Analyzing the delay in the trace

Purpose

In this worksheet, we look at the frame delay for a specific trace of the system. The service rate is based on the network-trace and the video trace is based on numbers of VBR video traces taken independently from the network-trace.

Method

We analyze the collected traces based on network calculus methods, evaluating mainly delay, but also noting the buffer requirements.

Video playback methods

The video playback method is central to how delayed frames influence the video playback. We now present two general playback methods that will be the basis for our analysis.

1. Continuous video playback: Is playing back every frame of the video in chronological order. Whenever a frame is delayed, the overall video playback delay increases. The strength is that every frame of the video is present, the weakness is that there is no upper bound on either the playback delay, or the buffer of the sender.
2. Delay bounded video playback: sets a maximum delay bound. The receiver buffers video and starts the playback so the video is delayed by an exact amount of time. Frames delayed beyond the threshold are discarded. In this way, the video playback delay is guaranteed, and an upper bound on the sender and receiver buffer can be calculated.

Common for both playback methods are that they will experience video freezes if the delay of certain frames is large. The playback method is application specific. Some applications, e.g. sporting events or equipment inspection might want to use the continuous playback, so every detail is captured. Others, e.g. military operations might need a real-time feed required by delay bounded video playback.

Frame delay figure

The top plot on Figure 1 shows the data rate of the trace. Since the raw trace is highly fluctuant, an averaged plot has been overlaid. The averaged trace is a moving average based on the 25 previous raw samples. From this overlay, we see that even though the raw trace drops to 0 Mb/s in some intervals, it is never 0 Mb/s in 25 continuous samples.

Figure 1 also shows three plots of frame delays. The (playback) delay is shown for each frame. The video trace used for the plot is of a video with 30 frames per second. Thereby, the network trace and the frame delays are directly comparable in the x-axis. We see that when the throughput drops, it causes delays of frames. In the table below, we have collect some interesting results from the three different videos displayed in Figure 1. It appears that the 5 and 10 Mb/s videos performs almost identically. The difference comes when we look at the 20 Mb/s. The longest delayed frame is delayed twice as long compared to the other video rates.

Video rate	5 Mb/s	10 Mb/s	20 Mb/s

# of continuous playback freezes	3	3	4
Longest delay	1.0316 s	1.0744	2.1023
# of 500ms delay bounded playback freeze periods	5	6	11
Total length of freeze periods for 500ms delay bounded playback	1.133 s	2.533 s	15.833 s

Distribution of delays

As seen in Figure 1 the delay of the frames shows a spiky behavior. Most of the time a frame is delayed under a certain value. Figure 2 shows a histogram of the frame delays for the three video bit rates. Clearly, the 20 Mb/s video stands out from the others. It is also clear that for the lower video rates, a higher proportion of the frames are delayed. This would translate into longer and more frequent freeze periods.

Single spike analysis

Figure 3 shows a segment of Figure 1. First thing to notice is the playback delay line, which at the two lower rates is not changed during this period. For the 20 Mb/s video the delay is significantly larger and causes the longest delay of the entire trace. The cause becomes apparent when one correlates the averaged service rate for the period with the video bitrate. For an extended period, the average bitrate resides around 10 Mb/s, making the two lower rate videos serviceable, but the 20 Mb/s video is stacking up delay. In a situation like this, it would make perfect sense to lower the data rate. For the 20 Mb/s video, 8 seconds of video in Figure 3 is delayed more than 500 ms. Choosing the 5 Mb/s video for this period would keep the playback delay under 500 ms.

Changing the video bitrate based on PER

From the above observations, we suggest adapting the video source coding based on feedback about the current throughput. For optimal performance, it would be rational to lower the source coding before the throughput is lowered to the same rate as the throughput. That is, the source coding should be lowered before getting to the level of the throughput.

Buffer size considerations

As mentioned earlier, the required buffer size is unbounded when continuous playback is used. The required buffer size on the sender side, to support continuous playback of the given trace at the 20 Mb/s video is 41 MB, see Figure 4. For the delay bounded playback with a 500 ms bound, the buffer maximally keeps 500 ms of video in the buffer. Since the video is variable bitrate and has strong periodicity with I-frames every second, the worst-case delay is having a large I-frame and 14 small p-frames in the buffer. If the video has an average bitrate of 20 Mb/s it is most likely that the I-frame will not exceed 20 Mb. The worst-case buffer requirement then becomes 20 Mb ≈ 2.5 MB.

Another trace

We went out and took a new trace, where we pushed the boundaries of the scenario, creating very challenging conditions for the drone. This resulted in a trace with very high PER and long periods of radio silence. The trace can be seen on Figure 6. All video bitrates have excessive delays/freeze periods. What's interesting about the traces, though, is the recovery times of the frame delays. Unsurprisingly, the recovery time is shorter the lower the video bit rate is. Again, a significant reduction in delay can be gained by switching down the video bitrate. Here we also see the buffer requirement take off. Figure 5 shows the buffered data over time. The requirement is 1.2 GB.

Optimal frame selection

A naive way to change between the rates for a continuous playback is: whenever none of the video rates can deliver a frame within the current playback delay, we choose the frame from the video rate, which will cause the lowest increase in playback delay, and increase the current_playback delay. This approach is described in pseudo code below. `frame_delay_XX(i)` is the playback delay of the ith frame from one of the three different bitrate videos.

```
current_playback_delay = 0.25s
for i = 0; last_frame > i; i++
  if frame_delay_20(i) < current_playback_delay
    pick the 20 Mb/s frame
  elseif frame_delay_10(i) < current_playback_delay
    pick the 10 Mb/s frame
  elseif frame_delay_5(i) < current_playback_delay
    pick the 5 Mb/s frame
  else
    pick the frame from the video with the lowest delay
    current_playback_delay =+ playback delay of the frame just picked
```

Figure 7 shows the trace, if this approach to frame selection is taken. As can be seen on the figure, whenever a spike appears, the frames from the 5 and 10 Mb/s videos are used. It is possible to use the 20 Mb/s video for most of the time. The behavior of a rapid change in video bitrates seen in Figure 7 might not hold in practice. Changing might not be possible due to the video encoding. I- and P-frames from different bitrate videos might not be compatible, meaning it is only possible to change rate every second.

For delay bounded playback the frame selection is even simpler. For every frame, you pick the frame from the highest video bitrate, which does not surpass 500 ms delay. If none of the videos has a frame with a delay below 500 ms no frame is picked. A section of the trace with this selection method can be seen on Figure 8. It is obvious that when the video throughput drops, the frame selection quickly choose the low rate, and when the throughput again rise, the higher bitrate videos are picked.

It is seen for both playback methods that the 10 Mb/s video sometimes have a smaller delay than the 5 Mb/s video. This is caused by unsynchronized video traces, because the videos have not been recorded at the same time. This adds measurement uncertainty allowing the 5 Mb/s video to have larger delays than the 10 Mb/s video in certain places

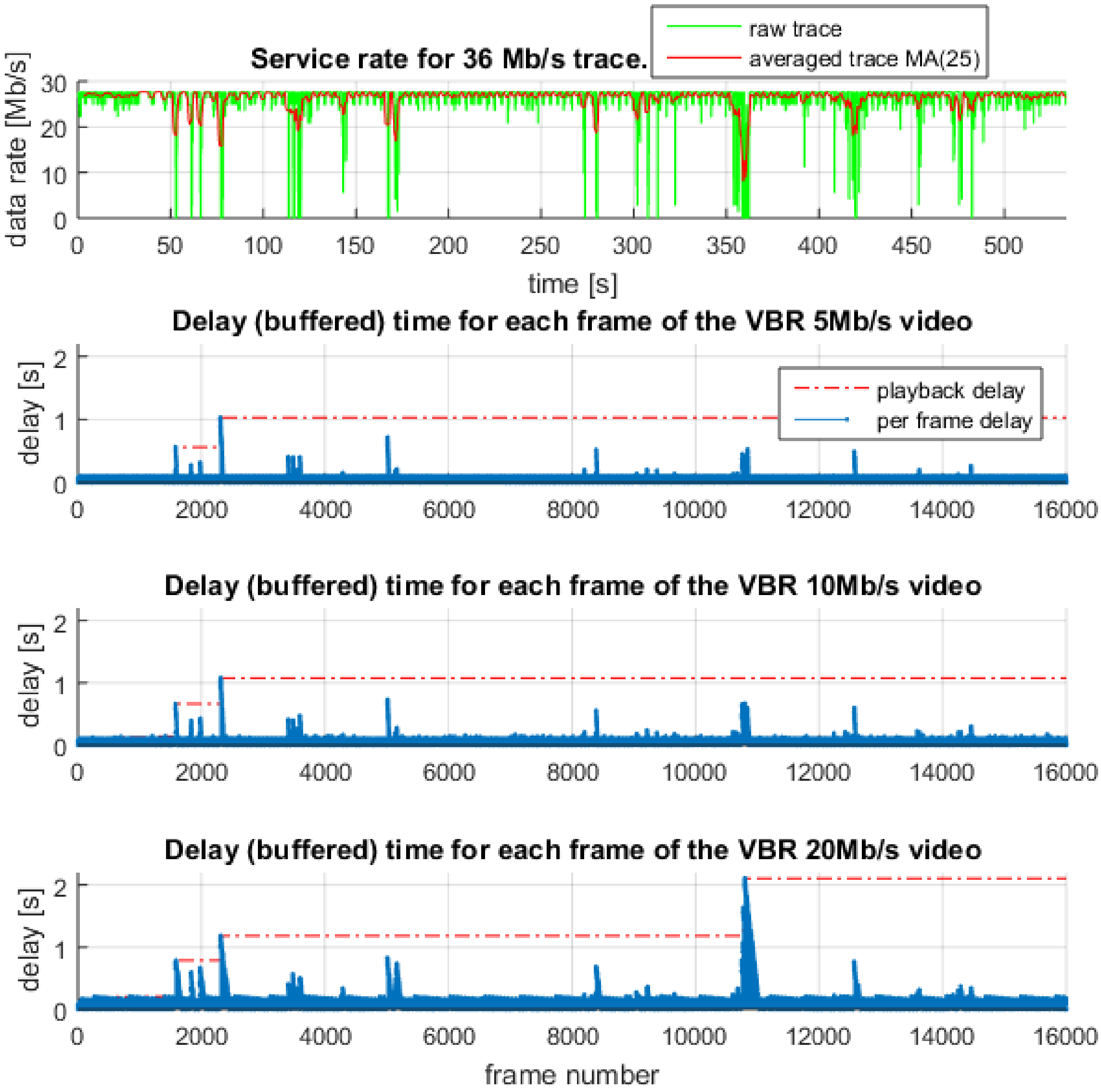


Figure 1: throughput from sender to receiver over time. The 3 lower plots shows the per frame delay of three different bit rate videos.

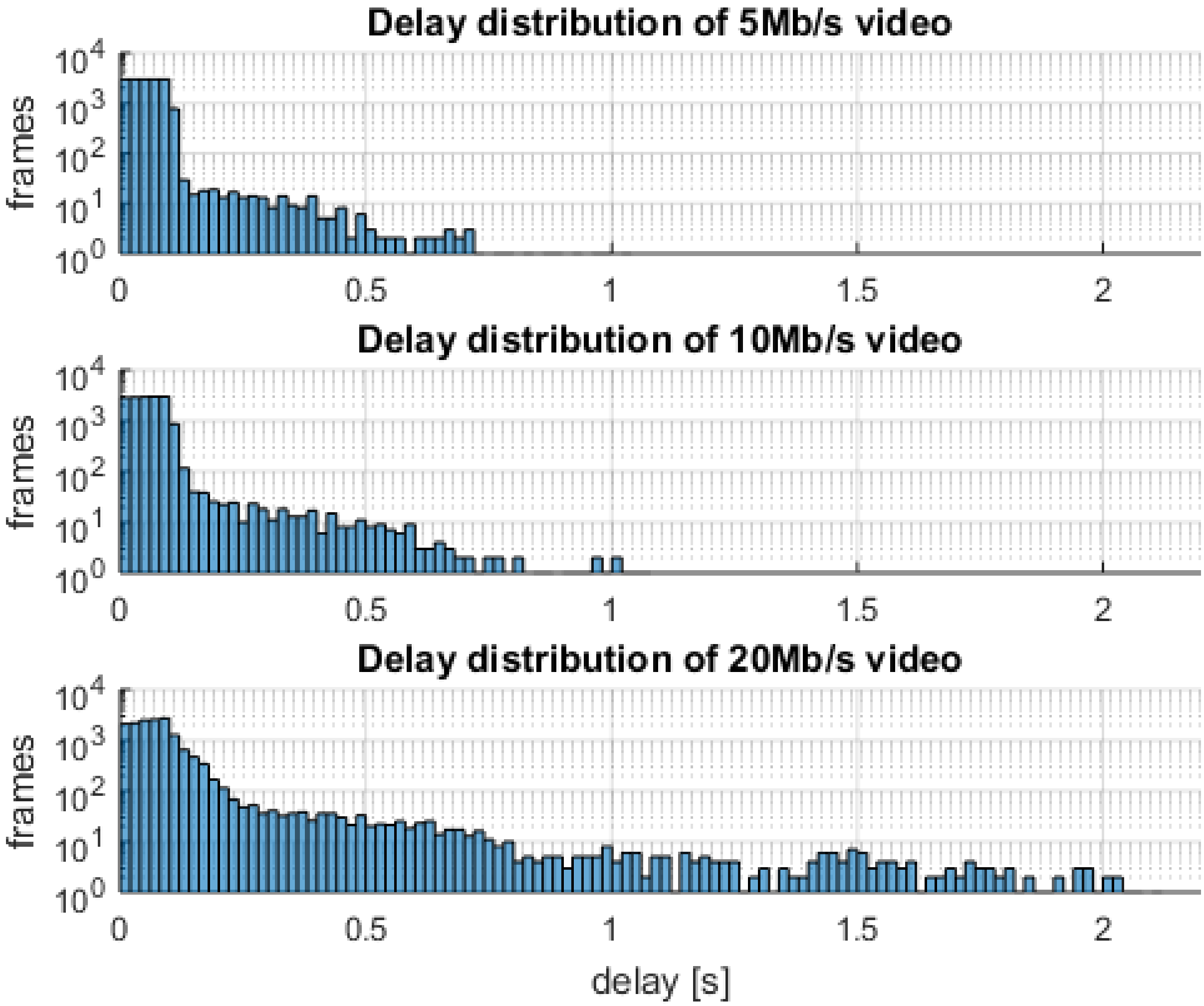


Figure 2: Distribution of the delay of frames from three different bit rate videos

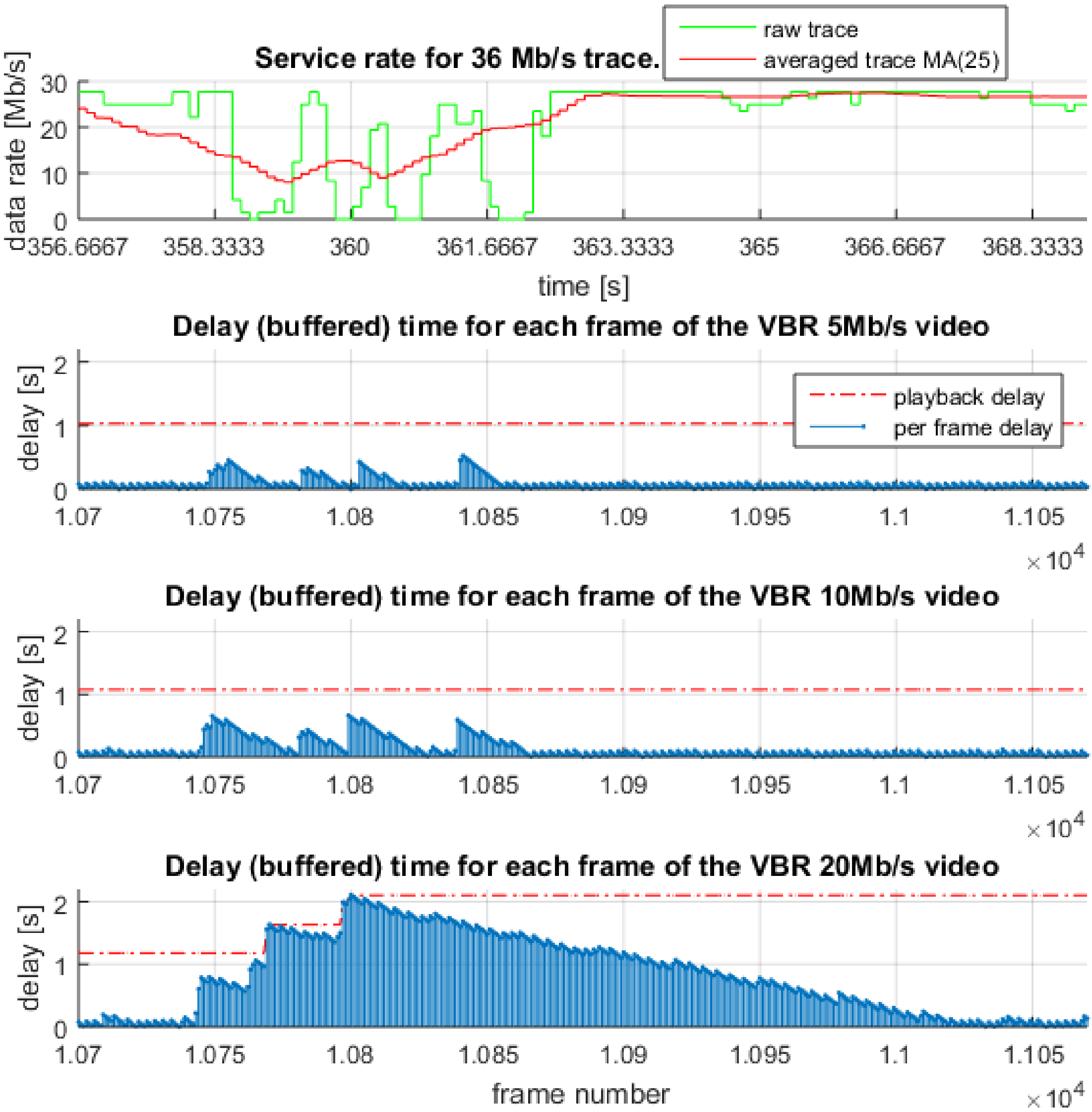


Figure 3: Closeup of figure 1

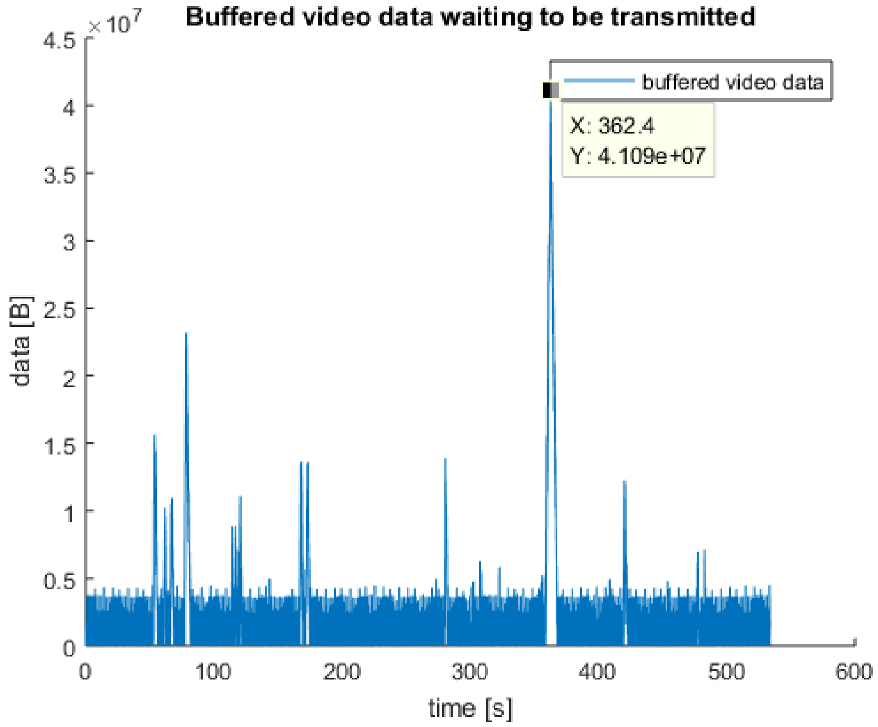


Figure 4: Buffered video data in the sender, based on figure 1 and the 20 Mb/s video.

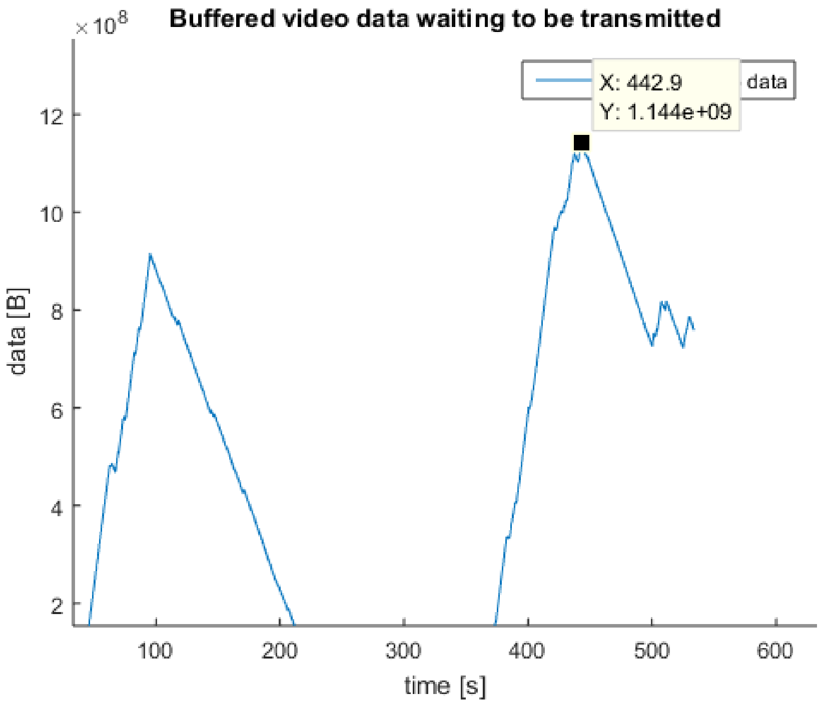


Figure 5: Buffered video data based on figure 6 and the 20 Mb/s video.

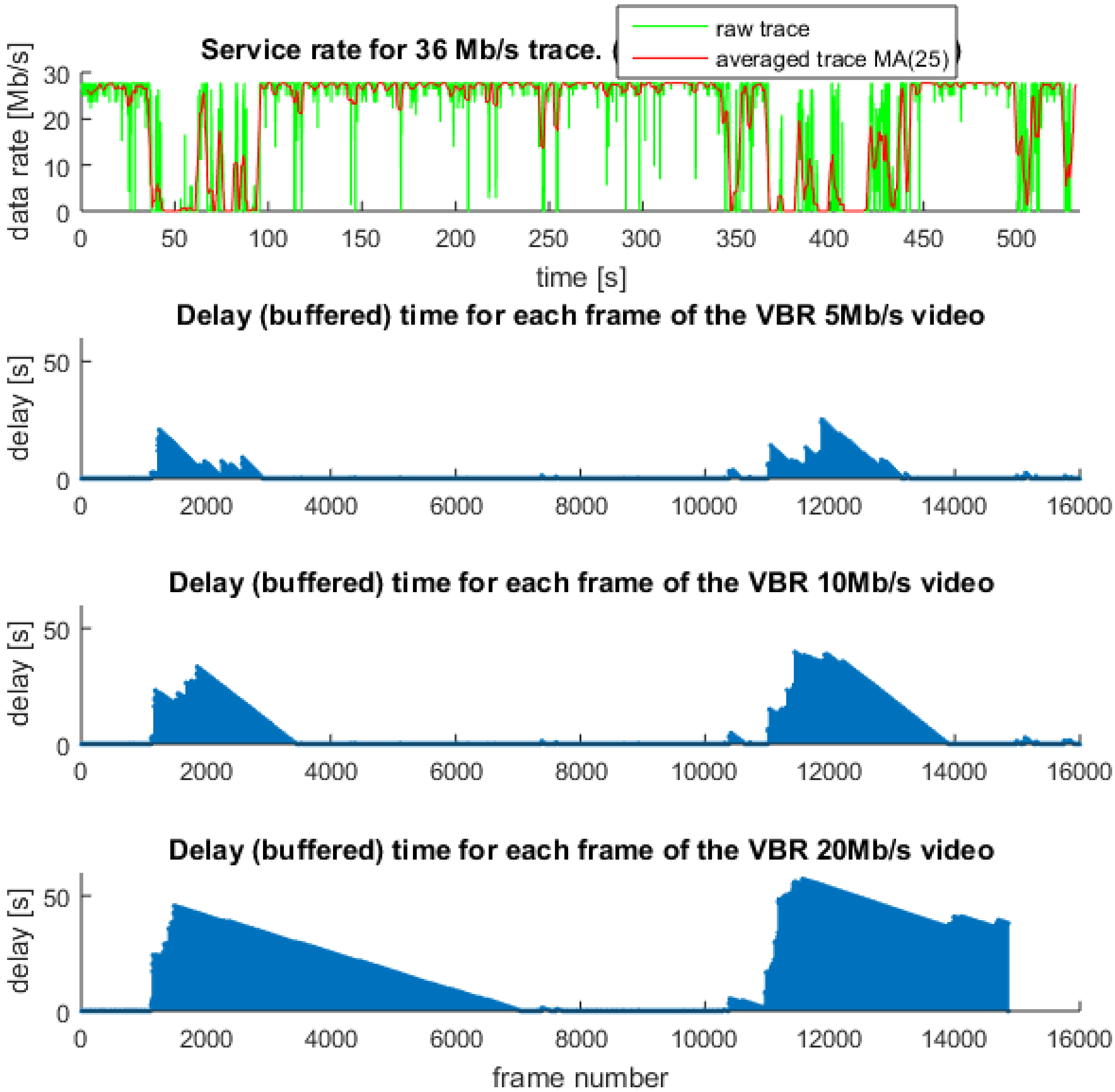


Figure 6: Throughput from sender to receiver over time. The 3 lower plots show the per frame delay of three different bit rate videos.

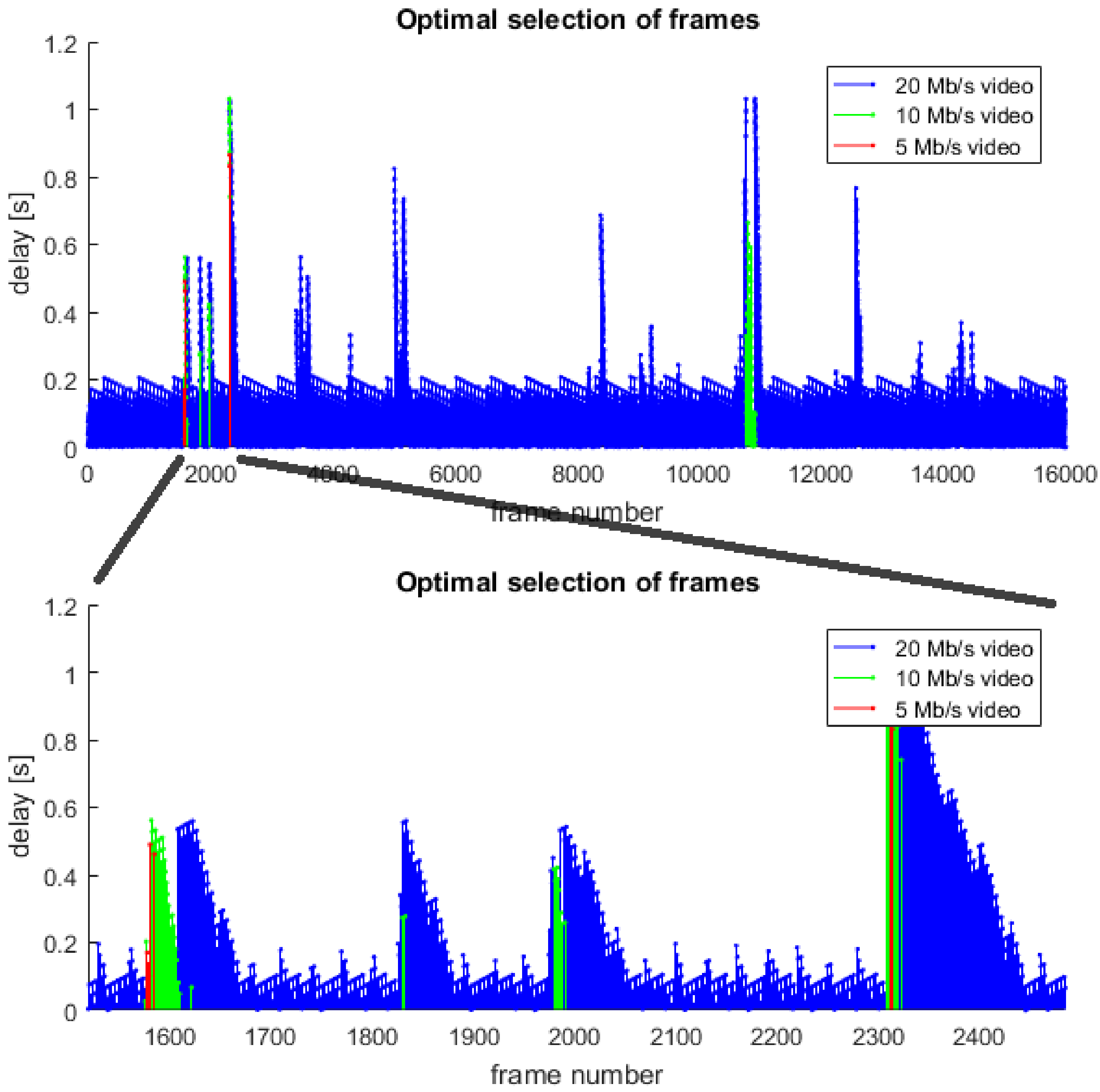
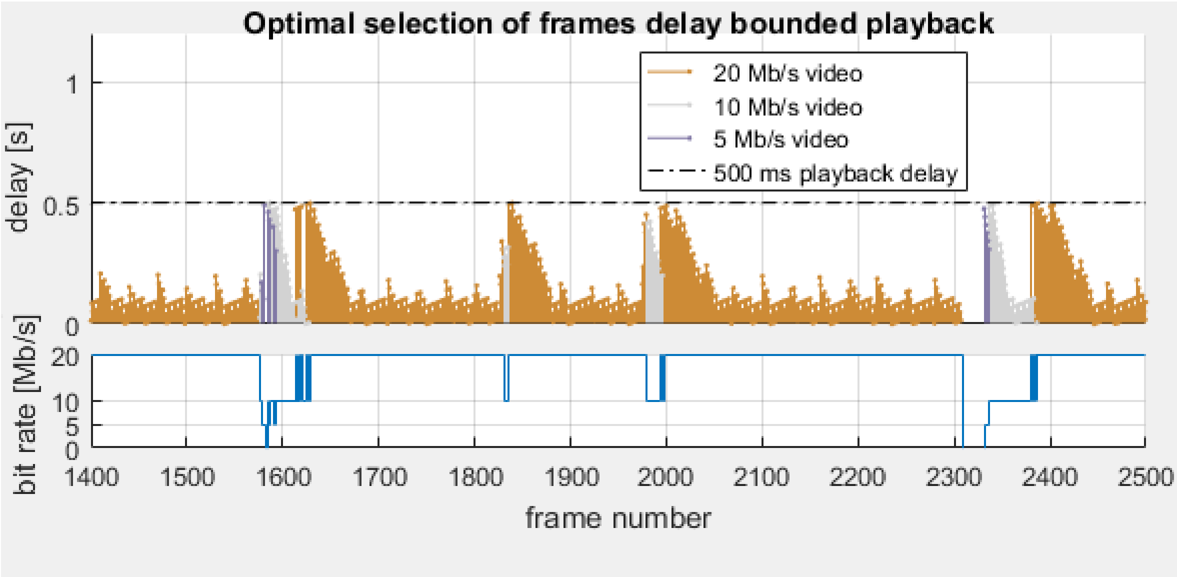


Figure 7 Selecting the fastest frame whenever all 3 traces forces the delay to go up, based on figure 1.



Figur 8 Selection of frames from the three different video bitrates.