The Evolving Streaming Media Landscape

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In the not so distant past, families gathered in their living rooms to watch their favorite shows on cable television. On occasion, they grabbed a DVD from the nearest rental store to watch a movie. Well, the DVD rental stores are now nearly gone (Blockbuster anyone?), and many viewers are "cutting the cord" to cable television, opting instead to watch their favorite shows and movies on-demand from streaming services such as Netflix, Hulu, Amazon Prime, and iTunes. This shift has caused several implications for streaming technology.

New Viewing Methods

The ability to watch videos on-demand (VoD) on an Internet-connected device such as a tablet, smartphone, PC, set-top box, or television is changing viewing behaviors. Some of the statistics surrounding online media streaming are simply mind-boggling. The subscription-based Netflix service recently reported having 40 million subscribers from the 40 countries where it's operational (see https://signup.netflix.com/MediaCenter/Overview). A majority of these subscribers, around 30 million, are in the US and Canada, and estimates from Sandvine suggest that Netflix video traffic accounts for a substantial fraction of Internet traffic in these countries (see www.sandvine.com/trends/global-internet-phenomena/). But even Netflix usage pales in comparison with YouTube: according to YouTube's recent statistics, each minute, roughly 100 hours of video content is uploaded, and about 1 billion unique users visit the service each month, watching around 6 billion hours of videos.

Major television networks have realized the importance of offering online video services through a model known as "catch-up" television. The BBC was one of the pioneers of catch-up services in which programs that have recently been broadcast are uploaded to a portal, and consumers can stream them at their convenience using a special-purpose application, such as the BBC's iPlayer, running on a device of the consumer's choosing. Unlike traditional VoD services, catch-up services make content available for a limited period following the program broadcast; these availability windows are sometimes based on content licensing agreements. Catch-up television services are becoming increasingly popular, and in some countries, such as Australia, their consumption figures are rivaling those of traditional television viewership.

All of this streaming media frenzy has been facilitated by the coming of age of the communication infrastructure, with high-speed broadband connectivity to devices becoming commonplace, and use of content distribution networks (CDNs) to optimize content delivery becoming widespread. Putting aside the technological innovations, the other obvious catalysts are the convenience of watching anytime, anywhere, and on-demand streaming's comparatively lower fees when compared with the cost of subscribing to cable television packages.

Will Technology Affect Content?

Video streaming on the Internet is changing people's viewing habits, and I'm excited — this could lead to substantial innovation with respect to how content is created, distributed, and consumed. A small example might help illustrate this point. Let's consider how people are using Netflix. The company generally doesn't divulge much about viewing behavior, but it recently noted that consumers sometimes indulge in "binge viewing," where they consume several episodes of a television show at one go. This is interesting because traditionally, content has been designed for scheduled broadcasts, which has guided production to focus on fixed lengths

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(such as 25 minutes of content with 5 minutes for advertisements). If, indeed, viewers love binge viewing, television shows could become longer, and there might be room for more creativity and personalization when most of the consumption is via on-demand streaming.

Let's elaborate on this content creativity and personalization aspect. Currently, we're accustomed to watching "linear" content — that is, content where the storytelling has a predetermined sequencing, and it makes sense to view it in this predetermined sequence. In the literature, researchers have discussed "nonlinear" content, which has multiple possible viewing sequences. I'm aware of one Hollywood film — the 1985 mystery *Clue* — that implemented this concept. *Clue* had three possible endings, and in the theatrical release, theaters received one of three possible versions. In the on-demand world, movies with multiple endings can be seamlessly supported, but there are other possibilities, such as reality shows where viewers could choose to stitch together their version of the show by following a certain subset of characters or events. I believe content personalization will play a big role in taking the viewing experience to the next level.

Keeping Pace with Demand

For a superlative viewing experience, and if we want users to continue patronizing on-demand streaming services, we need an infrastructure that can efficiently and reliably stream high-quality videos to large numbers of geographically distributed clients. This is extremely challenging because the Internet was never designed for such an experience. In the early to mid 2000s, the research community made many significant contributions that addressed the scalable streaming question; the idea was to group together requests for the same (popular) video and serve them using a single multicast stream. Effectively, these multicast-based streaming protocols, such as Stream Merging and Optimized Periodic Broadcast, tried to efficiently use server and network resources while serving large numbers of clients. Lack of Internet-wide multicast support has limited their deployment to networks with some form of multicast or broadcast capability.

Streaming solutions based on peer-to-peer (P2P) technology have been the subject of many research projects. These have seen some success with respect to commercial

deployment. Several Internet-based live television services have used P2P technology, the most notable one being the China-based PPLive service (see www.pptv.com). One early release of the BBC's iPlayer used P2P delivery, but the BBC stopped using this technology, apparently due to complaints from users regarding heavy use of upload bandwidths.

Today, on-demand streaming services typically use a combination of owned data centers, cloud services, and CDNs to meet the delivery challenge. Often, these services support some form of adaptive streaming, where the video quality being streamed is matched, sometimes dynamically during the course of playback, to the bandwidth available between the host serving the video and the client playing it. With respect to adaptive streaming, the industry has been able to draw on a large body of research on rate-controlled video streaming. With on-demand streaming's increasing popularity, we will probably need to innovate even more on content delivery technologies. After a hiatus of more than 10 years, the IETF has revived the effort to define the framework for CDN interconnection, which would let individual CDNs collaborate to increase the efficiency of their content delivery (see http://datatracker.ietf.org/wg/cdi/charter/ and https://datatracker.ietf.org/wg/cdni/charter/). Perhaps we will also finally see multicast running across the Internet and streaming systems utilizing multicast-based streaming protocols.

I would like to touch upon one final point — mobile video streaming. According to recent industry forecasts (such as Cisco's Visual Networking Index report; see www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-481360.pdf), video traffic currently accounts for a significant fraction of the total cellular data network traffic — in some cases, close to 50 percent — and this number is projected to grow in the years ahead. This is probably the elephant in the room, given that capital expenditures will most likely be unable to keep up with the demand placed on the network infrastructure. The rollout of LTE 4th-generation radio technology, which will improve spectral efficiency and enable higher data rates, will be useful in addressing the mobile video challenge. Nonetheless, I believe alternatives are needed to manage mobile video traffic over the long term. Here, content personalization and content recommendation engines could work in unison with machine-learned prediction engines. The personalization aspect could help the recommendation engine, and the recommendations' effectiveness could help with opportunistically preloading content into a user's mobile device when it's connected to a Wi-Fi network.

I'm excited about the future of video streaming. As I've foreshadowed, consumers are increasingly relying on services other than cable television for their content consumption. These ongoing changes can potentially consign cable television to the history books, at least in the form we've known them in the recent past. I believe we will continue to see substantial innovation in content creation, delivery, and the interaction between the content's consumers and the interfaces delivering it to their devices. Video streaming has finally become the killer application we've been hoping it would, and we've been hoping for at least a decade, if not more. These are interesting times.

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