Energy Efficiency Issues in Information-Centric Networking

Torsten Braun (University of Bern)
Tuan Anh Trinh (Budapest University of Technology and Economics)

Email: braun@iam.unibe.ch, trinh@tmit.bme.hu

Abstract. In this paper we address energy efficiency issues of Information Centric Networking (ICN) architectures. In the proposed framework, we investigate the impact of ICN architectures on energy consumption of networking hardware devices and compare them with the energy consumption of other content dissemination methods. In particular, we investigate the consequences of caching in ICN from the energy efficiency perspective, taking into account the energy consumption of different hardware components in the ICN architectures. Based on the results of the analysis, we address the practical issues regarding the possible deployment and evolution of ICNs from an energy-efficiency perspective. Finally, we summarize our findings and discuss the outlook/future perspectives on the energy efficiency of Information-Centric Networks.

Keywords: energy efficiency, information-centric networking

1 Introduction

The Information-Centric Network (ICN) paradigm has shown great potential in empowering the users in future networks as well as supporting new and emerging applications. Recently, the paradigm of ICN has been developed to support future Internet applications. ICN supports the content- and service-driven communication scheme on which computing infrastructures (e.g. cloud computing) are based on. Information-Centric Networking is based on caching data in network elements, which are extended by appropriate memory to implement large caches. Caching data in network elements allows reducing the delay when accessing the data multiple times and distributes data somehow automatically without explicitly triggering the movement of data. This should improve the QoE experienced by users when accessing their data in the networks.

It can be observed that much research work so far focuses on architectural issues including naming and addressing as well as transport, caching, error control, flow control in ICNs. Socio-economic issues of ICNs such as security, privacy, and new business models have also been considered. However, caching of data in network elements raises issues related to energy consumption as well. Despite this fact, energy issues in ICN have not been received much attention and has not been investigated

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thoroughly. In this paper, we address energy efficiency issues of ICN architectures. In the proposed framework, we investigate the impact of ICN architectures on energy consumption of networking hardware devices and compare them with the energy consumption of other content dissemination methods.

2 Investigation of caching strategies in ICNs from energy efficiency perspective

Fast memory to be used for the implementation of caches is expected to consume much more energy (e.g., for refreshing cycles) than secondary memory technologies such as solid state disks or hard disk drives. Since caching can only be beneficial for high cache hit rates, large memories in network elements should be used. This further increases memory consumption. To limit energy consumption by ICN, appropriate mechanisms must be developed. Among those might be smart caching strategies to optimally exploit cache memories. Moreover, appropriate transport mechanisms supporting energy-efficient data transfer between cloud services/storage and mobile devices must developed and/or selected. Finally, ICN operation on top of wireless networks should use as little radio resources as possible and allow end systems to enter power-saving states as frequently as possible. Energy-saving mechanisms, however, come at the cost of quality degradation, in particular caused by lower throughput and increased delays. Energy-saving mechanisms should, therefore, be designed with QoE required by the user in mind.

2.1 Impact of caching/replication strategies in ICNs

Assuming a layered network topology as depicted in Figure 1, an interesting question with ICNs - from the energy efficiency perspective - is where (at which layer) to cache the content. The higher the layer on which content is cached, the less the duplication of data (and thus the less energy for storage of those contents). On the other hand, the lower the layer the content is cached, the faster is the content transmission. We can see that there is a trade-off here. It is necessary to quantify the energy consumption of transmission links and storage in order to design and evaluate the caching / replication strategies in ICN. In addition, the nature and the characteristics of the requests and the content being requested, e.g. how frequently content objects are requested, popularity of contents, etc. should be investigated as well. We consider that this is an important research challenge to be addressed in terms of energy efficiency in ICNs. The idea of caching strategies mentioned above is illustrated in Figure 1. In this simple example, content can be cached in the lowest layer, close to the clients. In this case additional energy is needed for the storage of the duplicates of the content (2 duplicates). However, the end system has direct access to the content, only with one link (no hop in between). The other strategy is to cache the content one level higher. In this case, less energy for storage is needed, but the energy consumptions for the links are higher, because there is one hop in between (one more link needed).

Assuming that each of the clients requests the same content object, the energy costs for the case where the content is stored on the lower layer is 4T+2S with T = energy

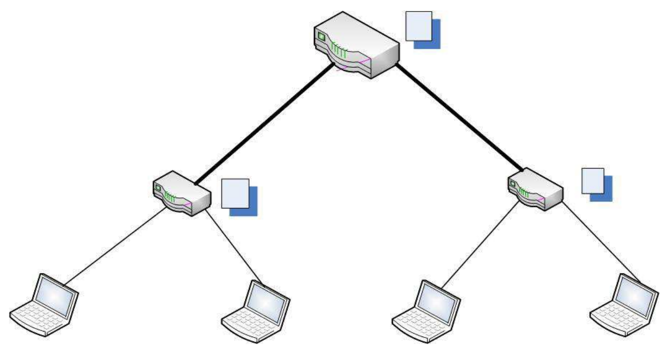

Figure 1: Caching options

costs for transporting a content object across a link, S = energy costs for storing a content object in the cache. For the case, where the content object is only stored at the highest layer, the overall energy costs are S + 8T. Caching on the lower layer is cheaper as long as S < 4T.

2.2 Hardware requirements

From a hardware perspective, it is important to note that memory access is the main bottleneck for packet processing of today's hardware router design. Energy consumption of additional memory largely depends on the performance of the memory components. Considering [1, 6] we estimate approximately 3 W/GB for DRAMs, 0.02 W/GB for hard disks, and 0.01 W/GB on SSDs in the following. The additional energy required for memory must be compared to energy required for transmission, which is estimated in [1] as 15 W/Gbps = 15 Joules/Gigabit.

ICN such as Content-Centric Networking (CCN, [9]) requires various additional memories in access and core routers. For CCN implementations additional memory for Forwarding Information Base (FIB), Pending Interest Table (PIT), and Content Store (CS) for packet caching is needed. To support line rates of 1 Gbps fast memories with possibly increased energy consumption are needed. [5] estimates that an appropriate core router consuming 5 kW without CCN support will use more than additional 3 kW due to additional memories needed for CCN. For the investigation of CCN-supported core routers, a Cisco CRS 1 router with 8 40-Gbps line cards has been considered. The authors propose to add 10 GB CS DRAM per line card plus some RL-DRAM for index tables as well as PIT and FIB memory in the range of GB range. As a result, the analysis in [5] concludes that the additional energy consumption to extend a core router to CCN functionalities would be of 3.3 W.

With respect to edge routers, a Cisco 7505 has been considered in [5]. In this case, the authors proposed to use a 1-TByte high speed SSD for the packet store, a 6 GByte

DRAM for HC-log indexing, and 200 Mbit SRAM for the on-chip FIB memory. Combined together, this configuration is expected to perform LPM (Longest Prefix Matching) on about 20 million prefixes at a maximum speed of 15 Mpackets/s. The analysis there also indicates that the additional energy consumption to extend an edge router (e.g. Cisco 7505) to CCN functionalities would be in the range of 200 W, while the original peak power is 400 W. A key lesson learnt from [5] is that it is possible and feasible to support CCN deployment in the CDN or ISP scale for reasonable additional cost and energy consumption. However, today's technology is not yet ready to support an Internet scale CCN deployment.

2.3 Analysis of energy overhead of ICN storage

In this section, we provide a simple calculation to analyse, in which conditions ICN makes sense in terms of energy-efficiency. This calculation is based on the assumption to use CCN as proposed by [9]. Whereas CCN is also considered as an approach with coupled name resolution and routing/forwarding of data, other decoupled approaches such as PSIRP [10, 11] have a preceding name resolution phase prior to data forwarding. The name resolution phase might add some slight overhead in terms of hops to be traversed compared to a situation, where CCN Interest and Data messages are transferred along the shortest path between requesting client and server/cache providing the requested content object.

In the following, we assume a scenario (Figure 2) with several clients, an intermediate CCN router, and a server. Further, the clients are all M hops away from the CCN router, which can serve the clients' content requests from its cache, and N hops (M < N) away from the server. The distance between server and CCN router is N-M. There are two options:

- No CCN support at all
- CCN support in the CCN router

For both options there are costs for the memory of the original content source. So, we can neglect those costs further, since they are the same in both options. We assume that there are K requests for the same content object by any of the clients from the server. Additional assumptions are that we have a rather optimal cache replacement strategy in the router. The additional required energy for serving K requests from the original content source is

$$E_{read\_from\_source} = K * N * E_{link} * datasize$$

The additional required energy for serving the request from the cache is

$$E_{read\_from\_cache} = K * M * E_{link} * datasize + T_{in-cache} * P_{storage} * datasize$$

ICN can help to decrease energy costs, if $E_{read\_from\_cache} < E_{read\_from\_source}$

This means:

$$\frac{K * (N - M) * E_{link}}{T_{in-cache}} > P_{storage}$$

$$\frac{(N - M) * E_{link}}{P_{storage}} > \frac{T_{in-cache}}{K}$$

Where:

$T_{in-cache}$: lifetime a content object is usually stored in the cache,
$P_{storage}$: power required to store a certain amount of data,
E_{link} : energy to transport a certain amount of data across a link.

$\frac{T_{in-cache}}{K}$ can be replaced by the average time between two accesses to the content object. We call this time the inter access time ($T_{inter-access}$). The access frequency (f) can be defined by $= \frac{1}{T_{inter-access}}$.

Thus, the equation above becomes to

$$\frac{(N - M)E_{link}}{P_{storage}} > 1/f$$

$$f > \frac{P_{storage}}{(N - M) * E_{link}}$$

As an example calculation we take the following numbers from above, with E_{link} = 15 Joules / Gigabit = 120 Joules / GB storage power = 3 W/GB for storage in DRAM, and assume that M = 1, N = 11. In this case, it can be shown that ICN only reduces energy consumption if *f* > (3 W / GB) / ((11-1) * (120 Joules / GB)) = 1 / 400 s.

This means that each content object should be accessed at least once from the cache within 400 s. This is equivalent to *9 accesses per hour*. Otherwise, ICN might not be energy efficient. In addition, there might some queuing issues due to energy costs for serving packets in the router queues. For example, if the K requests were served and the content objects were transmitted in parallel, then the calculation above would be valid again. If there is buffer (not cache) sharing and/or link sharing, then we might need to consider energy consumption for the buffer as well (in addition to $T_{in-cache}$). This energy consumption is different for different content objects, depending on when they arrive at the buffer (after fetched from the cache and before going out to the link). But again, there is also queuing delay (and consequently energy costs) in traditional CDN networks. It would be interesting to evaluate and compare the impact of queuing effects on ICN and other traditional CDNs.

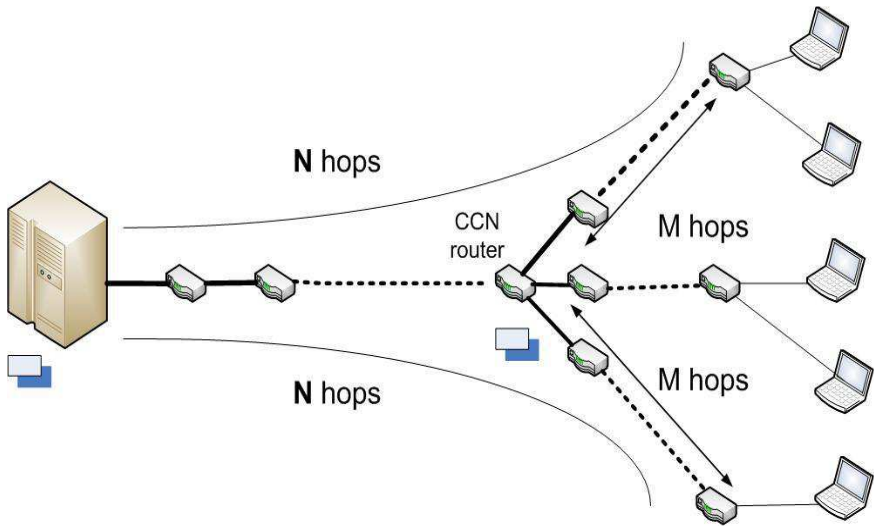

Figure 2: Network scenario for ICN energy analysis

2.4 Energy efficiency and performance trade-off in ICNs

The calculations above are a pure energy consumption perspective. However, to evaluate overall system performance, trade-offs between energy efficiency and performance could be of special interest. Note that one important aspect and also an advantage of CCN is to reduce networking delay, i.e., to serve the content as fast as possible, especially for delay-sensitive applications. In this perspective a useful and widely accepted metric to consider is the energy-delay-product. So even in the case of possibly higher energy consumption with respect to traditional CDNs, ICN might still be a useful approach for delivering data in terms of overall system performance.

3 Summary and outlook

This paper discussed energy efficiency issues in ICN. We provide an investigation on the impact of ICN architectures on energy consumption of networking hardware devices and compare them with the energy consumption of other content dissemination methods. In particular, by some preliminary investigation, we showed the consequences of caching in ICN from the energy efficiency perspective, taking into account the energy consumption of different hardware components in the ICN architectures. Based on the results of the analysis, we address the practical issues regarding the possible deployment and evolution of ICNs from an energy-efficiency perspective. There are still several open issues that require further investigation:

- The paper [1] deals with issues of CCN in fixed networks with simple calculations based on edge and core routers' energy consumption and trace-based simulations.

Since edge routers tend to spend more energy than core routers, it is argued that CCNs that try to bring routers close to content sources (using appropriate caching strategies) will help to reduce the overall energy consumption of the Internet. Issues remaining for CCN in fixed networks are power-aware routing traffic, consolidation in CCNs, and how to achieve/ensure energy proportionality (avoiding energy loss during idle time), among others.

- How the above mentioned issues can be done in CCNs for mobile/wireless networks can be considered as an open research issue. Furthermore, the analysis presented in [1] is rather based on brochure-like assumptions, no actual traffic modelling was mentioned. To have better understanding about the energy consumption with real/simulated network traffic included, a more detailed analysis would be required. A recent paper [12] substantiates the calculations and is a good starting point for further analysis.
- Optimal caching strategies of content objects for energy efficient content retrieval in ICNs (also trade-off between delay/performance and energy consumption) have to be investigated. Cache replacement strategies should explicitly consider energy costs in addition to performance-related parameters.
- There are several transport layer issues in ICNs from the energy efficiency perspective. What transport protocol should be used for energy-efficient data transfer in ICN? Can TCP still be used? If so, what phases can remain, what phases need be modified? Is coordination between TCP and edge/green routers needed? If so, how?
- The calculations presented in this report should be extended to include queuing delay (and probably for different caching strategies) to quantify the energy costs of storage/transmission in ICNs (in comparison with traditional CDNs). More advanced analytical models have to be developed. Simulations for larger network scenarios with different parameters for network topologies, content access models, content popularity, etc. have to be performed.
- The various solutions for the integration of ICN into wireless networks require further evaluation using both simulation and real-world testbeds.
- Network Coding might be useful for ICN in mobile wireless networks but it also requires additional caching decisions for withholding data in the memory. Consequently, feasibility analysis of Network Coding for mobile/wireless ICNs might be a research challenge (triple decision on caching time in the memory with respect to performance/energy efficiency).
- As proposed in this paper, ICN might be a networking technology to support cloud computing. Integration of ICN into data centres and possibly end systems should be investigated by means of real prototype implementations. Different approaches, e.g., coupled and decoupled ICN architectures, need to be investigated further.

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