Projet de Fin d'Études
2013 – 2014

[R | E]

Energy efficiency
And
Content distribution

[Description of work]

Nima Soroush Haddadi

Supervised by:
Joanna Moulierac

Frédéric Giroire

Reviewer:

Chadi Barakat

Université Nice Sophia Antipolis

02/23/2014

informatiques mathématiques

TABLE OF CONTENTS

1 INTRODUCTION

With the increased cost of energy and the sharp growth of demand, the need of energy-aware solutions has appeared as an imperative for governments, companies and individuals. This theme is particularly relevant for the networking community. It is estimated that the Information and Communication Technology sector is responsible for up to 10% of global energy consumption. 51% of that is attributed to telecommunication infrastructure and data centers. The objective is the reduction of the energy consumption to operate and manage the existing networks, especially with the development of new very demanding applications (e.g., audio/video streaming, cloud services). On the other hand, in order to reduce network load and improve quality of service, content providers and network operators try to disaggregate traffic by replicating their data in several points of the networks, reducing the distance between this data and their users. Recent years have seen, along the growing popularity of video over Internet, a huge raise of traffic served by Content Delivery Networks (Youtube, Akamai, ...). These kinds of networks operate by replicating the content among its servers and serving it to the end users from the nearest one.

2 DESCRIPTION AND COMMENTS

2.1 CONTENT DISTRIBUTION NETWORK (CDN)

2.1.1 Overview

If we look at the history of the network and specially internet we notice that when internet has been born there was no concern about how to delivering content from one side of the network to the other side. By growing up the internet, content delivery become more important and nowadays everyone knows that, the future internet it is just about how to deliver contents in a way that is more fast and reliable. This gives us the definition of the Quality of Service in the network (QoS).

For the brief definition of the CDN we can say CDN or “Content Delivery Network/Content Distribution Network” is a large distributed system of servers deployed in multiple data centers across the Internet (Wikipedia). The objective of the CDN is to serve content to end-users with high availability and high performance. For satisfying this aim CDN provide services that improve network performance by minimizing bandwidth occupancy, improving accessibility and maintaining correctness through content replication. In spite of these aim the CDN deal with the sudden spike in Web content requests, which is often termed as *flash crowd[1]* or *SlashDot[12]* effect. The idea of CDN is to redirect the users to the surrogate servers that are nearest to them.

A CDN provider is a proprietary organization or company that provides infrastructure facilities to content providers in order to deliver content in a timely and reliable manner. In fact CDN providers are the owner of network topology for the content providers that is included of the surrogate servers. A content provider is one who delegates the Uniform Resource Locator (URL) name space of the Web objects to be distributed among the end users by updating these name spaces in proxy servers. Proxy servers are deployed by ISPs to deal with increased Web traffic and optimize the content delivery on the Web and delivering the contents to the end users. Finally, Surrogate servers have the copy of the content that deliver directly to proxy servers. In picture below you can see as example of CDN network.

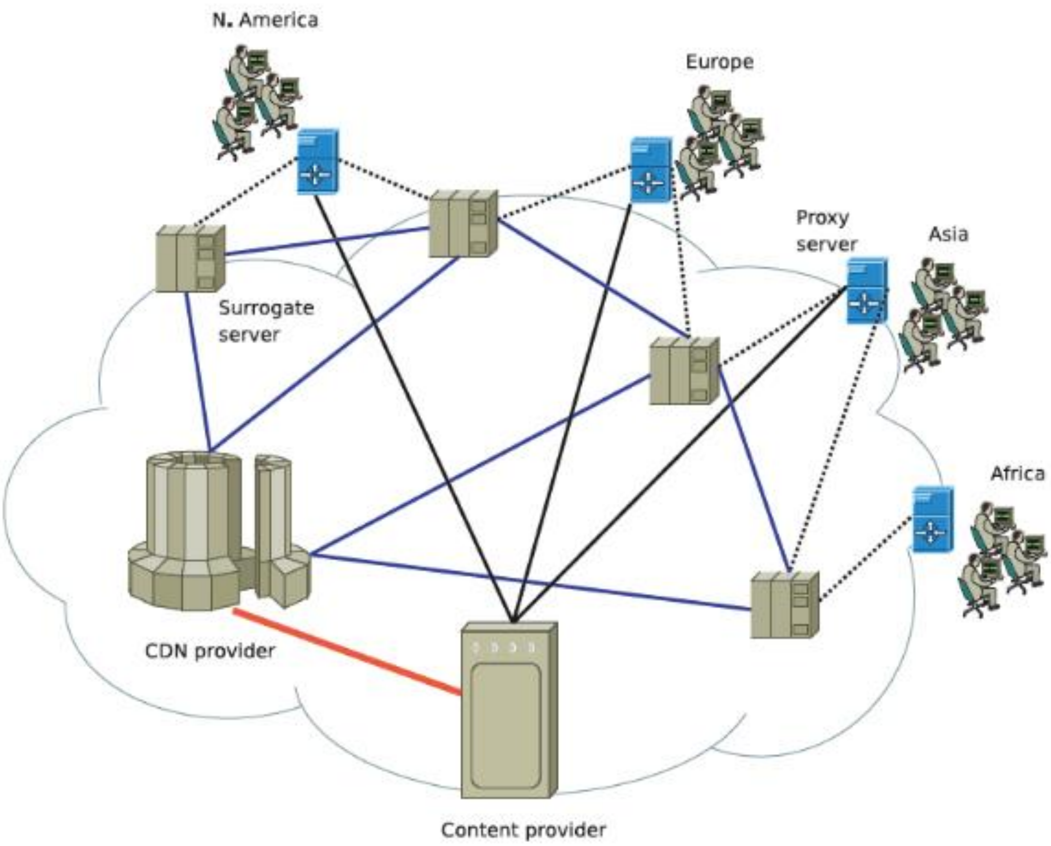


Figure 1. CDN network and component

2.1.2 CDN functionality

For understanding of how a CDN works first we have to see what the component of a CDN are. Usually a CDN is made up of:

- The end-users that are the customers of the CDN.
- The *content-delivery* component which consists of the origin server and a set of replica servers that deliver copies of content to the end users.
- The request-routing component which is responsible for directing client requests to appropriate edge servers and for interacting with the distribution component to keep an up-to-date view of the content stored in the CDN caches.
- The distribution component which moves content from the origin server to the CDN edge servers and ensures consistency of content in the caches.
- The accounting component which maintains logs of client accesses and records the usage of the CDN servers. This information is used for traffic reporting and usage-based billing by the content provider itself or by a third-party billing organization.

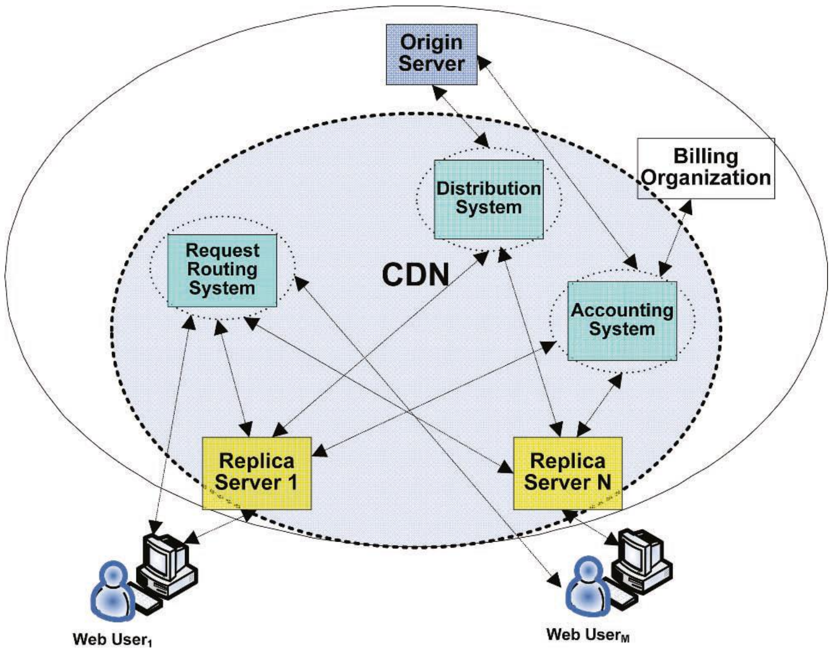


Figure 2. Architectural component view of CDN

For better understanding of a CDN here we describe several concept of CDN composition like different approaches, servers, relationship, protocols, and content types. In general there are two general approach to build a CDN: Overlay and Network approach. In the overlay approach servers and caches in the network handle the distribution of the specific type of the data in the network and but in the network approach the network elements like routers and switches are equipped with the code for specifying the application type and forwarding the requests based on predefined policies.

On the other hand there are two type of servers in the CDN: Origin server and surrogate servers. The origin server has the definitive version of the content and the servers that called surrogate servers have the responsibility of the delivering data to the end users and holding the replica of the content based on the policy of CDN providers.

There are two different relation between surrogate servers in the CDN, either they are connect together in pair or they are all connected to the main distribution server (master proxy) that replicate content to surrogates servers. The first model is proxy mesh and the second model is proxy array.

There are different protocols on the CDNs based on interaction between network elements (e.g. router and switches) and interaction between surrogate servers. Based on the CDNs managers it will be decided that which protocol will be implemented on the CDNs and some of these protocol are private and have been implemented just by specific companies (e.g. Akamai). The decision for selecting the protocol is based on the services that CDN provider going to give to its customers like QoS, Security, firewall, reliability and etc.

Generally there is three different type of the content in any CDNs: static content, streaming media and services. A good example for static content can be HTML pages, images, documents, audio and/or video and etc. streaming media can be live or on-demand streaming media that any sports, concerts, channel, and/or news companies broadcast over internet. Services provided by CDNs can be directory, Web storage, file transfer, and e-commerce services.

Surrogate placement: The content distribution in the CDN is one of the important part in the case of providing the services to the end users. The first concern in content distribution is where the best placement of surrogate servers is in the CDN networks. Technically it is not feasible if we decide to put surrogates server in any edge of network in case of cost and traffics. The goal of optimal surrogate placement is to reduce user perceived latency for accessing content and to minimize the overall network bandwidth consumption for transferring replicated content from servers to clients. Different algorithm have been proposed such as: *Minimum k-center problem [13], Greedy algorithm [14], Topology-informed placement strategy [15]*, *Hotspot [16]*, etc.

Content selection and delivery: After deciding for the best surrogate placement the important issue for the CDN provides is to decide how to deliver the content to the end-users. There are two main approach for doing this: Full-site and partial-site selection and delivery. In the full-site approach the entire set of origin server's objects is outsourced to the surrogate servers. With this approach, a content provider configures its DNS in such a way that all client requests for its Web site are resolved by a CDN server, which then delivers all of the content. The main advantage of this approach is its simplicity. But such a solution is not feasible when the size of the objects increase. Although the price of storage hardware is decreasing, sufficient storage space on the edge servers is never guaranteed to store all the content from content providers. Moreover, since the Web content is not static, the problem of updating such a huge collection of Web objects is unmanageable.

In the partial approach just surrogate servers doing 'partial-replication' of the contents and this partial replication consist of the embedded object – such as web page images – from the corresponding CDN. There are some policies to decide which object should be replicated from origin server. In *empirical-based* approach, the Web site administrator empirically selects the content to be replicated to the edge servers. Heuristics are used in making such an empirical decision. The main drawback of this approach lies in the uncertainty in choosing the right heuristics. In *popularity-based* approach, the most popular objects are replicated to the surrogates. This approach is time consuming and reliable objects request statistics is not guaranteed due to the popularity of each object varies considerably. Moreover, such statistics are often not available for newly introduced content. In *object-based* approach, content is replicated to the surrogate servers in units of objects. This approach is greedy because each object is replicated to the surrogate server (under storage constraints) that gives the maximum performance gain. Although such a greedy approach achieve the best performance, it suffers from high complexity to implement on real applications. In *cluster-based* approach, Web content is grouped based on either correlation or access frequency and is replicated in units of content clusters.

cache organization: One of the big issues in CDN network is cache organization that is correspond to methods of updating each surrogate server in the network because content object are change during the time in the network. There are some method for update surrogate servers in the network like periodic update, update propagation, on-demand update and invalidation. In *periodic update*, origin server decide to update each surrogate server in a specified period of time. Origin server will send the fresh version of the content to each surrogate. The drawback of this approach is that it make unnecessary traffic generated from update traffic in each interval. The *update propagation* approach is based the event of any change in content in origin server. The origin server will send the updated version of the content to surrogates whenever a change is made. This approach suffer from frequently changing content in the network that make excess update traffic. *On-demand update* approach is based on the assumption that nothing will change until someone request for that. Each time that a surrogate server receive a request for the content it check the version of the content with the origin server and just in case of change of the content origin server will update all the surrogate servers. The disadvantage of this algorithm is the traffic that goes each time between surrogate and server to ensure that delivered content is the latest. In *invalidation update* approach the origin server in case of change send an invalidation signal to all surrogate servers. The surrogate server as soon as receive any request from end-users for that contents will update that content to new version. The drawback of this approach is that it does not make full use of the distribution network for content delivery and belated fetching of content by the caches may lead to inefficiency of managing consistency among cached contents. Beyond all of these approaches content providers themselves can build their own policies or use some heuristics to deploy organization specific caching policies.

Request routing: The request routing component of the CDN is responsible for routing client requests to an appropriate surrogate server for the delivery of content. It consists of a collection of network elements to support request-routing for a single CDN. Based on distribution of the content in CDN network the request routing in the CDN can be different. Here there is a schema for the partial-site content request routing.

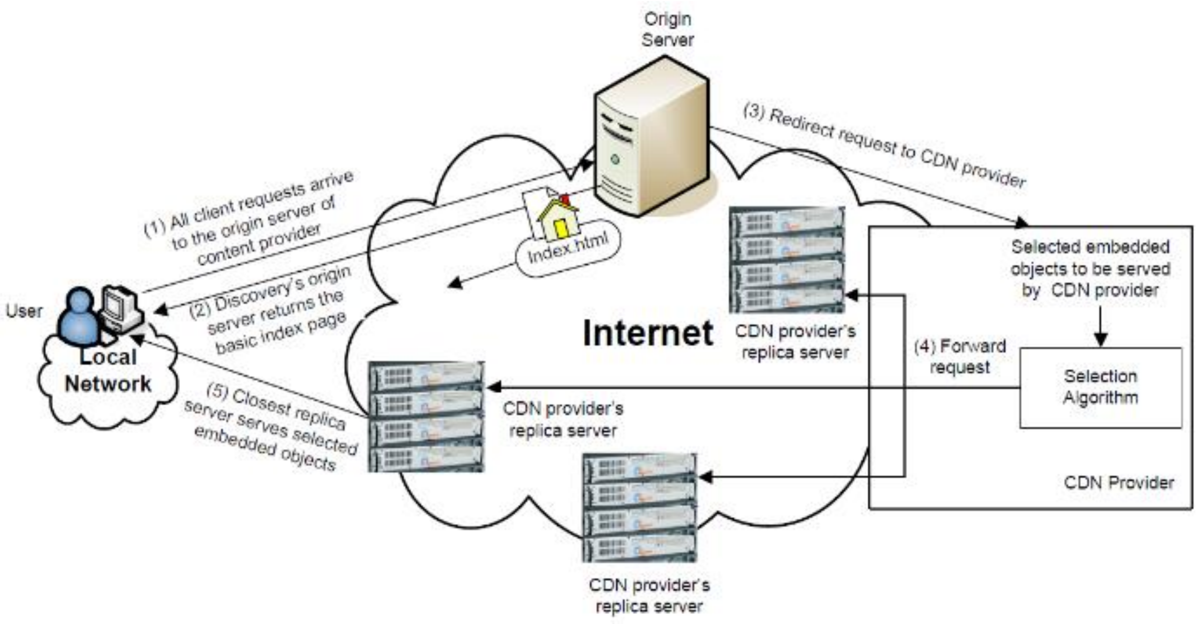


Figure 3. Request-routing in a CDN environment

The request routing algorithm can be adaptive or non-adaptive. Adaptive algorithm consider the current situation of the network for forwarding the requests considering by estimating some metrics like load on the replica servers or the congestion of selected network links and non-adaptive use some heuristic rather that considering current situation.

As an example of non-adaptive request routing is round robin algorithm which distribute all request to the CDN cache servers and attempts to balance load among them. Such algorithm assume that all surrogate servers are same. Each time when a request comes from the end-user the content distribution component take the token to one of the surrogates to deliver the content to end user. This algorithm does not perform well in wide networks and also may the request goes to a surrogate server that is far from end-user which cause poor performance perceived by the user and also the aim of load balancing is not fully achieved in this algorithm. In the other non-adaptive algorithm all the surrogates are ranked by predicted load on them. This prediction is done by the number of the request that this satisfy. This algorithm also take end-user and surrogate server into account and forward the request to the server in way that the load is balanced.

In the case of adaptive routing algorithm some algorithms have been proposed based on different measurement like client-server latency, network proximity, inter and intra AS distance, bandwidth that is currently available and etc. Some of big content providers like cisco and Akamai have their own algorithm for doing the request routing.

Request-routing mechanisms: Request-routing mechanisms inform the client about the selection of replica server, generated by the request routing algorithms. Request-routing mechanisms can be classified according to several criteria. In this section we classify them according to the variety of request processing. As shown in Figure 15, they can be classified as: Global Server Load Balancing (GSLB) [17], DNS-based request-routing [18][19], HTTP redirection [18][20], URL rewriting [21], anycasting [20], and CDN peering [18] [22].

2.1.3 CDN evaluation

After understanding the concept of the CDN we want to know that what is the advantage of using a CDN and why a company should use such this technology and what CDN will bring for that company. In the other hand we want to know what is the disadvantage of running a CDN and why is better to not using it in some cases.

CDN networks can bring very good network performance by:

- ✓ Improving the bandwidth traffic in the network by redirecting the request of the customers to proper surrogate server and reducing the amount of request from single server CDN will decrease the load on the some links in the network

- ✓ Improving the accessibility of the content by duplicating the content from single server (origin server) to other server will help users to achieve the best performance in case of accessibility of data.
- ✓ Maintaining the correctness of the content by replicating the content in different servers. In this case if any of content in different servers damaged or corrupted we can we can correct the content from the replicated servers.
- ✓ Solving flash crowd problem that happens by flood of request from users from a single server by redirecting the request to different surrogate servers.
- ✓ CDN approach is more close to the concept of IP independent internet (CCN).

In spite of all advantage of CDN cannot be the best choice sometimes considering:

- ✗ The average cost of CDN services is quite high and often out of reach for many small to medium companies.
- ✗ Since most organizations utilize third-party vendors to maintain the CDN, there is always the question of support availability. If a major issue arises, will the operator be able to fix it in a timely manner and prevent the same problem from occurring again?
- ✗ The CDN operator must also effectively maintain each server with the proper updates and patches without disrupting the client's content network. Placing a company's entire corporate network into the hands of an operator is a major step. Therefore, all factors must be considered and backup plans implemented prior to setup and usage. This also includes timely maintenance and application of updates.
- ✗ Organizations must research the location of the servers offered by each CDN and find those that best fit their customer's locations. It is pointless to utilize a CDN that is a significant distance from users, which will result in potential service disruptions, jittering streaming of video, downtime, low latency and thus low performance.
- ✗ Security in CDN network is still challenging matter. Today security is an add-on based on trusting the source via authentication and securing the channel via encryption.

2.2 CDNs and Energy in network

2.2.1 Energy efficiency in network

With the increased cost of energy and the sharp growth of demand, the need of energy-aware solutions has appeared as an imperative for governments, companies and individuals. This theme is particularly relevant for the networking community. It is estimated that the Information and Communication Technology sector is responsible for up to 10% of global energy consumption. 51% of that is attributed to telecommunication infrastructure and data centers. The objective is the reduction of the energy consumption to operate and manage the existing networks, especially with the development of new very demanding applications (e.g., audio/video streaming, cloud services).

2.2.2 Power-saving on CDN

In recent years, Traditional data center user content delivery mode has been diminishing and being replaced by content traffic over major CDN operators such as Google and Akamai [79]. There are different approaches for doing the energy efficient networking and, like switch off as many network devices as possible, build novel networking technologies, wireless transmission techniques, network architectures and protocols that can scale cost-effectively, development of the IEEE 802.3az Energy Efficient Ethernet (EEE) standard, packet coalescing, network coding, hardware approaches (D-Link's PowerLine Ethernet adapter), clocking the hardware at a lower speed and so on.

For better understanding of the relation between energy efficiency in the network and content distribution we consider different approaches that have been proposed as techniques for saving power consumption in the CDN networks. After studying each approach and considering the advantage and problems, we will do a general comparison between all of them. For studying this impact we formulate it as energy efficient content distribution problem. The objective is to find a feasible routing, so that the total energy consumption in the network is minimized subject to satisfying all the demands and link capacity.

2.2.3 General Power-saving Strategies

Energy Proportional Computing: The Energy-Proportional Computing was firstly proposed in[23]. The Idea is the CPU utilization of modern servers are within the range 10% to 50% most of the time and also an idle server consumes about 50% or more of its peak power. Ideally in the interest of the power consumption of a server should be proportional to its workload. In other word, no power should be consumed by an idle server. Based on this Idea, major research work has been motivated and as an important achievement, the development of *dynamic voltage scaling (DVS)* and *dynamic voltage and frequency scaling (DVFS)[24]* have been implemented. In practice these methods often used in conjunction with other power saving strategies.

Dynamic Provisioning: In a High power management schema the most effective power-saving strategy would be to provision only the servers or networking elements that are needed, while putting the remaining ones to sleep mode. Dynamic provisioning refers to the strategy that actively or passively adapts the provisioning of servers or networking elements based on the current or predicted future network load. Typically, during off-peak hours, the load can be consolidated to fewer servers or network path subject to their capacities, and the unused servers or networking elements can be temporary disabled by, e.g. entering the sleep mode.

Virtualization: Virtualization refer to the technology of establishing multiple virtual hardware instance (or virtual machines, VM) within one piece of physical hardware. There are two characteristic of the virtualization technologies that make it specifically suitable for being employed in power-saving schemas. Firstly, the workload on multiple VMs within one physical node can be consolidate onto one VM subject to its load capacities, without incurring extra network traffic. Secondly VMs can be moved between physical machines via live migration[25].

2.2.4 Energy efficient content distribution

The first approach that we consider with tittle of “Energy efficient content distribution” is an integer linear programming formulation to reduce energy consumption by using caches and properly choosing content provider servers for each demand. We model the problem as follow:

- Parameters

  Cache hit rate: It is defined as the ratio of the number of cached documents versus total documents requested. The cache located in the router and automatically cache the most popular content, potentially saving a fraction of any demands. We leave this fraction as a parameter α in our model that shows maximal part of any demands that can be cached.

  Cache power usage: in the model we have two type of element: links and caches. We keep the parameter β as power consumption of a cache divided by power consumption of a link.

- Problem definition

  We aggregate the traffic between cities as a demand matrix. The content of these matrix shows the traffics that is going between cities and also the content providers. This is because the content providers can also generate traffics. Knowing the topology of the network as a graph G (V, E) that V is the set of network element that present the cities in our problem and E is the link between them. Moreover, we are given a set of content providers P. The demand matrix is like below:

$$
\begin{array}{c}
\\ \boldsymbol{v_1} \\ \boldsymbol{v_2} \\ \boldsymbol{v_3} \\ \cdots \\ \boldsymbol{v_n}
\end{array}
\begin{array}{c}
\begin{array}{ccccccccc}
\boldsymbol{v_1} & \boldsymbol{v_2} & \boldsymbol{v_3} & \cdots & \boldsymbol{v_n} & \boldsymbol{p_1} & \boldsymbol{p_2} & \cdots & \boldsymbol{p_m}
\end{array} \\
\begin{bmatrix}
\mathbf{0} & \dot{D}_1^2 & \dot{D}_1^3 & \cdots & \dot{D}_1^n & \cdots & \cdots & \cdots & \dot{D}_1^m \\
\dot{D}_2^1 & \mathbf{0} & \dot{D}_2^3 & \cdots & \dot{D}_2^n & \cdots & \cdots & \cdots & \dot{D}_2^m \\
\dot{D}_3^1 & \dot{D}_3^2 & \mathbf{0} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
\dot{D}_n^1 & \dot{D}_n^2 & \cdots & \cdots & \mathbf{0} & \cdots & \cdots & \cdots & \dot{D}_n^m
\end{bmatrix}
\end{array}
$$

Figure 6. Demand matrix

Here in this matrix each entry shows the demand between nodes. The nodes are either cities that shown as $\dot{D}_s^t$, ($\forall s, t \in V$) that Is a city to city demand or content providers that shown as $\dot{D}_s^p$, ($\forall s \in V$, $\forall p \in P$) that is a city to content provider demand.

The goal is to find the feasible routing in the given network topology that satisfies all demands $\dot{D}_s^t$ and $\dot{D}_s^p$ under the capacity constraint that minimize the total energy consumption of the network. The total energy is the energy used by caches and the links.

- Integer linear programing formulation
  As our goal is to turn off links and caches in order to minimize the amount of energy used in underlying networks.

1. x_{uv} , $(\forall\{u, v\} \in E)$: Indicate if the link between node u and v is on or off. Each link uses l_c Unit of energy.
2. y_v , $(v \in V)$: Indicate if the cache at node v is on or off.
3. z_v , $(v \in V)$: Indicate the load of the cache on node v
4. ϒ : Is a fraction of β that indicate power consumption of idle cache

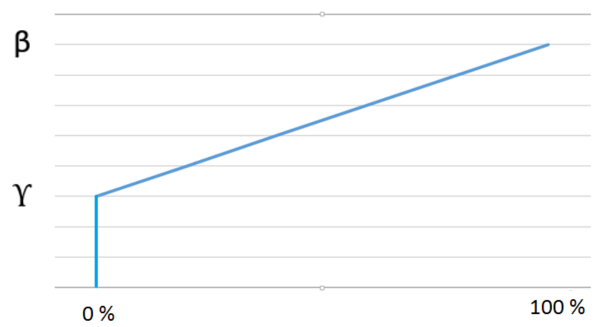


Figure 7. Idle Cache energy consumption

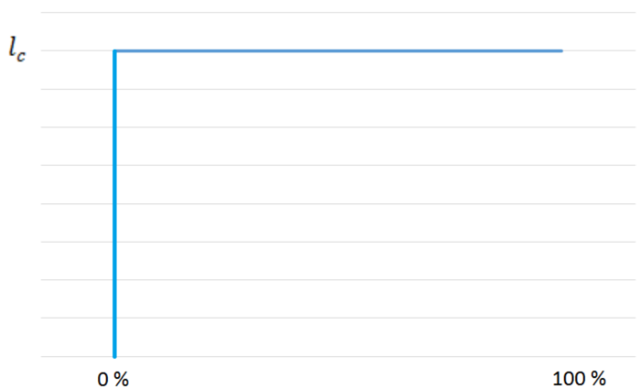


Figure 8. Link energy consumption

We can write the objective function for our problem is as follow:

$$\min \sum_{\{u,v \in E\}} x_{uv} + \sum_{\{u \in V\}} \beta\, \gamma\, y_v + \sum_{\{u \in V\}} \beta\,(1-\gamma) z_v$$

The variable constraint and the flow constraint are given in the original paper.

- Instance generation
  For testing the result here the problem tested on some instance of real network topologies.
  1. Atlanta- $|V| = 15$, $|E| = 22$
  2. Nobel-EU - $|V| = 28$, $|E| = 41$
  3. Germany50- $|V| = 50$, $|E| = 88$

- Empirical result
  The results that have been obtained from the instances based on the changing different parameters of the problems.

  1. Chace parameter

There are two different parameters related to cache: cache hit rate α and cache power usage β. The results show that by increasing the parameter α the energy consumption on the network will decrease. This shows when we save more part of any demand we save more energy and it also shows by saving just 15% of any demand we gain a big amount of the energy that will be save. After this portion the amount of energy saving goes slower

By changing the value of β we notice that even when the caches using no energy still network uses 60 unit of energy and by increasing the parameter the energy usage of the network also increase.

If we consider both parameters together we can realize that what the best value is where the power consumption of the network is less. This area is shown by dark places in the figure

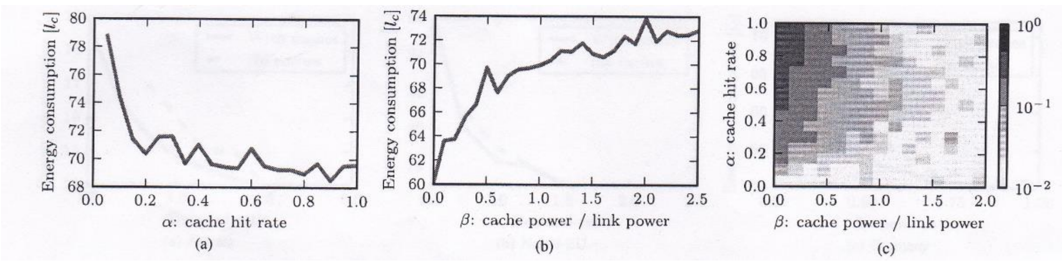


Figure 9. Effect of parameter α and β

2. CDN parameters

Here we want to see the impact of using caches in the network and compare it with the case that there is no cache. We see that in a case when there is no cache in the network and when we use cache we save the energy regarding to percentage of demand that goes through CDN network.

In a second case we want to see the impact of number of the CDN servers. as we can see in figure.10 with less than 3 server the routing is no feasible and by increasing the number of the server the energy consumption is decreasing till a point that increasing the number of servers has a little effect. In our case this number is 5.

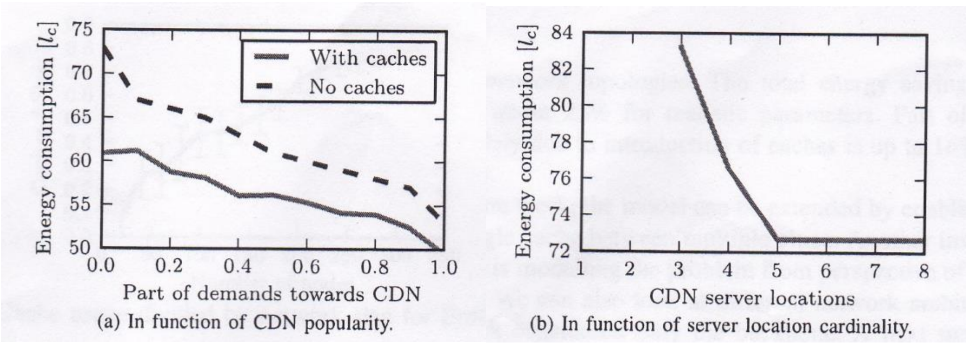


Figure 10. Energy consumption variation by CDN parameters

3. Impact of traffic level

Here we want to measure the impact of demand ratio that is the inverse of traffic level. In all cases enabling the caches make the routing feasible under much higher loads then case without caches. We see that is possible to route without caches but in higher energy cost. We observed that after some point there are no additional saving in energy because in that point if we turn of more devices in network we will disconnect the network.

4. Impact of network size

The last impact that we considered here is how the size of network impact the energy consumption using the caches. The claim is in bigger networks we could notice higher utility of using caches. As we see in the result that have been obtained in different graphs usage of caches grows with increasing network size.

2.2.5 Energy-Aware Network Management and Content Distribution

The second approach that we study is a research that has been propose a new approach to reducing power consumption for internet service providers (ISPs) and content providers (CPs) and aim to controlling whole system composed of ISP and CP in order to find the minimal set of network resources and servers that minimize the total power consumption while satisfying the current content requests.

In this paper they proposed two distributed algorithm to minimize power consumption while limiting the amount of shared information, such as network topology and the servers' load. They solved a multi-objective problem in which a CP an ISP cooperate to reduce the overall power consumption. They assumed that the ISP is the owner of a network infrastructure and CP infrastructure as a set of servers placed in different cities. They developed different algorithms based on two technique: the dual decomposition and Benders decompositions.

1.1. Problem definition

As assumed before the ISPs are the owner of the network infrastructures so that is manage the network topology i.e. a set of nodes and links. The CPs composed of a number of servers connected to the ISP. It assumed that the content copied among the CP's servers and when a user ask for particular content, they can be served potentially by any of the servers.

The problem defined by following hypothesis:

Input*:* Given di-graph G (V, E) that is the topology of network of ISP. V is the set of nodes (cities) of graph and E is the set of links between the nodes. For each of links we have a known capacity C. The average amount of traffic demands from users and the power consumption of links and nodes and also the power consumption of each CP's server is known.

Objective function*:* The total power consumption of the ISP network and the CP infrastructure

Subject to*:* maximum link utilization, maximum admissible delay, and maximum server utilization.

They named the model as *Centralized green model* by introducing the estimated demand (a continuous variable representing the amount of traffic between a source node and a terminal) and the estimated delay (for each link in the network). The objective function is as follow:

$$Min\ (P_{TOT} = P_{CP} + P_{ISP})$$

Considering the CP and ISP, compute their total power consumption and total energy consumption as assumed first is the summation of these two amount. The model belong to mixed-integer problem that can be solved using standard optimization programs.

The problem here is how they can compute the total amount of energy separately on their behalf while the amount of shared information is limited. Here the proposed the distributed algorithm to solve this problem that follow these two assumption:

1. The problem can be completely split between the ISP and the CP using a decomposition technique.
2. After the problem is split the amount of information shared by ISP and CP is limited.

The Dual green algorithm: They first apply a dual decomposition technique to derive a distributed algorithm. After the decomposition is applied, the ISP use an estimation of the traffic demands, while CP uses an estimation of the users' delay. For sharing the information they first introduce the Lagrange multipliers. The Lagrange multiplier then shared between the ISP and CP.

The ISP problem became as follow:

$$D\_GreenISP: \qquad Min\ (P_{ISP} - \sum_{st} \lambda^{st}\, \dot{x}_m^{st} + \mu_a d_a)$$

Considering above equation, λ^{st} is the Lagrange multiplier between any source node s and terminal t. $\dot{x}_m^{st}$ is the estimated delay for the content provider m and between any source s and terminal t. Respectively d_a is the delay among all link (consider that this value is not estimated because the ISP is the owner of the network and can calculate it) and μ_a associated with the consistency constraint between estimated delay and real delay (this constraint is one of the constraint for solving the linear equation that is mentioned in the paper).

The CP instead solve the following problem:

$$D\_GreenCP: \qquad Min\ (P_{CP} - \sum_{st} \lambda^{st}\, x_m^{st} + \mu_a \mathrm{d'}_a)$$

The different here is that CP know the real amount of traffic and not estimated, but for the delay it use the estimated delay between the s and t.

In order to get an optimal solution, the $D\_GreenISP$ and $D\_GreenCP$ are solved using an iteration method that involve the Lagrange multiplier. The intuition is that the Lagrange multiplier act as (penalty/reward) for the objective function. For example when

$$\dot{x}_m^{st}(k) - x_m^{st}(k) > 0$$

The associated multiplier $\lambda^{st}(k+1)$ is decreased. When $\lambda^{st}(k+1)$ is positive, it acts as a reward for the ISP and a penalty for the CP. In the example, at iteration $k+1$ the ISP will decrease $\dot{x}_m^{st}(k+1)$ since the associated reward $\lambda^{st}(k+1)$ is decreased, and the CP will increase $x_m^{st}(k+1)$ since the associated penalty $\lambda^{st}(k+1)$ is decreased. Here in the graph below you can see the exchange parameter for the *dual green algorithm*

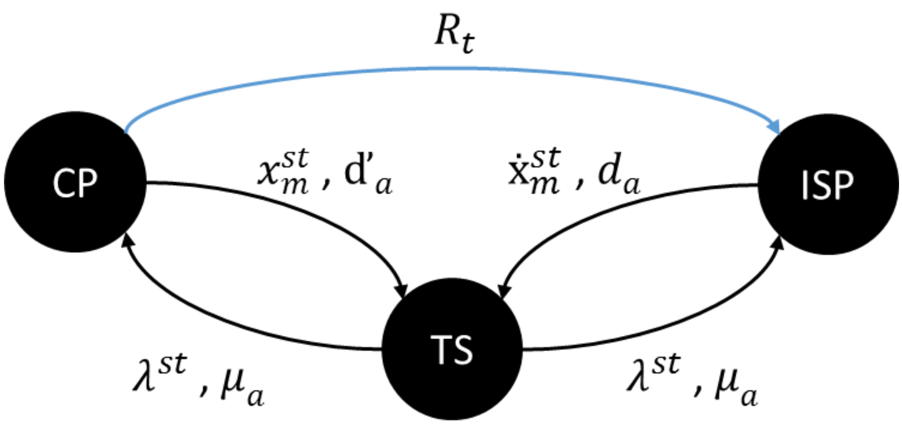


Figure 11. Exchange parameters for the dual green algorithm

Here R_t is the traffic demand between terminal t and the content provider S. Since the Lagrange multipliers' update need the demands and the delays from both the CP and ISP, here they proposed the adoption of a trusted third party server (TS) to delegate the manipulation of the Lagrange multipliers. The TS can be controlled by a trusted authority that ensures that both ISPs and CPs are actively cooperating in reducing power consumption.

The dual algorithm then works as follows: the Lagrange multiplier are initialized by the TS, then the $D\_GreenISP$ and the $D\_GreenCP$ are solved in parallel by the ISP and the CP, respectively, using the current Lagrange multipliers. At the end of each iteration the TS updates λ^{st} and μ_a . The distributed problems are iteratively solved until a maximum number of iterations K_{MAX} is maxed. The distributed problem does not converge to an equilibrium point, since the consistency constraint are not assured by the distributed approach. This impact the QoS of users, because traffic demands and delays are not properly estimated.

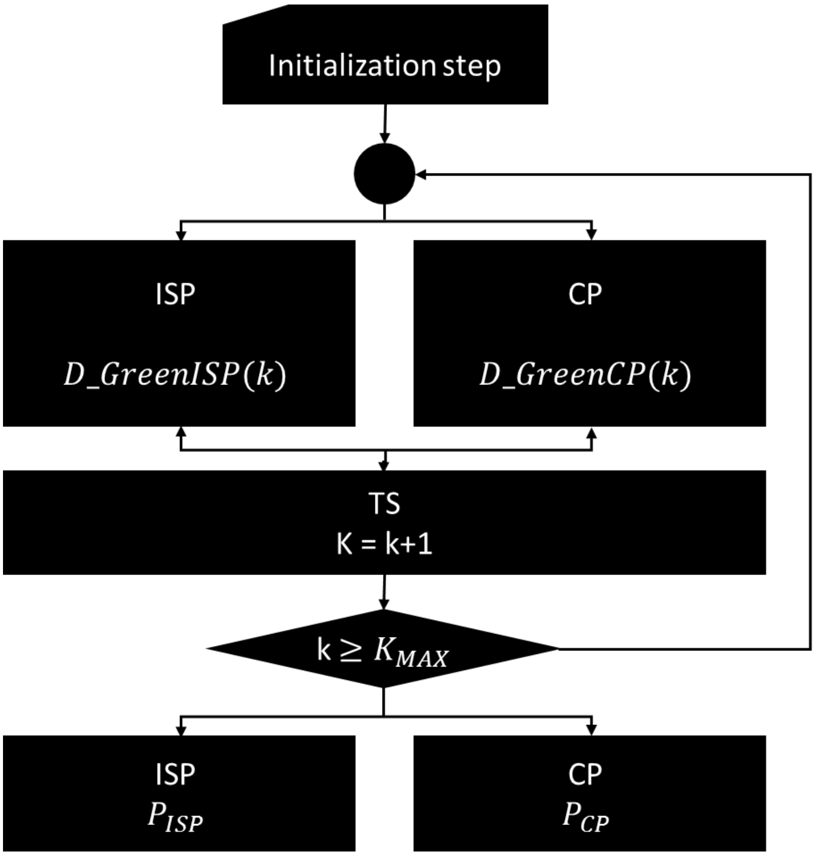


Figure 12. Dual green algorithm flowchart

The Bender green algorithm: The second approach that has been studied in this paper is Bender decomposition. This technique is well known in transportation system when the problem structure allows to separate some variables from the others. The intuition behind this technique is to individuate the variables that prevent from splitting the original problem into a set of new small problems. Such variables are named complicating variables. In particular with the Benders decomposition two new problem are defined: the sub-problem and the master-problem. The sub-problem uses parameterized values of the complicating variables. The master-problem can instead modify the complicating variables, but at each iteration it add new constraints in order to take into account the solution obtained by the sub-problem. The added constraint called Bender cuts.

Here in Bender green algorithm the complicating problem are the traffic demands x_m^{st}: intuitively, once they are fixed to constant values, the original problem can be split between the ISP and the CP.

The ISP will solve the following problem:

$$B\_GreenISP: \qquad Min\ (P_{ISP})$$

The CP solves instead the following master problem:

$$B\_GreenCP: \qquad Min\ (P_{CP} + \gamma)$$

Intuitively, γ is the lower bound on the ISP power consumption. Notice that when $= P_{ISP}$, the solution of the master problem is optimal. Finally, an upper and lower bound on the total power consumption are computed as follow:

$$P_{TOT}^{UP}(k) = P_{CP}(k) + P_{ISP}(k)$$
$$P_{TOT}^{DOWN}(k) = P_{CP}(k) + \gamma(k)$$

When the difference between the upper bound and lower bound is below a given threshold ε, the algorithm ends and a near-optimal solution is returned.

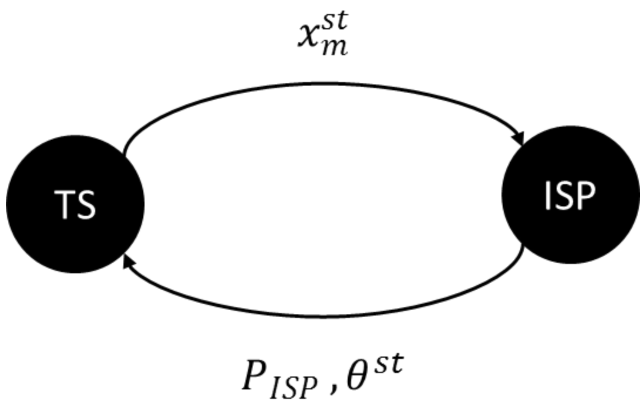


Figure 13. Exchange parameters for Bender green algorithm

Practically θ^{st} is the sub-problem solved by $B\_GreenISP$. The step of the algorithm shown in picture below:

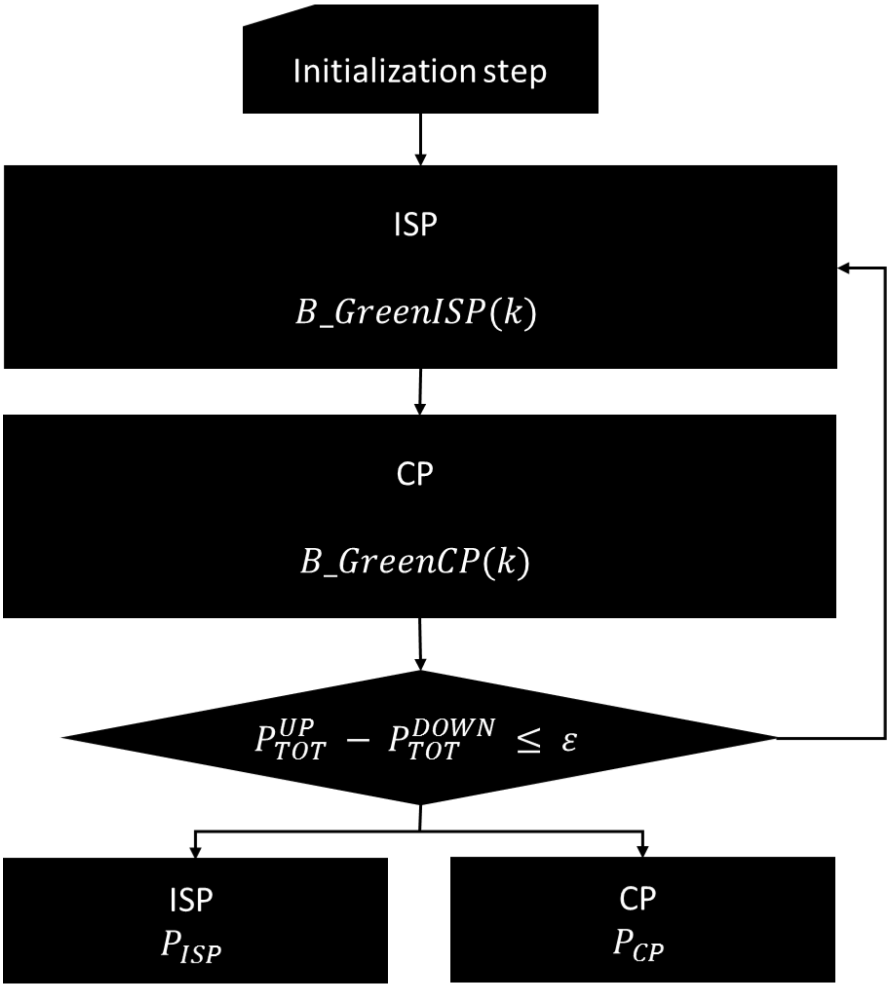


Figure 14. Bender green algorithm flowchart

2.2.6 Optimizing Server Power Consumption in Cross-Domain Content Distribution Infrastructures

In this paper the content provider network routing is based on some determination on virtual path based on the underlying network. As the ISP is the owner of the topology and content provider (CP) may ask for renting the bandwidth on underlying network for supporting the QoS in content delivery. This help the CP to generate the virtual path between their servers in the overlay network. The underlying network guarantee that this bandwidth will be always available for the CP. They also proposed a concept of PoP (point of presence) for server placement. These points in the network have the maximum traffic in the network.

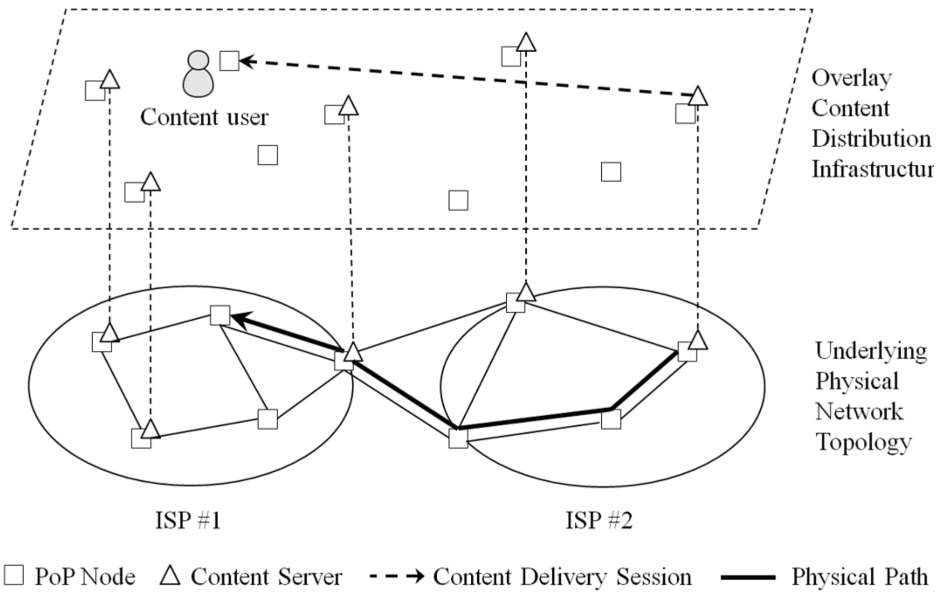
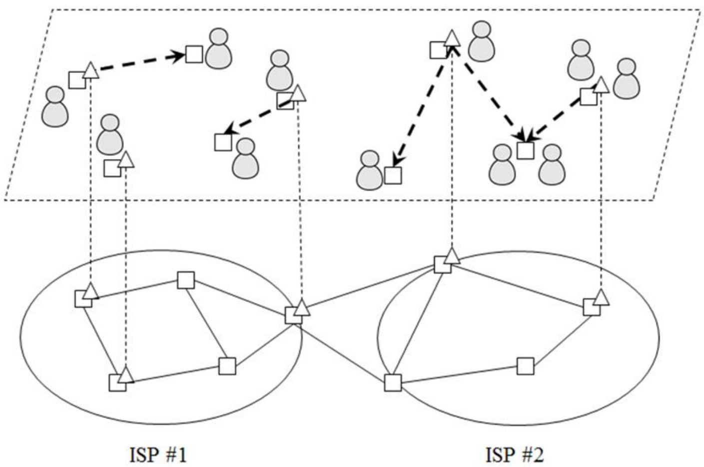
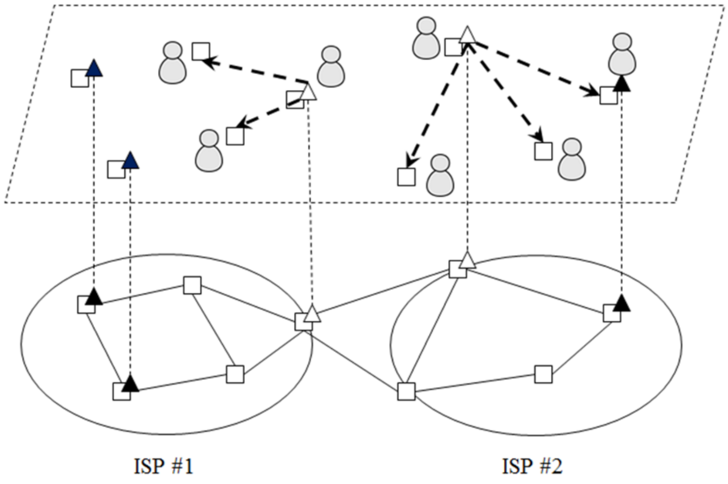


Figure 15. Overlay content distribution infrastructure

The idea of the work is when the CP monitor the incoming request from the user and if the amount of the request is low then they can decide to put some servers in sleep mode during off-peak hours. As severs are geographically distributed the problem of different time-zone for putting the servers in sleep mode during the off-peak hours appear. They should also consider the network resource availability for content delivery and not just the capability of the server side. They proposed a novel scheme that aims to optimize content servers' power consumptions in cross-domain content distribution infrastructure by strategically putting servers to sleep without violating service constraints on both the server side and the network side.



(a) Content sessions without server sleeping



(b) Content sessions with server sleeping

Figure 16. Working mechanism of the proposed scheme

Figure 16 (a) illustrates when five servers handle requests from nine PoP nodes within two domains. We can see that since the servers are attached to five of the PoP nodes, requests from these nodes can be handled locally without incurring inter-PoP delivery bandwidth cost. Requests from the other four nodes are directed to servers closest to them, which is often the case in practice to minimize user-experienced latency.

During normal period, all content servers are active for handling content requests, as shown in Fig. 2(a) where content requests are either served locally or by content servers nearby. However, keeping all content servers running may lead to considerable waste of power consumptions during off-peak hours. Firstly, the intensity of incoming content requests at a site varies across different times within a day, which becomes very low at midnight and early morning [5]. Secondly, since time-zone differences exist between PoP nodes (cities) which are distributed globally, it is unlikely to have high content request volumes at all nodes simultaneously. Based on these observations, it can be inferred that a subset of the content servers can be sufficient for handling all content requests during off-peak time, which may lead to considerable amount of power saving by putting the remaining servers to sleep mode

Assume that during off-peak time at some regions, the overall incoming content requests only require two active servers to handle them. Under such scenario, our approach takes as input the content distribution overlay topology (i.e., nodes, links and server locations), user content request volume from each PoP node, and determines which server(s) can be put to sleep without violating: (1) the load capacities of the active servers, and (2) bandwidth constraint on the links involved in the content delivery paths between PoP nodes. As shown in the figure, the content provider now puts three of the servers to sleep mode according to the off-peak content request intensity.

Problem formulation:

Here they assumed that CP knows the underlay network topology and traffic and based on that it decide to put the surrogate servers on its network.

Input: autonomous domain as a uni-directional graph G(V,E) where each vertex represents a PoP node and each edge represents an intra-domain link between two PoP nodes.

Objective: Minimizing the power consumption of the servers in CP

output: a set of servers that can be turned off during the off-peak time.

2.2.7 Cooperative Green Routing with Energy-efficient Servers

This paper also considered the cooperative interaction between the ISP and CP for solving the problem of energy consumption in CDN. Here unlike [7] they author assumed from first that the CP have the information about the network topology and both ISP and CP in corporate way try to reduce the energy consumption in the network.

Like [7], the author first consider "Classical Design" for minimization of the overall delay experienced by all users in the network without considering the energy consumption of the network and later propose a "Green Cooperation" design considering the shared information between ISP and CP to minimize the global power consumption.

The problem defined as follow:

$$GreenCoop: \quad Min\ (P_{TOT} = P_{CP} + P_{ISP})$$

The P_{TOT}, is the total energy consumption of the CDN and P_{CP} is the energy consumption of the CP and P_{ISP} is the energy consumption of the ISP. The CP servers are assigned to the cities with the highest connection degree, one CP server per city. The detailed problem formulation is same as [7].

Problem definition:

Input: Given the network topology of ISP as graph G(V, E)

Objective: minimization of the total power consumed by the CP and the ISP, subject to a user delay constraint.

Subject to: maximum link utilization, maximum admissible delay, and maximum server utilization

2.2.8 Evaluation of power-saving strategies

Regarding saving power in CDNs existing works in literature divided in two categories according to types of CDN architecture that they are based on. Firstly with respect to modern CDN architecture, schemas have been proposed to save the power consumption of either the content provider [28][7] or both the CP and ISP [9][8]. These strategies involve dynamic provisioning of content servers and/or network links while mapping content requests to fewer servers and network paths subject to their load capabilities, which we refer to as dynamic provisioning and request management strategies.

Here we attended more into detail in some research proposal and we will compare them. In [1] the authors considered the power consumption of the links, inter router caches and CP servers. They noticed that the inter router caches also consume considerable amount of energy. By selecting the best CDN servers and best path for delivering the content to the user they proposed to turn off the caches that have not been used in delivering the content. They strategy is to consolidate request to less servers and putting the unused servers to sleep, which is commonly used in power saving schemes of CDNs. They also consider the power consumption of the link and they tried to find the best routing for delivering the content and putting unused links to shout down mode. They observed up to 20% energy saving by putting devices to sleep mode outside peak hours. By storing the most popular content in caches at each router and by choosing the best content provider server they may save total 23% of power in backbone.

In [8][9] they proposed the cooperative scheme(GreenCoop) between CP and ISP. In their work after request mapping and content delivery are determined, unused routers and links are temporarily deactivated to save power. In their work up to 71% of power saving was observed compare to a non-energy aware scheme with the objective of minimal delay. However [8][9] requires full information sharing between CP and ISP to perform dynamic provisioning operation which is not valid in the world as both CP and ISP unwilling to share their information to others. This problem is the same also for other strategies that have been proposed here. In [8], with same objective as [chia] a dual composition based on distributed algorithm was developed to solve model without the need for information sharing between CPs and ISPs. However such an approach suffer from relatively high computational complexity.

Although the power saving performance of [1][8][9] are considerable, their limits are also significant. Firstly limited shared information and secondly, they are focusing on optimizing either ISP or CP's power lead to waste in their overall power consumption. However such a statement was based on the assumption of next generation networking elements which are able to adapting their power to their load. And according to [17], the power consumption of modern switches and routers are not affected much by their actual traffic load. Therefore it is arguable that ISP's networking elements can benefit as much as CP's content servers do from the proposed joint ISP-CP power optimization scheme.

By [7] the strategy is to dynamically provision servers strategically mapping the content request to the active servers. It is worth noting that although the proposed scheme has taken capabilities of both servers and network links as constraint to guarantee network performance, which is similar to GreenCoop, information sharing between ISP and CP is not necessary and CP is capable of adopting the proposed scheme independently. To achieve this the scenario of “bandwidth leasing” was employed. Their simulation has shown that up to 62% of overall power consumption can be reduced. It is worth to say that in none of the [7][8][9] they consider the inter router caches as important element of content delivery and power consumption.

It is also worth to mentioning that in CDNs, the scenario of dynamic provisioning is more complex. The reason is twofold. Firstly, at each nodes of the CDN, its local user activity in term of e.g. request volume varies at different times of a day. It is shown that a node typically enters peak period at around 10:00 am and enters off-peak period as around 23:00 pm [26]. Secondly, from the perspective of a global CDN, time difference exist among nodes in CDN at different geographical regions. The composition of these two factor lead us to think about adaptive scheme that can adapt itself during different peak times.

3 References

[1] Julio Araujo, Frederic Giroire, Yaning Liu, Remigiusz Modrzeewski and Joanna moulierac, “Energy Efficient Content Distribution”,Conselho nacional de desenvolvimento cientifico e technologico , Brazil and France, 2013.

[2] Vimal Mathew, Ramesh K. Sitaraman and Prashant Shenoy, “Energy-Efficient Content Delivery Networks using Cluster Shutdown”, IEEE, 2013.

[3] Seyed Kaveh Fayazbakhsh, Yin Lin, Amin Tootoonchian, Ali Ghodsi, Teemu Koponen, Bruce Maggs, K.C. Ng, Vyas Sekar and Scott Shenker, “Less pain, most of the gain: incrementally deployable ICN”, SIGCOMM '13, Hong kong, China, August 2013.

[4] Vimal Mathew, Ramesh K. Sitaraman and Prashant Shenoy, “Energy-Efficient Content Delivery Networks using Cluster Shutdown”, Arlington, Jun. 2013.

[5] Gang Ge, Zhili Sun and Ning Wang, “A Survey of Power-Saving Techniques on Data Centers and Content Delivery Networks”, United Kingdom, November 2012.

[6] Sherali Zeadally, Samee Ullah Khan and Naveen Chilamkurti, “Energy-efficient networking: past, present, and future”, USA, December 2012.

[7] Gang Ge, Zhili Sun and Ning Wang, “Optimizing Server Power Consumption in Cross-Domain Content Distribution Infrastructures”, United Kingdom, November 2012.

[8] Luca Chiaraviglio and Ibrahim Matta, “An energy-aware distributed approach for content and network management”, Torino, April 2011.

[9] Luca Chiaraviglio and Ibrahim Matta, “GreenCoop: Cooperative Green Routing with Energy-efficient Servers”, New York, NY, USA, 2010.

[10] Al-Mukaddim Khan Pathan and Rajkumar Buyya, “A Taxonomy and Survey of Content Delivery Networks”, Parkville, Australia, 2006.

[11] M. Arlitt, and T. Jin, “A Workload Characterization Study of 1998 World Cup Web Site,” IEEE Network, pp. 30-37, May/June 2000.

[12] S. Adler, “The SlashDot Effect: An Analysis of Three Internet Publications,” Linux Gazette Issue, Vol. 38, 1999.

[13] S. Jamin, C. Jin, Y. Jin, D. Raz, Y. Shavitt, and L. Zhang, “On the placement of Internet Instrumentation,” In Proceedings of IEEE INFOCOM, Tel-Aviv, Israel, pp. 295-304, March 2000.

[14] P. Krishnan, D. Raz, and Y. Shavitt, “The Cache Location Problem,” IEEE/ACM Transaction on Networking, Vol. 8, No. 5, 2000.

[15] S. Jamin, C. Jin, A. R. Kure, D. Raz, and Y. Shavitt, “Constrained Mirror Placement on the Internet,” In Proceedings of IEEE INFOCOM, Anchorage, Alaska, USA, April 2001.

[16] L. Qiu, V. N. Padmanabhan, and G. M. Voelker, "On the Placement of Web Server Replicas," In Proceedings of IEEE INFOCOM, Anchorage, Alaska, USA, pp. 1587-1596, April 2001.

[17] M. Hofmann, and L. R. Beaumont, Content Networking: Architecture, Protocols, and Practice, Morgan Kaufmann Publishers, San Francisco, CA, USA, pp. 129-134, 2005.

[18] A. Vakali, and G. Pallis, "Content Delivery Networks: Status and Trends," IEEE Internet Computing, IEEE Computer Society, pp. 68-74, November-December 2003.

[19] N. Bartolini, E. Casalicchio, and S. Tucci, "A Walk Through Content Delivery Networks," In Proceedings of MASCOTS 2003, LNCS Vol. 2965/2004, pp. 1-25, April 2004.

[20] G. Peng, "CDN: Content Distribution Network," Technical Report TR-125, Experimental Computer Systems Lab, Department of Computer Science, State University of New York, Stony Brook, NY, 2003.

[21] F. Douglis, and M. F. Kaashoek, "Scalable Internet Services," IEEE Internet Computing, Vol. 5, No. 4, 2001, pp. 36-37.

[22] R. Buyya, A. M. K. Pathan, J. Broberg, and Z. Tari, "A Case for Peering of Content Delivery Networks," IEEE Distributed Systems Online, Vol. 7, No. 10, IEEE CS Press, Los Alamitos, CA, USA, October 2006.

[23] L. A. Barroso and U. Holzle, "A Case for energy-proportional computing ," Computer, Vol. 40, No. 12, pp. 33-37, 2007.

[24] Q. Wu, P. Juang, M. Martonosi, L. –S. Peh and D. W. Clark, "Formal control technique for power-performance managment" IEEE Micro, Vol. 25, No. 5, pp. 52-62, 2005.

[25] C. Clark, K. Fraser, S. Hand, j. G. Hansen, E. Jul , C. limpach and I. Pratt, "live migration of virtual machines" in Proc, 2nd conference on symposium on network system, Berkley, CA, USA, Usenix association 2008.

[26] P. Gill, M. Arlitt, Z. li, and A. Mahanti, "youtube traffic characterization: a view from the edge" in Proc, 7th ACM SIGCOMM conference on internet measurement, Cer. IMC 07, New York, USA 2007.

[27] P. Mahadevan, P. Sharma, "A power benchmarking framework for network devices" in Proc, 8th International conference IFIP-TC 6 networking, ser. Networking '09' ,Berlin : Spring-verlag 2009.

[28] V. Mathew, R. K. Sitaraman and P. Shenoy, "energy-aware load balancing in content delivery networks " in Infocom, 2012 Proc, IEEE , Florida USA, March 2012.