Adaptive Streaming over Content Centric Networks in Mobile Networks using Multiple Links

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Abstract—**This paper presents the usage of Content Centric Networking (CCN) for adaptive multimedia streaming in mobile environments, leveraging the recent ISO/IEC MPEG Dynamic Adaptive Streaming over HTTP (DASH) standard. The performance of DASH over CCN is evaluated using real-world mobile bandwidth traces and compared to previous evaluations of different DASH-based as well as proprietary systems. As there are no client-server connections in CCN, it offers the possibility to transfer data from multiple sources as well as over multiple links in parallel, which is definitely an important feature, e.g., for mobile devices offering multiple network links. This functionality is used and evaluated in this paper in combination with DASH, making it possible to dynamically choose the best performing link for media streaming, which is a clear advantage over DASH using HTTP and the TCP/IP protocol stack. The evaluation therefore investigates DASH over CCN in two scenarios using synthetic and real-world mobile bandwidth traces respectively, showing a significantly better performance than conventional DASH using only one connection.**

Index Terms – MPEG-DASH, CCN, Dynamic Adaptive Streaming over HTTP, Content Centric Networking, Evaluation

I. Introduction

Nowadays, multimedia is omnipresent in the Internet and already responsible for 58% of the total Internet traffic in North America's fixed access networks; forecasts predict it will be around 70% in 2017 in both wired and wireless environments [1]. Therefore, major content providers such as Netflix, Youtube, Hulu, and Vudu are leveraging HTTP-based multimedia transmission, which enables them to deploy their streaming service over the top of the existing Internet infrastructure. However, the Internet provides best effort services without Quality of Service (QoS) guarantees and is facing varying bandwidth conditions; it has not been designed for real-time multimedia streaming. In order to cope with these conditions, the adaptive delivery of multimedia content over HTTP got a lot of attention in recent years, mainly caused by proprietary solutions from the major industry players like, e.g., Microsoft Smooth Streaming, Apple HTTP Live Streaming, and Adobe Dynamic HTTP Streaming. This finally resulted in the standardization of Dynamic Adaptive Streaming over HTTP (DASH) [2] by ISO/IEC MPEG, which combines the features of these systems within a single standard.

In the past, several new Internet architectures have been proposed which are mainly content oriented and generally referred to as Information Centric Networks (ICN) enabling content-awareness within the network. In this context, Jacobson et al. [3] proposed Content Centric Networking (CCN) where content is addressed via Uniform Resource Identifiers (URI) as opposed to via its location. There are no end-to-end connections in this concept. The content is directly requested via *Interest* packets describing the content, wherever it may be located and without any connection setup. The actual data is transmitted as *Data* packets, which are cached on network routers making popular content widely available and fast accessible. As these Data packets are handled efficiently by the network nodes, it is possible to satisfy multiple Interest packets, originating from different clients and requesting the same content, with one Data packet from the actual origin server and, thus, providing implicit support for multicast.

CCN [1] and MPEG-DASH [2][4] have several elements in common such as the client-initiated pull approach, the content being dealt with in pieces as well as the support of efficient replication and distribution of content pieces within the network. As CCN is a promising candidate for the Future Internet (FI) architecture, it is useful to investigate its suitability in combination with multimedia streaming standards like MPEG-DASH. In this context, the purpose of this paper is to present the usage of CCN instead of HTTP in MPEG-DASH, and the performance thereof in mobile environments, which will play an important role in the future. In our previous evaluations [5] we have already shown various differences of existing adaptive streaming systems in terms of effective media throughput and adaption decisions. Furthermore, we evaluate the performance of DASH over CCN using multiple links which are encountering bandwidth variations. As CCN is not based on classical host-to-host connections, it is possible to consume content from different origin nodes as well as over different network links in parallel, which can be seen as an intrinsic error resilience feature w.r.t. the network. This is a useful feature of CCN for adaptive multimedia streaming within mobile environments since most mobile devices are equipped with multiple network links like 3G and WiFi.

The concept of CCN and its reference implementation CCNx (www.ccnx.org) is available to the community but the number of publications related to CCN and adaptive multimedia streaming is still limited. Authors concentrate on Voice over IP via CCN [7], non-adaptive multimedia streaming [8] or the caching aspects of adaptive multimedia streaming protocols like Apple HTTP Live streaming (HLS) [9]. In contrast to this, our work concentrates on the streaming performance of DASH over CCN, especially in mobile environments, as well as the efficient usage of multiple available network links.

The remainder of the paper is organized as follows. Section II evaluates the performance of MPEG-DASH in mobile environments. Section III comprises the multi-link

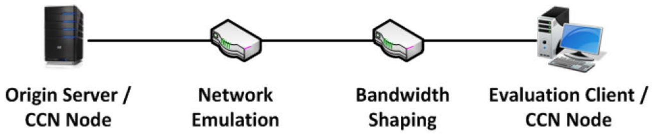

Figure 1: Streaming Performance Evaluation Setup.

performance evaluation in such environments and Section IV concludes the paper.

II. Real-World Mobile Streaming Evaluation

Due to the increasing availability of mobile high speed Internet connections like WiFi/3G/4G and the smartphone boom in recent years, mobile video streaming is becoming more and more important. This will also be the case in next generation networks, which makes it necessary to leverage adaptive video streaming technologies in such environments, specifically as multimedia traffic reaches a total share of up to 66% of the total mobile traffic in 2014 [4].

A. Methodology

For the evaluation we used the same DASH content and experimental setup (Figure 1) as in our previous papers [6][10] to provide an objective comparison of DASH over CCN.

We used the Big Buck Bunny (www.bigbuckbunny.org) video sequence, encoded at 14 different bitrates ranging from 100 to 4500 kbps and a segment length of two seconds [11]. The experimental setup consists of four network nodes, namely the evaluation client/CCN node, bandwidth shaping, network emulation, and origin server/CCN node. All nodes are using Ubuntu Linux 12.04 and are based on the same hardware. The bandwidth shaping node controls the maximum achievable bandwidth using the Linux Traffic Control system (tc) and the Hierarchical Token Bucket (htb) packet scheduler implementing Statistical Fair Queuing (sfq). The network emulation node controls all network related parameters such as round trip time (RTT), which has been set to 150 ms based on our measurements. The evaluation client and the origin server are running CCNx V6.1 (www.ccnx.org).

Our DASH over CCN implementation has been tested using three different real-world bandwidth traces, which have been recorded during several freeway car drives as depicted in Figure 2. We used a HUAWEI E169 HSDPA USB Stick as network device and a SIM-card of the Austrian cellular network provider A1. More detailed information concerning the experimental setup can be found in [10]. Furthermore, we used the same metrics as in [6][10]. As overall performance indicator for the comparison of the different systems we used the ***average bitrate*** of the transferred media stream.

Table 1. Comparison Mobile Bandwidth Traces Evaluations.

Name	Average Bitrate	Average Switches	Average Unsmoothness
Unit	**[kpbs]**	**[Number of Switches]**	**[Seconds]**
Microsoft [10]	1522	51	0
Adobe [10]	1239	97	64
Apple [10]	1162	7	0
DASH VLC [10]	1464	166	0
Improved DASH VLC [6]	2341	81	0
DASH SVC [6]	2738	101	0
DASH over CCN	1326	160	0

Figure 2. Bandwidth Traces [10].

Additionally, the ***number of quality switches*** has been used to measure the variances during the streaming sessions. A small number of quality switches is preferred as frequent quality switches may decrease the Quality of Experience (QoE) [13]. Finally, the smoothness of the streaming session is represented by the ***number of unsmooth seconds***, which shows the number of seconds where the playback stalls. This metric should be zero, since it is the goal of adaptive streaming systems to prevent stalls of the streaming session because stalls have a significant impact on the QoE [14].

B. Evaluation Results

Table 1 shows the results of the evaluation of our DASH over CCN implementations compared to previous evaluations of proprietary systems, i.e., Microsoft Smooth Streaming (MSS), Apple HTTP Live Streaming (HLS), and Adobe Dynamic HTTP Streaming (ADS). In terms of ***average bitrate*** of the transferred media stream, DASH over CCN can definitely compete with the proprietary systems of Apple and Adobe. Additionally, it is close to MSS and an early version of our DASH VLC Plugin [10]. However, it cannot compete with our improved DASH client presented in [6], which leverages advanced HTTP/1.1 features like HTTP pipelining and persistent TCP connections (cf. "Improved DASH VLC") or adopts a scalable video codec (cf. "DASH SVC"). In terms of the ***number of average switches*** during the streaming session, DASH over CCN got a relatively high number which indicates that the used adaptation logic based on [6] needs more adjustments to the characteristics of CCN. However, the main goal of adaptive streaming was reached as the ***number of unsmooth seconds*** is zero and thus there was no stall in any of the three streaming sessions.

Figure 3 gives a detailed view of the results for experiment 3. Due to space constraints, only this experiment is presented. Since this settings was also presented in our previous papers [6][10] evaluating other systems (c.f. Table 1), one can

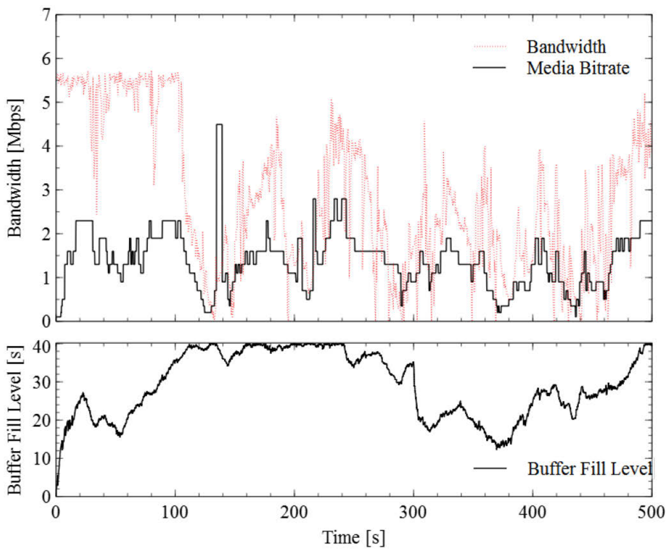

Figure 3: Evaluation Result Experiment 3.

compare the results and figures of those papers with this work. At the beginning of the session, DASH over CCN starts at the lowest representation to minimize the startup delay and quickly selects higher bitrate representations as soon as the minimum buffer fill level of 30 % is reached. As one can see, the adaptation follows the available bandwidth very well, maintaining a high buffer fill level over major parts of the streaming session. However, it is not able to choose higher representations than 2800 kbps (except one wrong adaptation decision around second 135) which is a result of several limitations and shortcomings of the CCNx implementation. First, the protocol overhead of the headers for routing and signing introduced by CCN is relatively high, accounting for ~24 % of the total transmitted data. Second, the DASH segments are not requested in a pipelined manner as it is done by the DASH VLC plugin in combination with HTTP/1.1. This results in a high sensibility for network delays, as shown in [11], which results from underutilizing the available bandwidth for the downlink while sending the Interest packet for the subsequent segment. If the Interest packets for the segments are sent in a pipelined manner, i.e., the Interest for the next segment is sent while the previous one is still downloading, the available bandwidth of the downlink is always fully utilized, which results in a higher average media bitrate. Third, the CCNx is a prototype implementation with shortcomings and not integrated into the operating system kernel, e.g., like TCP/IP is. These findings will be the basis for further work enhancing the streaming performance of DASH over CCN. Further improvements may also include the additional usage of location-based bandwidth information for the representation selection, like shown in [12].

III. MULTILINK TRANSMISSION

One of the advantages of CCN is the link independence of the data retrieval. In today's IP-based Internet, data transfer is bound to one network interface and cannot switch to other links without opening a new connection. In contrast, CCN is agnostic to the used network link and can switch between multiple available links during a data transfer. The decision which link should be used is done in the CCN strategy layer based on the routing information and the performance of each link in the past. The effective link throughput, i.e., influenced by bandwidth capacity and delay, is measured by the time needed for fetching a CCN chunk. That is, the time between sending the Interest packet and fully receiving the associated Data packet. Therefore, CCN routers automatically find the fastest link for retrieving specific content which is reflected in the self-organizing nature of the CCN routing concept. As shown in [7], this offers the possibility for the strategy layer to react very fast to link failures without noticeable problems for the data transfer. As soon as the response time of a link increases to a value which is higher than the response time measured on an alternative link, the subsequent Interests will be sent out on that alternative link which also has to offer the associated route for the Interest's name prefix. This behavior is not only useful for in-network routing; it may also be useful for client devices offering multiple links. This is the case for today's smartphones which typically offer both 3G/4G and WiFi interfaces. The bandwidth provided on both links depends on the location and the signal strength. This may even lead to link outages when the user moves out of range of a WiFi access point or a 3G base station. This is a major problem for IP-based traffic which is bound to the underlying network link. There are already solutions for this problem, e.g., 802.21 [13] enabling handover and interoperability between heterogeneous network types but they are not widely deployed.

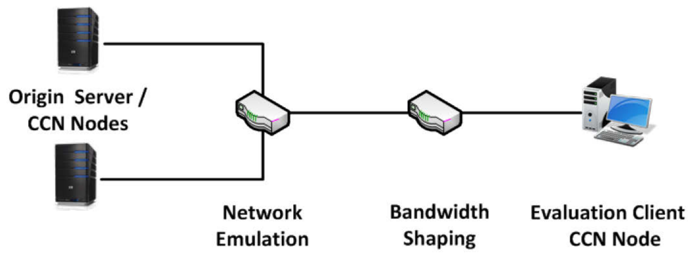

Figure 4: Multilink Streaming Evaluation Setup.

CCN offers this functionality out of the box which is beneficial when used for DASH-based services. In particular, it is possible to enable adaptive video streaming handling both bandwidth and network link changes. That is, CCN handles the network link decision and DASH is implemented on top of CCN to adapt the video stream to the available bandwidth.

The following evaluation investigates the performance of DASH over CCN in combination with various bandwidth variations over different network links and the traffic handover between them, managed by CCN. In this context, the influence of network link variations to the media streaming performance of DASH is analyzed. As the previous performance evaluation shows a high network delay sensitivity of CCN, the experiment is done in different network delay scenarios to evaluate their influence to the media throughput performance of DASH over CCN. Furthermore, the experiment is done using two of our real-world mobile bandwidth traces, showing the multilink performance of DASH over CCN in such environments.

A. Methodology

Our evaluation is based on the experimental setup depicted in Figure 4 and represents a scenario where two links are available to the client. The experimental setup consists of the same elements and performance metrics as used previously in Section II.A. To show the transmission over different network links, we use two CCN origin nodes, which both provide the same content as used in Section II.A. The available bandwidth between the client and each origin node is shaped independently from each other using the bandwidth shaping node.

For the evaluation with synthetic bandwidth traces, the available bandwidth is predefined for two separate network links and changes every 20 seconds (cf. Figure 5 and Figure 6). At the beginning, the first link offers 1 Mbps and the second link 2 Mbps. This bandwidth difference is increased in the periods after seconds 80 and 140, to show the link selection in different scenarios. As the link connectivity can change rapidly, especially in mobile networks, we evaluate the handover from one link to another for each of those scenarios in seconds 20, 100, and 160. As previously shown, CCN is sensitive to high network delays, which is the reason why this evaluation is done using different RTTs, i.e., 0, 25, 50, 100, and 150 ms.

For the evaluation based on our real-world mobile traces we used the Traces 2 and 3, which cover the same route, as depicted in Figure 2. The available bandwidth was restricted for both origin nodes separately and adjusted every two seconds, the network delay was set to 150 ms, which is both equal to the evaluation in Section II.A.

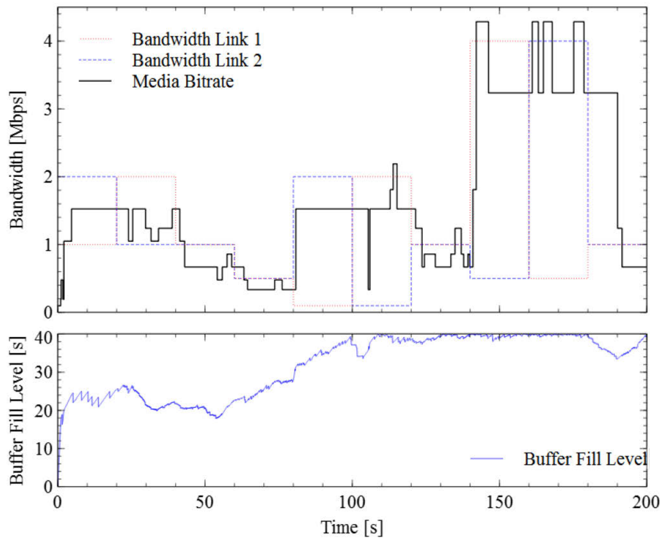

Figure 5: DASH over CCN over multiple links, RTT = 0 ms.

B. *Evaluation Results*

The experiments depicted in Figure 5 for RTT = 0 and Figure 6 for RTT = 150 ms show the previously described link independence of CCN as well as the adaptation of DASH to the bandwidth changes. The CCN strategy layer does the switch from a low bandwidth network link to one with a higher bandwidth. As CCN is monitoring the response time of the requested data (Interest and Data packet transmission time), the bandwidth drop at one link can be detected and subsequent Interests can be sent over the faster link. However, a short decrease of the effective media throughput is noticeable after a network link change occurred, which is due to the CCNx implementation of the Interest packet pipelining. That is, the pipeline of Interests has to be filled again after the handover of the network link which results in a temporary decrease of the effective media throughput.

Figure 5 depicts the multi-link scenario with RTT = 0 ms. The CCN strategy layer tries to select the fastest link to retrieve the requested data. In second 20, the bandwidth of link 1 increases from 1 Mbps to 2 Mbps and link 2 decreases from 2 Mbps to 1 Mbps, but the media bitrate stays constant. However, the media throughput is not enough to maintain the media bitrate of the chosen representation which causes a media bitrate drop in second 25. This is a result of the described effect of the Interest packet pipelining when switching between network links. Also the bandwidth change in second 100 causes a subsequent media bitrate drop. As the change from one link to the other causes a small drop of the effective media throughput, the adaptation logic of DASH requests a lower representation of the content in the subsequent seconds to maintain a smooth playback, which shows the benefit of the combination of MPEG-DASH and the multi-link features of CCN. Nevertheless, the strategy layer of CCN manages the handover from one link to another nearly seamlessly such that there are no stalls, which is shown by the associated buffer level. As already shown by the previous evaluations, the media throughput decreases in networks with higher delays, depicted in Figure 6 with RTT = 150 ms. Again, the bandwidth changes between the links, i.e., in the seconds 20, 100 and 160, have an effect on the media bitrate. When using RTT = 150 ms the effect becomes clearer and it can be observed after seconds 27, 102, and 162 depicted in Figure 6. The delay is due to the longer time needed to detect the bandwidth drop on the link with lower bandwidth.

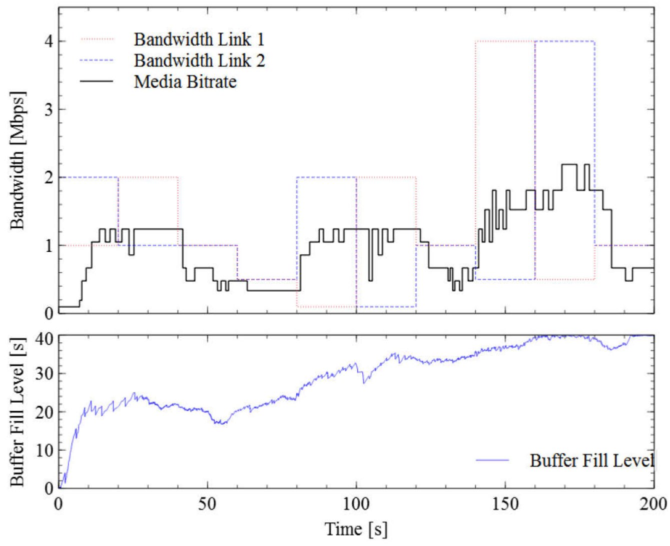

Figure 6: DASH over CCN over multiple links, RTT = 150 ms.

Figure 7 shows the performance of DASH over CCN using two separate links based on our real-world mobile bandwidth traces. The bandwidth trace of Trace 3 was used for constraining the bandwidth of link 1 and Trace 2 for link 2 respectively. Conducting the experiment with only one available link, the average bitrate was 1324 kbps for link 1 and 1490 kbps for link 2 respectively. Using both links together, the average bitrate was 1710 kbps, which is ~29 % and ~15 % higher than using link 1 and 2 separately. Additionally, the buffer fill level is higher over the whole streaming session than it would be in the case of only one network link. A detailed comparison of Figure 3, using Trace 3 only, and Figure 7, using Trace 2 and Trace 3, shows that the client's CCN strategy layer constantly chooses the fastest link during the experiment. This can be seen, e.g., around second 200, where the chosen representation is 1100 kbps in Figure 3 and 3400 kbps in Figure 7.

The conducted multi-link experiments show disadvantages of the current CCN implementation. A detailed analysis of the network traffic revealed that the bandwidth available to the client is the bandwidth of the fastest link (cf. Equation 1). In the current implementation of CCNx it is not able to split up the data transmission to multiple links, such that the total

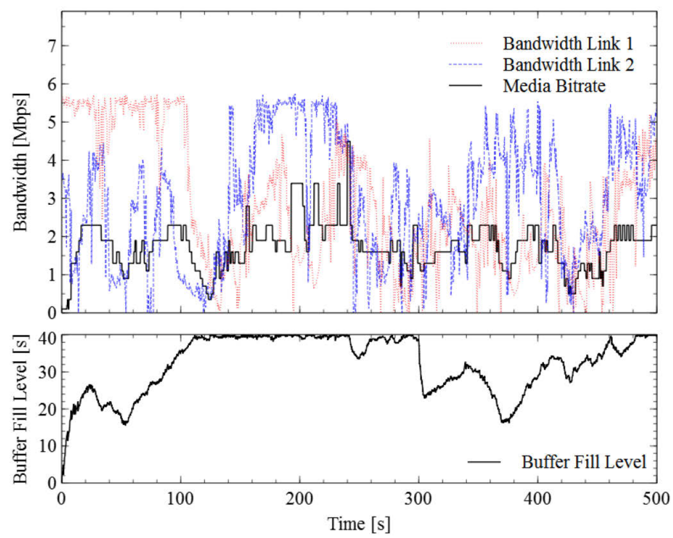

Figure 7: DASH over CCN over multiple links using mobile traces.

available bandwidth of all underlying links could be leveraged by the client (cf. Equation 2). Therefore, the improvement of the CCN strategy layer to support data retrieval over multiple links to achieve a higher media throughput is subject to future research and improvements.

$$\boldsymbol{bw_{CCNx} = max(bw_1, \ldots, bw_n)} \quad (1)$$

$$\boldsymbol{bw_{DASH} = \sum_{i=1}^{n} bw_i} \quad (2)$$

n ... $Number\ of\ available\ links\ for\ a\ name\ prefix$
bw_{CCNx} ... $Bandwidth\ available\ for\ media\ streaming\ in\ the\ current\ CCNx\ implementaiton$
bw_{DASH} ... $Bandwidth\ available\ for\ media\ streaming\ in\ using\ the\ improved\ strategy\ layer$

Future modifications of the CCN strategy layer can focus on such traffic load balancing between the available links. This would increase the effective media throughput of DASH, however, it could potentially lead to high variations of the resulting bandwidth which is available to the client. As DASH is designed for environments with dynamic bandwidth conditions, they can be compensated in general. However, more conservative adaptation algorithms may prevent too frequent switching between the content's bitrate representations as well as compensate short-term bandwidth drops caused by network link switches more smoothly.

IV. Conclusion and Further Work

This paper proposed and evaluated the combination of CCN with DASH for its usage in mobile environments, especially for devices equipped with multiple network interfaces. Therefore, an evaluation of DASH over CCN using real-world mobile bandwidth traces has been conducted and compared to previous evaluations of state-of-the-art DASH as well as proprietary adaptive HTTP streaming systems, summarized in Table 1. The results showed that our solution definitely can compete with the systems of major industry players like Adobe and Apple, and is close the Microsoft's Smooth Streaming. However, it cannot compete with our optimized DASH client implementations. Nevertheless, several improvements have been investigated and highlighted, which are the basis for future work.

Furthermore, the retrieval of data over multiple links in parallel and its benefits in combination with DASH have been evaluated. We have shown that this is a useful feature specifically for adaptive multimedia streaming, since it offers the possibility to dynamically switch between the available links depending on their bandwidth capabilities, transparent to the actual DASH client. As shown in the experiments based on synthetic bandwidth changes of two available network links, CCN exploits the highest bandwidth available. The noticeable drop of the media throughput when switching between network links can be smoothed out by DASH running on top of CCN. Additionally, our experiment using two of our real-world mobile bandwidth traces show that this is also the case for highly fluctuating bandwidth conditions resulting in a ~29 % and ~15 % higher average media bitrate, respectively, when compared to experiments using only one of the available links. Further optimization possibilities considering a more efficient utilization of all available links have been proposed and can further increase the media throughput while DASH eliminates the effect of resulting bandwidth variations. Future work will also include subjective evaluations based on QoE-related metrics to investigate the influence of the used quantitative metrics on the perceived quality.

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