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과학 빅데이터를 위한 엔디엔 테스트베드 분석: 현황, 응용, 특징, 그리고 이슈

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Analysis on NDN Testbeds for Large-scale Scientific Data: Status, Applications, Features, and Issues

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요 약

데이터 볼륨과 복잡도가 빠르게 증가함에 따라 과학 빅데이터를 다루는 데이터 집적 과학은 네트워크를 통해 보다 효과적인 데이터 저장 및 분배를 위한 새로운 기술을 발견하는 것을 필요로 한다. 최근 네임드 데이터 네트워킹 커뮤니티와 데이터 집적 과학 커뮤니티는 함께 과학 실험 빅데이터의 분배 및 관리에 있어서 혁신적인 변화를 꾀하였다. 본 논문 에서는 기후과학 및 고에너지물리 데이터 등과 같은 과학 빅데이터를 위한 현존하는 엔디엔 테스트베드들에 대한 분석이 처음으로 이루어진다. 과학 빅데이터를 위한 엔디엔 테스트베드들을 현황, 엔디엔 기반 응용, 특징 측면에서 묘사하고 토의한다. 마지막으로 과학 빅데이터를 위한 엔디엔 테스트베드 네트워크를 확립함에 있어서, 함정에 빠질 수 있는 다양한 이슈들을 엔디엔 테스트베드들에 대한 묘사 그리고 특징들로 부터 도출하여, 분석 제시한다.

ABSTRACT

As the data volumes and complexity rapidly increase, data-intensive science handling large-scale scientific data needs to investigate new techniques for intelligent storage and data distribution over networks. Recently, Named Data Networking (NDN) and data-intensive science communities have inspired innovative changes in distribution and management for large-scale experimental data. In this article, analysis on NDN testbeds for large-scale scientific data such as climate science data and High Energy Physics (HEP) data is presented. This article is the first attempt to analyze existing NDN testbeds for large-scale scientific data. NDN testbeds for large-scale scientific data are described and discussed in terms of status, NDN-based application, and features, which are NDN testbed instance for climate science, NDN testbed instance for both climate science and HEP, and the NDN testbed in SANDIE project. Finally various issues to prevent pitfalls in NDN testbed establishment for large-scale scientific data are analyzed and discussed, which are drawn from the descriptions of NDN testbeds and features on them.

키워드 : 데이터 집적 과학, 네임드 데이터 네트워킹, 엔디엔 테스트베드, 과학 빅데이터, 엔디엔 기반 응용
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Ⅰ. Introduction

Data-intensive science has transformed modern scientific research. Scientists now use observed and simulated data to translate abstract ideas into conclusive findings and concrete solutions. While scientific big datasets help modern scientific communities efficiently, the ever-increasing size of these datasets creates a considerable data management burden [1 - 3].

Since the data volume is very high, for example, the Large Hadron Collider (LHC) in HEP generates petabytes of data per year, accommodating all computation and storage needs at the data generation site is not feasible. Consequently, many scientific workflows routinely need to transfer a substantial amount of scientific data for remote storage, replication, or local analysis that range anywhere from tens of gigabytes to terabytes. While available bandwidth in scientific networks is significant, it is still insufficient. Therefore, such transfers must complete before a deadline to free up network resources for subsequent requests. Today this is often accomplished using complex applications and/or manually orchestrated high-speed paths [1 - 3].

Even with these intelligent applications, completing these transfers within a deadline is challenging. The inherent limitations of TCP/IP networking can slow down transfers and waste valuable network resources. Inability to use multiple data sources at the network layer, failure to reuse in-network data, and lack of access to in-network state are some of the limitations that make large-scale scientific data retrieval inefficient. The Earth System Grid Federation (ESGF) system and the Xrootd system were constructed to distribute and manage efficiently climate modeling data and LHC data, respectively, in global networks [4]. Each system architecture is based on a peer-to-peer federated infrastructure for data management in current TCP/IP networks. They provides users with easy access to distributed scientific data centers. Owing to the end-to-end transport control mechanism in the current Internet, they face potential problems of high latency and corrupted ratios [5-6].

Recently, NDN and data-intensive science communities have inspired innovative changes in distribution and management for large-scale experimental data. In this article, existing NDN testbed networks for large-scale scientific data such as climate science data and High Energy Physics (HEP) data is analyzed. NDN testbeds for large-scale scientific data are described and discussed, in terms of status, NDN-based application, and features. Finally various issues to prevent pitfalls in establishing NDN testbed networks for large-scale scientific data are analysed and discussed, which are drawn from the descriptions of NDN testbeds and features on them.

Ⅱ. NDN Works for Large-scale Scientific Data

The works of [1 - 2] on NDN-based climate science application design have been addressed. They have the strength of federating distributed catalog systems that store and manage NDN names in order to increase the speed of discovery of desired data in multiple domains.

The work of [3] presented a differentiated NDN-based application for providing metadata information for climate data files, while the work of [4] attempted a preliminary study on an overlay-based NDN and a partial experiment.

Through a discussion of similarities and differences of NDN in climate science and High Energy Physics (HEP), [5] addressed a preliminary work for designing an NDN-based Large Hadron Collider (LHC) network in the US.

A case study that focused on caching and aggregation effects in NDN, and a forwarding strategy for improving large-scale climate data distribution in many replica data producers were addressed [6]. This showed the dependence of the cache size on traffic volume and traffic patterns.

The work of [7] developed a deadline-based intelligent data transfer protocol for NDN, which creates a reserved path and bandwidth up to a cache. Through simulation-

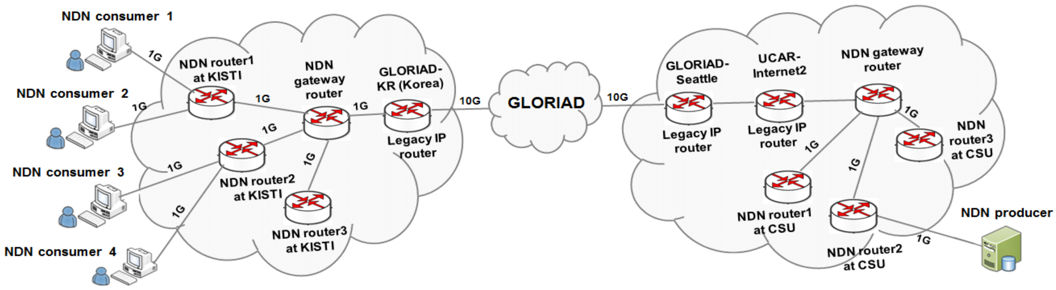

Fig. 1 NDN testbed for climate science established between Korea and US

based experiments, the authors compare the bandwidth savings effect of request NDN aggregation and strategic cache placement with the IP scenario.

The work of [8] developed an NDN consumer and producer following the CERN Virtual Machine File System (CVMFS) in order to serve HEP data based on NDN.

The SANDIE project has aimed to develop an NDN-based scientific data distribution testbed for data-intensive science such as HEP [9]. This provides optimization of NDN features such as caching, forwarding, and congestion control.

The authors in [10] addressed an intercontinental NDN testbed, an NDN-based climate science application with differentiated features and various experiments to justify the needs of using NDN for larges-scale scientific data.

Ⅲ. NDN Testbeds for Large-scale Scientific Data

In this section, we describe and compare three existing NDN testbeds for large-scale scientific data. First instance is an intercontinental NDN testbed for climate science established between Korea and the US. Second instance is an NDN testbed for both climate science and HEP that consists of several nodes across the US. Lastly, one new project called SDN-Assisted NDN for Data Intensive Science (SANDIE) has started in order to implement a SDN-Assisted NDN testbed for data-intensive science. The SANDIE project combines the existing works of several NDN research projects. We compare them in terms of representative features derived from the descriptions of the NDN testbeds.

3.1. NDN Testbed instance for climate science

An NDN testbed was established to explore name-based climate data delivery across continents between Korea and the US, as shwon in Fig. 1 [10]. The GLObal RIng network for advanced Applications Development (GLORIAD) research network with 10 Gbps links was used to provide direct connections between continents and to support a much greater BW than a consumer/producer speed (1 Gbps) between them [11]. A TCP tunnel between the NDN gateway routers on both continents was established to separate NDN traffic logically from other traffic in legacy IP routers and to support overlay-based NDN communication in the intercontinental network.

The authors of [10] have developed the NDN based climate application for data-intensive science, as shown in Fig. 2 and installed it on their testbed. The application provides climate data names searching, metadata browsing, and actual data retrieval capabilities. It supports the Coupled Modeling Intercomparison Project Phase 5 (CMIP5) [12-13] climate data that is utilized for data modelling and future climate change prediction. The CMIP5 data already follows a specific naming scheme and fitted with an NDN naming scheme. The application consists of the front-end and back-end systems that support NDN-based searching/fetching of CMIP5 data.

The front-end system consists of two parts: a) Front-

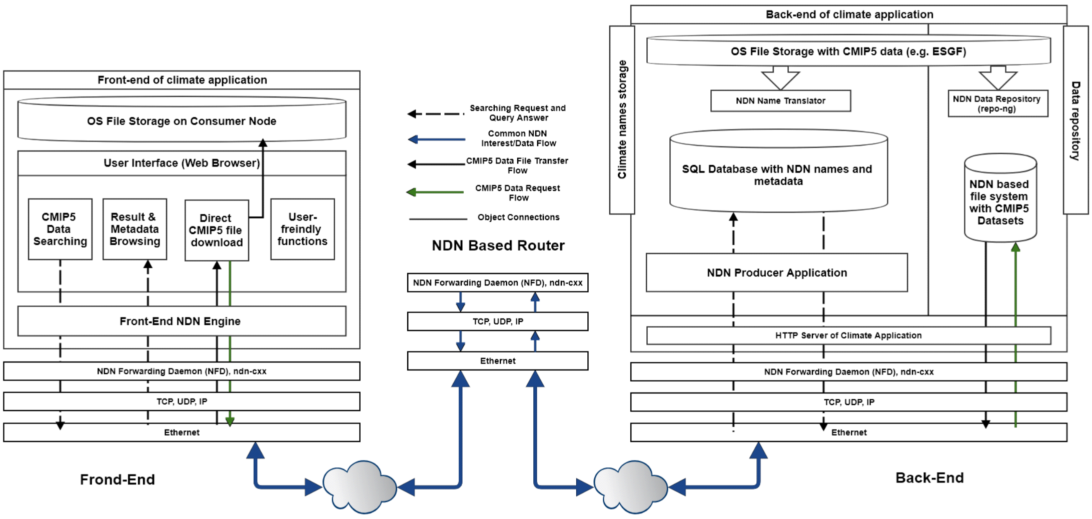

Fig. 2 Frond-end/back-end system in the NDN testbed for climate science established between Korean and US.

end NDN Engine (FNE) that processes the requested name list received from the producer, b) web-based user interface (UI) that makes possible for the user to search the certain name spaces and initiate fetching process [10]. When FNE receives the name list and metadata from the producer, it reconstructs names to the original structure of CMIP5 names for more simplified browsing. Each separate data name from the list can be accessed in order to show its metadata that contains detailed information about the dataset. Finally, the user can request the specific data file with the direct fetching function.

The back-end system consists of an NDN name translator/metadata manager, an NDN repository composed of a data container and a name/metadata container, and an NDN producer application [10]. The name translator converts the original CMIP5 file name to a hierarchical NDN name format for all climate data files. Converted NDN names and their metadata sets as well as original CMIP5 files, are stored in the NDN repository in order to provide more detailed information for CMIP5 files. The metadata manager extracts the metadata sets from each CMIP5 file and manages them in order to provide detailed information for CMIP5 files. The NDN repository is used to contain CMIP5 files and their datasets and allows for data-centric access and file fetching. The NDN repository is divided into two parts: a data container to store CMIP5 files and to support data fetching, and a name/metadata container to store converted NDN names and their metadata sets separately. The NDN producer application processes Interest packets issued by consumers. When receiving an Interest packet carried to search potential CMIP5 files, the NDN producer application attempts to identify the data name in the Interest packet among NDN name lists in the name/metadata container. In the case of a lookup hit, the corresponding NDN names and their metadata sets are returned to the requesting consumer.

3.2. Testbed instance for both climate science and HEP

The NDN testbed for both climate science and HEP is deployed on the testbed that consists of seven nodes and is connected through 10 Gbps links via ESnet in US, as shown in Fig. 3. The scientific data management application known as ndn-atmos was utilized in the NDN testbed, as shown in Fig. 4 [1]. The system design is based on multiple synchronized servers, also called a catalogue, together providing access to common scientific data name list. Through this system, the application provides access to such functions like scientific data

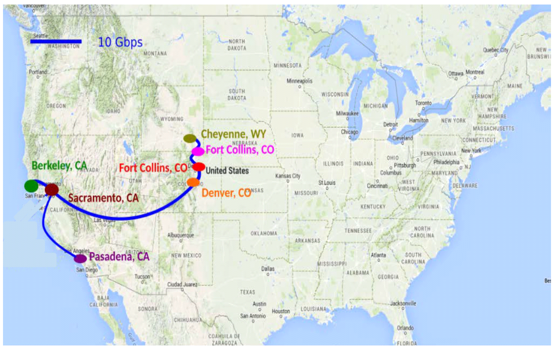

Fig. 3 NDN testbed established for HEP and climate science in US.

searching, direct patching, and file transfer between data storages. It operates with CMIP5 or High Energy Physics (HEP) data types, by supporting translation function for two different naming schemes. The ndn-atmos application consists of two main components: a backend catalog and a user interface, as shown in Fig. 4.

The catalog federation represents and multiple servers with NDN name translator and name storages in each of it. In a situation when the user cannot access the closest server, he/she will automatically get access to name list through another server of the federation. Such structure of federation ensures access to the service, even if one or more servers are down. Similar to the other climate applications, the NDN translator of ndn-atmos takes original data files of CMIP5 and xrootd (IP based HEP application) [14] and translate them into NDN names. The translated name will be added in the name storage of server that initially has translated it. However, all servers of the catalog group are linked with each other and synchronize their name lists in order to form a common name list that the client will see. Therefore, all the servers keep the same consistent name list even though publisher of data added it to only one name storage. On the other side, the data file will be stored in one of the data storages which may be located separately from the catalog server. If the data does not exist on the closest data storage instance, the system will deliver it from the other storage of federation. When a data storage gets down at a time of data fetching, all remaining interest messages will be automatically forwarded to another data storage that contains the same dataset and will be satisfied from there. The Web UI of ndn-atmos application helps users to discover and fetch dataset with use of the filters or simply typing the name prefix of the dataset.

3.3. Testbed Instance in SANDIE

The SDN-Assisted NDN for Data Intensive Science (SANDIE) project [15] was initiated by three parties Northeastern University, Colorado State University

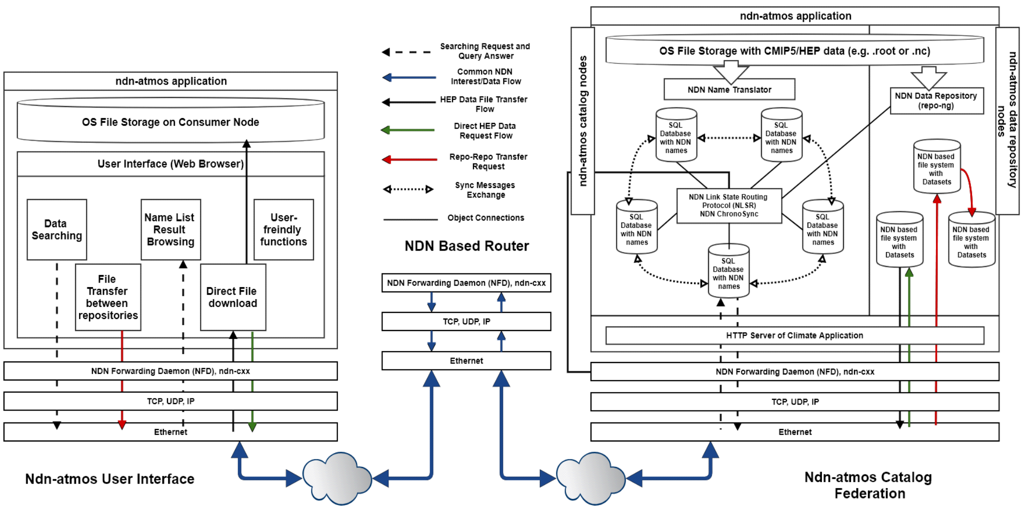

Fig. 4 ndn-atmos application.

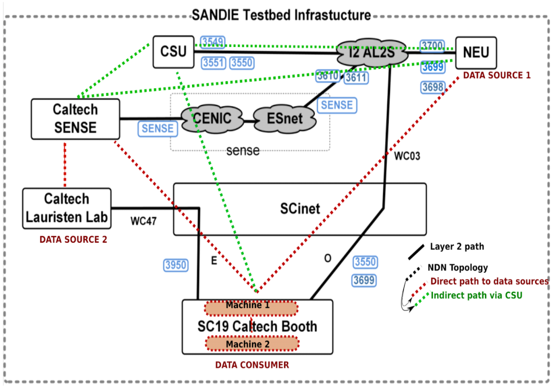

Fig. 5 SANDIE testbed infrastructure.

(CSU) and Caltech in the US. It was proposed to solve the existing and future problems of data-intensive science and Large Hadron Collider (LHC) HEP program that experiences a growing scale of dataset sizes, and complexity of its management. Not only data is growing, but the number of sites for data generation and distribution is growing along with it. The existing system cannot scale to accommodate such growth, that is why the SDN supported NDN architecture was proposed.

The project aims to derive NDN-based operation model for various data-intensive science programs including LHC. That includes provisioning of such capabilities like data distribution, processing, gathering and analyses of scientific data. The project also aims to optimize the NDN architecture in perspective of caching, forwarding, and congestion control that considered highly crucial for data-intensive science applications. Finally, it is planned to develop a naming scheme that will be fitting for HEP and other fields, and provide better scalability of NDN system in amount and type of data supported.

Initially, all three groups were already doing research and development of one or several aims, but that were mostly independent projects. The Northeastern University was working in terms of NDN forwarding and caching optimization and developed a Virtual Interest Packet (VIP) framework [16]. On the other side, Caltech was targeting to effectively merge the SDN and NDN architectures to improve the performance of existing scientific applications in LHC. In the case of CSU, the previously discussed application (i.e., ndn-atmos application) has already achieved aims to develop the data distribution application and naming scheme for climate science and HEP.

The SANDIE project has established the testbed [17], by merging and expanding already existing testbeds of Caltech, CSU, Northeastern, Fermilab and other sites, as shown in Fig. 5. The established testbed was supported with several terabytes of SSD storage, 40-60 terabytes of SAS storage, and up to 100 Gbps links. Both NDN and Xrootd software was deployed on it, in order to integrate them. As an initial step, the SANDIE team is targeting to implement an NDN-based plugin for Xrootd, as shown in Fig. 6. The NDN-based plugin allows XRootd server to query the NDN network via the Open Storage System (OSS) plugin layer. The plugin represents an NDN consumer that composes Interest packets for different system calls and waits for answers (Data packets). In this regard, a suitable NDN producer has been implemented

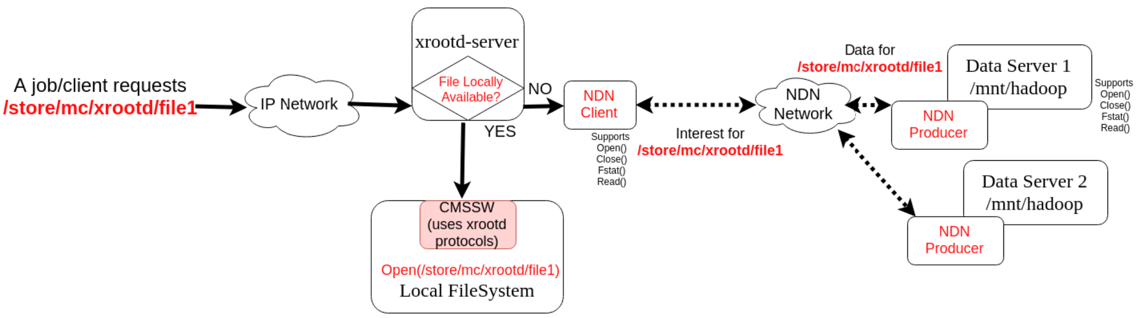

Fig. 6 NDN-based plugin for Xrootd (architecture and workflow).

which registers to the local NDN forwarder and is able to answer requests from the plugin for Xrootd. The NDN-based plugin component for Xrootd uses an NDN consumer that is able to translate different system calls into NDN Interest packets and send them over the network. The consumer embedded in the Xrootd plugin is able to request files over NDN network to a local or remote producer.

3.4. Features on NDN Testbeds for Large-scale Scientific Data

We analyze and discuss features on the NDN testbeds for large-scale scientific data. Fig. 7 compares NDN testbeds for large-scale scientific data in terms of various features, which are drawn from the descriptions of the NDN testbeds for large-scale scientific data.

All NDN testbed networks utilized TCP tunneling to cover IP overlay. All NDN nodes in SANDIE is controlled by a SDN controller, in order to make a dedicated end-to-end path between a consumer and a producer.

To support name-based searching/fetching for large-scale scientific data in NDN networks and to convert flat/unique names to hierarchical/unique ones, they designed NDN applications in their NDN testbeds. In their application design, a naming policy to make an unique and hierarchical name for climate and HEP data was supported using DRS syntax for climate data and Xrootd file system directory path for HEP data.

The NDN Testbed for both climate science and HEP utilized caching in edge nodes only. Even a 1-GB cache at the edge could significantly improve data distribution. Optimum data and pipeline size were applied in the NDN testbed for climate science only, in order to improve throughput.

NDN-AIMD (Additive Increase Multiplicative Decrease) algorithm was applied to control congestion in the NDN testbed network for climate science only. All NDN testbeds used public key in NDN platform for data security. For load balancing, a forwarding strategy in many replica producers that supports the nearest path from a consumer to a producer was supported in the NDN testbed instance for both climate science and HEP,

Fig. 7 Comparison between NDN testbeds for large-scale scientific data for various features on them.

Testbed / Feature	Testbed instance for climate science	Testbed instance for both climate science and HEP	Testbed instance in SANDIE
# of NDN nodes	8	7	4
Link bandwidth	1G~10G	10G	10G~100G
For covering classical IP networks	Using TCP tunneling	Using TCP tunneling	Using TCP tunneling
SDN support	No	No	Yes
NDN-based application for name-based searching/fetching	Frond-end/Back-end system	ndn-atmos application	NDN-based plugin for Xrootd
Naming policy to make an unique and hierarchical name	Using DRS syntax in CMIP5 for climate data	Using Xrootd file system directory path for HEP data	Using Xrootd file system directory path for HEP data
Caching	Caching in NDN gateway nodes	Caching in edge NDN nodes	Not presented
Optimum data and pipeline size	Applied	No	Not presented
Congestion control	NDN-AIMD applied	No	No
Data security	Using public key in NDN platform	Using public key in NDN platform	Using public key in NDN platform
Load balancing	No	Forwarding in many replica producers that supports the nearest path from a consumer to a producer	Dynamic forwarding Using Virtual Interest Packet (VIP)

while a dynamic forwarding using Virtual Interest Packet (VIP) was applied in the SANDIE testbed.

Ⅳ. Issues in NDN Testbeds for Large-scale Scientific Data

In this section, various issues to prevent pitfalls in establishing NDN testbed networks for large-scale scientific data are analyzed and discussed, which were drawn from the descriptions of NDN testbeds and features on them.

4.1. NDN-based Application Design

An NDN-based application should be designed for consumers and producers, in order to support name-based data searching/fetching and to convert flat/unique names to hierarchical/unique ones [1][5]. Each NDN-based application in each NDN testbed instance was described for data-intensive science in section III.

NDN-based application for large-scale scientific data should be able to support a hierarchical naming rule to leverage the name-based forwarding mechanism of NDN, such as the Data Reference Syntax (DRS) naming syntax in the climate research community and the HEP research community's flat/unique names for all LHC data.

For continually increasing scientific data, the effort to speed up the discovery of a target data name is a crucial issue [1][3].

4.2. Load Balancing

Distributing the load on a single producer and reducing the user latency on fetching large-scale scientific data are required. A forwarding strategy in many replica data producers that guarantees the nearest latency path from a consumer to a data producer and forwards the Interest packet to the nearest producer has been addressed [6]. Dynamic forwarding and caching using the Virtual Interest Packet (VIP) can be supported for load balancing in multiple domains [17].

4.3. Where and How to Cache

Where and how to cache large-scale scientific data in distributed NDN routers with limited cache size forms a variety of research issues [6]. Among these issues, a simulation study that showed the caching and aggregation effects on NDN for large-scale climate data was presented [6].

The numbers of climate data files (catalog size) at the producer is another factor that affects cache size. The cache replacement policy is also a new factor that affected cache size [6].

4.4. Data and Pipeline Size

Large-scale scientific data should be segmented into an optimum data size (i.e., packet size) by the NDN producer and transferred to NDN networks. Also, an optimum pipeline size should be determined by the NDN consumer [10]. To obtain better throughput, controlling the data size and pipeline size is an issue in forwarding large-scale scientific data in overlay-based NDN networks.

4.5. Scientific Data Attack

Recently, the Interest flooding attack that targets specific content in NDN was addressed [18]. The only effective and possible Interest flooding attack scenario in NDN is to send a flood of interests each with different non-existing random or dynamic content names to a victim namespace from a different location. Each interest will create a new PIT entry resulting in PIT exhaustion at routers, thus causing a denial of service for legitimate interests. Several techniques in the literature to mitigate this type of Interest flooding attack should be introduced [19].

4.6. NDN Congestion Control

The NDN congestion control mechanisms can be divided into three categories: receiver-driven, hop-by-hop control, and hybrid [20][21]. NDN congestion control schemes have been mostly designed for pure NDN networks.

A practical NDN congestion control scheme to consider overlay links together should be joined to transfer large-scale scientific data more rapidly across overlay-based NDN networks in a global network [21].

Ⅴ. Conclusion

As the data volumes and complexity rapidly increase, data-intensive science communities needed to investigate new techniques for intelligent storage and data distribution over networks. In an effort to overcome the crucial problems in current solutions, NDN and data-intensive science communities have established NDN testbed networks for innovative distribution and management for large-scale scientific data.

In this article, existing NDN testbeds established for large-scale scientific data were described and discussed in terms of status, NDN-based application, and features. The frond-end/back-end system for climate science, ndn-atmos application for both climate science and HEP, and NDN-based plugin for Xrootd in SANDIE project were deployed in each of them. Lastly various issues to prevent pitfalls in establishing NDN testbeds for large-scale scientific data were analyzed and discussed, which were drawn from the descriptions of NDN testbeds and features on them.

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REFERENCES

[1] C. Fan, C. Olschanowsky, S. Shannigrahi, C. Papadopoulos, S. DiBenedetto, and H. Newman, “Managing Scientific Data with Named Data Networking,” in *Proc. 5th Int. Workshop Network Aware Data Manage.*, pp. 1-7, Nov. 2015.

[2] C. Olschanowsky, S. Shannigrahi, and C. Papadopoulos, “Supporting Climate Research using Named Data Networking,” in *20th IEEE Int. Workshop Local and Metropolitan Area Networks*, pp. 1-6, May. 2014.

[3] D. Kim, I. Hwang, V. Srivastava, Y.-B. Ko, and H. Lim, “Implementation of a Front-end and Back-end NDN System for Climate Modeling Application,” in *Inform. and Commun. Technol. Convergence 2015 Int. Conf.*, pp. 554-559.

[4] H. Lim, A. Ni, D. Kim, and Y.-B. Ko, “Named Data Networking Testbed for Scientific Data,” *2nd International Conference on Computer and Communication Systems*, pp. 65-69, Jul. 2017.

[5] S. Shannigrahi, A. Barczuk, C. Papadopoulos, A. Sim, I. Monga, H. Newman, and J. Wu, “Named Data Networking in Climate Research and HEP Applications,” in *21st Int. Conf. on Computing in High Energy and Nuclear Physics, IOP Publishing. Journal of Physics: Conference Series*, vol. 664, pp. 1-8, 2015.

[6] S. Shannigrahi, C. Fan, and C. Papadopoulos, “Request Aggregation, Caching, and Forwarding Strategies for Improving Large Climate Data Distribution with NDN: A Case Study,” *2017 Proceedings of Information Centric Networking*, pp. 54-65, 2017.

[7] S. Shannigrahi, C. Fan, and C. Papadopoulos, “SCARI: A Strategic Caching and Reservation Protocol for ICN,” In *Proceedings of the Asian Internet Engineering Conference*, pp. 1-8. ACM, 2018.

[8] M. Alhowaidi, B. Ramamurthy, B. Bockelman, and D. Swanson, “The Case for Using Content-Centric Networking for Distributing High Energy Physics Software,” in *37th IEEE Int. Conf. on Distributed Computing Systems*, pp. 2571-2572, Jun. 2017.

[9] SANDIE [Internet]. Available: https://www.nsf.gov/awardsearch.

[10] H. Lim, A. Ni, D. Kim, Y.-B. Ko, S. Susmit, and C. Papadouplous, “NDN Construction for Big Science: Lessons Learned from Establishing a Testbed,” *IEEE Network*, vol. 32, no. 6, pp. 124-136, Nov. 2018.

[11] A. Ni, and H. Lim, “A Named Data Networking Testbed with Global NDN Connection,” *Journal of Korean Institute of Communications and Information Sciences*, vol. 40, no. 12, pp. 2419-2426, Dec. 2015.

[12] CMIP5 [Internet]. Available: http://cmip-pcmdi.llnl.gov/cmip5/.

[13] K. Taylor, R. Stouffer, and G. Meehl, “An Overview of CMIP5 and the Experiment Design,” *Bulletin of the American Meteorological Society*, vol. 93, no. 4, pp. 485-

498, 2012.

[14] A. Dorigo, P. Elmer, F. Furano, and A. Hanushevsky. Xrootd-a highly scalable architecture for data access. *WSEAS Transactions on Computers*, vol. 5, pp. 1-12, 2005.

[15] SANDIE project [Internet]. Available: http://Indico.hep.caltech.edu.

[16] E. Yeh, T. Ho, Y. Cui, M. Burd, Ran Liu, and D. Leong, "VIP: a Framework for Joint Dynamic Forwarding and Caching in Named Data Networks," in *Proc. 1st Int. Conf. Information-Centric Networking*, pp. 117-126.

[17] NSF project [Internet]. Available: https://grantome.com/grant/NSF/ACI-1659403.

[18] L. Cinquini, D. Crichton, C. Mattmann, J. Harne, and, G. Shipman, "The Earth System Grid Federation (ESGF): An open infrastructure for access to distributed geospatial data," *Future Generation Comput. Syst.*, vol. 36, pp. 400-417, Jul. 2014.

[19] L. Wang, "Economic Levers for Mitigating Interest Flooding Attack in Named Data Networking," *Mathematical Problems in Engineering*, vol. 2017, pp. 1-12, Jun. 2017.

[20] Y. Ren, J. Li, S. Shi, L. Li, G. Wang, and B. Zhang, "Congestion Control in Named Data Networking-A Survey," *Computer Communications*, vol. 86, pp. 1-11, Apr. 2016.

[21] M.-H. Wang, L.-W. Chen, P.-W. Chi, and C.-L. Lei, "SDUDP: A Reliable UDP-Based Transmission Protocol Over SDN," *IEEE Access*, vol. 5, pp. 5904-5916, May. 2017.

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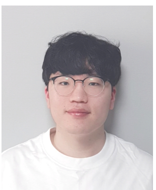

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