Research on the Energy-Efficient Caching Strategy in Content-Centric Networking

Tiantian Shi
School of Communication and Information Engineering,
Chongqing University of posts and telecommunications,
Chongqing, China,
E-mail: stt0802@126.com

Changbiao Xu
College of Photo electronic Engineering,
Chongqing University of posts and telecommunications,
Chongqing, China,
E-mail: xucb@cqupt.edu.cn

Li Zhang
School of Communication and Information Engineering,
Chongqing University of posts and telecommunications,
Chongqing, China,
E-mail: 243666882@qq.com

Abstract—Due to the current explosion of the network traffic generated by content production and dissemination applications like popular video, Content-Centric Networking (CCN) has been the topic of recent research. In-network caching for CCN is expected to achieve an adaptive content delivery in the network and to reduce traffic by storing content data on each router. The impact of caching content on Content-Centric Networking (CCN) taking into account the energy-efficient non-cooperative caching strategy is investigated. By monetary consumption and router revenue to design a reasonable threshold, the data which has higher popularity and energy-efficient will be cached first. A cost-performance ratio (CPR) algorithm is proposed to replace the content when the cache space is full. Thus, the network gets low service delay and communication energy, also the promotion of availability and efficiency can be achieved. Simulation results show that the strategy can effectively reduce network overhead and delay, and obtain better performance.

Keywords- Content-Centric Networking; threshold; energy-efficient; cache; replace;

I. INTRODUCTION

Due to the current explosion of the network traffic generated by content production and dissemination applications, like popular video and ICT (Information and Communication Technology) services, we can find a paradigm shift from host-to-host networking towards content-centric networking. Content-Centric Networking (CCN) has been the topic of recent research [1] [2] as it emerges as a new paradigm that shifts emphasis from content provider to the content itself that customers really care about. CCN use in-network storage in which every router along the delivery path caches content so later request for the content can be satisfied much early from the router that still has content cached, thus obviating the need not to go further to the exact content provider.

With cache used in such a scale, caching strategy can have significant influence over the performance of CCN. Optimization caching strategies have been studied extensively in other domains, such as CDNs [3], Web caching and IPTV. However, these are based on specific applications and are only suitable for particular topology types (e.g, hierarchical, adaptive overlay structures). The default cache strategy in CCN is LCE (Leave Copy Everywhere). LCD (Leave Copy Down) [4] and MCD (move copy down) [5] are simple caching strategies which have not consider the energy strategies form ISPs. The problem of energy efficient in-network caching in CCN is studied in [6].Then the energy consumption model for content distribution is built and an aging popularity-based in-network caching scheme is proposed to reach the energy efficiency. In [7], the authors investigate the problem of caching strategy about chunk placement in CCN, and a caching location and searching scheme (CLS) in CCN hierarchical infrastructure is proposed. Although much work has been done in CCN, however, the problem of content caching to optimize the whole network performance in CCN is not well considered. However, the caching optimization problem in CCN is one of the most important issues to balance the network load, save the energy consumption and achieve the green communication.

Therefore, an energy-efficient caching strategy (EECS) in Content-Centric Networking is proposed in this paper. By monetary consumption and router revenue to design a reasonable cache threshold, the data which has higher popularity and much higher energy-efficient will be cached first. In addition to, a cost-performance ratio (CPR) algorithm is proposed to replace the content when the cache space is full. Thus, the network gets low service delay and communication energy, also the promotion of availability and efficiency can be achieved. Simulation results show that the strategy can effectively reduce network overhead and delay, and obtain better performance.

II. CONTENT-CENTRIC NETWORKING

In the CCN network, users don't care about the location of the content, but the content itself. Network can unified identify the content, then location, routing and transmission based on the content, the user get the content by sending the interest packet which carries content request information, content providers provide the corresponding data packet according to the request information. In addition, CCN nodes can cache the content which can speed up the efficiency of other users access network, reduce network congestion status, improve the utilization rate of network resources. Caching mechanism has been one of hot topics in CCN research field.

A. Packet types

Fig .1 shows that CCN consists of Interest packet and Data packet. Interest packet carries a name that identifies the desired data. Once the Interest reaches a node that has the requested data, a Data packet is sent back, which carries both the name and the content of the data, together with a signature by the producer's key. This Data packet traces in reverse the path created by the Interest packet back to the consumer. Neither Interest nor Data packets carry any host or interface addresses; Interest packets are routed towards data producers based on the names carried in the Interest packets, and Data packets are returned based on the state information set up by the Interests at each router hop.

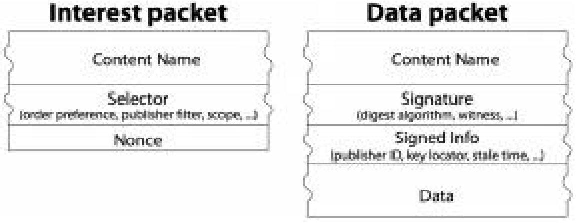

Figure 1.Packets in the CCN

B. Architecture of CCN nodes

CCN nodes include routers and end nodes, mainly through three elements to implement the packet forwarding mechanism and network storage function. They are respectively Content storage (CS), the Pending Interest Table (PIT) and Forwarding Information Base (FIB).

C. Packet forwarding mechanism

When an Interest packet arrives at a CCN face, the Content Name carried by this Interest is firstly checked in the CS. If there is a matching Data, it will be directly returned through the same face where the Interest arrived at. Otherwise the Content Name is further checked in PIT. If there is already a matching entry, the arrival face information is updated in the matching entry. If not, the FIB table is consulted for the forwarding information, and a new entry associated with the new arrival Interest and its incoming face is created in PIT.

When a Data packet arrives at a CCN node, the Content Name of the Data is checked in the CS. If there is already a matching content cached in the CS, this Data packet should be discarded. If there is no existing match in CS, the Data is checked in PIT. A PIT entry match means this Data has been required, it is sent out through the list of faces associated with the matching PIT entry, and the Data can be stored in the CS.

III. ENERGY-EFFICIENT CACHING STRATEGY FOR CONTENT-CENTRIC NETWORKING

Content caching in CCN can be coordinated or non-coordinated, similar to that in the Internet [8]. Non-coordinated caching mechanisms store only the locally most popular contents at each CCN router, without coordination with other routers. Non-coordinated caching mechanisms store is used in this paper. The related model definition as follows:

Topology model: CCN network is supported by the underlying infrastructures can be viewed as a connection diagram $G=(V,E)$, where $V=\{v_1,v_2,...,v_n\}$ is the set of network node and the node is just the router, E is the set of link, $e=(v_i,v_j)\in E$, where $(v_i,v_j)\in E$ shows that node v_i and node v_j are connected. Each node $v\in V$ provides caching and computing resources and the capacity of each node is C_i, each link provides bandwidth resource. All of these resources are limited in the CCN.

Content model: suppose a directory, there are m contents, $S=(s_1,s_2,...,s_m)$ and where $S=\sum_{k=1}^{m} s_k$.

A. Problem definition

Definition 1 Design the cache threshold f_{ik}.Assuming that $T_0(k)$ is the starting time that the content k via the node v_i for the first time, $T_1(k)$ is the time that content k via the node v_i for the number of f_{ik}, f_{ik} is he total number of content k via the node v_i form $T_0(k)$ to $T_1(k)$.

Energy-efficient model is that the node decides whether store the content when router revenue is higher than the cache consumption.

Form $T_0(k)$ to $T_1(k)$, cache consumption C_{ik} is defined as (1).

$$C_{ik}=D_k\cdot\left[T_1(k)-T_0(k)\right]\cdot P_{ic} \tag{1}$$

The router revenue S_{ik} is defined as (2).

$$S_{ik}=f_{ik}\cdot P_{ik} \tag{2}$$

Where C_{ik} is the total consumption that router v_i caches content k form $T_0(k)$ to $T_1(k)$, S_{ik} is the revenue that router caches content k, D_k is the size[bits] of the content k, P_{ic} is the consumption [\$/ (bit·s)] that the router caches the content k. P_{ik} is the router revenue that the user downloads the content k form the router each time. When $S_{ik}\ge C_{ik}$, the router decides whether store the content k, the detail as follows.

$$f_{ik}\cdot P_{ik}\ge D_k\cdot\left[T_1(k)-T_0(k)\right]\cdot P_{ic} \tag{3}$$

$$f_{ik}\ge\frac{D_k\cdot\left[T_1(k)-T_0(k)\right]\cdot P_{ic}}{P_{ik}} \tag{4}$$

For the content k, When f_{ik} meets (4), the router will store the content k, otherwise, the router does not store the content k.

Definition 2 Different routers have different cache mediums, so the cache consumption is different. In this paper, suppose the routers use the DRAM and the years of use are 5 years. So P_{ic} is 7.74*10^{-16}[$/ (bit·s)].

Definition 3 P_{ik} is the router revenue that the user downloads the content k form the router each time. In this paper, the contents mainly include Web、audio、video and so on. Where the price of web is 0, that is to say, the router revenue is 0 that the user obtains the web content form the router. The price of the rest content is random.

Definition 4 Assuming that the time of router v_i caches content k is $T_{ic}(k)$, which is defined as (5).

$$T_{ic}(k)=T_{ir}(k)-T_{is}(k) \tag{5}$$

The cost-performance ratio (CPR) R_{ik} of the cache content is defined as (6).

$$R_{ik}=\frac{N_{ik}\cdot P_{ik}}{D_k\cdot\left[T_{ir}(k)-T_{is}(k)\right]} \tag{6}$$

The router v_i has cached the content k (k =1, 2,…, *m*), $T_{is}(k)$ is the initial time of the content k is cached by router v_i , $T_{ir}(k)$ is the current system time. N_{ik} is the number of content k is downloaded during the time $T_{ic}(k)$. Comparing the cost-performance ratio R_{ik} of the content k, when the router v_i cache space is full, the content v_i will replace the content k which the R_{ik} is the minimum.

B. The steps of energy-efficient caching strategy

- Step1: When the content k arrives to a router, the router gets the information of content k and determines whether content k arrives the router for the first time, and if so, the router records the time $T_0(k)$ and the number f_{ik} =1, if not, the router updates the number f_{ik} that the content via the router. Then the router judges whether f_{ik} meets the energy-efficient model.
- Step2: If f_{ik} meets the energy-efficient model, the router stores the content k. At this time, if the router has cache space, the router stores the content k, if the cache space of router is full, the router performs the CPR replacement algorithm and selects the content which the cost-performance ratio R_{ik} is the minimum. At last, the content k replaces of the content which is substituted.
- Step3: If f_{ik} isn't meet the energy-efficient model, the router updates the number f_{ik}. In this paper, the size of the content is the same.

IV. SIMULATION EVALUATION

In this paper, the simulation is based on the ndnSIM of NS-3 under Linux environment, Fig .2 is the network topology. Service nodes provide 500 different contents, each content size is 1024 KB. The content popularity is a very important factor of influencing the CCN storage performance, the most typical data popularity is Zipf distribution [9], the distribution shows the different states of popularity distribution by the change of parameters α (≥0), the more α is close to 0, the smaller the popularity gap among contents, on the contrary, α is larger, the popularity gap among contents is bigger. Normally, α value is between 0.6 and 1.2 [10], therefore, the content's popularity follows Zipf distribution and α is 0.8 in this article.

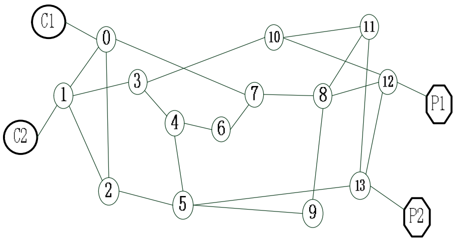

Figure 2.NSF Network

The request packets of users C1 and C2 enter the network by edge nodes 0 and 1, request frequency follows Poisson Distribution λ=10req/s, Service nodes P1 and P2 respectively connect with node 12 and node 13 which provide the users with corresponding request packets. Each In-network node has limited Content Store (CS). The total capacity of CS is 10%-50% of the total content size. Each CS performs CPR replacement strategy. Comparison algorithms are LCE and Prob (p) storage strategies, simulation time is 300 sec.

We now compare three caching policies in view of the average hit ratio in the network. Fig .3 shows the average hit ratio of user requests within the network, which is under different in-network storage conditions. The hit ratio is requests of all the service nodes divided by the total number of requests in each sampling instant. Compared with the other two strategies, EECS strategy improves the hit ratio of the request in the network. For example, when network storage capacity occupies 40% of the total content size, the average hit ratios of three strategies are 31.8%, 28.9%, 27.6%. Because that the router with EECS strategy can cache the content which is requested with much more times.

Fig .4 shows the average hit length under each scheme, where the hit length is measured in number hops from the client to the hit cache. The lower the average hit length, the better the performance. The average hit length in EECS strategy is lower than that in the other policies. Fig .5 shows the average delay of the client obtains content, the value is the average time of all nodes obtain content. The average delay in EECS strategy is lower than that in the other policies. By using the EECS strategy proposed in this paper, the nodes can cache more different contents which improve the content diversity. The download time is reduced in EECS strategy over the other strategies.

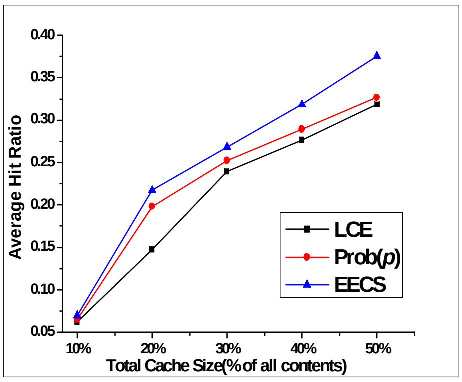

Figure 3.Average hit ratio

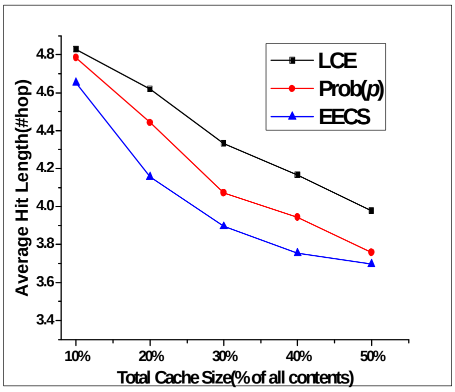

Figure 4.Average hit length

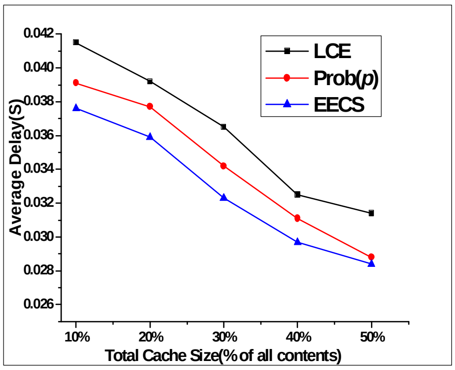

Figure 5.Average Delay (s)

Fig .6 shows the average bandwidth consumption required to satisfy a request. From the figures, it can be clearly seen that the EECS strategy results in much lower load on the network links than the other strategies. That is because EECS just cache the contents which are beneficial to the nodes. These results indicate that the threshold-based caching can use network resources such as memory usage and bandwidth.

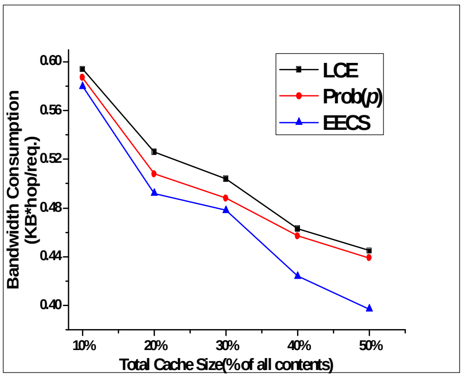

Figure 6.Bandwidth Consumption

V. CONCLUSIONS

In this paper, we consider a game between an Internet Service (access) Provider (ISP) and content provider (CP) on a platform of end-user demand. The energy-efficient non-cooperative caching strategy and replacement algorithm of the cost-performance ratio (CPR) in content-centric networking are proposed. Simulation results show that the strategy can effectively reduce network overhead and delay, and obtain better performance. As future work, we will further evaluate energy-efficient of the proposed mechanism under the different total size of CSs and we also plan to propose an energy-efficient cooperative cache strategy. Then the routers use different caching strategies to store contents under different situations to obtain better performance and improve the resource utilization.

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