

A METHOD AND DEVICE FOR PROCESSING AT LEAST A FIRST DIGITAL VIDEO AND A SECOND DIGITAL VIDEO; A COMPUTER READABLE MEDIUM AND A COMPUTER PROGRAM ELEMENT

5

BACKGROUND OF THE INVENTION

This invention relates to a method, a device, a computer readable medium and a computer program for processing at least
10 two digital videos, a first digital video and a second digital video with a high multiplexing efficiency, and a good inter-video fairness and intra-video smoothness for video broadcasting.

15 In most video broadcasting systems, a number of different programs, further denoted as digital videos, are usually transmitted over a constant bit-rate channel, and the channel bit-rate is thus shared among the different digital videos. Depending on the number of videos to be transmitted, a
20 different bit-rate is assigned to each video. A higher channel bandwidth and hence a higher bit-rate is assigned to a video of a higher priority,.

Statistical multiplexing is a method used to interleave
25 multiple bit-streams into a single bit-stream with a fixed bit-rate and is commonly used by video content providers to optimise coding quality of the videos sharing a constant bit-rate channel. When the bit-rate assigned to a video is changed, the bit-stream of the video is decoded, and re-
30 encoded into a bit-stream of the newly assigned bit-rate. This process of decoding and re-encoding a bit-stream is called trans-coding.

Trans-coding is a highly complex and computational intensive
35 process as described in [1]. To implement the process of trans-coding for real-time statistical multiplexing required for video broadcasting, high performance processors are needed. In most video broadcasting systems like DVB and ATSC, MPEG-1 or MPEG-2 video formats are used for the videos, and

each video consists of one bit-stream. Therefore, to change the bit-rate of a video, the entire bit-stream needs to be trans-coded to a new bit-stream with the assigned bit-rate.

- 5 When many videos are transmitted through the constant bit-rate channel, the multiplexing efficiency of the statistical multiplexer is said to be high. A high multiplexing efficiency is desirable for video content providers to transmit as many programs, i.e. videos, as possible through
10 the channel to maximise profit and channel utilization.

All the videos transmitted, which are of the same priority, should have about the same video quality. In other words, fairness among the videos transmitted should be ensured.

- 15 Improper allocation of bit-rates to the videos to be transmitted may result in some videos with good video quality and others with low video quality. Therefore, inter-program (inter-video) performance should be monitored to ensure fairness.

20

A smooth visual quality should also be ensured in each video. Such intra-program (intra-video) smoothness can be ensured by avoiding any drastic Peak Signal-to-Noise Ratio (PSNR) variation.

25

Therefore, a statistical multiplexing that does not require the complex computation of trans-coding of bit-streams, that has a high multiplexing efficiency and a good inter-program (inter-video) fairness and intra-program (intra-video)

30

smoothness is desired.

SUMMARY OF THE INVENTION

- 35 It is thus an object of the invention to provide a new method for statistical multiplexing of at least two digital videos for video broadcasting, so that the complex computation of trans-coding of bit-streams is avoided, and also to ensure a

high multiplexing efficiency, and a good inter-program (inter-video) fairness and intra-program (inter-video) smoothness.

5 A method for processing, in particular statistical multiplexing, at least two digital videos belonging to at least two video programs for video broadcasting is proposed.

10 The digital video which is used according to the invention is grouped into a base-layer bit-stream and an enhancement-layer bit-stream. The base-layer bit-stream provides a basic video quality and the enhancement-layer bit-stream includes a plurality of bit-planes which provides improvement to the basic video quality. The amount of improvement to the basic video quality of the video provided by the enhancement-layer
15 bit-stream is dependent on the number of bit-planes to be transmitted. The bit-rate of the digital video can be easily altered by changing the number of bit-planes of the enhancement-layer bit-stream as disclosed in [2] and [3] for a MPEG-4 fine granularity scalability video bit-stream, which
20 has a similar digital video bit-stream structure as the digital video used according to the invention. In other words, a video content provider needs only to truncate the number of bit-planes of the enhancement-layer bit-stream of the digital video to be multiplexed if the bit-rate allocated
25 for the digital video is changed. Therefore, the complex process and computational requirement for trans-coding of bit-streams is not necessary.

30 The base-layer and the enhancement layer bit-streams of the digital video comprises a plurality of I-frames, P-frames and B-frames, with the first frame of a Group of Pictures (GOP) of the bit-stream an I-frame. An I-frame, also known as an intra-frame, contains sufficient information required to construct an entire video frame, and acts as a reference point
35 for B-frames and P-frames to be built. A P-frame, also known as a predicted frame, is created by using motion vectors to predict the differences between it and the closest previous I-frame or P-frame. This forward prediction allows for higher compression compared to an I-frame. A B-frame, also known as

a bi-directional frame, is created by forward and backward referencing of a P-frame and an I-frame, respectively, and therefore has the highest compression compared to an I-frame and a P-frame.

5

Therefore, an I-frame has the highest bit-rate compared to a P-frame or a B-frame, resulting the bit-rate of the bit-stream to be irregular and varies drastically between the frames. In other words, the bit-stream is said to be 'burst'.

10

Correlation is an important function in the study of statistical behaviour as disclosed in [4], and a correlation function is used in the invention to relate two bit-streams. According to the invention, a high correlation has been found
15 between two I-frames. The correlation between an I-frame and a P-frame has been found to be lower compared to the correlation between two I-frames, and the correlation between an I-frame and a B-frame has been found to be the lowest. A high correlation corresponds to a larger irregularity of the
20 bit-rates, hence increasing the burstiness of the bit-stream, and a low correlation corresponds to a more stable bit-stream. Therefore, it is preferred that an I-frame of a bit-stream aligns with a B-frame of another bit-stream, so that a lowest correlation between the two frames is achieved, thereby
25 improving the multiplexing efficiency.

When a plurality of bit-streams from at least one digital video are aligned, the first picture frame of all the GOP of the bit-streams is an I-frame (Intra-frame), giving a high
30 correlation value, and hence a low multiplexing efficiency as fewer digital videos can be multiplexed into the constant bit-rate channel. Therefore a frame lag method is proposed such that at least one bit-stream is delayed by at least one frame, so that an I-frame of a bit-stream is aligned with either at
35 least a P-frame (Prediction-frame) and/or a B-frame (Bi-directional-frame) of at least one other bit-stream, resulting in a low correlation.

According to the preferred embodiment of the invention, the enhancement-layer bit-stream of a first digital video is delayed by one frame with respect to the base-layer bit-stream of the first digital video. Further, the base-layer bit-stream of a second digital video is delayed by two frames with respect to the base-layer bit-stream of the first digital video.

With the frame lag scheme according to the invention, the memory requirement for buffering the lagged bit-stream is low since the bit-stream is only delayed by one frame with respect to the previous bit-stream.

To ensure inter-program (inter-video) fairness and intra-program (inter-video) smoothness, a method for optimum bit-planes truncation is proposed.

The optimum number of bit-planes from an enhancement-layer bit-stream of a digital video to be multiplexed by the statistical multiplexer according to the invention is determined from the optimisation problem:

$$\text{Min}[F(j), G(j)]$$

with the constraints given by the following formula:

$$\sum_{n=1}^N \sum_{i=1}^{m_n} u^{\text{EL}}_{n,i}(j) \leq U^{\text{EL}}(j), \text{ and}$$

$$m_n(j-1) - \Delta_m \leq m_n(j) \leq m_n(j-1) + \Delta_m$$

wherein

- $F(j)$ is the fairness of all the digital videos at frame interval j ,
- $G(j)$ is the number of bit-planes to be multiplexed,
- 35 • $U^{\text{EL}}_{n,i}(j)$ is the number of the enhancement-layer in the i^{th} bit-plane of the digital video n in frame interval j ,
- $U^{\text{EL}}(j)$ is the total number of enhancement-layer of all the digital videos N in frame interval j ,

- $m_n(j)$ is the number of multiplexed bit-planes for digital video n , and
- Δ_m is an arbitrarily predefined smooth factor to ensure a smooth bit-plane variation.

5

Fairness is achieved by minimizing the deviation of the number of bit-planes of all the enhancement-layer bit-streams of all the digital videos which are not multiplexed. The fairness $F(j)$ is computed by minimizing the following formula:

10

$$F(j) = \left(\frac{1}{N} \sum_{n=1}^N \left((f_n(j))^2 - \left(\frac{1}{N} \sum_{i=1}^N (f_n(i)) \right)^2 \right) \right)^{1/2},$$

wherein

- 15 $f_n(j)$ is a function relating to the number of bit-planes which are not multiplexed.

The number of bit-planes to be multiplexed is determined using the following formula:

20

$$G(j) = -\sum_{n=1}^N \sum_{i=1}^{m_n} u^{EL}_{n,i(j)}.$$

- Minimizing $F(j)$ gives good fairness and minimizing $G(j)$ will maximize the number of bit-planes to be multiplexed, and hence
 25 will increase the multiplexing efficiency. Therefore, an optimized number of bit-planes to be multiplexed, without compromising the fairness $F(j)$, is determined.

- Since the optimized number of bit-planes to be multiplexed is
 30 an integer, the constant bit-rate channel, after the optimized number of bit-planes of all the digital videos are multiplexed, may still have a remaining bandwidth not utilized. The remaining bandwidth of the channel is allocated equally to all the digital videos.

35

Therefore, by using the statistical multiplexer according to the invention, the time consuming and tedious process of

trans-coding of bit-streams is avoided, which is required by conventional MPEG-1 or MPEG-2 based multiplexing.

5 A video content provider only needs to truncate a number of bit-planes of the enhancement-layer to be multiplexed to alter the bit-rate of a video program. The multiplexing efficiency of the proposed statistical multiplexer is further improved by the proposed frame lag scheme. By using the proposed optimal bit-plane truncation scheme, a good inter-program fairness and
10 intra-program smoothness is ensured.

The invention clearly can be seen in a combination of the statistical multiplexing and the **Fine Granularity Scalability** (FGS) scheme, which is used in the MPEG-4 video coding scheme,
15 for example.

The described embodiments of the invention apply not only to the method, but also to a device, a computer readable medium and a computer program.

20

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows an overview of a video broadcasting system.

25

Figure 2 shows the structure of a statistical multiplexing unit for video broadcasting according to the invention.

Figure 3 is a plot showing the number of bits for the I-frames, P-frames and B-frames in a series of group of
30 pictures.

Figure 4 shows a frame lag scheme according to the preferred embodiment of the invention.

35

DETAILED DESCRIPTION OF THE INVENTION

Preferred embodiments of the invention will now be described with reference to the accompanying drawings.

5

An overview of the video broadcasting system, incorporating the statistical multiplexor according to the invention is shown in Fig.1.

10

A plurality of video programs 101 to be transmitted are encoded to the digital video format, for example a MPEG-4 FGS video format, by an encoder 102. The encoder 102 outputs a base-layer bit-stream 103 and an enhancement-layer bit-stream 104 for each video program 101 encoded.

15

The base-layer bit-stream 103 provides a basic video quality which is the lowest quality of the digital video, and the enhancement-layer bit-stream 104, comprising a plurality of bit-planes, provides an improvement to the basic video

20

quality. The improvement to the basic video quality provided by the enhancement-layer bit-stream 104 is dependent on the number of bit-planes which are multiplexed by a statistical multiplexer 105 to be transmitted together with the base-layer bit-stream 103.

25

The base-layer bit-streams 103 and the enhancement-layer bit-streams 104 are buffered into a statistical multiplexer 105 according to the invention so that a single multiplexed bit-stream 106 is formed. The multiplexed bit-stream 106 is

30

modulated into a modulated bit-stream 108 in a modulator 107 and subsequently transmitted into a **Wide Area Network** (WAN) 111 by a transmitter 109. The transmitted bit-stream 110 may be transmitted via a satellite or via a terrestrial transmitter.

35

A receiver 113 receives the bit-stream 112 from the WAN 107. The bit-stream 114 received from the receiver 113 is demodulated in a demodulator 115. The demodulated bit-stream 116 is subsequently de-multiplexed in a de-multiplexer 117 to

recover the base-layer bit-streams 118 and the enhancement-layer bit-streams 119 of the digital videos transmitted. The recovered base-layer bit-streams 118 and the enhancement-layer bit-streams 119 are decoded by a decoder 120 into the
5 respective video programs 121, which can be viewed in a television set or any similar display devices.

The structure of the statistical multiplexer for multiplexing two digital videos according to the invention is shown in
10 FIG.2.

A first digital video and a second digital video, each containing a base-layer bit-stream 201, 203 and an enhancement-layer bit-stream 202, 204 are multiplexed into a
15 constant bit-rate channel 210 to be transmitted to a receiver via a WAN.

The base-layer bit-stream of the first digital video 201 is buffered into a first base-layer incoming buffer 205, and the
20 enhancement-layer bit-stream of the first digital video 102 is buffered into a first enhancement-layer incoming buffer 206. Similarly, the base-layer bit-stream of the second digital video 103 is buffered into second base-layer incoming buffer 207, and the enhancement-layer bit-stream of the second
25 digital video 104 is buffered into a second enhancement-layer incoming buffer 208.

All the outputs from the incoming buffers 205, 206, 207, 208 are fed into an outgoing buffer 209, and the output of the
30 outgoing buffer 209 is transmitted through the constant bit-rate channel 210.

The channel bandwidth of the constant bit-rate channel 210 is sufficient to transmit the base-layer bit-streams 201, 203 of
35 the first digital video and the second digital video, but is not sufficient to transmit both the base-layer bit-streams 201, 203 and the enhancement-layer bit-streams 202, 204 comprising of all the bit-planes of the first digital video and the second digital video.

It should be noted that the embodiment of the invention for the statistical multiplexer also includes multiplexing more than two digital videos.

5

The digital video bit-stream used according to the invention comprises a plurality of I-frames, P-frames and B-frames. A plot of the number of bits per frame on a y-axis 301 for a plurality of Group of Pictures (GOP)308 of a base-layer bit-stream 303 and an enhancement-layer bit-stream 304 against the frame number on a x-axis 302 is shown in the Fig.2.

As shown in Fig.3, the bit-rate of an I-frame 305 is higher than the bit-rate of a P-frame 306, and the bit-rate of a B-frame 307 is the lowest. Therefore, the bit-rate of the digital video bit-stream is irregular and changes drastically as it will have a high bit-rate at every I-frame 305 at the first frame of every GOP 308. This gives rise to a 'burst' effect as the frame format of a GOP is similar. Also the enhancement-layer bit-stream 304 has a similar frame type format as the base-layer bit-stream 303, resulting in a plurality of I-frames 305 of the enhancement-layer bit-stream 304 coinciding with the plurality of I-frames 305 of the base-layer bit-stream 303. In other words, the I-frames 305 of both the base-layer bit-stream 303 and the enhancement-layer bit-stream 304 are multiplexed into a same frame interval in the outgoing buffer 209 to be transmitted through the constant bit-rate channel 210. This result in fewer digital videos to be multiplexed due to the high bit-rate of the I-frames and therefore, the multiplexing efficiency of the statistical multiplexer is low.

A correlation function is used to measure the correlation between two bit-streams given by:

35

$$\text{Corr}[x(t_1), y(t_2)] = \frac{E[(x(t_1) - \mu_x) \cdot (y(t_2) - \mu_y)]}{\sigma_x \sigma_y} \quad (1)$$

wherein

$x(t_1)$ is the number of bits in bit-stream x at time t_1 ,
 $y(t_2)$ is the number of bits in bit-stream y at time t_2 ,
 μ is the mean, and
5 σ is the standard deviation.

The correlation measured between two I-frames is the highest,
the correlation measured between an I-frame and a P-frame is
lower, and the correlation measured between an I-frame and a
10 B-frame is the lowest. A high correlation corresponds to a
higher 'burst' effect and a low multiplexing efficiency and is
therefore, undesirable. In other words, a low correlation
corresponding to multiplexing an I-frame with either a P-frame
or a B-frame in a same frame interval is desired.

15

Therefore, four statistical observations have been made on the
features of the digital video bit-streams:

- 20 a) Burst effect - The bit-rates of both the base-layer
bit-stream and the enhancement-layer bit-stream are very
burst due to the plurality of I-frames, P-frames and B-
frames.
- b) Intra-layer correlation - Each bit-stream is similar
in each GOP.
- 25 c) Inter-layer correlation - The base-layer bit-stream
and the enhancement-layer bit-stream of the digital video
are highly correlated.
- d) Correlation ranking - The correlation between two I-
frames of two bit-streams is the highest than the
30 correlation between an I-frame and a P-frame, and the
correlation between an I-frame and a B-frame is the
lowest.

From the above observations, a frame lag scheme is proposed
35 according to the invention.

According to the preferred embodiment of the invention, at
least one bit-stream of at least one digital video is delay by
at least one frame, so that an I-frame and at least one P-

frame and/or a B-frame are multiplexed into a same frame interval of the outgoing buffer 209, resulting in a low correlation.

5 According to a further preferred embodiment of the invention as shown in Fig.4, the enhancement-layer bit-stream 202 of the first digital video is delayed by one frame with respect to the base-layer bit-stream 201 of the first digital video. The
10 base-layer bit-stream 203 of the second digital video is delayed by two frames with respect to the base-layer bit-stream 201 of the first digital video. The enhancement-layer bit-stream 204 of the second digital video is delayed by three frames with respect to the base-layer bit-stream 201 of the first digital video. In other words, the enhancement-layer
15 bit-stream 204 of the second digital video is delayed by one frame with respect to the base-layer bit-stream 203 of the second digital video.

The preferred embodiment described above may also include at
20 least one more digital video to be multiplexed. When a third digital video is to be multiplexed according to the invention, the base-layer bit-stream and the enhancement-layer bit-stream of the third digital video is delayed by one frame and two frames, respectively, with respect to the enhancement-layer
25 bit-stream 204 of the second digital video.

The frame lag scheme according to the invention is preferably implemented in the incoming buffers 205, 206, 207, 208 of the statistical multiplexer, wherein the buffers 205, 206, 207,
30 208 only need to buffer the number of the frames of the bit-streams to be delayed. For example, the incoming buffer 206 needs to buffer an additional frame as the enhancement-layer bit-stream of the first digital video 201 is delayed by one frame. Therefore, the memory requirement for the frame lag
35 scheme is low.

Further, the multiplexing efficiency is high since an I-frame with a high bit-rate is multiplexed together with at a least one P-frame and/or one B-frame, resulting in the channel

bandwidth of the constant bit-rate channel 210 to be utilized more efficiently.

To ensure inter-program fairness and intra-program smoothness,
5 an optimal bit-plane truncation scheme is proposed.

The fairness requirement requires the video quality of a plurality of digital videos transmitted to be about the same. This requirement is also called inter-program (inter-video)
10 fairness. In a plurality of enhancement-layer bit-streams from a plurality of digital videos to be transmitted, the video quality of all the digital videos are about the same when the number of bit-planes of each of the enhancement-layer bit-streams not multiplexed are equal.

15

Therefore, inter-program fairness is achieved when the following expression is satisfied:

$$f_1(j) = \alpha_1 \frac{(M_1(j) - m_1(j))}{\sum_{n=1}^N M_n(j)} = f_2(j) = \alpha_2 \frac{(M_2(j) - m_2(j))}{\sum_{n=1}^N M_n(j)} = \dots = f_N(j) = \alpha_N \frac{(M_N(j) - m_N(j))}{\sum_{n=1}^N M_n(j)} \quad (2)$$

20

such that

$$\sum_{n=1}^N a_n = 1 \quad (3)$$

25 wherein

$m_n(j)$ denotes the number of multiplexed bit-planes of digital video n at frame interval j ,

$M_n(j)$ denotes the total number of bit-planes of digital video n
30 at frame interval j , and

α_n is the quality weight associated with the digital video n .

A larger value of α_n can be assigned for the digital video n if a higher quality of the digital video is desired.

35

Inter-program (Inter-video) fairness is measured using the following formula:

$$F(j) = \left(\frac{1}{N} \sum_{n=1}^N \left((f_n(j))^2 - \left(\frac{1}{N} \sum_{i=1}^N (f_n(j)) \right)^2 \right) \right)^{1/2} \quad (4)$$

- 5 Minimizing $F(j)$ will minimize the deviation of the number of
bit-planes of the enhancement-layer bit-streams of the digital
video, and thus increasing fairness.

The total number of bit-planes to be multiplexed in frame
10 interval j is expressed in the formula below:

$$G(j) = -\sum_{n=1}^N \sum_{i=1}^{m_n} u_{n,i}^{EL}(j), \quad (5)$$

wherein

15

$u_{n,i}^{EL}(j)$ denotes the number of bits in i^{th} bit-plane of the
enhancement-layer bit-stream of digital video n .

Equation (4) is to be minimised to obtain good inter-program
20 (inter-video) fairness, and equation (5) is to be minimised so
that a maximum number of bit-planes is multiplexed to achieve
a high multiplexing efficiency.

Therefore, the following expression is used to determine the
25 optimised number of bit-planes of digital video n to be
multiplexed by minimizing both $F(j)$ and $G(j)$ at frame
interval j :

$$\text{Min}[F(j), G(j)] \quad (6)$$

30

With the constraints given by the following expressions:

$$\sum_{n=1}^N \sum_{i=1}^{m_n} u_{n,i}^{EL}(j) \leq U^{EL}(j), \quad (7)$$

$$35 \quad m_n(j-1) - \Delta_m \leq m_n(j) \leq m_n(j-1) + \Delta_m, \quad (8)$$

wherein

- $U^{EL}(j)$ is the total number of bits in the enhancement-layer of all the digital videos N in frame interval j ,
- 5 • $m_n(j)$ is the number of multiplexed bit-planes for digital video n , and
- Δ_m is a smooth factor to ensure a smooth bit-plane variation.

10 Equation (7) ensures that the number of bits multiplexed do not exceed the available bandwidth of the constant bit-rate channel.

15 The smoothness requirement requires that there is no drastic PSNR variation within a digital video due to a drastic change of number of multiplexed bit-planes between two consecutive frames. This requirement ensures intra-program smoothness by requiring that the number of bit-planes of a digital video to be multiplexed can only be increased or decreased with respect
20 to the number of multiplexed bit-planes of the previous frame by a number limited by the smooth factor Δ_m .

The expression (6) can be solved by the method disclosed in [5] to determine the optimal number of bit-planes to be
25 multiplexed for a digital video, while maintaining inter-program (inter-video) fairness and maximizing multiplexing efficiency.

30 In the preferred embodiment of the invention, the bit-planes are multiplexed and transmitted from the most significant bit-plane to the least significant bit-plane in a sequential manner. The enhancement-layer incoming buffers are refreshed at the new frame interval, and all the bit-planes not multiplexed in the current frame interval are discarded.

35 The value of the optimal number of bit-planes to be multiplexed from the expression (6) is an integer. Therefore, the bandwidth of the constant bit-rate channel may not be fully utilized after the optimal number of bit-planes

determined from (6) are multiplexed, and a remaining bandwidth is available.

5 To fully utilize the bandwidth of the constant bit-rate channel, the remaining bandwidth is allocated to all the digital videos equally for transmission of at least one additional bit-plane of the enhancement-layer bit-stream from each of the digital video.

10 With reference to Fig.1, the optimal bit-plane truncation scheme according to the invention is preferably implemented in the outgoing buffer 209. To prevent the outgoing buffer 209 from underflow or overflow, the outgoing buffer 209 target level is preferably set at half the size of the outgoing
15 buffer 209.

It should be noted that the proposed frame lag scheme and the optimal bit-plane truncation scheme described above can be implemented into the statistical multiplexer according to the
20 invention in combination or separately.

The described embodiments of the invention apply not only to a method but also a device, a computer readable medium and a computer program.
25

In this document, the following publications are cited:

- [1] S. Brigitte, B. Thébault, W.P. Li, Y.W. Chen, and E. François, "Fine Granular SNR Scalability: target applications," *ISO/IEC JTC1/SC29/WG11, MPEG99/M4426*, March 1999.
- [2] W.P. Li, J.-R. Ohm, M. van der Schaar, H. Jiang, S.P Li, "MPEG-4 Video Verification Model version 17.0," *ISO/IEC JTC1/SC29/WG11, N3515*, Beijing, July 2000.
- [3] W.P. Li "Overview of Fine Granularity Scalability in MPEG-4 Video Standard", *IEEE Trans. on CSVT*, Vol. 11, No. 3, pp. 301-317, March, 2001.
- [4] D. Wilson and M. Ghanbari, "Exploiting interlayer correlation of SNR scalable video", *IEEE Trans. on CSVT*, Vol. 9, No. 5, pp. 783-797, August, 1999.
- [5] C. L. Huang, A. S. M. Masud, *Multiobjective Decision Making Methods and Applications*, Springer-Verlag, 1979.



CLAIMS

1. A method for processing at least a first digital video and a second digital video, the first digital video and the second digital video comprising a sequence of digital picture frame, respectively, comprising the following steps:

- the first digital video is grouped into a first base-layer bit-stream for providing a basic video quality for the first digital video, and one first enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the first digital video compared to the basic video quality.
- the second digital video is grouped into a second base-layer bit-stream for providing a basic video quality for the second digital video, and one second enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the second digital video compared to the basic video quality.
- the first digital video and the second digital video are statistically multiplexed to a multiplexed bit-stream, which comprises at least the first base-layer bit-stream and the second base-layer bit-stream, and, dependent on the available network bandwidth, at least a part of the first enhancement-layer bit-stream and/or at least a part of the second enhancement-layer bit-stream.

2. The method according to claim 1, wherein at least one bit-stream from the first digital video and/or second digital video is delayed at least one picture frame after the first base-layer bit-stream.

3. The method according to claim 2,

- wherein the first enhancement-layer bit-stream is delayed at least one picture frame after the first base-layer bit-stream, and/or



- wherein the second enhancement-layer bit-stream is delayed at least one picture frame after the second base-layer bit-stream.

5 4. The method according to claim 2, wherein the second base-layer bit-stream is delayed at least two picture frames after the first base-layer bit-stream.

10 5. The method according to claim 1, wherein an optimum number of bit-planes from the enhancement-layer of at least one digital video to be multiplexed is determined by solving the following optimisation problem:

15
$$\text{Min}[F(j), G(j)]$$

with the constraints given by the following:

$$\sum_{n=1}^N \sum_{i=1}^{m_n} u^{\text{EL}}_{n,i}(j) \leq U^{\text{EL}}(j), \text{ and}$$

20
$$m_n(j-1) - \Delta_m \leq m_n(j) \leq m_n(j-1) + \Delta_m$$

wherein

- 25
- $F(j)$ is the fairness of all the digital videos at frame interval j ,
 - $G(j)$ is the number of bit-planes to be multiplexed,
 - $u^{\text{EL}}_{n,i}(j)$ is the number of bits in the i^{th} bit-plane of the enhancement-layer of the digital video n in frame interval j ,
 - 30 • $U^{\text{EL}}(j)$ is the total number of bits of enhancement-layer of all the digital video N in frame interval j ,
 - $m_n(j)$ is the number of multiplexed bit-planes for digital video n , and
 - Δ_m is a smooth factor to ensure a smooth bit-plane variation.
- 35

6. The method according to claim 5, wherein fairness is ensured by minimizing the deviation of a plurality of bit-



planes that are not multiplexed from a plurality of digital videos.

7. The method according to claims 5 and 6, wherein fairness, $F(j)$, is determined using the following formula:

$$F(j) = \left(\frac{1}{N} \sum_{n=1}^N \left((f_n(j))^2 - \left(\frac{1}{N} \sum_{i=1}^N (f_n(i)) \right)^2 \right) \right)^{1/2},$$

wherein

$f_n(j)$ is a function relating to the number of bit-planes not multiplexed.

8. The method according to claim 5, wherein the number of bit-planes to be multiplexed is determined using the following formula:

$$G(j) = -\sum_{n=1}^N \sum_{i=1}^{m_n} u^{EL}_{n,i}(j).$$

9. The method according to claims 5 to 8, wherein the bit-planes of the enhancement-layer bit-stream are transmitted from a most significant bit-plane to a least significant bit-plane in a sequential manner.
10. A device comprising a processing unit for processing at least a first digital video and a second digital video, the first digital video and the second digital video comprising a sequence of digital picture frame, respectively, comprising:
- a first grouping unit for grouping the first digital video into a first base-layer bit-stream for providing a basic video quality for the first digital video, and one first enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the first digital video compared to the basic video quality.



- a second grouping unit for grouping the second digital video into a second base-layer bit-stream for providing a basic video quality for the second digital video, and one second enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the second digital video compared to the basic video quality.
 - a statistical multiplexing unit for statistical multiplexing the first digital video and the second digital video to a multiplexed bit-stream, which comprises at least the first base-layer bit-stream and the second base-layer bit-stream, and, dependent on the available network bandwidth, at least a part of the first enhancement-layer bit-stream and/or at least a part of the second enhancement-layer bit-stream.
11. A computer readable medium, having a program recorded thereon, where the program is to make the computer execute a procedure for processing at least a first digital video and a second digital video, the first digital video and the second digital video comprising a sequence of digital picture frame, respectively, comprising the following steps:
- the first digital video is grouped into a first base-layer bit-stream for providing a basic video quality for the first digital video, and one first enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the first digital video compared to the basic video quality.
 - the second digital video is grouped into a second base-layer bit-stream for providing a basic video quality for the second digital video, and one second enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the second digital video compared to the basic video quality.



- the first digital video and the second digital video are statistically multiplexed to a multiplexed bit-stream, which comprises at least the first base-layer bit-stream and the second base-layer bit-stream, and, dependent on the available network bandwidth, at least a part of the first enhancement-layer bit-stream and/or at least a part of the second enhancement-layer bit-stream.
12. A computer program element which is to make the computer execute a procedure for processing at least a first digital video and a second digital video, the first digital video and the second digital video comprising a sequence of digital picture frame, respectively, comprising the following steps:
- the first digital video is grouped into a first base-layer bit-stream for providing a basic video quality for the first digital video, and one first enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the first digital video compared to the basic video quality.
 - the second digital video is grouped into a second base-layer bit-stream for providing a basic video quality for the second digital video, and one second enhancement-layer bit-stream with at least one bit-plane for providing enhanced video quality for the second digital video compared to the basic video quality.
 - the first digital video and the second digital video are statistically multiplexed to a multiplexed bit-stream, which comprises at least the first base-layer bit-stream and the second base-layer bit-stream, and, dependent on the available network bandwidth, at least a part of the first enhancement-layer bit-stream and/or at least a part of the second enhancement-layer bit-stream.