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Energy-efficient networking for content distribution over telecom network infrastructure

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ABSTRACT

The use of content-based services over telecom network infrastructures is growing rapidly as user-generated content, over-the-top videos, on-demand videos, personalized TV with CatchUp/PauseLive features, etc. are becoming increasingly popular. To meet the demands of such services, content-delivery networks (or content-distribution networks (CDN)) are being deployed over these telecom network infrastructures in a similar fashion as traditional CDNs. However, with the increasing energy consumption and carbon footprint of the information and communication technology (ICT) industry, these CDNs must be designed to include energy-efficiency measures. Our study presents energy-consumption models, analysis, and content-placement techniques for different types of CDNs over telecom networks to reduce energy usage. Our suggested content-placement strategies exploit variations between storage power consumption and transmission power consumption to achieve energy efficiency. Also, in dynamic traffic scenarios, our content-placement strategies utilize the time-varying traffic irregularities of content-based services. By creating more content replicas during peak load and less replicas during off-peak load, dynamic approaches can save substantial amount of energy. Illustrative numerical examples show a significant improvement in the CDN energy efficiency using these approaches.

1. Introduction

Content-based services have gained tremendous popularity in recent years. As a result, telecom networks have experienced remarkable growth in content-delivery traffic [1]. This growth has been driven by the ubiquitousness of user-generated content, over-the-top (OTT) videos, video-on-demand (VoD), personalized IPTV with CatchUp/PauseLive features, etc. In addition, popularity of software application downloads and online entertainment content purchase are contributing to the increasing traffic. This worldwide traffic is already measured to be on the order of exabytes per month and forecasted to grow considerably [2]. Telecom service providers are experiencing challenges in meeting this increasing demand of content delivery. Fig. 1 (primary *y*-axis) shows the predicted growth of traffic for telecom networks. Hence, telecom service providers are considering the deployment of content-delivery networks or content distribution networks (CDNs) over the telecom infrastructure to meet these demands. CDNs over telecom networks bring the contents closer to the end-users or customers by hosting them at nearby locations. These CDNs also distribute the contents to balance the load on the network.

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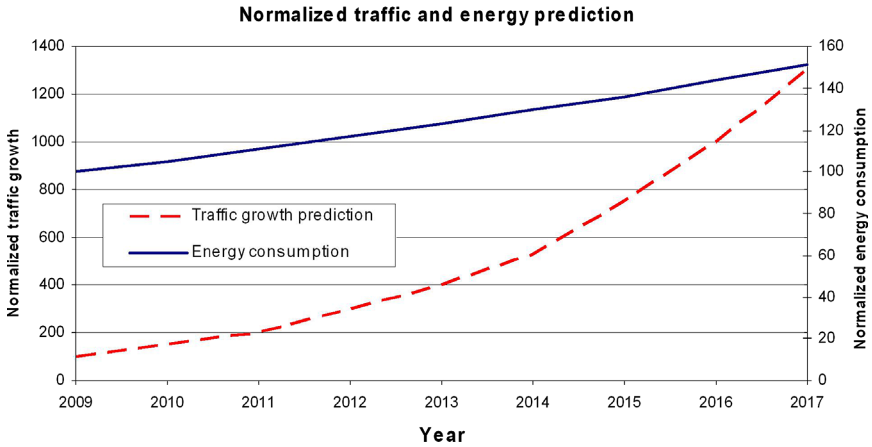

Fig. 1. Energy consumption forecast of telecom networks [4,11].

Contents can be hosted and delivered either from a few centralized locations, e.g., data centers, or from a large number of geographically distributed caching locations, e.g., caching nodes. CDNs replicate contents over these locations and route end-user requests to the nearest one. Large number of caching locations can bring the contents close to the customers but will increase the operational expense (OpEx). On the other hand, CDNs with a few centralized hosting locations are easier to manage and may be cost-effective but contents reside away from the customers. In this study, we investigate and analyze the energy-efficiency tradeoffs among these CDN architectures. Again, note that we consider CDNs over telecom network infrastructures, and these CDNs can be deployed and operated in a similar fashion as traditional CDNs.

Energy consumption – and hence the carbon footprint – of the information and communication technology (ICT) industry is a major concern [3]. With growing traffic demands and network usage, energy consumption of content-delivery services will add to this high carbon footprint. Lange et al. [4] estimated a substantial growth in future energy consumption of provider networks using state-of-the-art architectures and system technologies. The secondary *y*-axis in Fig. 1 shows the predicted energy consumption growth. Service providers, therefore, must ensure energy efficiency of their networks for current and upcoming services [5–7]. Moreover, energy-efficient networks will reduce the OpEx. Hence, service providers are exploring innovative energy-efficient ideas to reduce the energy consumed by their networks [8–10]. Consequently, design and implementation of CDNs should also consider energy efficiency.

Energy consumption of a CDN consists of three factors: transmission energy; storage energy; and energy consumed by heating, ventilation, & air conditioning (HVAC). While HVAC equipments are important contributors to the energy consumption, we do not consider them in our study as reducing transmission and storage energy will automatically reduce the HVAC energy. Storage energy is increased with more number of content replicas using more storage devices. However, many content replicas can bring contents closer to the end-users, thereby resulting in lower transmission energy. On the flip side, fewer content replicas and hence fewer caching locations will reduce the storage energy consumption but will increase the transmission energy. Our approach tries to find the appropriate content-placement strategies that will balance storage and transmission energy to reduce the overall CDN energy consumption.

Note that energy efficiency of CDNs depends on appropriate selection of content-caching locations which can reside at network edge, at network core (backbone), or at customer premises in a peer-to-peer (P2P) system. The authors in [12] show that a distributed CDN with multiple caching locations over a backbone network is more energy efficient than a centralized or a P2P approach. In a P2P system, with end-users as caching locations, contents have to travel the access network twice for remote delivery. This double traversal of the access network contributes to higher transmission energy. Moreover, a significant part of storage energy is offloaded to the end users by caching contents at end-user premises and thereby reducing storage energy consumption for the service providers. On the contrary, centralized caching of contents will increase the distance between customers and contents, thus increasing the transmission energy. Hence, in our study, we consider CDN solutions with multiple distributed caching locations over the backbone.

CDNs can also save energy by exploiting the difference between peak and low network usage. Networks are generally designed for peak load. However, their usage varies with the time of the day [13] as well as with social events, sometimes creating flash crowds [14]. As a result, the network consumes almost the same amount of energy during off-peak load as during peak hours. Turning off some equipments during off-peak hours and turning them back on during high traffic will reduce total energy consumption. We propose dynamic content replication schemes to exploit this network behavior to reduce energy consumption.

1.1. Related work

Energy-efficiency studies of CDNs are getting increasing attention in recent times. In [15], the authors analyzed