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Energy-aware cache management at the wireless network edge for information-centric operation

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ABSTRACT

Information-centric networking (ICN) promises to overcome the networking challenges of the current Internet, e.g. the explosion of content consumption and the widening gap between traffic and capacity growth, by decoupling the content from the network locations. Simultaneously, the dominant mode of content access in Internet is materializing as IP-based broadband wireless networks with advanced user devices and ubiquitous mobile systems. Current caching-based solutions largely focus on improving the efficiency of content delivery while mostly overlooking energy efficiency aspects. However, the expanding networking infrastructure is expected to be more energy-efficient conforming to "green communications" concept while serving burgeoning traffic demands. Motivated by this concern, we study caching at the edge of an infrastructure-based mobile network supporting ICN with a focus on energy consumption of the considered system. We devise a greedy heuristic for cache management which incorporates energy reward, popularity, Time-To-Live (TTL) and delay (i.e. chunk loss due to delay sensitivity) factors. Our numerical analysis proves the energy savings achieved by the proposed greedy approach with low-complexity operation.

1. Introduction

The Internet usage has drastically evolved from a point-to-point communication and exchange paradigm to a content dissemination and retrieval context. This circumstance has necessitated a more content-centric rather than a host-centric design. Information-centric networking (ICN) builds on this premise to overcome the shortcomings of address based routing/operation in the emerging era of pervasive and ubiquitous networking. ICN identifies content rather than network locations enabling the addressing schemes facilitated by application-level/social considerations. The incumbent design factor of resource sharing for the conventional IP is translated to a requirement for more service- and content-oriented operation (Carzaniga et al., 2011).

Another emerging condition is the mobile broadband explosion propelled with new services and content available anytime-anywhere. Hence, the upcoming broadband wireless standards are putting a bigger burden on mobile networks for serving the Internet traffic surge. Moreover, this diverse range of services and modalities bring forth new players and factors such as OTT (Over-The-Top) service providers (e.g. Netflix, Skype and YouTube) and P2P (Peer-to-Peer)-based content sharing, which heavily tax network resources. However, network operators generally cannot charge for these high bandwidth services while the network resources are stretched to provide adequate QoS levels. Additionally, administrative partitioning of networks among content and network providers impedes cooperation leading to lack of optimization on the end-to-end path. Therefore, countermeasures and remedies are crucial to mitigate these problems in next-generation IP networks. Information-centric operation is also posed as a vital apparatus towards this goal.

In this work, we consider an infrastructure-based wireless network which utilizes ICN paradigm for content (or information) based networking. Caching is a fundamental capability for ICN systems in order to enable scalable and cost-efficient content dissemination (Carzaniga et al., 2011). We elaborate on this aspect and propose an energy-aware cache replacement mechanism for improving the system performance. Energy efficiency (EE) at each network component has become more critical with dwindling energy supplies and deepening environmental issues. Accordingly, it is paramount to devise widely applicable algorithms and solutions for energy-efficient network operation (Gür and Alagöz, 2011). Although the adoption of information-centric approach for network architecture has the potential for enabling energy-efficient content dissemination, this new approach has to be energy-efficient in addition to being an energy-efficiency enabler (Lee et al., 2011). Therefore, our main focus as the

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performance objective is EE in this work. We develop our proposed mechanism considering the prominent factors on caching from the perspective of EE and low complexity.

The intersection of ICN and wireless networks are yet to be explored comprehensively, especially for the prospective 5G systems. Similarly, caching has been typically studied for ad hoc wireless systems and usually dealing with performance metrics other than EE. In that regard, the contributions of our work are as follows:

1. We propose a heuristic cache management scheme for energy-efficient operation of ICN in wireless content dissemination.
2. We devise a system model for caching at the edge of infrastructure-based mobile networks. This model is focused on EE analysis. However, it can be extended for other analytical purposes.
3. We investigate the effect of caching on the energy consumption of these systems. We present multifaceted experimental results on the interplay between different factors such as cache size, object size composition and popularity distribution in this setting.

In the next section, caching for wireless networks is described with a brief overview of related issues. Section 3 presents related work in the literature. In Section 4, we present the system model and system requirements. We also describe *Energy Aware Caching for Wireless ICN* (*ENACI*) which is a greedy algorithm for energy-efficient cache management problem for this setting. In Section 5, the experimental results are discussed for performance evaluation. Finally, we draw conclusions in Section 6 with a perspective on potential research directions.

2. ICN and caching at the edge of infrastructure-based wireless networks

The challenges faced by the current Internet architecture have led to numerous proposals for Future Internet protocols and architectures. The explosion of video and P2P traffic are among the prominent driving factors in these efforts. Although application-layer solutions, namely CDNs (Content Delivery Networks), P2P overlays and HTTP proxies, have already been deployed through the current Internet ecosystem, more substantial architectural changes are evident. For instance, CDNs are generally effective in shortening transport paths resulting in smaller delays and better throughput (Hasslinger and Hohlfeld, 2010). However, the deployment cost of CDNs and scalability issues are also prevalent (Pallis and Vakali, 2006). Therefore, research projects such as SAIL, PSIRP, COMET and 4WARD have proposed various networking models to realize Future Internet concept (Muscariello et al., 2011). ICN has been an active field in that regard with related efforts and proposals such as Data Oriented Network Architecture (DONA), Content-Centric Networking (CCN), and Publish/Subscribe Internet (PURSUIT) (Alzahrani et al., 2015).

An example ICN network is shown in Fig. 1. The ICN approach implies context resolution/service resolution instead of machine resolution (Psaras et al., 2011). Receiver-driven model and caching are two salient features of ICN. Clearly, this approach benefits the delivery of popular content (e.g. reduced delivery delay) and alleviates resource requirements (e.g. bandwidth and server load) in the network (Choi et al., 2011). Thus, the loose coupling between content and its originator provides opportunities to facilitate mechanisms for many of the prevalent issues with the current network architecture such as multicast, multipath routing and mobility (Jacobson et al., 2009). However, there are also substantial obstacles such as security and object naming/identification against ICN proliferation. Simply, the content has to be secure with proper confidentiality and credentials while being uniquely identifiable among a huge number of objects present in the network. Moreover, deployment of caches and in-network storage at different points in the interconnection, backbone and aggregation levels of a network is critical to improve the system performance for content consumption (Xu et al., 2014). According to Hasslinger and Hohlfeld (2010), main trends and forecasts regarding the Internet traffic envisage the doubling of global IP traffic through 2013 with video becoming the major source of traffic (video traffic will account more than 90% of consumer traffic

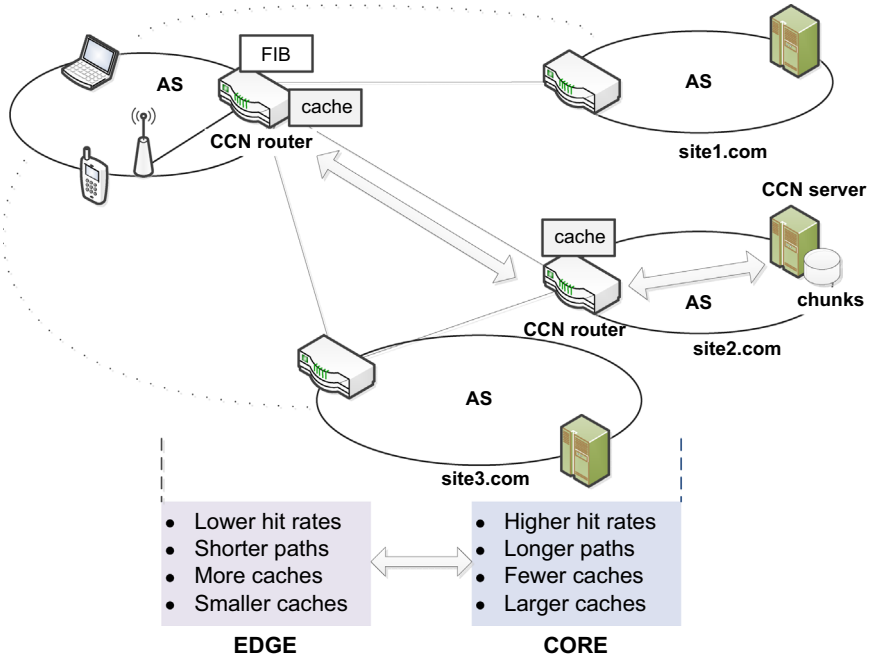

Fig. 1. An ICN example considered in CCN (Content-Centric Networking) proposal (AS, autonomous system; FIB, forwarding information base).