Analysis and Performance Evaluation of Data Transport Methods in Content-Centric Networking

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***Abstract*—The volume of global IP traffic is expected to exponentially grow because of the increasing consumption of multimedia contents and the increasing usage of mobile devices. To cost-effectively handle the data traffic explosion, Content-Centric Networking (CCN) was proposed as an alternative to the traditional IP networking. A CCN's basic data transport method is pull-based but some of applications require a push-based method as well; there are three different approaches to support push in CCN. In this paper, we propose a bandwidth consumption model of the CCN-based pull and three push methods and evaluate bandwidth performances of them using the proposed model.**

***Index Terms*—Content-Centric Networking, Data Transport Methods, Performance Evaluation**

I. Introduction

Current IP-based networking lacks of ability to cost-effectively handle the data traffic explosion incurred by increasing consumption of multimedia contents and increasing usage of mobile devices. As an alternative to the traditional IP networking, Content-Centric Networking (CCN) [1] was proposed. CCN is a new approach for data communications that focuses on the content itself rather than the destination host, and it is regarded as a promising candidate for complementing or (eventually) substituting current IP networks. CCN has advantages in terms of bandwidth consumption, security, and mobility in comparison with IP-based networking.

A CCN's basic data transport method is pull-based but some of applications require a push-based data transport method as well. For example, a VoIP service has to push call signalling information from a caller to a callee. We have found three different CCN-based push methods from the literature [2]–[4], which have their own advantages and disadvantages. In this paper, we propose a bandwidth consumption model of the CCN-based pull and three push methods and evaluate bandwidth performances of them using the proposed model.

II. CCN-based Data Transport Methods

In CCN, data transport is basically pull-based, *i.e.*, a data consumer (C) requests data via an Interest packet containing the name that specifies the requesting data, and a data producer (P) provides the requested data via a Content Object packet containing the requested data (Fig. 1a). Various network applications, however, have to support both pull and push depending on the characteristics of required data. To do so, three different push methods have been suggested: 1) Long-lived Interest Push (Fig. 1b) [2], 2) 4-way Handshake Push (Fig. 1c) [3], and 3) Embedded Interest Push (Fig. 1d) [4]. Each push method has its own advantages and disadvantages in terms of delay sensitivity, data throughput efficiency, and processing overhead.

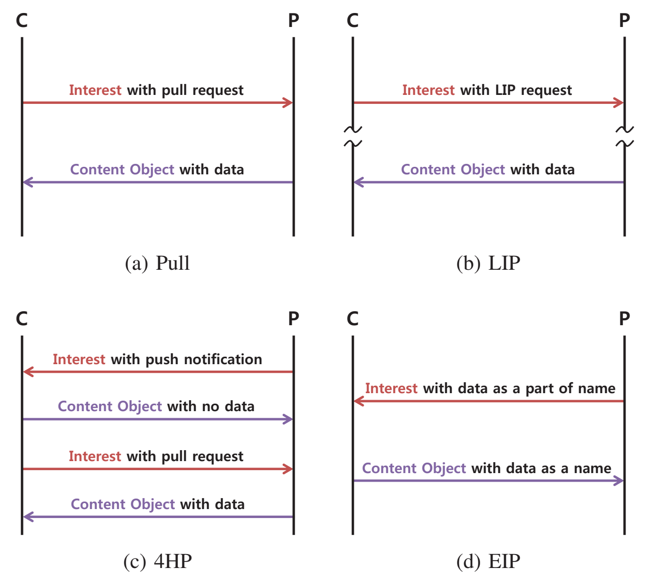

Fig. 1. Flows of Interest and Content Object packets in four data transport methods of CCN: Pull, Long-lived Interest Push (LIP), 4-way Handshake Push (4HP), and Embedded Interest Push (EIP).

1) Long-lived Interest Push (LIP) [2]: LIP is similar to the normal pull in CCN, as shown in Fig. 1b, except the two points: 1) the requesting Interest packet has longer lifetime than pull's one and 2) P, C, and intermediate CCN routers defer processing of the Interest when the requested data are not immediately available. The two points allow C to send an Interest packet that requests data to P before the requested data is actually acquired; this makes possible for LIP to work as

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TABLE I
NOTATIONS

Notation	Description
S_n	Average size of a CCN name
S_d	Average size of data
α_I	Average size of overhead of an Interest packet
α_{CO}	Average size of overhead of a Content Object packet
D	Ratio of consumers that collect the same data of which another consumer already has received
$L_{X,Y}$	Link between a node X and Y
BW_L	Bandwidth consumption of a link L

push. Accordingly, LIP is suitable for pushing delay-sensitive data. LIP, however, also introduces additional processing overheads to CCN routers to maintain larger Pending Interest Table (PIT) and to network applications (both C and P) to maintain pending data requests.

2) 4-way Handshake Push (4HP) [3]: 4HP consists of two parts: push notification and pull (Fig. 1c). In the push notification part, P sends an Interest packet to C to notify that it has obtained new data that needs to be pushed to C. Then, C sends a Content Object packet that has no data to meet a CCN's flow balance requirement—one Interest generates one Content Object. The latter part of 4HP is the same with the normal pull process; C requests data by sending an Interest packet to P, and P replies to the Interest by sending a Content Object packet containing the requested data. Unlike LIP, 4HP does not burden CCN routers or network applications. However, it introduces additional delay for pushing data because it consists of the two phases. Accordingly, 4HP is suitable for pushing delay-non-sensitive data.

3) Embedded Interest Push (EIP) [4]: EIP pushes data from P to C by using an Interest packet that contains data as a part of its name (Fig. 1d). The C that has received the data sends back the Content Object packet that contains no data to P to meet a CCN's flow balance requirement. Note that the CCN name can contain any type of data including binary data. EIP is intuitive, easy to implement, and suitable for pushing delay-sensitive data, whereas it requires higher bandwidth than the other push methods. The reason of the higher bandwidth usage is two-fold. First, EIP cannot utilize CCN's data caching advantages because P has to deliver data to each C using a separate Interest packet containing the data even if the data are same for every C. The second reason is that the replying Content Object from C to the EIP Interest packet also carries the same name that contains the data; *i.e.*, the data is delivered as a name in a Content Object packet from C to P unnecessarily.

III. BANDWIDTH CONSUMPTION MODEL

In this section, we propose a mathematical bandwidth consumption model for the four CCN-based data transport methods (Pull, LIP, EIP, and 4HP). We define several notations shown in Table I and assume a network topology for deriving a bandwidth consumption model shown in Fig. 2. We analyzed the data transport methods of CCN in term of bandwidth consumption at L_{R_1,R_2} in which case all data consumers C_1–C_m collect the data from P_1 once. D represents the ratio of data consumers that collect the same data of which another consumer already received; i.e., the higher the D is, the more cache-hit ratio of CCN router R_1 gets.

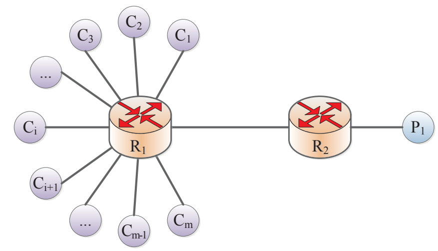

Fig. 2. Topology for deriving a bandwidth consumption model.

CCN-based Pull and LIP consume almost the same amount of bandwidth because they exchange similar Interest and Content Object packets even though the packet exchange timing is different (compare Fig. 1a and 1b). When the D is 1, just one Interest and one Content Object packets need to be exchanged for either Pull or LIP regardless of the number of consumers thanks to a CCN's caching feature as follows.

$$\begin{aligned} BW^{P/L-D1}_{L_{R_1,R_2}} &= \text{Interest} + \text{Content Object with } S_d \\ &= (S_n + \alpha_I) + (S_n + S_d + \alpha_{CO}) \\ &= 2S_n + S_d + \alpha_I + \alpha_{CO} \end{aligned} \tag{1}$$

When the D is 0, i.e. every consumer requests different data, the Interest and Content Object packets need to be exchanged m-times separately. Thus,

$$BW^{P/L-D0}_{L_{R_1,R_2}} = m(2S_n + S_d + \alpha_I + \alpha_{CO}) \tag{2}$$

By combining the equations (1) and (2) we obtain the following equation of bandwidth consumption for either Pull or LIP.

$$BW^{P/L}_{L_{R_1,R_2}} = \{\lceil D \rceil + m(1-D)\}(2S_n + S_d + \alpha_I + \alpha_{CO}) \tag{3}$$

$BW_{L_{R_1,R_2}}$ for EIP is not influenced by the D; an Interest and a Content Object packet need to be exchanged m-times because EIP cannot utilize CCN's caching at all. Therefore,

$$\begin{aligned} BW^{EIP}_{L_{R_1,R_2}} &= m(\text{Interest with } S_d + \text{Content Object with } S_d) \\ &= m(2S_n + 2S_d + \alpha_I + \alpha_{CO}) \end{aligned} \tag{4}$$

4HP consists of two parts: push notification and pull. The former cannot utilize a CCN's caching feature, so the Interest and Content Object packets for the push notification need to be exchanged m-times regardless of D value. The latter, on the other hand, is same with the CCN-based Pull case, so it varies depending on the D value. By combining these two parts we obtain the following equation of bandwidth consumption for 4HP.

$$\begin{aligned} BW^{4HP}_{L_{R_1,R_2}} =& m(2S_n + \alpha_I + \alpha_{CO}) \\ &+ \{\lceil D \rceil + m(1-D)\}(2S_n + S_d + \alpha_I + \alpha_{CO}) \end{aligned} \tag{5}$$

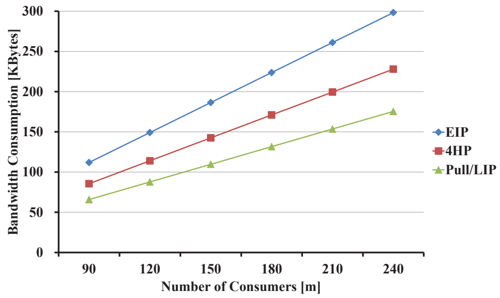

Fig. 3. Bandwidth consumption (y) versus number of data consumers (x) when $D = 0$ and m changed from 90 to 240.

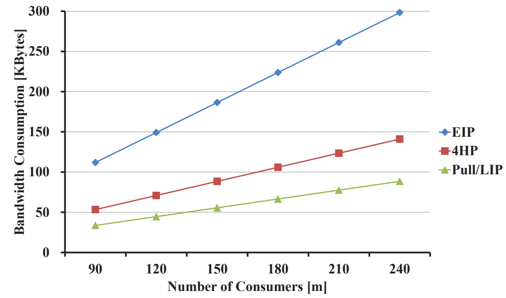

Fig. 4. Bandwidth consumption (y) versus number of data consumers (x) when $D = 0.5$ and m changed from 90 to 240.

IV. Bandwidth Performance Evaluation

This section describes performance evaluation results of the four CCN-based data transport methods in term of bandwidth consumption using the equations derived in section III. For the performance evaluation, we assumed several parameters as follow: $S_n = 70$, $S_d = 512$, $\alpha_I = 27$, and $\alpha_{CO} = 52$[1].

Fig. 3 shows a comparison of the calculated bandwidth consumption in the case where the D was fixed to 0 and the m changed from 90 to 240. In this case, CCN's content caching was meaningless because every data consumer collected different data. The bandwidth consumption of EIP was the largest and its increasing rate according to the number of data consumers was the highest (about 1243 bytes per a data consumer). Pull/LIP consumed the least bandwidth and 4HP's bandwidth consumption was in between EIP and Pull/LIP. The bandwidth consumption was linearly increased when the number of data consumers was increased for all data transport methods.

Fig. 4 shows a comparison of the calculated bandwidth consumption in the case where the D was fixed to 0.5 and the m changed from 90 to 240. In this case, CCN's content caching was applied to the half amount of the entire transported data. Bandwidth consumption of EIP did not change compared with the case where D was 0 (in Fig. 3) and still EIP's bandwidth consumption was the largest. Bandwidth consumptions of 4HP and Pull/LIP, however, were reduced about 38% and 49%, respectively, in comparison with the case where D was 0. Also the bandwidth consumption increasing rates of 4HP and Pull/LIP according to the number of data consumers were lowered.

To explicitly show the impact of D value on bandwidth consumption, we calculated bandwidth consumptions by increasing D from 0 to 1 and fixing m to 180 as shown in Fig. 5. As expected, bandwidth consumptions of Pull/LIP and 4HP were linearly decreased as the D value was increased, and bandwidth consumptions of EIP did not change at all regardless of D value. For all cases, Pull/LIP showed the least bandwidth consumption and EIP showed the most.

[1]S_n and S_d values were chosen arbitrarily; α_I and α_{CO} values were obtained from a traffic trace of ndnSIM [5].

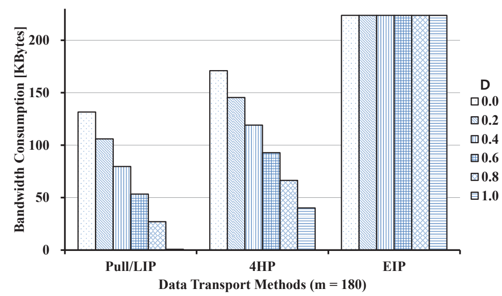

Fig. 5. Mathematical model based bandwidth consumption when $m = 180$ and D changed from 0.0 to 1.0.

V. Concluding Remarks

CCN's basic data transport method is pull-based and there have been suggested three CCN-based push methods (LIP, 4HP, and EIP) to complement the basic pull. We have proposed a bandwidth consumption model of the four CCN-based pull and push methods, and evaluated bandwidth performances of them using the model. We also compared the four methods in terms of bandwidth consumption, cache efficiency, initial transport delay, and processing overhead. Since each data transport method has its own advantages and disadvantages, CCN-based application designers have to carefully choose an appropriate data transport method considering the application's requirements.

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