Streamloading:
Low Cost High Quality Video Streaming for Mobile Users

Ayaskant Rath, Sanjay Goyal, and Shivendra Panwar

Department of Electrical and Computer Engineering, Polytechnic Institute of New York University

{arath01, sgoyal01}@students.poly.edu, panwar@catt.poly.edu

ABSTRACT

Video streaming applications are a major contributor to the recent dramatic rise of data traffic in cellular networks. Mobile users in a cellular network suffer fluctuating data rates, which almost directly reflects on the quality of video they view in a streaming service. Although replacing such video *streaming* services with video *downloading/renting* services could potentially allow such mobile users to enjoy consistently higher quality videos, traditionally such services cost a lot more than video streaming services because of legal copyright pricing and management issues. We propose a novel scalable video delivery service called *streamloading* that can potentially allow mobile users to enjoy *download* quality videos, while still being legally classified as a *streaming* service. We describe the implementation of the service and perform extensive simulations to evaluate streamloading, in comparison to traditional streaming services.

Categories and Subject Descriptors

H.5.1 [**Multimedia Information Systems**]: Video

General Terms

Design, Algorithms, Performance, Legal Aspects

1. INTRODUCTION

Modern cellular networks are evolving at a tremendous rate. Over the past few years, with the advent of smart mobile devices, an exponential increase of data consuming applications, and a manifold increase in capacity, users in cellular networks have become extremely data hungry. Cisco predicts cellular data traffic will grow by over eight times in the next four years, with more than two-thirds of it consisting of mobile video [4], as shown in Figure 1. Traffic from next year's video alone is projected to exceed current total mobile traffic. Moreover, a major portion of the mobile video traffic will be contributed by video streaming services [6].

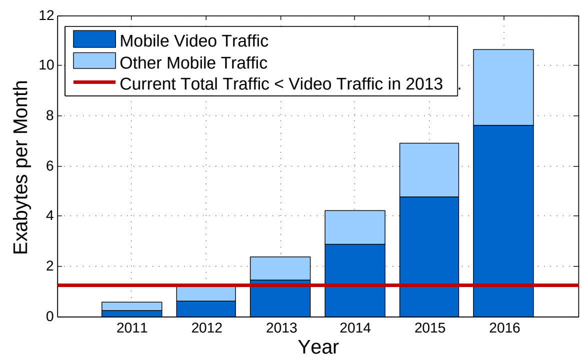

Figure 1: Mobile Video Traffic Projection [4]

The data rate experienced by a mobile user is inherently variable in a cellular network. A user located closer to a base station experiences a higher data rate compared to one who is far away at the edge of the macrocell. Additionally, high data rate small cells such as picocells (deployed by the service providers), femtocells, and potentially even WiFi hotspots (deployed by users) are also overlaid on these cellular networks. This results in extreme variations in data rates experienced by a mobile user in a cellular network. Another source of bandwidth variability are periods of congestion in the network, e.g., during peak hours. In a video streaming system, the data rate available to a user almost instantaneously reflects on the quality of video experienced. For example, when a user is watching a streaming video, the video quality becomes poor almost as soon as the user moves into a low data rate region. Thus, it is clear that providing good video streaming services is going to become an essential aspect of improving cellular network services in the near future.

In recent years, there have been a few proposals from industry to exploit adaptive video streaming in wireless networks, where the video bit rate is switched on-the-fly to provide the best video quality to the user based on the available resources in the network. Microsoft's IIS Smooth Streaming [16], Adobe's Flash Dynamic Streaming [7], and Apple's HTTP Adaptive Bit-rate Streaming [10] use various techniques to efficiently deliver streaming video to users by dynamically switching among different streams of varying quality and bit-rate to provide a smooth and seamless video to users. The research community has also been very active in this area. For example, an intelligent bit-rate switching based adaptive video streaming (ISAVS) algorithm is proposed in [9]. This algorithm provides the best possible video

This work is supported in part by National Science Foundation (Grants 1230773 and 0905446), the New York State Center for Advanced Technology in Telecommunications (CATT), and the Wireless Internet Center for Advanced Technology (WICAT), an NSF I/UCRC.

MoVid '13, February 26-March 1, 2013, Oslo, Norway.

quality to users with minimum replay interruptions. Similarly, an optimized H.264/AVC-based bit stream switching for mobile video streaming has been proposed in [14]. The advanced bit stream switching capabilities using SP/SI pictures defined in the H.264/MPEG-4 AVC standard [15] were exploited in this work.

In this paper, we propose a new innovative video delivery service, *streamloading*, that while legally qualifying as a *streaming* service [2], offers users video quality potentially as good as those offered by a traditional, more expensive *downloading* service. We use Scalable Video Coding (SVC), which is an extension of the H.264 video coding standard [13], to encode the video into multiple scalable layers, the lowest layer being the Base Layer, while the higher layers being Enhancement Layers. A *streamloading* system allows users to *download* enhancement layers, while actually *streaming* only the base layer of the video. As the enhancement layers cannot be decoded without the base layer, a streamloading service legally qualifies as a streaming service; the key legal feature of streaming as opposed to downloading being the continuous connection between the server and the user while video content is being viewed [2]. We propose a detailed implementation of a streamloading system, and extensively evaluate its performance in comparison to a traditional streaming system in a cellular network environment.

The rest of the paper is organized as follows. We begin Section 2 by contrasting the traditional video delivery systems, vis-à-vis streaming and downloading, and describing how they may behave in a cellular network environment. Section 3 then introduces the proposed streamloading system and Section 4 presents details of its possible implementation, and the simulation system used for its evaluation, followed by results and analyses. We end with a discussion of possible extensions to our work on streamloading, and conclusions in Sections 5 and 6, respectively.

2. TRADITIONAL VIDEO DELIVERY

In this section, we discuss traditional video delivery services and investigate their drawbacks when used over modern wireless networks, thus motivating us to propose the *streamloading* system.

2.1 Streaming and Downloading

Video traffic has increased to the point that it now constitutes more than half of all Internet traffic [4]. A wide range of video delivery services, and a surge in the quality of videos, together account for this phenomenon. In this paper, we categorize all video delivery services in use today into *Streaming* and *Downloading*. A video *streaming* service is one where the consumer is not allowed to cache more than a short period of video data ahead of the point being watched [2]. Services such as Hulu, Netflix, and Amazon Instant Video would be examples of video streaming [3]. On the other hand, a video *downloading* service is one where the consumer tries to cache as much of the video as their network bandwidth allows, irrespective of the point of video being watched. Examples of video downloading services would include iTunes Movie Rentals, Google Play Movies, as well as YouTube [3]. While video playback is always aborted as soon as a device loses its connection to the network in a streaming service, it may play all the way to the end in a downloading service. Also, unlike a downloading service, seeking back on the video to replay a portion of it requires the data to be downloaded again in a streaming service. Video downloading services are typically ten to a hundred times more expensive than video streaming services, because of the charges imposed by content owners. As a result, from the price point of view, a user would, in most cases, prefer a streaming service to a downloading one.

2.2 Streaming in Wireless Networks

With the dramatic increase in the use of mobile devices, more users now intend to watch high quality videos on these devices using wireless network connections such as WiFi or 3G/LTE. These wireless networks inherently provide variable bandwidths to users, especially for those who are mobile. Bandwidths experienced by users in these wireless networks can vary from tens of Mbps to a few kbps, depending on where the user is located with respect to the Base Station, in case of cellular networks, and with respect to the access point, in case of a WiFi hotspot, and traffic demand from other users. Since higher quality videos require higher data rates, when the user moves to a low data rate region, or if there is traffic congestion, video streaming service providers prefer to lower the quality of the video delivered rather than causing an interruption in its playback.

2.3 Scalable Video Coding

Lowering the video quality by reducing its bit rate can also be implemented using SVC, an extension of the H.264 video coding standard. SVC allows a high quality video to be decomposed into multiple bit streams, with a subset of these bit streams requiring a lower bandwidth that can be used to display a lower quality version of the original video. In other words, a video can be divided into several bit stream layers such that each additional upper layer adds to the quality of the video. Every layer consists of predictions that are based on data decoded by all the layers below it. Thus, every layer depends on its lower layers, and can only be used when all layers below it are available to be decoded. The lowest layer, referred to as the *Base Layer* of the video, can be decoded by itself, independent of any other layer. The higher layers of the video that progressively enhance its quality further, are referred to as its *Enhancement Layers*.

Because of its scalability in quality and bit rate of the video, SVC is considered to be a suitable encoding method for mobile TV broadcast/multicast [8] as well as video streaming services [12]. The video to be streamed is first divided into chunks, where each chunk contains data for a small portion of the video, of the order of a second. In simpler terms, the video can be represented as the sequential playlist of all its chunks. Each chunk is then divided into a base layer and a few enhancement layers using SVC. The chunks are then *streamed* in sequence to the user, who plays them one by one as they become available. A chunk cannot be played while it is still being downloaded. The user tries to download as many layers of a chunk of video as the available bandwidth allows, until it is time to start playing the chunk. Thus, users can avoid interruptions by continuing to watch the video at a lower quality when their bandwidth drops, by downloading fewer layers of the chunks of the video.

2.4 The Limitations of Streaming

Although using SVC for streaming videos over wireless networks helps in reducing interruptions to the video as the user experiences varying bandwidths, it still suffers from a

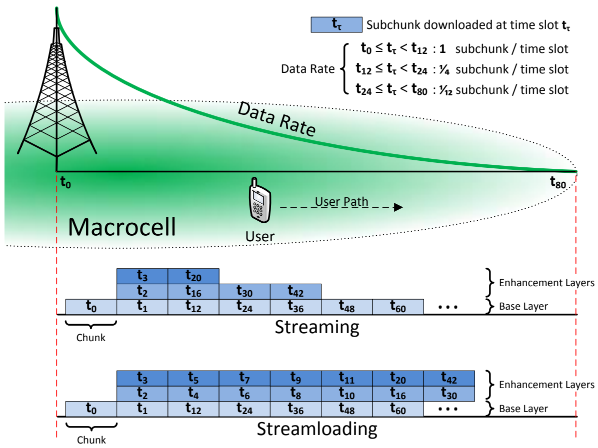

Figure 2: An example of Streamloading *v.* Streaming when a user moves from the center of a cell to its edge.

few drawbacks when compared to other kinds of video delivery services. For instance, since a user streaming video cannot cache future chunks of the video, even if they are close to the base station, and have surplus bandwidth available, the quality of video drops as soon as they move away from the base station and their bandwidth falls below the required level to download all layers of the video. If on the other hand, when a user is downloading a video, the surplus bandwidth available can be used to download future chunks of the video, so that even when the bandwidth falls, the user can continue to enjoy the same high quality video stored in cache. Thus, while the user may prefer to use a video streaming service from the price perspective, a video downloading service may be preferable from the quality perspective. Consequently, a service that can potentially provide download quality video, while still qualifying legally as a streaming service, is highly desirable for wireless networks.

3. STREAMLOADING VIDEO

With the motivation to design a video delivery service that can deliver download quality video, and yet qualify as a video streaming service, we try to exploit the important property of SVC that makes every enhancement layer of the video completely dependent on all its lower layers. In other words, any amount of enhancement layer data is of no use as long as the base layer data for the video is unavailable. We propose a video delivery service that allows enhancement layers of any number of future chunks of a video to be delivered in advance, much like a downloading service, while restricting the delivery of base layers of chunks to a limited set of chunks just about to be viewed, just like a streaming service. Simply put, this service allows users to stream the base layer data of the video and download the enhancement layer data. We call this a video *streamloading* service.

Just like a video streaming service, the video playback aborts as soon as the network connection is lost in a video streamloading service, because the video cannot be played as soon as the streaming of the base layer stops. Similarly, seeking back on the video to replay a portion of it requires the base layer data to be downloaded again thus replicating regular streaming. In addition, any Digital Rights Management (DRM) technologies used to protect content in current streaming technologies can also be used with streamloading. It is because of these properties that a video streamloading service legally qualifies as a video streaming service, thus allowing the content owners to allow pricing similar to other video streaming services.

As an example, we consider the case when a streamloading user is close to the base station, where the surplus bandwidth can be used to download enhancement layers of future chunks of the video. When it eventually moves away from the base station, even a low bandwidth that can only sustain the streaming of base layer data is sufficient to deliver high quality video because the enhancement layer data for those chunks has already been downloaded. This phenomenon is illustrated in Figure 2. Each layer of a chunk, called a *subchunk*, is labeled with t_τ, denoting the time slot at which it was downloaded. A chunk of the video takes twelve time slots to play. As the user moves from the center of the cell to its edge, the data rate falls. As evident in the figure, a user in a streamloading system was able to download all future enhancement layer subchunks before the available bandwidth dropped, and hence can sustain high quality video even when located far away from the base station. Thus a video streamloading service can potentially deliver video quality as good as a video downloading service. In fact, the quality of video in a streamloading service is equivalent to that of a streaming service in the worst case, and to a downloading service in the best case.

A potential disadvantage to using a streamloading system, as opposed to a streaming system, is that it may result in a comparatively higher amount of wastage of downloaded data, where users decide to not view a video further for any reason [6]. They then discard videos that they have not finished watching yet. However, this wastage being smaller when the user discards a video early in the video, combined with the fact that the probability of a user discarding a video decreases as the video progresses, ensure that the additional wastage of downloaded data is kept to a minimum. We will study this phenomenon further in our future work.

4. PERFORMANCE EVALUATION

In order to evaluate the performance of streamloading, we simulate its implementation and compare it with streaming. In this section, we describe a detailed implementation of a video streamloading service, build a simulation model for it, and compare its performance with a streaming service.

4.1 Streamloading Implementation

We consider a video to be divided into N sequential chunks, $\{c_i \mid 0 \le i < N\}$, each containing an equal length of playing time of the video. Each chunk c_i is encoded in M layers, resulting in M subchunks, $\{s_{ij} \mid 0 \le j < M\}$, where s_{i0} is the base layer subchunk of chunk c_i and $\{s_{ij} \mid 1 \le j < M\}$ are its enhancement layer subchunks. The user must start playing chunk c_i as soon as chunk c_{i-1} finishes playing and subchunk s_{i0} has finished downloading. A video interruption takes place if subchunk s_{i0} has not finished downloading by the time chunk c_{i-1} finishes playing. Once a user starts playing chunk c_p in any system, only the future subchunks $\{s_{ij} \mid p < i < N, 0 \le j < M\}$ may be downloaded.

For a user playing chunk c_p, a video streaming service only allows subchunks from S_p^{stream} to be downloaded, where

$$S_p^{stream} = \{s_{ij} \mid p < i < (p + b), 0 \le j < M\}.$$

Here, b is the legally allowed buffer size measured in number of chunks.

In streamloading system, when a user is playing chunk c_p, only subchunks from $S_p^{streamload}$ may be downloaded, where

$$\begin{aligned} S_p^{streamload} = & \{s_{i0} \mid p < i < (p+b)\} \quad \cup \\ & \{s_{ij} \mid p < i < N, 1 \leq j < M\}. \end{aligned}$$

Thus, base layer subchunks are downloaded based on the allowed buffer size b, while all future enhancement layer subchunks are allowed to be downloaded.

We define a quality window consisting of $w > b$ chunks immediately following chunk c_p being played, and aim to continuously optimize the quality of video within this window. If S_p denotes the set of all downloadable subchunks when chunk c_p is playing, in streaming and streamloading systems, subchunk $s_{ij} \in S_p$ may be downloaded before subchunk $s_{i'j'} \in S_p$, iff any of the following conditions is true.

- $i < i' \leq p + w$ and $j = j'$
- $i\ ,\ i' \leq p + w$ and $j < j'$
- $i \leq p + w < i'$
- $p + w < i = i'$ and $j < j'$
- $p + w < i < i'$

Thus, while chunk c_p is playing, at first, all downloadable base layer subchunks are requested for download, earlier subchunks being requested first. Downloadable enhancement layer subchunks falling within the quality window are then requested for download layer by layer, earlier subchunks being requested first within a layer. After all subchunks belonging to the quality window are downloaded, any remaining downloadable subchunks are then requested for download chunk by chunk, lower layer subchunks being requested first within a chunk.

4.2 Simulation Model

For performance evaluation of the proposed streamloading video delivery system, we simulated a cellular network using the C programming language, which, compared to other simulation platforms, allows for a more flexible implementation of lower layers of the network stack as well as the application layer. We simulated a macrocell and overlaid femtocells with interfering transmissions of video packets to mobile users in both streaming and streamloading systems. Note that the femtocells could have been replaced by WiFi hotspots, as long as the unrelated problem of maintaining mobile connectivity for a single connection across these two technologies, cellular and WiFi, is assumed to have been solved. We will also present results for the case when there are no femtocells available. We measure various aspects of the quality of videos served to evaluate them.

4.2.1 Network Model

In our simulation, one macrocell covers the region under consideration, which is a circle with a radius of 1000 m, with the Base Station located at the center. Deployed randomly within the region, following a uniform random distribution, are 20 femtocells. The macrocell downlink transmission power is set such that the received SNR at the cell edge is 6 dB, which is the minimum requirement for decoding data in IEEE 802.16e (WiMAX) [1]. The femtocell transmission power is controlled as in [11], achieving a consistent range of 50 m. WiMAX is adopted as the cellular standard for our simulation; we expect similar results if we followed the LTE standard instead, which is also based on similar OFDMA technology. Figure 3 illustrates an example

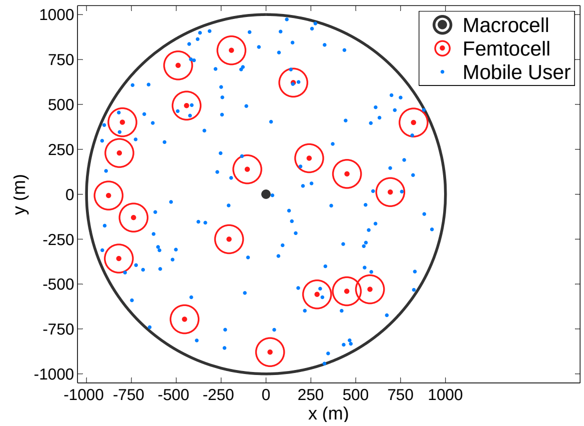

Figure 3: Example area under consideration for simulation with 20 femtocells overlaid on one macrocell, and 120 mobile users.

area being simulated. We simulate two downlink channels for transmissions throughout the network, each representing a group of channels in a WiMAX OFDMA system. The macrocell uses both channels and the femtocells reuse only the second. Throughput statistics, the path loss, and other network parameters are set as in [11].

4.2.2 Transmission Scheduling

Transmissions to users are scheduled in a TDMA fashion with time slot lengths of 2 ms each. The macrocell/femtocell base stations schedule transmissions to one user on each channel in every time slot based on the proportional fairness criterion [5], with a throughput window length of 1 s. One fairness index is maintained for base layer video data transmissions and one for enhancement layer video data transmissions. Base layer video data transmissions are scheduled with absolute priority over any enhancement layer video data. Data requests of different enhancement layers are scheduled with equal priority. With this prioritized proportional fairness scheduling, when user mobility and demand from users are identical, the initial delay (time between when the demand from a video arrives, and when the video starts playing) and interruptions in the videos are identical for streaming and streamloading services. Identical demand arrivals, initial delays, and interruptions ensures identical video playback in the two systems and thus enables a fair comparison of performance.

4.2.3 Video Data

Videos are split into chunks and subchunks as discussed in Section 4.1, with a chunk length of 1.2 s. All videos are 100 min in length, and coded into four layers, i.e., $N = 5000$ and $M = 4$. Quality window size, $w = 1$ for streaming and $w = 50$ for streamloading systems. We consider CIF, Enhanced Definition (ED), and High Definition (HD) quality videos, whose data rates are shown below in Table 1.

Table 1: Video Data Rates (kbps)

Quality / Video Type	CIF	ED	HD
Base Layer Only	67	533	1067
Up to 1 Enhancement Layer	107	800	1600
Up to 2 Enhancement Layers	120	933	1867
All Layers	133	1067	2133

4.2.4 User Behavior

All users in the region under consideration are mobile, and thus switch their associated cells based on their locations.

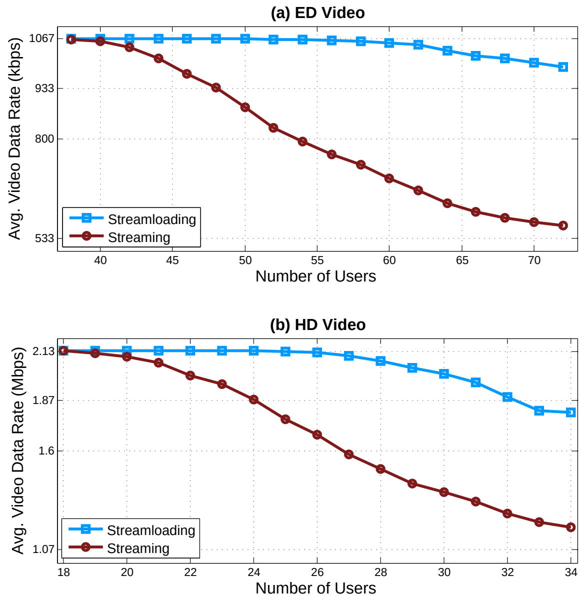

Figure 4: Video Quality Measurement for Streaming and Streamloading systems with increasing number of users consuming ED and HD videos, respectively, with a buffer size of 4.8 s.

The users follow the Random Walk mobility model with reflection at the edge of the macrocell, with an average speed of 11 mph, which corresponds to the average vehicle speeds in congested urban areas, and a direction change periodicity randomly and uniformly distributed between 0 to 100 s. The first demand from every user arrives at uniformly distributed time points (to avoid undesirable synchronization), following which every user places a new demand as soon as they finish watching a video.

4.3 Results and Analyses

We measure the quality of video served to the users by their average video data rate. Figures 4 (a) and (b) show the video quality comparison between streaming and streamloading for an increasing number of users in the system for ED and HD videos, respectively. The measurements are done for a buffer size of 4.8 s ($b = 4$). As is clear from the figures, the average quality of video in a streaming service starts to drop from near perfection much sooner than that in a streamloading service, as the number of users in the network increases. For a network with 70 users consuming ED video, for example, a streamloading service provides more than two enhancement layers of video to the users on the average, while a streaming service is only able to provide a little better than only the base layer. Similarly, for a network with 34 users consuming HD video, while a streamloading service provides almost two enhancement layers of video to the users, a streaming service is able to provide slightly better than only the base layer. When the network is overloaded with a large number of users, or when the network is underloaded and has few users, the quality of videos in streamloading is almost identical to that in streaming.

Since the average video quality may not represent a complete picture of how the video quality is spread through the chunks of all the videos served, we now look at the distribution of video quality in streamloading and streaming systems. Figures 5 (a) and (b) show the number of chunks served at various quality levels, defined by the number of layers served, for a system with 66 users consuming ED videos and a system with 31 users consuming HD videos, respectively. We can see here that while a streaming system serves major portions of videos at base layer quality (79% of ED Video chunks and 62% of HD video chunks), a streamloading system is able to serve a large majority of perfect quality chunks for both ED and HD videos (86% of ED Video chunks and 73% of HD video chunks).

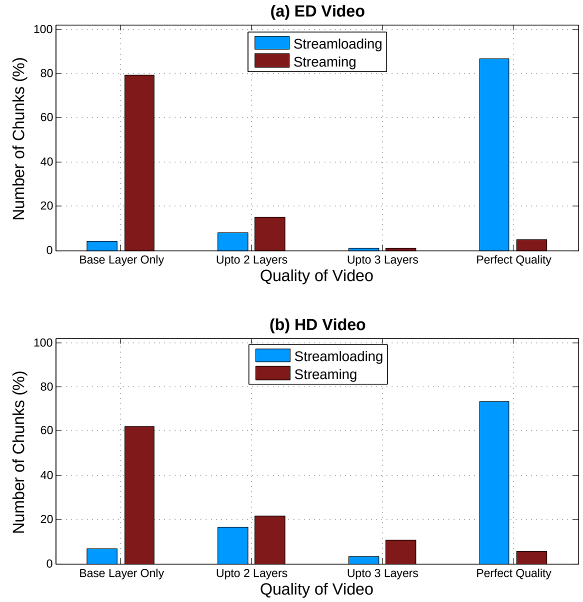

Figure 5: Video Quality distribution for Streamloading and Streaming in systems with 66 and 31 users consuming ED and HD videos, respectively, with a buffer size of 4.8 s.

We also analyzed cellular networks without any femtocells. Since the performance of streamloading relies on the fluctuations in data rates experienced by users, and since such fluctuations are comparatively lower in cellular networks with only a macrocell, the benefit of streamloading over streaming is expected to be lower. Thus, in such a system, we consider users consuming lower quality CIF videos (as specified in Table 1), and with lower buffer size of 3.6 s ($b = 3$). The comparison of video qualities is presented in Figures 6 (a), where we can see that for a system with 340 users, streamloading delivers up to two additional layers of video when compared to streaming on an average. Even though the difference in average video qualities delivered by streamloading and streamloading systems is less here, a large portions of videos actually show much better quality as evident in Figure 6 (b), which shows the quality distribution for a system with 360 users, as an example. We can see that while almost 70% of the CIF Video chunks served were of the first enhancement layer quality or worse in a streaming system, more than 82% of the CIF Video chunks served in a streamloading system were of perfect quality.

We find that for all kinds of videos, a streamloading system is able to serve more than 50% additional users with near perfect video quality, as compared to a streaming system, in the presence of 20 femtocells in the macrocell. Even in the absence of femtocells, this number is found to be as high as 35%. This shows that by using streamloading, network operators can increase their network capacity, and content providers can serve a higher number of users with better quality video using the same network resources.

Fluctuations in quality of video during playback may af-

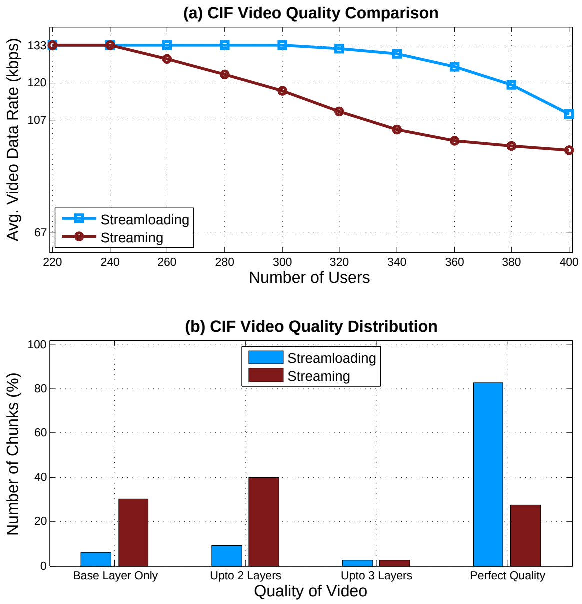

Figure 6: Average Video Quality and 360-User Video Quality Distribution for systems with no femtocells and users consuming CIF Quality videos, with a buffer size of 3.6 s.

fect user satisfaction negatively. We find the fluctuations grow as the quality of the video deteriorates. Since a streamloading system serves better quality videos in almost all scenarios, the perception of fluctuation in quality of video is also generally found to be lower in streamloading.

5. DISCUSSION

The implementation of a streamloading system proposed in this paper can be further extended in a variety of ways. The femtocells used in the simulations could easily be replaced by WiFi hotspots, as long as mobile connectivity for a single connection across these two technologies, cellular and WiFi, can be maintained. The proposed implementation of a streamloading system can be further improved by more sophisticated algorithms dictating the order of enhancement layer subchunks to download, so that the quality of video experienced is improved and/or the fluctuations in the quality level of the video are reduced. Also, better transmission scheduling algorithms in the cellular network targeted at streaming video in particular can help reduce the airtime consumed by streamloading users such that download of enhancement subchunks at higher data rate regions is favored by the scheduler to that in lower data rate regions.

6. CONCLUSIONS

In order to provide better service to users in wireless networks with highly variable data rates, we proposed a novel video delivery service, streamloading, that allows users to download enhancement layer data while streaming only the base layer data, thus improving the quality of the video served to the users, while still legally qualifying as a video streaming service offered at cheaper video streaming service prices. The quality of video enjoyed by users in streamloading, in the worst case scenario, is no worse than that in streaming, while in the best case scenario, it can be as good as that in downloading. We proposed a detailed implementation of streamloading for video coding using SVC, and extensively simulate the system for a cellular network with overlaid femtocells. We show that streamloading can benefit mobile wireless users by serving them with better quality video. Only when the network is severely overloaded or underloaded does streamloading perform just as well as a streaming service. It can also be used to improve the capacity of a macrocell, thus benefiting the network operator as well as video delivery service providers.

7. REFERENCES

[1] 802.16e-2005 and IEEE Std 802.16-2004/Cor1-2005. IEEE 802.16e Standard, 2006.

[2] Rates and Terms for use of Musical Works under Compulsory License for Making and Distributing of Physical and Digital Phonerecords. *Title 37 Patents, Trademarks, and Copyrights; Chapter III Copyright Royalty Board, Library of Congress; Subchapter E Rates and Terms for Statutory Licenses; Part 385*, 37 CFR 385.11, February 2009.

[3] C. Breen. Where to look for streaming movies and TV shows. July 2012. http://goo.gl/JlW0I.

[4] Cisco. Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011-2016. February 2012. http://goo.gl/reBfY.

[5] E. Dahlman, S. Parkvall, J. Skold, and P. Beming. *3G Evolution: HSPA and LTE for Mobile Broadband.* Academic Press, 2008.

[6] J. Erman, A. Gerber, K. K. Ramakrishnan, S. Sen, and O. Spatscheck. Over The Top Video: the Gorilla in Cellular Networks. In *Proceedings of the 2011 ACM SIGCOMM conference on Internet Measurement*, IMC'11, pages 127–136. ACM, November 2011.

[7] D. Hassoun. Dynamic streaming in Flash Media Server 3.5 - Part 1: Overview of the new capabilities. August 2010. http://goo.gl/0G95h.

[8] S. Hua, Y. Guo, Y. Liu, H. Liu, and S. Panwar. Scalable Video Multicast in Hybrid 3G/Ad-Hoc Networks. *Multimedia, IEEE Transactions on*, 13(2):402–413, April 2011.

[9] X. Qiu, H. Liu, D. Li, S. Zhang, D. Ghosal, and B. Mukherjee. Optimizing HTTP-based Adaptive Video Streaming for wireless access networks. In *Broadband Network and Multimedia Technology (IC-BNMT), 2010 3rd IEEE International Conference on*, pages 838–845, October 2010.

[10] R. Pantos (Ed.) and W. May. HTTP Live Streaming. *Apple Inc.*, September 2012.

[11] A. Rath, S. Hua, and S. Panwar. FemtoHaul: Using Femtocells with Relays to Increase Macrocell Backhaul Bandwidth. In *INFOCOM IEEE Conference on Computer Communications Workshops, 2010*, pages 1–5, March 2010.

[12] T. Schierl, T. Stockhammer, and T. Wiegand. Mobile video transmission using scalable video coding. *Circuits and Systems for Video Technology, IEEE Transactions on*, 17(9):1204–1217, September 2007.

[13] H. Schwarz, D. Marpe, and T. Wiegand. Overview of the Scalable Video Coding Extension of the H.264/AVC Standard. *Circuits and Systems for Video Technology, IEEE Transactions on*, 17(9):1103–1120, September 2007.

[14] T. Stockhammer, G. Liebl, and M. Walter. Optimized H.264/AVC-based Bit Stream Switching for Mobile Video Streaming. *EURASIP J. Appl. Signal Process.*, 2006:127–127, January 2006.

[15] T. Wiegand, G. Sullivan, G. Bjontegaard, and A. Luthra. Overview of the H.264/AVC video coding standard. *Circuits and Systems for Video Technology, IEEE Transactions on*, 13(7):560–576, July 2003.

[16] A. Zambelli. Mobile video transmission using scalable video coding. *Microsoft Corporation*, March 2009.