Traffic Analysis and Video Quality Evaluation of Multiple Description Coded Video Services for Fourth Generation Wireless IP Networks

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Abstract. For the performance evaluation of future wireless communication systems, such as the fourth generation wireless networks, traffic traces of realistic services are needed. Multiple description coding (MDC) is gaining a lot of interest lately and is a viable solution to provide robust video services over single or multi hop wireless networks and MDC introduces more flexibility for network coding. Furthermore it has the capability to support heterogeneous terminals as they are accepted to be used in 4G wireless networks. By means of twelve well known video sequences, in different video formats, we generate the frame size traces and evaluate the multiple description coding characteristics. In addition to that we highlight the expected overhead due to the underlying RTP/UDP/IP protocol suite. As an objective quality measurement at the application layer, we investigate the video quality in dependency of lost and error–prone descriptors. This allows researcher to convert the network losses of their network models directly into video quality values. This step makes the work unique as single layer coded video streams would always need further postprocessing to retrieve the video quality.

Keywords: multiple description coding, network coding, video trace, video quality, wireless communication

1. Introduction and Related Work

Future Fourth Generation (4G) mobile systems are envisioned to offer wireless services to a wide variety of mobile terminals ranging from cellular phones and Personal Digital Assistants (PDAs) to laptops [1]. These wide variety of mobile terminals are referred to as heterogeneous terminals. Heterogeneous terminals have various processing power, memory, storage space, battery life and data rate capabilities. Unlike DVB–T and DVB–H, where the same spectrum is reserved for the support of each technology in a time multiplex fashion, heterogeneous terminals in 4G should use the same spectrum in case the users are interested in the same services, to use the spectrum efficiently. One solution is the use of Multiple Description Coding (MDC), where the source information is splitted into multiple streams. MDC has the capability to split the information stream into multiple sub–streams, where each of the sub–streams can be decoded without the information carried by the neighboring sub–streams and therefore has no dependencies to other sub–streams such as layered video coding. In a multicast scenario, high class terminals would receive a large number of streams, while low class terminals would go for a smaller number. Note, that the sub–streams of the low class terminal are also received by the high class terminal. Therefore the spectrum is used more efficiently. The quality at the receiver in terms of video size, frame rate, etc. increases as the number of received descriptors increases. The flexibility of the bandwidth assigned to each descriptor and the number of descriptors assigned to end users makes MDC a very attractive coding scheme for 4G networks.

Unfortunately, the advantage of MDC is achieved at the expense of higher bandwidth usage due to the smaller video compression of the encoding process. Therefore existing video traffic characterizations such as single and multiple layer coding, as presented in [2], can not be used for the evaluation of future wireless communication systems as they would underestimate the bandwidth required. In this work we use frame splitting approach. The frame splitting is done on raw video pictures and can not be done on the encoded frames. Splitting the video pictures beforehand will introduce larger differences between neighboring pictures resulting in higher bandwidth requirements.

In this paper, we present traffic traces of MDC and derive their characteristics. The traffic traces can be used by other researchers to feed their network models for any kind of performance measurements. Furthermore additional information is presented, that allow deriving the video quality after receiving a number of, possibly error–prone, sub–streams at the receiver. The results are discussed in this paper and the traces are made publicly available on our web page [3]. To our best knowledge no work in the field of MDC traffic trace were presented so far.

1.1. Related Work

MDC is being utilized by various network infrastructures such as multi–cast services in cellular networks, multi–hop networks and wired networks to provide path diversity to the transmitted video application. The advantages of MDC has been exploited for multi–hop networks [4, 5], Orthogonal Frequency Division Multiplexing (OFDM) [6], Multiple Input Multiple Output (MIMO) systems [7], ad–hoc networks [8], Universal Mobile Telecommunications System (UMTS) [9], Transport Control Protocol (TCP) [10] and Content Delivery Networks (CDN) [11]. Protocol layers can cooperate to decide on the total number of descriptors transmitted and/or received based upon the best optimization solution in case cross–layer optimization is being exploited [12].

1.2. Basics of Video Encoding regarding Multiple Description Coding

Because of the large bit rates, digital video is almost always encoded (compressed) before transmission over a packet–oriented network. The limited bandwidths of wireless links make compression especially important. The resulting frames compressed by encoding the original pictures in the temporal domain are named as: I (Intra), P (Inter), and B (Bi–directional) frames, as introduced in the MPEG–1 standard [13] and also used in MPEG–2 [14], MPEG–4 [15], or H.264 [16]. These encoding methods are applied on the frame or block level, depending on the codec. I–frames can be reconstructed without any reference to other frames. Therefore the splitting process of MDC does not affect the frame sizes of the I–frames. The P–frames are inter coded leading to a higher compression gain and thus smaller frame sizes than I–frames. They are predicted from the last frame (I–frame or P–frame) i.e. it is not possible to reconstruct them without the data of the previous frame (I or P). Therefore, to prevent error propagation, I–frames are repeated periodically. The sequence of frames between two intra–coded frames is referred to as a Group of Picture (GoP).

2. Evaluation Methodology

There are many MDC techniques available in the literature. The MDC technique used in this study is not optimal in terms of coding efficiency, improvements in quality, frame size and frame rate. However, the objective of this study is not on the analysis of an optimum MDC technique but on the analysis of the video quality in dependency of lost and error–prone descriptors and the behavior of frame size traces. Thus, we have chosen a simple MDC technique in this study. Since this technique is very simple it can be applied to mobile terminal platforms. All the descriptors are treated equally and independently from each other.

2.1. GENERATION OF MDC DESCRIPTORS

MDC divides a single stream raw video sequence into multiple streams by exploiting quantizers or using the frame based approach. The later one is done by putting consecutive frames into the generated streams in a round robin fashion. In this work MDC splits the video stream into multiple descriptors by a frame based approach using a splitter entity. The splitter takes the raw video sequence and splits it into J sub–sequences, ($J > 1$), such that the i–th sub–sequence contains picture i, $J + i$, $2J + i$, and so on. Once the splitted sequences are ready, then each stream is feeded into standard video encoder, i.e. H.264 or H.263. At this point the encoded descriptors are analyzed. Using bit stream parsers, the encoded streams are evaluated and traces are generated. Consequently, the main difference in terms of traffic between the standard single layer video coding and the MDC technique used in this study is coming from the splitting and merging operations.

The relationship between the various encoding types and how frames rely on each other in a typical frame sequence for MDC with three descriptors is illustrated in Figure 1 for $GoP = 12$.

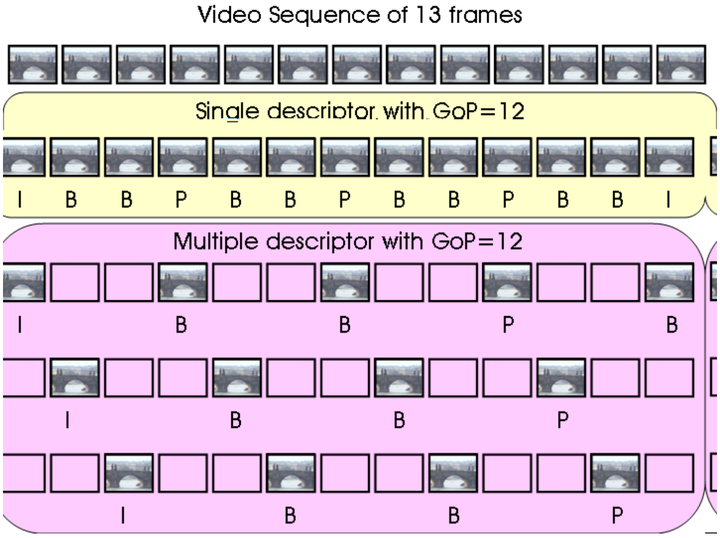

Figure 1. Frame based construction of multiple descriptions for GoP of twelve video frames.

2.2. ERROR PRONE DESCRIPTORS

To evaluate the video quality two different error models are taken into account. We distinguish between lost descriptors and error prone descriptors (combination of both are also possible). If a complete descriptor is lost, we are assuming that all of its frames are lost completely. This is a realistic scenario for the support of heterogeneous terminals and for multi–hop networks. Heterogeneous terminals may listen only to a subset of descriptors which is due to their bandwidth limitations [12, 17]. In case of multi–hop networks, if one of the hop in the transmission is completely down, then the descriptors transmitted via that hop are completely lost. In case or error–prone descriptors, bit errors with a given probability are added to the encoded descriptors.

2.3. RECONSTRUCTION AND VIDEO QUALITY

For simulation purpose it is also interesting to map the channel losses to a video quality value. For this purpose we have chosen the peak signal to noise ratio (PSNR) value. To calculate the PSNR values in dependency of the percentage of successfully received descriptors we select a sub–set of descriptors randomly and feed this to the merger after decoding each descriptor individually. The merger will reconstruct the single information stream using all available descriptors. In case descriptors are lost, some frames will be missing in the video sequence. As a very simple error concealment, we are *freezing* the last successfully received frame until we have a new one. By freezing we mean that we make a copy of the last successfully received frame for the next frame until an update frame is received.

Once the video is reconstructed and decoded we are measuring the quality in terms of PSNR in case of missing descriptors. A video frame is composed by $N \cdot M$ pixels (where M is the length and N the height of the frame). Each pixel is presented by one luminance value and a set of pixels by two chrominance values. Due to the fact that human eye is more sensible to the changes in the luminance value we focus only on this parameter. The mean squared error (MSE) and the average PSNR values in decibels are computed by the following two equations [18]:

$$MSE = \frac{\sum\limits_{\forall i,j} [f(i,j) - F(i,j)]^2}{N \cdot M} \tag{1}$$

$$PSNR = 20 \cdot log_{10} \left(\frac{255}{\sqrt{MSE}} \right) \tag{2}$$

where $f(i,j)$ represents the original source frame, $F(i,j)$ represents the reconstructed possibly error–prone frame containing N by M pixels. It is important to note that the PSNR value calculated by Equation 2 gives only an objective quality measure. In [19] the subjective quality

Q is described as a function of the PSNR value and the frame rate FR as given by Equation 3:

$$Q \;=\; -0.45 \cdot PSNR + 17.9 - (FR - 5)/10 \qquad (3)$$

As we have generated our descriptors by using a frame sub–sampling approach each lost descriptor is reducing the frame rate. In this study, we are concentrating on the objective video quality as given by Equation 2.

If a descriptor is lost, we are assuming that all of its frames are completely lost. Each descriptor is decoded individually and then merged to a single stream. This stream will be conveyed towards the application. The calculation of PSNR values is done as given in [18] using the videometer tool [20]. We have repeated the measurements multiple times with a confidence interval of 99% for the PSNR value. The video sequences with frame length and a short information are given in Table I for the QCIF and CIF formats. The PSNR curves for various video sequences which are presented in this study can be used to directly map the video quality onto the encoded video sequence for a given percentage of successfully received descriptors. In this way, the error–prone video sequence is obtained without the need of decoding and merging processes followed by the simulation of the channel and/or link losses.

3. Frame Size Evaluation

The results presented in this section concentrate on the frame size traces for MDC. In this work we use the H.264 video coding standard [22]. For illustration issues a plot of the frame size trace versus time for single and multiple description coding for the `bridge close` video sequence is given in Figure 2. This video sequence includes relatively slow motion compared to other video sequences. The peaks occur when I–frames are generated by the encoder. The size of the I–frames are similar to each other in case of single, five and fifteen descriptors. However if we look at each descriptor individually, we can observe that the frame size increases with increasing number of descriptors. This is due to the increasing time difference between inter–coded frames due to splitting process.

In Figure 3 a frame size trace for single and multiple description coding for the `highway` video sequence is given. Similar to Figure 2, the generated frame sizes have peaks when I–frames are generated. The `highway` video sequence is characterized by high motion scenes. Therefore the peaks in the trace occur when the motion increases in

Table I. YUV QCIF/CIF from [21]

video sequence name	video format	frames	info
bridge–close	QCIF and CIF	2000	Charles Bridge.
bridge–far	QCIF and CIF	2101	Charles Bridge far view.
highway	QCIF and CIF	2000	Driving over highway.
carphone	QCIF	382	Man talking at the phone.
claire	QCIF	494	Female talking to the camera.
container	QCIF	300	Ship leaving the harbor.
foreman	QCIF	400	Man speaking to the camera.
grandma	QCIF	870	Grandma in front of the camera.
mother and daughter	QCIF	961	Mom and daughter speaking to the camera.
news	QCIF	300	News studio and two speakers.
salesman	QCIF	449	Salesman in his office
silent	QCIF	300	Woman doing sign language.
mobile	CIF	300	Train is moving
paris	CIF	1065	Two people talking to each other
tempete	CIF	260	Moving Cam

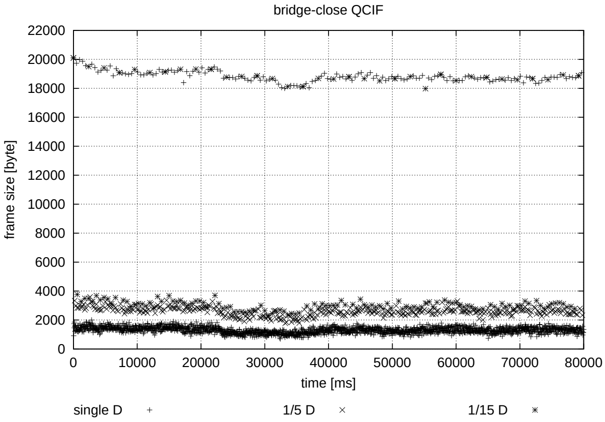

Figure 2. Mean frame size values versus time for `bridge-close` video sequence in the QCIF format

the video. Obviously inter–frame differences increase with larger J. This also means that compression gain of P–frames is less than single description case which leads to higher frame sizes with increasing J. However, the size of the I–frames are not affected by increasing J.

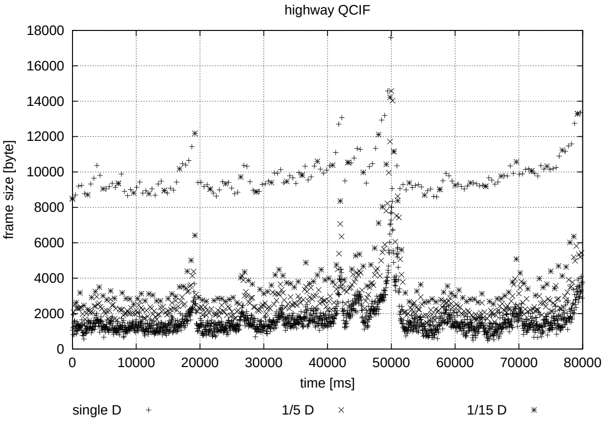

Figure 3. Mean frame size values versus time for `highway` video sequence in the QCIF format

Table II presents mean frame size values versus different number of descriptors for five different video sequences in the CIF format. Table III presents mean frame size values versus different number of descriptors for 12 different video sequences in the QCIF format. Video content plays a crucial role on the mean frame size values. If the video has a relatively low motion, then increasing number of descriptors does not increase the mean frame size values dramatically as in the case of `bridge-far` video sequence. However, if the video has a high motion activity as in the case of `highway` video sequence, mean frame size values increases dramatically with the increasing number of descriptors. As seen in Tables II and III, mean frame size values increases with increasing number of descriptors except at some points. For example the mean frame size values of the `bridge-far` video sequence in QCIF format decreases from 687.2 to 683.3 whereas the number of descriptors is increased from 3 to 4. This effect can be explained by the used GoP structure. By changing the number of descriptors even the ratio of used I frames changes with has a slight impact on short video sequences.

Table II. Mean frame size value in byte for the CIF video sequences

# of descriptors	bridge–close	bridge–far	mobile	paris	tempete
1	12864.5	2431.8	45011.4	17200.0	32406.7
2	16223.2	2789.5	51426.6	20153.6	36769.7
3	17683.9	3043.9	55578.8	21907.3	40038.9
4	18220.1	3176.3	59585.9	23308.4	42080.6
5	18757.2	3259.3	60996.1	24100.2	44234.9
6	18892.2	3360.1	65837.9	24902.1	45599.2
7	19132.2	3355.1	67734.4	25677.8	48083.0
8	19207.5	3383.1	71639.3	26609.0	47968.5
9	19525.0	3447.6	71335.7	26521.6	50144.2
10	19600.8	3487.6	73915.4	27007.3	51766.7
11	19860.6	3472.5	77124.1	27196.9	50566.2
12	19708.7	3545.6	80241.2	28506.7	52167.6
13	19918.9	3600.6	77084.5	28531.6	53479.6
14	19980.5	3631.6	79939.4	29339.3	55467.5
15	20380.6	3636.1	82730.8	28706.1	56967.0
16	20268.8	3630.3	87622.6	29737.0	58941.5
17	20314.4	3739.9	88782.5	30758.1	60010.6
18	20533.7	3687.1	91566.5	29623.3	62010.8
19	20481.9	3776.0	94099.2	30186.2	63526.1
20	20699.4	3683.2	94488.5	31115.4	64471.3

4. Video Quality Evaluation

In Figure 4, PSNR measurements versus percentage of successfully received sub–streams for a total of $J = 10$ descriptors are given. In this figure, it is assumed that all the frames belonging to the successfully received descriptors are received without any error coming from the propagation through the channel. The results are obtained using six different video sequences.

The `foreman` video sequence includes the highest motion. Whereas `clarie` and `container` video sequences include relatively lower motion than `foreman`. As we can observe in the figure, if the motion in a given video sequence is high, the slope of the PSNR degradation curve is also high. For example, for a loss of 60 % out of $J = 10$ descriptors, the PSNR degradation is 6 dB for `foreman`, 2 dB for `claire` and 1 dB

Table III: QCIF

# of descriptors	bridge–far	claire	grandma	highway	bridge–close	container	mthr_dotr	salesman	silent	news	carphone	foreman
1	658.5	1445.8	1763.5	2323.1	2763.3	2127.0	2234.5	2615.7	3314.1	3267.1	4628.1	4329.7
2	674.4	1748.2	2045.8	2781.3	3380.5	2476.2	2763.7	3111.5	4029.7	4125.1	5572.6	5358.6
3	687.2	1997.1	2272.1	3018.1	3697.1	2813.2	3155.4	3482.2	4517.8	4719.5	6198.2	6203.8
4	683.3	2201.3	2455.0	3261.7	3835.7	3033.8	3481.6	3809.9	4823.2	5101.1	6623.6	6869.7
5	709.2	2367.1	2564.5	3432.8	3965.2	3083.0	3698.4	3931.1	4857.2	5213.7	6957.1	7306.7
6	709.7	2384.8	2712.4	3590.8	4011.2	3531.3	4039.5	4217.9	5321.7	5754.7	7326.7	7679.5
7	711.6	2498.1	2800.3	3653.3	4065.6	3626.2	4248.8	4438.6	5448.0	5844.1	7585.9	8081.2
8	708.1	2658.1	2784.4	3826.4	4098.4	3944.6	4423.0	4518.0	5759.1	6158.9	7733.6	8404.0
9	730.8	2669.9	2833.0	3924.6	4195.3	3752.2	4602.1	4721.6	5642.6	6142.3	7980.7	8549.4
10	741.1	2918.2	3035.2	4061.7	4236.8	4059.7	4657.2	4634.3	5830.9	6329.0	8391.3	9165.0
11	765.7	2839.8	3073.1	4117.5	4328.4	4468.4	5027.1	4947.6	5996.7	6694.5	8473.1	9013.7
12	724.8	2932.8	3036.6	4170.1	4275.3	4729.9	5063.3	5258.3	6314.2	6887.3	8586.8	8936.2
13	740.7	2958.9	3207.3	4188.9	4340.7	4344.3	5334.2	4940.0	5908.1	6529.3	8879.7	9517.3
14	740.7	2918.8	3287.6	4217.1	4354.8	4498.6	5381.8	5117.2	6023.6	6816.3	8881.7	10057.1
15	780.4	3064.5	3215.0	4357.2	4458.1	4794.4	5425.8	5371.5	6279.6	6931.6	9040.9	10246.1
16	765.5	3025.8	3315.5	4510.9	4440.9	4968.8	5396.1	5442.5	6357.7	7173.7	8865.0	10592.9
17	754.1	3063.4	3490.3	4487.8	4431.5	5175.0	5685.5	5585.8	6354.8	7336.4	8911.2	9868.8
18	795.6	3133.0	3195.3	4550.1	4535.9	5366.5	5982.4	5090.3	6566.5	7612.5	9046.0	9917.4
19	760.2	3261.2	3248.5	4593.7	4496.3	5554.6	6013.2	5192.7	6847.4	7896.5	9422.8	10072.7
20	783.6	3062.6	3538.0	4645.4	4571.0	5628.2	5779.0	5412.0	6718.9	7711.4	9677.4	10582.8

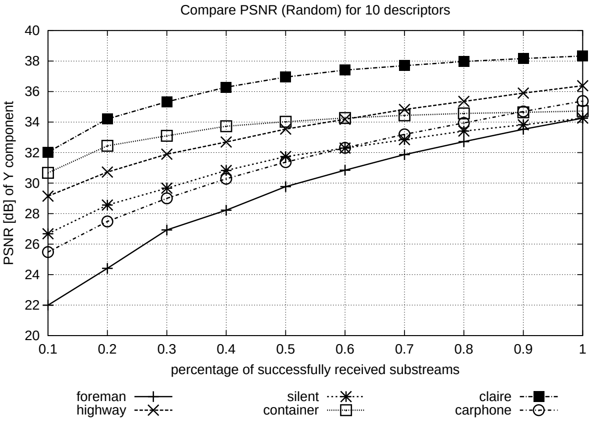

Figure 4. PSNR values for different numbers of descriptors versus the percentage of received sub–streams for various video sequences.

for `container` video sequence. Thus, we conclude that the more the motion in a given video sequence, the more important is to receive as many descriptors as possible for a given J.

Figures 5 and 6 present PSNR values versus percentage of successfully received descriptors of the `container` and `foreman` video sequences for 2, 4, 8 and 16 descriptors. Encoding overhead versus number of descriptors is also plotted for each video sequence as it presents the additional bandwidth required by MDC in terms of the bandwidth required by single stream video. Encoding overhead increases with increasing number of descriptors and depends on the video content. The percentage of received descriptors are assumed to be received with a certain Bit Error Probability (BEP) at the IP level of 10^{-4} (bad channel), 10^{-5} (medium channel) and 10^{-6} (good channel). To get these results we encoded the descriptors with H.263 and added a given BEP. Afterwards we assumed to receive a subset of all descriptors and decoded them together. We repeated the measurements until we got a relative error of 1% for an 99% confidence interval. As in the case explained in Figure 4, the effect of lost descriptors again depends on the relative motion in the video sequence. Since `foreman` video sequence has relatively higher motion than `container` video sequence, the effect of lost descriptors is more visible in Figure 6 than the case in Figure 5.

As it is obvious in Figures 5 and 6, bit errors affects the video quality. Therefore, it is of utmost importance to look at the channel characteristics when deciding on the best optimization solution in case cross–layer optimization is exploited with MDC. Interested readers may refer to our study in [12].

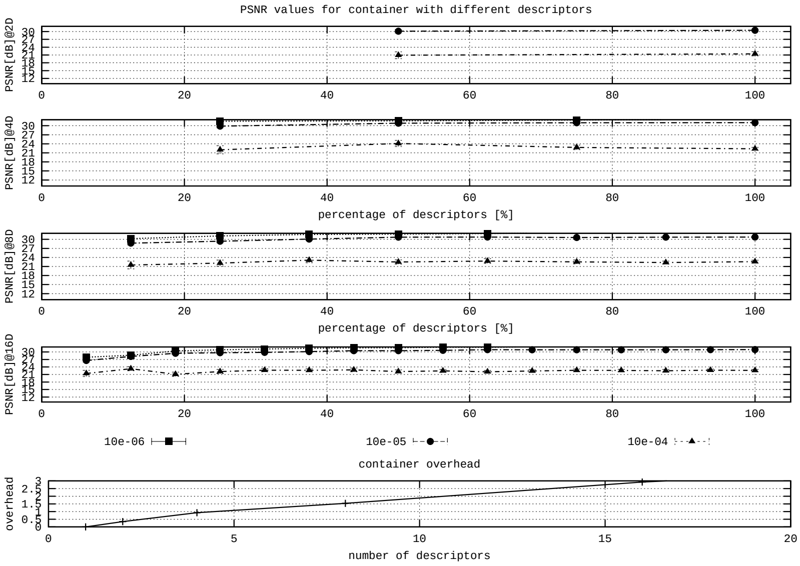

Figure 5. PSNR values for the container video sequence versus percentage of received descriptors for J = 2, 4, 8 and 16

5. Network Overhead Evaluation

Before the frame size traces are used, we have to take into account that the different descriptors are transmitted over IP based communication channels. This will lead to an additional overhead due to the IP header information including higher layer protocols such as Transport Control Protocol (TCP) or User Datagram Protocol (UDP). Under the assumption that the RTP/UDP/IPv4 is used, each frame, carrying the full header information of each protocol layer (so no header compression is used), has an additional overhead of 40 bytes. For IPv6 the overhead equals 60 bytes. In case of fragmentation or framing the overhead has to be adjusted properly according to the chosen scenario. The effect of network overhead on MDC is presented in our study in [23]. A possible solution to decrease the overhead is introduced in [24].

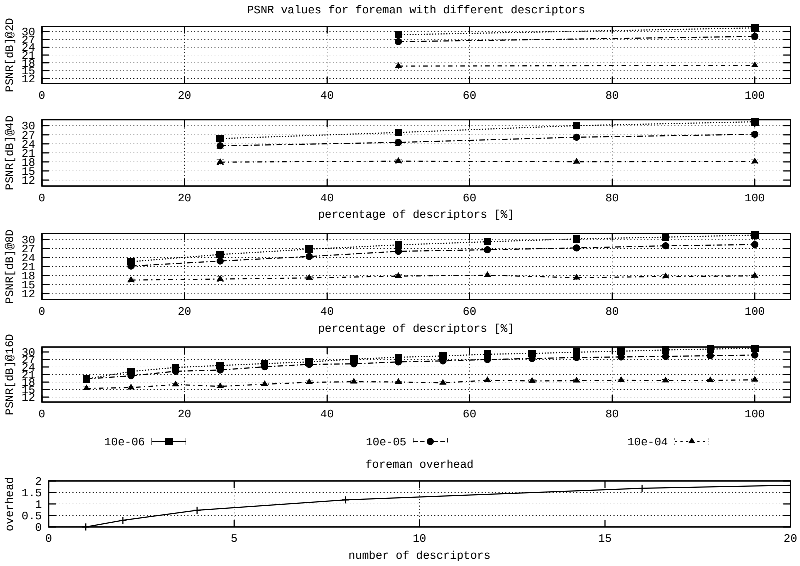

Figure 6. PSNR values for the foreman video sequence versus percentage of received descriptors for J = 2, 4, 8 and 16

6. Conclusion and Outlook

The study in this paper presents for the first time a sophisticated library of frame size traces for MDC for commonly used video sequences, which has never been done before. Besides the frame size traces and their characteristics, we come up with a simplified mapping function to translate loss of descriptors of the multiple description process to a video quality metric.

Acknowledgements

This paper is based upon work supported by SAMSUNG, Korea. We would like to thank Patrick Seeling for his support in the methodology. Furthermore we would like to thank Prof. Martin Reisslein for his support in hosting our traces.

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