Network Traffic Reduction through Smart Network

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Abstract

To cope with exploding Internet traffic, telecommunication companies are considering smart network technology. In this paper, we try to evaluate the impact of the smart network to the Internet traffic. First, ISP utilizes nodes smartly so that they can do smart caching. Second, ISP controls both routing and traffic matrix as a Telco-CDN so that they can decide more efficient traffic routing policy. Third, ISPs cooperate with each other so that they efficiently control IX traffic between them as a Telco-CDNi. Finally we estimate economic value of smart network from the traffic reduction of these points.

I. Introduction

Internet service providers (ISP) have been experiencing difficulties in dealing with increasing Internet traffic. According to CISCO, Internet traffic growth rate is 34% per year due to increasing large size video contents [1]. ISPs are expected to invest on their network infrastructure to maintain quality networks, which incurs big spending on the ISP sides. However, it is more and more difficult to recover the investment cost as the market is saturated and customers do not want to spend more.

Smart Network [2] or CDN-I [3] is an emerging technology to cope with ever-increasing Internet traffic. By exploiting locality of traffic through local caches, CDN service has been known to be an effective way to reduce Internet traffic by transmitting data from a local cache server instead of a remote original server. It also can improve interactivity as the delay performance improves. Telco's such as British Telecom introduces CDN services and started to provide CDN services through their networks and would like to expand their services through interconnection for the purpose of improving coverage [4]. CDN-interconnect or CDN-I enables interconnections between CDN-enabled ISPs for the purpose of improving CDN coverage.

Research has been done to improve delivery environment of ISP. Kamiyama et al. proposed ISP operated CDN [5]. The authors formulated an optimal cache placement problem and presented a greedy heuristic algorithm. Cho et al. proposed iCODE (ISP-centric content delivery) for reduced delivery latency by placing the contents closer to end hosts [6].

In this paper, we study the traffic reduction impacts of CDN-I. We formulated three different optimization models: No CDN, CDN only, and CDN-I. By comparing total traffic of three different models, we would like to understand how much traffic can be reduced using CDN and CDN-I against the No CDN model. Furthermore, we try to calculate the cost savings out of the traffic reduction.

The remainder of this paper is organized as follows. In section 2, we presented three optimization models. In

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section 3, we present numerical study and show the traffic reduction impacts. We also show the economic implication of traffic reduction using CDN-i. Finally, we conclude the paper in section 4 with discussions on future work.

II. Network Models

There are two ISPs and a single CDN service provider (CDN) in our model. Each ISP i, $i = \{1,2\}$ in our model, owns a network represented by a graph $G(V_i, L_i)$, where V_i is a set of nods and L_i is a set of links possessed by ISP i. For ISP i, a node $v \in V_i$ is either a server node or a user node. Specifically, a server node $s \in S_i$ generates traffic to a user node $t \in T_i$, where S_i and T_i are a set of servers and a set of users, respectively. A user t is assumed to have demand of D_t, and a server s has a limited server storage of B_s. For user demand D_t of ISP i, all traffic requests by users may not be successfully provided from servers of ISP i. In other words, some portion of user demand D_t, $t \in T_i$, is stored at local servers S_i while the rest demand can be served from outside, i.e., servers at other ISPs. Let the portion of demand provided locally be α, thus αD_t is internal demand and $(1-\alpha)D_t$ is external demand. In our model, a traffic flow is identified by a pair of one server and one user (s,t), which may be split into multiple paths to be delivered. We denote a traffic volume from a server s to a user t by x_{st}. A link $l \in L_i$ with a capacity of C_l carries a portion of traffic of each flow (s,t), which we denote by r_l^{st}, thus $0 \le r_l^{st} \le 1$ for all $l \in L_i, s \in S_i, t \in T_i$. Then, it is clear that the total traffic over the link l, f_l, is a sum of partial amount of each flow, i.e., $f_l = \sum_{(s,t)} x_{st} r_l^{st}$.

Model 1: Independent CDN

In first model, a single CDN provider affords CDN service independently on the ISP networks. ISP 1 and ISP 2 independently interact with a CDN so that we can focus only on the interaction between each ISP and a CDN, separately. A traditional ISP's role is to manage a balance of traffic load inside its network. In particular, an ISP i adjusts its own *routing matrix*, i.e., how much portion of each traffic flow to be passed through each link with given traffic volume of all flow, denoted by $[r_l^{st} \mid l \in L_i, s \in S_i, t \in T_i]$, to minimize congestion. This can be represented as an optimization problem of Table 1 that minimizes the total traffic of the network with constraints about demand, link capacity limit, and the flow conservation. The last constraint about flow conservation means that inflow and outflow should be the same in middle of the paths, i.e., except a server and a user. For any node v, $In(v)$ and $Out(v)$ refer to a set of incoming links to v and outgoing links, respectively.

Table 1. Optimization problem of ISP i

Objective	minimize $\sum_{l\in L_i} f_l$
Constraints	$f_l = \sum_{\{(s,t)\mid s\in S_i, t\in T_i\}} x_{st} r_l^{st} \le C_l$
	$\sum_{l\in In(v)} r_l^{st} - \sum_{l\in Out(v)} r_l^{st} = I_{v=t}$
Variable	$0 \le r_l^{st} \le 1$

Similarly, a CDN determines server locations, i.e., which servers should deliver content traffic to each user of ISP i, called *traffic matrix* and denoted by $[x_{st} \mid s \in S_i, t \in T_i]$, so that it can minimize the total delay disutility of the network $\sum_{l\in L_i} h_l(f_l)$, as shown in Table 2. Here, $h_l(x)$ is a delay disutility of the link l when x amount of flow rate passes the link. The constraints of this optimization problem are to meet server space and internal user demand.

Table 2. Optimization problem of CDN for ISP i

Objective	minimize $\sum_{l\in L_i} h_l(f_l)$
Constraints	$f_l = \sum_{\{(s,t)\mid s\in S_i, t\in T_i\}} x_{st} r_l^{st} \le C_l$
	$\sum_{s\in S_i} x_{st} = \alpha_i D_t$
	$\sum_{t\in T_i} x_{st} \le B_s$
Variable	$0 \le x_{st}$

In order to prevent network congestion and guarantee quality of service, each ISP and CDN interactively determine routing policy $[r_l^{st}]$ and server location $[x_{st}]$, respectively. This is a 2-person non cooperative game, and we solve above two optimization problems repeatedly to achieve equilibrium solution, which is called as a Nash Equilibrium in game theory.

Model 2: Telco-CDN

In second model, each ISP operates CDN service on its own network, called as a *Telco-CDN*, to jointly optimize both routing policy and server location. In model 1, ISP i determines routing matrix $[r_l^{st}]$ while CDN decides traffic matrix $[x_{st}]$ independently. Now, these two are jointly adjusted, by controlling $[x_l^{st}]$, to achieve higher efficiency rather than model 1. Optimization problem of Telco-CDN i is to minimize total traffic of the network while it additionally satisfies a threshold of total delay disutility, H.

Each ISP decides traffic volume of a flow from server s to user t over link l, x_l^{st}, by considering both routing and traffic matrix. However, ISP 1 and ISP 2 solve the problem independently with each other without any cooperation. Thus, each ISP efficiently utilizes its network only for own internal traffic demand, whereas IX(Internet eXchange) traffic, i.e., inter-ISP traffic (total external demand), is still inefficiently utilized.

Table 3. Optimization problem of Telco-CDN i

Objective	$minimize \quad \sum_{l \in L_i} f_l$
Constraints	$f_l = \sum_{\{(s,t) \mid s \in S_i, t \in T_i\}} x_l^{st} \le C_l$
	$\sum_{l \in L_i} h_l(f_l) \le \mathrm{H}$
	$\sum_{s \in S_i} \left(\sum_{l \in In(v)} x_l^{st} - \sum_{l \in Out(v)} x_l^{st} \right) = \alpha_i D_t \cdot I_{v=t}$
	$\sum_{t \in T_i} \sum_{l \in Out(s)} x_l^{st} \le B_s$
Variable	$0 \le x_l^{st}$

Model 3: Telco-CDNi

In Model 3, two ISPs collaborate with each other using the CDN-I (CDN-interconnect) technology, which means two ISPs cooperatively run as one entity, called *Telco-CDNi*. Now, the network of a Telco-CDNi is $G(V, L)$, where $V = V_1 + V_2$, $L = L_1 + L_2$, $S = S_1 + S_2$, and $T = T_1 + T_2$. With collaboration, we expect to reduce IX traffic by using cooperative caching. Thus, with high level of cooperation between ISP 1 and ISP 2, traffic demand that can be successfully provided from local servers increases, i.e., α_1, α_2 increases. It means that external traffic level goes down. We assume that ISPs cooperate with each other completely, so that the whole demand of each user can be generated from local servers.

Table 4. Optimization problem of Telco-CDNi

Objective	$minimize \quad \sum_{l \in L} f_l$
Constraints	$f_l = \sum_{\{(s,t) \mid s \in S, t \in T\}} x_l^{st} \le C_l$
	$\sum_{l \in L} h_l(f_l) \le \mathrm{H}$
	$\sum_{s \in S} \left(\sum_{l \in In(v)} x_l^{st} - \sum_{l \in Out(v)} x_l^{st} \right) = D_t \cdot I_{v=t}$
	$\sum_{t \in T} \sum_{l \in Out(s)} x_l^{st} \le B_s$
Variable	$0 \le x_l^{st}$

Table 4 shows the optimization formulation of Telco-CDNi, which seems very similar to model 2. The difference is that two ISPs solve its own optimization problem independently in model 2 while only one single optimization problem is solved in this model.

III. Numerical Evaluation

In this section, we try to evaluate the impact of the smart network. Firstly, ISP utilizes nodes efficiently so that they can do smart caching. Secondly, ISP controls both routing and traffic matrix as a Telco-CDN so that they can decide more efficient traffic routing policy. Lastly, ISPs cooperate with each other so that they efficiently control IX (Internet eXchange) traffic between them as a Telco-CDNi.

1. Impact of Network Caching

To understand the impact of CDN cache server on the traffic reduction, we adopted the methodology of [7]. Our assumptions are as follows:

1. The number of Internet objects varies between 1B through 100Billion. 2. The size of cache storage ranges between 10TByte to 60TBytes. 3. The size of each object is 100MByte. 4. The cacheable contents over the Internet is 40%. 5. The content rank follows Zipf distribution. Table 6 shows the summary of the assumptions.

Table 1 Assumptions for smart caching

Size of Internet	1B~100B
Cache Storage Size	10TB~60TB
Object Size	100MB
CDN Traffic	40%

Figure 1 shows the cache hit ratio for different number of objects. We can see that the hit ratio ranges from 55% to 65% for different cache sizes. The hit ratio for 10B objects and that of 100B objects are indistinguishable.

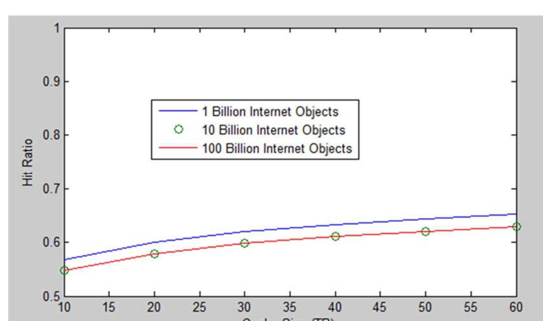

Figure 1. Smart Caching model: Hit ratio

Because not all traffic of the Internet is cacheable, if we take this into account, the traffic reduction due to caching can be calculated as in equation (1). The fraction R of traffic reduction is given by:

$$R = 1 - [(\alpha \times (1 - h) + (1 - \alpha)] , \qquad (1)$$

where α is a fraction of Cacheable traffic and h is a hit ratio. If we assume that the hit ratio h = 60%, and cacheable traffic fraction is α=40%, then the fraction R of traffic reduction is 24%.

2. Comparison of Three Models

We used the network topology based on KORNET as shown in Figure 2. There are 16 nodes (3 servers, 10 users, 3 routers) in the network and 28 links. We assume that server capacity is enough to cover user demand.

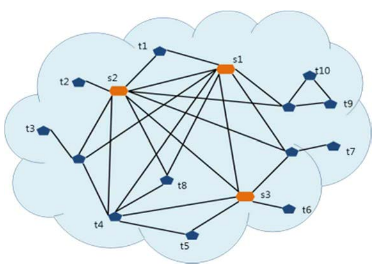

Figure 2. Kornet Topology

Figure 3 shows the total traffic over the network from three different models. We assumed that traffic between ISPs are 50% of total traffic and the other 50% is intra-ISP traffic in the numerical study. The demand is generated randomly. The x-axis corresponds to different total demands and y-axis shows the total traffic summed over all links. We can observe that model2 (Telco-CDN) is more helpful when traffic demand is higher while model 3 (CDNi) is helpful regardless of traffic demand. The average reduction impact of model2 against model 1 is 6.48% and that of model 3 against model 2 is 27.5% in our numerical study.

3. Economic Cost Savings

We evaluated the economic cost savings due to CDNi using economic data. We used existing network infrastructure cost for last 10 years in Korea and extrapolate the number for next 10 years to calculate the cost saving. Our study implies that the total saving of network infrastructure due to smart network can be 600 billion won to 1 trillion won for next 10 years due to mild assumptions. For details, refer to technical reports [8].

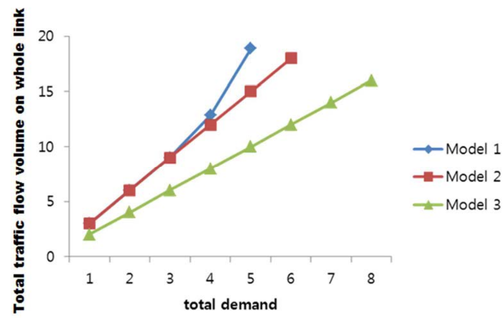

Figure 3 Model 1 vs. Model 2 vs. Model 3

IV. Conclusions

In this paper, we study the impact of Telco CDN and CDNi. We formulated three different optimization models and derived traffic reduction impact from the developed models. Our study shows that CDN caching can reduce 24% of traffic. Similarly, In Telco-CDN, traffic reduction is 6.48%, In Telco-CDNi, traffic reduction is 27.5%. Also we compare existing network construction cost with network construction cost decreased by smart network. As a result, network construction cost reduction of ISP who has 40% market share is from 600 billion won to 1 trillion won.

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