Comparative Study of Content-Centric vs. Content Delivery Networks: Quantitative Viewpoints

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Abstract

You may remember the battle between Asynchronous Transfer Mode (ATM) and IP/Ethernet in late 90s. When the ATM was first conceived, it was believed as the only viable technology that will allow true broadband networking services. Many research results strongly supported such beliefs for ATM, however, the markets today are not in favor of ATM any longer. Recently, *Content-Centric Networking (CCN)* is architected to bring significant advantages over current IP-based Internet, especially in reducing the traffic by eliminating redundant data transmissions. However, IP-based solutions such as *Content Distribution Networks (CDNs)* have already been widely deployed to cope with the same problem. Some comparison studies on this issue have been known, but they were done only in a qualitative manner. We have a strong sense of *deja vu* of the late 90s' battle. Qualitative comparison showing advantages and disadvantages of those technologies have failed to predict the final winner in the real world. This paper compares CCN and CDN in a quantitative manner by considering feasible CCN router implementation and typical CDN deployment topologies. Although we admit that our result may not be able to predict the final winner in the complex and uncertain future for now, we believe that it provides valuable insights in comparing the two continuously evolving networking technologies.

I. INTRODUCTION

Today's IP-based Internet is considered the most profound invention since its creation in 1960s. With IP, a packet in the network layer is delivered from a source to a destination using the destination IP address. Due to this address-based delivery scheme, the traffic explosion problem of the current Internet is exacerbated, since the duplicated requests for popular contents generate yet more redundant traffic.

To remedy such problem, the CCN [1] is proposed which is to replace "*where*" with "*what*". With IP, a packet is delivered from a source to a destination. However, these days the majority of current Internet usage consists of data being disseminated from a small number of sources to a great number of users. In this condition, heavy traffic congestion occurs in the most upstream links towards the servers due to the repeated requests on the relatively small number of popular contents.

With CCN, a packet is delivered by the requested content name, not the address. In addition, any intermediate node can reply to the data request packet as long as it has the data in its cache. In this way, CCN can reduce the congestion near the content server by eliminating the redundant data transmissions from the server.

CDN [7] also aims to alleviate the concentration of the web request traffic near the servers by rerouting the requests towards the surrogate cache servers deployed near the end users [2], thus enhancing user experience with reduced content access delay and high availability. CDN already serves a large fraction of the Internet content today.

Since both CCN and CDN address the same problem space, the comparative analysis of various aspects of CCN and CDN benefits has been one of the high priority issues in the future Internet research community [3]. Recently, qualitative comparative study results become available [4][5][6], however, quantitative comparison has remained one of the non-trivial research challenges due to the following reasons: 1) there is no real CCN deployment with referenceable router implementation and 2) specific CDN configuration in commercial deployment is generally not available to the public.

In this paper, we address the above issues and propose solutions: 1) a most likely reference implementation of CCN router architecture based on the available CDN setup, 2) a real CDN topology configuration obtained from one of major IPTV providers. Based on them, we estimated the total amount of network traffic, corresponding H/W and S/W costs and protocol overhead assuming a network topology deploying CDN servers and CCN routers, respectively.

This paper is organized as follows. In section 2, we compare CCN and CDN from the viewpoint of cost. In section 3, we

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briefly describe protocol overhead. Finally, section 4 provides concluding remarks with a discussion on the future works.

II. COST COMPARISON

In this section, we first show a real world reference CDN network model and compare CCN and CDN quantitatively. Based on the model, we estimate the total amount of network traffic, H/W and S/W cost, and protocol overhead for CCN and CDN, respectively.

A. A Reference Network Model

A reference network model for quantitative comparison is shown in Fig. 1. , which consists of a core network with 30 edge routers (CDN edge servers) and access networks. The topology and various parameter values are determined based on the information collected from one of the major Internet Service Provider (ISP) in Korea [19]. Typical ISP sub-graph for the core and access networks tend to be configured in the mesh and tree topologies, respectively [8].

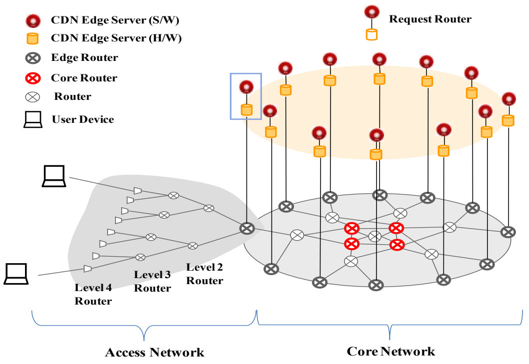


Fig. 1. A Reference Network Model.

The following network parameter values are used throughout the paper: the total number of subscribers – 3million, content encoding rate – 8Mbps (for High Definition TV), concurrent usage rate – 10%, number of CDN edge servers – 30. Each edge server holds 20TB of contents. The content popularity observes Zipf's law [17] with the exponent *s*.

B. Network cost

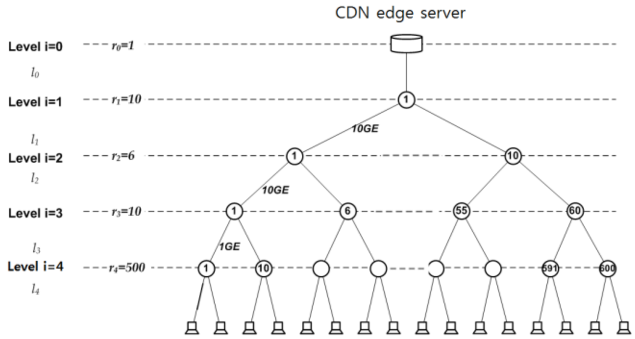


Fig. 2. A reference access network. The numbers in the circles represent the number of node, for example, there are 600 nodes at level 4.

Network cost analysis for CCN has been done [20][21] using network models such as Rocketfuel [8]. However, in this work, we use realistic the CDN topology and user requests information to estimate network costs described in the previous section.

Fig. 2. shows a detailed tree architecture of the access network shown in Fig. 1. It is assumed that one CDN edge server is placed over the level 1 router which connects to 10 level 2 sibling routers. The number of sibling routers for levels 2 and 3 are 6 and 10, respectively, so that the total number of access routers at level 4 is 600. The uplink capacity of access routers at each level is also shown to be 10Gbps at level $i = 2$ and 3, and 1Gbps at level $i = 4$.

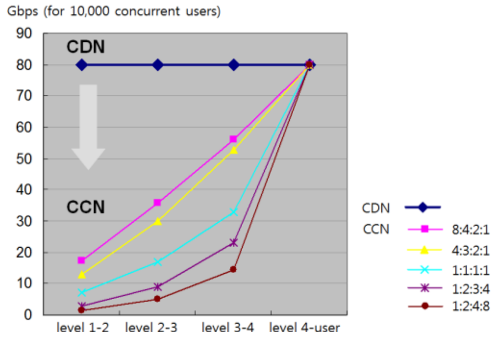


Fig. 3. Total amount of required network bandwidth. The ratio represents the caching capacity, for example, 4:3:2:1 means each level *i* (*i* = 1,2,3 and 4), node can store 40%, 30%, 20% and 10% of the total contents.

In Fig. 3. , the total amount of network bandwidth required for the given access network configuration is compared when there are 10,000 concurrent users. Note that in the CDN case there is no cache server between level *1* and level 4. In the CCN case, every router in each level (*i* = 1, 2, 3 and 4) is allocated pre-assigned amount of caches.

It shows that as the cache size allocated to the routers nearer to the users increase (8:4:2:1 → 1:2:4:8, the numbers represent the ratio of content amount cached at each level, *i* = 1,2,3 and 4), the total amount of network bandwidth required decreases. In other words, most of the content requests from the users can readily be served from the cached contents at the lower level routers. In this case, however, the total amount of allocated cache size should also increase, since the number of routers increases at the lower level (i.e., *i* → 4).

The estimated network costs per level are listed along the device configuration diagram shown in Fig. 4. We have consulted multiple H/W vendors to get the typical price quotes for the network equipments. For the level 1 and 2 routers, we have chosen Junipher MX960 [13]. For level 3, Cisco and Hitachi devices are used. For level 4 OLT (Optical Line Terminal), we selected Dasan V5724G [14]. For OADM (Optical Add-Drop Multiplexer), the SNH OADM 400G [15] is selected as a typical equipment in our study.

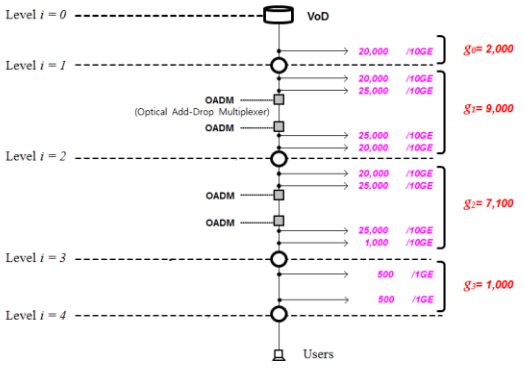


Fig. 4. Unit prices in USD for reference access network equipment per 1Gbps (between level 3 and 4) and 10Gbps (otherwise).

C. H/W cost

Fig. 5. shows a typical architecture of an IP router. For data planes, it has Forwarding Information Base (FIB), packet processor and ingress/egress buffers. For control plane, to use the OSPF routing algorithm, it has Link-State Data Base (LSDB), a topology map to compute shortest path to a destination, Routing Information Base (RIB), routing table stored in a router that lists the routes to destinations and MAC address table for layer 2 connections.

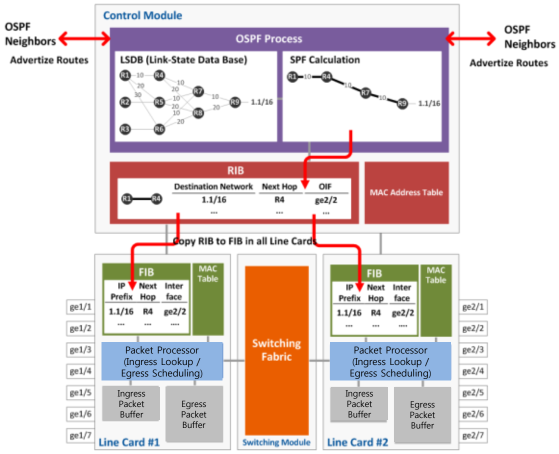


Fig. 5. A typical IP Router Architecture.

To know the implementation of a CND server, we benchmark cache servers from Netflix [12] since we can consider this Netflix cache server as a CDN edge server. Fig. 6. shows the high level diagram of its internal architecture. It contains Hard Disk Drive (HDD), Raid controller, processor, memory, LAN card and etc.

For CCN routers, a referenceable architecture has never been proposed. In this section, we propose a feasible architecture of CCN router based on the CCN literature suggested to date [1][3][10]. The architecture should be similar to that of IP routers except that the CCN routers have forwarding strategy layer, Pending Interest Table (PIT) and Content Store (CS). For the functionality of PIT and CSs, please refer to [1]. The forwarding strategy layer makes the dynamic choices needed to best exploit multiple connectivities under changing conditions. It is used for path optimization and keeping track of dynamic network conditions [1][3]. One thing to remember is that the CS should be able to handle a great amount of contents but it doesn't need to be so fast. So we can use relatively cheap storage such as HDD for CS.

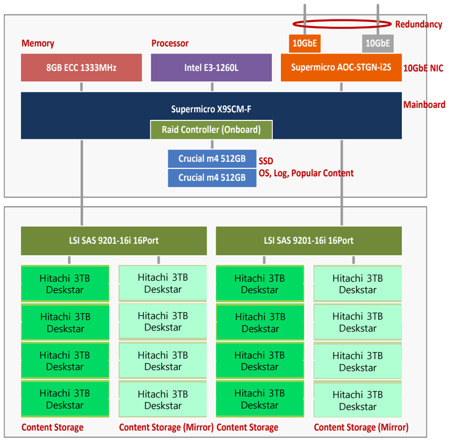


Fig. 6. CDN server architecture (Netflix Cache Server)

However, index search for the CS needs to be fast enough to support real-time processing, which means CS index should be stored on memory not disks. Fig. 7. shows the architecture of a CCN router.

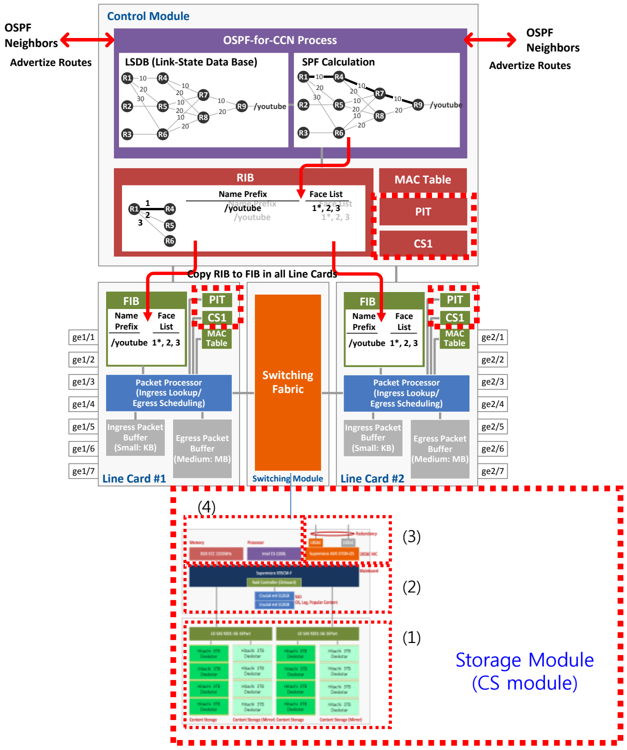


Fig. 7. CCN router architecture. Additional parts for CCN are marked with the red dotted boxes. We added PIT and CS controller to the IP router architecture. And we attached the storage module to the routing part.

Compared with IP routers, CCN routers have forwarding strategy layer, CS module and PIT. For the CS module design, we can refer to the Netflix server architecture in Fig. 6. We have made some changes needed to the architecture. The storage (1) and storage control part (2) can be same. But the LAN card (3) is not needed since the CS part can be embedded as a router module. So we replace it with a connector to the backplane and an interface chip. For the processor (4), we do not need a high-end processor since there is such overhead as the CDN server (e.g., no TCP overhead). So we downsize it to Intel Zeon 5060 (3.2GHz, Dual core). For memory (4), since the size of Linux Operating System (OS) is less than 400MB, we downsize it to 8GB from 32GB.

For strategy layer and PIT, we consider that relatively small amount of memory and computing power is needed since compared with contents, entries and policies handled by PIT and strategy layer should be much smaller.

For control plan, OSPF in IP routers can be extended to OSPF-N for CCN, so we can assume both architectures have almost same control plane functionality. TABLE I. shows the results of total cost comparison for CDN edge server and CCN CS module.

TABLE I. TOTAL COST COMPARISON (UNITS: USD)

	CDN edge server		CCN (CS module)	
CPU	350	Intel E3-1260L	105	Intel Zeon 5060(3.2GHz, Dual Core)
Memory	320	4 x 8GB ECC 1333MHz	80	8GB ECC 1333MHz
Main board	250	Supermicro X9SCM-F	250	Supermicro X9SCM-F
LAN Card	550	Super micro AOC-STGN-i2S	100	Broadcom (Connector, I/F Chip)
HDD	3,600	Hitachi Deskstar 7K3000 1TB * 40	3,600	Hitachi Deskstar 7K3000 1TB * 40
Raid	1,000	LSI SAS 9201-16i 16 port	1,000	LSI SAS 9201-16i 16 port
SSD	600	Crucial m4 512GB	600	Crucial m4 512GB
Chassis	200	TST custom	0	-
Power	1,000	Zippy MRW-5600V4V/DMRW-5600V4V	0	-
Total		**7,870**		**5,735**

D. CS index cost

As discussed before, CS index should be processed very fast so the index should reside in memory. CS index cost can be quite expensive as the CS size increases. In this section, we estimate CS index cost according to the CS size.

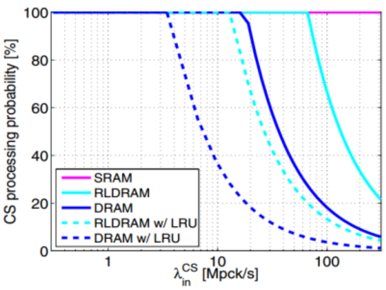


Fig. 8. Memory processing speed [10]

CS index consists of contents name and index for the location of the contents. Contents name is a human readable plain text so usually it is hashed to save memory space. In [10], three hashing schemes are suggested. The bits/packet for those schemes is 40, 72 and 136, respectively. We will choose 136 bits/packet. We assume the corresponding packet payload size is 1.5KB. Then we can compute the total CS index size when the total contents size stored at CS is given.

Memory type should be determined since to support high enough searching speed, relatively expensive memory should be used, e.g., SRAM. Fig. 8. shows that the packets coming in less than 3 million per second can be processed with the indices stored in DRAM [10]. In our reference network applications, we can use DRAM for CS index since when the Zipf's law exponent *s* of user request is equal to 0.5, the highest packet rate is around 370 K packets/sec at the level 1 router. Routers at level *i* > 1 have slower incoming rate. And it is known that the Zipf's law exponent for user traffic is between 0.5 and 1 in general [9]. The packet rate increases as the exponent becomes smaller, we can consider that 370 K packets/sec would be the maximum rate in the access network.

E. S/W cost

To provide services such as IPTV services, specific softwares such as streaming are needed. We have looked at the CDN solution prices of CISCO [16] as shown in TABLE II. Per stream cost is given. Service routers and content acquirers reside only in the center server thus their costs can be ignored.

TABLE II. S/W PRICE FOR CISCO CDN SOLUTION

Product	Product Description	Discount Price*
CDN Edge Server (CDS-TV)	CDS-TV (RTSP Streaming, RTSP Session Management, Content Placement, Server Heath-Report, etc.)	$30.4 per Stream
Content Acquirer (CDS-CA)	CDS-CA (Reverse Proxy, Content Placement, etc.)	-
Service Router	-	-

F. Total cost

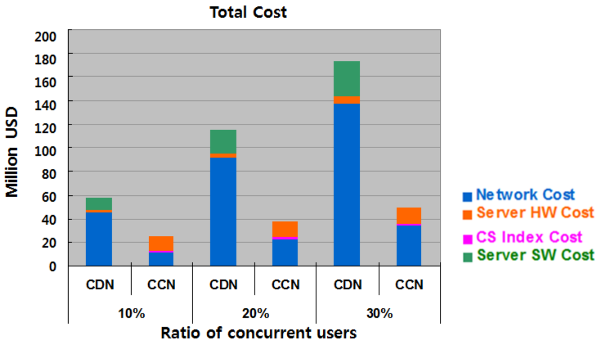


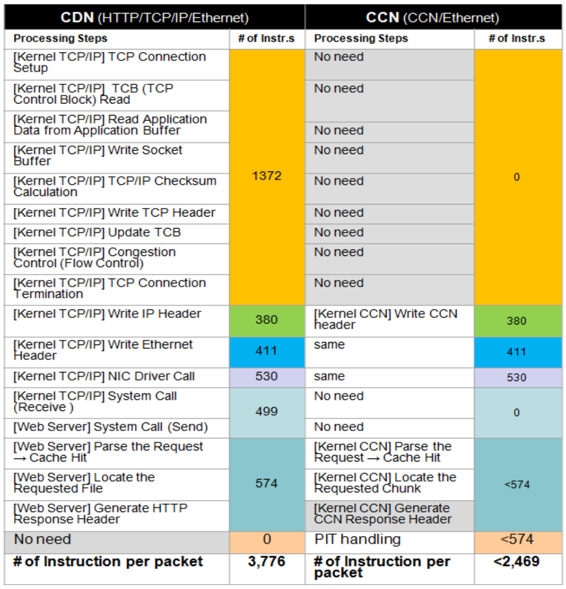
Fig. 9. Total cost comparison corresponding to the ratio of the concurrent users (*s* = 1, caching rate = 4:3:2:1)

In this section, we compute the total cost to provide CDN and CCN services to the entire subscribers. We converted all the network, H/W and S/W cost estimation results to the total sum for the nationwide 3 million subscribers.

Fig. 9. shows the total costs. As the ratio of the concurrent user increases, the costs for the CDN is doubled and tripled. On the contrary, with CCN, the increase rates are only 45% and 91%. When the ratio of the concurrent user is 30%, the cost for CDN is over 3.5 times bigger than that of CCN.

Compared with CDN, CCN requires less network bandwidth by placing caches more flexibly thus we can save lots of costs. But H/W cost for CCN increases fast as the storage cost increase. The S/W cost for the CDN increases linearly as the number of concurrent users increases. For CCN, we didn't count S/W cost since we assumed that it is included in the router cost. It might be unfair to assume that S/W costs for IP and CCN routers are same since CCN routers have more functionality. But we would say that CCN is not aware of the service so the software for CCN would not change much as services change. The price of CCN router software would stay steady, which may be supplied for free eventually.

III. PROTOCOL OVERHEAD



CDN (HTTP/TCP/IP/Ethernet)		**CCN** (CCN/Ethernet)	
Processing Steps	**# of Instr.s**	**Processing Steps**	**# of Instr.s**
[Kernel TCP/IP] TCP Connection Setup	1372	No need	0
[Kernel TCP/IP] TCB (TCP Control Block) Read		No need	
[Kernel TCP/IP] Read Application Data from Application Buffer		No need	
[Kernel TCP/IP] Write Socket Buffer		No need	
[Kernel TCP/IP] TCP/IP Checksum Calculation		No need	
[Kernel TCP/IP] Write TCP Header		No need	
[Kernel TCP/IP] Update TCB		No need	
[Kernel TCP/IP] Congestion Control (Flow Control)		No need	
[Kernel TCP/IP] TCP Connection Termination		No need	
[Kernel TCP/IP] Write IP Header	380	[Kernel CCN] Write CCN header	380
[Kernel TCP/IP] Write Ethernet Header	411	same	411
[Kernel TCP/IP] NIC Driver Call	530	same	530
[Kernel TCP/IP] System Call (Receive)	499	No need	0
[Web Server] System Call (Send)		No need	
[Web Server] Parse the Request → Cache Hit	574	[Kernel CCN] Parse the Request → Cache Hit	<574
[Web Server] Locate the Requested File		[Kernel CCN] Locate the Requested Chunk	
[Web Server] Generate HTTP Response Header		[Kernel CCN] Generate CCN Response Header	
No need	0	PIT handling	<574
# of Instruction per packet	**3,776**	**# of Instruction per packet**	**<2,469**

Fig. 10. CPU processing overhead comparison.

Another point of view to compare CDN with CCN should be the protocol overhead. Due to the overlay approach of CDN, we can expect the overhead for the CDN servers to process packets would be larger than that of CCN. In this section, we compute protocol overhead when a CDN server and CCN router process a packet.

Every CDN node in the network including the endpoint should have a protocol stack from physical, data link, network, transport and application same as the end nodes. However, the CCN nodes need to have only the lower three layers (Of course, the end nodes should have some functionalities similar to transport and application, but now, we consider only the intermediate nodes).

Fig. A. in the next page shows the schematic diagram of the processing steps to handle HTTP packets shown below.

1. Accept a new connection from a client.
2. Receive an HTTP request over the connection.
3. Parse the request.
4. Locate the requested file.
5. Generate the appropriate HTTP response header.
6. Send the header and file over the connection.
7. Close the connection.

Fig. 10. shows the CPU processing overhead comparison results. For the CDN case, we use the results in [11] to count the number of instructions per IP packets in each steps listed above. To compute the CCN packet processing overhead, we estimate values for each step as in Fig. 10. For TCP process such as connection setup, it requires 1,372 instructions to run. But CCN does not need any connection setup process. For network and Ethernet layer packet processing and Network Interface Card (NIC) driver call, we assume that the same number of instructions would be needed. Steps for request parsing and locating the contents would incur same overhead to both CCN and CDN. But the number of instructions for generating HTTP response header will be more than generating CCN response data packet header since CCN data packet format is very simple.

For PIT handling, we assumed that the steps of parsing the request and locating the chunk would be the same to the steps of parsing the content name of the data reply packet and locating it in the PIT. The results show the CCN routers require less instructions than the CDN servers by around 35%, which means CCN routers are faster than the CDN servers in processing packets.

IV. CONCLUSION

In this paper, we proposed a typical nation-wide CDN topology, a corresponding CCN deployment and the first feasible CCN router architecture. Based on them, we estimated the total amount of network traffic, corresponding H/W and S/W costs and protocol overhead for both CCN and CDN. Qualitatively, CCN seems to provide many advantages such as maintenance, flow control, traffic engineering, security and mobility over CDN. However, for CCN to survive in the market, it also has to secure quantitative advantage over CDN. The analysis results show that CCN can overcome CDN services even from the quantitative viewpoints. However, the results are not conclusive since many of CCN technologies still remain incomplete and the cost can increase as the technologies evolve. Even then, we believe our work can be a design guide for how the CCN need to evolve to overcome IP-based services such as CDN.

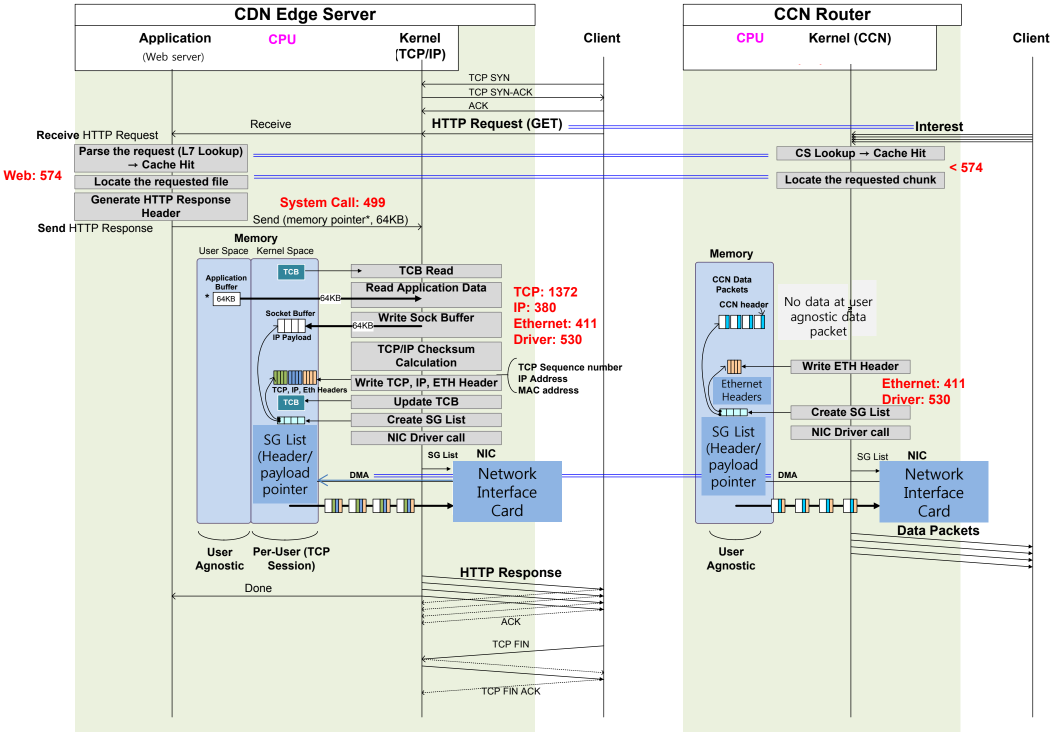


Fig. A. Left part of the figure shows the processing steps in an HTTP/TCP server when a server sends contents to a destination. Right part shows the corresponding steps assuming it is a CCN node.

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