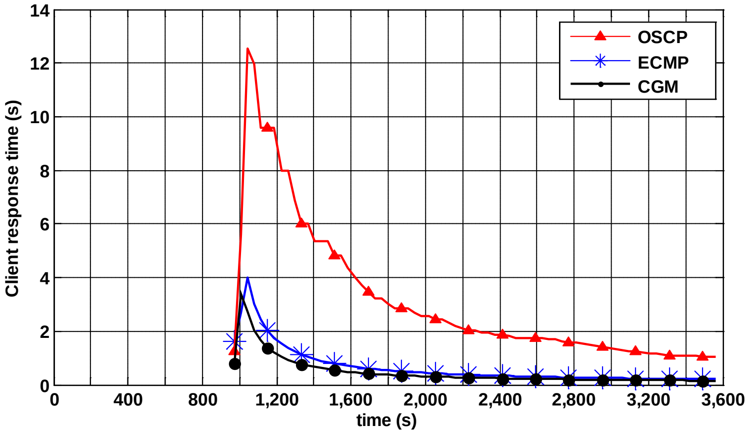


Fig. 4. User response time

In this experiment, users request content halfway through the simulation. User response time is the specified time that required to retrieve the instant content with all the objects contained online. **Fig. 4** shows user response time for each scenario. Since popular content is pre-delivered in Scenario C, users in these scenarios receive the majority of requested content from the local edge content server. In most cases, however, the capacity of the cache server is lower than the original server, and the bandwidth of the backbone network is larger than the other networks. To this effect, acquiring content from distant cache servers for an extended period is considered inefficient.

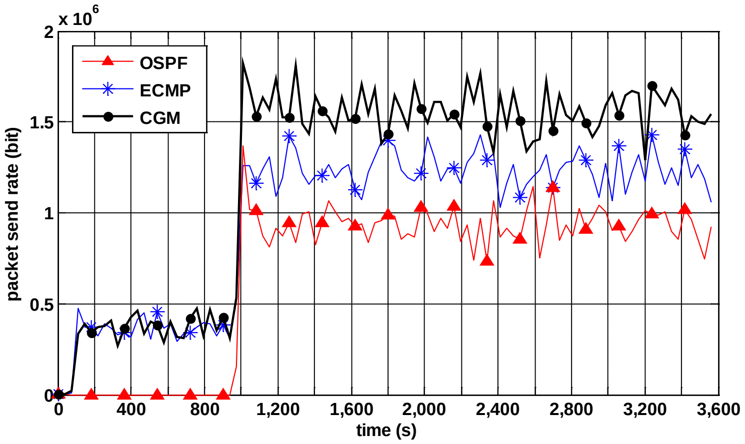


Fig. 5. Content send rate

Fig. 5 shows the content transmission rate in simulation experiment. Content transmission rate (y axis) becomes stable with increased simulation time (x axis).All the flows are sent by OSPF in Scenario A, by ECMP in Scenario B and by CGM in Scenario C. As shown in **Fig. 5**, the content transmission rate of ECMP and CGM is more efficient than OSPF, because not only multi-path routing has more available path resources, but also popular content is distributed before possible future access time. CGM uses the game theory to optimize the path utilization, but ECMP do not consider the link weight. Even if ECMP uses more paths to transmit content, its average content send rate is lower than that of CGM.

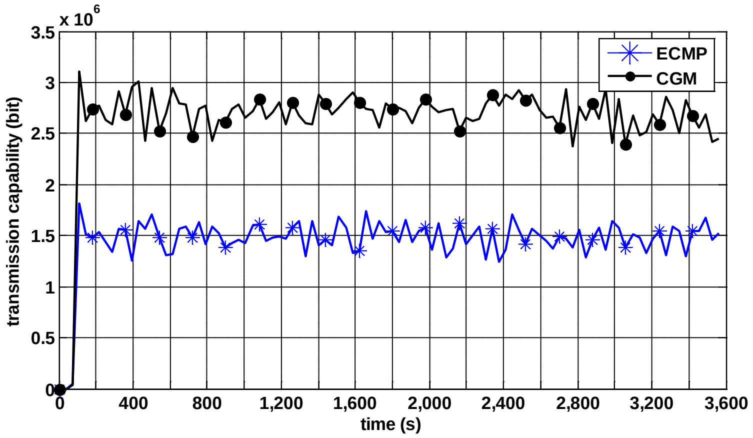


Fig. 6. Transmission capacity

Fig. 6 shows a transmission capacity overlay chart for ECMP and CGM. Both methods use multiple paths to distribute content. ECMP equalizes the distribution of content on multiple paths. Path bandwidth, delay, and reliability of links are different. If all links have the same weight, the bandwidth is useless, because differences in path status lead to more disadvantageous effects. The CGM proposed in this paper maintains a real-time adjustment for allocation of resources according to path states.

Based on the simulation results, it is possible to conclude that the proposed popular content routing policy achieves an ideal outcome. The proposed policy shows better performance in a wide range of traffic features and network scenarios compared to the other content routing and distribution policies. Again, as a novel approach, the proposed system gathers the history of content popularity along with latest popularity status to predict the content's dynamic popularity. CGM policy is utilized in order to disseminate popular content efficiently between the original server and cache servers to satisfy the public demands. The routing method separates the content proportionally, in accordance with path resources.

The proposed method distributes popular content preferentially to edge cache servers which store the most popular data, thus burst flow in the backbone network is minimized and the server load is cut down. Routing content through multiple paths increases the efficiency of the network transmission. At the same time, distributing content for possible future access improves QoE of users.

5. Conclusions and Future Research Works

This study proposes a content-based QoS routing policy which uses CGM to optimize content routing efficiency.

The advantages of the proposed policy can be summarized as follows. Firstly, content popularity is predicted by both history of content popularity and current hit rate. Secondly, network cost is modeled to analyze both storage cost and transmission cost. Thirdly, CGM policy is proposed to divide content between multiple paths to facilitate efficient transmission.

Future research works will focus on the behavior of network users to manage content generated in complex networks, and will investigate regularity in size of routed content and cache servers. Additionally, we plan to deploy the proposed method in a real network to investigate effective implementation of the system.

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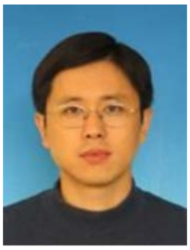

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