2014 14th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing

Energy Consumption of Photo Sharing in Online Social Networks

Fatemeh Jalali, Chrispin Gray, Arun Vishwanath, Robert Ayre, Tansu Alpcan, Kerry Hinton, Rodney S. Tucker
Centre for Energy-Efficient Telecommunications (CEET), University of Melbourne
{jalalif, cgray, arun.vishwanath, rayre, tansu.alpcan, k.hinton, r.tucker}@unimelb.edu.au

***Abstract*—Online social networks (OSNs) with their huge number of active users consume significant amount energy both in the data centers and in the transport network. Existing studies focus mainly on the energy consumption in the data centers and do not take into account the energy consumption during the transport of data between end-users and data centers. To indicate the amount of the neglected energy, this paper provides a comprehensive framework and a set of measurements for understanding the energy consumption of cloud applications such as photo sharing in social networks. A new energy model is developed to estimate the energy consumption of cloud applications and applied to sharing photos on Facebook, as an example. Our results indicate that the energy consumption involved in the network and end-user devices for photo sharing is approximately equal to 60% of the energy consumption of all Facebook data centers. Therefore, achieving an energy-efficient cloud service requires energy efficiency improvement in the transport network and end-user devices along with the related data centers.**

***Index Terms*—Energy consumption; Online social networks; Photo sharing; Cloud computing; Measurement;**

I. INTRODUCTION

Cloud computing moves data processing and storage away from end-user devices into data centers [1], [2], and underpins many online social networks (OSNs) such as Facebook, Twitter and LinkedIn. The ubiquity of broadband and wireless networking provides users with instant connection to their social networks via their PCs or handheld devices.

These cloud services generate considerable amount of traffic and could change the Internet traffic landscape [3]. Associated with this increasing traffic is an increase in energy consumption for transporting, processing, and storing data. Since the data in cloud services is processed and stored in data centers, an obvious focus for studying energy consumption of cloud services is the data centers. Cloud provider companies are continually striving to keep their data centers energy-efficient [4]-[6]. However, the energy consumption of a cloud service includes three components: energy consumption of the data centers, energy consumption of the transport network that connects the users to the cloud, and the energy incurred by end-user devices when accessing the cloud [2], [7]. Energy consumption of the transport network and end-user devices have been ignored in most studies of energy consumption in cloud based applications and services [8], [9].

Among cloud based services social networking, and in particular photo sharing services, have become extremely popular and are generating significant network traffic volume. In this paper, we study the energy consumption of a photo sharing service in an OSN. We choose Facebook as a representative photo sharing ONS service to analyze, acknowledging that Facebook is more than just a photo sharing service, and that it is becoming the biggest photo sharing website in the world [10]. Facebook currently hosts more than 240 billion photos, and users upload more than 350 million photos every day [11]. We analyze the energy consumption of end-user devices and the transport network when uploading and downloading[1] photos to and from Facebook.

The work in this paper builds upon our earlier work in [7], but differs in two significant ways: we propose new energy models for shared and unshared network elements, and apply the energy models to a non-interactive cloud computing application which is photo sharing in an OSN. In this context, the contributions of this paper are: (a) a new energy model for shared network elements in the transport network is proposed; (b) an energy model for end-user terminals (such as a tablet) while accessing cloud applications is developed; (c) network structure and behavior of photo sharing in OSNs are studies (using Facebook as an example); (d) we obtain a realistic energy consumption estimate of photo sharing in OSNs by power consumption measurement and traffic measurement of end-user terminals.

We estimate the total energy consumption for uploading and downloading photos on Facbook in one year to be about 304 Gigawatt hour(GWh). By comparison, according to Facebook [12], it consumed about 500 GWh of energy in 2012 for the IT facilities in its data centers [12]. Therefore, the energy consumption of the transport network and end-user devices for photo sharing is equivalent to approximately 60% of the total energy consumption of the Facebook data centers including all services such as photo and video sharing, game, chat and many more.

We conclude that the energy consumption of cloud services in the transport network and end-users devices is considerable and should not be ignored when studying the energy consumption of cloud computing services.

The rest of this paper is organized as follows. We describe photo sharing in a social network in §II. The energy models for photo sharing are presented in §III. In §IV , we report relevant traffic measurements. The energy consumption of end-user devices, access network, and edge (and core) network is studied in §V, §VI and §VII , respectively. The energy consumption of Facebook photo sharing over one year is considered in §VIII. Finally, the paper is concluded in §IX.

---

[1] We use *download photos* and *view photos* interchangeably in this paper.

978-1-4799-2784-5/14 $31.00 © 2014 IEEE
DOI 10.1109/CCGrid.2014.68

IEEE computer society

II. Photo Sharing In a Social Network

In social networks, new uploaded photos are often more popular than older photos. The term *Hot* is used by Facebook to describe the status of these popular photos [11]. The popularity of the photos typically decreases after a while (the status of the photos changes to *Warm*). After a few days or weeks, there are generally few downloads (the status of the photos changes to *Cold*) [11]. Figure 1 shows the percentage of user requests for Facebook photos and the volume of photos stored over time [11]. It can be observed that the majority of user requests are for Hot photos. For example, approximately 82% of requests are for 8% of photos that are new to the system. 13% of photo requests are for Warm photos and 5% of requests are for Cold photos [11].

Facebook mostly relies on a content delivery network (CDN) for sharing and distributing Hot and Warm photos (e.g Akamai) [13], [14]. Cold photos are directly served from the Haystack cache (a CDN within Facebooks data center [10]) and are not distributed by the external CDN.

In the next sub-sections, a network model for uploading and downloading photos to and from Facebook is described.

A. Uploading photos

The uploaded photos are transmitted to the data center closest to the user. Figure 2 shows a high-level view of the Facebook network and its connectivity to users. There are a few Facebook data centers which are connected to the core of the Internet.

When a user uploads a photo, the data traverses an access network which might be an ADSL, Ethernet, WiFi, 3G or 4G connection, or a combination of these. Then, the data passes through an edge (metro) network which generally consists of a metro Ethernet switch, broadband network gateways (BNGs) and edge routers [2], [7]. Subsequently, the data traverses the core network comprising large core routers and optical links. The final destination for storing photos is a physical disk drive within a data center. The data center network includes one or a few edge routers, aggregation switches and application servers and storage servers.

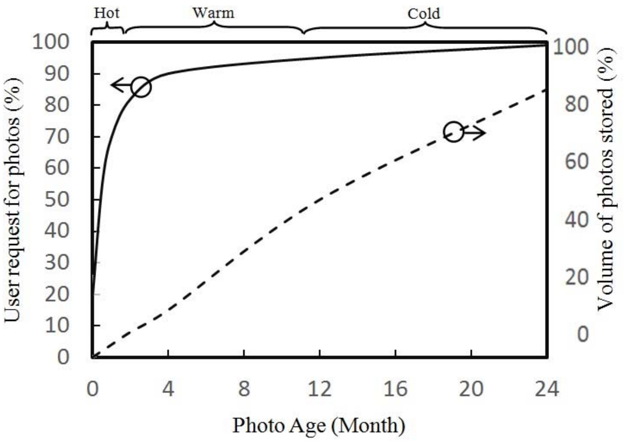


Fig. 1: Access patterns to photos on Facebook, source: [11]

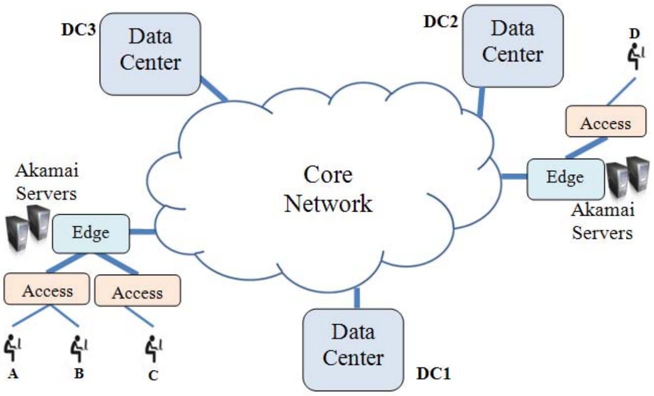


Fig. 2: Network model of an online social network

B. Downloading photos

When a user views a photo, the user's browser first sends a request to a web server to find where to download the photo from [10]: a CDN (Akamai) server or a server within the Facebook data center. For Hot and Warm photos, the browser is directed to Akamai servers. Access to Cold photos is directly from the Facebook data center without passing through the Akamai network [10]. Figure 2 indicates Akamai servers in the edge of the network collocated with other ISP equipment. Distribution of photos by Facebook is based on the location of friends who are interested in the photos.

When user A in Figure 2 wants to share a photo on Facebook, the photo is sent to a Facebook data center (DC1). Then, all friends (user B, C and D) can see the shared photo. When friends request the photo, DC1 sends the photo to Akamai intermediate nodes [15] and then after a few hops it goes to an Akamai server at the edge of the network which is very close to the users. Local friends such as users B and C who are connected to the same edge network can see the photo from the edge of the network. In contrast, when User D requests the photo, another route is used from Akamai servers in the core of the network to a server at the edge of the network near user D to respond to the request.

III. Energy Consumption Models

In this section, we describe models for energy consumption in network elements. The models will be used to estimate the incremental energy consumption of a cloud service (such as Facebook) traffic flow through the transport network connecting the user and the data centers. We mean energy consumption arising from the additional power consumed by the use of the application/service (i.e. photo sharing) where the user will unavoidably already be using the device or network. For example, a gateway (without sleep mode) that is kept on 24/7 for reasons unrelated to using the application/service of interest will incur the idle power irrespective of the application/service. In this case we want estimate of energy consumption not to be biased or influenced by any other background activity that could also be taking place. For example, network connection maintenance, other applications or services operating simultaneously with and independent from the photo sharing activity.

We divide network elements into two types: 1) elements that are dedicated to a single user (or few users) and 2) elements that are shared by many users. We examine the energy consumption (energy-per-bit) of each type separately.

The incremental energy (E_{inc}) due to the introduction of an additional traffic flow with throughput, $\Delta C(t)$ (bit/sec), from time t_1 to t_2, added to an element or network with existing throughput C (bit/sec) can be expressed as:

$$\begin{aligned} E_{\text{inc}} &= \int_{t_1}^{t_2} P(C+\Delta C(t)) - P(C)\mathrm{d}t = \int_{t_1}^{t_2} \Delta P(t)\mathrm{d}t \\ &= \frac{\partial P(C)}{\partial C}\int_{t_1}^{t_2} \Delta C(t)\mathrm{d}t = \frac{\partial P(C)}{\partial C} N_{\text{bit}} = E_{\text{b}}(C)N_{\text{bit}} \qquad (1) \end{aligned}$$

where $E_{\text{b}}(C)$ is the energy-per-bit for the network element with throughput C and N_{bit} is the number of transmitted bits. In this we require $\Delta P << P(C)$. To apply this form, we need to derive the form of $E_{\text{b}}(C)$ for the given element or elements.

A. Incremental energy consumption model for single user network elements

A single user network element such as a home modem is typically shared by a small number of users. The network elements consume some power even when there is no traffic load. This idle power consumption, P_{idle}, can be a large fraction of the maximum power consumption, P_{max}, of the device ($P_{idle} = 60\% - 95\%$ of P_{max}) [2], [7], [16]. Furthermore, the power consumption of the device increases when the load increases. The power consumption of each network device typically follows a linear trend [2], [7], shown schematically in Figure 3. This linear trend is validated by experimental results published in [17]. For the devices located in end-user premises, we consider the idle power, P_{idle}, to be power consumed irrespective of the service. (It is required to maintain network connectivity and provide background services.) Therefore the incremental energy associated with a user device for photo sharing is

$$E_{\text{inc-ter}} = \int_{t_1}^{t_2} (P(t) - P_{\text{idle}})\mathrm{d}t = \frac{P_{\text{max}} - P_{\text{idle}}}{C_{\text{max}}} N_{\text{bit}} = E_{\text{b-ter}} N_{\text{bit}} \qquad (2)$$

In this $P(t)$ is the power consumption of the device from time t_1 to time t_2 which are the start and end times of the upload or download transaction and $E_{\text{b-ter}}$ is the incremental energy-per-bit for the customer terminal equipment and C_{max} is the maximum throughput capacity of the equipment.

B. Incremental energy consumption model for shared network elements

We now estimate the incremental energy consumption of shared network elements in the transport networks. With cloud services expected to grow rapidly, operators need to scale-up their existing network capacity (by deploying additional equipment) to cope with the increasing traffic demand.

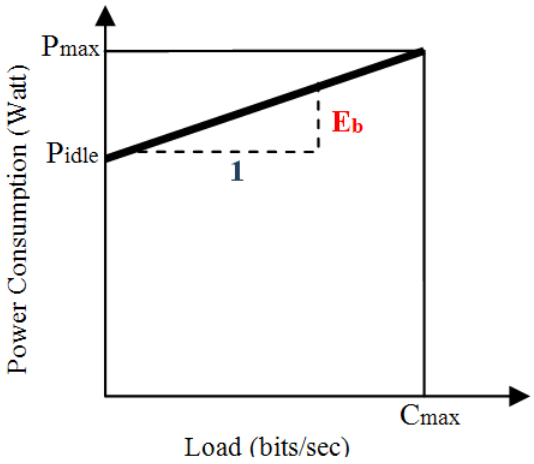


Fig. 3: Power consumption trend in network equipment

The power consumption of the network is the cumulative consumption of the shared elements that comprise the network. As more equipment is added to the network nodes accommodate demand the total network power consumption can be represented by the “staircase” curve as shown in Figure 4 Each “step” in the figure corresponds to a network upgrade event, where the operator progressively adds equipment to increase capacity when the average long-term load, in the various elements, exceeds a certain operating load threshold (typically, $\rho < 50\%$ of the maximum load). We consider a network comprising of n network elements with $n >> 1$. Let $< P_{\text{idle}} >$ be the mean idle power over all the network elements. That is:

$$< P_{\text{idle}} > = \frac{1}{n}\sum_{j=1}^{n} P_{\text{idle,j}}$$

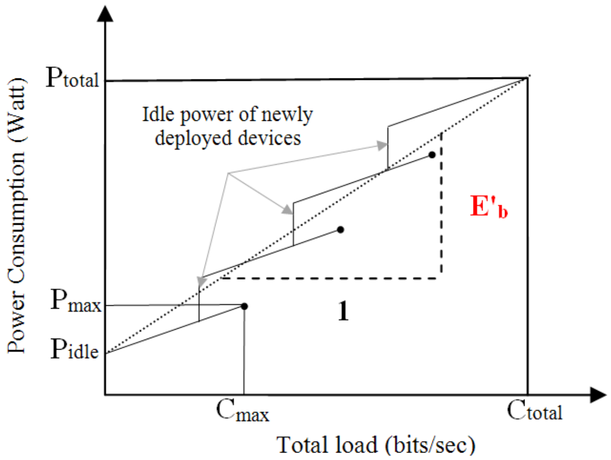


Fig. 4: Power consumption trend under large-scale equipment deployment

where, $P_{\text{idle,j}}$ is the idle power of the j-th network element. Similarly, we define the mean network element maximum power, $< P_{\max} >$, and mean network element maximum capacity, $< C_{\max} >$. Also, we define the mean incremental energy per bit as

$$< E_{\text{b}} > = \frac{< P_{\max} > - < P_{\text{idle}} >}{< C_{\max} >}$$

With these definitions, the total power consumption of the network with $n >> 1$ network elements is:

$$P_{\text{total}} = n(< P_{\text{idle}} > + \rho E_{\text{b}} < C_{\max} >)$$

where, ρ is the utilization threshold of the network elements for adding new equipment. The average incremental energy-per-bit ($E_{\text{b}}^{'}$) for $n >> 1$ network elements (base stations, edge and core devices, servers, etc.) is given by

$$E_{\text{b}}^{'} = \frac{P_{\text{total}} - < P_{\text{idle}} >}{C_{\text{total}}} \approx \frac{(\frac{1}{\rho} - 1) < P_{\text{idle}} > + < P_{\max} >}{< C_{\max} >} \quad (3)$$

where, C_{total} is the capacity of the network elements.

C. Incremental energy consumption model of cloud services

The incremental energy consumption of a cloud-based service ($E_{\text{inc-cloud}}$) in the end-user devices and transport network can be determined as follow:

$$E_{\text{inc-cloud}} = E_{\text{b-ter}} N_{\text{bit}} + N_{\text{bit}} (E_{\text{b-access}}^{'} + E_{\text{b-edge}}^{'} h_{\text{e}} + E_{\text{b-core}}^{'} h_{\text{c}}) \quad (4)$$

where, $E_{\text{b-ter}}$ is the incremental energy-per-bit of the end-user terminals. $E_{\text{b-access}}^{'}$, $E_{\text{b-edge}}^{'}$ and $E_{\text{b-core}}^{'}$ are the incremental energy-per-bit of the equipment in the access, edge and core networks which are shared and the values are calculated using (3). h_{e} and h_{c} are the number of edge and core routers traversed. N_{bit} is the number of transmitted and received bits when interacting with a cloud service [2], [7].

IV. TRAFFIC MEASUREMENT

In order to examine the number of transmitted and received bits (N_{bit}) when sharing a photo on an OSN, we measured the volume of traffic generated for uploading a photo to Facebook and then downloading the same photo from Facebook. To do this, we used a packet analyzer software utility (Wireshark [18], running on the end-user device) to capture all packets exchanged between the browser (Google Chrome) and Facebook.

Photos of different sizes ranging from 1 MB to 10 MB were uploaded to Facebook with normal resolution. Figure 5 shows the number of bytes exchanged during uploading and downloading photos versus the size of original photos. The upload curve indicates the traffic volume exchanged during uploading is very much smaller than the original size of the photos. Based on our measurements, we deduced that Facebook compresses photos heavily in user browsers before sending them to Facebook servers. Photos are compressed to 960 × 640 pixels for normal quality and 2048 × 1536 pixels for high quality. However, Facebook does not compress small photos with fewer pixels than the above mentioned thresholds. In addition, Figure 5 shows the uploading traffic of this cloud service is higher than the downloading traffic.

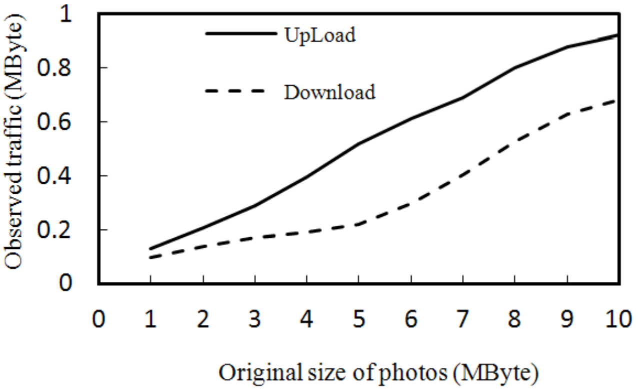


Fig. 5: Observed traffic during uploading and downloading various sized photos to and from Facebook versus the original sizes of photos

We noted from the Wireshark logs that uploading (downloading) a photo is sent (or received) as 1314 Byte TCP packets to (or from) the servers followed by ACK packets from the servers (or end-user devices). Both data and ACK packets are included in the traffic count.

The observed traffic for uploading a 5-MB photo in normal quality using a laptop with WiFi and Ethernet technology is about 500 KB. We also uploaded the same photo using a smartphone with WiFi and 4G technologies. The observed traffic was about 1.1 MB.

The download curve also shows that the uploaded photos on Facebook are compressed since the observed traffic during downloading photos is smaller than the original size of photos. The observed traffic for downloading the uploaded photo (5-MB photo) using a laptop with WiFi and Ethernet technology is 200 KB.

The observed traffic when using the Facebook mobile application on a smart-phone (WiFi and 4G) was 120 KB.

Considering the fact that Facebook is not a Storage-as-a-Service [2] service, photo compression is a very effective solution for saving bandwidth, increasing the upload speed and avoiding high traffic in the network.

V. ENERGY USAGE OF END-USER DEVICES

In a global context, we need to consider all contributions to energy consumption. Therefore, we do include the energy consumption of the end-user devices. In order to estimate the incremental energy consumption of end-user devices when interacting with an OSN, we consider the energy consumption of a low power laptop and a smart-phone.

The laptop used in these experiments is a Sony VAIO Duo 11 running Windows 8 [19], chosen as representative of a modern low energy laptop computer. We used a PowerMate power meter (resolution of 10 mW) [20] and measured the

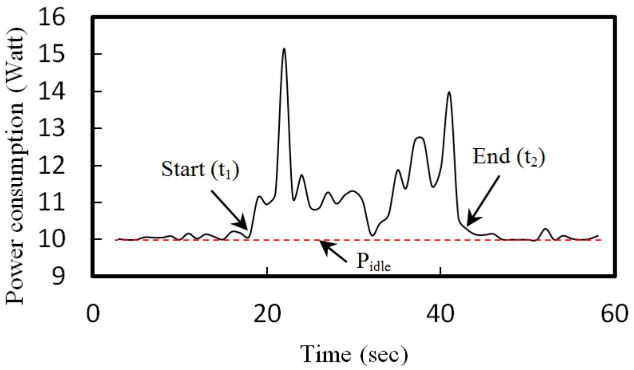


Fig. 6: Power consumption of a laptop while uploading a photo to Facebook

	Laptop		**Mobile phone**	
	Ethernet	WiFi	4G	WiFi
Upload	106 J	114 J	40 J	23 J
Download	23 J	33 J	18 J	8 J

TABLE I: Energy consumption of end-user devices for sharing a photo (with original size of 5MB) in a social network

power consumption of the laptop when interacting with the cloud by Ethernet and WiFi connections. Figure 6 shows the power consumption of the laptop versus time during uploading a 5-MB photo in normal quality. The power consumption of the laptop when connected to Facebook via wired Ethernet, but in an idle state is 10 Watt (W).

From (2), the incremental energy consumption for uploading a 5 MB photo is 106 J. In addition, the energy consumption for a WiFi connection is 114 J.

The same measurement and calculation methods are used to calculate the energy for downloading photos by the laptop. The results are listed in Table I.

Increasingly, end-users are turning to mobile devices and wireless access networks, rather than PCs/laptop computers and wired connections. Currently, more than half of the users access Facebook via mobile devices [21], the incremental energy for uploading a photo using a smart-phone is obtained by a mobile phone application named *PowerTutor* [22], [23]. The energy consumed by a smartphone with WiFi and 4G technologies for uploading 1.1 MB are measured to be 23 J and 40 J, respectively.

For viewing the uploaded photo by the smart-phone, the incremental energy by WiFi and 4G for downloading the photo (file size 120KB) are 8J and 18J, respectively. All results are summarized in Table I.

VI. ENERGY CONSUMPTION OF ACCESS NETWORK EQUIPMENT

Access network equipment includes customer premises equipment (CPE) , and shared equipment at the network edge. CPE would include an Ethernet gateway, DSL modem, optical fiber network unit, etc while the network edge might include a large Ethernet Switch, an LTE base station, an optical line terminal (OLT), etc. Table II lists the energy-per-bit for access network equipment when receiving data from the users (uplink) and transmitting data to the users (downlink). The data for gateways is gathered from [24] and the energy-per-bit is calculated based on (2) (because they are not shared). The idle power, maximum power and maximum capacity of a typical Ethernet switch is gathered from [7] and the energy-per-bit is obtained according to (3) assuming a typical utilization of 20% (because they are shared). Finally, to determine the energy-per-bit for LTE base stations, we observe from [25] that the idle and maximum power consumption of a 3-sector 2x2 MIMO 4G/LTE base station deploy in an urban area are 528W and 333W, respectively. In addition, 4G/LTE base stations consume more energy in the downlink direction which is 87% of the total energy consumption according to [25]. The aggregate throughput of this base station is 72 Mbps with 20 MHz spectrum [26]. The average energy-per-bit of this base station is 76.2 μJ/bit in the downlink and 19 μJ/bit in the uplink assuming a typical utilization of 5% over a 24-hour cycle. Should be noted that overall, 4G/LTE as an access technology is much less efficient than the others considered.

The uplink column (the last column in Table II) is used for calculating incremental energy consumption while uploading a photo and the downlink column is used for downloading a photo.

Based on the values in Section IV, the traffic for uploading a 5-MB photo by a laptop via Ethernet and WiFi is 500 KB. Hence, the incremental energy consumption of Ethernet and WiFi equipment for uploading this photo is 0.2 J and 0.5 J, respectively. For uploading the same photo by a smart-phone via WiFi and 4G, for which the observed traffic is 1.1 MB, the incremental energy is 1.2 J and 670 J, respectively. Similar calculations have been done for downloading the photo. These results are outlined in Table III.

	Power (Watt)		Capacity (Mbps)		Energy (nJ/bit)	
	Idle	**Max**	**Downlink**	**Uplink**	**Downlink**	**Uplink**
Ethernet Gateway (CPE)	2.8	4.6	100	100	18	18
ADSL2+ Gateway (CPE)	4.1	6.7	24	3.5	108	866
Ethernet Switch (Network edge)	1,589	1,766	256,000	256,000	31.7	31.7
LTE Base Station (Network edge)	333	528	72	12	76,200	19,000

TABLE II: Energy-per-bit of equipment in access network

VII. ENERGY CONSUMPTION OF EDGE AND CORE NETWORK EQUIPMENT

The maximum energy consumption, maximum capacity and the incremental energy-per-bit ($E_b^{'}$) of the network equipment in the edge (metro) and core networks are listed in Table IV. Although we do not know what equipment is used in ISP networks, those listed in the table are representatives of reality. The maximum energy consumption and maximum capacity are gathered from Cisco's power consumption calculator [27]. The values of $E_b^{'}$ are calculated based on (3). We used the value of 20% for ρ.

By using *traceroute* from end-user device to the Facebook servers, we estimate that on average five core routers and three edge routers are along the path between the users and the servers.

Bringing together the results above for the incremental energy-per-bit ($E_b^{'}$) and the traffic measurements for uploading the photo, the incremental energy of edge and core equipment for uploading the photo when using a laptop (with WiFi and Ethernet) is determined to be 0.8 J. The incremental energy when using a mobile phone (with WiFi and 4G) is about 1.8 J. These results are summarized in Table V.

For downloading the photo from a server within a data center, the traffic comes from the data center to core routers, edge router, BNGs, Ethernet switch and access network, in turn. Therefore, the incremental energy consumption of all of this equipment should be considered. The incremental energy for edge and core network is obtained from the numbers in Table IV and the measured traffic from Section IV. The incremental energy of equipment in the edge and core networks during downloading the photo (the observed traffic is 200KB) is estimated to be 0.3 J. When the observed traffic is 120KB, the incremental energy is estimated to be 0.2 J. These results are shown in the second row of Table V.

According to [14], the majority of friends using an OSN are relatively closely located geographically so we can assume that half of the friends of a Facebook user are in a local area. For local users in the same geographic region, the photo can be cached to an Akamai server once and then other friends download it from the edge network. Hence, there will be only a few core and edge router hops. The incremental energy consumption in the core and edge networks for downloading one photo for a local friend is summarized in the third row of Table V.

By using Akamai servers in the edge network, the number of hops in core routers and edge routers decreases and energy can be saved. However, the energy consumption of a server in the edge network is added. The maximum power consumption and maximum capacity of a typical content server are gathered from [2] and reported to be 225 W and 800 Mbps, respectively. The idle power consumption of this server is typically 80% of the maximum power consumption, therefore the incremental energy-per-bit, based on (3), is 1.0 μJ/bit. Then, the power consumption of a server when traffic is 200 KB (the traffic comes from a Laptop) is 1.7 J and when traffic is 120 KB (the traffic comes from a mobile phone) is 1 J. The results are presented in the last row of Table V.

	Access via a laptop		Access via a phone	
	Ethernet	**WiFi**	**4G**	**WiFi**
Upload	0.2 J	0.5 J	670 J	1.2 J
Download	0.08 J	1.4 J	18.2 J	0.8 J

TABLE III: Energy consumption of equipment in access network for sharing a photo in a social network

Type	**Max power** (Watt)	**Max capacity** (Gbps)	$E_b^{'}$ (nJ/bit)
BNG	1890	320	27
Edge router	4550	560	37
Core router	12300	4480	12.6
Server	0.8	225	1037

TABLE IV: Energy-per-bit of equipment in edge and core networks

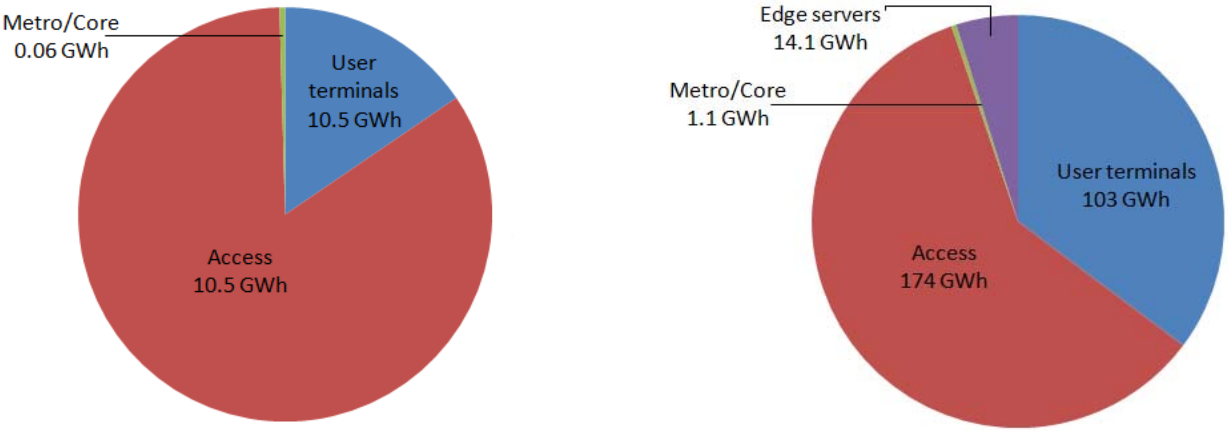
VIII. PHOTO SHARING ENERGY CONSUMPTION OVER ONE YEAR

We have estimated the total incremental energy consumption for uploading and downloading one average sized photo to and from Facebook including the end-user devices and transport network. The energy consumed for uploading and downloading the photo is 355 J (0.1 Wh) and 100 J (0.03 Wh), respectively. We now use these results to estimate the energy consumption of photo sharing in one year and compare this value to the total energy consumed fot IT facilities in entire Facebook data centers in one year which is 500 GWh [12].

Users upload more than 350 million photos to Facebook every day and all the uploaded photos can be downloaded by the users friends. Each Facebook user has 140 friends on average [28] and we have assumed that 90% of the friends (126 people) view the new uploaded photos. In addition, about 68% of Facebook users are mobile users (751 million of the 1.1 billion) [21]. Since 35% of mobile traffic is WiFi traffic and 65% is cellular traffic [29], we infer 24% (0.68×0.35) of the users are connected to Facebook by WiFi and 44% (0.68×0.65) of users are connected by 4G. Additionally, we set the number of users connect to Facebook by Ethernet with a low power device such as laptops/ultrabooks is the same as the number of users by WiFi with laptops/ ultrabooks [29],

	Core & edge via a laptop		Core & edge via a phone	
	Ethernet	**WiFi**	**4G**	**WiFi**
Upload	0.8 J	0.8 J	1.8 J	1.8 J
Download from data center	0.3 J	0.3 J	0.2 J	0.2 J
Download from edge network	0.2 J	0.2 J	0.1 J	0.1 J
Server in edge network	1.7 J	1.7 J	1 J	1 J

TABLE V: Energy consumption of equipment in core and edge networks for sharing a photo in a social network



(a) Upload energy consumption (GWh)

(b) Download energy consumption (GWh)

Fig. 7: Annual energy consumption of photo sharing on Facebook

[30]. Therefore, 16% is assumed for laptop users by Ethernet and 16% for laptop users by WiFi.

Using these data, we estimate the total incremental energy consumption for uploading photos to Facebook in one year to be 12.5 GWh. The energy consumed in end-users devices, access network and edge (and core) network is estimated to be 2 GWh, 10.5 GWh and 0.06 GWh, respectively (as shown in Figure 7a).

Based on the data presented above, we estimate the total incremental energy consumption for downloading recently uploaded photos (Hot photos) from Facebook in one year to be 868 TJ. The request for Hot photos is 82% of all requests, 13% of all requests are for Warm photos (Hot and Warm photos are downloaded from the edge network) and 5% of requests are for Cold photos (Cold photos are downloaded from the data center)[11], the total energy consumption for downloading photos from Facebook is approximately 292 GWh per year. The consumed energy in end-users devices, access network, edge (and core) network and servers in the edge network is estimated to be 103 GWh, 174 GWh, 1 GWh ,and 14 GWh, respectively (as shown in Figure 7b).

IX. CONCLUSION

In this work we developed models to estimate energy consumed by cloud services across the range of infrastructure employed, including end-user devices, the access network and metro/core network. This energy consumption is ignored by most of the works that have evaluated the energy consumption of cloud based services. The models and measurement techniques were applied to the photo sharing service on Facebook to evaluate the energy consumption of user devices and the transport network while uploading and downloading photos. Given the current profile of access technologies used by Facebook users, the estimated annual energy consumption in the transport network and end-user devices for uploading and downloading Facebook photos are about 12.5 GWh and 292 GWh, respectively. Facebook does not explicitly report the energy consumption of their data centers for specific services such as photo sharing. Instead, what they report is the gross data center energy consumption, which is 500 GWh. Comparing our estimate of 304 GWh with 500 GWh, we note that the energy consumption incurred in the transport network and end-user devices is about 60% of the energy consumption of all Facebook data centers. This figure would be higher if we could compare our estimate with just the fraction of data center energy consumption attributed to the photo sharing service.

The results in this paper show that achieving an energy-efficient cloud service, requires improving the energy efficiency of the transport network and the end-user devices along with that of the data centers. The goal of this study is to gain insights that can inform network designers for future energy-efficient deployment of cloud services and applications. The greatest energy consumption gain would come from improving the energy-efficiency of the access network, especially for wireless 3G/4G/LTE. For example, initiatives for networks to serve wireless users through WiFi hotspots or small cells, in preference to Macro base stations. In addition, the results presented in this paper indicate that network designers will need to deal with applications and services in near future for which the upstream traffic is greater than its downstream traffic. Consequentially, there needs to be focus on the re-designing network structures so that this change in traffic profile can be accommodated without a significant increase in energy consumption.

The proposed energy models (for shared and single-user network equipment) and measurement techniques are not specific to social networks and are being used to assess the energy consumption of different services and use cases.

ACKNOWLEDGMENTS

The authors would like to thank Dr Leith Campbell and Grant Underwood for their helpful comments. This research is supported by Bell Labs, Alcatel-Lucent.

REFERENCES

[1] Y. Gong, Z. Ying, and M. Lin, "A survey of cloud computing," in *Proceedings of the 2nd International Conference on Green Communications and Networks 2012 (GCN 2012)*, 2013, vol. 225, pp. 79–84.

[2] J. Baliga, R. Ayre, K. Hinton, and R. Tucker, "Green cloud computing: Balancing energy in processing, storage, and transport," *Proceedings of the IEEE*, vol. 99, no. 1, pp. 149–167, 2011.

[3] A. Nazir, S. Raza, D. Gupta, C.-N. Chuah, and B. Krishnamurthy, "Network level footprints of facebook applications," in *Proceedings of the 9th ACM SIGCOMM conference on Internet measurement conference*, ser. IMC '09, 2009, pp. 63–75.

[4] Google green. [Online]. Available: www.google.com.au/green/bigpicture/

[5] Open compute project. [Online]. Available: http://www.opencompute.org/

[6] Facebook sustainability. [Online]. Available: http://newsroom.fb.com/sustainability.aspx

[7] A. Vishwanath, F. Jalali, R. Ayre, T. Alpcan, K. Hinton, and R. Tucker, "Energy consumption of interactive cloud-based document processing applications," in *Communications (ICC), 2013 IEEE International Conference on*, 2013.

[8] Y. Gu, V. March, and B.-S. Lee, "Gmoca: Green mobile cloud applications," in *Green and Sustainable Software (GREENS), 2012 First International Workshop on*, 2012, pp. 15–20.

[9] L. Liu, H. Wang, X. Liu, X. Jin, W. B. He, Q. B. Wang, and Y. Chen, "Greencloud: a new architecture for green data center," in *Proceedings of the 6th international conference industry session on Autonomic computing and communications*, 2009, pp. 29–38.

[10] D. Beaver, S. Kumar, H. C. Li, J. Sobel, P. Vajgel *et al.*, "Finding a needle in haystack: Facebooks photo storage," *Proc. 9th USENIX OSDI*, 2010.

[11] J. Parikh. Technical talk on Facebook cold storage, open compute summit 2013. [Online]. Available: www.opencompute.org/OCP-SUMMIT-IV-VIDEOS/

[12] Facebooks carbon and energy impact 2012. [Online]. Available: www.facebook.com/green/app_439663542812831

[13] A.-J. Su, D. R. Choffnes, A. Kuzmanovic, and F. E. Bustamante, "Drafting behind akamai: inferring network conditions based on cdn redirections," vol. 17, no. 6, pp. 1752–1765, 2009.

[14] F. Zhou, L. Zhang, E. Franco, A. Mislove, R. Revis, and R. Sundaram, "Webcloud: Recruiting social network users to assist in content distribution," in *Network Computing and Applications (NCA), 2012 11th IEEE International Symposium on*, 2012, pp. 10–19.

[15] E. Nygren, R. K. Sitaraman, and J. Sun, "The Akamai network: a platform for high-performance internet applications," *SIGOPS Oper. Syst. Rev.*, vol. 44, no. 3, pp. 2–19, Aug 2010.

[16] U. Lee, I. Rimac, D. Kilper, and V. Hilt, "Toward energy-efficient content dissemination," *Network, IEEE*, vol. 25, no. 2, pp. 14–19, 2011.

[17] A. Vishwanath, J. Zhu, K. Hinton, R. Ayre, and R. Tucker, "Estimating the energy consumption for packet processing, storage and switching in optical-ip routers," 2013, p. OM3A.6.

[18] Wireshark - packet analyzer. [Online]. Available: www.wireshark.org/

[19] Sony vaio duo 11. [Online]. Available: www.sony.com.au/it-personal-computer/range/VAIO-Duo/561835/

[20] Power-mate power meter. [Online]. Available: www.power-mate.com.au

[21] Facebook's key facts. [Online]. Available: http://newsroom.fb.com/KEY-FACTS

[22] L. Zhang, B. Tiwana, Z. Qian, Z. Wang, R. P. Dick, Z. M. Mao, and L. Yang, "Accurate online power estimation and automatic battery behavior based power model generation for smartphones," in *Proceedings of the Eighth IEEE/ACM/IFIP International Conference on Hardware/Software Codesign and System Synthesis*, 2010, pp. 105–114.

[23] Powertutor mobile application. [Online]. Available: https://play.google.com/store/apps/details?id=edu.umich.PowerTutor&hl=en

[24] Code of conduct on energy consumption of broadband equipment, version 4.1. [Online]. Available: www.telecom.pt/NR/rdonlyres/75F0D218-04AA-48EA-AA96-8AD6C457E97B/1465560/EnergyConsumptionofBroadbandEquipment.pdf

[25] V. G. Gunther Auer, Oliver Blume. Energy efficiency analysis of the reference systems, areas of improvements and target breakdown (earth). [Online]. Available: http://ec.europa.eu/information_society/apps/projects/logos/3/247733/080/deliverables/001_EARTHWP2D23v2.pdf

[26] D. Fritz. The evolving wireless world. alcatel lucent presentation. [Online]. Available: http://ceet.unimelb.edu.au/pdfs/aluteddocument.pdf

[27] Cisco's power consumption calculator. [Online]. Available: http://tools.cisco.com/cpc

[28] One billion fact sheet - facebook. [Online]. Available: http://newsroom.fb.com/PHOTOS-AND-B-ROLL/4227/ONE-BILLION-FACT-SHEET

[29] Cisco white paper- "Cisco Visual Networking Index: Global mobile data traffic forecast update, 2012-2017.

[30] Cisco white paper- "The zettabyte era, 2012-2017". [Online]. Available: www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/VNI_Hyperconnectivity_WP.pdf