Comparing the Energy Efficiency of Protocols in Real Networks

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Abstract

This work examines energy-efficient distribution of static content within real networks. Energy use is an increasing concern, with the global telecommunications system and attached devices (ICT) consuming a larger supply of the global energy budget—already somewhere between 2-10%—and with network traffic growing exponentially. Exact numbers for the energy consumption of content distribution methods remain elusive, particularly for complex autonomous systems within the Internet. One proposal that is amenable to gradual migration of existing infrastructure is the insertion of content-centric networking (CCN) capabilities in selected routers; we examine here the energy efficiency of CCN-hybrid networks as compared to unicast and multicast dissemination in full-sized examples of several classes of real network topologies and physical hardware. Prior efforts at estimating the energy efficiency of content distribution methods have not taken specific, real, large-scale router-level network topologies into sufficient consideration; topology has an effect on performance in other areas of network estimation that raises interest in its effect on this question as well.

Introduction

The decades-long move toward a lower-carbon economy centers about modernizing the sources and uses of energy [3]. Cutting our energy use has been identified as one of the top global challenges facing society [4]. Historically, however, energy use has not been a primary concern in data networks, where the focus has been on cost, performance, thermal limits, and ease of maintenance [5]. Yet when any aspect of any system is growing exponentially, priorities can change rapidly; trends and events could conspire to bring the energy efficiency of network infrastructure under scrutiny. By the year 2020, Kilper has projected that traffic growth will overtake the best-case aggressive efficiency improvements that have been targeted today [6].

Content-delivery networks of servers (CDNs) are explicitly built to maximize specific objectives, but net energy minimization has typically not been one of them. In the past decade, research toward information-centric-network (ICN) delivery of static content has resulted in strategies that can deliver content efficiently in a more ad-hoc way, driven by local demand, and capitalizing on dissemination of content via recent demand to satisfy subsequent demand more locally. This can result in a quicker response with less network traffic, and Guan and Lee have also shown it to save energy, Guan over CDNs [7] and Lee over unicast [8].

Our goal is to assess the likely overall energy efficiency gain from gradually converting existing Internet infrastructure to an ICN model of content delivery. The work outlined here looks at this from a larger context of the energy efficiency of today's predominant and common forms of content distribution, bracketing the effect of best-case CCN hybridization using the model originally introduced by Jacobson [2]. Our work gauges the likely energy benefit of moving towards ICNs.

Methods & Results

Our observations are made in real terms of energy expenditure: the actual Joules saved at routers and switches from non-transmission of individual packets and bytes at individual routers and switches. Both ICNs and multicast capitalize on redundancy within multiple requests for content. For CCNs, these savings arise from satisfying the request more locally; whereas for multicast, savings arise instead from transmitting one copy of the content packets per link in the spanning tree from source to receivers. The full proposition and benefit of both multicast and CCN hybridization are captured based on the energy consumption on traffic due to unicast transmission from the source location to the set of receivers; this unicast traffic has no optimizations in place that minimize redundancy such as multicast or other forms of in-network caching.

We observe the utility of CCN features at each node of several large data networks. We then derive the CCN fielding scenario for which this transmission energy gain is maximized across a set of multiple large traffic logs generated for the network. This gives an ideal number and placement of CCN routers as substitutes for specific routers within the existing network infrastructure of router- and switch nodes and links.

We use simulated traffic over measured networks. For tractability traffic is considered for at most two of the incoming sources at the network periphery. The

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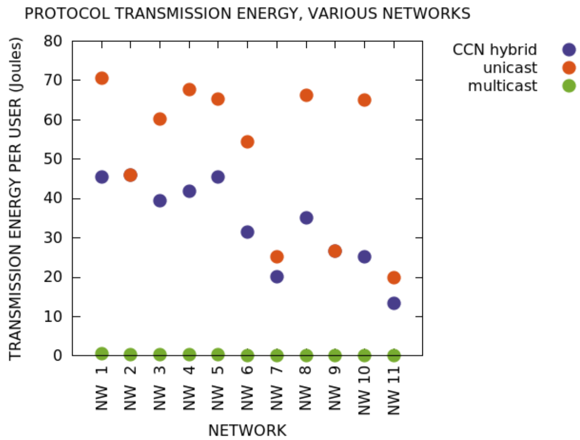

Fig. 1. Transmission energy per user for three content distribution protocols, as found in eleven separate networks. Multicast cost is 1% that of unicast; Networks 2 & 9 show no CCN hybrid improvement.

TABLE I
ELEMENTS AND VALUES WITHIN THE METHODS OF ASSESSING ENERGY EFFICIENCY.

Element	**Value [Attribution]**
physical networks	eleven intra-AS networks [9]
traffic	simulated unicast; 100 trials × 100K-5M requests [10]
content	4′12″ Youtube video, & www.google.com mobile
packetsize	1500 bytes [11]
source node	Border Router-connected [9]
delivery method	unicast/CCN hybrid [2]
router energy, switch energy	packet processing e [12] + store & forward e [12]
hybridization criterion	cost-based traffic log compression [10]
CCN features	incremental power [8]
link energy	load-independent [13], [14]

networks come from a study of eleven major autonomous systems that measured their physical level (within-AS-level) topology, for networks fulfilling various functions in the Internet (Tier-1, Transit and Stub) [9] collected by Marchetta and Mérindol [9]. This paper reports on some preliminary results of this investigation. Table I shows the details of the assessment and any simplifying assumptions made to provide the initial results; further detail will be reported in future work [10].

Figure 1 shows results on the relative cost of the three content distribution methods we have assessed so far. The Joules expended over the network on behalf of each user represent the different energy efficiencies of the three approaches, which capitalize to a different degree on content sharing between users' requests. The normalized values are arrived at by examining 100,000 content requests for a large network or 20,000 requests for a small campus network: a number sufficient to stabilize the results. Evident is the greater energy efficiency of adding CCN hybridization to the network over conventional point-to-point transmission to receivers. Also evident is the large savings from multicast transmission—encountered only if the requests are multicasted to the entire receiver group, in unison.

Preliminary findings provide an energy efficiency perspective on migrating existing real networks to support ICN features, relative to two common forms of Internet traffic today, unicast and multicast. It is anticipated that exponential growth in ICT traffic will increase the importance of these differing rates of energy consumption.

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