

# Flash-Forward CCN: Flow-driven Forwarding Architecture for Content Centric Networks

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## ABSTRACT

Content-centric Networking (CCN) promises significant advantages over the current Internet architecture by replacing its host-centric design with a content-centric one, and enabling in-network caching and name-based forwarding. However, despite its advantages, wire-speed forwarding in CCN remains a challenge, as CCN uses stateful forwarding and requires lookups on packets carrying hierarchically structured and variable-length content names. As a result, storage and computing requirements to support name-based forwarding in CCN determines the forwarding capacity.

In this paper, to address the forwarding scalability concerns in CCN, we propose an overlay forwarding architecture that utilizes a flow-driven adaptive forwarding strategy and tradeoffs between flexibility and scalability. The proposed architecture exploits the correlations in user traffic to create active flow states in content routers to bypass the default CCN forwarding for future requests.

## 1. INTRODUCTION

Information-centric Networking (ICN) is a new networking paradigm that addresses the shortcomings of the current Internet architecture by shifting the focus from host-centric communication model to a content-centric one [1]. ICN uses a unique naming convention to name the content, which represents the main driving force for information dissemination. ICN architectures are uniquely defined by how they handle *naming* and *name resolution*. Our research focuses on the Content-centric Networking (CCN) architecture [2], which uses hierarchically structured names, and addresses one of its major challenges, scalable forwarding [3].

CCN relies on the pull model to acquire content, with client sending explicit requests (*i.e.*, *Interests*) for the named content (*i.e.*, *Data*). *Interests* are forwarded using name-based forwarding, with each Content Router (CR) resolving content name to an outgoing interface by performing lookups on the forwarding information base (FIB) (if no match is found in the Content Store (CS)). As FIB size is expected

to scale to hundreds of millions of entries, or more, in CCN, accessing FIB entries in a timely manner to support forwarding at line speeds of 100Gbps or higher becomes a critical concern. As FIB access requires the use of longest prefix matching (LPM), false positives limit the efficiency of LPM. Furthermore, since FIB is implemented on the high-latency off-chip memory, accessing those entries and making a forwarding decision can easily take hundreds (or thousands) of processing cycles [4]. The above problem is exacerbated if the router regularly receives packets leading to many false-positive triggered checks, for instance, in the case of end-to-end content flows that can generate hundreds or thousands of requests during the lifetime of a flow.

To efficiently address the scalable forwarding problem in CCN, we need approaches that are capable of switching an incoming packet over the matching outgoing interface after parsing the header, instead of performing lookups locally. In this paper, we present one such approach, which supports flow-based fast forwarding for CCN.

## 2. PROPOSED ARCHITECTURE

The proposed flow-driven forwarding solution limits the number of lookups performed on an end-to-end basis by enabling the bypassing of certain hops along the path to the content source. For that purpose, we make use of the previously made *local* forwarding decisions to speed up the processing of *Interests*. To support *hop-bypassing*, we include three additional fields in the Interest header (as shown in Figure 1), namely the Flow-State (FS) field, the Forwarding Segment Label (FSL) field, and the Flow-Hash (FH) field. FS indicates whether or not the Interest packet utilizes or takes advantage of flow state information, and if it is, the status for the flow.<sup>1</sup> FH is used to identify the flow as assigned by the Producer. Variable-sized FSL carries the related fast-forwarding information, *i.e.*, number of hops using Hop-Count (HC) field, and forwarding interface list, using a sequence of forwarding-component size (F-CS) and forwarding-interface value (F-IV) fields. F-CS represents the number of name components initially used by the local forwarder to find the outgoing interface towards the next hop, and F-IV identifies the outgoing interface value at the given hop. Note that, components included within the FSL are updated at each forwarding hop.<sup>2</sup>

<sup>1</sup>A bit-string of 00 indicates default *no-flow* state; 01 signals the need to set-up flow-states along the path; 11 indicates the presence of an active flow; and 10 signals the end of an active flow.

<sup>2</sup>For instance, HC is decremented at each hop, while the local forwarding parameters (F-CS and F-IV) are removed from the Interest before forwarding it to the next hop.

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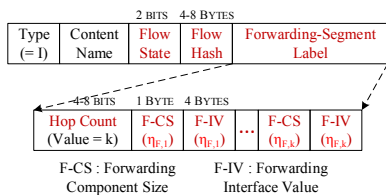


Figure 1: Proposed PDU format for the Interest.

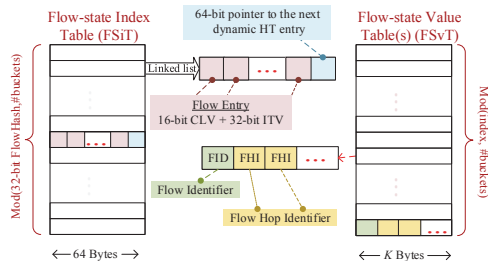


Figure 2: Structure of the flow state table.

To enable quick access to local flow states as opposed to directly accessing the FIB, we create a third database (in addition to Pending Interest Table (PIT) and FIB) referred to as the Flow State Table (FST) to contain all the active flow state information. The general structure for FST is shown in Figure 2, which uses compact array buckets to organize the flow table entries (as suggested in [4] for the FIB). FST is hierarchically structured to include two sub-tables: Flow-state Index Table (FSiT) and Flow-state Value Table (FSvT). FSiT is used to (i) check for the existence of entries, by locating with the initial 4-Byte portion of the FH, and matching Component-Length-Value (CLV) field<sup>3</sup>, and, if the entry exists, (ii) locate the associated forwarding parameters using Index-Type-Value (ITV) field pointing to a matching entry in FSvT. Each FSvT entry consists of a Flow Identifier (FID) field (representing the last 4-Byte portion of FH and 2-Byte long outgoing interface metric), and multiple Flow Hop Identifier (FHI) fields (representing forwarding parameters for the future hops).<sup>4</sup> For each flow, forwarding parameters are stored within one of the available FSvTs (depending on the maximum allowed hop count).

To setup the flow states, Consumer sends the first Interest with FS set to 1, and FH equal 0. After the Interest is received by the Producer, Data delivery ensues along the reverse path, using CCN’s breadcrumb approach. Data packet format is modified to enable flow table setup along the reverse path, by assigning the FH and setting the FS to 1. Each hop extracts the flow information from the Data to update its FST, while updating FSL within Data. After an FST is populated with active flow entries, forwarding lookup procedure follows the state flow diagram shown in Figure 3 (summarizing the steps after CS/PIT check, with no match).

To terminate an ongoing flow and clear the active flow-states at a CR, either (i) Consumer side sends an Interest with FS set to 2<sup>5</sup>, or (ii) Producer sends Data with FS set to

<sup>3</sup>CLV combines component and character length for the routable portion of content name extracted from the Data packet.

<sup>4</sup>FID is 6-Byte long, and FHI is 5-Byte long.

<sup>5</sup>If a flow’s data is shared by multiple Consumers, then corresponding flow entries are placed into a pending state, and a timer

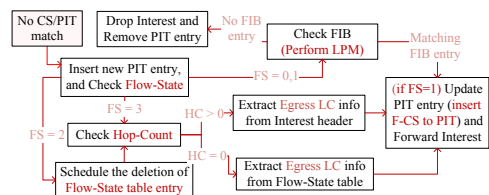


Figure 3: Modified forwarding lookup procedure at an FF-CCN router, based on FS/HC values.

2, requiring matching entries to be immediately flushed out from the routers along the reverse path to the Consumer.

### 3. PERFORMANCE ANALYSIS

We numerically analyzed the performance of our solution following the architecture considered in [4], which studied the performance of an optimized NDN forwarder implemented on an ISM-enabled ASR9000 router running on 2 multi-core 2GHz Xeon processors. We analyzed the overhead (consisting of parsing, hashing, PIT/CS lookup and/or insert or delete, and FIB lookup including reads from the high-latency off-chip memory) corresponding to Interest/Data processing, and approximated the ratio of FIB lookup, which can reach up to 60%.

We observe that by minimizing the need on FIB lookup or avoiding it whenever possible, which is possible with the proposed architecture, we can reduce the overall processing overhead for an Interest-Data pair by more than 44%, allowing a CCN router to almost double the number of packets it can process per second. Furthermore, with additional hardware support (i.e., on-chip Bloom filters to search for existing PIT/FIB entries), use of faster memory components to store the PIT entries, and overhead limited to memory access (which suggests that the majority of the overhead is due to FIB lookups), we observe 4-to-12 times performance (i.e., forwarding capacity) improvement. By also storing FST entries on faster memory components (due to smaller space requirements, e.g., same number of entries requires 70% less space with FST when compared to FIB), we can significantly reduce access time to flow entries (i.e., more than 5 times when compared to FIB access latency).

Lastly, we observe that significant energy savings are possible with the proposed architecture, with improvements proportional to active flow count, ratio of flow-based traffic, and line rate, to support green networking.

### 4. REFERENCES

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is started to initiate their purge, if no request is received during that period.