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Published in:
14th International Conference on Frontiers of Information Technology (FIT)

DOI:
10.1109/FIT.2016.037

Publication date:
2017

Document Version
Peer reviewed version

Link to publication in ResearchOnline

Citation for published version (Harvard):
Nazir, S & Kaleem, M 2017, Multi path multi priority (MPMP) scalable video streaming for mobile applications. in *14th International Conference on Frontiers of Information Technology (FIT).* IEEE.
https://doi.org/10.1109/FIT.2016.037

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Multi Path Multi Priority (MPMP) Scalable Video Streaming for Mobile Applications

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***Abstract*—Video is the predominant data traversing the Internet. Increase in processing power, storage and screen resolution of mobile devices coupled with advances in communication technologies has resulted in proliferation of video applications. Multiple data interfaces on a mobile device can support parallel data streams for high bandwidth and delay sensitive video streaming application. This paper investigates combination of rateless codes with multi priority scalable video to optimize data flow along multiple paths in mobile devices. The results show improved video quality and better resource utilization.**

Keywords—quality; rateless codes; unequal loss protection; scalable.

I. INTRODUCTION

The video traffic over mobile devices is increasing [1] [2] as more applications are deployed placing heavy demands on the available bandwidth. Video communications is mostly over IP (Internet protocol) thus providing opportunities for simultaneous data flow over multiple paths to the multiple communications interfaces of a mobile device. In case of limited bandwidth, parallel flows can also benefit from data prioritisation resulting in better user experience.

H.264 Scalable video coding (SVC) [3] is scalable extension of H.264 Advanced Video Coding (AVC) standard. Scalable video is encoded in layers with a low quality base layer and one or more enhancement layers. Decoding of each successive enhancement layer improves the video quality. Thus it is possible to encode the video only once and depending on its supported resolution, frame rate and processing, a receiving device can choose to decode full video data or a subset (few layers). SVC thus addresses the problem of video transmission to heterogeneous devices. Scalable video can be prioritised to match the network bandwidth hence improving the video quality under given constraints.

In order to sustain the high video data rate it is logical to stream video over multiple paths simultaneously utilising the aggregate bandwidth. Multiple virtualised interfaces are used for simultaneous downloads in [4]. Mobile devices have had multiple data interfaces for a long time but previously the data rates across these were asymmetrical such that only one interface could support the video traffic while other interfaces could provide insignificant contribution. With improvements in cellular data rates it is possible to make simultaneous use of multiple interfaces for supporting video streaming applications.

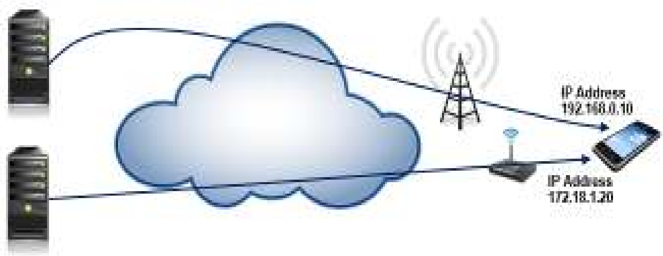

Fig. 1. Video streaming over multiple mobile interfaces.

Content distribution networks (CDNs) provide video data at multiple locations. Although the SVC layered video packets can flow across multiple paths as shown in Fig 1 but packet scheduling is still a problem. Effective bandwidth utilisation across multiple paths requires that important data is sent at a higher priority on all paths. Rateless codes are Forward Error Correction (FEC) codes that can be used to protect and combine the video data arriving independently on the multiple interfaces. Video scalability layers with multiple priorities (importance) can be combined with rateless codes for transmissions over multiple paths.

Rateless codes can generate potentially unlimited coded symbols from a given set of source symbols. One class is Random Network Coding (RNC) [18]. The encoded symbols are linear combinations of the source symbols and each symbol has similar contribution for video decoding. Thus it becomes simpler to schedule traffic over multiple interfaces compared to schemes where for example different quality layers are scheduled according to path capacities or FEC applied to cater for the worst channel conditions. Mobile video transmission with applications of FEC codes for SVC video is described in [5].

The aim of this paper is to propose a method for multi priority (layered) video streaming over multiple paths from

```
+---------------+---------------+---------------+
|0|1|2|3|4|5|6|7|0|1|2|3|4|5|6|7|0|1|2|3|4|5|6|7|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|R|I|   PRID    |N| DID |  QID  | TID |U|D|O| RR|
+---------------+---------------+---------------+
```

Fig. 2. Structure of H.264 SVC 3-byte NAL unit header.

source to a multiple interface device. The paper has the following contributions: (1) proposes rateless codes for prioritised transmission of scalable video data over multiple paths (2) provides a mechanism to maximise the bandwidth utilisation for better video quality. The rest of this paper is organized as follows: Section II briefly covers relevant background on scalable video, RNC and mobile interfaces. System model is described in Section III. Section IV provides the results. The related work is presented in Section V and finally Section VI concludes the paper.

II. BACKGROUND

A. Scalable Video Coding

Scalable video means that it is possible to extract video at different frame resolutions (spatial scalability), qualities (SNR or quality scalability) and frame rates (temporal scalability). H.264/SVC is the first widely adopted scalable coding standard that can target heterogeneous devices. Thus it is possible for a device to selectively download important (yielding best quality for given network constraints) video content depending on its supported frame rate and resolution.

H.264/SVC adds three types of scalability (i) Spatial (ii) temporal (iii) quality or Peak Signal-to-Noise Ratio (PSNR). The video data is divided into network abstraction layer units (NALU) which can be independently decoded. Three byte NAL unit header [6] is shown in Fig 2, where DID, QID, and TID represent the spatial, quality and temporal priority respectively. Thus an application or Media aware network elements (MANE) [3][5] can prioritise the transmission of a NAL unit based on its importance which is also reflected in the field 'PRID' and 'D' that signify the priority and whether a unit is discardable. The SVC layers are interdependent such that data loss of a lower layer may prevent decoding of dependent higher layer, even if received correctly [1].

Scalable video coding divides the video data into various layers which can be added to achieve better quality and throughput. The base layer for SVC comprises the minimum amount of data which must be received in order for a low-resolution, low-quality and low-temporal video to be reconstructed. In order to decode the higher enhancement layers the corresponding lower layers must be available. Loss of base layer will render the video decoding of the whole Group of Pictures (GOP) to fail. Scalability can be combined with prioritised transmission in the form of unequal error protection (UEP) [5].

B. Rateless Codes

Forward error correction (FEC) is a preferred method to combat packet losses especially in applications such as broadcasting where multiple receivers cannot send acknowledgements for each received packets to the server as it would cause data implosion. With rateless codes, it is unimportant as to which packets are received but rather how many (a little more than the source packets) are received that determines successful decoding. This feature makes it simpler for data aggregation over multiple interfaces to a single device. The source packets however must be of the same size in order to apply rateless codes.

Random network codes (RNC) are rateless codes that are increasingly being used [7] for error correction. The decoding is based on Gaussian Elimination (GE) and implementations on smart phones was investigated [8] concluding that decoding with short codes (source length $k = 64$ or 128) are feasible.

RNC are an ideal solution to overcome burst packet losses and out of order packet delivery [2]. It can handle data rate differential between paths or even an intermittent or unavailable link. However, for RNC decoding to succeed, the number of received packets must be more than the source symbols. If the receiver receives packets fewer than the source symbols then these packets cannot be decoded and video decoding will not take place resulting in the whole GOP (or the generation) to be lost.

C. Mobile Interfaces

The primary interfaces for fetching video data at high speed are the Wi-Fi and 3/4/5G network. With better communication infrastructures such as 4G and 5G, the data rates for cellular networks are now comparable to Wi-Fi data rates. In most cases Wi-Fi is free or cheaper to use as compared to 4/5G channel and saving of bandwidth in the costly path could be cost-effective [2]. The data aggregation over mobile device interfaces can help in faster downloads, better error mitigation, and better quality of video.

Emerging cellular networks have provision for fast feedback, e.g., every 2ms feedback [5]. Also for a mobile device there are variations in throughput, delays and transmission errors that determine the actual quality of reception [5]. Measures also are required to overcome link failures [9].

III. SYSTEM MODEL

A. Network Framework

The system model with two transmission paths that may correspond to Wi-Fi and cellular network connection of a mobile device is shown in Fig 3. It is assumed that same encoded scalable video configuration is available at multiple locations for download. We utilise the unequal importance (for video reconstruction) of base and enhancement layer video data to prioritise the transmission of the base layer.

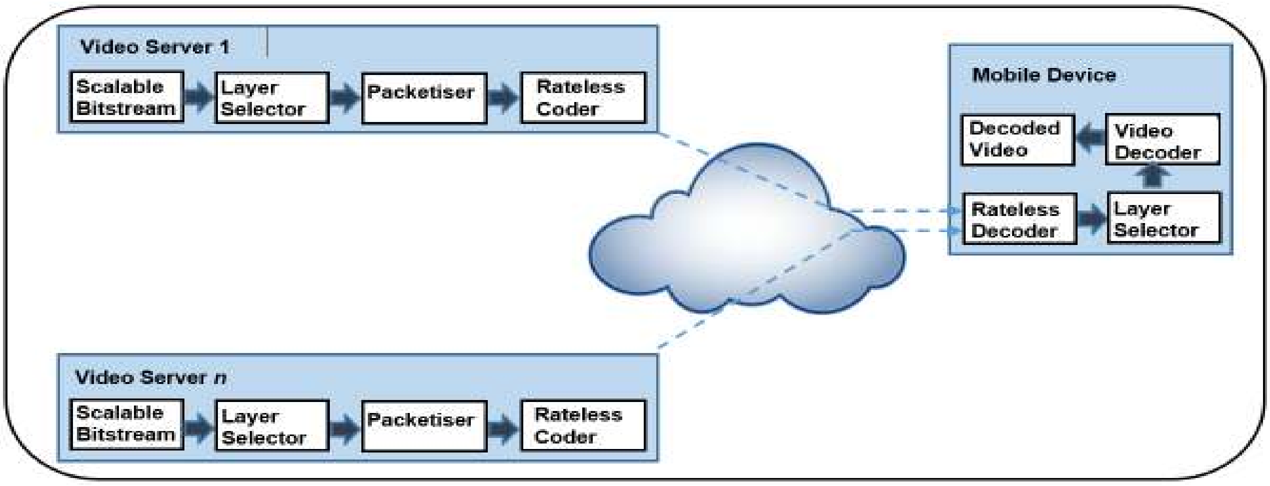

Fig. 3. System model for Scalable video streaming over multiple paths with rateless codes.

TABLE I. VIDEO CHARACTERISTICS AND PACKETISATION-CREW SEQUENCE

Category	*Temporal Layer*	*Temporal Enh Layer*	*SNR Enh. Layer*	*SNR Enh. Layer*	*Total*
Layer ID	*0*	*1*	*2*	*3*	
NAL units	18	54	70	102	102
Size (Bytes)	36,800	70,742	144,887	185,259	185259
IP Packets	26	49	100	127	127
Source Rate (kbps)	550	1057	2167	2767	2767
Frame Rate (fps)	7.5	30	30	30	30
PSNR(dB)	37.37	36.20	38.19	38.83	38.83

TABLE II. VIDEO CHARACTERISTICS AND PACKETISATION-SOCCER SEQUENCE

Category	*Temporal Layer*	*Temporal Enh Layer*	*SNR Enh. Layer*	*SNR Enh. Layer*	*Total*
Layer ID	*0*	*1*	*2*	*3*	
NAL units	18	54	70	102	102
Size (Bytes)	87,811	127,128	209,053	310,707	310707
IP Packets	60	87	143	213	213
Source Rate (kbps)	1314	1901	3129	4648	4648
Frame Rate (fps)	7.5	30	30	30	30
PSNR(dB)	34.98	33.79	35.11	36.83	36.83

The mobile device requests video data over multiple interfaces and the data is received over both interfaces starting with the most important or the base layer. In all cases we assume availability of a feedback channel with negligible delay. The acknowledgement of successful reception of base layer to the video server, results in transmission of the next important layer. This process continues until either the whole of GOP data is received within its playback deadline or curtailed because of limited bandwidth with some layers not requested. In both cases, download of next GOP can start.

For this study, we consider a special case with the availability of two interfaces on the device with data rates corresponding to base and enhancement layers' rates. However the results can be generalised to any number of paths. These interfaces connect to video source to download the same content over multiple connections.

We assume a random packet loss rate (PLR) on each path. For a realistic comparison, at each loss rate, the schemes are compared for the same total data rate and using the same seed for random generator controlling the path loss [13]. We also consider network coding to exploit the unequal importance of video data for scalable video coding.

B. *Video Configuration*

The video sequence Crew and Soccer [1] in 4CIF (704x576) resolution [10] were encoded using Joint Scalable Video Model (JSVM) software version 9.8 [11] at 30 frames per second with a GOP size of 16. We consider a video packet size of 1460 bytes [12]. Medium grain scalability (MGS) feature was used which provides higher coding efficiency [1][5]. Depending on the channel conditions, the number of scalability layers could be combined to provide lesser number of layers reducing the number of rateless code generations. The video is arranged in four layers [13] and the relative characteristics across layers for Crew and Soccer sequence are shown in Table I and II respectively. Please note that layer 0 in both tables has a lower frame rate, so for this study we consider only two layers for video transmission, video data for

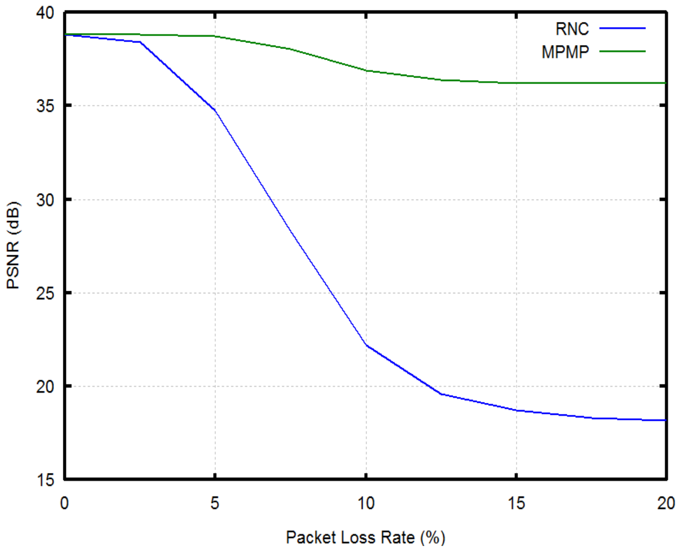

Fig. 4. PSNR for Crew sequence at different packet loss rates.

layer 0 and 1in the tables constitutes the base layer whereas the remaining layers are considered as an enhancement layer.

The NAL units generated as a result of video encoding are placed together in IP packets to generate packets of equal length. The GOP (Group of pictures) data is grouped into multi priority layers (as described above) and each layer is treated as a generation or source block for the RNC. If the base layer fails to decode we assume a reconstruction of PSNR based on the last frame of previous GOP.

We compare two schemes: (1) RNC, with base and enhancement layers on different paths but individually protected with RNC. (2) MPMP with prioritised layered transmission over multiple paths to ensure reception of important video data protected with RNC.

MPMP consists of providing protection to and transmitting of the prioritised video data on a layer-by-layer basis. Thus, the video data (layers) that manage to get across to the mobile receiver has the maximum contribution to the PSNR.

At the decoder, we adopt a basic error concealment strategy based on frame/slice copy to compensate for non-decodable frames and slices.

IV. Results

A. Video Quality at Different Loss Rates

We considered a packet loss rate in increments of 2.5% from 0 to 20% thus covering for a wide variety of mobile signal conditions.

The results for the two schemes are shown in Fig 4. The RNC scheme tries to make use of the available bandwidth by sending the base and enhancement layer separately on the two paths but after the PLR increases beyond 5% the RNC fails to effectively protect the data. MPMP performs much better with very little degradation in quality as it takes advantage by prioritising base layer transmission over both available paths. It can be seen that the degradation in video quality happens gracefully. At 20% PLR, although all the video data has not been received but the proposed MPMP scheme manages to get across the important data.

Thus as long as there is cumulative bandwidth across multiple paths to support the base layer data, MPMP scheme will be able t maintain an acceptable video quality and user experience. The multiple paths can also be used to download video in accordance with the data rates and data tariffs. This may result in substantial savings for the consumers where the Wi-Fi is used in preference of other costlier channels over the cellular network. Similar results were obtained for the Soccer sequence.

V. Related Work

There has been lot of research for supporting multipath scalable video. UEP strategy is considered in [13] to protect H.264/SVC layers with Raptor codes by extending the protection of enhancement layer to base layer. In [14] scalable video is streamed from multiple servers using rateless codes but assumes the knowledge of path loss probabilities to arrive at optimised error protection for each path. The streaming utilises paths with lowest error probability first. Multipath SVC streaming is considered in [15] with bandwidth estimation for each path to change the streaming strategy. Raptor codes are used with SVC in [1] to assess several packetisation options and protection schemes over a single path. Multipath delivery of H.264 SVC video to users in multihomed mobile networks is described in [16] but does not include any FEC. [4] uses transmission of separate layers over separate virtual interfaces for mobile devices. FEC for multipath media streaming is used in [17] to propose an optimisation framework for finding solutions to rate allocation and scheduling but does not use rateless codes so does not take advantage of symbol aggregation across multiple paths.

The work presented here has focused on using rateless codes to exploit unequal loss protection by protecting important layers in scalable video data. The prioritised video content (base layer) is transmitted as a code block over multiple paths protected with RNC to ensure a guaranteed delivery. The feedback of correct reception of the base layer is signalled to the source to switch to transmission of enhancement layers. Thereafter more layers could be optionally protected based on the prevailing channel conditions and the video configuration. The proposed scheme thus differs from earlier work in that it requires no knowledge of path losses. The rateless feature of RNC to support multi path multi-priority video streaming has not been considered in these earlier studies.

VI. Conclusion

The proposed scheme performs better compared to other schemes not taking advantage of multiple paths because it transmits the important base layer first. There is some additional processing required for the rateless codes' decoding at the mobile device which is manageable considering the current state of the devices. However, to keep the decoding complexity low it is also possible to protect just the base layer (ensuring an acceptable quality), and send the remaining video data without any encoding. For multi-path multi-priority transmission scheme, there is no need to ascertain channel capacity or for path selection based on loss rate because rateless codes make such considerations irrelevant. The video quality is determined by the number of received packets only.

The scheme is not bound to transmit along all available paths but rather video quality can be adjusted based on the channels' cost model. The proposed scheme can be used to schedule more of the download to the free (or lower tariff) channel while at the same time ensuring a good quality of service. The proposed solution is generic and can be easily extended to support more layers and/or more data interfaces or to exploit other forms of video scalabilities.

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