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Optimal design of Information Centric Networks

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ABSTRACT

Information-Centric Networking (ICN) has recently gained momentum as a promising paradigm for the next-generation Internet architecture. The first prototypes for ICN-capable routers have already been developed; however, to migrate the devices to this novel architecture, non-negligible investments should be made. Therefore, it is of utter importance to provide clear quantitative insights of the expected economic benefits that operators will experience by switching to the ICN paradigm. For these reasons, in this paper we tackle the *content-aware network-planning* problem, and we formulate a novel optimization model to study the migration to an ICN, in a budget-constrained scenario. Our formulation takes into accurate account traffic routing and content caching. We prove that the optimization problem is NP-Hard, then we formulate heuristics to efficiently solve it. An extensive simulation campaign with real network topologies shows that our greedy heuristic cuts the computation time while finding close to optimal solutions, and therefore can effectively support network operators to evaluate the effects of a migration to ICN.

1. Introduction

Recent traffic measurements have clearly shown that more than 50% of the overall Internet traffic is generated to retrieve contents, as illustrated in the Sandvine Report and Cisco VNI forecasts [1,2]. However, being able to accommodate the content distribution needs of the users is still in today's Internet a challenging task, and adequate technical solutions such as Content Delivery Networks (CDNs) have specifically been designed to achieve this objective [3,4].

Meanwhile, innovative paradigms known under the name of Information-Centric Networking (ICN) have recently gained momentum in the research community. Despite the fact that there are many different designs that belong to this category, all of them are based on the idea that by directly intervening on the protocol stack, the content distribution capabilities of the network can be boosted [5]. Among all the advantages that can be experienced by switching to this novel infrastructure, *traffic offloading* stems out as being the most relevant achievement [6]. Despite that, other advantages can also be gained: lower delays, better security and multipath routing all integrate as positive features of these networks [7,8].

Rather than being in their preliminary steps, these research efforts have already reached the point where the first working prototypes for ICN-enabled routers have been realized by Alcatel [9], Cisco [10] and Parc [11]. Specific hardware and software components are required in order to support ICN packet forwarding at wire-speed, and thus operators will certainly have to make non-negligible investments to purchase the new ICN devices. As a result, they will be willing to transition their infrastructures to ICN only if clear economic benefits are envisioned: by upgrading a router to ICN and by installing a given amount of storage to memorize frequently requested contents, it will directly serve incoming requests

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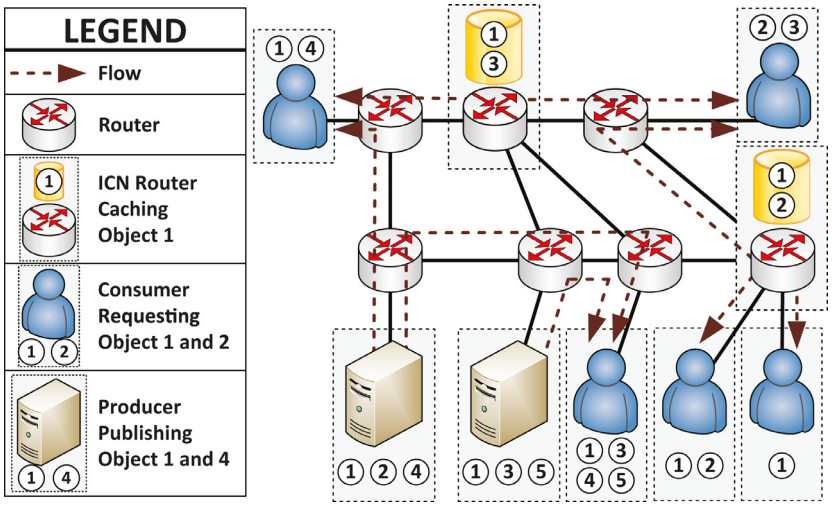

Fig. 1. *System model.* Given the network topology, consumers' requests, and objects served by content providers, our optimization model chooses which routers should be migrated to ICN, and which objects should they cache.

for the cached objects. In this way, given the fact that the content popularity is very skewed (i.e: few objects generate most of the traffic [12,13]), the operator can experience significant economic savings accountable to traffic offloading [14]. While CDNs may also be used to efficiently serve clients' requests, they are usually regarded as an expensive solution, since they demand to centrally orchestrate replica placement and request routing [15], while in ICN each network device will autonomously perform these choices, thus reducing the overall management costs.

To pave the way for a potential paradigm shift from a TCP/IP network to ICN, we specifically consider the *migration* step to the ICN architecture and we formulate a novel *content-aware network planning model* that we use to compute the optimal *migration strategy* for the operator. On top of that, by considering relevant economic parameters, our model can also be used to understand which economic benefits are expected as a result of the transition to ICN. To achieve all these objectives, we take into account three economic parameters: (1) a traffic-proportional link cost, (2) the router migration cost and (3) the storage cost, proportional to the amount of memory installed at a given ICN-migrated node.

To summarize, in this paper we provide the following contributions:

1. We formulate a model to evaluate the optimal content-distribution performance of an IP network under unsplittable routing conditions.
2. We propose a novel *content-aware network-planning* Mixed Integer Linear Programming (MILP) model for the *migration* to an ICN. Our formulation determines the optimal node migration and cache allocation in a budget-constrained scenario. Unsplittable routing conditions are still enforced by non-migrated routers.
3. We prove that the content-aware network-planning problem is NP-Hard, therefore we propose a novel and very efficient *greedy* heuristic, that outperforms the *randomized rounding* algorithm we designed in [16].
4. We compare the performance of the *randomized rounding* heuristic with the new *greedy* solver, showing that the latter dramatically improves the quality of the final solution while cutting the computation time of the heuristic of at least an order of magnitude.
5. We quantitatively evaluate the benefits of migrating to ICN, with different budgets as well as pricing configurations.

Our key findings suggest that (1) for a very large span of pricing policies, by migrating only few nodes to ICN remarkable traffic reductions will be experienced by the operator; (2) ICN benefits also content providers since it significantly offloads their distribution infrastructures, and (3) when the content popularity distribution is very skewed (i.e: most of the traffic is generated by few popular objects), the storage space installed at the migrated nodes is an order of magnitude smaller than for less skewed distributions.

This work highlights the importance of performing an economic analysis of the advantages that can be obtained by migrating to ICN, while performing a content-aware network-planning and explicitly taking into account the migration, storage and traffic costs.

This paper is structured as follows: in Section 2 we introduce the system model. In Section 3 we extensively describe the optimization models we use to compute the overall content delivery cost of an IP network and the content-aware planning model for the migration to an ICN. In Section 4 we illustrate our proposed *randomized rounding* and *greedy* heuristics for ICN, while numerical results are discussed in Section 5. Related works are presented in Section 6, and finally, concluding remarks are illustrated in Section 7.

2. System model

In this section, we describe the system model and discuss the rationale of our approach. A comprehensive introduction to some of the most notable ICN proposals can be found in [6].

Fig. 1 represents an example to describe relevant features of our proposed system model. Three types of nodes are available in the topology: consumers, producers and routers.