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Review

Congestion control in named data networking – A survey

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ABSTRACT

As a typical Information Centric Networking, Named Data Networking (NDN) has attracted wide research attentions in recent years. NDN evolves today's host-centric network architecture TCP/IP to a data-centric network architecture. It turns the end-to-end connection-oriented transport of TCP/IP into receiver-driven connectionless transport. Compared with the traditional TCP/IP networking, the transport in NDN has new characteristics: *Receiver-driven, One-Interest-one-Data, Multi-Source, and Multi-Path.* These distinguished features pose new challenges to NDN congestion control mechanisms. This paper presents a comprehensive survey of state-of-art techniques aiming to address these issues, with particular focus on improving the effectiveness of congestion detection and the efficiency of Interest rate shaping. As a new research area, this paper also points out research challenges and open issues in this subject.

1. Introduction

Information-Centric Networking (ICN) has emerged as a promising candidate for the future Internet architecture. Named Data Networking (NDN [1,2]) is recognized as one of the most typical ICN architectures [3,4].

NDN was first proposed by Van Jacobson in 2009 [1]. Soon, it got positive responses from many researchers, as well as the NSF project support [5], and it has become a hotspot in the research of future Internet architecture. NDN rethinks and redesigns the current Internet architecture. The traditional Internet architecture is originally designed mainly for communication between exactly two machines. Most of the traffic on the Internet consists of connection-oriented TCP conversions between pairs of hosts. However, after a rapid development for more than half a century, great changes have taken place in the scale and applications of the Internet. Humans have entered into the era of "Big Data" and the main application mode has also been changed from text communication to information accessing and distribution. However, it is difficult for the current Internet architecture which is designed for the end to end communications to meet this change. Many problems emerge in terms of transport efficiency, security, mobility, etc [75–77]. Therefore, the NDN architecture is proposed to tackle these challenges by changing the focus of the Internet architecture from the current "where" (location) to "what" (content), centering on the named content (Data) rather than IP.

Compared to the traditional TCP/IP networking, NDN basically has the following new features [1,2,5]:

- It defines the name identifying content, and the routing is based on content name rather than IP address;
- It utilizes pervasive in-network caching to serve the requests by any potential content sources in the network rather than a single content source;
- It separates the routing and forwarding plane so that the forwarding strategy can be adjusted according to the data plane delivery feedback, allowing natural implementation of multi-path adaptive forwarding [6];
- It adopts the receiver-driven transport mode so that the data transfer can be controlled by adjusting request strategies at the receiver side;
- It secures the content itself rather than the communication channel [7].

Thanks to the above characteristics, NDN has many advantages in transfer efficiency [1], security [89] and mobility support [90] and some other aspects [91] compared to the traditional network. Therefore, it can better satisfy the requirements of the present and future applications.

Since the research on NDN is still in its initial phase, a number of specific technologies are still being studied, such as content naming [78], routing [79,80], transporting, content caching

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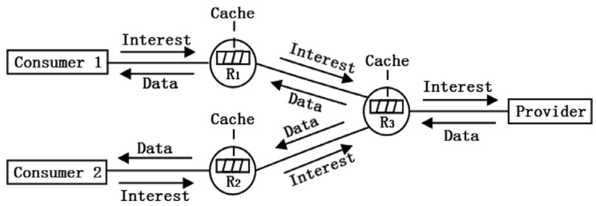

Fig. 1. NDN transport mode.

[48] and forwarding [29,81], security and privacy protection [82] . In this paper, we will analyze and summarize one of the key technologies, transport control technology especially the congestion control mechanism.

The contributions of this paper mainly include the following aspects.

- We identify the congestion control problems in NDN by analyzing the new features of the transport control in NDN, the problems of the traditional TCP[1] congestion control algorithms in NDN and the advantages of congestion control in NDN.
- We conclude and propose the methods of designing congestion control mechanisms for NDN, mainly including the receiver-based congestion control method, the hop-by-hop Interest shaping method, and the hybrid method. We also analyze the specific ideas of these methods and give typical examples. Moreover, we highlight the comparison among current typical schemes.
- We discuss and point out the research challenges and open issues for congestion control in NDN.

The rest of this paper is organized as follow. In Section 2, we introduce the transfer mode of NDN, compare the transport modes between NDN and the traditional TCP/IP networking, and point out the problems of using the traditional TCP congestion control algorithms in NDN and the advantages of the transport control of NDN itself. In Section 3, we analyze the methods of designing congestion control mechanisms for NDN and classify them into three categories: receiver-based control, hop-by-hop control and hybrid method. During the analysis, we discuss and compare the typical existing NDN congestion control algorithms and transport protocols. In Section 4, we point out the research challenges and open issues for congestion control in NDN, including the NDN transport model, congestion control mechanisms and performance metrics. Lastly, in Section 5, we conclude the whole paper.

2. Congestion control issues of NDN

2.1. NDN transport mode and new features

The transport control mechanism is one of the key technologies that need to be studied in NDN. The transport mode in NDN is quite different from the traditional TCP/IP network. As illustrated in Fig. 1, there are two NDN packet types, Interest and Data. Each NDN node (as shown in Fig. 2) has three main data structures: the Forwarding Information Base (FIB), which serves like IP FIB for routing, the Content Store (CS), which is used to cache content passing through, and the Pending Interest Table (PIT), which keeps track of Interests forwarded upstream toward content source(s) so that returned Data can be sent downstream to its requester(s)).

The basic communication process can be described as follows: Consumer 1 asks for content by sending out an Interest packet,

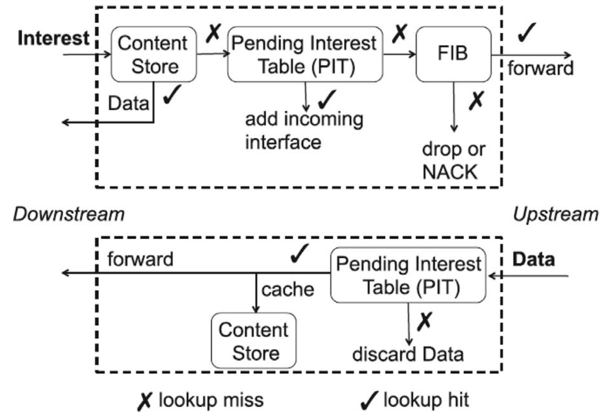

Fig. 2. Interest and Data processing in NDN node [6].

which carries a name that identifies the requested data. When received the Interest, the router R_1 first checks its CS, if there is already a Data packet in the CS that matches the Interest, R_1 will respond directly and send back the requested Data packet. Or else, it will record this Interest in the PIT table and forward this Interest by the FIB table. When the provider receives the Interest, it replies by sending back the corresponding Data. Data is not routed but simply follows the chain of PIT entries back to the original requester(s). While transferring Data, to maximize the probability of sharing, which minimizes upstream bandwidth demand and downstream latency, it will be cached in all the routers along the path as long as possible (Replacement algorithm is used, e.g., LRU or LFU). If Consumer 2 requests for the same Data, it can get it from the cache of router R_3 instead of the provider.

Compared to the traditional TCP/IP networking, transport in NDN mainly has the following new features:

- *Receiver-driven "Pull" mode*. A receiver requests content by sending Interest packets, and then, the data source nodes that satisfy the requirements return the requested data.
- *One-Interest-one-Data transport mode*. One Interest retrieves at most one Data packet. This basic rule ensures that flow balance is maintained in the network. Multiple Interests may be issued at once before Data arrives to consume the first Interest.
- *Multi-source transport*. As the transport of NDN is connectionless and content can be stored in network, a receiver can obtain the content responded by multiple content sources including the original content repositories and caches of intermediated nodes.
- *Multi-path transport*. NDN architecture intrinsically supports dynamic multi-path forwarding. The IP routing usually adopts a single best path to prevent loop[2]. The Multi-path TCP [33] only performs at the receiver over static paths. However, in NDN, routing is separated from forwarding, so it can adjust the forwarding strategy according to the delivery performance of data plane to make multi-path forwarding [29]. Interest loop is likely to be prevented, since the name plus a random nonce can effectively identify duplicates to discard [5]. On the other hand, Data do not loop since they take the reverse path of Interests. Thus multi-path communications can be safe of looping problems in NDN.

[1] There are many variants of TCP [12]. For simplicity and convenience, in this paper, when we mention TCP, it means the basic TCP version Reno TCP [97].

[2] There are some multi-path IP routing strategies like ECMP [92]. However, there may be significant problems in deploying multi-path routing in practice [92] and multi-path routing is not yet widely deployed in practice [93].