Position Paper

An Overview of Recent Research in Content-Centric Networking

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Abstract: In this paper, we provide an overview of the research papers published in the recently concluded content-centric networking workshop (CCN) held with IEEE MASS 2015. Our goal is to provide the reader a summary of the state-of-the-art research in the area of CCN, discuss some open problems and explore avenues of future research.

1. Introduction

In this paper, our goal is to provide the networking community a quick review of the state-of-the-art research in content-centric networking[2]. Specifically, we present a summary of the papers published in the recently concluded IEEE MASS 2015 Content-Centric Networking (CCN) Workshop and discuss some of the open challenges. We encourage the reader to refer the workshop proceedings [2] for detailed understanding of the papers. We next describe the aims and scope of the CCN workshop, quoted from [2] with minor modifications.

"With the exponential growth of content in recent years (e.g., videos) and the availability of the same content at multiple locations (e.g., same video being hosted at Youtube, Dailymotion), users are interested in obtaining a particular content and not concerned with the host housing the content. Also, the ever-increasing numbers of mobile devices that lack fixed addresses call for a more flexible network architecture that directly incorporates in-network caching, mobility and multipath routing, to ease congestion in core networks and deliver content efficiently. By treating content as first-class citizen, content-centric networking (CCN) aims to evolve the current Internet from a host-to-host communication based architecture to a content-oriented one where named objects are retrieved in a reliable, secure and efficient manner.

The CCN workshop provided researchers and practitioners an opportunity to meet and discuss the latest developments in this field. The outcomes of the workshop included 1) investigating and understanding some of the challenges in CCN, 2) fostering collaboration among researchers interested in CCN."

[2] Other names for content-centric networking include information-centric networking or named-data networking. There are multiple research efforts currently underway involving academic institutions and industry aimed at designing and implementing CCN prototypes [1, 3].

2. CCN Research Overview

The workshop facilitated some interesting discussion in CCN. Specifically, the participants explored and discussed issues related to routing and caching, fragmentation, security and multimedia streaming in CCN. We next present a summary of the published workshop papers.

Routing and Caching.

Unlike prior work that has mainly investigated routing and cache management techniques in CCN [5, 14, 15], papers presented at the CCN workshop explored deeper issues related to the routing overhead, energy consumption and distributed file sharing, that points to the increasing maturity of the field. *Hemmati et. al* compare the performance (i.e., overhead) of two name-based content routing protocols, namely the Named-data Link State Routing (NLSR) protocol and Distance-based Content Routing (DCR) protocol [9]. The performance metrics used for comparison purposes are the number of control messages sent, number of events processed, and number of operations performed by routers after the protocols are initialized. Their simulation results indicate that there is no clear winner; while NLSR incurs lower control overhead than DCR to react to name prefixes changes when the number of replicas is very small, DCR incurs less overhead than NLSR as the number of replicas increases.

In his keynote presentation [6] at the workshop, Prof. J.J. Garcia-Luna-Aceves also discussed the issue of overhead in CCN. He points out in his paper that *"the number of FIB entries stating name prefixes required for NDN and CCN to operate at Internet scale today is likely $O(10^8)$. By comparison, the size of routing tables maintained by high-end routers today is $O(10^6)$"* (quoted verbatim). He reexamines the mechanisms used in the forwarding plane in CCN architectures and proposes CCN-GRAM (Gathering of Routes for

Anonymous Messengers), an approach that reduces overhead by operating with a stateless forwarding plane. *Kurihara et. al* propose a strategy for grouping interest packets with similar information into a single one so as to decrease the computational overhead needed to look up large number of names of incoming interests in the FIB/PIT/CS entries in routers [10]. They demonstrate that their proposed scheme can reduce the computational overhead in routers to approximately 40% of a standard CCN implementation that works on individual packets.

The authors [16] analyze the energy consumption in CCN and demonstrate that in-network caching alone does not significantly reduce energy consumption. They then demonstrate that in-network caching compliments the energy-aware routing protocol proposed in [19] and enhances the energy reduction gains. In [4], the authors first showcase the advantages of the NDN architecture that supports the seamless integration of secure and distributed file sharing applications. They then present Chronoshare, a mobile-friendly distributed file-sharing applications that allow users to seamlessly share files regardless of device type, mobility (i.e., stationary, mobile) or connectivity patterns (i.e., constantly or intermittently connected).

Fragmentation.
Another important issue in CCN that received significant attention in the workshop is fragmentation. CCN disseminate data using hierarchical names for the different data chunks; if these data chunks exceed the maximum transmission unit (MTU) for Ethernet, then they need to be fragmented. In recent times, multiple hop-by-hop, end-to-end, and mid-to-end fragmentation schemes for CCN have been proposed. Instead of proposing a new fragmentation protocol, *Ueda et. al* analyze the performance of end-to-end fragmentation in terms of cache hit ratio and header overhead [17].

Secure fragmentation is investigated in [18], where the authors propose Named Network Fragments (NNF), an approach that improves upon the existing FIGOA protocol [8]. One of the main drawbacks of FIGOA is that signature verification is delayed until the last fragment is received as the signature is dependent on the hash computed based on the entire message (content object chunk). Additionally, the hash-based content retrieval in FIGOA is dependent on the message name; as content names in CCN may be potentially unbounded, this presents a significant challenge. The NNF protocol not only overcomes the above-mentioned challenges of FIGOA, it also allows users or routers to selectively request and retransmit fragments of a content object chunk.

Multimedia Streaming over Wireless Networks.
The workshop also included interesting papers related to multimedia streaming over wireless CCN. Via a small scale measurement study over a WiFi media streaming testbed comprising of five nodes [13], the authors show that *"bandwidth consumption between a content publisher and its forwarder (i.e., access point) over Wi-Fi can be effectively and dramatically reduced by NDN, offering much better scalability than IP"* (quoted verbatim). However, their experimental study also indicates that CPU utilization in NDN can be significantly higher in comparison to IP networks, indicating a need for further exploration. *Liu et. al* [12] combine caching and software-defined networking techniques in the design of CloudEdge, a computation-capable and programmable wireless access network architecture that maintains a good Quality of Experience (QoE) of multiple videos streams, while taking wireless transmission capacity and in-network computation power constraints into consideration.

4. Conclusion
The papers presented at the workshop provided preliminary solutions to important research problems related to routing overhead, security and improving quality of experience of video streams in CCN. The primary factors impeding real-world implementation and adoption of CCN architectures are related to the overhead incurred in maintaining the data structures needed in CCN. Future research should focus on analyzing and reducing the overhead incurred in CCN.

Security and privacy in CCN have received limited attention so far. Cybersecurity has been identified by NSF as one of the research areas requiring immediate attention [11]. Hence the success of CCN hinges on identifying attacks exclusive to CCN architectures and implementations and proposing effective countermeasures. In-network caching opens up the possibility of a plethora of new denial of service (DoS) and timing attacks that exploit cache characteristics to degrade performance and steal private information. An overview of possible DoS attacks in CCN is provided in [7], but in-depth investigation of these attacks is an important area of future research.

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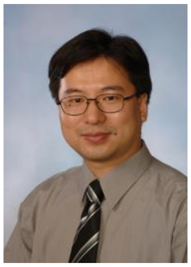

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