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A Tentative Comparison on CDN and NDN

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***Abstract*—With the pretty prompt growth in Internet content, future Internet is emerging as the main usage shifting from traditional host-to-host model to content dissemination model, e.g. video makes up more than half of Internet traffic. ISPs, content providers and other third parties have widely deployed content delivery networks (CDNs) to support digital content distribution. Though CDN is an ad-hoc solution to the content dissemination problem, there are still big challenges, such as complicated control plane. By contrast, as a wholly new designed network architecture, named data networking (NDN) incorporates content delivery function in its network layer, its stateful routing and forwarding plane can effectively detect and adapt to the dynamic and ever-changing Internet. In this paper, we try to explore the similarities and differences between CDN and NDN. Hence, we evaluate the distribution efficiency, network security and protocol overhead between CDN and NDN. Especially in the implementation phase, we conduct their testbeds separately with the same topology to derive their performance of content delivery.**

Finally, summarizing our main results, we gather that: 1) NDN has its own advantage on lots of aspects, including security, scalability and quality of service (QoS); 2) NDN make full use of surrounding resources and is more adaptive to the dynamic and ever-changing Internet; 3) though CDN is a commercial and mature architecture, in some scenarios, NDN can perform better than CDN under the same topology and caching storage. In a word, NDN is practical to play an even greater role in the evolution of the Internet based on the massive distribution and retrieval in the future.

Keywords—architecture; content delivery network; named data networking; comparison; evaluation

I. Introduction

When architecture, principles and protocols of current Internet were initially created in 1960s and 70s, the Internet based on TCP/IP protocol as the core technology is confronted with increasingly serious technical challenges. The main target of today's network is to solve the large-scale, high efficiency, safe content accessing and distribution problems. The communication model leads to a conversation between two exactly entities, one requesting the content and the other providing it. So people care about the Internet for what content it contains, instead of the location information [1]. However, designing a good network architecture is difficult, which should:

- have good scalability, resilience, and flexibility to the dynamic of the Internet, so that its structure can become simple and easy to greatly reduce the cost and so forth;
- achieve high security and low complexity for data security, user privacy protection, anti-attack mechanism and etc;
- offer positive QoS, including short latency, high speed transmission and low packet loss;
- obtain high bandwidth utilization by making full use of already known information to avoid redundancy.

To the best of our knowledge, no prior method can satisfy all above ambitious goals simultaneously.

In order to satisfy these needs, some overlay network architectures come into being, such as CDN [2], P2P. But as content distribution traffic growing, more efficient solutions are needed. Directly, a unified method to solve them is to replace *where* with *what*. Traditional host-to-host model is a network abstraction chosen to solve the problems of the 1970s. Named Data Networking (NDN) [3], also called Content Centric Networking (CCN) [4], as a wholly new designed type of network architecture, provides a promising solution. The fundamental principles of NDN have been provided by some designs such as Content Oriented Architecture or Information Centric Networking. Some related designs are DONA [5], TRIAD [6], PSIRP [7] and etc. NDN is based on named content, which has no notion of host at its lowest level and no source and destination addresses. In NDN, because of this key feature, each content packet has a unique name, and it is forwarded by a lookup on its name. What's more, basic network function, such as routing, forwarding and security, are named data based instead of link state or session based. Consequently, it is more suitable for content distribution.

In this paper, we study and compare CDN and NDN on distribution efficiency, protocol overhead, security and other aspects. As NDN is one of the main frameworks of information centric networking (ICN) [8] and a contender of the existing TCP/IP network architecture, it is worthwhile to investigate its transmission performance in comparison with CDN. In summary, this work is the first step to understand the difference between CDN and NDN. As far as we're concerned, this paper is the first systematic comparison of these two content delivery solutions. Although this comparison may not be perfectly fair, it is still helpful to identify their commons and differences, advantages and disadvantages, and the merits need to be further exploited for both types of architecture.

The remainder of the paper is organized as follows. Section II gives some background and related work about our research. Section III provides a principle comparison between CDN and NDN in the metrics of security, cost, etc. Section IV comprises the actual transmission performance evaluation. Finally, Section V concludes the paper and addresses the future work.

II. BACKGROUND

A. Content Delivery Network

The goal of CDN is to solve a fundamental challenge for the Internet: content dissemination − how to distribute and retrieve content effectively, meanwhile reduce the delay of end hosts. It is the initial design that tries to avoid the peak channels and links limiting the efficient and reliable transport as far as possible, for the purpose of prompt and timely content distribution.

The key component of CDN is a method to achieve load balancing using request routing/redirection. And according to each node's network flow, load condition, the distance between users or source sites, and the response time, CDN can speedily locate the user requests to the service node closest to the user. This strategy benefits declining the user access time and improving the status of network congestion. As a result, content can be cached and redistributed by utilizing CDN caching proxies. Fig.1 shows how CDN works.

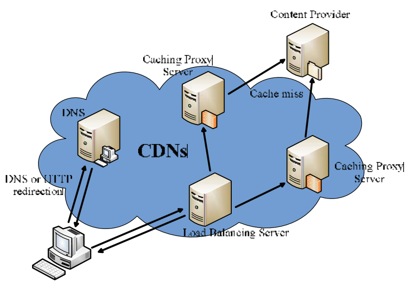


Fig. 1. The mechanism of CDN.

The current CDN infrastructures consist of a series of complicated management tools and scheduling policies. Under such circumstance, some significant data centers adopt appropriative high-speed links to configure the route and management of data objects accompanied by high cost. Since the specific CDN is proprietary, there's no doubt that the operation is not interoperable, namely, the data cannot be shared and the systems are unable to be connected among different CDNs. Meanwhile, because of the high cost of data centers synchronous updating, some applications having strong real-time, little data granularity or frequent interaction, such as SNS, microblog, video conference et al, are lack of superiority.

B. Named Data Networking

Named data networking (NDN) (a.k.a. information centric networking or content centric networking) is a promising alternative to the current Internet architecture. In 2010, NDN project was supported by FIND (Future Internet Design) of NSF (National Science Foundation) focusing on next generation Internet transformative research, including 12 US colleges and PARC (Palo Alto Research Center) [3].

NDN is based on the fundamental principle that communication networks should allow users to focus on what the content is rather than where the content is. By enabling automatic and application agnostic in network caching, NDN can support efficient content distribution intrinsically. Fig.2 compares the IP and NDN protocol stacks. We find that NDN's protocol stack is similar with today's TCP/IP network, both in featuring an hourglass appearance, while the difference is in the "thin waist", where content chunk replaces IP. From the network perspective, the change of "thin waist" brings about some differences on data security regime and various routing strategies.

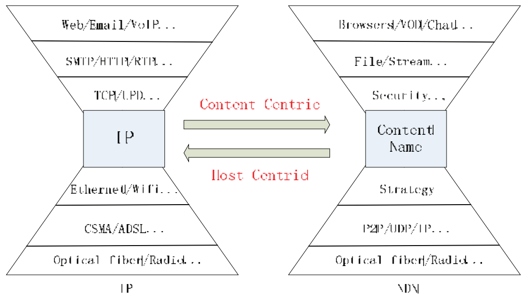


Fig. 2. Protocol stack comparison between IP and NDN.

In NDNs, each packet has a unique name and there are two types of packets, Interest packets and Data packets. Communication is driven by the requester. A requester generates an Interest packet for a certain piece of content and the network provides the requester with such content when the requested content is available. The NDN node consists of three main data structure: Content Store (CS), Forwarding Information Base (FIB) and Pending Interest Table (PIT). The FIB structure is the forwarding table in NDN. The basic structure of IP routing table is set of destination IP and the next hop. Similarly, the FIB of NDN maintains the prefix of the name and next hop. The NDN node processes the NDN protocol and takes charge of forwarding interest referring to FIB table, caching NDN packets in CS and responsing to interest with content object according to PIT.

Overall, NDN not only avoids network congestion and conflict, gets rid of the dependence on end-to-end connection, but also realizes the multi-homing, load balancing and DTN ability feasible, which markedly improves reliability, performance and efficiency of large-scale content distribution.

C. Related Work

This section is a summary of the most notable works related to our proposition.

CCNx[1] is an open source project developed by PARC and a software prototype which implements the NDN architecture. The key component of CCNx is the ccnd daemon, which supports packet forwarding and caching function. The CCNx implementation used in this paper is the version (0.8.0) released on Aug 12, 2013.

The seminal paper by Jacobson et al. [4] firstly provides the blueprint of NDN architecture, which could be viewed as the guideline of NDN research. Yaoqing Liu, Beichuan Zhang

[1] http://www.ccnx.org/

et al. [9] presents in-depth analysis on forwarding of NDN, which are three FIFA (Fast Incremental FIB Aggregation) algorithms to control the growing FIB size. In [10], A K M Mahmudul Hoque, Lixia Zhang et al. studies the mechanism of NDN router and designs a NLSR protocol (Named-data Link State Routing) for NDN compared with IP-based link.

The performance evaluation of data transfer between HTTP and NDN on real testbeds has been done by H. Yuan et al. [11] using the Open Network Laboratory (ONL) and the results show that with the CCNx prototype available in 2011, HTTP is 10 times faster than NDN, because decoding and restructuring data and performing lookup of chunk names increase the computational overhead, as detailed in [12]. N. Zhang et al. [13] makes contrast of content delivery models, including CDN, NDN and P2P, in the view of value network and two-sided markets in order to analyze the feasibility of NDN. G. Carofiglio et al. [14] proposes the essential building blocks of NDN and theoretically analyzes their role in the content delivery ecosystem. Stefan Lederer et al. [15] compares the performance of DASH (Dynamic Adaptive Streaming over HTTP) over NDN and the HTTP 1.0 and 1.1.

Our work differs from the previous approaches in the following characteristics. CDN as a mature and commercial architecture has developed for more than ten years, and NDN as a new architecture is still in the procedure of evolution, so there is absence of a comprehensive and systematical contrast study. The present article gives us a clear summary of CDN and NDN.

III. CDN vs. NDN in Principle

In this part, different aspects of principle results are extensively discussed and analyzed.

A. Protocol overhead

The protocol overhead is the ratio of total bytes transmitted to content bytes received, as shown in Equation 1.

$$Overhead = \frac{\sum bytes\ transmitted}{\sum bytes\ of\ content\ received} - 1 \quad (1)$$

CDN adopts TCP on the transport, introducing an overhead of 20 bytes for the TCP header and 12 bytes for the optional header fields, and IP on the network layer, introducing another 20 bytes for the IP header. Generally, the MTU (Maximum Transportation Unit) of Ethernet is 1500 bytes and the Ethernet frame size is 1514 bytes, including additional 14 bytes frame header. So the lower bound of the TCP/IP protocol overhead is 4.56% ignoring the packets for TCP connection establishment, ACKs, as well as other Ethernet related overhead, e.g. check sequence.

In order to be compatible to today's infrastructure, NDN can be used on top of TCP/IP. In CCNx, the default of a packet contains a maximum payload of 4096 bytes, a header of approximate 550 bytes and the interest packet segment with sizes from approximate 150 to 250 bytes. Thus, transmitting a NDN packet needs 4 Ethernet frames, causing the total overhead to be about 23.6%. Besides, it's considered that the overhead is caused by retransmission of lost packets which is more expensive in NDN, due to the large 4096 bytes chunk payload. And in Sec. IV-C we will verify the theoretical results.

B. Rubustness

The topology and deployment of CDN are static which is Connection-based, that's to say in a fixed area, users are redirected to accessing a certain edge node server. If the server broke down, the network of the area would collapse. Additionally, as possessing numerous edge nodes, the CDNs still face network congestion threat in massive access.

By contrast in NDNs, each node is equal serving as a source server, a router, a client, even a cache. Anyone breaking down doesn't affect the whole network at all. Furthermore, according to the real-time network flows, links and load condition, NDN nodes are able to choose the best way to fetch content to avoid the network congestion efficiently.

NDN routes are managed hierarchically, the same as IPs', supporting various routing protocols. However, NDN routes are identified by name prefixes instead of address prefixes. In fact, NDN route tables are much larger than IPs', because names are longer and more numerous, which have multiple components similar with URLs resulting in inefficient lookup.

C. Security

DNS control scheduling and private data center guarantee CDNs from being attacked, which is accompanied with huge cost. As we know, trust in content is easily misplaced by untrustworthy location and connection information. Thus, once the edge node servers of CDN are deployed, the access paths are determined, where the threat exists. Moreover, The CDNs still face DoS attack.

a) In NDNs, packets are signature-signed and encoded. And its design principles remarkably improve the security of transmitting and routing, such as:

b) All the packets including route messages have to be signed, preventing forging and tempering;

c) Multipath routing reduces the prefix hijacked, therefore, routers can check the abnormities caused by prefix and attempt to retrieve data from other paths;

NDN's messages only interact with the response data and are not always sent to the hosts. So evil packets are less possible to be forwarded to certain targets.

This mechanism realizes the separation of data security and network transmission reduces the difficulty of management and enhances the flexibility. So it is a natural method based on the content requests.

D. Cost

Most of CDN nodes are different, in the aspects of source site, proxy cache server, load balancing, DNS, which complicates configuration as well as implementation of network services. Thus, each node server should be configured independently. However, all over the nodes of NDN, including client, are equal, that is, each node can have multiple roles at the same time. Thus, only configuring one node server and the system is formed through migrating. The only difference among NDN nodes lies in hardware, e.g., the size of CS is larger than others'. So deployment cost of CDN is much higher than that of NDN.

Uichin Lee et al. [17] of Alcatel-lucent Bell Labs analyze different content distribution strategies, including CDN, P2P and NDN, confirming that NDN energy use is more effective than others, especially in the aspect of resource utilization. What's more, it is verified in the Sec. IV-B.

To summary, Tab. 1 lists the comparison results of CDN and NDN in principle.

Table 1. CDN v.s. NDN in principle

Field	**CDN**	**NDN**
Protocol overhead	low	high
Robustness	low	**high**
Security	low	**high**
Cost	high	**low**

IV. Comparison in Content Transmission

This section specifically analyzes and discusses numerical experiment results. First of all, we will introduce our testbed infrastructure.

A. Network Topology

To further cross comparison, we conduct a testbed with a real network topology referring to [18], which is publicly available through Rocketfuel: the Abilene network (11 routers, 14 links). Fig. 3 represents a diagram of the Abilene topology, which is topology we'll refer to in the following unless otherwise specified. Furthermore, a gradual process based on above topology can help evolve into a different and usually more complex form.

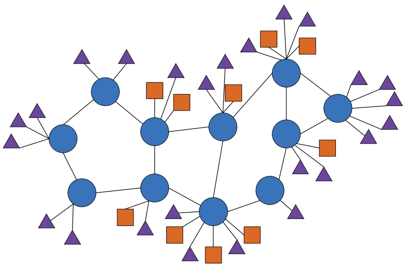


Fig. 3. Abilene topology. Blue circles represent routers, yellow squares represent content producers and purple triangles represent clients.

We set every producer or consumer is connected to only one router in the network. For the comparison purpose, all the hosts used in the testbed are installed on *Debian* Linux 6.0 (64 bit version) with the same hardware configuration. Each machine is connected through a 1Gbps line card.

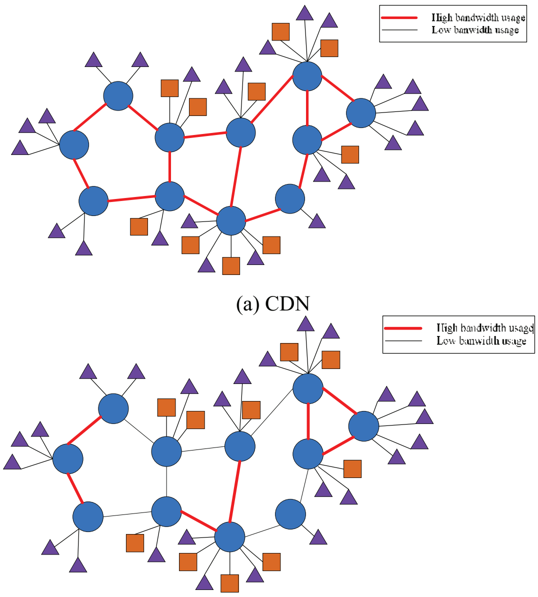
B. Bandwidth Usage

To compare the bandwidth usage between CDN and NDN, we design an experiment referring to the scenario in [19].

According to the file size, we broadly classify content items into two categories: Small and Large. The average size of a content item is 200MBytes and 2GBytes in Small and Large respectively. The total number of them is more than 100,000. Content providers are eager to protect their offered content, thus, we assume that each content item can be served only from one single producer.

Experiment 1 measures the bandwidth usage. We fix 10 producers and 25 clients. Let every client requests 5 interests/s satisfying the Poisson process. The testbed is connected by 10MB/s download speed to our campus Ethernet. The size for CDN and NDN cache is 10GBytes and the cache strategy refers to [16]. When reaching dynamic balance, we'll record the result illustrated in Fig. 4.

Experiment 2 evaluates the scalability. We add CDN nodes and records their average bandwidth compared with NDN. The result is described in Fig. 5(a).



(a) CDN

(b) NDN

Fig. 4. Bandwidth Usage.

Fig. 4 shows a comparison between the bandwidth usage of CDN and NDN. We define that the bandwidth usage is high if it is more than 50%, otherwise is low. We observe that the number of line with high bandwidth usage in CDN is more than that in NDN. Furthermore, in NDN, the bandwidth usage is proportional to the number of clients. On the contrary, in CDN, the bandwidth usage is high even if the amount of consumer is few. And in this experiment, we don't exploit the character of multi-homing in NDN. If we take the connection among clients into consideration, the bandwidth utilization of NDN will be higher.

From the Fig. 5(a), we find that with the CDN nodes increasing, the total bandwidth is decreasing and when the number of CDN nodes is 6, CDN is equivalent to NDN in terms of bandwidth. That is, under the same workload, CDN needs more nodes to equal NDN.

C. Data Throughput

In Sec. III-A, we analyze the theoretical protocol overhead of CDN and NDN. In this part, we will verify the value by experimentation.

Experiment 3 measures the data throughput. We let one client download a 5Mbytes file from a certain fixed producer, and the amount of pipelining ranges from 1 to 50 separately. The result is shown in Fig. 5(b).

Fig. 5(b) illustrates that CDN throughput asymptotes to 87% of the link bandwidth, reflecting its protocol header

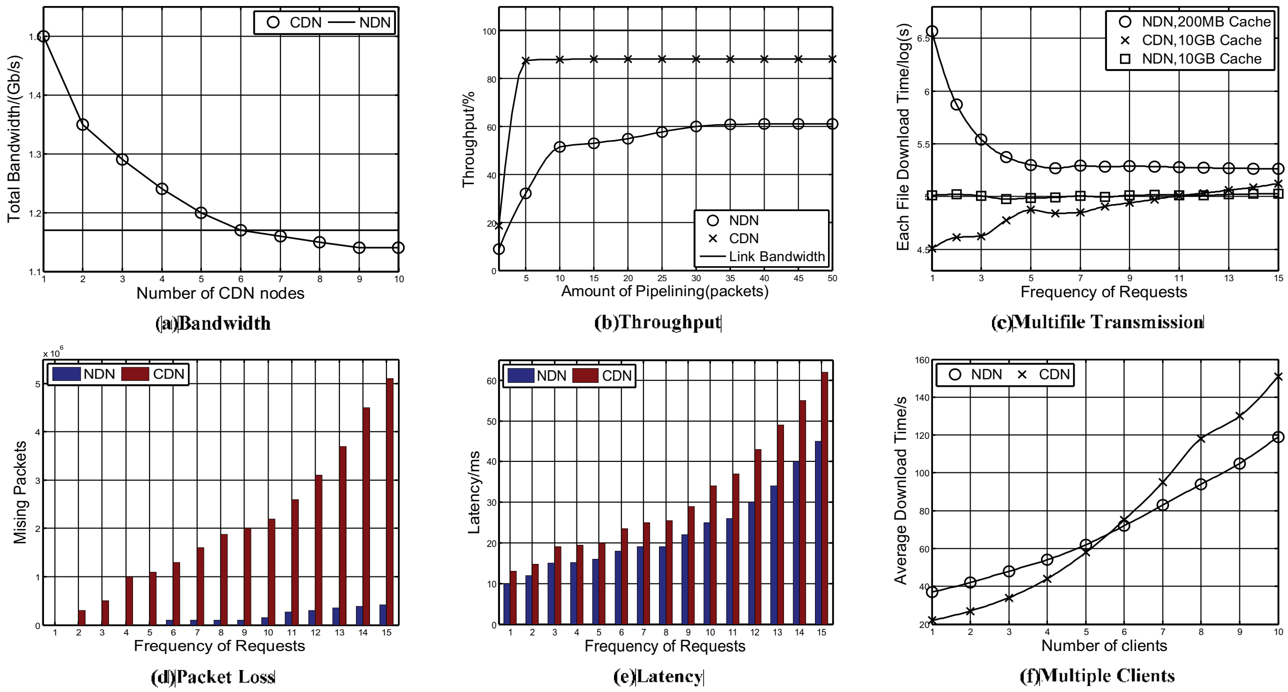


Fig. 5. CDN vs. NDN.

overhead. NDN asymptotes to 60% of the link bandwidth which is lower than theoretical value. Since NDN is encapsulated on TCP/IP for this experiment, it has its own 23.6% overhead plus an additional overhead of TCP. So the data throughput of NDN is lower than CDN due to its larger protocol overhead.

D. QoS

This part compares the QoS between CDN and NDN. And we models the download time of CDN and NDN, which is formulated as follows:

$$DT_{CDN} = t_{DNS} + t_{\text{que}} + \frac{n_{http}}{1-\alpha} t_{trans} + \frac{t_{delay} \times n_{http}}{c} + t_{other} \,, \qquad (2)$$

$$DT_{\text{NDN}} = t_{\text{que}} + \frac{n_{http}}{1-\alpha} t_{trans} + t_{decode} + \frac{t_{delay} \times n_{http}}{c} + t_{other} \,, \qquad (3)$$

where DT is download time; t_{DNS} is resolve domain name time; t_{decode} is data decoding and restructuring to normal data time; t_{que}, t_{trans}, t_{delay}, t_{other}, n_{http}, α and c are query time, transfer time, latency, uncertain time, the number of http request, packet loss and concurrency.

So we explore QoS by checking download time, packet loss, latency and concurrency.

Experiment 4 downloads a Large file (size: 2GBytes) and client requests multiple files simultaneously, the number of which is varied from 1 to 15. Fig. 5(c), 5(d) and 5(e) summarizes the results of DT, α and t_{delay}.

Experiment 5 evaluates the difference in c. We record corresponding time as multiple users request the same Small file (size: 200MBytes) in Fig. 5(f).

Through the Fig. 5(c), we conclude that when downloading bulk files, CDN's average download time of a single file is incremental, NDN 200MBytes Cache's trend is diminishing and NDN 10GBytes Cache's is smooth. In particular, 11 requests each time are sufficient, on average, to make NDN be equivalent to CCN in terms of transmission performance. 10GBytes is enough to store the file, but 200MBytes is too small and the data in local cache could transfer itself quickly.

Fig. 5(d) and 5(e) show a direct comparison between CDN and NDN for the packet loss and latency. The number of NDN lost packets is significantly less than that of CDN, and the average latency of NDN is lower than CDN. This is because NDN adaptively forwards requests to the most suitable links and surrogates.

In Fig. 5(f), we find that with the client request increasing, NDN is better than CDN gradually, benefiting from the difference of cache granularity. Because CDN's cache granularity is file-level, there is more pressure on bandwidth when request growing. While NDN also automatically chooses the optimal paths. In addition, NDN has the additional character of multi-homing, so in reality the speed is faster. Furthermore, synthesizing Fig. 5(c) and 5(f) turns out that the concurrency of NDN is higher than that of CDN.

All of above results share a similar feature: when the network traffic is light, the query time, packet loss and latency are almost identical. Thus, t_{trans} is the main factor of DT_{NDN}, so that the performance of CDN is better. However, when the network traffic is heavy, the packet loss and latency of CDN is higher and NDN performs better. The fundamental reason is that NDN is able to make full use of current content to obtain a shortest path. It relieves network congestion effectively and reduces packet loss as well as latency. In a word, NDN performs better QoS to current content distribution.

E. Transfer Time

In above experiments, we find that t_{decode} takes much of DT_{NDN}, which is detailed in [14]. In order to simply compare t_{trans}, we do the following experiment.

Experiment 5 measures the download time under download speed of 50Kbytes/s. The file size is 5MBytes and Tab. 2 records DT.

Table 2. Limit the download speed

	CDN	NDN
Normal time/s	< 1	< 3
Limit time/s	100	120

By limiting the download speed, we extend network t_{trans}, so that $DT \approx t_{trans}$. From the data in Tab. 1, it is illustrated that simple network t_{trans} of NDN and CDN are adjacent.

V. CONLUSION AND FUTURE WORK

In this paper, we comprehensively and systematically study and compare CDN and NDN on principle and content transmission. By performing theoretical and experimental analysis, we summary that: 1) NDN design greatly simplifies CDN design leading to better robustness, and the data signature verification enhances NDN data credibility and security. 2) Under the same network workload, the bandwidth utilization of NDN is higher, and with the same bandwidth utilization CDN need more nodes. Thus, NDN strengthens the scalability and reduces the deployment cost. 3) When the network traffic is heavy, NDN has lower packet loss and latency and higher concurrency. Thus, NDN increase the QoS level. 4) NDN introduces anycast mechanism to improve availability and performance, e.g. it ensures the routing to shortest path. So when the workload is heavy, NDN performs better than CDN with the same topology and cache size.

We also point out some limitations of NDN as follows: 1) The protocol overhead of NDN is much larger than CDN, which reduces the transmission efficiency. 2) NDN routes are identified by name prefixes instead of address prefixes resulting in low efficient lookup. 3) The process from data packets to normal content takes too much download time, making performance drop. Thus, the CCNx need some improvement on protocol overhead, in routing strategy and prefix lookup, there is enough research space to ameliorate NDN; and maybe in the future we could directly scan data packets of NDN and decoding were unnecessary.

In the future, we want to deploy NDN in a moderate scale, integrate local computing and storage, and design a new kind of computing architecture, to realize the data in the media to calculate directly through the network. What's more, we will complete the system and do some specific application big data analysis.

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