Shipping to Streaming: Is this shift green?

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Abstract

Streaming movies over the Internet has become increasingly popular in recent years as an alternative to mailing DVDs to a customer. In this paper we investigate the environmental- and energy-related impacts of these two methods of movie content delivery. We compare the total energy consumed and the carbon footprint impact of these two delivery methods and find that the non-energy optimized streaming of a movie through the Internet consumes approximately 78% of the energy needed to ship a movie, but has a carbon footprint that is approximately 100% higher. However, by taking advantage of recently proposed "greening of IT" techniques in the research literature for the serving and transmission of the movie, we find that the energy consumption and carbon footprint of streaming can be reduced to approximately 30% and 65% respectively of that of shipping. We also consider how this tradeoff may change in the future.

Categories and Subject Descriptors

E.m [**Miscellaneous**]:

General Terms

Measurement, Performance.

Keywords: Network, Streaming, Shipping, Energy, Carbon Footprint and Environmental Impact.

1. Introduction

With the increasing deployment of broadband connectivity, online movie streaming is becoming increasingly popular, with many predicting that streaming will replace more traditional mail-based shipping of movies. Some companies (e.g., Netflix) provide both delivery methods. With streaming service, a customer selects a movie and is then able to view the movie immediately as it is streamed from Internet-connected servers to the customer's display device. With mail-based delivery, a customer orders a movie online, and the movie (in DVD form) is then mailed (shipped) to the user, who later returns the DVD via mail. Although mail delivery of DVDs is currently more popular, online streaming is gaining popularity [3, 5].

There is currently considerable interest in both using information technology (IT) to "green" other industries and in "greening" the IT infrastructure itself. Movie content delivery offers a case study that illustrates and quantifies the potential of both of these opportunities. In this paper we quantify the amount of energy consumed and environmental impact (carbon footprint) of two methods for movie delivery (traditional DVD mail delivery versus on-line streaming), allowing us to determine the extent to which streaming can "green" this service. We find that non-energy optimized Internet streaming consumes approximately 78% of the energy needed to ship a movie, but has a carbon footprint that is approximately 100% higher.

Considering recently proposed methods for decreasing energy use in data centers and networks, we find that the energy consumption and carbon footprint of streaming can be reduced to approximately 30% and 65% respectively of that of shipping – making streaming delivery even more attractive, but still not overwhelmingly so. Lastly, we also consider longer term trends in both content itself (e.g., increased size, with 3D high-def movies) and potential changes in both network and mail-based delivery. Here we find that greening gains decrease, as the amount of data associated with a movie increases.

As a case study, this work reminds us that IT – even greened IT – is not always a panacea for significantly "greening" traditional industries, despite the rather intuitive appeal of delivering data via a gleaming, modern IT infrastructure versus a traditional bricks, mortar, and roadway system. The energy- and environmentally-related benefits to be had are modest and only in certain areas of the movie-content delivery service design space. However, our results do point to the fact that there are such indeed benefits to be had, and quantifies the extent to which ongoing research efforts in greening IT data centers and Internet infrastructure can be used to realize, and increase, these benefits.

The remainder of this paper is organized as follows. Section 2 overviews related work. We describe shipping and streaming delivery methods and assumptions about movie viewing in Section 3. We quantify the energy consumed in the shipping and the online streaming cases in Section 4 and Section 5 respectively. We present the carbon footprint and evaluation results in Section 6 and 7 respectively. We discuss the results in Section 8, and conclude in Section 9.

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2. Related Work

Several recent studies have compared the environmental impact of online versus retail store purchases. In [14], the authors compare the environmental impact of renting a DVD from Blockbuster with that of ordering a DVD from Netflix. The environmental impact of online versus retail purchase of electronics was examined in [16]. Both [14] and [16] observe that the online option is advantageous from the environmental standpoint. [19] provides more mixed results, noting that in urban areas, online purchases consume more energy, while in rural areas the two options have similar energy consumption.

In [17], the authors compare the energy cost and carbon footprint of Internet-downloading of songs versus traditional retail purchasing of a CD. Part of their analysis is a calculation of the energy spent in transmitting a bit of information. The analysis in [4] compares the dollar (not energy) costs of sending a large amount of data over the Internet versus shipping the same data via mail; the focus of our paper is on the energy and environmental costs of two methods of movie content delivery, and the schemes that can be used to "green" these methods.

Nano Data Centers (NaDa) [15] is a distributed computing platform that the authors argue can save approximately 20-30% in energy compared to traditional data centers for VOD services. In contrast, this paper compares the energy and environmental costs of traditional data centers with mail delivery, considers both manufacturing and transmission energy costs, and also estimates the carbon footprints. The savings envisioned in NaDa could be realized by replacing the data center VOD services that we consider with NaDa distributed services.

3. Shipping and Streaming Delivery Methods

In this section we describe the infrastructure and energy consumption/carbon footprint model of shipping a DVD via mail versus streaming a movie through the Internet. For assessing the energy and environmental costs[1] in shipping a DVD, we consider Netflix's DVD mail-delivery service as a representative example [14]. The costs of manufacturing the various components involved in shipping (DVDs, packaging, trucks), operating the distribution centers, and transporting the DVDs are determined and added to determine the cost of delivering a single DVD.

In the streaming case, costs are incurred in transmitting the movie over the Internet and in manufacturing the various equipment involved in streaming. The costs of recycling are also taken into account (both for streaming and mail delivery). We calculate these costs and amortize them appropriately in estimating the cost of a single streaming of the movie. We perform these calculations assuming two scenarios – a non-energy optimized scenario (roughly, using today's technology and operating at peak power ratings at all times, even when idle) and an energy-optimized scenario (where recent research results for decreasing the energy consumption of data centers and networking are taken into account). The parameters used in our calculations are given in Table 1; for a detailed discussion of these parameters, see [5].

Table 1: Parameter values used in assessing costs

Parameter	Value
Movie Size	8 *8 *10^9 bits
Movie duration	2 * 3600 seconds
# Movies streamed in a day	2.2 *10^6
# Movie titles [3,5]	10^5
Lifetime of IT equipment	3 * 365 days
Recycling factor	0.87

Once the movie has been delivered to the customer (whether by mail or via streaming), the customer watches the movie on a laptop or display device such as a flat panel TV. The total energy cost of watching a movie on a laptop and television are 2.788MJ and 5.44MJ respectively [5]. As these costs are common to both shipping and streaming we will not consider these costs further. We note here, however, that these costs are larger (by a factor of roughly 3 to 5) than the delivery costs discussed in the remainder of the paper, making display costs the dominant factor in viewing in-home movies.

4. Energy Spent Shipping a DVD

For evaluating the energy costs for shipping a DVD we use data provided in prior work [14]. After the DVDs are manufactured, they are first transported to the main distribution center in Sunnyvale, California [14]. Then the DVDs are put in plastic cases and trucked to the various regional warehouses. We assume this distance as 3800Km [14]. The weight of the DVD is 18g and the weight of the plastic case is 85g [14]. Once at the regional warehouses, DVDs are shipped to customers on request, and returned to the warehouse by the customer, until the life of the DVDs expire. The reusability of DVDs is taken as 12 [5]. For this last-leg-shipping between the warehouse and customer, DVDs are removed from the plastic case and transported in a custom-made paper sleeve. The approximate weight of the DVD with paper sleeve is 21g. This last-hop transportation is assumed to be done by a truck, with a round trip distance of 210Km [14].

Warehouse. We consider the number of regional distribution centers to be 55 [5], each having an area of 20000sq ft [5]. Considering an annual energy consumption of 7.6kWh per sq ft for the warehouse [5], we determine that the total energy consumption attributed to a single shipping of the DVD is 0.069MJ.

DVD. We assume that the paper sleeves and plastic cases used for DVD packaging are recycled [5]. The energy savings when paper and plastic are recycled are about 64%

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[1] Throughout this paper, when we use the term "costs", we will be referring to the energy consumed and/or the environmental (carbon) footprint, rather than dollar costs.

and 80% respectively [5]. Since we could not find the energy savings of DVD recycling, we assume that it is 13%, as with other IT equipment [5]. Using these recycling factors, we estimate the marginal energy cost incurred in manufacturing a DVD, plastic case and paper sleeve for a single shipping of a DVD to be 0.976MJ, 0.125MJ and 0.1764MJ respectively [14]. We have amortized the manufacturing cost of the DVD and the plastic case over the reusability of the DVD.

Transportation. We assume that a 20,000lb delivery truck is used for transportation, which has an energy cost of 18MJ/mile [17] and a lifetime of 155000 miles [5]. The energy spent in the transportation of the DVD package to the distribution center, and in the last leg, which should be attributed to a single shipping are 0.0403MJ and 0.0054MJ respectively. The total cost of manufacturing the truck is 200932 MJ [5]. The fraction of energy associated with manufacturing the truck that should be associated with shipping a movie once is 0.0033MJ. Thus the total cost of shipping a DVD is 1.396MJ.

Table 2 summarizes the energy consumption of the various steps associated with mail-based DVD delivery. Note that the energy consumption of DVD manufacturing accounts for 70% of the overall energy cost.

Table 2: Energy Costs: DVD Shipping Method (in MJ)

	Transportation	**Manufacturing**	**Total**
Warehouse	0	0.069	0.069
DVD	0	0.976	0.976
Plastic case	0	0.125	0.125
Paper sleeve	0	0.1764	0.1764
Truck	0.046	0.0033	0.0493
Total	**0.046**	**1.35**	**1.396**

5. Energy Spent in Online Streaming

In this section, we estimate the total energy consumed in streaming a movie via the Internet. In this scenario, a streamed movie originates from the data center, traverses a set of backbone and edge routers, and finally passes through the home router to reach the customer. The customer watches the movie on a display device. We assume the data center is provisioned to meet a peak demand of 2.2 million requests (based on the fact that Netflix currently ships 2.2 million DVDs per day [3,5] and most movies are watched between 6 pm and 12 am).

We consider two scenarios – a non-energy optimized scenario (roughly, using today's technology and operating at peak power ratings at all times, even when idle) in section 5.2 and an energy-optimized scenario (where recent research results for decreasing the energy consumption of data centers and networking are taken into account) in section 5.3. We begin by considering manufacturing costs associated with a single streaming of a video, which are common to both scenarios.

5.1 Energy Spent in Equipment Manufacturing

An exact analysis of the energy expended in manufacturing servers, hard drives and routers is not available in literature. Therefore we estimate these costs from data given in [8, 18]. Since manufacturing accounts for only 12% of the total energy cost (Table 3), even if our estimates differ from the actual values, they are unlikely to affect our overall conclusions. We again assume that 13% of the total energy expended in manufacturing IT equipment is recovered by recycling [5] and assume that IT equipment has a lifetime of 3 years [5], as noted earlier.

Data Center and Routers. To store 10^5 movie titles each of size 8GB, we assume a 1PB store is used. The manufacturing cost of a disk drive of size 30GB was 2926MJ in 2000 [18], from which we estimate the manufacturing cost of a 1PB data storage today as 1463000MJ [5]. The fraction of the total manufacturing cost of this 1PB storage attributable to a single streaming of a movie is thus 0.000528MJ.

We estimate the total energy expenditure in manufacturing a server from the total energy spent in manufacturing a desktop as 5345MJ, excluding the manufacturing cost of the CRT monitor [18]. We estimate the number of servers required to satisfy the peak load in Table 1 to be 42151 [5]. Therefore, the server-related manufacturing energy cost attributable to streaming a single instance of a movie is 0.081MJ.

To obtain the manufacturing energy cost of a router, we scale the value obtained for the desktop proportional to the weight of a router. We amortize this manufacturing energy cost over the total traffic flowing through the router (including the 2 hour video) during the router's lifetime to calculate the manufacturing energy cost to be attributed to a single streaming of a movie. We assume there are 15 routers in the path [15]. Hence the manufacturing energy cost attributable to a single streaming of a movie, is 0.05MJ. Thus the combined manufacturing cost of the data center and router is 0.1315MJ.

Home Router. The total cost of manufacturing a home router is 258MJ. This value is obtained by scaling the manufacturing cost of a desktop proportionally with respect to the weight of a router [8,18]. At present, the monthly median traffic flowing through a home router is 4GB [5]. If we assume that the subscriber streams 5 movies in a month, this would result in 40GB of traffic being generated by movie streaming alone. If we were to amortize the manufacturing cost of the home router on the basis of total traffic flow, we would assign almost the entire manufacturing cost of the home router to movie content alone; this seems unreasonable. Thus, instead of attributing cost based on number of bits transmitted, we attribute costs as a percentage of time used for a given service. Under this cost-assignment model, the manufacturing energy cost is 0.0177MJ. Note here that the manner in which costs are assigned (per-bit versus per-time-unit-of-use) can result in very different energy cost estimates.

5.2 Non-energy optimized Transmission

In this subsection we evaluate the energy consumed in transmitting the movie through the Internet in a non-energy optimized scenario. For this case we perform all calculations considering the peak power ratings and assuming that the power consumed by idle equipment is equal to the power consumed in the active state.

Data Center and Routers. Since a conventional 1PB storage consumes 864.2kW [5], the energy consumed in storage, which should be attributed to a single streaming of a movie is 0.03393MJ. Considering the model of a typical server in [9], the total energy consumed by servers for a single streaming of a movie is 0.415MJ. To simplify the calculation of router costs, we assume that only M7i (edge router - 400W, 10Gbps) and M40 (backbone router - 1600W, 40Gbps) Juniper routers are involved in the streaming of the movie [5]. The total energy spent for streaming an 8GB movie by all the routers is 0.128MJ. The servers and storage are dedicated and so the total energy cost required for operating the servers and storage in a day is split evenly among the 2.2 million movies streamed during the day. For routers, the total energy consumed is the sum of the energy required to transmit the 8 GB movie and the idle state energy amortized over the total traffic flowing through the router in a day. The total traffic flowing through the router is determined from the utilization of the router (30% [13]) and the transmission rate of the router.

Just as our analysis of DVD mailing had warehouse overhead costs, so too must data center operating and overhead costs (e.g., cooling) be taken into account. To incorporate the cooling and infrastructure costs for the above equipment, we assume a Power Usage Effectiveness (PUE) of 1.5. The values in Table 3 are obtained by scaling the transmission energy costs we discussed earlier for storage, servers and routers by this PUE value of 1.5.

Home Router. We consider the home router to be a Linksys Wireless Broadband Router (12 W) [5]. As in our earlier analysis of manufacturing costs of the home router, we amortize the transmission costs of the router on a per-unit-of-time (rather than per-bit) basis. In this case, the energy spent in receiving the streaming movie for 2 hours is 0.0864MJ.

Combining the entire set of data, the total energy spent in a single streaming of a movie (including manufacturing) is 1.1 MJ. Table 3 summarizes the results of this section. As can be seen, this value is lower than the 1.39 MJ cost for shipping, computed in Table 2.

Table 3: Energy Costs: Non-Energy Optimized Streaming Method (in MJ)

	Transportation	**Manufacturing**	**Total**
Data Storage	0.051	0.000528	0.0515
Servers	0.6225	0.081	0.7035
Routers	0.192	0.05	0.242
Home Router	0.0864	0.0177	0.1041
Total	**0.9519**	**0.15**	**1.1**

5.3 Energy-optimized Transmission

In this subsection, we evaluate the potential savings when various greening strategies are used to decrease the energy consumption of transmission. Since storage consumes a negligible fraction of the total energy, we do not discuss the greening of storage.

Green Datacenter. A two-fold approach can be taken to make datacenters more energy-efficient. First, IT equipment can be made (or operated) in a greener manner. Secondly, the energy spent in cooling and infrastructure (as reflected in the PUE) can be decreased.

Although today's servers are non-energy proportional, the benefits of energy-proportional equipment have been widely advocated, e.g., [7, 9]. We thus expect that in the future, server power consumption will reflect server utilization. Server utilization levels typically lie between 10-50% [7]. For a conservative estimate of the energy savings with energy-proportional servers, we assume a 30% server utilization and that idle energy-proportional machines consume 10% of the power consumed in the active state.

The reduction of the PUE of data centers has received considerable attention. [10] identifies best practices to decrease the PUE. Using energy-efficient methods, Google has reduced the PUE from 1.5 to 1.1 [2] in some of its data centers. Indeed, one can even reduce the PUE below 1 by locally generating power from waste heat (although we do not consider this option here). In computing costs for energy-optimized energy transmission, we will assume a PUE of 1.1.

Green Networking. Networking devices, like servers, are often under-utilized, and substantial savings can be obtained by sleeping and link-rate-adaptation [12,13]. Sleeping reduces the energy consumption in the idle state, while link-rate adaptation decreases active state and idle state energy consumption. [13] demonstrates that by using a buffer-and-burst approach to realize wake-on-arrival schemes on high-speed links, a 20-30% savings can be obtained. Similarly, using rate adaptation and Dynamic Voltage Scaling, the energy savings can be as high as 50% [13]. As discussed above, assuming that equipment operates with energy-proportional costs (with idle state power costs of 10% of the active-state power) and applying a conservative additional reduction in energy of 30% obtained by sleeping and rate adaptation, router energy consumption (including the home router) can be reduced from 0.278 to 0.06. Additional energy-reduction approaches, such as consolidation of network traffic [11], using light-weight switches in parallel with high-power switches [6] have also been suggested to decrease energy consumption.

Table 4: Energy Savings (MJ) with Green Transmission

	Streaming (Non-energy optimized)	**Streaming (Energy optimized)**
Data Storage	0.051	0.0374
Servers	0.6225	0.169
Routers	0.192	0.036
Home Router	0.0864	0.0223
Total	**0.9519**	**0.265**

Table 4 summarizes the gains that can be obtained by adopting the greening options discussed above. With these optimizations, the energy costs of optimized transmission are only 28% of the costs of non-energy optimized transmission.

6. Carbon Footprint

To determine the carbon footprint of various delivery mechanisms, we determine the amount of carbon dioxide emitted due to shipping and streaming a movie. The carbon footprint is the product of the carbon dioxide emission coefficient and the energy consumed. We use the mean value of carbon coefficient for electricity (1.297lbs/kWh) [1] in our calculations. We note that in some locations, e.g., where the primary source is hydro-electric supplemented by nuclear, the carbon footprint of electricity generation can be 95% lower than this carbon loading e.g., [20]. These significant reductions, however, would be shared by both forms of delivery. We also take into account the manufacturing, transportation and transmission carbon costs for shipping and streaming respectively. The carbon dioxide emission values are shown in Table 5. Due to space constraints we omit our calculations. Details are available in [5].

Table 5: Carbon Footprint (in grams)

	Streaming (Non-energy optimized)	**Streaming (energy optimized)**	**Shipping**
warehouse	n.a.	n.a.	11.27
DVD	n.a.	n.a.	48.84
Plastic case	n.a.	n.a.	8.82
Paper sleeve	n.a.	n.a.	6.26
Truck	n.a.	n.a.	3.37
Data Storage	8.4	6.29	n.a.
Servers	104	29.88	n.a.
Routers	33.77	8.329	n.a.
Home Router	14.85	4.44	n.a.
Total	**161.02**	**48.939**	**78.56**

7. Results

Figures 3 and 4 summarize the energy consumption and carbon footprint costs of streaming and shipping. We observe that the energy consumption of streaming with non-energy-optimized transmission is 78% of that of shipping. But, the carbon footprint of streaming for the non-energy-optimized transmission is approximately 205% of that of shipping. However, when energy-optimized transmission is used, the energy consumption of streaming can be reduced to 29% of that of shipping, while the carbon footprint for this scenario reduces to 63% of that of shipping. Thus, by using greening techniques one can obtain substantial savings in energy as well as carbon footprint.

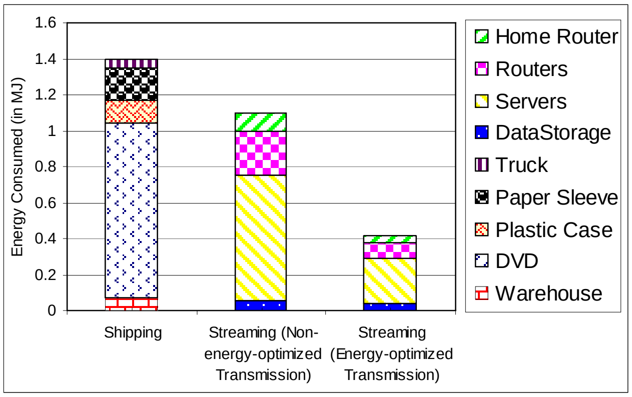

Figure 3: Comparison of Energy Consumption

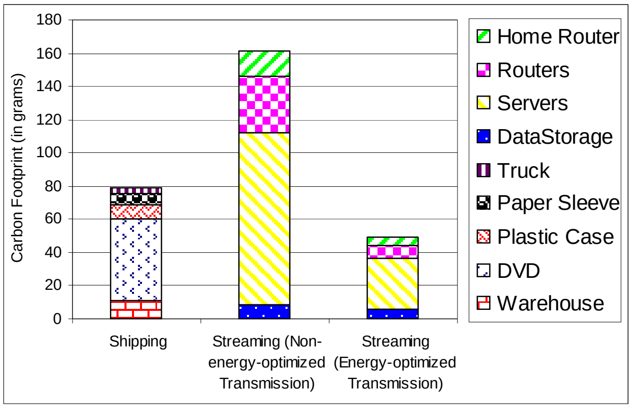

Figure 4: Comparison of Carbon Footprint

8. Discussion

Our analysis thus far has considered current and near-time future energy consumption scenarios. What might the longer-term future bring?

Higher-data-rate movies. One can already have a superior viewing experience using Blu-Ray, with the size of Blu-Ray discs ranging between 25 and 50 GB. With viewers watching 3-D at home, we can imagine future movie sizes of 150 GB. If we assume the energy cost of manufacturing a Blu-Ray to be similar to that of a DVD, then since Blu-Ray discs have the same form factor as

DVD, the energy costs of shipping will likely remain approximately the same. However this would not be the case with streaming, where the increased data sizes would result (using the same methodology as above, only assuming a higher data rate) in a per-movie energy cost in an energy-optimized scenario of 7.7MJ, making shipping significantly more energy-efficient than streaming delivery. In this scenario, the per-transmitted-bit costs of servers and routers would need to drop by a factor of 6 for the energy costs of streaming and shipping to remain comparable.

Multiple views. Some customers might want to watch movies multiple times. This would not incur any additional environmental cost in the shipping scenario, as the customer can watch a movie multiple times before returning the DVD. However, in the streaming case, the same movie would need to be streamed multiple times, since local storage at the display device is currently not allowed. It is possible, however, that encrypted local storage and key-based access could be used in the future to allow multiple views of streamed content at no additional energy cost.

Greener Shipping. We have focused much of our attention on greening streaming movie transmission. One can similarly argue that transportation will be greened in the future as well, e.g., by using green vehicles. It is also possible for the movie service provider to obtain licensing so that DVDs could be reproduced onsite. If ship-to-burn were to be the case, there would be no need for the DVDs to be shipped from the distribution centers to the regional warehouses, obviating the need for the plastic cases and decreasing the distance that DVDs needed to be shipped. As noted earlier, the manufacturing energy cost of DVDs dominates the cost of shipping DVDs. This manufacturing energy cost could be decreased by increasing the durability and reusability of the DVD. If the reusability of a DVD could be doubled, the energy expended in shipping a DVD once could be reduced to 0.74 MJ. But even with this reduction we observe that energy-optimized streaming would still be 56% of shipping a DVD. It may also be possible to ship movies stored on greener reusable media such as USB flash disks, increasing the number of times the media can be used.

9. Conclusion

In this paper we have quantified the total energy consumed and the carbon footprint of two methods of movie content delivery – traditional mailing of DVDs and online streaming. Our results have shown that by adopting data center and networking-related energy reduction techniques from the literature, consumption and the carbon footprint of streaming can be reduced to approximately 30% and 65% respectively of that of shipping – making streaming delivery an attractive option. However, this advantage may not last if movie data rates continue to scale.

Reducing energy needs and the carbon footprint by approximately a factor of two is certainly a significant achievement – energy is one of the major costs in running a data center, and any less CO_2 emitted into the environment is for the better. However, our field is in many ways used to orders-of-magnitude and exponential increases in performance and utility, e.g., Moore's Law, Metcalfe's Law, and the concomitant increase in link transmission capacity (e.g., from 10 Mbps to 10 Gbps Ethernets in a short period of time). Filtered through this lens, a factor of two improvement in performance could be perceived as small. Perhaps it is the case that advances in energy-related aspects of content delivery systems (and green networking in general) will be slower, although hopefully just as steady. Indeed, this has been the case in other industries (e.g., the automotive) and our sense is that it has been historically true in the IT industry as well. It may also be the case that significant gains result primarily as a sum of gains in the many individual component technologies that comprise the system, e.g., as has arguably been the case with laptops, where advances in CPU technology and energy efficiency, disk drives, displays, solid state drives and battery technology have all contributed significantly.

We realize that some of the assumptions might not be true, and certain factors (like energy/environmental impact of general and administrative services) have not been accounted. But we believe, that the analysis is fairly reasonable for comparison and emphasizes that there is still a lot of work to be done to make streaming a compelling alternative. As future work, we will study the cost-benefit tradeoff of such innovations to determine which techniques can reduce the energy footprint at the least cost.

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