POLITECNICO DI TORINO

Master's Thesis

ENERGY CONSUMPTION OF CONTENT DELIVERY NETWORK (CDN) BASED ON A REAL INTERNET MODEL

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ABSTRACT

According to studies, now days Internet user are growing very fast and internet traffic also increasing Exponentially. The main reason of the traffic growth is a large number of users start using wider range of services. Data distribution system is one of the most preferable system to deliver those vast amounts of user's content. Those Data distribution system consumes considerable amount of Energy. There are different type Data Distribution Systems. Namely: Single Data Center, Content Delivery Network (CDN), P2P networks, and Content Centric Network (CCN).

This Thesis Mainly focused on Content Delivery Network(CDN) and covered these three points.

First, a new model introduced to compute the Total Energy Consumption of Content Delivery Network which is more realistic Internet Map (Hierarchical Internet representation - Three Tier Model). Synchronization Energy Consumption (in previous study which is not considered) is mentioned as a part of Total Energy Consumption and computed the way, when a new content is available or changed. So, in our new Model Total Energy consumption is the Summation of four different elements namely, Storage Energy Consumption, Sever Energy Consumption, Synchronization Energy Consumption and Transmission Energy Consumption.

Second, Total Energy Consumption of Content Delivery network with and without considering Synchronization Energy Consumption is computed and analyzed.

Third, the performance of three different caching strategies are compared, namely Static, LRU and LU. Then analyzed the impact of those cache strategies on content delivery Network.

Finally Discussed, the impact of increasing Surrogate Servers on Synchronization Energy Consumption and the effect of Synchronization Energy Consumption on Total Energy Consumption of Content Delivery Networks.

Based on the simulation results, it concluded that Total Energy Consumption in content delivery network is not always decreased by adding surrogate servers, it strongly depends on the ratio between the number of request and the number of content modification. From the three-cache strategies, Static cache strategy is the simplest one and consumes larger energy than LRU and LU. This is because, LRU and LU cache strategy implement popularity techniques. Therefore, surrogate servers housed popular contents which is closes to end users. This popularity technique decreases the transition energy consumption and the total energy consumption.

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GLOSSARY OF TERMS

CDN	Content Delivery Network
ICT	Information Communication Technology
IPTV	Internet Protocol TV
EPA	Environmental Protection Agency
DVFS	Dynamic Voltage and Frequency Scaling
P2P	Peer-to-Peer
DSL	Digital Subscriber Line
GPON	Gigabit Optical Network
DSLAM	Digital Subscriber Line Access Multiplexer
OLT	Optical Line Terminal
HTCP	Hypertext Cache Protocol
NECP	Network Element Control Protocol
ICP	Internet Cache Protocol
TCP	Transport Control Protocol
WCCP	Web Cache Control Protocol
WWW	World Wide Web
POP	Point of Presence
ISP	Internet Service Provider
CCN	Content Centric Network
CPU	Central Processing Unit
DNS	Domain Name Server
ICN	Information Centric Network
IP	Internet Protocol
LRU	Least Recently Used
RU	Recently Used

CHAPTER ONE

INTRODUCTION

1. Energy Efficiency in Content Delivery Networks

According to studies, this days Internet user are growing very fast and internet traffic also increasing Exponentially. The main reason, of the traffic growth is a large number of users start using wider range of services. Data distribution system is one of the most preferable system to deliver those vast amounts of user's content. Those Data distribution system consumes considerable amount of Energy [31]. Although, several studies show Information and communication Technology consuming alarming figures of Energy and it is also in charge of global emissions [11].

Today's, a significant portion Internet usage consists of users generated contents, those data are text, image and video. Large service providers, are starting to expand their data centers to fulfil this growing user demands [34]. Beside the expansion of data centers, backbone network providers also increasing network device capacities, such as router, fiber cables, switches.

Computing and annualizing the network energy-proportional, could reduce significant amount energy consummation for content distribution network. As studies shows, when the number of internet user increase, the total internet traffic also increases, as well the total energy consumption. Sometimes, when the internet users grow dramatically, it could halt the whole transport system and dropping down internet performance. Now a time optical network is quickly reaching the Shannon capacity boundary, so it is really difficult to improve the network efficiency because of energy sensitivity [36].

To reduce a significant amount of energy consumption one of the best method is, to push content to Network Edges. So, this will decrease the transition traffic and save energy used for data transport. Surrogate server placement is one of the crucial step to reduce user perceived latency for accessing content and to minimize the overall network bandwidth consumption for transferring replicated content. Optimal placement of surrogate servers permits a CDN to deliver high quality services.

1.2 Energy Efficient Content Dissemination Networks

- Content Delivery Networks (CDN)

Before CDN was introduced, internet users have been requesting and fetching content directly from content providers in a centralized manner. When Internet users start to increase, it has been very difficult to serve all users from a single server. So, CDN developed to advance content delivery performance. CDN strategically establishes a number of Data centers that houses content, which are positioned at multiple geographically location at the Edge of Internet.

Content Delivery Network distinguished based on where the surrogate servers are located. Some service Providers choose, to build large data centers at few strategic locations, other choose large number of small content server at multiple locations. Both tactics have advantage and disadvantage. The former, consumes a significant amount of energy to deliver content to end user, because of a numbers hops. The latter, is good in terms of energy consumptions but it need sophisticated algorithms to monitor real-time activities. The studies show that, energy consumption in CDN is less than Data Center Delivery Network due to the number of hopes. If the number of hops dramatically decrease the energy consumption decrease, if the number of hops increase the energy consumption also increase.

- **P2P Architecture**

Peer-2-Peer is one of the advanced form of content dissemination network, in which the content server located in user's computer. The data are divided into slight parts called chunks and Tracker which plays as coordinator among peer. When the Users hold parts of the content, they share all, though Tracker supports users' position finder one another.

- **Content-Centric Networking**

Content-Centric Network is one of the new energy effective content distribution network, it reduces bandwidth usage and has a better scalability and security. CCN deliver content by using name based routing, which enables popular content to be tracked and stored at intermediate nodes. CCN more energy efficient when we compared with CDN. In addition, CCN further save energy through proportional computing and networking.

> "An end user who is interested in a particular type of content sends out an interest packet with the content name. The interest packet propagates along the routing path towards the content source. Each router receiving an interest should firstly check whether the request content is present in its local cache by looking up a content store table. If there is a hit, the router ends up forwarding the interest and

sends out the matched data to the requester along the reverse path. Otherwise, it forwards the request to the interfaces determined by the Forwarding Information base. All requests for content not satisfied within the ISP are routed to the source situated outside the ISP. Ongoing requests are recorded in a pending interest Table for later sending back the requested data through the reverse path towards the sources of the interests. When the target objects are sent in reply to interest packets and travel along the way back to the requester following the chain of pending interest table entries, the content-centric Network router on the path determines whether to replicate the object according to the deterministic caching strategy" [39, 40] (Uichin Lee, Ivica Rimc, 2011, 2012)

- **Data Center**

Data Center Network (DCN) is one of the content dissemination network holds a crucial role in a data center, as it interconnects all of the data center resources together. The trade-off Data center network is that, it should have an accessible and competent to serve the growing demand of computing. DCN centrally manage a number of servers in single location.

CHAPTER TWO

2. Overview of Content Delivery Networks (CDNs)

2.1 Introduction

Today, a significant amount of traffic on the Internet delivered by CDNs. A content delivery network is a large distributed system that stores content at multiple locations in different geographic area. When a client makes a request to content, a CDN applies an algorithm to choose the nearest server, which houses the requested content. The goal of content delivery network is to improve user fulfilment by reducing the delay and ensuring performance. In Content Distribution Network content is delivered to end users through host servers that are centrally managed in a few data centers [2].

Other part of Content Delivery Network is Decentralized CDNs, it was originally considered to improve throughput and delay performance but it comforts the transport energy consumption. To reduce transit traffic and consequently the associated energy consumption, different data centers are deployed at multiple locations of core networks. As such, a decentralized CDN pushes the content closer to the network edge and end users [6].

Based on network principle, the very first step for user request for content is, passing a user request to the Domain Name Server (DNS), which than translates the surrogate server address to machine understandable IP address. Then the user request is forwarded to the Provider server, which responds to the user request. Surrogate server is responsible for distributing the content of the Provider(origin) server, between the CDN content servers. When a user request is received at the DNS, it is forwarded to the Request-Routing System (RRS) which is responsible for pointing users to their matching CDN surrogate server. The selection of the Surrogate server depends on the accessibility of content and the distance between the user and the content server based on the number of hops and the network performance.

One of the essential thing to improve the Content Delivery Network is, continuously update surrogate server information. Which include the content location and the whole the network performance. It is useless, if the surrogate servers housed the content while the network is disfunction.

2.2 **CDN Organization**

There are two general approaches for building CDNs. Those are: *Overlay approach* and *Network approach*.

- *Overlay approach*: servers which has specific role for application-explicit content, placed in different geographic area. Network components such as Router and Switch have no energetic part in content delivery network without connecting and providing quality of services for specific request. At the time content request delivered from users, it forwarded to the nearest surrogate server, which advance reply time. In overlay approach, content distribution network provider has not a capacity to control the fundamental network elements, the management is open for new services and opportunities.

- *Network approach*: the network components including routers and switches has a specific role to identify and forward the requests based on specified procedures. One of this approach is, the devices that redirect content requests to local caches to specific servers, optimized to serve specific content types.

There are CDNs, which implement both network and overlay approaches. In this situation, a network element can perform as front end of servers and redirects the content request to adjacent application-specific surrogate server [7].

2.3 **Servers**

There are two types servers in Content Delivery Network. Those are: Origin Server and Replica server.

- *Original Server*: is the server where the final version of the content be located. It is continuously updated by the Provider Server. The original server communicates with disseminated Surrogate servers to update the content housed in it.

- *Replica Server*: is a server which houses a copy of the content but may act as a confident position for client responses. In CDN, replica server could perform as a media server, Web server or as a cache server. A media server serves any digital and encoded content. A media server should contain a media server software. Depending on client request, a media server replies to the query with the explicit request. A Web server contains the links to the streaming media as well as other Web-based content that a CDN wants to handle. A cache server houses a copy of content at the network edge, bypass the need of accessing origin server to satisfy every content request.

2.4 **Content Types**

In general, there are three types content. Those are: static content, dynamic content, streaming media. Difference types of contents needs to adopt application-specific characteristics, architectures and technologies to delivered in CDN. Therefore, some of the CDNs are dedicated for delivering content.

- *Static content*: is a content its rate of change is very low. Most of the time static content does not change depending on user requests. Example of static contents are: HTML pages, embedded images, executables, PDF documents, software patches, audio and video files. Every Content Delivery Network providers support Static contents. Static contents cached without difficulty, and their freshness can be continued using traditional caching technologies.

- *Dynamic content*: is a content it rates of change is very high, it changes frequently depending on user requests. Most of the time Dynamic content is created on-request of different application process. Dynamic contents in general considered as uncatchable content, it is because of its frequency of change natures. Example of Dynamic contents are: animations, scripts, and DHTML.

- *Streaming media:* is one of the content can be live media or no-demand. Live media delivery is used for live events. Some of the live media are: sport, concerts, channel, and news broadcast. In this case, content is delivered immediately on the time of event, the live media data encoder to the media server than forwarded to media client. In case of no-demand delivery, the content is encoded and then is stored as streaming media files in the media servers. The content is available upon requests from the media clients. Some of On-demand media contents are: audio, video on-demand, movie files and music clips.

2.5 **Surrogate Placement**

Studies have shown, Surrogate Sever Placement is one of the crucial issue in content delivery network, which empowers a CDN to provide high quality services and low CDN prices. The goal of optimal surrogate server placement is, to decrease user perceived latency and to minimize the general network bandwidth consumption [21].

CDN administrator is the one who determine the optimal number of surrogate servers and surrogate server placement, in case of single-ISP or multi-ISP approach.

- *Single-ISP approach*: a CDN provider typically arranges around 50 surrogate servers around the network edge. In single -ISP approach one or two surrogates are putted in each major city inside the ISP coverage. The ISP prepares the surrogates with large caches. An ISP with global network can thus have extensive geographical coverage with relying on other ISPs. The disadvantage of Single ISP approach is that surrogates may be placed at a distant place from the clients of the CDN provider [28].

- *Multi-ISP approach*: CDN Provider places several surrogate servers in different geographical areas. Multi-ISP approach decrease the problems which mentioned in single-ISP approach. Because of surrogates are placed close to the users, contents are delivered to users reliably and timely. Other than the cost and complexity of setup, the main disadvantage of the multi-ISP approach is that each surrogate server receives fewer content requests which may result in idle resources, and poor CDN performance [24].

2.6 **Content Outsourcing**

In Content Delivery Network, in addition to Surrogate server placement, content outsourcing is one of the vital element. There are three main content outsourcing approaches. Those are: cooperative push-based, non-cooperative pull-based, and cooperative pull-based approaches.

- Cooperative push-based approach depends on the pre-fetching of content to the surrogates. Content is pushed to the surrogate server from the Provider, and surrogate servers cooperate to reduce replication and update cost. In this scheme, the CDN maintains a mapping between content and surrogate servers, and each request is directed to the closest surrogate server or otherwise the request is directed to the origin server. Under this approach, greedy-global heuristic algorithm is suitable for making replication decision among cooperating surrogate servers [25].

- In non-cooperative pull-based approach, client requests are directed to their closest surrogate servers. If there is a cache miss, surrogate servers pull content from the origin server. Most popular CDN providers use this approach. The disadvantage of this approach is that an optimal server is not always chosen to serve content request [26]. Many CDNs use this approach since the cooperative push-based approach is still at the experimental stage [24].

- The cooperative push-based approach differs from the non-cooperative approach in the sense that surrogate servers cooperate with each other to get requested content in case of cache miss. In the cooperative pull-based approach client requests are directed to the closest surrogate through DNS redirection. Using a distributed index, the surrogate server finds nearby copies of requested content and store it in the cache. The cooperative pull-based approach is reactive wherein a data object is cached only when the client requests it.

2.7 **Cache Organization and Management**

Content management is important for CDN performance, which is mainly dependent on the cache organization approach followed by the CDN. Cache organization is in turn composed of the caching techniques used and the frequency of cache update to ensure the freshness, availability, and reliability of content. Other than those two, the cache organization may also involve the integrated use of caching and replication on a CDN's infrastructure. Such integration may be useful for a CDN for effective content management. Potential performance improvement is also possible in terms of perceived latency, hit ratio if replication and caching are used together in a CDN [27].

2.8 Cache Management

Surrogate servers are responsible to store a fraction of the entire data set based on the cache policy. In different cache strategy (50 % of the entire data, 40 %, and 20 %) hit probability is considered to be the same as the percentage of housed data. The strategy to choose the contents to be cached in each surrogate server is of fundamental importance. There are three main types of caching Policy.

- *Static*: contents are pre-fetched according to uniform distribution from the primary server to surrogate servers and they remains in the surrogates without any change during the network life time.

- *Least Recently Used (LRU)*: base on the idea that if a content has been requested recently, there is a good probability that it will be requested again in a relatively short time. Therefore, it is more convenient to replace content that has not been requested for long time. LRU conceptually maintains a list of cached objects, ordered by accessed time, new objects are positioned at the head of queue, while the objects at the queue, being older, are replaced when the cache is full. On each cache miss in a surrogate server (i.e. the closest server to the request ISP does not house the content), the surrogate server fetches the missed content from the closest surrogate server and stores that content from the closest surrogate server and stores that content in a place of the largest Time. In this scheme, after a while, the most popular contents are stored in each surrogate, this increase the hit probability.

- *Recently Used (RU):* This strategy is very similar to LRU. The only different is that the newly requested and missed content is each surrogate replaces the content which is requested the least number of times. In this strategy the popularity of the stored contents is computed according to the number of requests. While in the LRU the popularity is based on the age of recent request.

2.9 **Performance Measurement**

One of the key point to measure about content delivery network is, it performance. Performance measurement is the capability to serve the users request with the favorite data. Performance measurement can be accomplished either on internal performance or on user's satisfaction. There are five key criteria's, namely: *Cache hit ratio, Reserved bandwidth, Latency, Surrogate server Utilization, Reliability* [22].

- *Cache hit ratio*: is the ratio of the total number of content compared with total content request. When the ratio of the total content with content request is large enough, it indicates that the content delivery network is using effective caches technique.

- *Reserved bandwidth*: is a bandwidth which used by provider. Reserved bandwidth is measured in megabyte which retrieved from the provider.

- *Latency*: is a delay before the content transfer starts, it is the time taken to respond the users request. Reduced latency shows that, less bandwidth is reserved by the provider.

- *Surrogate server Utilization*: a duration time which the surrogate server running to respond users request. The administrator is the one who compute, the running time, the number of user request, the storage usage, the total time to respond the request.

- *Reliability*: Content Distribution Network check the reliability of the content by measuring the Packet-loss. If Packet-loss is very small, it indicates that the reliability is High. High reliability shows that a CDN acquires less packet loss and contents are reaching to users without loss.

CHAPTER THREE

3. New Model to Compute Energy Consumption of CDNs

3.1 **Introduction**

In this work it is tried to consider a graph as close as possible to the Internet Map (Hierarchical Internet representation), there for a three-tier model is chosen to include all the three-layer ISPs.

In this section, a new model is introduced and the integration of Synchronization Energy Consumption in Total Energy Consumption described, a new Formula to compute Total Energy consumption of CDN presented, three different caching strategies, namely Static, LRU and LU compared. Then analyzed the impact of those cache strategies on content delivery Network. At the end the result will discussed and based on the result the whole work will concluded .

3.2 **Internet Map**

In this work a graph close to the real Internet Map. There are three tiers of ISPs.

- *Tier Three ISP*: This is the edge of Tier in which, layer three ISPs are located. Layer three ISPs are connected to end users by edge routers. Edge routers are located in Points of Presence (POP) which are from one side connected to customer Edge routers (CE) or Subscribers Edge routers (SE). Subscribers Edge routers connect end users to Internet. Tier three ISPs are Internet boarders and to send content to end users. Layer three ISPs are connected to layer Two ISPs.

- *Tier Two*: This is the layer through which lots of ISPs of layer three get connected to each other. Each tier two ISP is connected to tier three ISPs by boarder routers. There for tier three ISPs which are not far from each other may get connected to the same tier two ISP. They can communicate independent form other core network (Tier one network) or other tier two ISPs through the common tier two ISP. Tier two ISPs are also interconnected through the core network.

- *Tier one*: Here is where Tier two ISPs and Tier three ISP are Connected. Which make the full internet Graph.

3.3 **Surrogate Server Placement**

In a typical CDN network, there is Provider or an Original server and some surrogate servers. The reason to use surrogate servers is to move the content to network edge, close to end users.

There are S surrogate servers available (S < number of tier two ISPs (C)). There is at most one surrogate present in all tier three ISPs connected to the same tier two ISPs. Surrogates are placed randomly in tier three ISPs. Therefore, for each tier two ISP there is at most one Surrogate placed in one of the tier three ISPs connected to that tier two ISP. The Provider has the map of all surrogates.

3.4 **Content outsourcing**

Content outsourcing can be chosen among cooperative push-based, cooperative pull-based, or non-cooperative pull-based approaches. In this Thesis cooperative push-based approach is considered in which content is pre-fetched to the surrogates. Content is pushed to the surrogates from the Provider. In this scheme, the provider keeps a mapping between content and surrogate servers, and each request is directed to the closest surrogate and if content is not hit there, the request is directed to Provider. It is also important to note that when a new content piece is available, modified or deleted, the change is propagated from provider to all surrogates that house that content.

3.5 **Cache Management**

In this work we consider some different scenarios regarding cache size.

- Considering the whole storage size need to house entire data as M, each surrogate house 50/100 * M of the entire data. It is the size of each surrogate cache.
- Considering the whole storage size need to house entire data as M, each surrogate house 40/100 * M of the entire data. It is the size of each surrogate cache.
- Considering the whole storage size need to house entire data as M, each surrogate house 20/100 * M of the entire data. It is the size of each surrogate cache.

Cache size strongly affects the hit probability (P_{hit}). The bigger the cache is, the more content chunks are housed, and as a result hit probability grows.

3.6 **Symbols and Definition**

- There is a Provider which has the map of contents replicated in different surrogate servers so that each request from the users, the closest surrogate server that contain the content is chosen the introduced to the user, the user in directed to that server.
- There are Three Tiers in Internet, Tier 3, which includes ISPs connected to end users. Tier 2, which interconnects Tier 3 ISPs by itself or by Tier 1 network, which is considered as core network.
- Links are assumed to be Optical Fibers.
- Surrogate servers follow a uniform distribution to be located in Tier 3 ISPs, which means the probability of being a server in each ISP layer 3 is equal.
- It is assumed that as an average there are **K** Tier 3 ISPs. Each Tier 3 ISPs is connected to **n** end users, so there are **N = n * k** end users connected to Tier 3 ISPs.
- It is considered that for each **f** Tier 3 ISPs there is one Tier 2 ISP, while Tier 1 ISPs in Internet are determined and considered here concatenated making one core network.
- Normalizing the size of contents, each content is considered to be a chunk with the size **B** bit, so in this work content refers to the fixed chunks.
- According to the mentioned approach used in placing surrogates, it is assumed that in case there are **S** surrogates and there are N end user each N/S users are closed to each surrogate.
- It is considered that the provider houses all contents and as an average there are $Hsd^C = 20$ hops to reach provider for each user in case of cash miss of surrogates.
- All computations are based on uniform requests coming from all over the users.

3.7 **Table of Items and Numerical Assumption**

In this table all the symbols and Energy consumption of Server, Link, Storage Device and Router are mentioned.

Symbol	Default Value	Description
M	1000	Number of content pieces
B	10^6	Size of each content in bits
T	100s	Time period in seconds
n_m	----	Number of replica for content m.
q_m	100 – 100 000	Number of request for content m during time period t.
Q_m	100 – 10 000	Number of change content m during time period t.
H_{sd}	4,12,20	Number of hops from Source to Destination
H_{ps}	14	Number of hops from Provider to each Surrogates server
K	1000	Number of Tier-3 ISPs
F	20	Number of Tier 3 ISPs connected to each Tier 2 ISPs
C	K/F = 50	Number of Tier 2 ISPs
N	2 000 000	Number of End users
n	2000	Number of End users per Tier 3 ISPs
S	1,2,3,5,8,10,20	Number of surrogate servers
P_{st}	$7.84 * 10^{-12}$	Storage Energy consumption per bit in Joules
P_r	$1.2 * 10^{-8}$	Router Energy consumption per bit in Joules
P_l	$1.48 * 10^{-9}$	Link Energy consumption per bit in Joules
P_{sr}	$2.81 * 10^{-7}$	Server Energy consumption per bit in Watts
P_{hit}	0.2, 0.4, 0.5	Probability to hit a content in a surrogate

3.8 **Total Energy Consumption Formula**

Total Energy consumption is the Summation of four different elements namely, Storage Energy Consumption, Sever Energy consumption, Synchronization Energy consumption and Transmission Energy consumption.

- *Storage Energy consumption* is the Energy consumption to store the whole contents in the servers.
- *Server Energy consumption* is said to the energy consumed by all servers when requests are sent to the them, it is the response energy consumption of the servers.
- *Synchronization Energy consumption* is the energy consumed to propagate new content to the related Surrogate servers when new content is available.
- *Transmission Energy consumption* the energy consumed when to transmit contents.

$$E_{Total} = E_{Storage} + E_{Server} + E_{Synchronization} + E_{Transmission}$$

Where:

❖ Storage Energy Consumption:

$$E_{Storage} = \sum_{m}^{n} B * t * nm * Pst$$

Where B is the size of the chunk, m is the number of contents, t is the period in which the energy consumption is being computed, n_m is the amount of replica for each content and p_{st} is the storage energy consumption.

❖ Server Energy Consumption:

$$E_{Server} = \sum_{m}^{n} B * qm * Psr$$

Where B is the size of each chunk, m is the number of contents, q_m is the number of request for each content during the period t and p_{sr} is the server energy consumption.

❖ Synchronization Energy Consumption:

Single Server:

$$E_{Synchronization} = 0$$

When there is only one server there is no Synchronization Energy Consumption.

S surrogate Servers:

$$E_{Synchronization} = \sum_{m}^{n} B * Qm * nm * [\Pr(Hps + 1) + Pl(Hps)]$$

Where H_{ps} is the average number of hops from the provider to each surrogate server. Q_m stands for the number of content chunks inserted, modified or deleted during the period t. P_r and P_l are router and link energy consumption per bit.

❖ Transmission Energy Consumption:

When a user in a tier 3 ISPs makes a request, five different scenarios may happen.

1. There is a surrogate in the same Tier 3 ISP and the requested content is hit in that surrogate. The probability that this situation happens is called P_A.

$$P_A = \frac{s}{C} * \frac{1}{f} * Phit$$

2. There is a surrogate in the same Tier 3 ISP, but the requested content is not hit in that surrogate. In this case, due to the existence of only one surrogate in each Tier 2 ISP, the content should be fetched through the core network. The probability that this situation happens is called $P_{A'}$

$$P_{A'} = \frac{s}{C} * \frac{1}{f} * (1 - Phit)$$

3. There is not a surrogate in the same Tier 3 ISP, but there is a surrogate in the same Tier 2 ISP, and the requested content is hit in that surrogate. The probability that this situation happens is called P_B.

$$P_B = \frac{s}{C} * (1 - \frac{1}{f}) * Phit$$

4. There is not a surrogate in the same Tier 3 ISP, but there is a surrogate in the same Tier 2 ISP, however, the requested content is not hit in that surrogate. In this case the content should be fetched through the core network. The probability that this situation happens in called $P_{B'}$.

$P_{B'} = \frac{S}{C} * (1 - \frac{1}{f}) * (1 - Phit)$

5. There is not a surrogate neither in the same Tier 3 ISP nor in the same Tier 2 ISP. In this case the requested content should be fetched through the core network. The probability that this situation happens in called P_{else}.

   The cases 2, 4 and 5 are the ones in which the requested content should be fetched from the core network. It means the content is not found in same Tier 2 or Tier 3. We sum them up and call them P_c.

   $P_c = 1 - (P_A + P_B)$

Now it is possible to compute transmission energy consumption when there are S surrogates.

$$E_{Tran} = \mathrm{PA}\sum_{m}^{n} B * qm * [\Pr\left(Hsd^{A} + 1\right) + Pl\left(Hsd^{A}\right)] +$$
$$\mathrm{PB}\sum_{m}^{n} B * qm * [\Pr\left(Hsd^{B} + 1\right) + Pl\left(Hsd^{B}\right)] +$$
$$\mathrm{Pc}\sum_{m}^{n} B * qm * [\Pr\left(Hsd^{C} + 1\right) + Pl\left(Hsd^{C}\right)]$$

Where Hsd^C is the number of hops to fetch the content from the core network, Hsd^B is the number of hops to fetch the content form a surrogate in the same Tier 2 ISP but not the same Tier 3 ISP, and Hsd^A is the number of hops to fetch the content from a surrogate in same Tier 3 ISP.

Where Hsd^C is equals to 20 which is the number of hopes to get the content when there is cache miss and content should be fetched from developer, Hsd^B equals to 12 which is the number of hopes to get the content when content and requester are in the same Tier 2 ISP but not the same Tier 3 ISP, and Hsd^A equal to 4 which is the number of hops to get content when content and request are on the same Tier 3 ISP.

3.9 **Results and Discussion**

In this part Total Energy consumption with and without considering Synchronization energy is compared. The results are gaining by implementing different situation to see the effect of synchronization on Energy consumption of data delivery in Internet.

Different considerations are shown in the table below along with their Graphs in the following part. Finally, the explanation part represents the issues acquired implementing the formula.

3.9.1 Table of Results

Tables are filled with Total Energy consumption and Total Energy consumption without considering Synchronization Energy consumption in case there is only one server or there are 2, 3 ,5, 8, 10, 20 Surrogate Servers.

3.9.2 First Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,5000
Number of changed content (data chunk – Q_m) = 100,1000,5000
Surrogate server Cache size = 20 %
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 100		q_m = 1000 Q_m = 1000		q_m = 5000 Q_m = 5000	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E(Total-Synch)	E(Total)	E (Total - synch)
1	56.2985	56.2985	559.616	559.616	2801.92	2801.92
2	64.1651	56.3371	634.813	556.933	3196.3	2790.65
3	69.8238	56.3756	677.393	554.553	3346.77	2769.5
5	73.3709	55.9082	754.519	554.2	3759.39	2760.81
8	85.3433	55.2353	865.339	546.395	4313.81	2719.49
10	96.1394	55.594	952.447	539.968	4715.1	2703.28
20	132.8	55.3222	1323.91	524.442	6641.41	2602.73

3.9.3 Second Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,5000
Number of changed content (data chunk – Q_m) = 100,1000,5000
Surrogate server Cache size = 40%
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 100		q_m = 1000 Q_m = 1000		q_m = 5000 Q_m = 5000	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	56.0592	56.0592	558.048	558.048	2796.49	2796.49
2	72.4496	55.5891	715	556.03	3575.92	2765.01
3	82.2448	55.9505	797.768	548.875	3949.37	2743.05
5	95.3918	55.85	950.641	539.968	4737.52	2713.87
8	122.159	56.1218	1183.2	523.228	5824.27	2638.45
10	138.149	56.0544	1310.07	523.249	6638.42	2609.97
20	219.072	54.883	2112.13	490.714	10502.8	2431.42

3.9.4 Third Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,5000
Number of changed content (data chunk – Q_m) = 100,1000,5000
Surrogate server Cache size = 50 %
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 100		q_m = 1000 Q_m =1000		q_m = 5000Q_m = 5000	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	56.0794	56.0794	557.543	557.543	2781.99	2781.99
2	79.5354	56.4526	749.834	553.932	3763.32	2756.71
3	86.858	55.7464	852.442	547.95	4207.71	2735.83
5	108.413	56.2253	1029.98	536.01	5181.54	2684.38
8	138.708	55.8103	1336.49	520.565	6643.98	2587.43
10	153.094	53.938	1500.14	512.394	7538.69	2538.96
20	247.791	53.4936	2468.6	484.478	12383.5	2332.09

3.9.5 Forth Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,5000
Number of changed content (data chunk – Q_m) = 10,100,500
Surrogate server Cache size = 20%
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 10		q_m = 1000 Q_m = 100		q_m = 5000 Q_m = 500	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	56.2985	56.2985	560.455	560.455	2801.64	2801.64
2	56.6614	56.0592	564.409	556.38	2829.78	2788.43
3	57.3792	56.3756	567.374	555.933	2829.41	2763.37
5	57.5855	56.1804	572.081	551.206	2853.31	2752.35
8	58.98	55.7685	579.839	546.118	2891.87	2735.1
10	59.6016	55.5872	579.769	544.442	2882.85	2689.96
20	65.8897	56.0544	604.931	525.446	2966.56	2581.98

3.9.6 Fifth Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,5000
Number of changed content (data chunk – Q_m) = 10,100,500
Surrogate server Cache size = 40%
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 10		q_m = 1000 Q_m = 100		q_m = 5000 Q_m = 500	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	56.3371	56.3371	557.214	557.214	2793.7	2793.7
2	56.9969	55.5918	572.851	554.385	2845.7	2761.19
3	58.7606	55.9505	578.86	550.759	2858.65	2737.61
5	60.2106	55.594	589.042	546.289	2918.64	2713.3
8	62.5422	55.1156	592.737	529.309	2969.05	2642.88
10	62.4046	54.5765	607.153	523.452	3009.86	2615.44
20	72.0003	55.9427	646.288	484.508	3211.98	2415.73

3.9.7 Sixth Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,5000
Number of changed content (data chunk – Q_m) = 10,100,500
Surrogate server Cache size = 50%
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 10		q_m = 1000 Q_m = 100		q_m = 5000 Q_m = 500	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	56.0794	56.0794	558.651	558.651	2782.82	2782.82
2	58.6606	56.4526	570.679	551.21	2854.23	2759.69
3	60.0951	56.2814	579.185	548.475	2866.26	2712.91
5	60.1534	54.9347	587.491	537.111	2916.38	2670.1
8	64.2406	55.8103	602.926	525.649	3001.81	2609.8
10	65.7155	54.8766	619.673	516.503	3049.68	2548.08
20	75.1787	54.7053	667.551	469.24	3330.14	2325.33

3.9.8 Seventh Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,10000
Number of changed content (data chunk – Q_m) = 1,10,100
Surrogate server Cache size = 20%
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 1		q_m = 1000 Q_m = 10		q_m = 10000 Q_m = 100	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	56.0188	56.0188	560.735	560.735	5613.21	5613.21
2	56.3371	56.3371	558.295	557.492	5594.06	5585.43
3	56.3756	56.3756	558.243	557.039	5576.32	5564.48
5	55.8367	55.636	553.22	552.016	5511.67	5490.59
8	55.9692	55.7685	546.812	542.397	5481.77	5451.86
10	55.2691	55.0683	544.888	541.275	5434	5391.44
20	55.6098	54.8069	531.064	524.239	5281.4	5199.3

3.9.9 Eighth Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,10000
Number of changed content (data chunk – Q_m) = 1,10,100
Surrogate server Cache size = 40%
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 1		q_m = 1000 Q_m = 10		q_m = 10000 Q_m = 100	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	55.5035	55.5035	556.38	556.38	5586.27	5586.27
2	55.7898	55.5891	554.632	553.829	5544.32	5526.66
3	56.6919	56.4912	554.466	552.66	5488.17	5464.29
5	55.8712	55.0683	546.278	542.866	5455.3	5416.56
8	56.17	55.3671	536.289	531.07	5327.74	5266.72
10	56.2825	55.0782	533.055	524.022	5223.23	5144.74
20	55.8693	54.2635	499.651	482.389	4970.77	4817.02

3.9.10 Ninth Consideration

Number of requests to each content (data chunk – q_m) = 100,1000,10000
Number of changed content (data chunk – Q_m) = 1,10,100
Surrogate server Cache size = 50%
Number of new content available during the period t = 100 s

	q_m = 100 Q_m = 1		q_m = 1000 Q_m = 10		q_m = 10000 Q_m = 100	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	56.0794	56.0794	555.051	555.051	5557.49	5557.49
2	56.8541	56.4526	552.601	550.393	5539.72	5522.46
3	55.6128	55.2114	548.754	545.543	5480.55	5447.64
5	55.4709	54.6681	543.46	538.642	5407.61	5353.82
8	55.3794	54.5765	526.03	518.002	5278.55	5200.67
10	54.6389	53.4346	523.005	514.574	5184.8	5088.66
20	56.9164	55.7121	496.624	476.953	4885.38	4683.05

3.9.11 Tenth Consideration

Number of requests to each content (data chunk – q_m) = 1000,10000,100000
Number of changed content (data chunk – Q_m) = 1,10,100
Surrogate server Cache size = 20%
Number of new content available during the period t = 100 s

	q_m = 1000 Q_m = 1		q_m = 10000 Q_m = 10		q_m = 100000 Q_m = 100	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	561.574	561.574	5589.71	5589.71	56060.5	56060.5
2	559.437	559.437	5590.73	5589.32	55731.1	55722.9
3	557.791	557.59	5564.35	5563.94	55504	55493.7
5	551.403	551.203	5523.39	5522.19	55188	55165.3
8	545.458	545.057	5441.01	5438	54582	54550.5
10	544.193	544.193	5410.09	5404.27	54188.4	54150.5
20	522.406	521.201	5177.12	5169.49	52434.5	52352.2

3.9.12 Eleventh Consideration

Number of requests to each content (data chunk – q_m) = 1000,10000,100000
Number of changed content (data chunk – Q_m) = 1,10,100
Surrogate server Cache size = 40%
Number of new content available during the period t = 100 s

	q_m = 1000 Q_m = 1		q_m = 10000 Q_m = 10		q_m = 100000 Q_m = 100	
Surrogate servers	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E(Total - Synch)
1	558.88	558.88	5572.07	5572.07	55925.3	55925.3
2	553.142	552.74	5556.46	5554.65	55422.6	55403.5
3	548.875	548.875	5498.63	5497.23	54958.8	54932.5
5	543.046	542.845	5398.72	5394.3	53956	53920.9
8	528.049	527.045	5299.73	5294.31	52703	52636.2
10	521.438	520.836	5231.03	5223.81	51874.5	51791.8
20	487.281	485.073	4840.32	4824.86	48090.4	47927

3.9.13 Twelfth Consideration

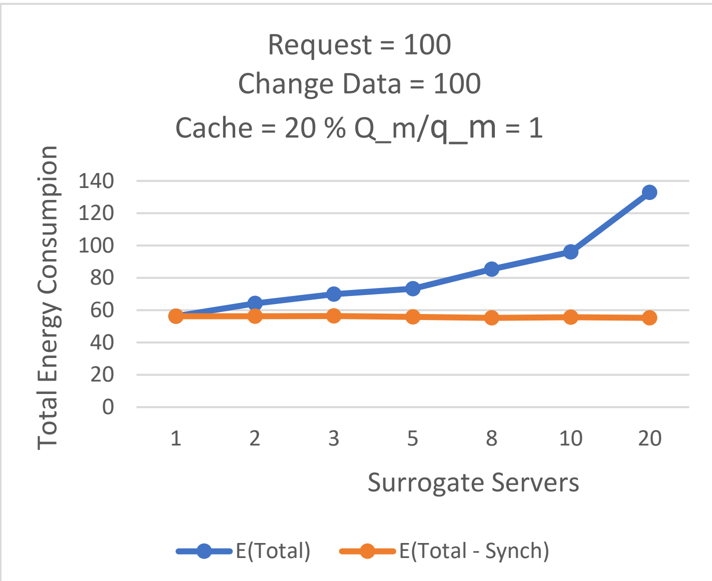
Number of requests to each content (data chunk – q_m) = 1000,10000,100000
Number of changed content (data chunk – Q_m) = 1,10,100
Surrogate server Cache size = 50%
Number of new content available during the period t = 100 s

Surrogate server	q_m = 1000 Q_m = 1		q_m = 10000 Q_m = 10		q_m = 100000 Q_m = 100	
	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)	E(Total)	E (Total - Synch)
1	556.148	556.148	5578.27	5578.27	55711.1	55711.1
2	552.288	552.288	5515.97	5514.17	55366.5	55346.9
3	544.102	543.902	5453.96	5451.75	54528.1	54498.6
5	529.935	529.333	5326.61	5320.79	53511	53460.1
8	522.17	521.568	5207.48	5199.85	52110	52030.7
10	511.371	510.568	5107.94	5098.91	51311.3	51215.1
20	476.063	474.257	4699.84	4678.36	46886.7	46694.2

3.10 Graphs

Here the Graph related to each Result table mentioned above can be seen and Total Energy consumption with and without Synchronization can be compared.

3.10.1 First Consideration



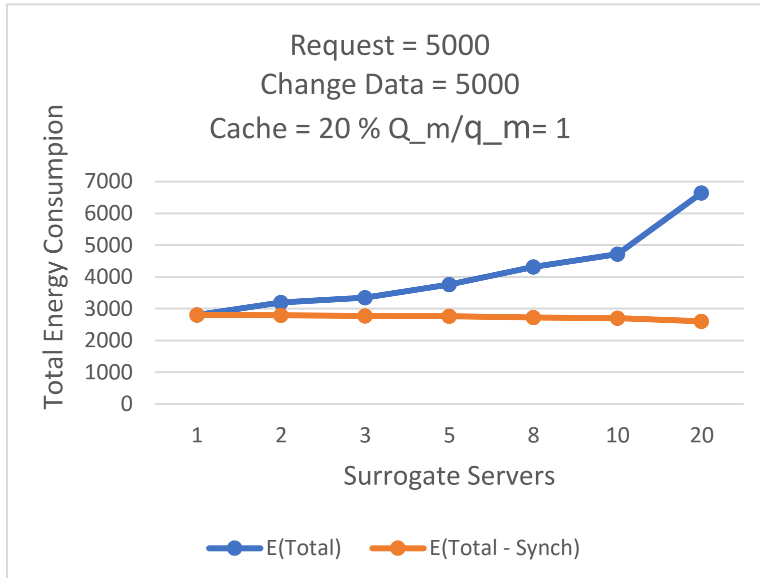
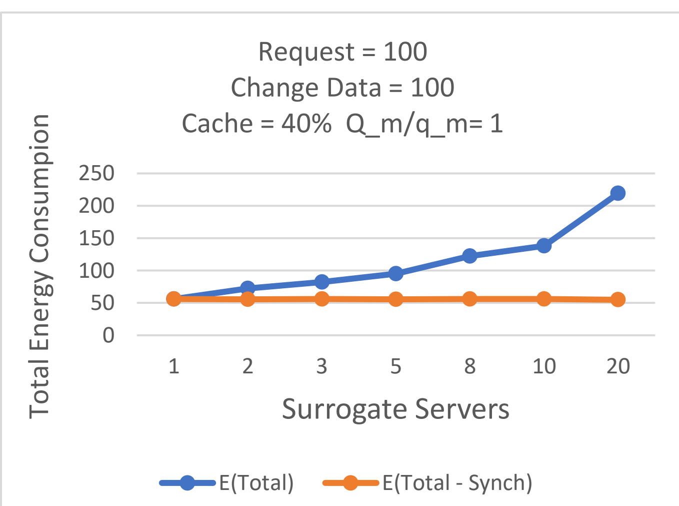


Figure 1: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 20 % Q_m/q_m = 1

3.10.2 Second Consideration



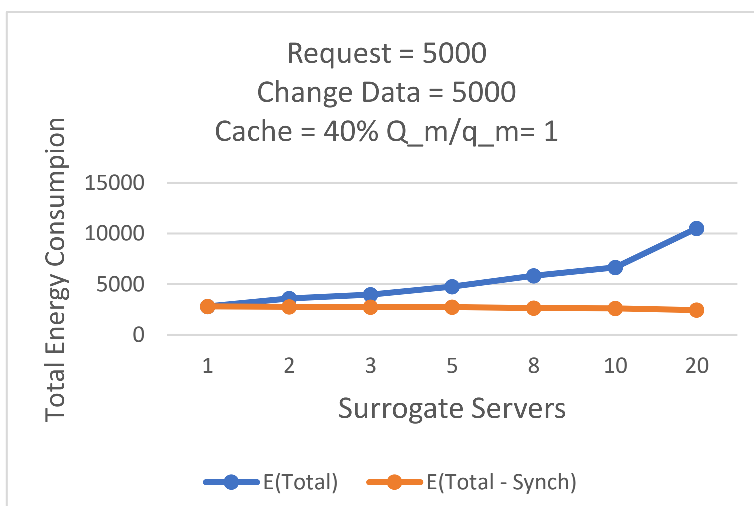
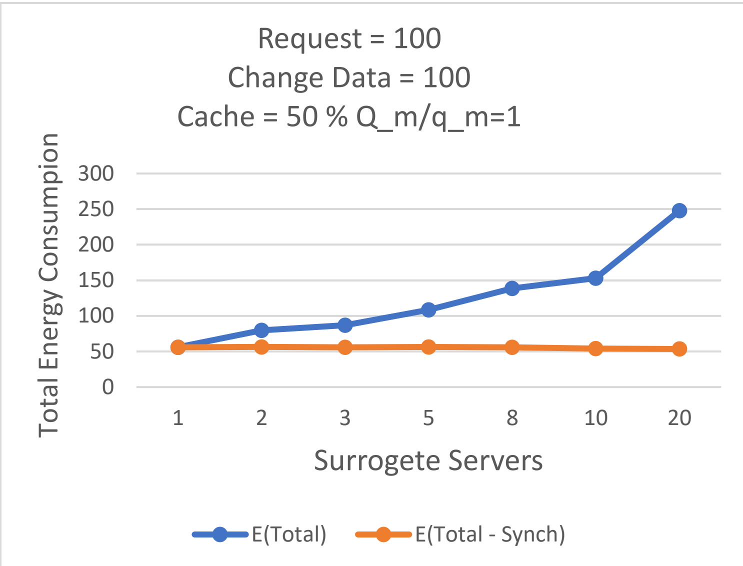


Figure 2: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 40 % Q_m/q_m = 1

3.10.3 Third Consideration



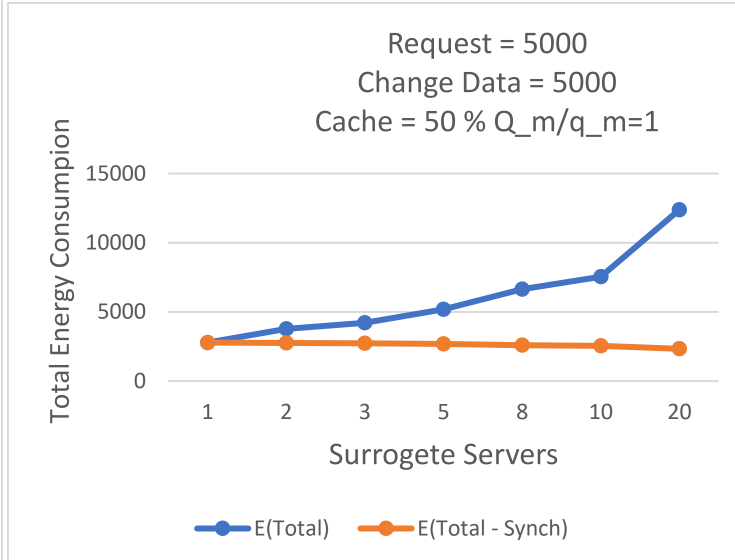
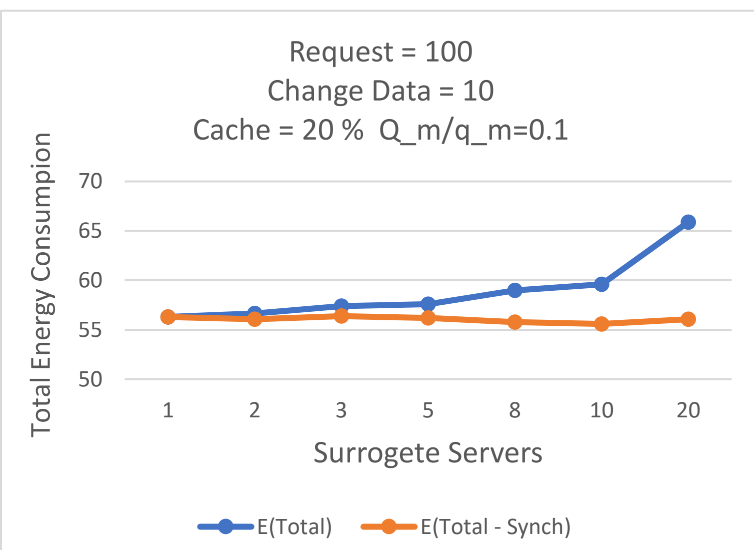


Figure 3: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 50 % Q_m/q_m = 1

3.10.4 Fourth Consideration



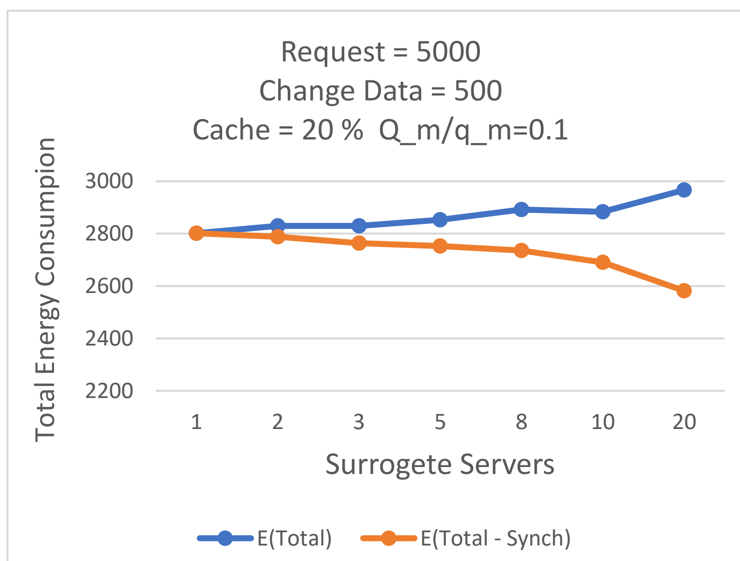


Figure 4: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 20% Q_m/q_m = 0.1

3.10.5 Fifth Consideration

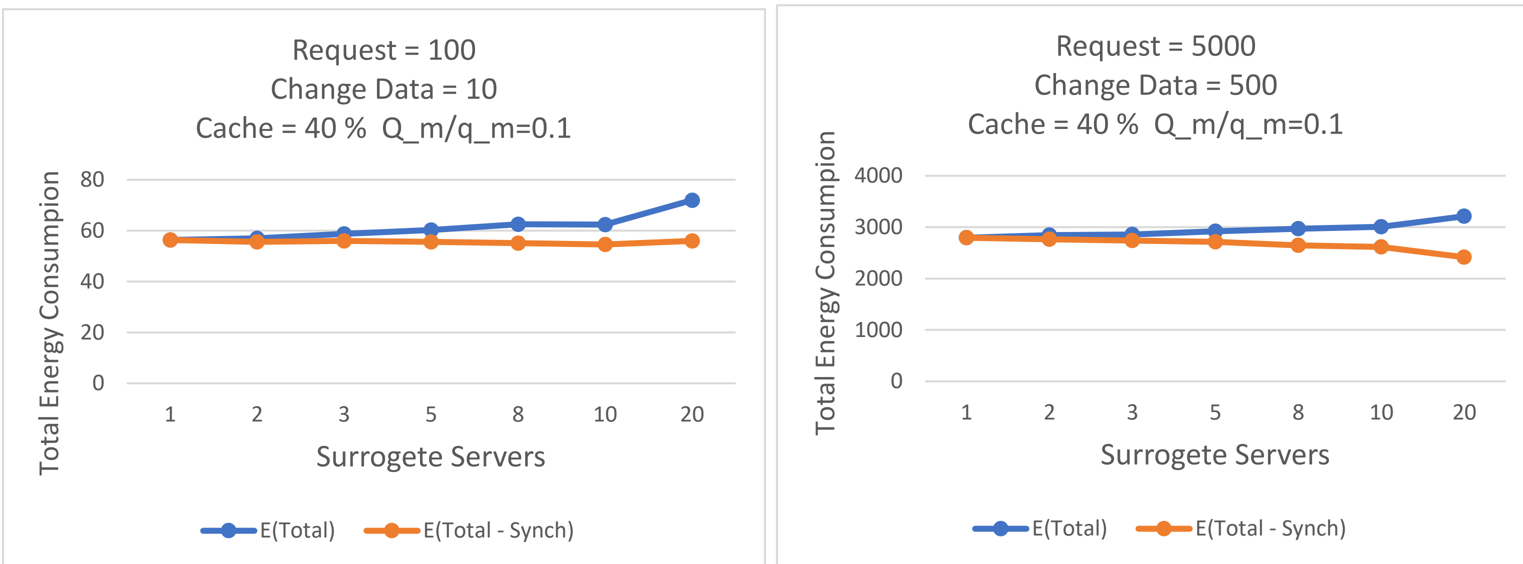


Figure 5: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 40% Q_m/q_m = 0.1

3.10.6 sixth Consideration

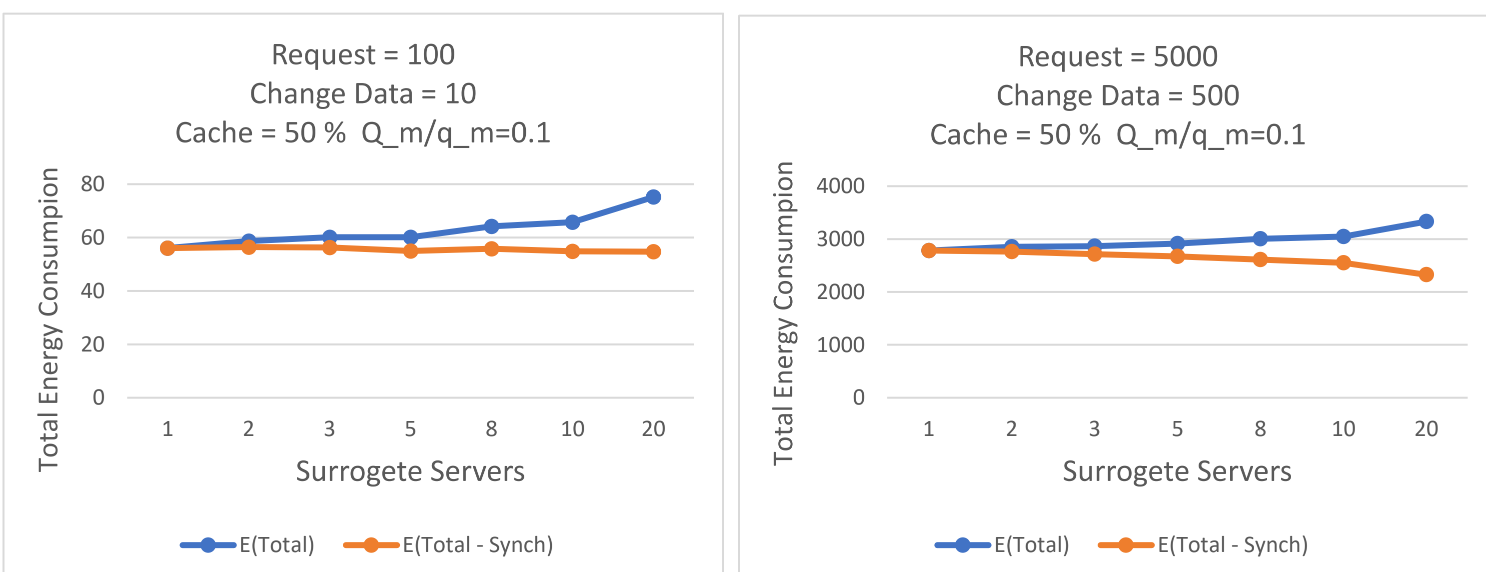


Figure 6: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 50 % Q_m/q_m = 0.1

3.10.7 Seventh Consideration

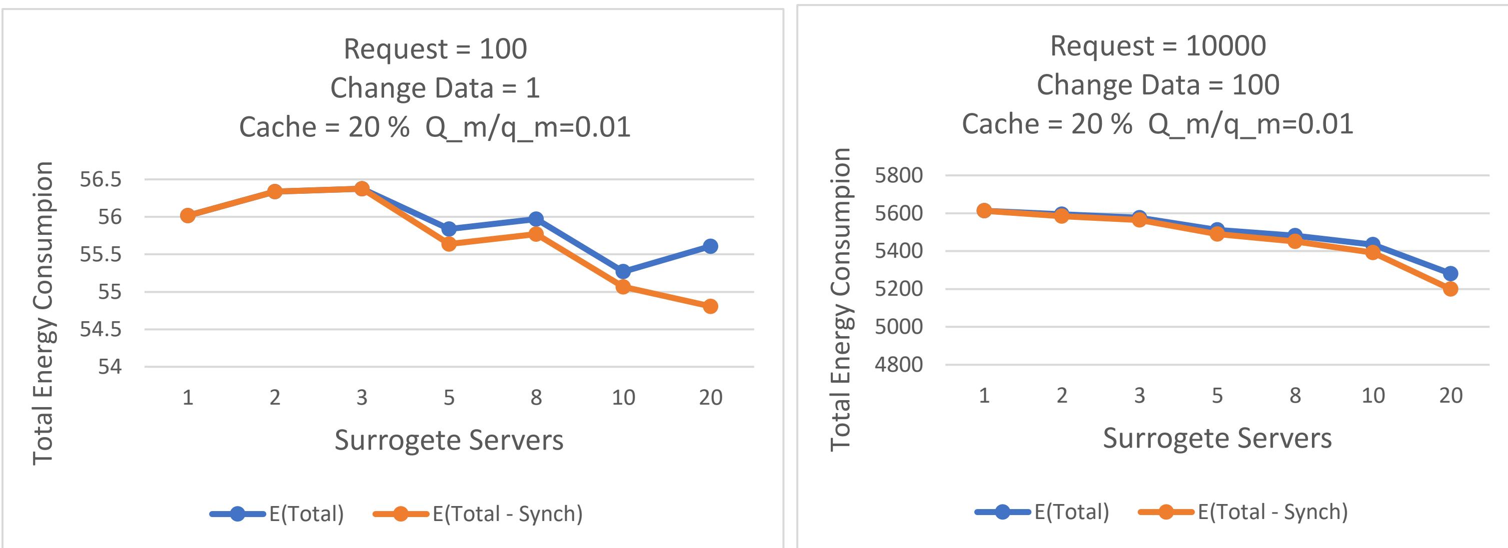


Figure 7: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 20 % Q_m/q_m = 0.01

3.10.8 Eighth Consideration

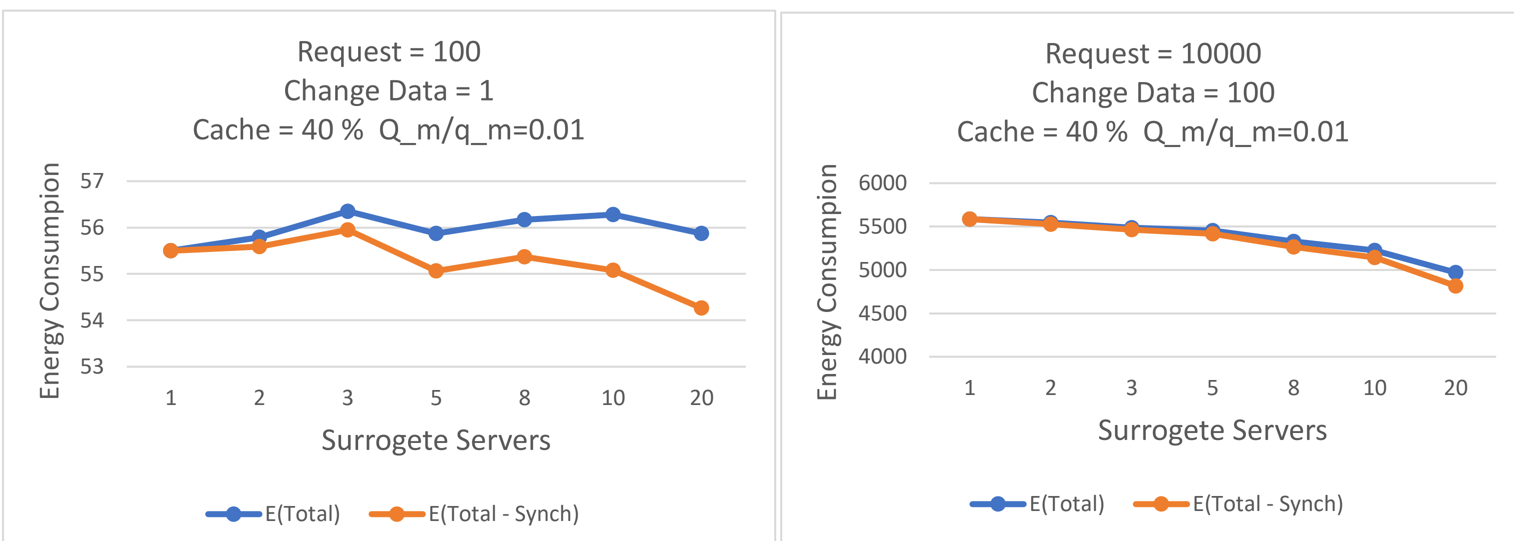


Figure 8: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 40 % Q_m/q_m = 0.01

3.10.9 Ninth Consideration

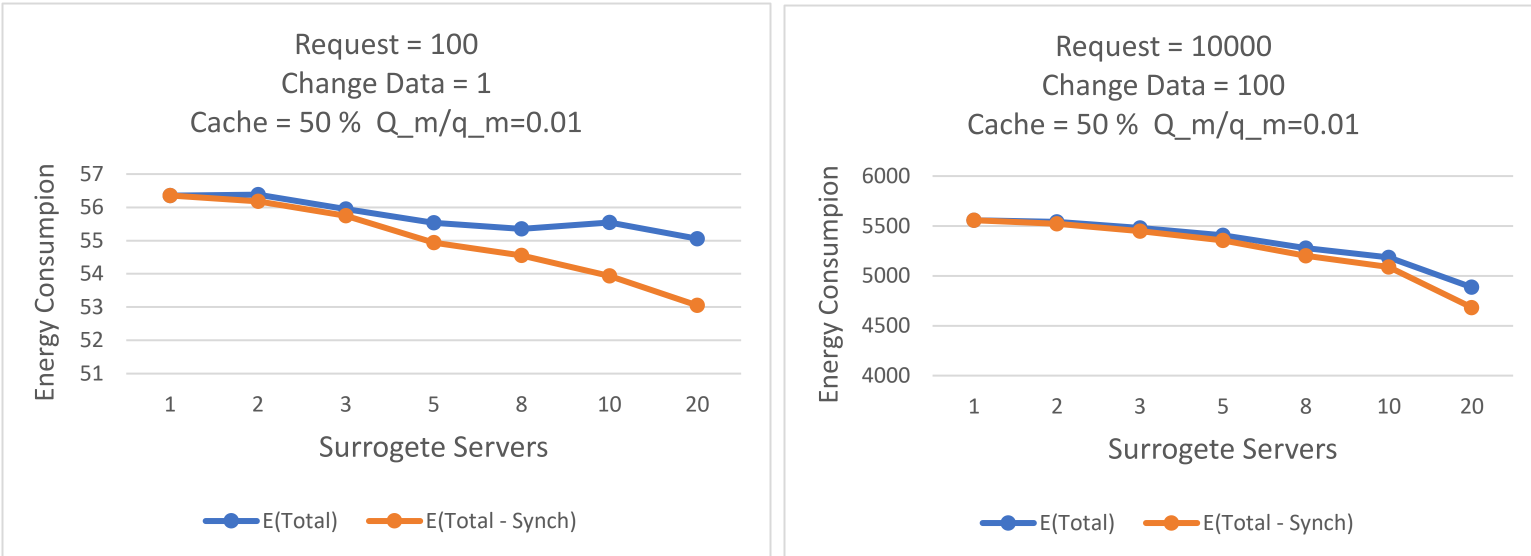


Figure 9: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 50 % Q_m/q_m = 0.01

3.10.10 Tenth Consideration

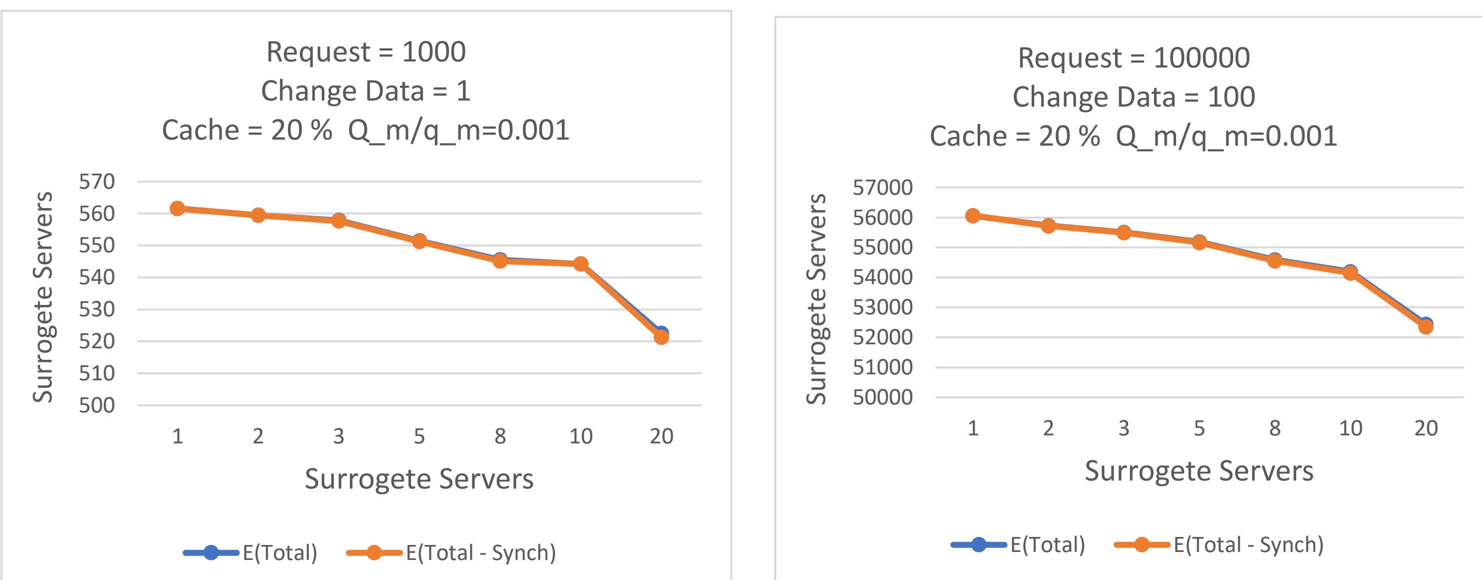
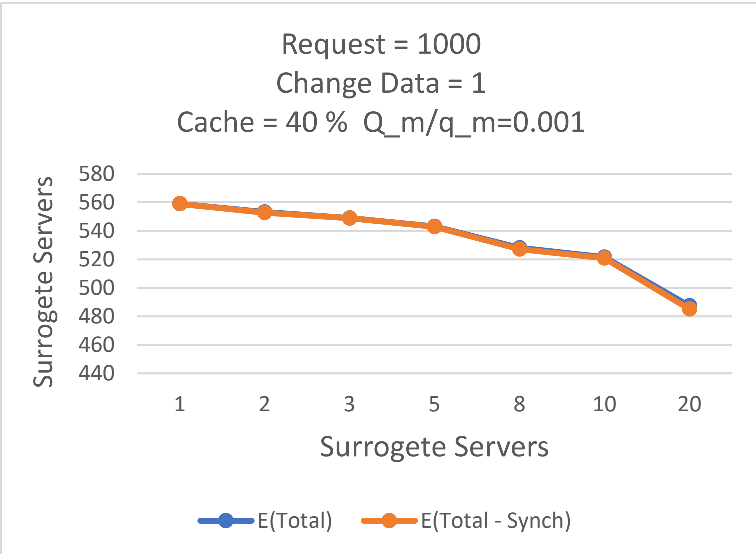


Figure 10: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 20% Q_m/q_m = 0.001

3.10.11 Eleventh Consideration



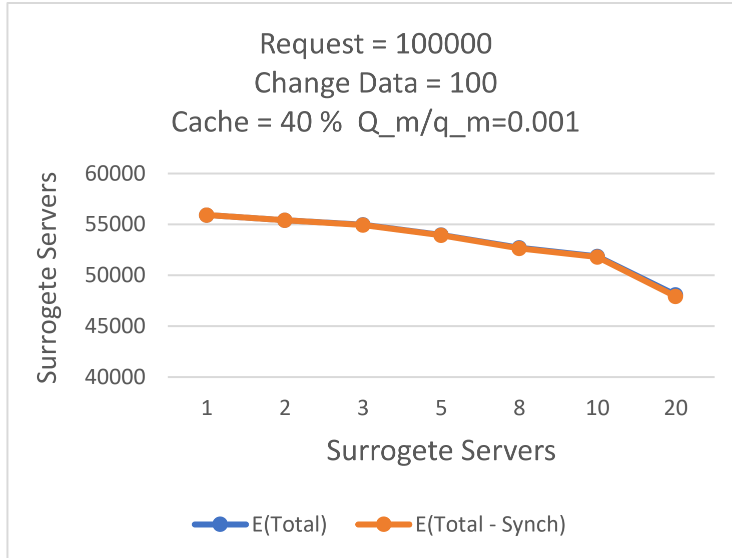
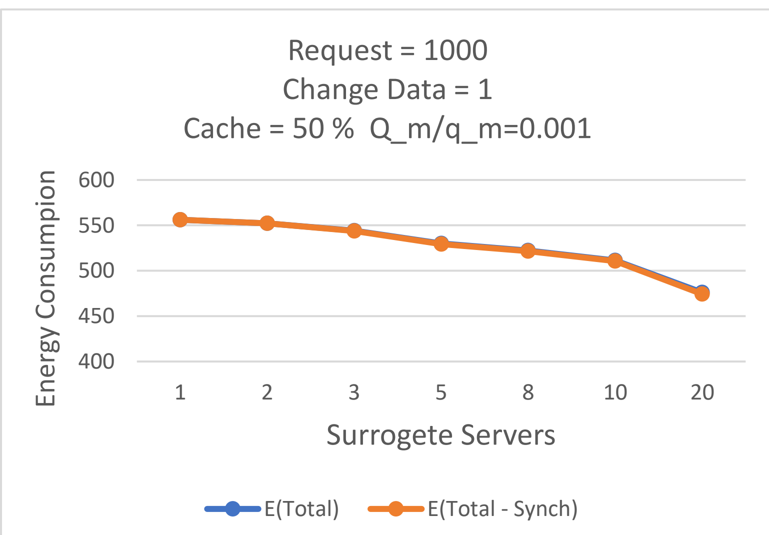


Figure 11: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 40% Q_m/q_m = 0.001

3.10.12 Twelve Consideration



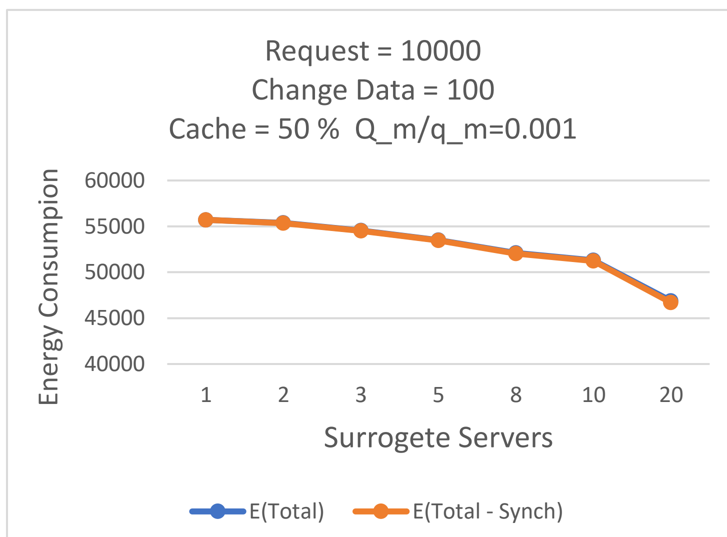


Figure 12: Total Energy Consumption with and without Synchronization Energy Consumption. Cache size 50% Q_m/q_m = 0.001

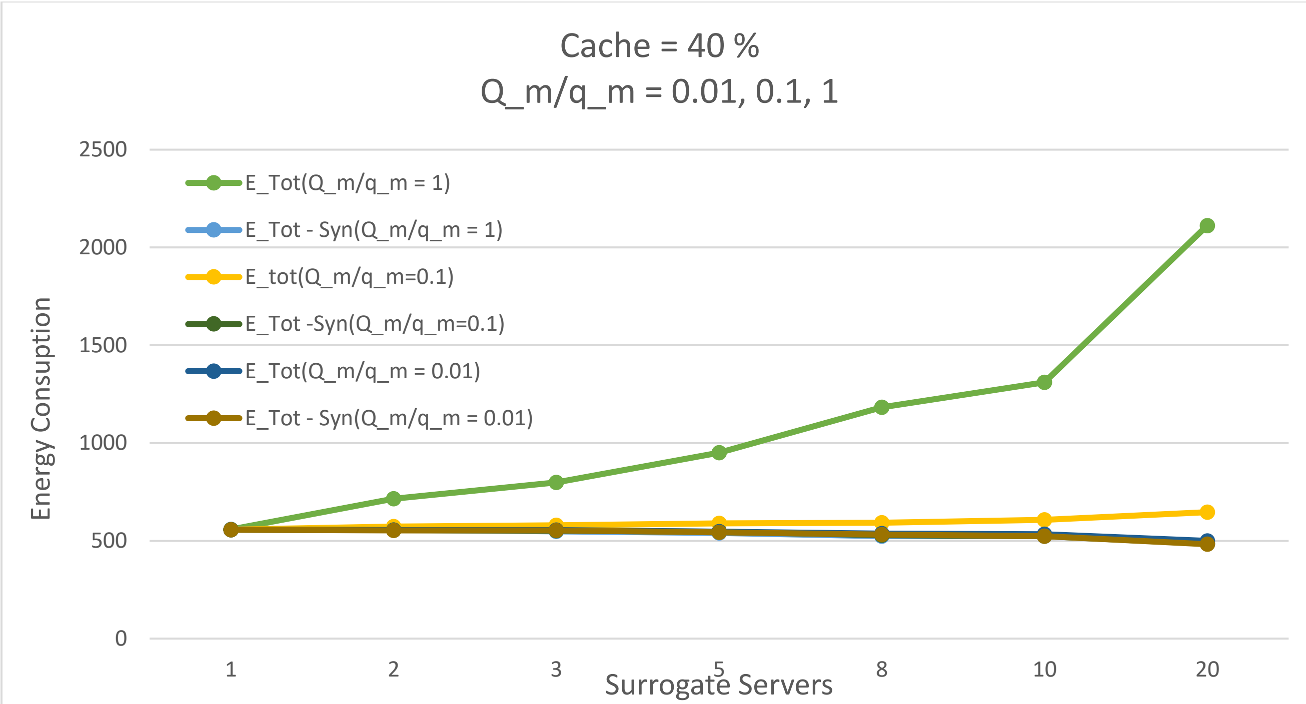


Figure 13: E_Tot with and without E_Tot-Syn. Different ratio between Q_m/q_m = 0.01, 0.1,1.

Figure 13: shows cache size 40 % of the total content size and in three different ratio cases (request to content and change to content), Q_m/q_m = 0.01, 0.1, 1. As it has seen clearly in the figure when the ratio Q_m/q_m = 0.01 Total energy consumption with and without synchronization energy consumption is decrease, when the number of surrogate servers increased. In other case when the ratio Q_m/q_m = 0.1 and Q_m/q_m = 1 the Total Energy Consumption start increasing, when we add surrogate servers. This is the effect of Synchronization Energy Consumption.

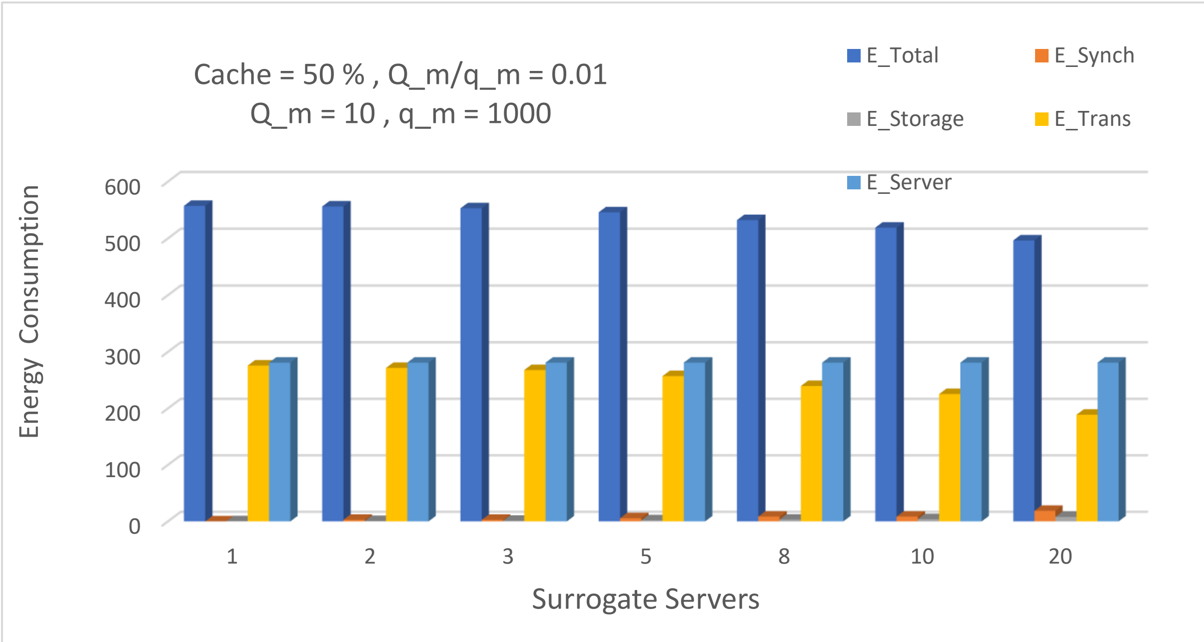


Figure 14: E_Total, E_Storage, E_Server, E_Synch, E_Trans Energy Consumption Q_m/q_m = 0.01

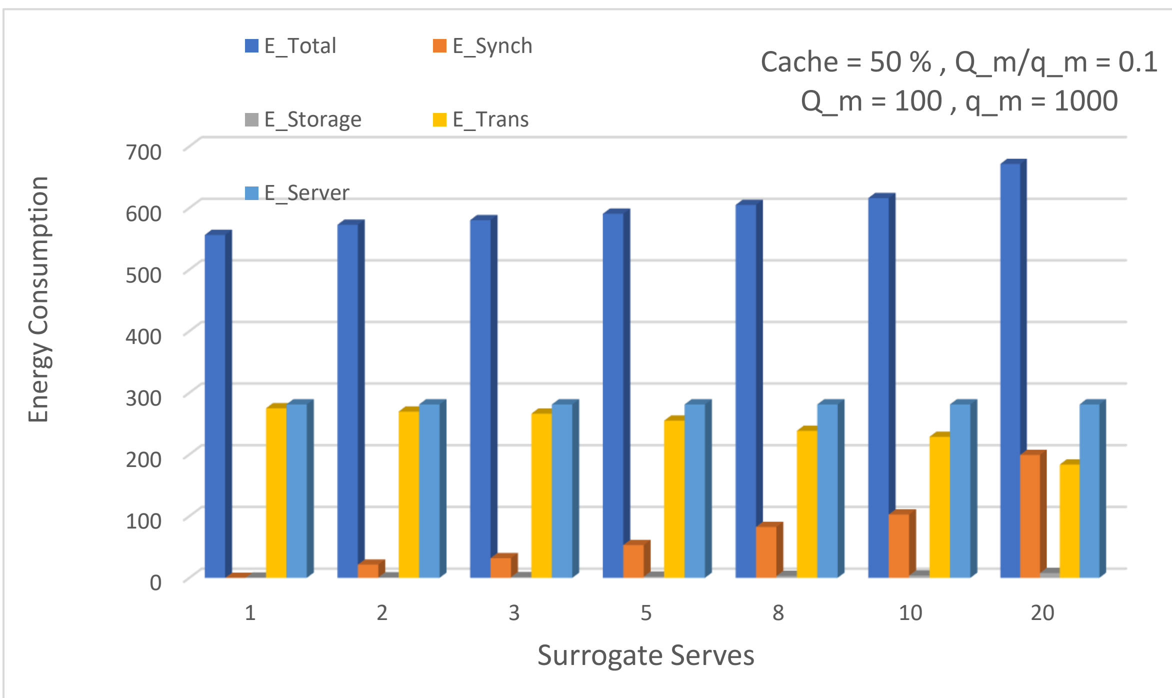


Figure 15: E_Total, E_Storage, E_Server, E_Synch, E_Trans Energy Consumption Q_m/q_m = 0.1

Figure 14 and 15 represent energy consumption of each element (Total Energy Consumption, Synchronization Energy Consumption, Storage Energy Consumption, Transition Energy Consumption and Server Energy consumption) in computation of Total Energy consumption. Storage energy consumption is very low because as an assumption total amount of data in system is assumed M = 1000 content pieces, each B = 10^{6} bits. And energy consumption of servers to store a single bit of data is equal to Pst =$7.84 * 10^{-12}$ which is low in comparison with other energy elements. It is also obvious that in case synchronization energy consumption reaches a threshold, relating to number of requests to each content piece, it affects total energy consumption.

In both figure 14 and 15 Server Energy consumption is the same, because Server Energy consumption only changed when request of the content changed. In figure 16 Synchronization Energy consumption is negligible but in case Q_m/q_m = 0.1 in figure 17 Synchronization energy consumption increase from 21 J to 200 J when we increase surrogate servers from 2 to 20.

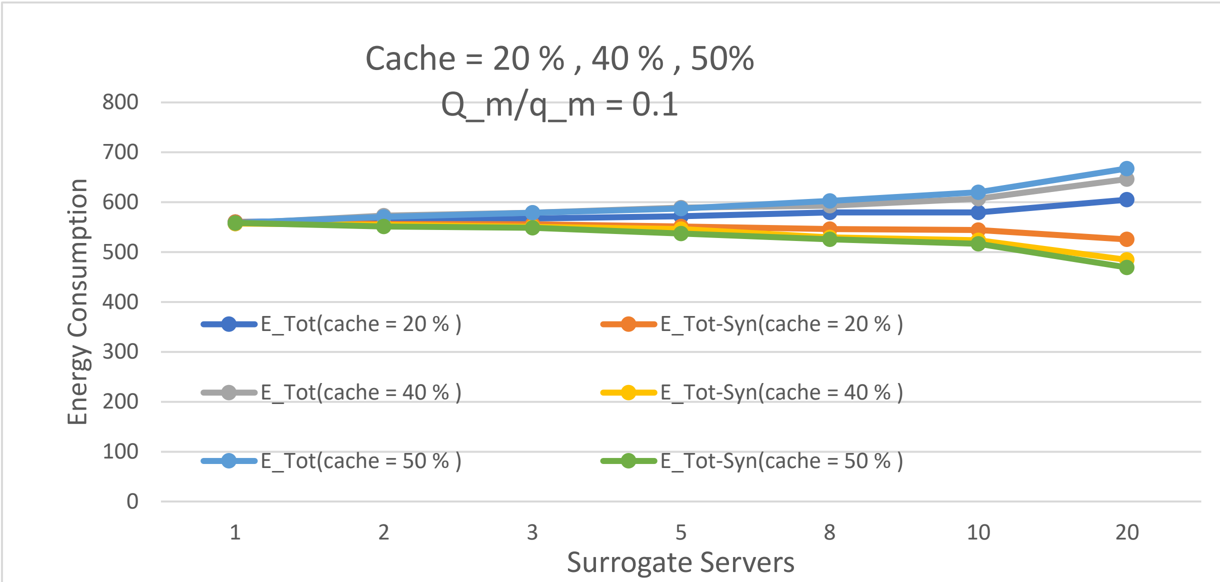


Figure 16: E_Tal with and without Synchronization. Different Cache size scenarios. Q_m/q_m = 0.1

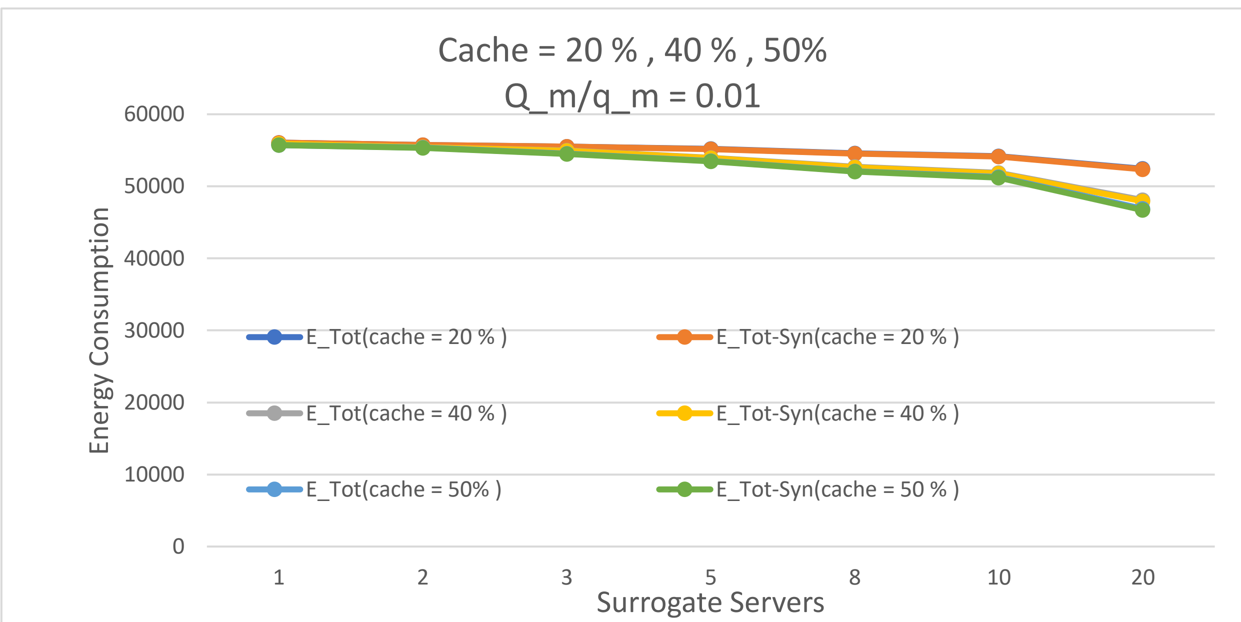


Figure 17: E_Tol with and without Synchronization. Different Cache size scenarios. Q_m/q_m = 0.01

Figure 16 and Figure 17 shows, the total Energy consumption with and without considering synchronization energy consumption in three different cache size scenarios (each surrogate store 20 %, 40 % or 50 % of the entire data). As it clearly seen in the figure the effect of the synchronization Energy is high.

3.11 Total Energy Consumption with and without Synchronization Energy consumption, Static Cache and Uniform Content Distribution.

	Q_m/q_m = 0.001		Q_m/q_m = 0.01		Q_m/q_m = 0.1	
Surrogate Servers	Tot Eng	Etot - syn	Tot Eng	Etot - syn	Tot Eng	Etot - syn
1	1	1	1	1	1	1
2	0.9874	0.987	0.994	0.9904	1.0222	0.99591
3	0.9781	0.97774	0.99	0.9849	1.044749	0.99426
5	0.97398	0.9732	0.97539	0.96749	1.04536	0.97288
8	0.9583	0.9562	0.9501	0.9394	1.0554	0.952658
10	0.931	0.9284	0.94912	0.9344	1.0842	0.942199
20	0.8822	0.87866	0.907	0.8779	1.15051	0.86385

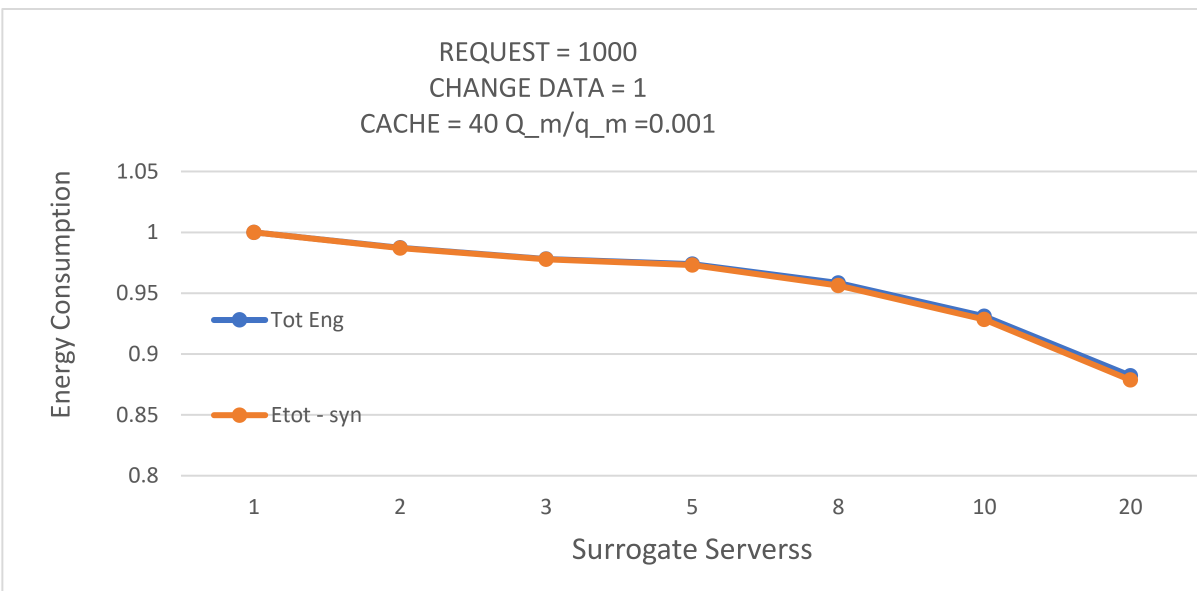


Figure 18: Total Energy Consumption with and without Synchronization, Static Caching, Uniform Content Request Distribution. When Q_m/q_m = 0.001

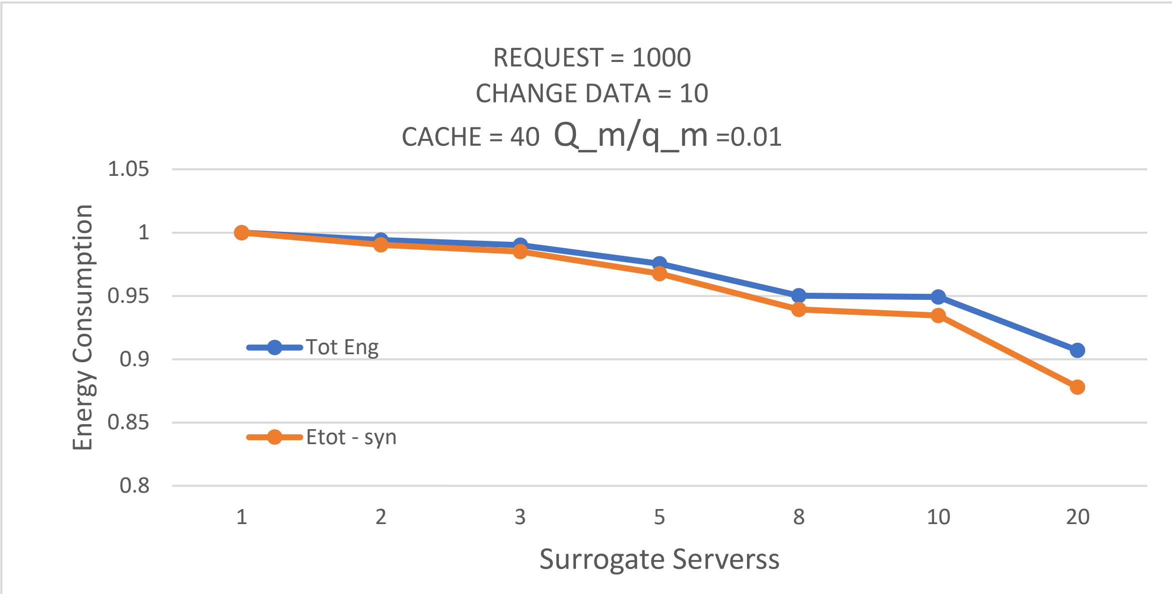


Figure 19: Total Energy Consumption with and without Synchronization, Static Caching, Uniform Content Request Distribution. When Q_m/q_m = 0.01

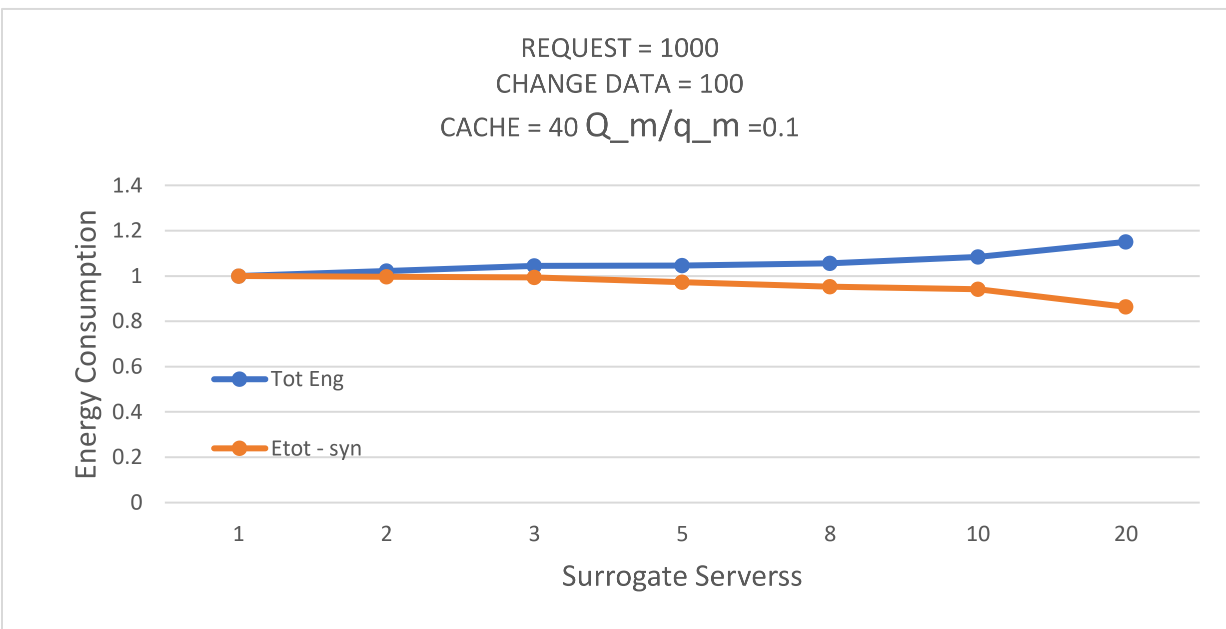


Figure 20: Total Energy Consumption with and without Synchronization, Static Caching, Uniform Content Request Distribution. When Q_m/q_m = 0.1

Figure 18, Figure 19 and Figure 20 shows, Total Energy consumption with and without synchronization Energy for Static cache policy and Uniform Content Distribution with Cache size 40 % of the total content. The Energy consumption always decreases when adding surrogate servers if we ignore synchronization energy. When the number of modifications for each content is increase, the synchronization Energy consumption will be getting larger. By increasing the ration Q_m/q_m (Content Modification over Content Request), the Synchronization Energy consumption also increase. This means Total Energy Consumption will increase when we add surrogate servers. Figure 18 and Figure 19 shows the total energy Consumption of CDN for ratio between number of content modifications (Q_m) and number of request (q_m) equal to 0.001 and 0.01. In those two cases, the total energy consumption with and without synchronization energy consumption decrease. But when the ratio Q_m/q_m increase to 0.1 and as we can see in above Figure 20, the increasing the surrogate server will increase the Total Energy consumption. In this case considering synchronization energy is very important.

3.12 Comparison among Caching Strategies

In this part, it compared the performance of Static, LRU and LU Cache Strategies by using Uniform and Zipf content distribution mechanisms. As it describes in chapter two, in Static Caching contents are first pushed to the surrogate servers and never replaced with other contents with in network life time. In LRU Caching Strategies, when the content missed in a surrogate server, the surrogate server fetches the missed content from the closest surrogate servers. The most popular contents are stored in each surrogate servers. In LU caching strategy the newly requested and missed contents in each surrogate servers replaces the content which requested the least number of times.

Below Figure 23, Figure 24 and Figure 25 shows the Total Energy Consumption with and without considering synchronization Energy consumption for Caching Strategies, Static, LRU and LU when requests arrival is Uniform and Zipf distribution.

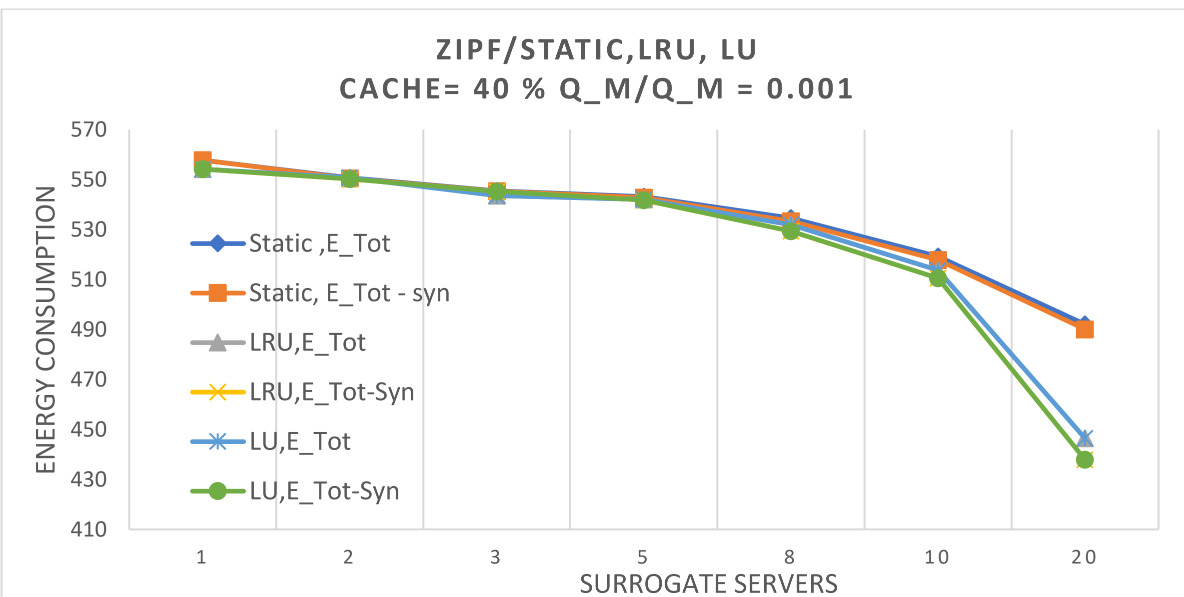


Figure 21: Total Energy Consumption with and without Synchronization, Static, LRU, LU Caching, Zipf and Uniform Content Request Distribution. When Q_m/q_m = 0.001

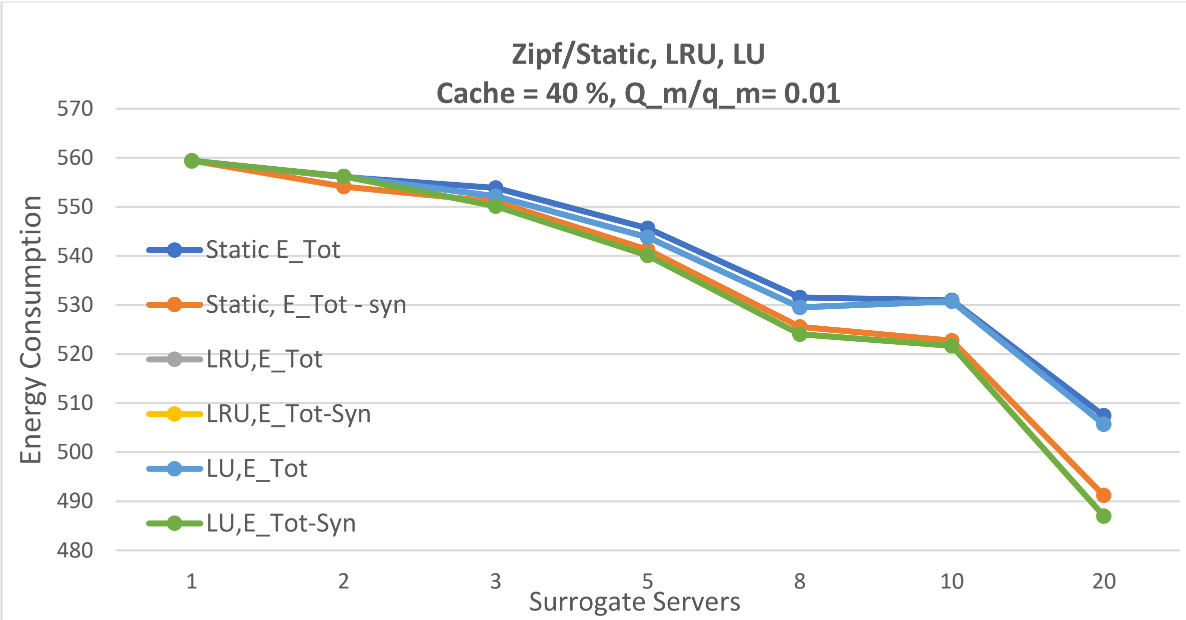


Figure 22: Total Energy Consumption with and without Synchronization, Static, LRU, LU Caching, Zipf and Uniform Content Request Distribution. When Q_m/q_m = 0.01

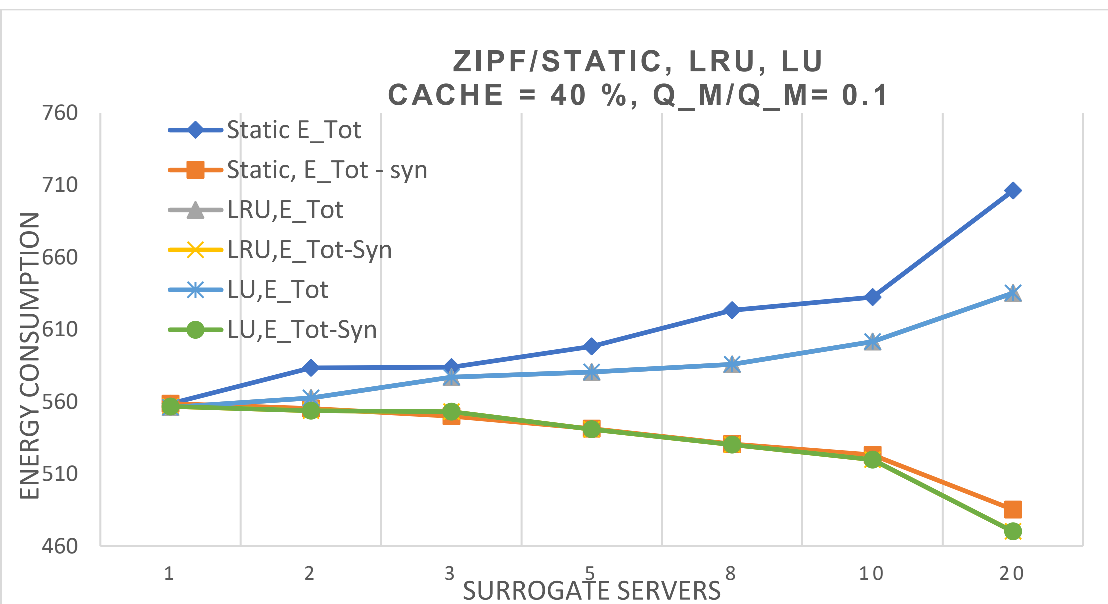


Figure 23: Total Energy Consumption with and without Synchronization, Static, LRU, LU Caching, Zipf and Uniform Content Request Distribution. When Q_m/q_m = 0.1

When the ratio of the number of modifications and the number of requests are between 0.001 and 0.01 as it seen in Figure 21 and Figure 22, total energy consumption with and without considering synchronization energy consumption is decrease, when the surrogate servers are increase. When the ratio reaches 0.1, as represented in Figure 23, the increasing of surrogate servers will also increase the synchronization energy consumption and the total energy consumption.

From Figure 21, 22 and 23 what we could learn is that, among the three caching strategies static caching consumes higher energy than LRU/LU caching policies. It is because of that, requests to contents arrive according to their popularity, the most popular contents are more likely to get requested.

LRU and LU caching strategies, replace the least popular contents with the most popular ones. Therefore, popular contents are usually housed in the surrogates and consequently they are closer to end users. This strategy decreases the transition energy consumption and consequently the total energy consumption with and without considering synchronization Energy consumption. Form the result what we understand is that, the difference between energy consumption of LRU and LU caching is very low. In general, the above three Figures concludes, LRU and LU caching, has better performance than static caching, when the number of servers are increased. This is because LRU and LU caching strategies implements popularity technique, which help the surrogate server to house the popular contents.

3. 13 GRAPHS AND RESULTS EXPLANATION

According to the Tables Results and the Graphs it is concluded that, without considering Synchronization Energy Consumption, the Total Energy Consumption decreases by adding Surrogate Servers, but this is not true always when we consider Synchronization Energy Consumption. Graphs show that by increasing the number of new content (change for content) the Total Energy Consumption increase while number of surrogate servers are increased. Because for each new data or modification Synchronization is needed which increase the Synchronization Energy consumption and as the result Total Energy consumption also increase.

Graph and results also elaborate the impact of number of Requests to each content on the Total Energy Consumption. By increasing the number of Requests to each content Transmission Energy Consumption and Server Energy Consumption increases. Increasing the number of change content also increase the Total Synchronization Energy consumption.

In addition, the table and the graph shows, cache strategy and request distribution technique has big impact on Total Energy consumption of content distribution network. Even if a good cache strategy has a trade-off in terms of memory usage and transition delay, in general it has a significant energy saving capability.

CONCLUSION

In this Thesis First, it was tried to consider a realistic model (Hierarchical Internet representation) for the Internet, previous works were mostly simulations on a Random Graph. In this work the three Tier network was used in which End user were connected to Tier 3 ISPs and Tier 3 ISPs were connected to Tier 2 ISPs which were connected finally with Tier one.

Second, Synchronization Energy Consumption is mentioned as a part of Total Energy Consumption and computed the way, when a new content is available or changed. Which has a significant impact on total energy consumption of the Content Delivery Network. Despite it is thought that adding surrogate server decreases the total energy consumption, it may even increase when the ratio between the number of request and the number of changed data in time period is more than a threshold. The results show that, on the ratio between the rate with which contents are modified over the request arrival rate, the total energy consumption does not decrease by adding more surrogate servers. If this ratio overcomes a given threshold (Q_m/q_m >= 0.1), the total energy consumption of the network increases with the number of surrogate servers. This is due to the increase in the synchronization energy consumption.

Third, the performance of three different caching strategies are compared, namely Static, LRU and LU. Then analyzed the impact of those cache strategies on content delivery Network. From the three-cache strategies, Static cache techniques is the simplest one and consumes larger energy than LRU and LU. This is because, LRU and LU cache strategy implement popularity techniques. Therefore, surrogate servers housed popular contents which is closes to end users. This popularity technique decreases the Transition Energy Consumption and the Total Energy Consumption.

In conclusion, the Total Energy Consumption in content delivery network is not always decreased by adding surrogate servers, it strongly depends on the ratio between the number of request and content modification.

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