Master's Thesis

Energy-efficient media content storage and distribution

By

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Abstract

Internet is a disruptive technology that has changed the way of how we see the world now. Since its appearance in the 60's it has been spread to almost every field in our quotidian life.

Nowadays Internet usage accounts for 2% of the global energy usage, but it is expected that its growth will be increasing and increasing within the next years, as the number of users increases by the appearance of different mobile devices.

It is also remarkable that the usage of the Internet; on the last years and encouraged by the increasing of the broadband services, multimedia content delivery is the most common usage of the Internet.

The concept of energy efficiency has become more popular on the last years, but the fact is that besides the widespread of the ecological issues, there is also an important economical part behind this since electricity has a price.

Since all models and evaluation of the different ways of optimizing energy efficiency for digital media distribution are complex and depend on different variables, in this thesis it is pretended to shed some light on which are the most common used architectures: Content Delivery Networks, Peer to Peer and Content Centric Networking. Also different solutions and procedures for delivering media content among the network that do not belong specifically in the aforementioned structures are considered.

It is also treated a particular case of study where the best oriented solution in terms of energy efficiency is analyzed. After deeply analyzing which is the state of the art and new trends with its pros and its cons, I will conclude that there is no standard and directly applicable solution which would be valid for all models.

Key words: energy efficiency, green Internet, media content, datacenter, networks, CDN, P2P, CCN, VoD, Set-top box

Summary

Internet is a tool that today has become indispensable in our lives. Its use has become a fact so important that this network infrastructure deployed today requires a lot of energy to make it work.

Depending what you visit when you surf the Internet, it requires a certain amount of energy or another. So, for actions that only involve text, such as sending an email or read a blog without pictures the energy used to bring these bits of data is scarce due to the relatively little information is sent over the network. However, pictures and videos are watched, this transfer of bits and therefore the energy for transferring all data, greatly increase.

Many content providers are now offering their programs or movies on the net. Thus, users can have the content without being tied to a schedule and choose from a variety of content from all over the world, without having to worry of install any antenna. This benefits, together with the flexibility and interactivity of the Internet has led to users and providers opt for this method. As a consequence of this, nowadays most of the data traffic on the network, which is about 65%, is due to viewing multimedia content.

For this reason, and in order to calm the rise in energy demand in the network and avoid a possible systematically shutdown, in this master thesis different architectures are studied that are used for distributing the media content (related to both the storage and the transport through the network). It is also analyzed their energy efficiency and which strategies can be applied in order to save energy and consequently save money and carbon dioxide emissions.

Methods that do not fall within a specific architecture and can be used in almost any architecture are also discussed. These methods relate to four basic aspects of the content distribution chain: storage, how the information that is sent is coded in order to use less energy, the transport layer and finally, how to make more efficient the devices that users use to connect their TV with the network and display content on the screen.

Finally, it is analyzed the particular case of a population and which possible solutions can be applied to reduce the energy consumption of the network, without worsen image quality.

To my parents:
They gave me two best things I have:
My life and a brother.

Acknowledgments

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Josep Grau Miró
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CHAPTER 1

1 Introduction

The Internet has changed the whole perspective of how we see the world and it is a powerful tool of which today we could not do without. Sending an email to someone, paying by credit card in a commerce instead of using cash, reading your favorite newspaper, watching your favorite program on streaming, calling over IP, videoconference your relatives, sharing popular video on the net, or sending this picture recently taken through any Instant Messaging Service (IMS) is the most common usage of this popular technology; but the fact is that its usage encompass many other fields and therefore the number of devices and business.

According to different studies in terms of energy, Information and Communication Technology (ICT) is responsible for a percentage that goes from 2% to 10% [1] of the world power consumption, of which 51% is due to networking and telecommunication infrastructure.

On the present days, the carbon footprint produced by ICT is almost the same as the global airline industry and since Internet is growing faster than airline industry and it is expected to overcome the carbon footprint produced by the airline industry. In Figure 1 are shown the emissions in 2002 and the forecast for 2020. By [1] ICT could become the world's largest single greenhouse emitter.

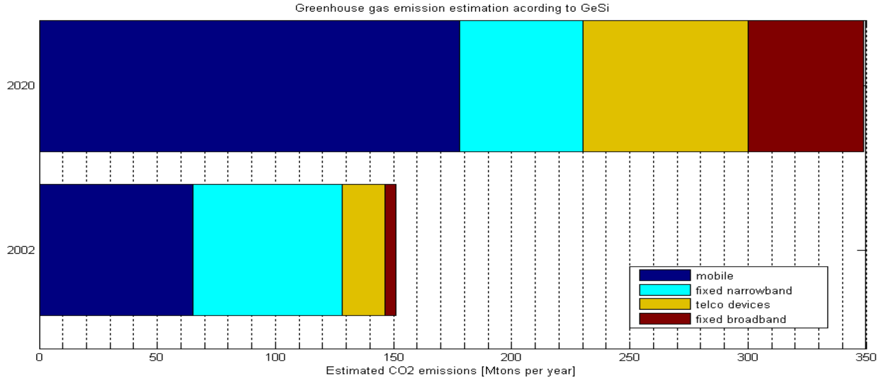

Figure 1: Greenhouse gas emission and forecast according to Global e-Sustainability Initiative (GeSI) [4]

Internet is considered as a network of networks, and is composed of billions of different components and devices, but where is the major part of the energy spent? According to a study from [4] and the **Figures 2, 3 and 4**, we observe that despite the number of elements in core and transport network are less than the number of elements in access network, the power consumption per device in the core networks and also in the transport networks is almost 5 times and 3 times more than in access networks.

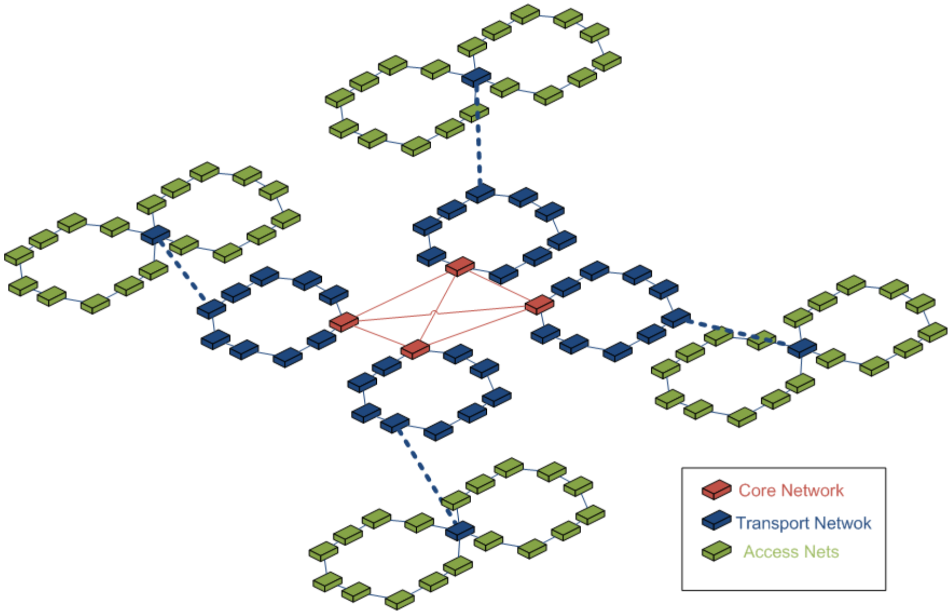

Figure 2: Typical network deployment. Source [3], [4]

Since the number of elements in access network is much higher than the other two aforementioned, this entails to that the major part of the energy is consumed in the access layer (70%) vs. the transport and core layer (30%).

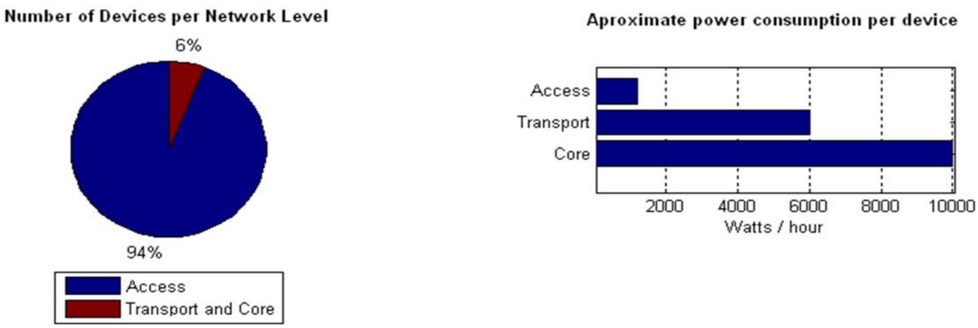

Figure 3: Access, metro and core device energy density and energy requirements in today's typical networks deployed by telco's. Source: [3], [4]

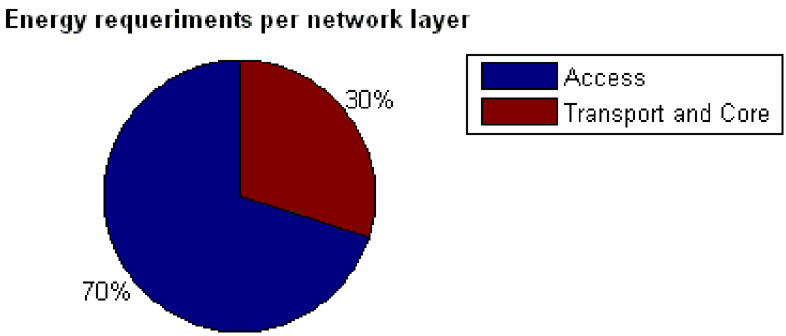

Figure 4: Overall energy requirements of access and metro/core networks. Source: [3], [4]

Energy efficiency on networking is a growing concern since last few years. Triggered by the increase of the price of the energy and the conscience about the global warming due to CO_2, many researchers have been studying the consumption and the behavior of different network components and ICT elements.

Finding more energy efficient ways of networking is seen as the Holy Grail of the future development of network technologies. This is the consequence of many facts like the spread of broadband access, the growth of the customer population, the appearance and constant use of tablets, smartphone and the eagerness from Internet Service Provider (ISP) to expand the services offered to the customers.

In order to support such number of new devices, network infrastructures should be ready for this change, and therefore, Telco's and ISP's will have to increase the number of devices with sophisticated hardware to handle such amount of traffic. A simple example of what could happen on high-end IP routers is depicted in Figure 5: its router capacity is increased by 2.5 times each 18 months, and traffic load is doubled each 18 month according to Moore's law, whereas Complementary Metal Oxide Semiconductor (CMOS) energy efficiency follows Dennard's scaling law and is increased by 1,65 times each 18 month [3].

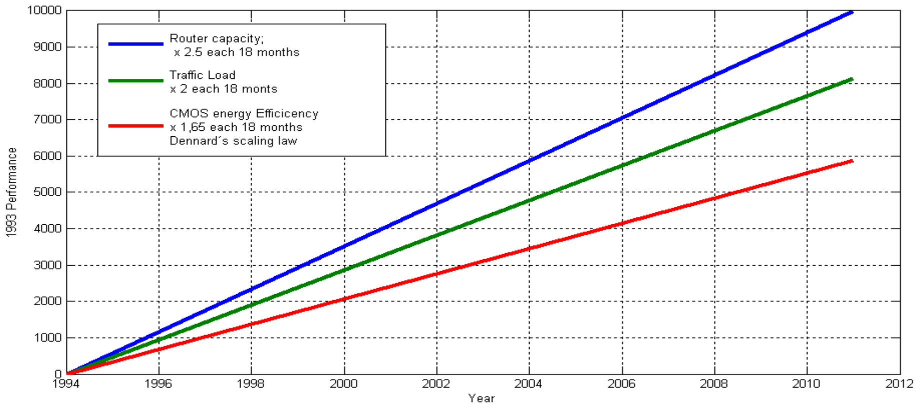

Figure 5: Evolution from 1993 to 2010 of high-end IP routers' capacity (per rack) vs. traffic volumes (Moore's law) and energy efficiency in silicon technologies [2] and [3]

The carbon footprint caused by the usage of devices is larger than the carbon footprint produced during the embodiment of these devices. The emissions due to its usage are produced every year, whilst carbon due to embodiment it is only produced once. Therefore it seems wise to focus on cutting down the emissions produced by its usage meanwhile more re-engineering should be applied in order to cut the embodiment carbon.

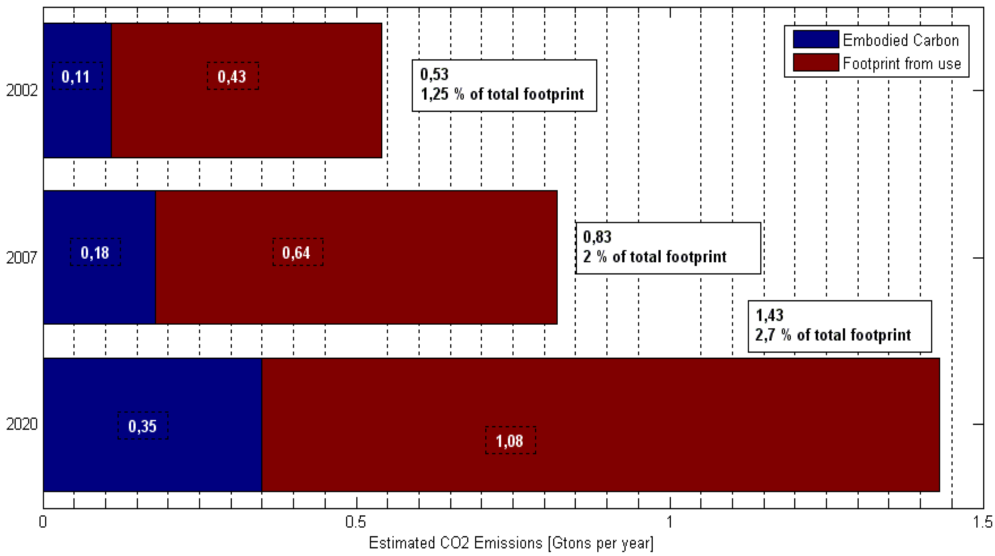

Figure 6: Estimate of the global carbon footprint of ICT (including PC's, telco's networks and devices, printers and datacenters). Source: Smart 2020 report by GeSI [4]

It is a fact that energy can be saved and therefore save energy which is directly translated into billion $ of savings and reducing CO_2 greenhouse emissions, but is it really possible? Which are the real savings?

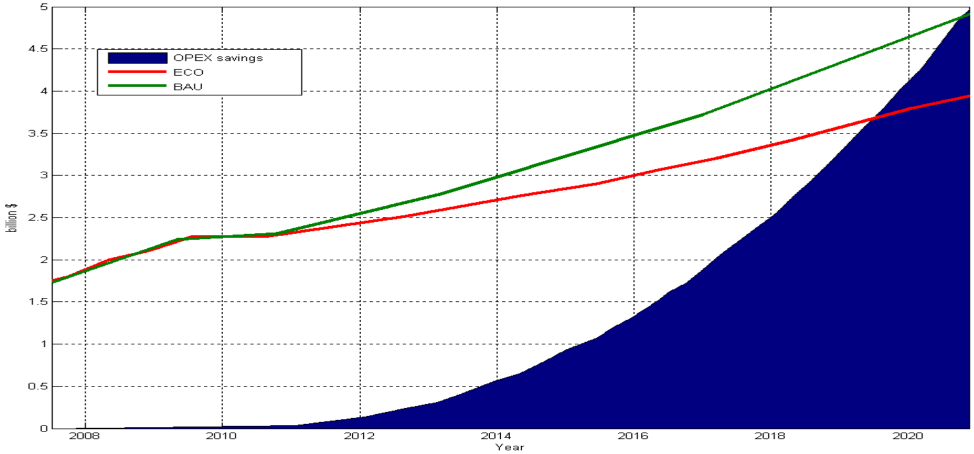

Figure 7: OPEX estimation related to energy costs to European telcos' network infrastructures in the "Business as Usual" (BAU) and the Eco sustainable (ECO) scenarios and cumulative savings between the two scenarios. Source: European commission DG INFSO report [4] and [3]

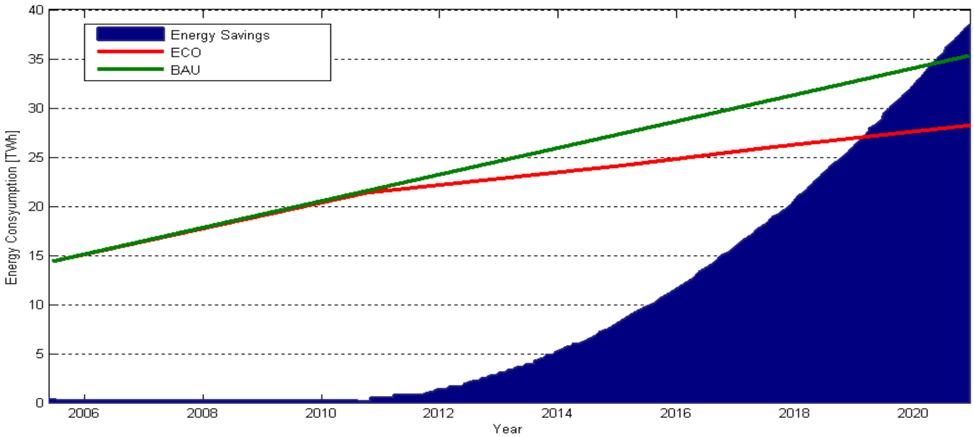

Figure 8: Energy consumption for the European telcos' network infrastructures in the business-As-Usual (BAU) and in the Eco sustainable (ECOM) scenarios and cumulative energy savings between the two scenarios. Source: European commission DG INFSO report in [4] and [3]

In Figure 7 and Figure 8, thanks to GeSi study [4], we are able to show how much energy and money could be saved in different scenarios. Also cumulative savings are plotted. We can observe that every year the savings in terms of energy consumption and also in terms of money, could be increased. It is due to new technologies for saving energy could be applied, and also because the number of devices is increasing and consequently in absolute numbers, more savings can be achieved.

After considering Figure 6, 7 and 8 we could state that according to this data, it would be convenient to save some energy in terms of CO_2 and also in terms of energy consumption or money.

The energy outages happened in many cloud services like Microsoft Live Hotmail cloud-based-email, Gmail and Amazon EC2 experienced in December 2010, February 2011 and in April 2011 respectively, clarify that energy power supply could become a bottleneck for the Internet in the next few years. Therefore, saving energy becomes a must in the present and future Internet.

1.1 *Internet usage trends*

Under these previous mentioned circumstances, we decided to analyze Internet usage study from CISCO and according to this study; most of the Internet traffic is due to video streaming.

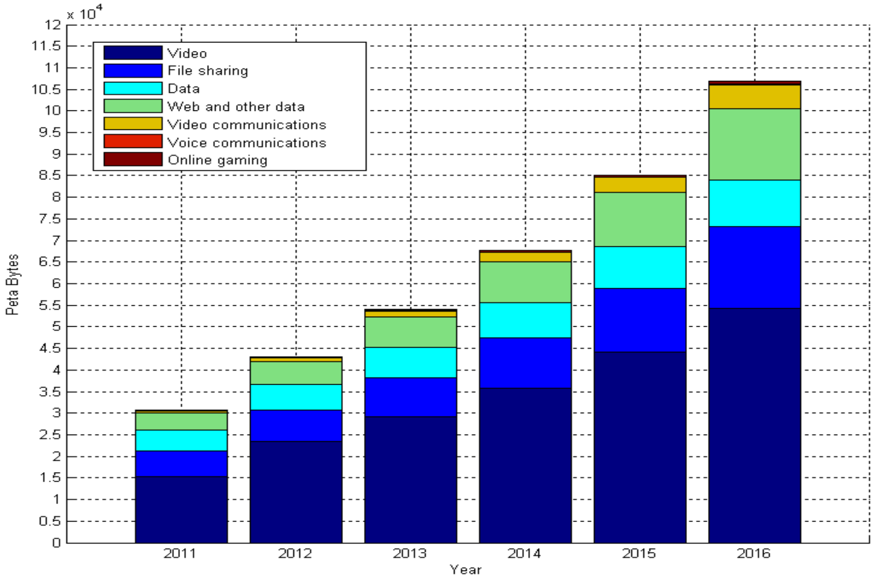

Figure 9: Global Internet traffic and forecast for next 4 years. Source: Cisco VNI (Visual Networking Index) [5]

Online video traffic continues to surge in 2012 and beyond, as seen in Figure 9 and Figure 10. According to these results, by 2013 online video will account for 70 percent of all consumers IP traffic. Furthermore, the compound annual growth rate is projected to be a staggering 32% from 2011-2016.

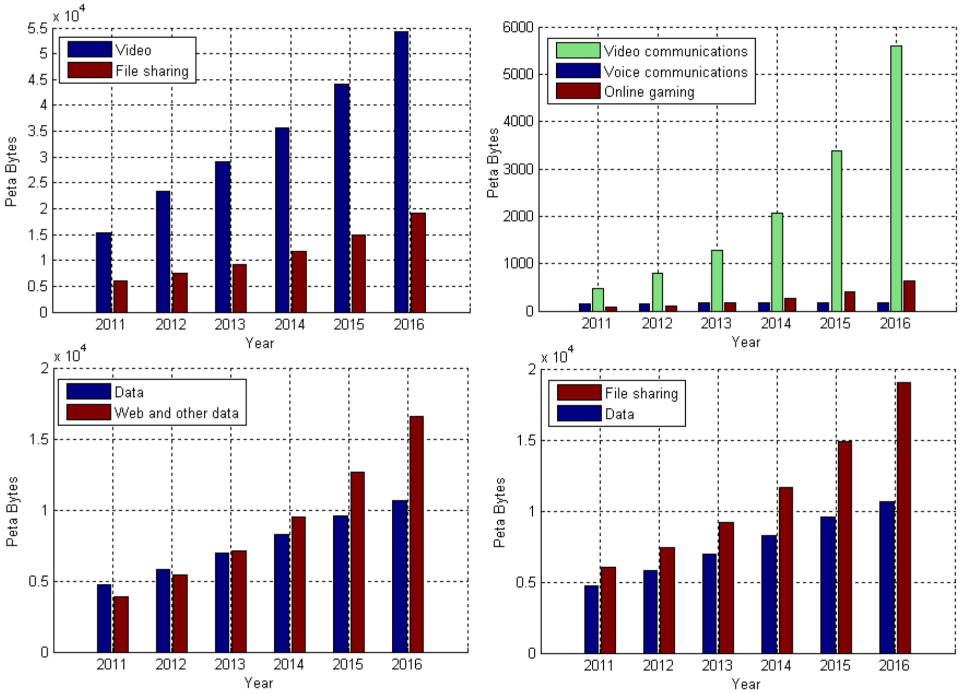

Figure 10: Global Internet traffic by different families usage and forecast for next 4 years. Source: Cisco VNI (Visual Networking Index) [5]

During 2013 video traffic will continue its spectacular ascent, and it will be mainly due to Internet Protocol Television (IPTV), Over The Top Content (OTT), video conferencing, or other video applications like video gaming. Gartner's bandwidth-estimating model [66] indicates that data growth per user can easily reach 30% to 50% a year.

1.2 *IPTV*

Internet Protocol Television is a digital television broadcasting method that uses Internet Protocol for delivering multimedia content to the users through an IP network and managed by an operator. Thanks to this, IPTV can be delivered using different networks, including Managed Networks and the open Internet.

This service is most of the times offered by an operator. When the operator also provides the user access to browse the Internet and making long distance calls using the Voice over IP (VoIP), this service is known as Triple Play package.

In addition to viewing user demanded content, IPTV also offer a bunch of services like oriented advertising, voting and rating the programs, sharing your watching preferences or other content with people you like, and many others as worldwide content availability as we can see in Figure 11.

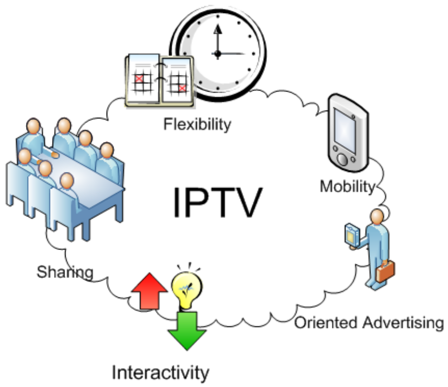

Figure 11: IPTV benefits. Source: Based on [64]

Regarding the technical part of IPTV, in Figure 12 it is shown a typical configuration for IPTV network. This scheme is presented by J. Baliga et al in [6].

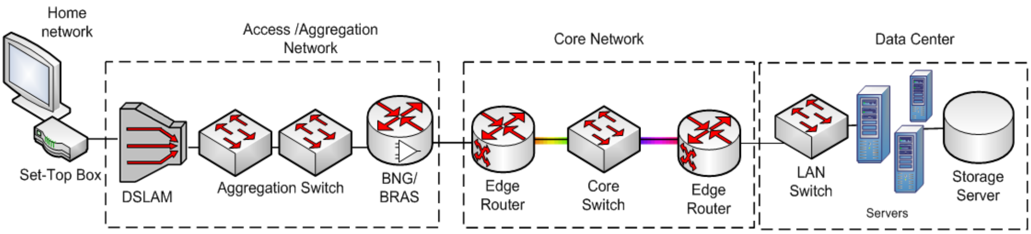

Figure 12: Typical IPTV network. Source: [6]

As we can observe, IPTV networks are composed of different elements mainly distributed in three parts [7].The first part is placed on the furthest place from the user: the storage and server components which store the main content. The second part is related to the transport and it includes access, the aggregation and the backbone networks. The third one belongs to the end user and it contains the set-top boxes used for delivering the content to the final user.

According to the authors of [7] the main power consuming elements in an IPTV network are the **Digital Subscriber Line Access Multiplexers** (DSLAM), **routers**, the **data centers** and finally the **Set-Top Boxes** (STB).

Consequently, by improving the efficiency on these elements it could be easy to think that the problem is solved, but the fact is that it requires a deeper study and being treated as an end-to-end issue.

1.3 *Set-top Box*

A set-top box is an information appliance that is connected to a television and to an external source of signal. The set-top box turns the source of signal into content in a form that can be displayed on the screen.

Initially the set-top box was only a decoder for cable or satellite TV broadcasting services, but the fact is that nowadays a set-top box also can receive and decode signals great variety of sources. For the purpose of this master thesis, I will focus on the usage for IPTV broadcasting.

Other features that set-top boxes have are Electronic Programming Guide (EPG), internal storage, Smart TV access which provides additional film download services from *Netflix* or *Lovefilm*, and many other features.

First of all, the most easy and basic way to save energy on the device is checking the status of the device. According to [8], there are different power modes in the devices:

- **On Mode:** the device is connected to a power source and provides the main functions for which is designed.
- **Passive Standby Mode**: the device is switched off by signals from the remote, but is still connected to a power source. The device does not perform main functions but it can be switched to another mode by internal signals.
- **Active Standby Mode:** Is the same as passive Standby Mode but in addition, is receiving or sending minimum data from/ to a service provider.
- **Off Mode:** The power switch is turned off. The device does not perform any function and cannot be switched to another mode neither internal nor external signals.

So, it means that choosing the right status for each period of the day, could cause an important saving in terms of each device at the end of the year.
Nevertheless, the incorporation of different stand-by methods could affect directly to content providers and therefore it is important to develop a low-power set-top box that will ensure service quality meanwhile tries to be as greener as possible.

CHAPTER 2

2 Content Delivery Networks

Internet scale distributed systems, such as Content Delivery Networks (CDN), operate hundreds of thousands of servers, deployed around the globe. But what is a CDN? Why is a CDN used?

2.1 *Insight*

When a regular visitor goes to a webpage, it makes the query into a webhost. The webhost then sends all the information to the user. It includes the html page, CSS, JavaScript, images, video, etc. The transfer could be slow if the user is far from the main webhost. It can also be slow if many people make the same request, for instance when a video becomes viral, it can turn the server down.

A CDN replicates the content from the original server to cache servers (also called replica servers or surrogate servers which are in multiple locations over the world). So, when a visitor tries to access a webpage, it is redirected to his nearest edge location in order to access all media content and therefore save time and increasing download speed.

The firsts CDNs appeared in the early 90's motivated by the increase of Internet traffic due the Internet bubble. The main reason of the existence of CDN is to reduce backbone traffic and improve the end-user performance in term of shorter latency, lessen delay jitter and provide higher bandwidth to user [9].

Historically, there appeared different ways of spreading the content among the different replica servers [10]: **Tree based** [11], **Greedy Algorithm**, **hotspot algorithm** and **random algorithm**.

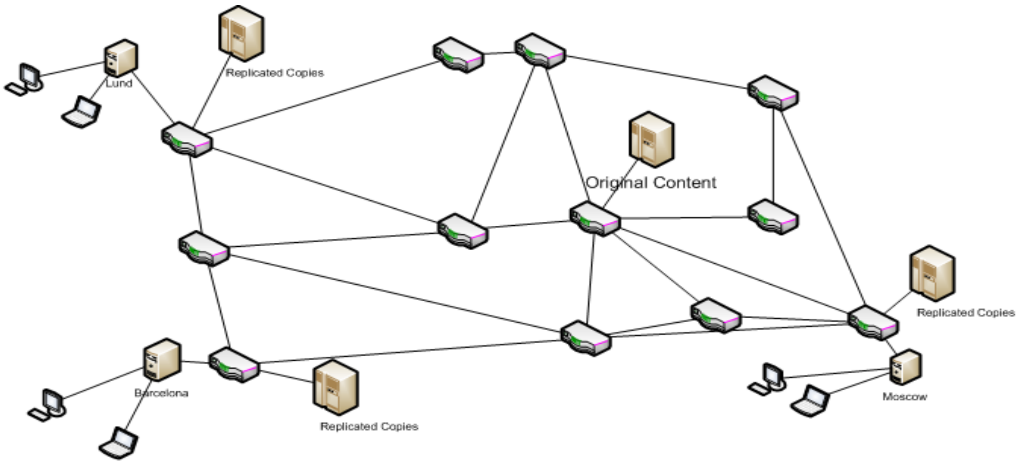

Figure 13: Typical CDN Deployment Architecture. Source [41]

2.2 *Different approaches*

Several solutions are proposed in order to improve the response to power usage when using CDNs.

The authors in [12] propose two different solutions that are related to coordinated CDN system. In coordinated CDN systems, different CDN that are close form a cluster and they cooperate with each other in order to serve the user requests arriving at these sites.

The first method is based on improving the local hit ratio by pooling together the storage of the servers within a cluster (different severs that are near and cooperate with each other in order to serve the user requests that arrives at these sites) and consequently, forming a large cache storage space.

According to [12], “local hit ratio” is a key determining factor to energy efficiency on a CDN. For further details on the calculation, see Part III of their paper. According to their results, the more sites are clustered together; the more improvement of the energy can be achieved. Nevertheless, it should be considered that edge coordination needs extra signaling and traffic exchange among edge sites, which implies a tradeoff when designing the size of the cluster. In addition, a possible drawback is the increase of latency when enlarging the cluster.

The second possible solution proposed by [12], is to aggregate user requests and to allow switching off part of the servers during low hours. As we can see in Figure 14, there are several hours where the Internet demand is lower.

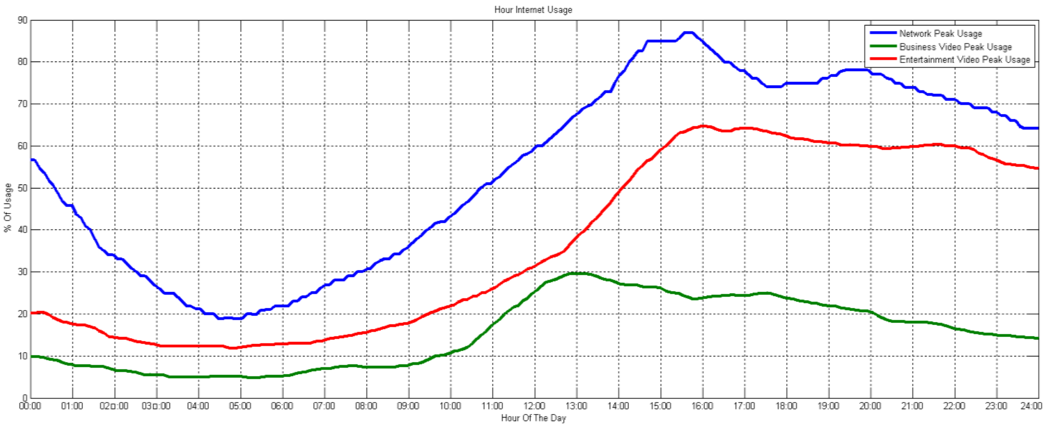

Figure 14: Network Usage per Hour. Source [19]

Usually, video delivery systems are designed for being able to hold peak hours, but most of the non rush hours; they are still working at their maximum. This technique is quite commented on other papers like: [15], [16], [17].

According to the results obtained in [12], the larger is the cluster, the larger is the energy saving, but some delays and overhead problems could appear. Another issue to keep in mind is to create an accurate pattern and algorithm for deciding which of the servers should be on sleep mode.

Regarding the method of turning off CDN servers during periods of low load, in [14], V. Matheu et al., propose different algorithms in order to achieve a compromise between the main aspects that are in conflict when trying to apply energy saving techniques in datacenters. One example is the Service-Level Agreement (SLA) with the customer, that most of the times has to be about 99, 99% (a maximum of 52.56 minutes downtime per year) and also minimize the wear and tear related with energy reduction. By this proved algorithms and applying them to real traffic from ***Akamai Network***, they say that up to 51% of energy can be saved.

In [13], K. Guan et al, evaluate the energy efficiency of dynamic optical decentralized CDNs and with their study they show how much energy can be saved when delivering large files with high download rate.

Since the amount of unwired devices like smartphones, tablets and other gadgets with Internet connectivity is increasing, I did not wanted to end without referencing a paper from D. Boscovic et al. [18]. In this paper, an analytical approach is presented, and by using a computer analysis based on Mixed Integer Linear Programming (MILP), they derive the optimal content placement and caching strategies. As a result, they prove a strong dependency between the energy efficiency and its associated hit ratio. In addition, they point out the need to build context driven wireless video delivery networks in which content caching placement strategies would vary dynamically according to the user's request changes, user's mobility and content popularity.

2.3 *Netflix*

Netflix is an online rental on-demand Internet video streaming, available in several countries like United Kingdom, Ireland, Sweden, Denmark, US, Canada and others. Only in the US, Netflix accounts for 29,7 % of the downstream peak traffic.

Initially, Netflix used to host the majority of functions in its datacenter. However, in order to continue being competitive and because designing and building a huge video streaming platform is challenging, Netflix decided to change and started using cloud services and other CDN as it can be depicted in the Figure 15.

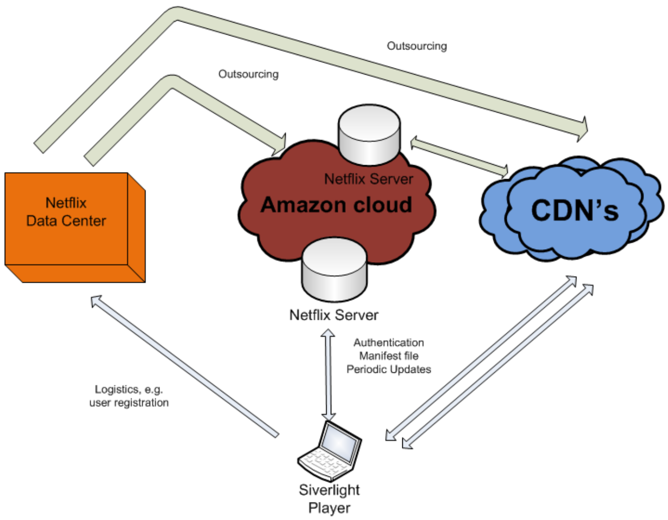

Figure 15: Netflix architecture. Source [21]

Thanks to this strategy used by Netflix which is deeply analyzed on [21], by choosing the best performing CDN up to 12% bandwidth can be saved compared to a static CDN. By using three CDN's simultaneously, average bandwidth can be improved by more than 50% compared to static CDN. By combining aforementioned strategies regarding to CDN in previous points, and architectures like the one used by Netflix could help to encourage other similar on demand streaming services in order to save energy.

2.4 *Conclusions*

Content Delivery Networks offer several advantages in respect to central server based system in terms of performance, reliability of the data and low latency. However, the energy used for powering the different datacenters that constitute this architecture should be reduced in order to achieve sustainable growth and avoid an unnecessary energy waste.

Energy optimization of a CDN is a complex end to end problem that requires intricate coordination between software, application systems, networks, virtual machines, middleware, and applications and is always tied to different user behavior.

An improvement of cache hit ratio would really help since smart caching algorithms including edge server coordination can make a CDN greener.

According to the aforementioned papers, the next research trend should be focused on how to include workload prediction techniques into the hibernate algorithm and in addition create more use and tear resistant systems.

Despite the difficulties, it is quite important to minimize the overall energy consumption. The end user should be conscious of its energy repercussions when using any device connected to the networks. However, this is not a problem that should be migrated to the users.

CHAPTER 3

3 Peer To Peer

Content distribution in the Internet has been historically carried out by a client-server model. This model has been shaping all Internet applications as we know the Internet today such as the web pages, electronic mail messaging, and File Transfer Protocol (FTP). This context started to change several years ago when the first CDN's started to appear, but what was a disruptive change was the continued growth of Peer to Peer usage.

According to [27], 70% of Internet traffic is P2P so by reducing the cost of usage of this technology, therefore real emissions of CO_2 and the energy consumption would be reduced significantly.

3.1 *Insight*

Internet based peer to peer networks growth started in the latter years of the 90's decade, due to the development of applications like Napster. There are mainly two types of Peer to Peer architectures:

3.1.1 Pure Peer to peer

In a pure P2P architecture, does not exists any centralized server and each client is an equal participant. The main benefits of this architecture are that pure P2P has a simpler structure than the hybrid one since no central server is required and that pure P2P can tolerate higher fault rates [28]. However, as every single thing in this life, there is nothing perfect and it has drawbacks like its low scalability and that consumes more network resources. Some examples are *Gnutella* and *Freenet.*

Pure P2P is mostly in disuse, but I considered it properly to include it in our study since it is the base for other architectures that are still being used nowadays.

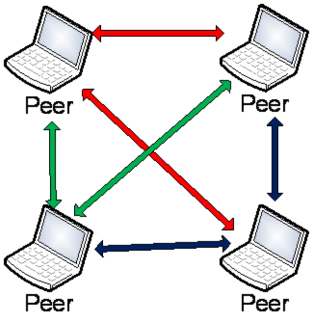

Figure 16: Pure P2P architecture sample, based on [28]

3.1.2 Assisted P2P or Hybrid P2P

In this architecture, there exists a central server who controls the list of the clients and does lookups among other user's files. The files are transferred between the different peers, but it is the server who helps the different computers to interact with each other and keeps a log of the different files and which clients that have them. As a result, it is a more scalable architecture and consumes fewer resources compared with pure P2P [28]. Nevertheless, it depends on the server for its proper working and it is less tolerant in front of occasional faults. Some examples of its architecture are *Napster* and *Bit Torrent*.

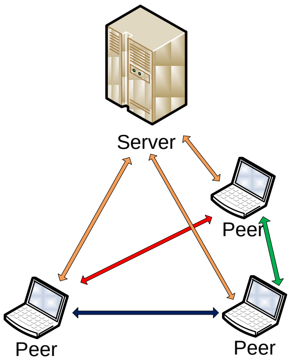

Figure 17: Hybrid P2P architecture sample, based on [28]

3.2 *Sub-Architectures*

Considering that pure peer to peer is barely used nowadays, it is actually out of our scope of study. So that, we will focus on the assisted P2P or hybrid P2P and another architecture which is a sub-category of this last one: Nano Datacenters.

3.2.1 Assisted P2P or Hybrid P2P

Energy used in peer-to-peer systems can be classified in two parts: the one used by the content distribution routes and the one used in end devices [29]. Regarding the end-devices, the same authors, suggest introducing sleep proxies in peer to peer networks in order to maintain the network presence and allow the end users to be turned off. This issue is treated deeply in [30], that shows the benefits of doing this.

Pollution of corrupted files in P2P networks is a problem [31] that incurs directly to the energy spent when downloading a file that a user is not going to use: network resources are used, HDD storage and of course computing resources into either client and server that provide the corrupted file. All this useless usage has also an impact on the energy wasted. Therefore, in [29] they analyze this problem and offer detailed information of how much energy is spent due to this problem. According to [33], the most popular files and recently released files are the main targets of the attacks from polluters. In worst case the number of retrials for a user before the proper file is downloaded is more than three, which could quadruple the P2P traffic load.

It is a trivial solution to delete corrupted files as soon as the user is aware of the corrupted file is downloaded, but not all users do this, and also sometimes is just a bad quality copy and it is the user decision to continue sharing this degraded copy or not. This issue is presented in [29] and also treated in [32].

They also propose two different methods in order to improve the energy effectiveness and also provide its models and different analysis. The first one is an **adaptive user behavior to balance energy consumption and content survival**, where several users that experimented pollution previously, they stay longer after downloading non polluted content in order to share its clean copy to others in order to help the system recover.

Other method is to create a **scheme of reputation** and flag different bad copies and decide whether this user is trustworthy or not according to previous behavior.

Their results conclude something quite obvious since they indicate that the overall power consumption increases as the arrival rate of new requests goes up, as well as the number of polluted copies inserted by attackers goes up. The small effort that volunteers should do in terms of their time and energy spent is clearly rewarded in terms of overall consumption and network performance.

In the particular case for the most representative protocol of P2P delivering methods, Bit Torrent, there are several papers that try to implement some enhancements and although they fix its guidelines on legacy protocol, its improvements show quantitative energy savings.

In [30], the authors propose changes like allowing peers to sleep without being dropped from peer lists and with this they achieve up to 25% energy savings without affecting significantly the time to download a file.

In the same line of research, [34] compare the legacy BitTorrent protocol with EE-BitTorrent, where a proxy downloads the file for the user and user goes to sleep. Once the file is downloaded to the proxy and the user reconnects, the file can be downloaded from the proxy as if would be the case of a normal client. They conclude that when the available uplink rate is low, EE-BitTorrent outperforms the legacy BitTorrent in terms of average download time and energy consumption at the user’s PC. On the contrary, when uplink rate is good, it occurs the opposite.

Due to this situation, they present AdaBT, an algorithm that selects the best option between either EE-BitTorrent or legacy BitTorrent in order to achieve best performance and therefore energy savings.

3.2.1.1 Other algorithms

In [35] K.Verma et al. propose several collaborative P2P algorithms which have the intention of reducing energy consumption compared to centralized distribution systems and their results show important savings. The authors also present a framework that pretends to constitute the basis for the design of an energy efficient protocol for distributing files.

Other authors as M. Jimeno and K. Christensen, in [36] proposed a prototype power management proxy for Gnutella P2P protocol. According to their studies, up to 25% energy could be saved thanks to a proxy that allow P2P hosts to enter into a low-power sleep and waking up them when the files had to be served.

3.2.2 Nano Datacenter

With the aim of changing the whole concept of distributing content, Nano Datacenter (NaDa) pretend to be between the P2P architecture and the server based model, combining the best parts of both. NaDa's propose a complete different solution to data delivering and hosting for the future Internet.

NaDa's architecture follows the P2P philosophy, with the main difference that it is coordinated and managed by an ISP that installs gateways in the edge network and run them as nano datacenters. The main components in a nano datacenters are the gateways, the tracker and the server, which are going to be explained in more detail afterwards.

The key behind NaDa is to create a distributed service platform around the edge network based on tiny managed entities that work as a server. By this innovative approach, NaDa become integrated into home gateways or set-top boxes which can communicate with other NaDa using a peer to peer communication infrastructure. A single entity, i.e. a content server, controls them and also the access bandwidth to those servers as it is shown in Figure 18.

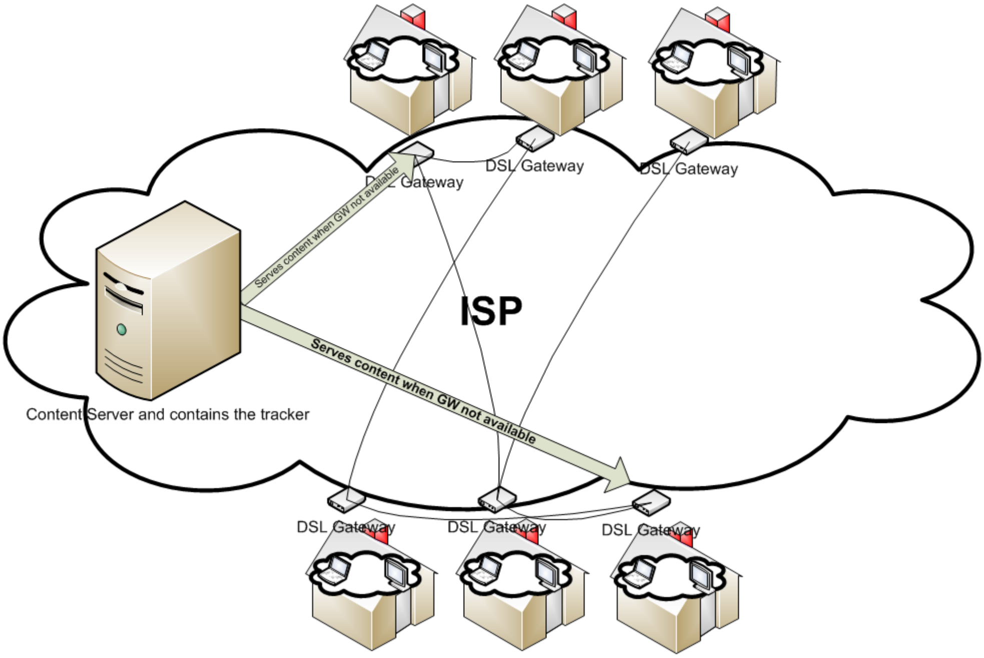

Figure 18: High level NaDa architecture. Content is served from home gateways when is possible. Source [26]

3.2.2.1 Main Benefits of NaDa

NaDa's can reduce the energy costs. The main reasons that make them better for delivering content compared to legacy datacenters are related to its **self-scalability**, and the **energy efficiency**, **heat dissipation** and the **server proximity**.

3.2.2.1.1 Self scalability:

Legacy datacenters have to be over provisioned in order to overcome peak hours and mostly of the time are running under their capabilities, which incurs to a waste of energy. Furthermore, since these infrastructures are built for lasting in time, it is difficult to modify such a rigid structure.

However, in NaDa as the user population grows, so does the number of available gateways to NaDa. For this reason, NaDa reduces over provisioning while providing built-in redundancy and performs a scalable delivery network.

3.2.2.1.2 Energy Efficiency

Routers and servers spend most of their energy in baseline activities like powering the backplane, spinning the disks, powering the memory, running the fans. Despite idling can save part of this energy, the fact is that these systems still consume from 50% to 80% of the total consumed energy in maximum load [21] and [22].

3.2.2.1.3 Heat dissipation

As aforementioned, most of the energy for powering legacy datacenters is used for cooling or chilling them. According to [23] and [24] the heat dissipation accounts for 20% to 50 % of the energy consumption. It can also be measured by a factor called Power Usage Effectiveness (PUE). In that cases, this factor goes from 2 in old legacy datacenters to 1.2 in more recent ones, where lower is better. In formula 1, we can observe how this factor is calculated.

$$PUE = \frac{\text{Total annual facility kWh}}{Annual\ kWh\ IT\ Load}$$

Formula 1: Power Usage Effectiveness (PUE). Source [25]

For more information about how this factor is calculated you can refer to [25].

3.2.2.1.4 Server proximity

In order to reduce delays/communication costs and improve fault tolerance, in legacy distribution methods, multiples copies are stored in big datacenters. Due the cost of the capital expenditure (CAPEX) and operating expense (OPEX) of such big infrastructures, small amount of them are built. With NaDa this problem does not exists and by replicating content on the network edge, users are closer to the content they want to access.

Thus, service proximity reduces the distance that information has to travel and thus also the energy in powering and cooling the networking equipment that has to carry it apart from reducing delays.

3.2.2.2 NaDa for Video on Demand

In this field, V. Valancius et al. [26], analyze the potential energy savings on a Video on Demand (VoD) services. Therefore, they create a model for VoD in traditional and in NaDa datacenters and evaluate them using a large amount of empirical VoD data.

Since the details of the main parameters used in [26] are out of the scope of our study, for further details of the models used, please check the paper. What we will show is the architecture they present, for delivering content in a more efficient way.

Regarding to the architecture used in [26], in the VoD case there are:

I. **Gateways**: are in charge of the storage replicas of the content and manage the resources. NaDa Gateways have two separate virtual circuits on their upstream line. One is used for conventional Internet usage, and the other one is for NaDa use.

II. **The tracker**: its role is to coordinate all VoD related activities in NaDa. Controls different content and monitors the different availability of the content across the network and content possession on gateways.

III. **Content servers**: provide the content from legacy datacenters. They also pre-load gateways from content that consequently they can re-distribute. Furthermore, if no request could be served from the gateway, they are able to treat the request.

3.2.2.2.1 Placement strategy

Their content placement strategy is based mainly in the **hot-warm-cold** method. It means that popular content (hot) should be replicated to all gateways; warm content should be replicated according to the model they present (more detailed information on 4.3 [26]) and finally, cold content is not stored within NaDa.

Just for depicting some of their achievements, in Figure 19 we can observe the results of the diurnal patterns of energy use.

The more usage, the best results achieved. As we can see, 30% can be achieved in peak usage in comparison to legacy datacenter.

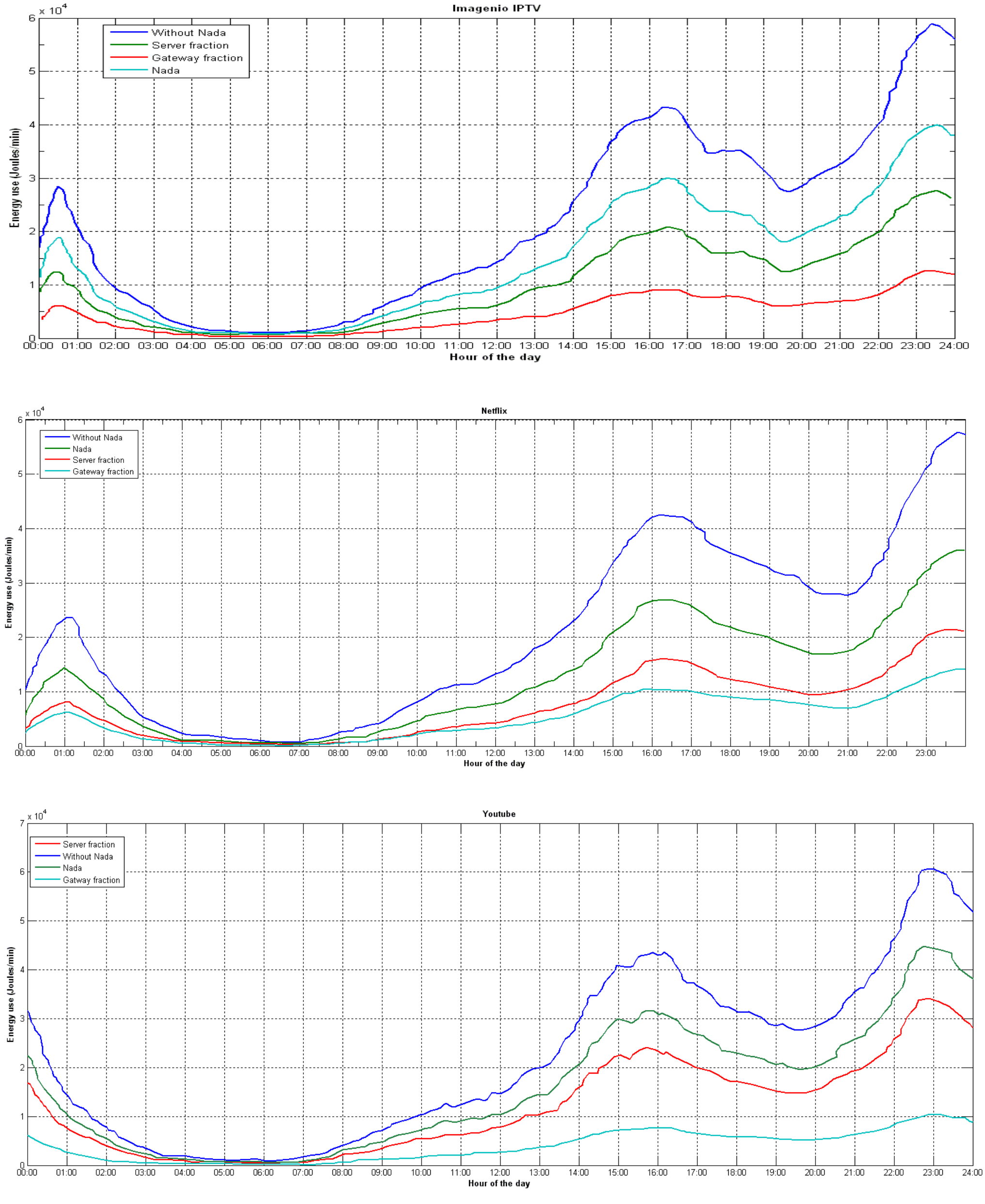

Figure 19: Representative diurnal patterns of energy use. NaDa energy use is further split into server and gateway components. Source: [26]

3.3 *Conclusion*

NaDa appears to be one of the architectures for delivering content where more energy can be saved. According to previous studies and results, with NaDa up to 30% of the energy can be saved in comparison to legacy datacenters. But despite these good results, we have to consider benefits and the drawbacks of using this architecture.

Most of the energy saved is not only because in NaDa's the baseline power is reused; the fact that cooling is not. Apart of the aforementioned main benefit, the energy saving is also achieved by reducing hop counting, since content is nearer to the end-user and the bandwidth adaptation managed by the gateway.

Usage of NaDa has other remarkable benefits, like self-scalability which help to not oversize the infrastructure. By using NaDa's, the traffic in the backbones is reduced and localized services can be served.

Despite all aforementioned benefits, the first drawback that could come out of our mind is about the cost for powering the gateway and if the user should receive compensation. NaDa is ISP friendly, since users are spending certain amount of energy that ISP is saving. Therefore, ISP should incentive users for accepting to hold these services.

Related to the users, there's also the question of how reliable this delivering network could be, where its performance is based mainly on the grade of commitment of the users.

Bandwidth usage could be another limitation in the deployment of nano datacenters; since initially Internet usage was asymmetric (more downlink traffic than uplink). Performance of the network could be tied to wide enough bandwidth of the gateways and therefore, symmetrical Internet for access networks would be appropriate. Fiber To The Home (FTTH) should help to improve the performance. In addition broadband Internet in outskirts is still far from the desired bandwidth. In case of not consider this, users would in some situations experience bad Quality of Service (QoS). An example is two-way, full-motion videoconferencing, in which broadband data must flow in two directions between two end users.

Security and privacy for users is also a concern that should be solved before implementing to big scale. In order to prevent information leaking and avoid access to the content to users that are not allowed or to just avoid a massive attack to strategically placed gateways, new security systems should be developed.

Finally, the CAPEX of the different gateways, and who would have to afford this cost is also an opened question.

Saving amount of energy is not always 30%, since sometimes users would want to switch of their gateway.

CHAPTER 4

4 Content Centric Networking

In a typical Transmission Control Protocol/ Internet Protocol (TCP/IP) model, when a user creates a request, the router stores a copy of the requested content during a certain amount of time. It turns into a critical situation when different people asks for the same content, and since the router is not aware about the what is “inside” this request the router has to store same content several times.

4.1 *Insight*

The main idea of Content Centric Networking (CCN) is that users do not get the content from data’s location address: what matters is the name of the files.

Data is addressed by name or content rather than IP addresses; it differs from today’s Internet conception, where the network use centers around moving content and work in terms of host-to-host conversations. Thanks to this, popular content can be tracked and stored in intermediate nodes [37] and pushed to the edge of the network, which from an energy perspective means energy saving, since content router are one order more efficient than content servers used in conventional CDN [37].

Despite the loss of simplicity that IP offers, CCN is presented as new networking architecture that potentially can reduce bandwidth usage and offer better scalability and security and disruption tolerance as compared to current IP based networks [38]. In addition to these advantages and more based on energy efficiency, CCN outperforms different architectures presented previously in terms of energy efficiency despite the additional energy needed for the deployment of this architecture [37], [65].

4.2 *Architecture*

Based on the literature [39], [40], [41], [38] we can depict one possible configuration of how content is cached and distributed across the network in Figure 20.
As we can see in Figure 20, by using name based routing, popular content is able to be tracked and stored at intermediate nodes. The most popular content is stored in CCN router's buffer memory and is placed close to the edge router, in order to be as close as possible to end-user.

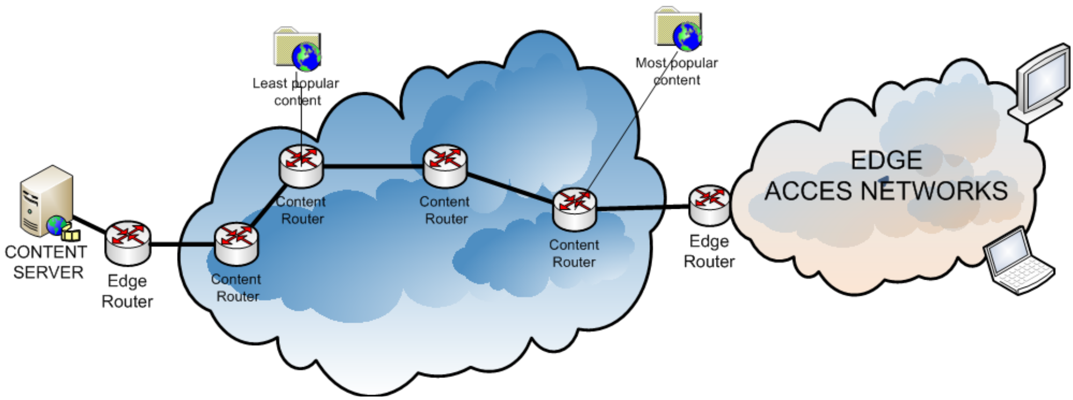

Figure 20: Content Centric Networking Architecture. Source: based on [41]

4.3 *Deep analysis*

CCN is a recent architecture and is still being object of study and deployed on low-scale. Nevertheless, is fully compatibility with the legacy IP networks and although nowadays is not affordable a full deployment [42], it can be incrementally deployed as an overlay on IP or as standalone protocol. CCN provides functional advantages [38] without the requirement of an universal and disruptive adoption and is also scalable. A forecast of the adoption is depicted on Figure 21.

CCN can be deployed to significantly reduce network capital cost, at the lowest operating expense [38].

CCN provides low dissemination latency and network transport reduction that incurs directly to lower energy consumption. Although, one possible drawback is the additional energy requirement in order to provide the caching capability of the content across the different routers.

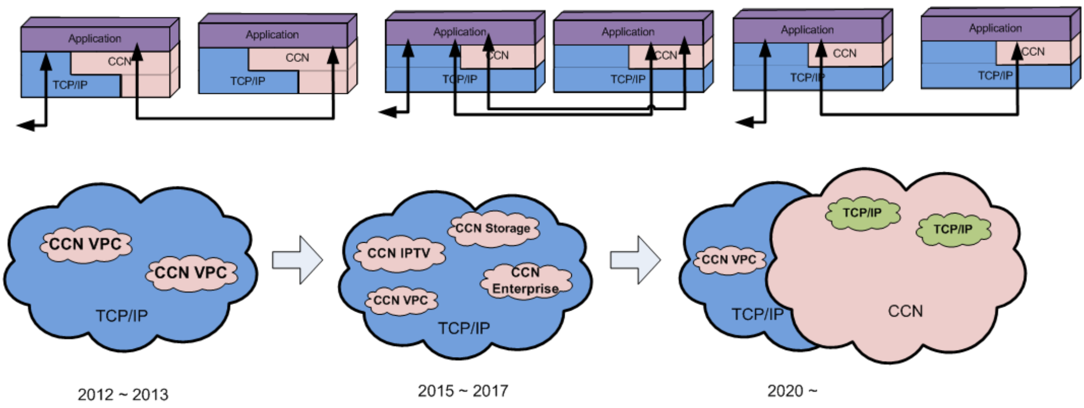

Figure 21: CCN Deployment Forecast and legacy TCP/IP compatibility [45]

By pushing the content near the users, the hop count is reduced, with a direct consequence to lessen the energy usage on the content distribution.

In [41] K. Guan et al. provide an assessment of the relative energy benefit of CCN in comparison with other content delivery architectures. The architectures compared there are mainly one presented on the related work part: optical bypass. After their study they conclude that optical bypass is more efficient when delivering not common content. Nevertheless, in this chapter I will focus more on CCNs.

The authors also compare the efficiency between CCN and CDN and despite that they state that the results depend on the parameters of the network they use, they can conclude that legacy CDN architectures are more efficient when delivering large content catalog. Even though, when the catalog tends to be smaller, CCN becomes more energy-efficient.

The model used for all different structures is shown in part III in [41]. One of the problems the authors point out and had to face was optimizing the distance between the hops and the caching on the network. In order to achieve this trade-off, they set a pair of equations and plotted the result.

According to the plotting, they conclude that when the request rate is low, few copies of the content are cached on the network and as a consequence the energy is dominated by the transport.

When the content is accessed more frequently, more files are cached and therefore the transport energy is reduced. In the case where the transport energy is reduced to the minimum, only the core router that connects to edge networks contributes to the transport energy consumption and although the caching energy is maximized, it is amortized by the increasing number of requests.

The same authors in [39], present a network model based in 64 nodes, which is studied and analyzed in order to obtain results about which is the minimum energy consumption that CCN can achieve with optimal cache locations by considering different caching hardware technologies, number of downloads per hour, catalog size and content popularity.

The results that they obtain are quite in favor to this network model. They classify these results in 3 subsections:

- **Impact of caching power efficiency on optimal total energy per bit:**

According to the results plotted and available in the paper, optimal total energy per bit increases as energy consumption of the caching hardware decreases.
One possible explanation is when the caching power per bit is low; many copies of the content can be cached in the network without increasing significantly the caching power consumption. Therefore, the number of hops is reduced, and consequently the energy consumption decreases.
Also a low dimension of the catalog correlates directly to a low energy per bit usage. The main reason is because at least one copy of the content should be cached in the network so that the CCN can serve this content.

- **Impact of maximum cache size on optimal total energy per bit**

According to the plots in [39], it is observed that as the number of download rate increases, the number of copies cached on the network also does. The plots also show that as the download rate increases, the number of cached copies increases across different popularity to the extent that every router has the entire catalog.

By increasing the memory size limit, more catalogs can be stored and therefore, reduce the transport energy. Energy proportional caching improves the energetically efficiency of CCN by reducing energy consumption caused by under utilization.

- **Impact of transport delay requirement on total energy per bit.**

Considering their plots, they agree that there should be a tradeoff between energy and delay; if hop distance is larger than the energy optimal average hop distance, the transport energy dominates the caching energy. One solution for solving this issue is to increase the number of different number of caches. This way two benefits are achieved: on one hand the delay is reduced and on the other hand the energy per bit is reduced also.

Although that the authors in [39] believe that CCN is more energy efficient; special attention should be given to how the caches are distributed and how to tradeoff between the energy and the delay, because a delay increase is directly reflected to energy consumption.

Similarly to the problem of how to deploy the content around the network in order to make it more efficient its distribution pointed by [39], Llorca et al. in [44] went one step beyond and focused on the problem of how to distribute video more efficiently through CCN.

By using 3 different architectures (processing at the source, processing at the edge and processing at intermediate node), network power usage models and 2 different topologies (line or star), they analyze all this data by using Integer Linear Programming (ILP) and RSTAR algorithm plus Dijkstra algorithm.

The authors consider that as the number of the special views increase, the energy savings can be obtained by processing these different specialized views in different subsets in the different nodes in the network. Finally, they conclude that no architecture can be generalized and, depending on the different usage patterns one is better than the other.

It is a fact that networks are not working at peak time all 24h 365 days at year and actually Rate Adaptation (RA) methods have already been used in other architectures. In [43], the authors consider implementing rate adaptation mechanisms in CCN networks and they observe an energy consumption reduction from 10 to 20 percent.

When using a tree topology, their results show that CCN only requires slightly more energy regarding to IP, but if rate adaptation is implemented, more benefits like the aforementioned regarding to the efficiency are obtained.

4.4 *Conclusion*

After considering different literature and papers, I could reach different conclusions referring to the goals achieved by CCN and which are the next decade challenges and the state of the art of this method.

CCN improves legacy distribution networks in terms of latency, security, scalability and energy efficiency. According to the major research studies it seems that energy saving and less carbon dioxide emissions can be achieved by using this architecture [46]. Nevertheless, all studies must be considered in detail and no generalization should be done since CCN is still base of study and research.

In addition, future research should be focused on designing a practical in-network caching protocol in order to achieve a greener CCN. Also as previously discussed, CCN should be able to perform energy-aware routing and traffic consolidation in order to save more energy. In some cases CCN routers should be able to dynamically turn off themselves for energy conservation. Furthermore, depending on which usage of the network is done, other solutions could adapt better to the energy usage [41], like dynamic optical bypass.

Other possible discussions and different positions found are the fact that content diffusion companies do not support CCN since they might lose the control of the content management and since they base their benefits on the valuable data stored on their servers. They have strong opinions about this since they do not want to give this power back to the network. In addition, ISP’s have some caching solutions deployed and they don’t like changes and unexpected expenses.

The CAPEX or the energy used for embodying and deploying this architecture should also be considered since the different companies will need economical incentives (they have to evaluate the CAPEX versus the possible savings of OPEX). In [43] the authors also consider this issue.

CHAPTER 5

5 Other possible solutions

Energy efficiency has been treated in many ways. There is a huge number of literature regarding this issue. Despite that, I have treated different solutions for P2P, CCN and CDN; there are other procedures, algorithms or improvements that allow saving energy. The reason why I include them in this category is because they don't belong to particular architectures.

5.1 *Coding techniques*

There are a wide range of codecs used for compressing the video and audio and then send it through Internet. Most commonly used in IPTV are MPEG-2 or a MPEG-4, but lately H.264 (other nomenclature for MPEG-4) is increasingly used in order to replace MPEG-2. Until now the possibility of sending video through mobile devices has not been treated in this master thesis. Because mobile video communications are arising too, I decided to include this issue.

The way a video is encoded affects directly to CPU usage and also to energy used. Traditional video coding is based on a complex coder and simple decoder. The authors in [55] propose a parallel decoding architecture using Wyner-Ziv (WZ) video codecs. Thanks to this, the complexity is moved from the encoder to the decoder and according to the results for a four-core multicore processor is achieved a reduction of 70% without any significant Rate-Distortion penalty and with the achievement of 60% reduction of the energy consumption in the decoder.

5.2 *Storage*

The content has also to be stored somewhere, generally into a Hard Disk Drive (HDD). Since this millions of bytes are stored somewhere and this somewhere consumes energy; it is also necessary to reduce its consumption in case that it would be possible. There are several approaches and I will try to shed some light on this topic by presenting most important approaches in this field.

5.2.1 Stoppable and Non-Stop HDD

The first approach consists in stopping the rotation of disks while the HDD's are not being accessed but the main problem regarding this is the restarting rotation time, which need about 10-30 seconds. In order to solve this problem, in [47] the authors combine utilization of cache and data placement based on access frequency where popular video files are located on HDD that are never stopped, and unpopular videos are stored on stoppable HDD.

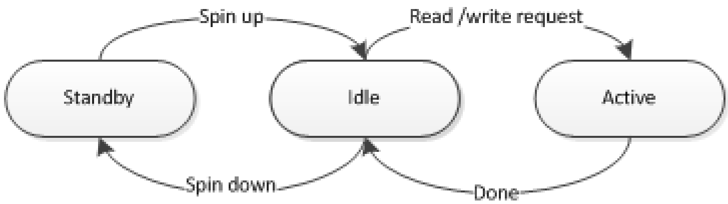

Figure 22: State transition in HDD. Source [47]

5.2.1.1 Proposed scheme

The proposed energy scheme [47] consists mainly of two groups of HDD; the **stoppable** and the **non stop**.

- **Non-Stop:** popular videos are stored in this HDD group. Never stop disk rotations despite they are idle for long time. Only the active and idle states are allowed for them
- **Stoppable:** are used to locate non popular videos. Can stop disk rotations and when time of idle exceeds the threshold they are turned into standby.

There are three types of different data stored in the HDD: **videos, metadata** and **prefix cache**.

- **Videos**: depending on its popularity the videos are stored in stoppable (unpopular videos)or non-Stop (popular videos)
- **Metadata**: are a set of keywords associated to the video used for searching it and its reallocation.
- **Prefix cache**: contains initial frames extracted from the full video which are created when a video is moved from non-stop to a stoppable HDD. All prefix cache are stored in non-stop disks since this fragments are delivered in first instance until the transition from standby to idle of the stopped HDD is completed.

Popularity of videos is measured and compared to a threshold, which will determine how popular is or not. By using a round robin strategy, videos are periodically reallocated.

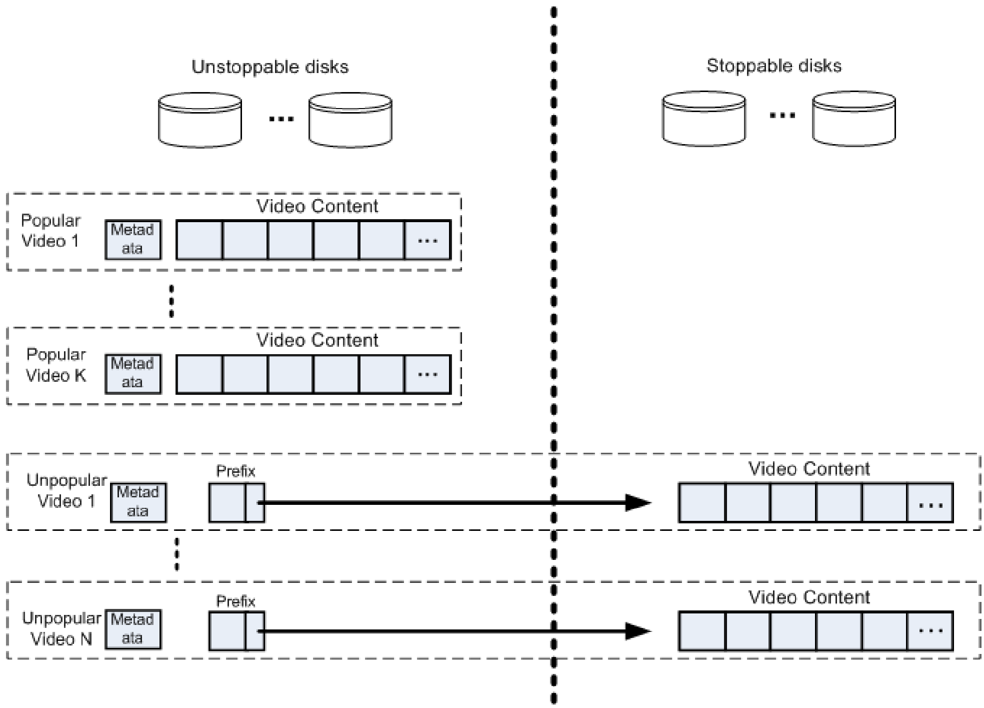

Figure 23: Overview of the proposed storage scheme. Source: [47]

According to the results in the paper, 40% of energy could be saved by this proposal in the particular case of Deskstar 7K2000. However, the cumulated delay is increased from 700ms (never stopping) to 8200 ms (more energy saved). As we can see, once again the main issue is finding a tradeoff between delay and energy consumption.

5.2.2 Explicit Energy Saving Disk Cooling

Other authors like Y. Chai et al. in [48] propose a method named Explicit Energy Saving Disk Cooling (EESDC). In this algorithm, **EESDC** first selects the disks which are going to be the Explicit Energy Saving Disks (EESD) depending on the system load.

After this, EESDC Exchanges hot data (data that is going to be more accessed) with the cold data in non-EESD disks by doing this, EESD can be cooled down and therefore achieve better efficiency in terms of energy. By explicitly confirming EESD and then focusing on the data migration of a handful of the important hot data, EESDC can reduce data migration overhead. Thanks to this method, it is possible to save up to 29,33% of energy compared to other methods. For more information, please consult paper [48].

Using Solid State Drives (SSD) could be another possible option since the energy usage and heat dissipation is less than HDD. In addition, SSD are faster and more durable than HHD. However, its high price makes this option difficult to implement in the short term since most of the datacenters have already its architecture implemented and the cost of changing could be enormous and the companies have not recovered their investment of HDD installation. Nevertheless, a good choice would be to replace the HDD for SSD in the measure that HDD will be broken.

5.3 *Transport*

As the users want more quality when watching video and different devices are ready for this High Definition Television (HDTV), it needs to be checked whether the present transportation IP based technology is able to scale to the increasing traffic for the future due the energy consumption associated to it and whether it can become a bottleneck. As we can see in Figure 24, the bandwidth usage tendency is to grow and grow with a peak on future 3DTV. According to the study in [50], the capacity for future networks will be 1000 times larger than today's capacity.

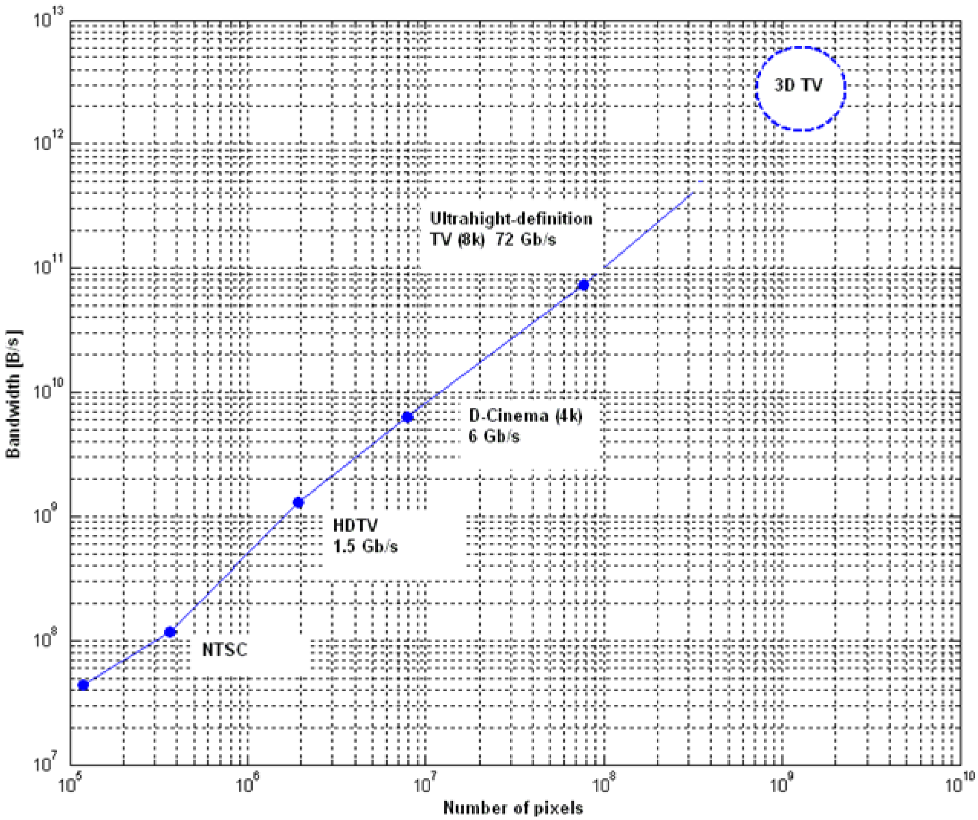

Figure 24: BW needed to transmit the uncompressed content vs. number of pixels, source [50]

In today's network most of the elements, are electronic devices. In fact, routing function will dominate energy consumption in the future [51].

Some researchers have been considering the fact of changing to optical switching since they believe that optical packet switching technologies should replace the current ones.

Nowadays in the network, the energy consumption is driven by the energy in the user modem [52]. According to the same authors; PON (Passive Optical Networks) provides the best solution in terms of energy efficiency for the broadband access network since at low rates, the total power consumption is dominated by the access network. The same authors also suggest that optical packet and bursting switching will reduce energy consumption when they are compared with the electronic routers and could exist the possibility of replace different elements like the buffer and the switch fabric for optical components. They conclude by stating that energy consumption of Wavelength-Division Multiplexing (WDM) links is small compared to other technologies.

Due to this, S. Namiki et al. on [50] propose the concept of Dynamic Optical-Path Network (DOPN). In DOPN, all the switching functions on the network are done by optical switches. In this network, optical switches are mutually connected in a mesh configuration that provides end-to-end connections dynamically. Since video content usually has fixed size and it tends to be large, according to their studies, circuit switching also fits better, in terms of QoS, when transmitting large stream bits. In this paper, they also analyze the coexistence of IP-based networks with the optical circuit switching model that they propose. After discussing how to scale DOPN to the WAN, they realize that the energy savings are substantial.

Also related, in [53], up to 18% energy could be saved using the approach they present. By employing an optical infrastructure and using few backbones as caching nodes, the energy problems found in NaDa's architecture can be solved, and at the same time the content is served close to the user.

For solving the problem, they consider two heuristics:

- TopDown: replicates the content by starting from the root network, but only have local knowledge of the network.
- Bottom up: replicates the content by starting from the bottom of the network but in that case assumes knowledge of the network.

Both cases try to replicate the content the most popular content before than the less popular content and both heuristics are scalable too.

In papers like [49], the authors compare the network efficiency when delivering content and they conclude (as aforementioned in previous chapter) that when distributing not popular content it is more efficient to use optical bypass.

Optical bypass is also a considered solution in [54] for rates up to 100 Mb/s where it is possible to save up to 30% compared to legacy networks. The same authors conclude that for distributing video, it is more efficient doing it through dedicated network than through public network.

5.4 *Set-top boxes*

As we have seen in the first chapter, in an IPTV network there are different elements that compose this "big chain" from the provider to the final user.

Regarding to set-top boxes, there are no specific algorithms or architectures in the literature because the vendors are the main responsible of their products and literature about this topic is also scarce. What was found were some guidelines and things to consider when designing set-top boxes.
Since to set-top boxes are the last link on this chain, should be conveniently considered to take a look on which are the studied and latest trends. According to [56] better designed set-top boxes could reduce the energy used by 30 to 50% by 2020.

According to [8], this issue should be faced through two aspects: the hardware and the software.

- Hardware: In this category is included the system on chip, output parts the tuner, network interfaces,
- Software: Middleware, operating system and different running applications.

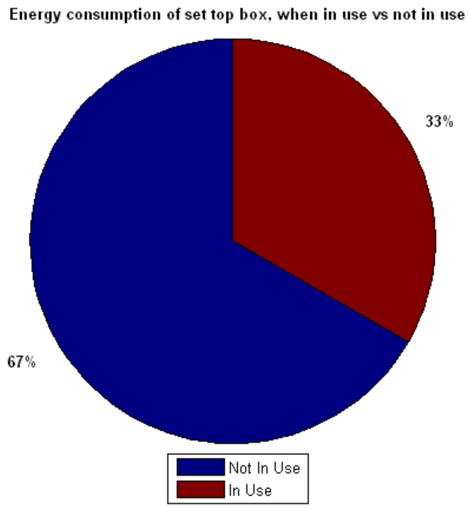

Figure 25: Set-top box energy consumption, when In Use (Users are viewing /Recording content) vs. Not in Use, in USA. Source: [56]

The main part of the problem is related to different power modes mentioned on the introduction. As we can see in Figure 25, most of the usage of energy in a set-top box occurs when the user is not using it (2/3). Therefore, by introducing different power modes that adjust to the needs, this waste of energy could be mitigated.

Some of the technical requirements for greener set-top box are listed below:

- Using system on chip that support low power standby mode.
- High energy efficient uninterruptible power supply.
- Operating system that support different power modes of system on chip.
- Insert middleware able to control the power supply.
- Use power control for all individual blocks of the hardware.

CHAPTER 6

6 Case Study

Based on the study of Henrik Abrahamson and Mattias Nordmark, in *Program Popularity and Viewer Behaviour in a Large TV-on-Demand System* [58], and all my background achieved during this master thesis, I am going to describe a possible implementation with the purpose of saving energy in the complete process.

The paper that is going to be analyzed in this chapter is a study of the access patterns in a large TV-on-Demand system over four months. The authors also have studied the user behavior and its impact on caching.

6.1 *Constraints:*

In order to provide the best solution, in this section a list with the major requirements and most important constraints will be shown.

The study is based on a TV-on-Demand where the users choose programs to watch that are outside the TV schedule, however, and for the sake of a major scalability of this study, I will also consider a possible scenario of a broadcast IPTV system.

Different user behavior:

- Rental movies, news and TV shows changes over in time in very different ways.
- Programs jumps in and out of the top 100 list.
- TV show increase in rank when the next episode is shown.
- Children's programs are top ranked in mornings and early evenings.
- Program popularity conforms to the Pareto principle or 80-20 rule.
- Very high cacheability. Hit ratio with Least Recently Used (LRU) above 50% when watching 5% of daily demand.
- Demand is 4 times higher during peak hour than compared to daytime.

- Requests for the top 100 most popular programs increase during prime time.
- Highest numbers of requests are on Friday and Saturday Evening. Daytime demand also increases during weekends.
- Some programs have a very short lifespan.
- Video viewing follows a Zipf distribution.

6.2 *Strategies*

After evaluating different options and all aforementioned and treated architectures, algorithms and procedures, I realized that there is no magical solution that could be applied directly and solve the problem. Therefore, what I propose is based in my background and always under an unempirical scope since I couldn't get any numerical results by find any example based on the mentioned constraints.

Part of the solution passes through pushing the content next to the user. By doing this, also Quality of Experience (QoE) and QoS is improved.

As we see in Figure 26 trying to improve the energy efficiency in IPTV system is an end-to-end issue and therefore, I will show the best solution to the different parts of this chain.

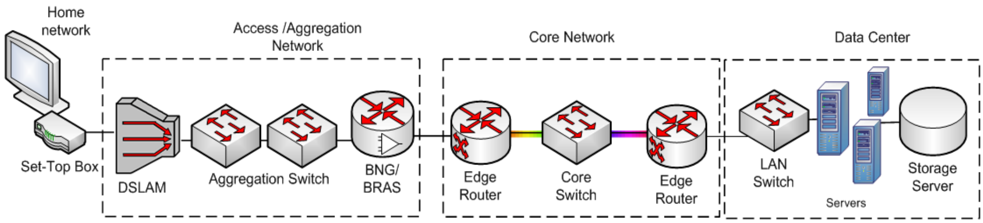

Figure 12: Typical IPTV network. Source: [6]

6.2.1 Data center:

Improving energy in datacenter is a quite discussed topic. However, most of the literature treats Heating, Ventilation, and Air Conditioning (HVAC), power supplying, Dynamic Voltage Frequency Scaling (DVFS) and others. For this case, I will focus mainly in how the video content is stored and what can be done for serving it in a more efficient way.

Serving content close to users is extremely important. In this case, most popular content should be stored in several cache servers placed close to user [57]. These cache servers should refresh the content according to popularity and viewing patterns. Also in datacenters and cache servers, a storing scheme should be used as the scheme used in [47] and studied in **5.2.1** that places content in stoppable disks and non-stoppable in function of its popularity: Popular videos and also prefix caches of unpopular video should be stored in non stoppable HDD’s, which contain initial frames of the video files stored on stoppable HDD’s. When a non popular video is requested, prefix cache is used instead of original video file until disk rotation restarts.

I think this system would work according to the patterns shown in [58], where the 20% of the content account for the 80% of the requests. In addition, a suitable content popularity pattern analyzer should be implemented in order to keep the content classified properly since it changes rapidly the viewing pattern.

In order to reduce the hop count and therefore keep content closer to users, multi CDN structure strategically deployed, like Netflix has performed in [20]. Thanks to this, the system performance is not only tied to one provider, and also for one specific region it may be better to use one than the other based in technical reasons.

In order to take advantage of the fact that 20% or the content accounts for the 80% of the requests, by aggregating user requests and also considering the time when the requests come from , it is possible to switch off part of the datacenter, specially during the night time.

6.2.2 Network

As before was announced, the routing functions will dominate energy consumption in the future. Networks are dynamic, and its usage should be adapted to different hours and traffic since they don’t work all time at the full capacity they were designed. In [58] we can observe that the demand is not always the same; being the peak demand is mainly at nights and weekends.

For this purpose I consider to apply two different schemes for elasticity in networks: modulation format adaptation and symbol rate adaptation. These schemes are presented in [61] by A. Morea et al.

Power consumption on the transceiver and the reach of optical signals as a function of the data rate have a major impact on the overall consumption on the network, and by adapting them to different demand notably energy savings could be achieved. Concretely, by combining both schemes 30% savings could be fulfilled.

IPTV or VoD traffic also could be diverted around all core routers using optical bypass, which would lead to considerable savings.

As described before, a common approach for saving energy is to allow network elements to sleep mode which has been treated in papers like [62], [63].

6.2.2.1 IPTV

IPTV operators distribute all their IPTV channels to everywhere all the time for minimizing delay when switching channel [59]. In IPTV, DSLAMs are leafs of a multicast tree of every TV channel.

For the particular case of study, since a small number of channels are very popular meanwhile about 80% are not, is possible to apply the scheme that is presented in [59].

By applying this, each node pre-join only a selection of channels automatically according to the probability of that channel being watched in the future. The saving achieved in that case is about bandwidth, which is directly translated to relevant energy savings.

According to the data in [59], popularity of the content is changing rapidly. This solution is easy to implement and also is quite dynamic, what makes it perfect for this case.
The benefit achieved is not much at the present, but in the future and since content will need more bandwidth, savings will be increased.

A brief description of how the scheme in [59] works is described below.

The node will join:

1. The channels that are being used by the viewers (active channels)
2. Small subset of inactive channels

And the scheme requires two simple data structures:

1. To maintain information on the pre-joined channels.
2. The other records if each of them is active or inactive.

In Figure 26 is shown the algorithm that is followed when a channel becomes inactive.

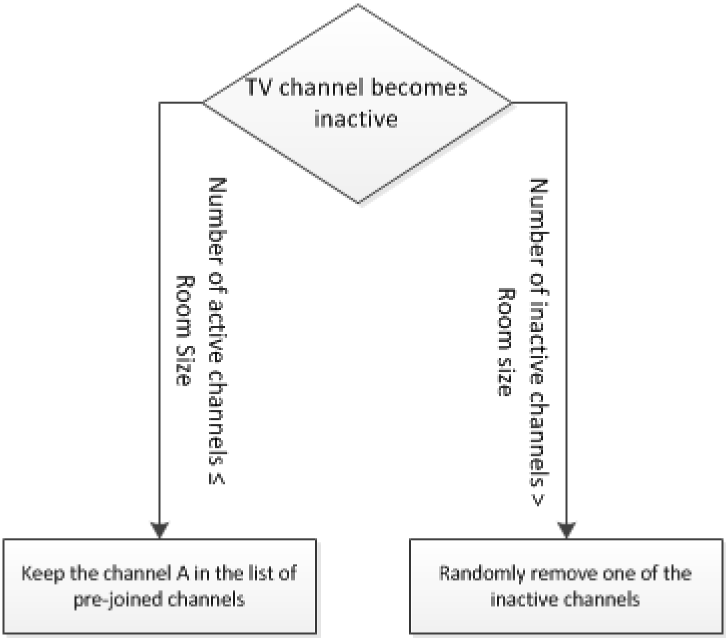

Figure 26: Selective pre joining algorithm. Source: [59]

According to the authors, room size is the number of inactive channels that are pre-joined in the node [59].

One possible drawback of this procedure would be the experience of a larger than usual delay, but according to the data, I consider that is a small price for such a good results and therefore I think is the most suitable for this particular case.

6.2.2.2 Video On demand:

For the VoD content access, I propose the algorithm presented in [60]. This algorithm has its bases on finding the optimal caching size for the files stored in cache memory in the intermediate cache server. By optimizing this, the power consumed is minimized.

According to the results presented in [60], there are a minimum number of requests needed for surpassing the threshold where energy savings start to be achieved. If we observe different data charts in [58], particularly for the rental movies [58] and we check this data against the minimum threshold for this algorithm to work in [60], we observe that for the periods with more demand (Friday and Saturday evening), it could work perfectly.

For more accuracy and specific percentage, we should adapt the algorithm according to the data and different constraints and equipment characteristics and then run it. Nevertheless, at first glance it seems to be best choice, and since this solution is presented in a paper from February 2013, it is updated to state of the art technologies.

6.2.3 End user

Most of the IPTV content could be watched indistinctly from any device with a display and Internet connectivity. However for the sake of this study I will consider that the major part of the content in [58] is distributed to a set-top box.

Energy consumption in that case does not affect to ISP or the content provider, and the savings will be reflected into user energy bill, the environment and the energy demand overall. However, when there are millions of small savings, it turns into a big saving.

What I propose are different guidelines to follow in order to sooth energy consumption in the final part of the content distribution chain. These guidelines can be found in section **5.4** of this master thesis.

CHAPTER 7

7 Conclusions

The importance of ICT is increasing and as we could see, this trend will continue.
In order to lessen CO_2 emission, the first thought is to use green energy to power different networking elements, but the main aim of this thesis was how to do this content delivering chain more efficient. Cutting CO_2 emissions and saving money are consequences and also the main reason at the same time.

When trying to implement any technique or improving energy efficiency in hardware in order to cut CO_2 emissions, it should also be considered the energy of embodiment and real carbon footprint in life cycle assessment.

When money is what matters, capital expenditure and operational expenditure should be studied. However, as commented before, there will be peak demand over next years and it could be unaffordable for present power network. For this case, it could be reasonable that the expenses for improving energy efficiency in order to continue expanding the network and the number of devices able to be connected despite the investment is not directly covered by the energy savings, if not by the final user.

Energy optimization in distribution is a complex end-to-end problem that must be solved by splitting into smaller parts that are directly involved.

There are common thoughts that are important in terms of energy efficiency. Distance matters, and also the number of devices where the data have to get through.

Improving the energy efficiency is the main goal, but the scenario where a lower energy consumption could imply the augment of the demand should be studied and questioned, which leads us to the question; where is the limit? Do we want to base our model in continuous growing?

I have presented different techniques and concepts, but there is not a particular solution that could be applied directly without studying the particular case.

There is a lot of literature, but after reading and studying them, I realized that solutions they propose are partially suitable for different particular scenarios, which makes it very difficult to choose the best solution that fits better in all cases.

All studies from papers I found are based on models or particular data with different hardware and therefore comparing them is difficult. What would be suitable is to compare them with the same dataset and then analyze the conclusions afterwards. Despite are several papers that compare them, in their benchmark do not propose the solution for improving the efficiency or performance.

Serving content from correct placement in the network depending on the user demand is crucial for achieving best savings. Few popular content should be stored and served from cache servers close to users. These servers should have limited storage and should refresh the content according to the popularity and be switched off in low-peak hours.

Transport networks are majorly responsible for the energy usage. A large part of the energy losses are due to the transport networks. Electronic switching starves lots of energy whereas optical switching does not. Consequently, optical technologies should be deeply studied and also improved in order to lessen these avoidable energy loses. In access network, FTTH also could reduce significantly losses and therefore making it more efficient.

More coordination among research groups and companies should be needed in order to achieve the best results although there already exist IEEE and ITU.

Finally, a firm solution should be implanted in the coming future in order to avoid a possible energy bottleneck, since energy will constrain the development of future Internet.

7.1 *Future work*

Future solution for delivering storing and delivering media content in an efficient way must be scalable and downward compatible system in order to use previous deployment of delivering content is growing and growing.

CCN is a new concept that is been studied in content dissemination field, but it needs a deeper and practical study of its real impact on today's networks and analyze if its deployment is really affordable nowadays.

Since pushing content close to the user, better caching strategies and algorithms should be developed in order to predict user future demand and optimize the storage used in caching servers.

Mobile devices and mobile networks will suffer a spectacular increase of the users. Future work should be focused also in covering new device and mobile network energy needs when distributing content.

List of Figures

List of Acronyms

ADSL	Asymmetric Digital Subscriber Line
BNG	Broadband Network Gateway
BRAS	Broadband Remote Access
CapEx	Capital expenditure
CCN	Content Centric Networking
CMOS	Complementary Metal Oxide Semiconductor
DOPN	Dynamic Optical-Path Network
DSL	Digital Subscriber Line
Ebit	Energy per Bit
EPG	Electronic Programming Guide
FTP	File Transfer Protocol
FTTH	Fiber to the Home
GeSI	Global e-Sustainability Initiative
HDD	Hard Disk Drive
HDTV	High Definition Television
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information Communication Technologies
IMS	Instant Message Service
IP	Internet Protocol
ISP	Internet Service Provider
LRU	Least Recently Used
MILP	Mixed Integer Linear Programming
NaDa	Nano Datacenter
OpEx	Operating expense
OTT	Over The Top
P2P	Peer to Peer
PoP	Point of Presence
PUE	Power Usage Effectiveness
QoE	Quality of Experience
QoS	Quality of Service
RA	Rate Adaptation
SLA	Service Level Agreement
TCP	Transmission Control Protocol
VPC	Virtual Private Cloud
WDM	Wavelength-Division Multiplexing
WZ	Wyner-Ziv

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