

# Prefetching Bloom Filters to Control Flooding in Content-Centric Networks

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## ABSTRACT

We address an issue relevant to Content-Centric Networks, in which content is discovered by flooding a request over the entire network. In our design, the collection of objects resolvable by a router is represented using Bloom filters. In response to the flooding, we send Bloom filters – in essence transmitting all the object names represented within a router – along with the object. In this manner, any subsequent request to an object represented within that Bloom filter will not need to be flooded. We present preliminary observations to validate our claims.

**Categories and Subject Descriptors:** C.2.5 [Computer-Communication Networks]: Local and Wide-Area Networks - *Internet*

**General Terms:** Design, Performance

## 1. INTRODUCTION

There is growing interest in an information-centered paradigm for the future Internet, in which there is less focus on the physical machines where content is located. This involves a shift from the traditional host-to-host communication paradigm to an object-based communication paradigm in which content is the focal point. There are several ongoing projects aimed at developing this new paradigm: 4WARD project [9]; PSIRP [8]; Content-Centric Networks [6]; DONA [7].

Content-Centric Networks (CCN), proposed by Van Jacobson at PARC, is one of the more prominent ones. CCN uses URIs as global identifiers to name objects. It has two types of packets: Interest and Data packets. A CCN node requests an object/content by flooding an Interest packet. Since CCN uses hierarchical (URI) names, it adopts the longest-prefix match of IP addressing.

Two issues of scalability present themselves: a large number of object names have to be dealt with even after aggregation (e.g., there are currently more than 120 million two-

level domain names such as `www.acm.org`); flooding Interest packets for every object seems too burdensome. Hence, CCN needs a scalable representation for the object names – so that they can fit in the routing tables – and a controllable number of flooded messages that do not overwhelm the network. Our proposal focuses on these issues. We are currently focusing on intra-domain routing, leaving inter-domain routing for future work.

## 2. PROPOSAL

Bloom filters (BFs) [1] have been used in the context of IP forwarding for longest prefix matches [2]. A BF is a probabilistic bit-vector data structure that uses hash functions to demarcate element membership in a set. A BF can then be queried for elements using the same hash functions. The relative size of the BF vs. the set is called the load ratio and critically determines the rate of false positives.

Christian et al. [3] proposed a forwarding plane that is generic for Information Networks. They represent each interface with a variation of BF which is updated with object names that are accessible through that interface. It is important to note that advertisements – flooded Interest packets in the CCN case – for these objects will arrive on that same interface. In the case of CCN, the number of advertisements updating such BFs will be very large because there is a limit to the amount of object aggregation achievable with two-level domain names. We examine the number of such advertisements and how to control them.

We propose an approach similar to that of Fan et al. [4] in which BFs are transmitted as content summaries between web caches. A router B that is able to respond to a received Interest will transmit Data packets back to router A which ‘originated’ that Interest; with the Data packets, we also include a BF summary, which is a collection of aggregated object names known to router B. A subsequent Interest from router A for an object in the BF summary could then follow the same route discovered by the previous (flooded) Interest packet without itself needing to be flooded.

Figure 1 shows a network in which router R6 wants an object ‘located’ at R8. Initially, routing tables contain BF summaries only for the objects available at a router’s local subnet. An Interest packet originating from the local subnet of R6 is flooded into the network. R4 will receive two duplicate Interest packets (via R2 and R5). Assuming, the one from R2 arrives first, it will be forwarded and the other, from R5, will be discarded. R8 will satisfy the Interest by

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sending Data packets along the reverse path of the Interest. This is the normal operation in CCN.

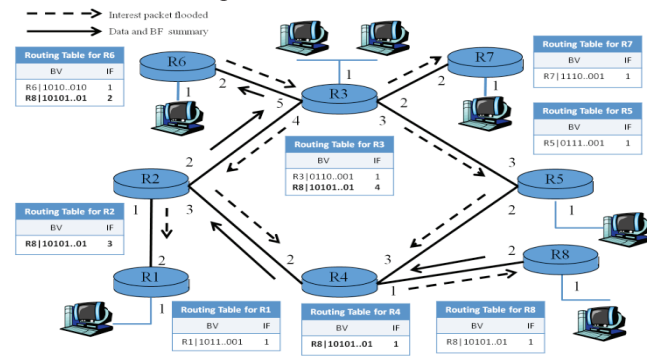


Figure 1: Interest, data and BF in the network

In our case, we will also send R8's BF summary along with the Data packets. Intermediate routers (R4, R2 and R3) along the reverse path from R8 to R6 store the BF summary in their routing tables, as does R6. Received BF summaries are associated with the interface on which they arrive. Subsequent Interests for objects known to R8 can then be satisfied from R2, R3, R4, and R6 without flooding. Moreover, after a certain period most BF summaries will be known to most routers and little to no Interest flooding will be required in the network.

### 3. PRELIMINARY OBSERVATIONS

In essence, our scheme has each router prefetch the BF summaries of other routers to avoid flooding. To illustrate the potential efficiency gain of this approach, suppose that the number of objects initially known to a router is 1 million ( $2^{10}$ ). With two hash functions, a BF of size 256KB/1Mb – i.e., load ratio 8 – yields a false positive rate of 0.0489 [5]. Using SHA hash functions, an object name in an Interest packet can be represented as a 16KB fixed-length string.

In Figure 1, flooding a single Interest packet requires the transmission of a 128KB total in the network (16KB x number of links). The overhead involved in transmitting a BF summary from R8 to R6 is 1MB (256KB x 4 links). The break-even point is when 9 requests, each for a distinct object, are made from R6 to R8. Under normal operation, each of these would have to be flooded. Under our scheme, the first request would be flooded and the corresponding Data incur the BF summary transmission overhead, but the remaining eight requests would not. Further such requests would, under normal operation, continue to incur additional flooding cost, but not so under our scheme using BF summaries. As the BF summaries spread, the amount of overall Interest flooding will continue to diminish in the network.

### 4. FUTURE WORK

We are still in the early stages of this work. Our initial scheme is conservative, whereby BF summaries are transmitted following the Data packets. We are exploring enhancements to the schemes that are more aggressive: (a) the BF summaries are transmitted following Interest and Data packets; and (b) the BF summaries not only are transmitted

following Interest and Data packets, but all intermediate routers transmit their BF summaries while forwarding an Interest and Data packet. Using these schemes, the routing tables fill-up quickly compared to our current conservative scheme. Overall, they will incur lower overhead. We use an extra entry in the routing table to avoid redundant transmission of duplicate BF summaries.

We need to look into the interplay of BF summary sizes and the possible need to split a growing AS into distinct sub area (along the lines of OSPF). This in itself necessitates researching the mechanisms for implementing the backbone, which in turn has striking similarities with important aspects of how inter-domain routing would need to be implemented.

At the present preliminary stage, we are assuming that all routers are in the same relatively small internet; and hence, are using the same hash functions. The query computation is simplified if all the BF summaries associated with an interface were merged – OR operation – into a single BF summary of the same size. But this reduces the load ratio and increases the rate of false positives. We are exploring the notion of using different hash functions at each router to create the BF summaries as an alternative solution. The query computation cost will increase as each BF summary at a router is evaluated using its own corresponding hash functions. Additionally, these hash functions will need to be exchanged between routers. We are also viewing the feasibility of applying this same technique for inter-domain routing, for which the AS's are under different administration so using the same hash functions is not feasible. All these are important items of future work for us.

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