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(12) **United States Patent**
Wang

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(54) **SEI MESSAGE DEPENDENCY SIMPLIFICATION IN VIDEO CODING**

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(73) Assignee: **Huawei Technologies Co., Ltd.**, Shenzhen (CN)

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(22) Filed: **Apr. 21, 2023**

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(Continued)

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H04N 19/102	(2014.01)

(Continued)

(52) **U.S. Cl.**
CPC ***H04N 19/46*** (2014.11); ***H04N 19/102*** (2014.11); ***H04N 19/105*** (2014.11);
(Continued)

(58) **Field of Classification Search**
CPC H04N 19/46; H04N 19/102; H04N 19/105; H04N 19/132; H04N 19/172;
(Continued)

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(Continued)

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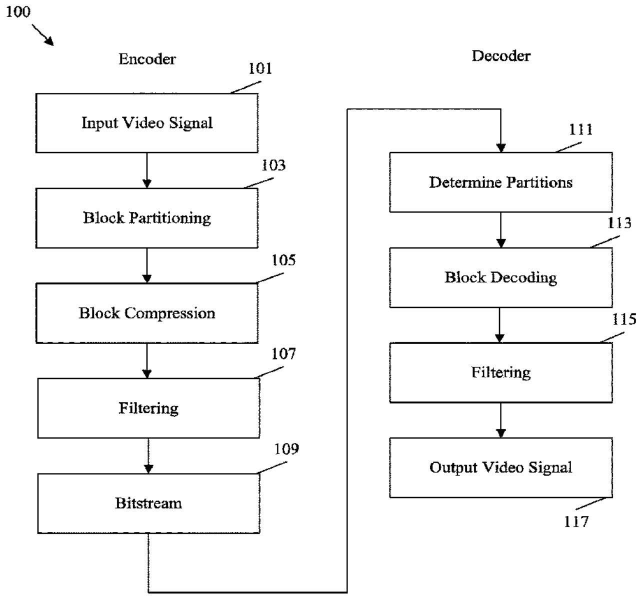
(57) **ABSTRACT**

A video coding mechanism is disclosed. The mechanism includes encoding a coded picture into a bitstream. A current supplemental enhancement information (SEI) message that comprises a decoding unit (DU) hypothetical reference decoder (HRD) parameters present flag (du_hrd_params_present_flag) is also encoded into the bitstream. The du_hrd_params_present_flag specifies whether DU level HRD parameters are present in the bitstream. A set of bitstream conformance tests is performed on the bitstream based on the current SEI message. The bitstream is stored for communication toward a decoder.

20 Claims, 11 Drawing Sheets



Related U.S. Application Data

continuation of application No. PCT/US2020/051316, filed on Sep. 17, 2020.

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(51) **Int. Cl.**

H04N 19/105	(2014.01)
H04N 19/132	(2014.01)
H04N 19/169	(2014.01)
H04N 19/172	(2014.01)
H04N 19/174	(2014.01)
H04N 19/46	(2014.01)
H04N 19/30	(2014.01)
H04N 19/70	(2014.01)

(52) **U.S. Cl.**
CPC ***H04N 19/132*** (2014.11); ***H04N 19/172*** (2014.11); ***H04N 19/174*** (2014.11); ***H04N 19/188*** (2014.11); *H04N 19/30* (2014.11); *H04N 19/70* (2014.11)

(58) **Field of Classification Search**
CPC H04N 19/174; H04N 19/188; H04N 19/30; H04N 19/70; H04N 21/44004; H04N 19/186; H04N 19/423; H04N 19/184; H04N 19/44
See application file for complete search history.

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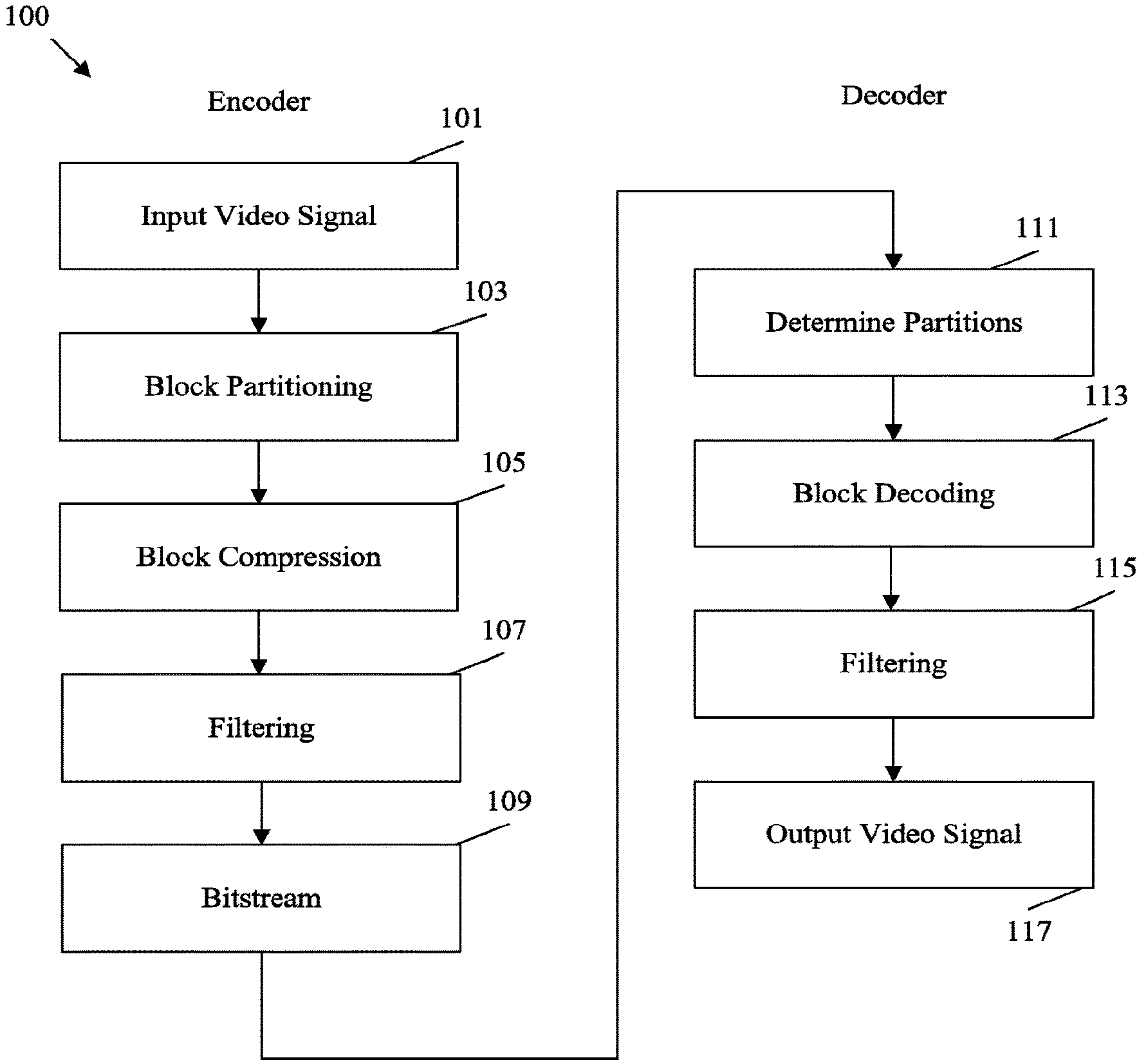
100
Encoder
101
Input Video Signal
103
Block Partitioning
105
Block Compression
107
Filtering
109
Bitstream
Decoder
111
Determine Partitions
113
Block Decoding
115
Filtering
Output Video Signal
117

FIG. 1

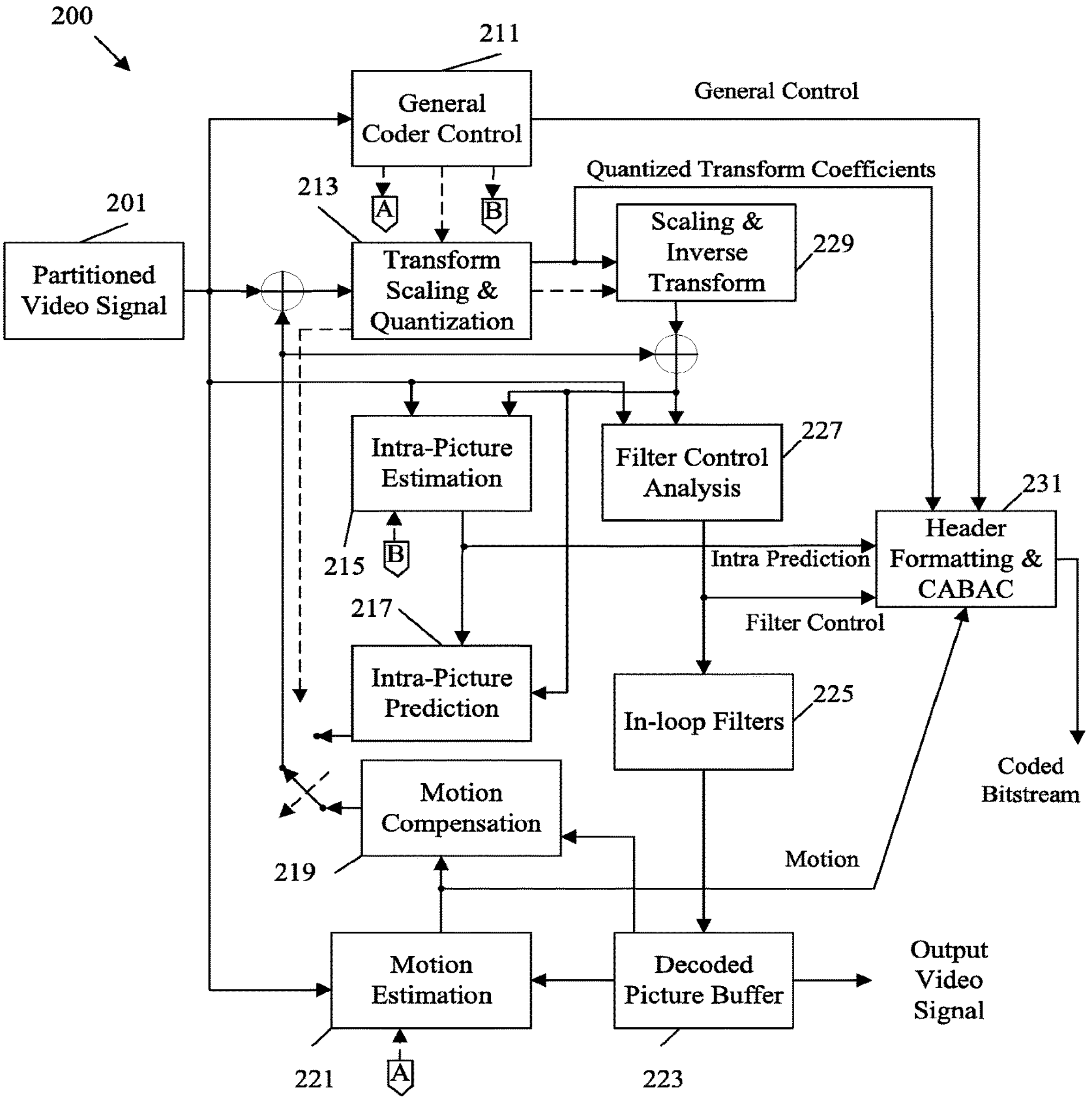
200
211
General Coder Control
General Control
Quantized Transform Coefficients
213
A
B
201
Partitioned Video Signal
Transform Scaling & Quantization
Scaling & Inverse Transform
229
Intra-Picture Estimation
Filter Control Analysis
227
231
Header Formatting & CABAC
215
B
Intra Prediction
Filter Control
217
Intra-Picture Prediction
In-loop Filters
225
Coded Bitstream
Motion Compensation
219
Motion
Motion Estimation
Decoded Picture Buffer
Output Video Signal
221
A
223

FIG. 2

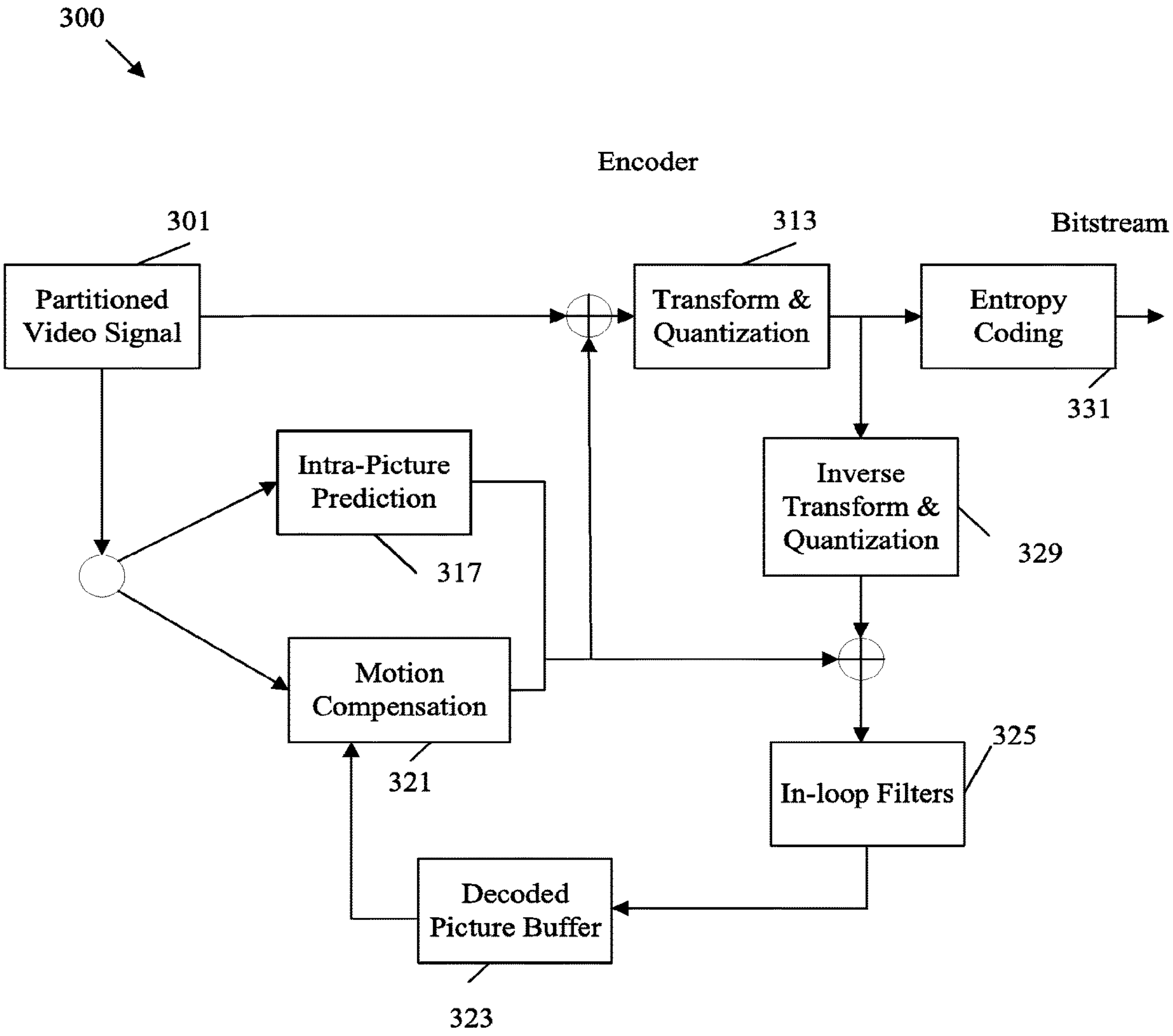
300
Encoder
301
Partitioned Video Signal
313
Transform & Quantization
Bitstream
Entropy Coding
331
Intra-Picture Prediction
317
Inverse Transform & Quantization
329
Motion Compensation
321
325
In-loop Filters
Decoded Picture Buffer
323

FIG. 3

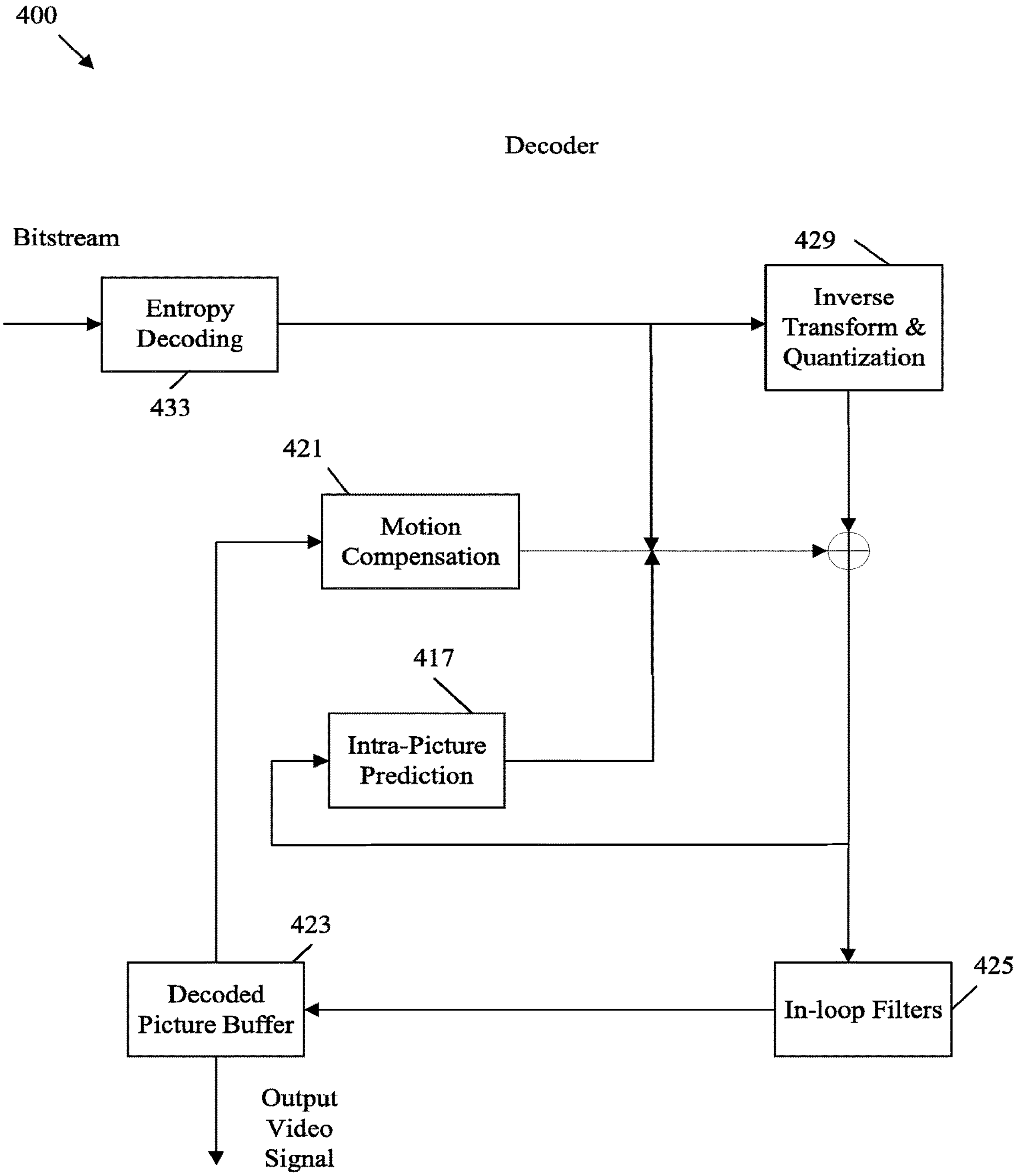
400
Decoder
Bitstream
Entropy Decoding
433
429
Inverse Transform & Quantization
421
Motion Compensation
417
Intra-Picture Prediction
423
Decoded Picture Buffer
In-loop Filters
425
Output Video Signal

FIG. 4

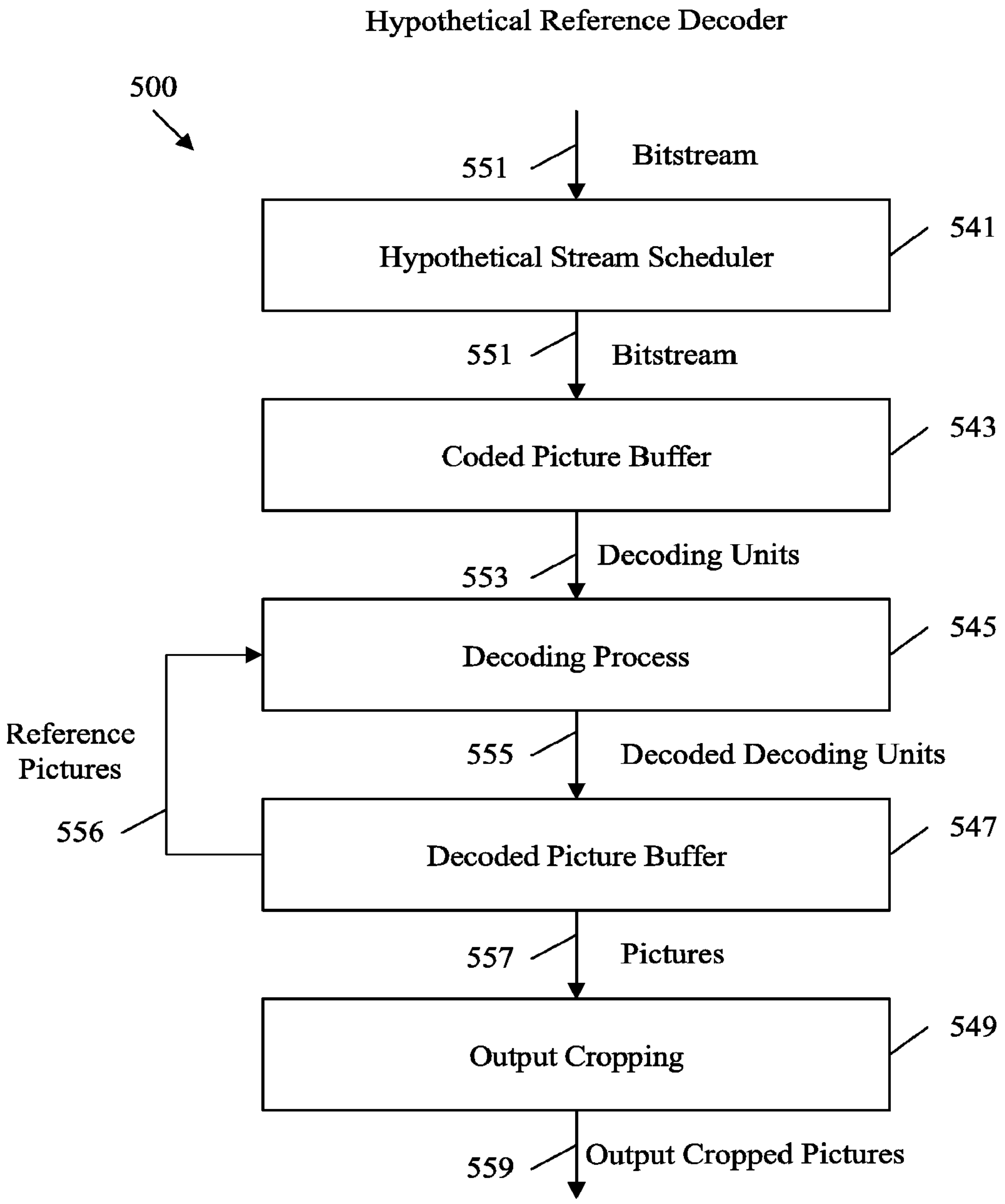
Hypothetical Reference Decoder
500
551
Bitstream
Hypothetical Stream Scheduler
541
551
Bitstream
Coded Picture Buffer
543
Decoding Units
553
Decoding Process
545
Reference Pictures
555
Decoded Decoding Units
556
Decoded Picture Buffer
547
557
Pictures
Output Cropping
549
559
Output Cropped Pictures

FIG. 5

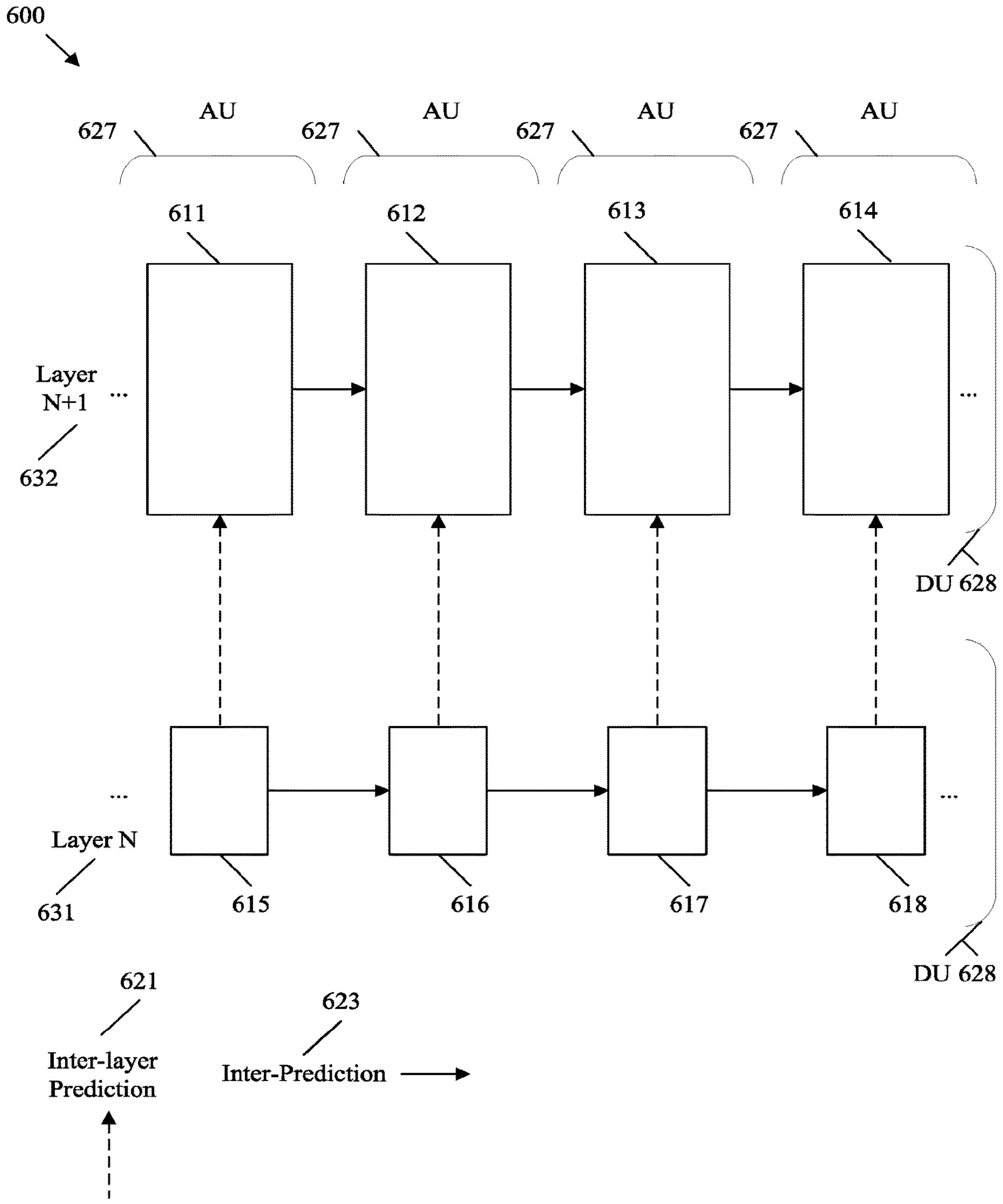
600
AU
AU
AU
AU
627
627
627
627
611
612
613
614
Layer N+1
632
...
...
DU 628
...
...
Layer N
631
615
616
617
618
DU 628
621
Inter-layer Prediction
623
Inter-Prediction

FIG. 6

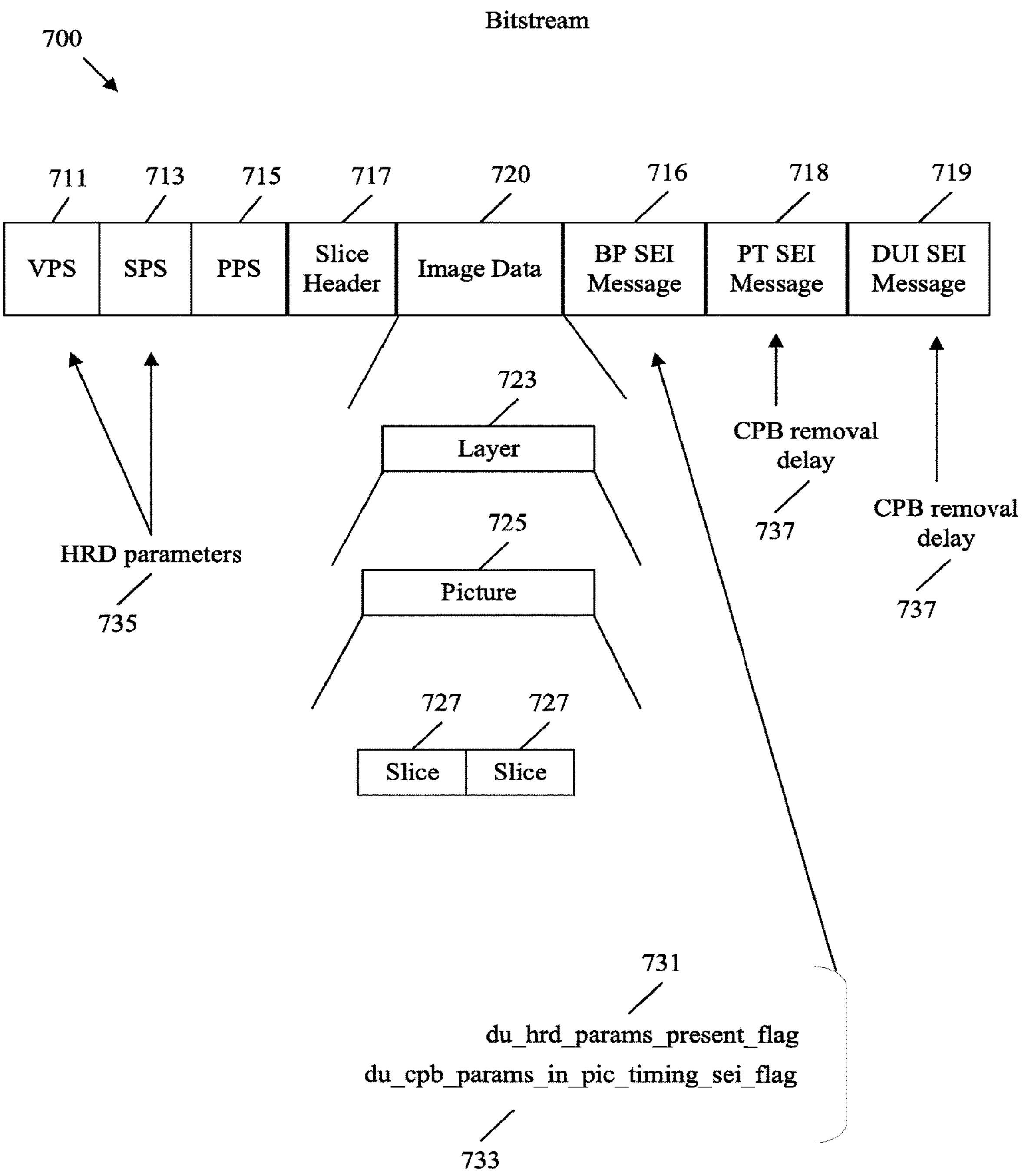
Bitstream
700
711
713
715
717
720
716
718
719
VPS
SPS
PPS
Slice Header
Image Data
BP SEI Message
PT SEI Message
DUI SEI Message
723
Layer
725
Picture
727
727
Slice
Slice
HRD parameters
735
CPB removal delay
737
CPB removal delay
737
731
du_hrd_params_present_flag
du_cpb_params_in_pic_timing_sei_flag
733

FIG. 7

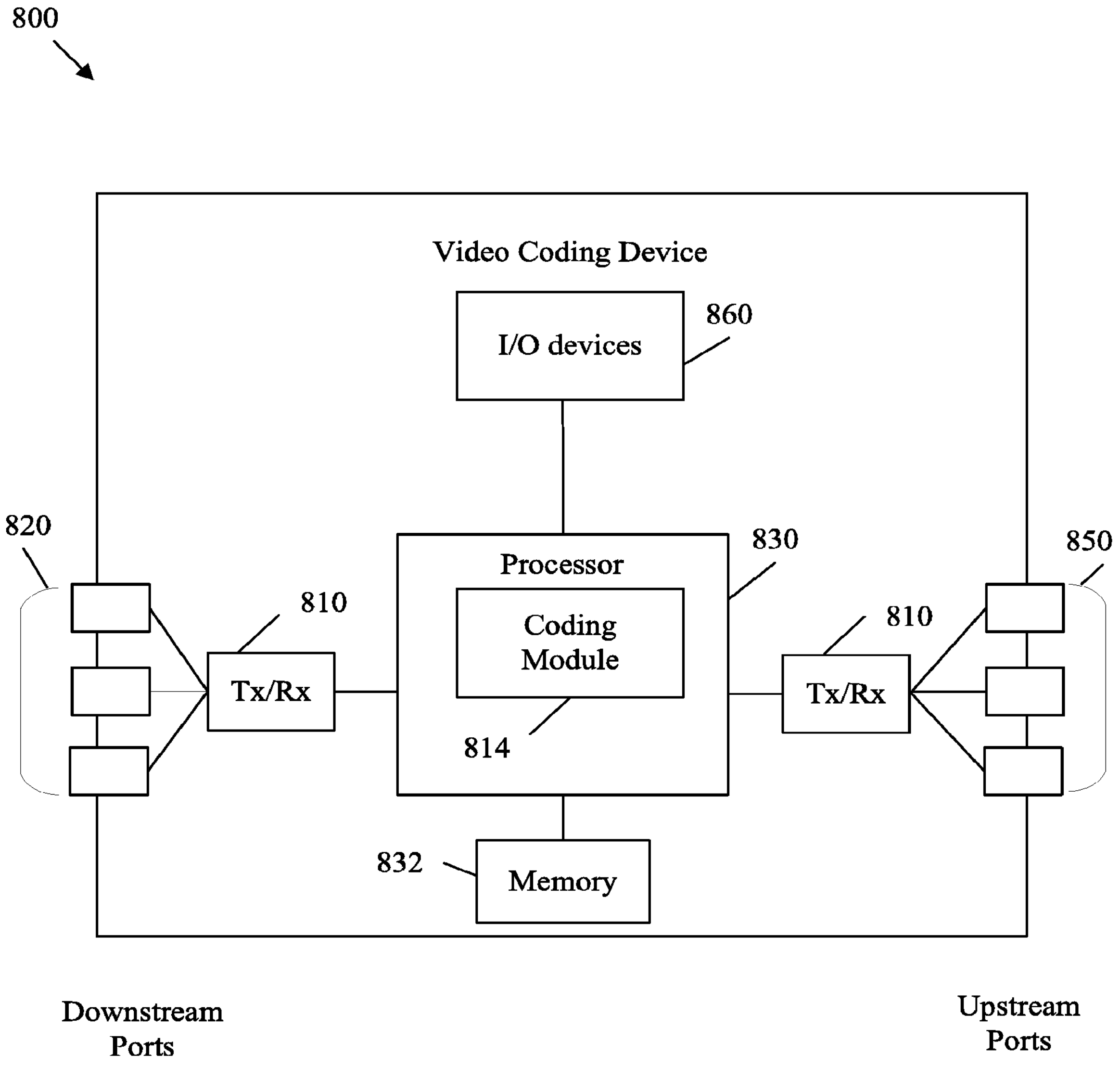
800
Video Coding Device
I/O devices
860
820
810
Processor
830
850
Coding Module
810
Tx/Rx
Tx/Rx
814
832
Memory
Downstream Ports
Upstream Ports

FIG. 8

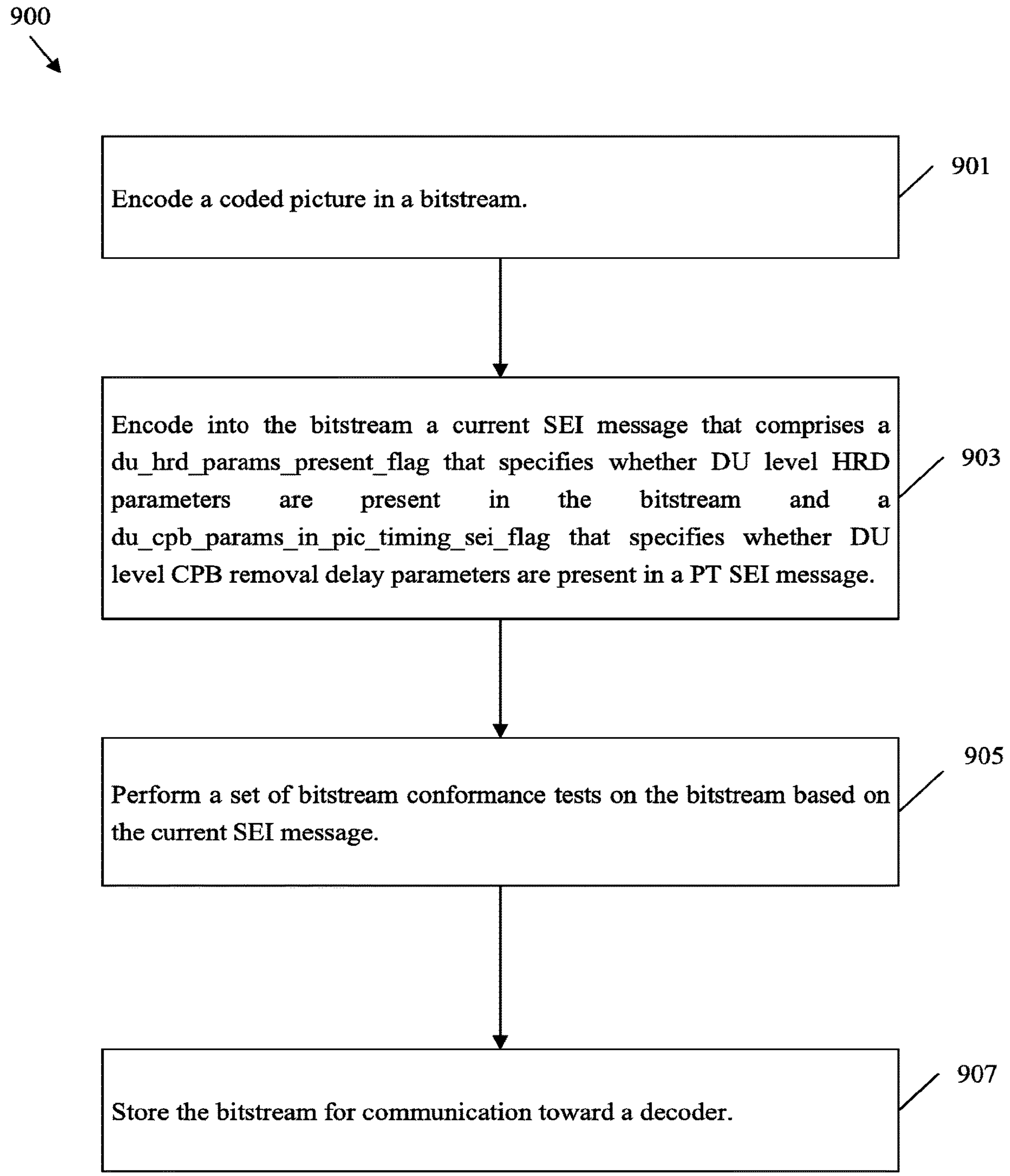
900
Encode a coded picture in a bitstream.
901
Encode into the bitstream a current SEI message that comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream and a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message.
903
Perform a set of bitstream conformance tests on the bitstream based on the current SEI message.
905
Store the bitstream for communication toward a decoder.
907

FIG. 9

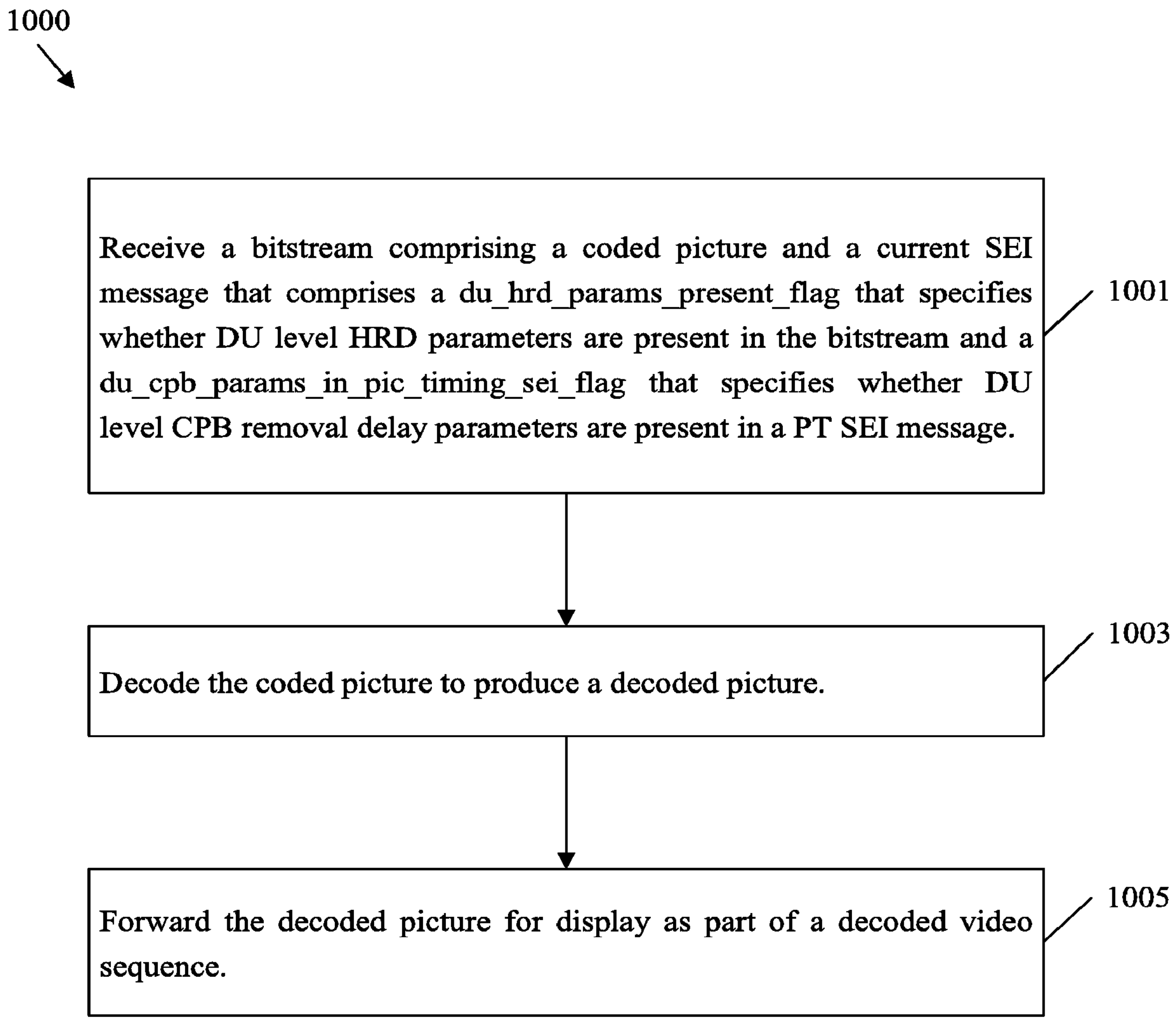
1000
Receive a bitstream comprising a coded picture and a current SEI message that comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream and a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message.
1001
Decode the coded picture to produce a decoded picture.
1003
Forward the decoded picture for display as part of a decoded video sequence.
1005

FIG. 10

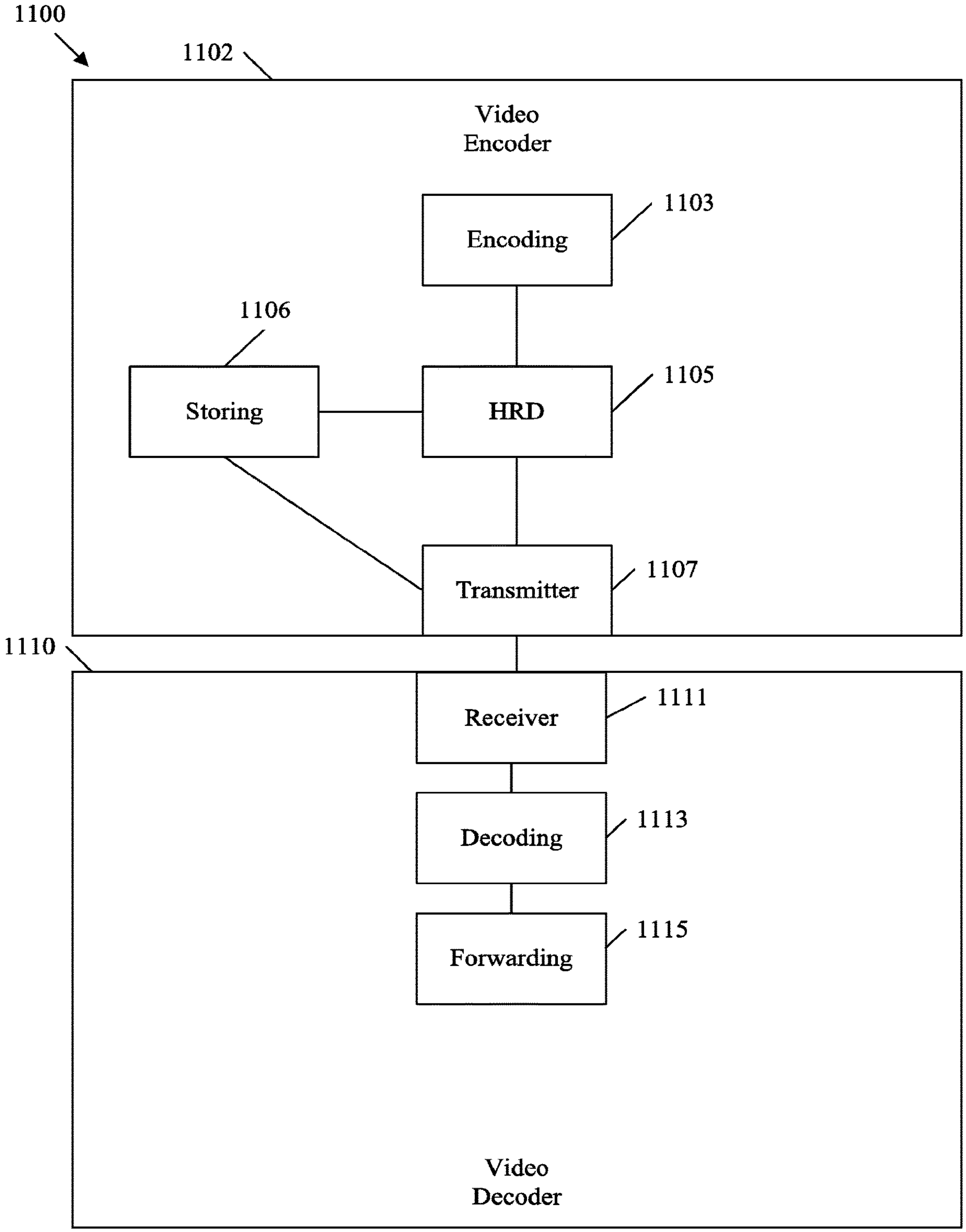
1100
1102
Video
Encoder
Encoding
1103
1106
Storing
HRD
1105
Transmitter
1107
1110
Receiver
1111
Decoding
1113
Forwarding
1115
Video
Decoder

FIG. 11

SEI MESSAGE DEPENDENCY SIMPLIFICATION IN VIDEO CODING

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation of U.S. application Ser. No. 17/701,407, filed on Mar. 22, 2022 by Ye-Kui Wang, and titled "SEI Message Dependency Simplification In Video Coding," which claims the benefit of International Application No. PCT/US2020/051316, filed Sep. 17, 2020 by Ye-Kui Wang, and titled "SEI Message Dependency Simplification In Video Coding," and U.S. Provisional Patent Application No. 62/905,236 filed Sep. 24, 2019 by Ye-Kui Wang, and titled "Video Coding Improvements," which are hereby incorporated by reference.

TECHNICAL FIELD

The present disclosure is generally related to video coding, and is specifically related to improvements in signaling parameters to support coding of multi-layer bitstreams.

BACKGROUND

The amount of video data needed to depict even a relatively short video can be substantial, which may result in difficulties when the data is to be streamed or otherwise communicated across a communications network with limited bandwidth capacity. Thus, video data is generally compressed before being communicated across modern day telecommunications networks. The size of a video could also be an issue when the video is stored on a storage device because memory resources may be limited. Video compression devices often use software and/or hardware at the source to code the video data prior to transmission or storage, thereby decreasing the quantity of data needed to represent digital video images. The compressed data is then received at the destination by a video decompression device that decodes the video data. With limited network resources and ever increasing demands of higher video quality, improved compression and decompression techniques that improve compression ratio with little to no sacrifice in image quality are desirable.

SUMMARY

In an embodiment, the disclosure includes a method implemented by a decoder, the method comprising: receiving, by a receiver of the decoder, a bitstream comprising a coded picture and a current supplemental enhancement information (SEI) message that comprises a decoding unit (DU) hypothetical reference decoder (HRD) parameters present flag (du_hrd_params_present_flag) that specifies whether DU level HRD parameters are present in the bitstream; and decoding, by a processor of the decoder, the coded picture to produce a decoded picture.

Video coding systems may encode a video sequence into a bitstream as a series of coded pictures. Various parameters can also be coded to support decoding of the video sequence. For example, a video parameter set (VPS) may contain parameters related to the configuration of layers, sublayers, and/or output layer sets (OLSs) in the video sequence. In addition, the video sequence can be checked by a HRD for conformance with standards. To support such conformance testing, the VPS and/or the SPS may contain HRD parameters. HRD related parameters may also be contained in SEI

messages. A SEI message contains information that is not needed by the decoding process in order to determine the values of the samples in decoded pictures. For example, the SEI messages may contain HRD parameters that further describe the HRD process in light of the HRD parameters contained in the VPS. In some video coding systems, the SEI messages may contain parameters that directly reference the VPS. This dependency creates certain difficulties. For example, the VPS may be removed from a bitstream when transmitting an OLS that contains a single layer. This approach may be beneficial in some instances as the VPS does not contain useful information when the decoder only receives one layer. However, omitting the VPS can prevent the SEI messages from being properly parsed due to the dependency on the VPS. Specifically, omitting the VPS can cause the SEI messages to return an error as the data upon which they depend in the VPS is not received at the decoder.

The present example includes a mechanism to remove dependencies between the VPS and the SEI messages. For example, a du_hrd_params_present_flag can be coded in a current SEI message. The du_hrd_params_present_flag specifies whether the HRD should operate on an access unit (AU) level or a DU level. Further, the current SEI message can include a DU coded picture buffer (CPB) parameters in picture timing (PT) SEI flag (du_cpb_params_in_pic_timing_sei_flag) that specifies whether DU level CPB removal delay parameters are present in a PT SEI message or a decoding unit information (DUI) SEI message. By including these flags in the current SEI message, the current SEI message does not depend on the VPS. Hence, the current SEI message can be parsed even when the VPS is omitted from the bitstream. Accordingly, various errors may be avoided. As a result, the functionality of the encoder and the decoder is increased. Further, removing the dependency between the SEI messages and the VPS supports removal of the VPS in certain cases, which increases coding efficiency, and hence reduces processor, memory, and/or network signaling resource usage at both the encoder and the decoder.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_hrd_params_present_flag further specifies whether a HRD operates at an access unit (AU) level or a DU level.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_hrd_params_present_flag is set to one when specifying that DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level, and wherein the du_hrd_params_present_flag is set to zero when specifying that DU level HRD parameters are not present and the HRD operates at the AU level.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the current SEI message further comprises a DU coded picture buffer (CPB) parameters in picture timing (PT) SEI flag (du_cpb_params_in_pic_timing_sei_flag) that specifies whether DU level CPB removal delay parameters are present in a PT SEI message.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_cpb_params_in_pic_timing_sei_flag further specifies whether DU level CPB removal delay parameters are present in a decoding unit information (DUI) SEI message.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_cpb_params_in_pic_timing_sei_flag is set to one when specifying that that DU level CPB removal delay parameters are present in a PT SEI message and no DUI SEI message is available, and wherein the du_cpb_params_in_pic_timing_sei_flag is set to zero when specifying that DU level CPB removal delay parameters are present in a DUI SEI message and PT SEI messages do not include DU level CPB removal delay parameters.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the current SEI message is a buffering period (BP) SEI message, a PT SEI message, or a DUI SEI message.

In an embodiment, the disclosure includes a method implemented by an encoder, the method comprising: encoding, by a processor of the encoder, a coded picture into a bitstream; encoding into the bitstream, by the processor, a current SEI message that comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream; performing, by the processor, a set of bitstream conformance tests on the bitstream based on the current SEI message; and storing, by a memory coupled to the processor, the bitstream for communication toward a decoder.

Video coding systems may encode a video sequence into a bitstream as a series of coded pictures. Various parameters can also be coded to support decoding of the video sequence. For example, a VPS may contain parameters related to the configuration of layers, sublayers, and/or OLSs in the video sequence. In addition, the video sequence can be checked by a HRD for conformance with standards. To support such conformance testing, the VPS and/or the SPS may contain HRD parameters. HRD related parameters may also be contained in SEI messages. A SEI message contains information that is not needed by the decoding process in order to determine the values of the samples in decoded pictures. For example, the SEI messages may contain HRD parameters that further describe the HRD process in light of the HRD parameters contained in the VPS. In some video coding systems, the SEI messages may contain parameters that directly reference the VPS. This dependency creates certain difficulties. For example, the VPS may be removed from a bitstream when transmitting an OLS that contains a single layer. This approach may be beneficial in some instances as the VPS does not contain useful information when the decoder only receives one layer. However, omitting the VPS can prevent the SEI messages from being properly parsed due to the dependency on the VPS. Specifically, omitting the VPS can cause the SEI messages to return an error as the data upon which they depend in the VPS is not received at the decoder.

The present example includes a mechanism to remove dependencies between the VPS and the SEI messages. For example, a du_hrd_params_present_flag can be coded in a current SEI message. The du_hrd_params_present_flag specifies whether the HRD should operate on an AU level or a DU level. Further, the current SEI message can include a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message or a DUI SEI message. By including these flags in the current SEI message, the current SEI message does not depend on the VPS. Hence, the current SEI message can be parsed even when the VPS is omitted from the bitstream. Accordingly, various errors may be avoided. As a result, the functionality of the encoder and the decoder is increased. Further, removing the dependency between the SEI messages and the VPS supports removal of the VPS in certain cases, which increases coding efficiency, and hence reduces processor, memory, and/or network signaling resource usage at both the encoder and the decoder.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_hrd_params_present_flag further specifies whether a HRD operates at an AU level or a DU level.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_hrd_params_present_flag is set to one when specifying that DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level, and wherein the du_hrd_params_present_flag is set to zero when specifying that DU level HRD parameters are not present and the HRD operates at the AU level.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the current SEI message further comprises a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_cpb_params_in_pic_timing_sei_flag further specifies whether DU level CPB removal delay parameters are present in a DUI SEI message.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the du_cpb_params_in_pic_timing_sei_flag is set to one when specifying that DU level CPB removal delay parameters are present in a PT SEI message and no DUI SEI message is available, and wherein the du_cpb_params_in_pic_timing_sei_flag is set to zero when specifying that DU level CPB removal delay parameters are present in a DUI SEI message and PT SEI messages do not include DU level CPB removal delay parameters.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the current SEI message is a BP SEI message, a PT SEI message, or a DUI SEI message.

In an embodiment, the disclosure includes a video coding device comprising: a processor, a receiver coupled to the processor, a memory coupled to the processor, and a transmitter coupled to the processor, wherein the processor, receiver, memory, and transmitter are configured to perform the method of any of the preceding aspects.

In an embodiment, the disclosure includes a non-transitory computer readable medium comprising a computer program product for use by a video coding device, the computer program product comprising computer executable instructions stored on the non-transitory computer readable medium such that when executed by a processor cause the video coding device to perform the method of any of the preceding aspects.

In an embodiment, the disclosure includes a decoder comprising: a receiving means for receiving a bitstream comprising a coded picture and a current SEI message that comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream; a decoding means for decoding the coded picture to produce a decoded picture; and a forwarding means for forwarding the decoded picture for display as part of a decoded video sequence.

Video coding systems may encode a video sequence into a bitstream as a series of coded pictures. Various parameters can also be coded to support decoding of the video sequence. For example, a VPS may contain parameters related to the configuration of layers, sublayers, and/or OLSs in the video sequence. In addition, the video sequence can be checked by a HRD for conformance with standards. To support such conformance testing, the VPS and/or the SPS may contain

HRD parameters. HRD related parameters may also be contained in SEI messages. A SEI message contains information that is not needed by the decoding process in order to determine the values of the samples in decoded pictures. For example, the SEI messages may contain HRD parameters that further describe the HRD process in light of the HRD parameters contained in the VPS. In some video coding systems, the SEI messages may contain parameters that directly reference the VPS. This dependency creates certain difficulties. For example, the VPS may be removed from a bitstream when transmitting an OLS that contains a single layer. This approach may be beneficial in some instances as the VPS does not contain useful information when the decoder only receives one layer. However, omitting the VPS can prevent the SEI messages from being properly parsed due to the dependency on the VPS. Specifically, omitting the VPS can cause the SEI messages to return an error as the data upon which they depend in the VPS is not received at the decoder.

The present example includes a mechanism to remove dependencies between the VPS and the SEI messages. For example, a du_hrd_params_present_flag can be coded in a current SEI message. The du_hrd_params_present_flag specifies whether the HRD should operate on an AU level or a DU level. Further, the current SEI message can include a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message or a DUI SEI message. By including these flags in the current SEI message, the current SEI message does not depend on the VPS. Hence, the current SEI message can be parsed even when the VPS is omitted from the bitstream. Accordingly, various errors may be avoided. As a result, the functionality of the encoder and the decoder is increased. Further, removing the dependency between the SEI messages and the VPS supports removal of the VPS in certain cases, which increases coding efficiency, and hence reduces processor, memory, and/or network signaling resource usage at both the encoder and the decoder.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the decoder is further configured to perform the method of any of the preceding aspects.

In an embodiment, the disclosure includes an encoder comprising: an encoding means for: encoding a coded picture into a bitstream; and encoding into the bitstream a current SEI message that comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream; a HRD means for performing a set of bitstream conformance tests on the bitstream based on the current SEI message; and a storing means for storing the bitstream for communication toward a decoder.

Video coding systems may encode a video sequence into a bitstream as a series of coded pictures. Various parameters can also be coded to support decoding of the video sequence. For example, a VPS may contain parameters related to the configuration of layers, sublayers, and/or OLSs in the video sequence. In addition, the video sequence can be checked by a HRD for conformance with standards. To support such conformance testing, the VPS and/or the SPS may contain HRD parameters. HRD related parameters may also be contained in SEI messages. A SEI message contains information that is not needed by the decoding process in order to determine the values of the samples in decoded pictures. For example, the SEI messages may contain HRD parameters that further describe the HRD process in light of the HRD parameters contained in the VPS. In some video coding systems, the SEI messages may contain parameters that directly reference the VPS. This dependency creates certain difficulties. For example, the VPS may be removed from a bitstream when transmitting an OLS that contains a single layer. This approach may be beneficial in some instances as the VPS does not contain useful information when the decoder only receives one layer. However, omitting the VPS can prevent the SEI messages from being properly parsed due to the dependency on the VPS. Specifically, omitting the VPS can cause the SEI messages to return an error as the data upon which they depend in the VPS is not received at the decoder.

The present example includes a mechanism to remove dependencies between the VPS and the SEI messages. For example, a du_hrd_params_present_flag can be coded in a current SEI message. The du_hrd_params_present_flag specifies whether the HRD should operate on an AU level or a DU level. Further, the current SEI message can include a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message or a DUI SEI message. By including these flags in the current SEI message, the current SEI message does not depend on the VPS. Hence, the current SEI message can be parsed even when the VPS is omitted from the bitstream. Accordingly, various errors may be avoided. As a result, the functionality of the encoder and the decoder is increased. Further, removing the dependency between the SEI messages and the VPS supports removal of the VPS in certain cases, which increases coding efficiency, and hence reduces processor, memory, and/or network signaling resource usage at both the encoder and the decoder.

Optionally, in any of the preceding aspects, another implementation of the aspect provides, wherein the encoder is further configured to perform the method of any of the preceding aspects.

For the purpose of clarity, any one of the foregoing embodiments may be combined with any one or more of the other foregoing embodiments to create a new embodiment within the scope of the present disclosure.

These and other features will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts.

FIG. **1** is a flowchart of an example method of coding a video signal.

FIG. **2** is a schematic diagram of an example coding and decoding (codec) system for video coding.

FIG. **3** is a schematic diagram illustrating an example video encoder.

FIG. **4** is a schematic diagram illustrating an example video decoder.

FIG. **5** is a schematic diagram illustrating an example hypothetical reference decoder (HRD).

FIG. **6** is a schematic diagram illustrating an example multi-layer video sequence.

FIG. **7** is a schematic diagram illustrating an example bitstream.

FIG. **8** is a schematic diagram of an example video coding device.

FIG. **9** is a flowchart of an example method of encoding a video sequence into a bitstream by employing a supplemental enhancement information (SEI) message that may not depend on a video parameter set (VPS).

FIG. **10** is a flowchart of an example method of decoding a video sequence from a bitstream that employs a SEI message that may not depend on a VPS.

FIG. **11** is a schematic diagram of an example system for coding a video sequence using a bitstream that employs a SEI message that may not depend on a VPS.

DETAILED DESCRIPTION

It should be understood at the outset that although an illustrative implementation of one or more embodiments are provided below, the disclosed systems and/or methods may be implemented using any number of techniques, whether currently known or in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, including the exemplary designs and implementations illustrated and described herein, but may be modified within the scope of the appended claims along with their full scope of equivalents.

The following terms are defined as follows unless used in a contrary context herein. Specifically, the following definitions are intended to provide additional clarity to the present disclosure. However, terms may be described differently in different contexts. Accordingly, the following definitions should be considered as a supplement and should not be considered to limit any other definitions of descriptions provided for such terms herein.

A bitstream is a sequence of bits including video data that is compressed for transmission between an encoder and a decoder. An encoder is a device that is configured to employ encoding processes to compress video data into a bitstream. A decoder is a device that is configured to employ decoding processes to reconstruct video data from a bitstream for display. A picture is an array of luma samples and/or an array of chroma samples that create a frame or a field thereof. A slice is an integer number of complete tiles or an integer number of consecutive complete coding tree unit (CTU) rows (e.g., within a tile) of a picture that are exclusively contained in a single network abstraction layer (NAL) unit. A picture that is being encoded or decoded can be referred to as a current picture for clarity of discussion. A coded picture is a coded representation of a picture comprising video coding layer (VCL) NAL units with a particular value of NAL unit header layer identifier (nuh_layer_id) within an access unit (AU) and containing all coding tree units (CTUs) of the picture. A decoded picture is a picture produced by applying a decoding process to a coded picture.

An AU is a set of coded pictures that are included in different layers and are associated with the same time for output from a decoded picture buffer (DPB). A decoding unit (DU) is an AU or a subset of an AU including one or more VCL NAL units in an AU and associated non-VCL NAL units. A NAL unit is a syntax structure containing data in the form of a Raw Byte Sequence Payload (RBSP), an indication of the type of data, and interspersed as desired with emulation prevention bytes. A VCL NAL unit is a NAL unit coded to contain video data, such as a coded slice of a picture. A non-VCL NAL unit is a NAL unit that contains non-video data such as syntax and/or parameters that support decoding the video data, performance of conformance checking, or other operations. A layer is a set of VCL NAL units that share a specified characteristic (e.g., a common resolution, frame rate, image size, etc.) as indicated by layer ID and associated non-VCL NAL units.

A hypothetical reference decoder (HRD) is a decoder model operating on an encoder that checks the variability of bitstreams produced by an encoding process to verify conformance with specified constraints. A bitstream conformance test is a test to determine whether an encoded bitstream complies with a standard, such as Versatile Video Coding (VVC). HRD parameters are syntax elements that initialize and/or define operational conditions of an HRD. HRD parameters may be included in supplemental enhancement information (SEI) messages, in a sequence parameter set (SPS), and/or in a video parameter set (VPS). A DU HRD parameters present flag (du_hrd_params_present_flag) is a syntax element that specifies whether DU level HRD parameters are present in the bitstream. An AU level is a description of an operation as being applied to one or more entire AUs (e.g., applied to one or more entire groups of pictures sharing the same output time). A DU level is a description of an operation as being applied to one or more entire DUs (e.g., applied to one or more pictures).

A SEI message is a syntax structure with specified semantics that conveys information that is not needed by the decoding process in order to determine the values of the samples in decoded pictures. A SEI NAL unit is a NAL unit that contains one or more SEI messages. A specific SEI NAL unit may be referred to as a current SEI NAL unit. A buffering period (BP) SEI message is a type of SEI message that contains HRD parameters for initializing an HRD to manage a coded picture buffer (CPB). A picture timing (PT) SEI message is a type of SEI message that contains HRD parameters for managing delivery information for AUs at the CPB and/or a decoded picture buffer (DPB). A decoding unit information (DUI) SEI message is a type of SEI message that contains HRD parameters for managing delivery information for DUs at the CPB and/or the DPB. A DU CPB parameters in PT SEI flag (du_cpb_params_in_pic_timing_sei_flag) is a syntax element that specifies whether DU level CPB removal delay parameters are present in a PT SEI message and/or a DUI SEI message. A CPB is a first-in first-out buffer in a HRD that contains DUs in decoding order. A CPB removal delay is an amount time that one or more pictures may remain in a CPB prior to transfer to a DPB in a HRD. A VPS is a syntax structure that contains data related to the entire bitstream. A SPS is a syntax structure a syntax structure containing syntax elements that apply to zero or more entire coded layer video sequences. A coded video sequence is a set of one or more coded pictures. A decoded video sequence is a set of one or more decoded pictures.

The following acronyms are used herein, Access Unit (AU), Coding Tree Block (CTB), Coding Tree Unit (CTU), Coding Unit (CU), Coded Layer Video Sequence (CLVS), Coded Layer Video Sequence Start (CLVSS), Coded Video Sequence (CVS), Coded Video Sequence Start (CVSS), Joint Video Experts Team (JVET), Hypothetical Reference Decoder HRD, Motion Constrained Tile Set (MCTS), Maximum Transfer Unit (MTU), Network Abstraction Layer (NAL), Output Layer Set (OLS), Picture Order Count (POC), Random Access Point (RAP), Raw Byte Sequence Payload (RBSP), Sequence Parameter Set (SPS), Video Parameter Set (VPS), Versatile Video Coding (VVC).

Many video compression techniques can be employed to reduce the size of video files with minimal loss of data. For example, video compression techniques can include performing spatial (e.g., intra-picture) prediction and/or temporal (e.g., inter-picture) prediction to reduce or remove data redundancy in video sequences. For block-based video coding, a video slice (e.g., a video picture or a portion of a video picture) may be partitioned into video blocks, which may also be referred to as treeblocks, coding tree blocks (CTBs), coding tree units (CTUs), coding units (CUs), and/or coding nodes. Video blocks in an intra-coded (I) slice of a picture are coded using spatial prediction with respect to reference samples in neighboring blocks in the same picture. Video blocks in an inter-coded unidirectional prediction (P) or bidirectional prediction (B) slice of a picture may be coded by employing spatial prediction with respect to reference samples in neighboring blocks in the same picture or temporal prediction with respect to reference samples in other reference pictures. Pictures may be referred to as frames and/or images, and reference pictures may be referred to as reference frames and/or reference images. Spatial or temporal prediction results in a predictive block representing an image block. Residual data represents pixel differences between the original image block and the predictive block. Accordingly, an inter-coded block is encoded according to a motion vector that points to a block of reference samples forming the predictive block and the residual data indicating the difference between the coded block and the predictive block. An intra-coded block is encoded according to an intra-coding mode and the residual data. For further compression, the residual data may be transformed from the pixel domain to a transform domain. These result in residual transform coefficients, which may be quantized. The quantized transform coefficients may initially be arranged in a two-dimensional array. The quantized transform coefficients may be scanned in order to produce a one-dimensional vector of transform coefficients. Entropy coding may be applied to achieve even more compression. Such video compression techniques are discussed in greater detail below.

To ensure an encoded video can be accurately decoded, video is encoded and decoded according to corresponding video coding standards. Video coding standards include International Telecommunication Union (ITU) Standardization Sector (ITU-T) H.261, International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) Motion Picture Experts Group (MPEG)-1 Part 2, ITU-T H.262 or ISO/IEC MPEG-2 Part 2, ITU-T H.263, ISO/IEC MPEG-4 Part 2, Advanced Video Coding (AVC), also known as ITU-T H.264 or ISO/IEC MPEG-4 Part 10, and High Efficiency Video Coding (HEVC), also known as ITU-T H.265 or MPEG-H Part 2. AVC includes extensions such as Scalable Video Coding (SVC), Multiview Video Coding (MVC) and Multiview Video Coding plus Depth (MVC+D), and three dimensional (3D) AVC (3D-AVC). HEVC includes extensions such as Scalable HEVC (SHVC), Multiview HEVC (MV-HEVC), and 3D HEVC (3D-HEVC). The joint video experts team (JVET) of ITU-T and ISO/IEC has begun developing a video coding standard referred to as Versatile Video Coding (VVC). VVC is included in a Working Draft (WD), which includes JVET-O2001-v14.

Video coding systems may encode a video sequence into a bitstream as a series of coded pictures. Various parameters can also be coded to support decoding of the video sequence. For example, a video parameter set (VPS) may contain parameters related to the configuration of layers, sublayers, and/or output layer sets (OLSs) in the video sequence. In addition, the video sequence can be checked by a hypothetical reference decoder (HRD) for conformance with standards. To support such conformance testing, the VPS and/or the SPS may contain HRD parameters. HRD related parameters may also be contained in supplemental enhancement information (SEI) messages. A SEI message contains information that is not needed by the decoding process in order to determine the values of the samples in decoded pictures. For example, the SEI messages may contain HRD parameters that further describe the HRD process in light of the HRD parameters contained in the VPS. In some video coding systems, the SEI messages may contain parameters that directly reference the VPS. This dependency creates certain difficulties. For example, the VPS may be removed from a bitstream when transmitting an OLS that contains a single layer. This approach may be beneficial in some instances as the VPS does not contain useful information when the decoder only receives one layer. However, omitting the VPS can prevent the SEI messages from being properly parsed due to the dependency on the VPS. Specifically, omitting the VPS can cause the SEI messages to return an error as the data upon which they depend in the VPS is not received at the decoder.

Disclosed herein is a mechanism to remove dependencies between the VPS and the SEI messages. For example, a decoding unit (DU) hypothetical reference decoder (HRD) parameters present flag (du_hrd_params_present_flag) can be coded in a current SEI message. The du_hrd_params_present_flag specifies whether the HRD should operate on an access unit (AU) level or a decoding unit (DU) level. Further, the current SEI message can include a DU coded picture buffer (CPB) parameters in picture timing (PT) SEI flag (du_cpb_params_in_pic_timing_sei_flag) that specifies whether DU level CPB removal delay parameters are present in a PT SEI message or a decoding unit information (DUI) SEI message. By including these flags in the current SEI message, the current SEI message does not depend on the VPS. Hence, the current SEI message can be parsed even when the VPS is omitted from the bitstream. Accordingly, various errors may be avoided. As a result, the functionality of the encoder and the decoder is increased. Further, removing the dependency between the SEI messages and the VPS supports removal of the VPS in certain cases, which increases coding efficiency, and hence reduces processor, memory, and/or network signaling resource usage at both the encoder and the decoder.

FIG. **1** is a flowchart of an example operating method **100** of coding a video signal. Specifically, a video signal is encoded at an encoder. The encoding process compresses the video signal by employing various mechanisms to reduce the video file size. A smaller file size allows the compressed video file to be transmitted toward a user, while reducing associated bandwidth overhead. The decoder then decodes the compressed video file to reconstruct the original video signal for display to an end user. The decoding process generally mirrors the encoding process to allow the decoder to consistently reconstruct the video signal.

At step **101**, the video signal is input into the encoder. For example, the video signal may be an uncompressed video file stored in memory. As another example, the video file may be captured by a video capture device, such as a video camera, and encoded to support live streaming of the video. The video file may include both an audio component and a video component. The video component contains a series of image frames that, when viewed in a sequence, gives the visual impression of motion. The frames contain pixels that are expressed in terms of light, referred to herein as luma components (or luma samples), and color, which is referred to as chroma components (or color samples). In some examples, the frames may also contain depth values to support three dimensional viewing.

At step **103**, the video is partitioned into blocks. Partitioning includes subdividing the pixels in each frame into square and/or rectangular blocks for compression. For example, in High Efficiency Video Coding (HEVC) (also known as H.265 and MPEG-H Part 2) the frame can first be divided into coding tree units (CTUs), which are blocks of a predefined size (e.g., sixty-four pixels by sixty-four pixels). The CTUs contain both luma and chroma samples. Coding trees may be employed to divide the CTUs into blocks and then recursively subdivide the blocks until configurations are achieved that support further encoding. For example, luma components of a frame may be subdivided until the individual blocks contain relatively homogenous lighting values. Further, chroma components of a frame may be subdivided until the individual blocks contain relatively homogenous color values. Accordingly, partitioning mechanisms vary depending on the content of the video frames.

At step **105**, various compression mechanisms are employed to compress the image blocks partitioned at step **103**. For example, inter-prediction and/or intra-prediction may be employed. Inter-prediction is designed to take advantage of the fact that objects in a common scene tend to appear in successive frames. Accordingly, a block depicting an object in a reference frame need not be repeatedly described in adjacent frames. Specifically, an object, such as a table, may remain in a constant position over multiple frames. Hence the table is described once and adjacent frames can refer back to the reference frame. Pattern matching mechanisms may be employed to match objects over multiple frames. Further, moving objects may be represented across multiple frames, for example due to object movement or camera movement. As a particular example, a video may show an automobile that moves across the screen over multiple frames. Motion vectors can be employed to describe such movement. A motion vector is a two-dimensional vector that provides an offset from the coordinates of an object in a frame to the coordinates of the object in a reference frame. As such, inter-prediction can encode an image block in a current frame as a set of motion vectors indicating an offset from a corresponding block in a reference frame.

Intra-prediction encodes blocks in a common frame. Intra-prediction takes advantage of the fact that luma and chroma components tend to cluster in a frame. For example, a patch of green in a portion of a tree tends to be positioned adjacent to similar patches of green. Intra-prediction employs multiple directional prediction modes (e.g., thirty-three in HEVC), a planar mode, and a direct current (DC) mode. The directional modes indicate that a current block is similar/the same as samples of a neighbor block in a corresponding direction. Planar mode indicates that a series of blocks along a row/column (e.g., a plane) can be interpolated based on neighbor blocks at the edges of the row. Planar mode, in effect, indicates a smooth transition of light/color across a row/column by employing a relatively constant slope in changing values. DC mode is employed for boundary smoothing and indicates that a block is similar/the same as an average value associated with samples of all the neighbor blocks associated with the angular directions of the directional prediction modes. Accordingly, intra-prediction blocks can represent image blocks as various relational prediction mode values instead of the actual values. Further, inter-prediction blocks can represent image blocks as motion vector values instead of the actual values. In either case, the prediction blocks may not exactly represent the image blocks in some cases. Any differences are stored in residual blocks. Transforms may be applied to the residual blocks to further compress the file.

At step **107**, various filtering techniques may be applied. In HEVC, the filters are applied according to an in-loop filtering scheme. The block based prediction discussed above may result in the creation of blocky images at the decoder. Further, the block based prediction scheme may encode a block and then reconstruct the encoded block for later use as a reference block. The in-loop filtering scheme iteratively applies noise suppression filters, de-blocking filters, adaptive loop filters, and sample adaptive offset (SAO) filters to the blocks/frames. These filters mitigate such blocking artifacts so that the encoded file can be accurately reconstructed. Further, these filters mitigate artifacts in the reconstructed reference blocks so that artifacts are less likely to create additional artifacts in subsequent blocks that are encoded based on the reconstructed reference blocks.

Once the video signal has been partitioned, compressed, and filtered, the resulting data is encoded in a bitstream at step **109**. The bitstream includes the data discussed above as well as any signaling data desired to support proper video signal reconstruction at the decoder. For example, such data may include partition data, prediction data, residual blocks, and various flags providing coding instructions to the decoder. The bitstream may be stored in memory for transmission toward a decoder upon request. The bitstream may also be broadcast and/or multicast toward a plurality of decoders. The creation of the bitstream is an iterative process. Accordingly, steps **101**, **103**, **105**, **107**, and **109** may occur continuously and/or simultaneously over many frames and blocks. The order shown in FIG. **1** is presented for clarity and ease of discussion, and is not intended to limit the video coding process to a particular order.

The decoder receives the bitstream and begins the decoding process at step **111**. Specifically, the decoder employs an entropy decoding scheme to convert the bitstream into corresponding syntax and video data. The decoder employs the syntax data from the bitstream to determine the partitions for the frames at step **111**. The partitioning should match the results of block partitioning at step **103**. Entropy encoding/decoding as employed in step **111** is now described. The encoder makes many choices during the compression process, such as selecting block partitioning schemes from several possible choices based on the spatial positioning of values in the input image(s). Signaling the exact choices may employ a large number of bins. As used herein, a bin is a binary value that is treated as a variable (e.g., a bit value that may vary depending on context). Entropy coding allows the encoder to discard any options that are clearly not viable for a particular case, leaving a set of allowable options. Each allowable option is then assigned a code word. The length of the code words is based on the number of allowable options (e.g., one bin for two options, two bins for three to four options, etc.) The encoder then encodes the code word for the selected option. This scheme reduces the size of the code words as the code words are as big as desired to uniquely indicate a selection from a small sub-set of allowable options as opposed to uniquely indicating the selection from a potentially large set of all possible options. The decoder then decodes the selection by determining the set of allowable options in a similar manner to the encoder. By determining the set of allowable options, the decoder can read the code word and determine the selection made by the encoder.

At step **113**, the decoder performs block decoding. Specifically, the decoder employs reverse transforms to generate residual blocks. Then the decoder employs the residual blocks and corresponding prediction blocks to reconstruct the image blocks according to the partitioning. The prediction blocks may include both intra-prediction blocks and inter-prediction blocks as generated at the encoder at step **105**. The reconstructed image blocks are then positioned into frames of a reconstructed video signal according to the partitioning data determined at step **111**. Syntax for step **113** may also be signaled in the bitstream via entropy coding as discussed above.

At step **115**, filtering is performed on the frames of the reconstructed video signal in a manner similar to step **107** at the encoder. For example, noise suppression filters, deblocking filters, adaptive loop filters, and SAO filters may be applied to the frames to remove blocking artifacts. Once the frames are filtered, the video signal can be output to a display at step **117** for viewing by an end user.

FIG. **2** is a schematic diagram of an example coding and decoding (codec) system **200** for video coding. Specifically, codec system **200** provides functionality to support the implementation of operating method **100**. Codec system **200** is generalized to depict components employed in both an encoder and a decoder. Codec system **200** receives and partitions a video signal as discussed with respect to steps **101** and **103** in operating method **100**, which results in a partitioned video signal **201**. Codec system **200** then compresses the partitioned video signal **201** into a coded bitstream when acting as an encoder as discussed with respect to steps **105**, **107**, and **109** in method **100**. When acting as a decoder, codec system **200** generates an output video signal from the bitstream as discussed with respect to steps **111**, **113**, **115**, and **117** in operating method **100**. The codec system **200** includes a general coder control component **211**, a transform scaling and quantization component **213**, an intra-picture estimation component **215**, an intra-picture prediction component **217**, a motion compensation component **219**, a motion estimation component **221**, a scaling and inverse transform component **229**, a filter control analysis component **227**, an in-loop filters component **225**, a decoded picture buffer component **223**, and a header formatting and context adaptive binary arithmetic coding (CABAC) component **231**. Such components are coupled as shown. In FIG. **2**, black lines indicate movement of data to be encoded/decoded while dashed lines indicate movement of control data that controls the operation of other components. The components of codec system **200** may all be present in the encoder. The decoder may include a subset of the components of codec system **200**. For example, the decoder may include the intra-picture prediction component **217**, the motion compensation component **219**, the scaling and inverse transform component **229**, the in-loop filters component **225**, and the decoded picture buffer component **223**. These components are now described.

The partitioned video signal **201** is a captured video sequence that has been partitioned into blocks of pixels by a coding tree. A coding tree employs various split modes to subdivide a block of pixels into smaller blocks of pixels. These blocks can then be further subdivided into smaller blocks. The blocks may be referred to as nodes on the coding tree. Larger parent nodes are split into smaller child nodes. The number of times a node is subdivided is referred to as the depth of the node/coding tree. The divided blocks can be included in coding units (CUs) in some cases. For example, a CU can be a sub-portion of a CTU that contains a luma block, red difference chroma (Cr) block(s), and a blue difference chroma (Cb) block(s) along with corresponding syntax instructions for the CU. The split modes may include a binary tree (BT), triple tree (TT), and a quad tree (QT) employed to partition a node into two, three, or four child nodes, respectively, of varying shapes depending on the split modes employed. The partitioned video signal **201** is forwarded to the general coder control component **211**, the transform scaling and quantization component **213**, the intra-picture estimation component **215**, the filter control analysis component **227**, and the motion estimation component **221** for compression.

The general coder control component **211** is configured to make decisions related to coding of the images of the video sequence into the bitstream according to application constraints. For example, the general coder control component **211** manages optimization of bitrate/bitstream size versus reconstruction quality. Such decisions may be made based on storage space/bandwidth availability and image resolution requests. The general coder control component **211** also manages buffer utilization in light of transmission speed to mitigate buffer underrun and overrun issues. To manage these issues, the general coder control component **211** manages partitioning, prediction, and filtering by the other components. For example, the general coder control component **211** may dynamically increase compression complexity to increase resolution and increase bandwidth usage or decrease compression complexity to decrease resolution and bandwidth usage. Hence, the general coder control component **211** controls the other components of codec system **200** to balance video signal reconstruction quality with bit rate concerns. The general coder control component **211** creates control data, which controls the operation of the other components. The control data is also forwarded to the header formatting and CABAC component **231** to be encoded in the bitstream to signal parameters for decoding at the decoder.

The partitioned video signal **201** is also sent to the motion estimation component **221** and the motion compensation component **219** for inter-prediction. A frame or slice of the partitioned video signal **201** may be divided into multiple video blocks. Motion estimation component **221** and the motion compensation component **219** perform inter-predictive coding of the received video block relative to one or more blocks in one or more reference frames to provide temporal prediction. Codec system **200** may perform multiple coding passes, e.g., to select an appropriate coding mode for each block of video data.

Motion estimation component **221** and motion compensation component **219** may be highly integrated, but are illustrated separately for conceptual purposes. Motion estimation, performed by motion estimation component **221**, is the process of generating motion vectors, which estimate motion for video blocks. A motion vector, for example, may indicate the displacement of a coded object relative to a predictive block. A predictive block is a block that is found to closely match the block to be coded, in terms of pixel difference. A predictive block may also be referred to as a reference block. Such pixel difference may be determined by sum of absolute difference (SAD), sum of square difference (SSD), or other difference metrics. HEVC employs several coded objects including a CTU, coding tree blocks (CTBs), and CUs. For example, a CTU can be divided into CTBs, which can then be divided into CBs for inclusion in CUs. A CU can be encoded as a prediction unit containing prediction data and/or a transform unit (TU) containing transformed residual data for the CU. The motion estimation component **221** generates motion vectors, prediction units, and TUs by using a rate-distortion analysis as part of a rate distortion optimization process. For example, the motion estimation component **221** may determine multiple reference blocks, multiple motion vectors, etc. for a current block/frame, and may select the reference blocks, motion vectors, etc. having the best rate-distortion characteristics. The best rate-distortion characteristics balance both quality of video reconstruction (e.g., amount of data loss by compression) with coding efficiency (e.g., size of the final encoding).

In some examples, codec system **200** may calculate values for sub-integer pixel positions of reference pictures stored in decoded picture buffer component **223**. For example, video codec system **200** may interpolate values of one-quarter pixel positions, one-eighth pixel positions, or other fractional pixel positions of the reference picture. Therefore, motion estimation component **221** may perform a motion search relative to the full pixel positions and fractional pixel positions and output a motion vector with fractional pixel precision. The motion estimation component **221** calculates a motion vector for a prediction unit of a video block in an inter-coded slice by comparing the position of the prediction unit to the position of a predictive block of a reference picture. Motion estimation component **221** outputs the calculated motion vector as motion data to header formatting and CABAC component **231** for encoding and motion to the motion compensation component **219**.

Motion compensation, performed by motion compensation component **219**, may involve fetching or generating the predictive block based on the motion vector determined by motion estimation component **221**. Again, motion estimation component **221** and motion compensation component **219** may be functionally integrated, in some examples. Upon receiving the motion vector for the prediction unit of the current video block, motion compensation component **219** may locate the predictive block to which the motion vector points. A residual video block is then formed by subtracting pixel values of the predictive block from the pixel values of the current video block being coded, forming pixel difference values. In general, motion estimation component **221** performs motion estimation relative to luma components, and motion compensation component **219** uses motion vectors calculated based on the luma components for both chroma components and luma components. The predictive block and residual block are forwarded to transform scaling and quantization component **213**.

The partitioned video signal **201** is also sent to intra-picture estimation component **215** and intra-picture prediction component **217**. As with motion estimation component **221** and motion compensation component **219**, intra-picture estimation component **215** and intra-picture prediction component **217** may be highly integrated, but are illustrated separately for conceptual purposes. The intra-picture estimation component **215** and intra-picture prediction component **217** intra-predict a current block relative to blocks in a current frame, as an alternative to the inter-prediction performed by motion estimation component **221** and motion compensation component **219** between frames, as described above. In particular, the intra-picture estimation component **215** determines an intra-prediction mode to use to encode a current block. In some examples, intra-picture estimation component **215** selects an appropriate intra-prediction mode to encode a current block from multiple tested intra-prediction modes. The selected intra-prediction modes are then forwarded to the header formatting and CABAC component **231** for encoding.

For example, the intra-picture estimation component **215** calculates rate-distortion values using a rate-distortion analysis for the various tested intra-prediction modes, and selects the intra-prediction mode having the best rate-distortion characteristics among the tested modes. Rate-distortion analysis generally determines an amount of distortion (or error) between an encoded block and an original unencoded block that was encoded to produce the encoded block, as well as a bitrate (e.g., a number of bits) used to produce the encoded block. The intra-picture estimation component **215** calculates ratios from the distortions and rates for the various encoded blocks to determine which intra-prediction mode exhibits the best rate-distortion value for the block. In addition, intra-picture estimation component **215** may be configured to code depth blocks of a depth map using a depth modeling mode (DMM) based on rate-distortion optimization (RDO).

The intra-picture prediction component **217** may generate a residual block from the predictive block based on the selected intra-prediction modes determined by intra-picture estimation component **215** when implemented on an encoder or read the residual block from the bitstream when implemented on a decoder. The residual block includes the difference in values between the predictive block and the original block, represented as a matrix. The residual block is then forwarded to the transform scaling and quantization component **213**. The intra-picture estimation component **215** and the intra-picture prediction component **217** may operate on both luma and chroma components.

The transform scaling and quantization component **213** is configured to further compress the residual block. The transform scaling and quantization component **213** applies a transform, such as a discrete cosine transform (DCT), a discrete sine transform (DST), or a conceptually similar transform, to the residual block, producing a video block comprising residual transform coefficient values. Wavelet transforms, integer transforms, sub-band transforms or other types of transforms could also be used. The transform may convert the residual information from a pixel value domain to a transform domain, such as a frequency domain. The transform scaling and quantization component **213** is also configured to scale the transformed residual information, for example based on frequency. Such scaling involves applying a scale factor to the residual information so that different frequency information is quantized at different granularities, which may affect final visual quality of the reconstructed video. The transform scaling and quantization component **213** is also configured to quantize the transform coefficients to further reduce bit rate. The quantization process may reduce the bit depth associated with some or all of the coefficients. The degree of quantization may be modified by adjusting a quantization parameter. In some examples, the transform scaling and quantization component **213** may then perform a scan of the matrix including the quantized transform coefficients. The quantized transform coefficients are forwarded to the header formatting and CABAC component **231** to be encoded in the bitstream.

The scaling and inverse transform component **229** applies a reverse operation of the transform scaling and quantization component **213** to support motion estimation. The scaling and inverse transform component **229** applies inverse scaling, transformation, and/or quantization to reconstruct the residual block in the pixel domain, e.g., for later use as a reference block which may become a predictive block for another current block. The motion estimation component **221** and/or motion compensation component **219** may calculate a reference block by adding the residual block back to a corresponding predictive block for use in motion estimation of a later block/frame. Filters are applied to the reconstructed reference blocks to mitigate artifacts created during scaling, quantization, and transform. Such artifacts could otherwise cause inaccurate prediction (and create additional artifacts) when subsequent blocks are predicted.

The filter control analysis component **227** and the in-loop filters component **225** apply the filters to the residual blocks and/or to reconstructed image blocks. For example, the transformed residual block from the scaling and inverse transform component **229** may be combined with a corresponding prediction block from intra-picture prediction component **217** and/or motion compensation component **219** to reconstruct the original image block. The filters may then be applied to the reconstructed image block. In some examples, the filters may instead be applied to the residual blocks. As with other components in FIG. **2**, the filter control analysis component **227** and the in-loop filters component **225** are highly integrated and may be implemented together, but are depicted separately for conceptual purposes. Filters applied to the reconstructed reference blocks are applied to particular spatial regions and include multiple parameters to adjust how such filters are applied. The filter control analysis component **227** analyzes the reconstructed reference blocks to determine where such filters should be applied and sets corresponding parameters. Such data is forwarded to the header formatting and CABAC component **231** as filter control data for encoding. The in-loop filters component **225** applies such filters based on the filter control data. The filters may include a deblocking filter, a noise suppression filter, a SAO filter, and an adaptive loop filter. Such filters may be applied in the spatial/pixel domain (e.g., on a reconstructed pixel block) or in the frequency domain, depending on the example.

When operating as an encoder, the filtered reconstructed image block, residual block, and/or prediction block are stored in the decoded picture buffer component **223** for later use in motion estimation as discussed above. When operating as a decoder, the decoded picture buffer component **223** stores and forwards the reconstructed and filtered blocks toward a display as part of an output video signal. The decoded picture buffer component **223** may be any memory device capable of storing prediction blocks, residual blocks, and/or reconstructed image blocks.

The header formatting and CABAC component **231** receives the data from the various components of codec system **200** and encodes such data into a coded bitstream for transmission toward a decoder. Specifically, the header formatting and CABAC component **231** generates various headers to encode control data, such as general control data and filter control data. Further, prediction data, including intra-prediction and motion data, as well as residual data in the form of quantized transform coefficient data are all encoded in the bitstream. The final bitstream includes all information desired by the decoder to reconstruct the original partitioned video signal **201**. Such information may also include intra-prediction mode index tables (also referred to as codeword mapping tables), definitions of encoding contexts for various blocks, indications of most probable intra-prediction modes, an indication of partition information, etc. Such data may be encoded by employing entropy coding. For example, the information may be encoded by employing context adaptive variable length coding (CAVLC), CABAC, syntax-based context-adaptive binary arithmetic coding (SBAC), probability interval partitioning entropy (PIPE) coding, or another entropy coding technique. Following the entropy coding, the coded bitstream may be transmitted to another device (e.g., a video decoder) or archived for later transmission or retrieval.

FIG. **3** is a block diagram illustrating an example video encoder **300**. Video encoder **300** may be employed to implement the encoding functions of codec system **200** and/or implement steps **101**, **103**, **105**, **107**, and/or **109** of operating method **100**. Encoder **300** partitions an input video signal, resulting in a partitioned video signal **301**, which is substantially similar to the partitioned video signal **201**. The partitioned video signal **301** is then compressed and encoded into a bitstream by components of encoder **300**.

Specifically, the partitioned video signal **301** is forwarded to an intra-picture prediction component **317** for intra-prediction. The intra-picture prediction component **317** may be substantially similar to intra-picture estimation component **215** and intra-picture prediction component **217**. The partitioned video signal **301** is also forwarded to a motion compensation component **321** for inter-prediction based on reference blocks in a decoded picture buffer component **323**. The motion compensation component **321** may be substantially similar to motion estimation component **221** and motion compensation component **219**. The prediction blocks and residual blocks from the intra-picture prediction component **317** and the motion compensation component **321** are forwarded to a transform and quantization component **313** for transform and quantization of the residual blocks. The transform and quantization component **313** may be substantially similar to the transform scaling and quantization component **213**. The transformed and quantized residual blocks and the corresponding prediction blocks (along with associated control data) are forwarded to an entropy coding component **331** for coding into a bitstream. The entropy coding component **331** may be substantially similar to the header formatting and CABAC component **231**.

The transformed and quantized residual blocks and/or the corresponding prediction blocks are also forwarded from the transform and quantization component **313** to an inverse transform and quantization component **329** for reconstruction into reference blocks for use by the motion compensation component **321**. The inverse transform and quantization component **329** may be substantially similar to the scaling and inverse transform component **229**. In-loop filters in an in-loop filters component **325** are also applied to the residual blocks and/or reconstructed reference blocks, depending on the example. The in-loop filters component **325** may be substantially similar to the filter control analysis component **227** and the in-loop filters component **225**. The in-loop filters component **325** may include multiple filters as discussed with respect to in-loop filters component **225**. The filtered blocks are then stored in a decoded picture buffer component **323** for use as reference blocks by the motion compensation component **321**. The decoded picture buffer component **323** may be substantially similar to the decoded picture buffer component **223**.

FIG. **4** is a block diagram illustrating an example video decoder **400**. Video decoder **400** may be employed to implement the decoding functions of codec system **200** and/or implement steps **111**, **113**, **115**, and/or **117** of operating method **100**. Decoder **400** receives a bitstream, for example from an encoder **300**, and generates a reconstructed output video signal based on the bitstream for display to an end user.

The bitstream is received by an entropy decoding component **433**. The entropy decoding component **433** is configured to implement an entropy decoding scheme, such as CAVLC, CABAC, SBAC, PIPE coding, or other entropy coding techniques. For example, the entropy decoding component **433** may employ header information to provide a context to interpret additional data encoded as codewords in the bitstream. The decoded information includes any desired information to decode the video signal, such as general control data, filter control data, partition information, motion data, prediction data, and quantized transform coefficients from residual blocks. The quantized transform coefficients are forwarded to an inverse transform and quantization component **429** for reconstruction into residual blocks. The inverse transform and quantization component **429** may be similar to inverse transform and quantization component **329**.

The reconstructed residual blocks and/or prediction blocks are forwarded to intra-picture prediction component **417** for reconstruction into image blocks based on intra-prediction operations. The intra-picture prediction component **417** may be similar to intra-picture estimation component **215** and an intra-picture prediction component **217**. Specifically, the intra-picture prediction component **417** employs prediction modes to locate a reference block in the frame and applies a residual block to the result to reconstruct intra-predicted image blocks. The reconstructed intra-predicted image blocks and/or the residual blocks and corresponding inter-prediction data are forwarded to a decoded picture buffer component **423** via an in-loop filters component **425**, which may be substantially similar to decoded picture buffer component **223** and in-loop filters component **225**, respectively. The in-loop filters component **425** filters the reconstructed image blocks, residual blocks and/or prediction blocks, and such information is stored in the decoded picture buffer component **423**. Reconstructed image blocks from decoded picture buffer component **423** are forwarded to a motion compensation component **421** for inter-prediction. The motion compensation component **421** may be substantially similar to motion estimation component **221** and/or motion compensation component **219**. Specifically, the motion compensation component **421** employs motion vectors from a reference block to generate a prediction block and applies a residual block to the result to reconstruct an image block. The resulting reconstructed blocks may also be forwarded via the in-loop filters component **425** to the decoded picture buffer component **423**. The decoded picture buffer component **423** continues to store additional reconstructed image blocks, which can be reconstructed into frames via the partition information. Such frames may also be placed in a sequence. The sequence is output toward a display as a reconstructed output video signal.

FIG. **5** is a schematic diagram illustrating an example HRD **500**. A HRD **500** may be employed in an encoder, such as codec system **200** and/or encoder **300**. The HRD **500** may check the bitstream created at step **109** of method **100** before the bitstream is forwarded to a decoder, such as decoder **400**. In some examples, the bitstream may be continuously forwarded through the HRD **500** as the bitstream is encoded. In the event that a portion of the bitstream fails to conform to associated constraints, the HRD **500** can indicate such failure to an encoder to cause the encoder to re-encode the corresponding section of the bitstream with different mechanisms.

The HRD **500** includes a hypothetical stream scheduler (HSS) **541**. A HSS **541** is a component configured to perform a hypothetical delivery mechanism. The hypothetical delivery mechanism is used for checking the conformance of a bitstream or a decoder with regards to the timing and data flow of a bitstream **551** input into the HRD **500**. For example, the HSS **541** may receive a bitstream **551** output from an encoder and manage the conformance testing process on the bitstream **551**. In a particular example, the HSS **541** can control the rate that coded pictures move through the HRD **500** and verify that the bitstream **551** does not contain non-conforming data.

The HSS **541** may forward the bitstream **551** to a CPB **543** at a predefined rate. The HRD **500** may manage data in decoding units (DU) **553**. A DU **553** is an Access Unit (AU) or a sub-set of an AU and associated non-video coding layer (VCL) network abstraction layer (NAL) units. Specifically, an AU contains one or more pictures associated with an output time. For example, an AU may contain a single picture in a single layer bitstream, and may contain a picture for each layer in a multi-layer bitstream. Each picture of an AU may be divided into slices that are each included in a corresponding VCL NAL unit. Hence, a DU **553** may contain one or more pictures, one or more slices of a picture, or combinations thereof. Also, parameters used to decode the AU, pictures, and/or slices can be included in non-VCL NAL units. As such, the DU **553** contains non-VCL NAL units that contain data needed to support decoding the VCL NAL units in the DU **553**. The CPB **543** is a first-in first-out buffer in the HRD **500**. The CPB **543** contains DUs **553** including video data in decoding order. The CPB **543** stores the video data for use during bitstream conformance verification.

The CPB **543** forwards the DUs **553** to a decoding process component **545**. The decoding process component **545** is a component that conforms to the VVC standard. For example, the decoding process component **545** may emulate a decoder **400** employed by an end user. The decoding process component **545** decodes the DUs **553** at a rate that can be achieved by an example end user decoder. If the decoding process component **545** cannot decode the DUs **553** fast enough to prevent an overflow of the CPB **543**, then the bitstream **551** does not conform to the standard and should be re-encoded.

The decoding process component **545** decodes the DUs **553**, which creates decoded DUs **555**. A decoded DU **555** contains a decoded picture. The decoded DUs **555** are forwarded to a DPB **547**. The DPB **547** may be substantially similar to a decoded picture buffer component **223**, **323**, and/or **423**. To support inter-prediction, pictures that are marked for use as reference pictures **556** that are obtained from the decoded DUs **555** are returned to the decoding process component **545** to support further decoding. The DPB **547** outputs the decoded video sequence as a series of pictures **557**. The pictures **557** are reconstructed pictures that generally mirror pictures encoded into the bitstream **551** by the encoder.

The pictures **557** are forwarded to an output cropping component **549**. The output cropping component **549** is configured to apply a conformance cropping window to the pictures **557**. This results in output cropped pictures **559**. An output cropped picture **559** is a completely reconstructed picture. Accordingly, the output cropped picture **559** mimics what an end user would see upon decoding the bitstream **551**. As such, the encoder can review the output cropped pictures **559** to ensure the encoding is satisfactory.

The HRD **500** is initialized based on HRD parameters in the bitstream **551**. For example, the HRD **500** may read HRD parameters from a VPS, a SPS, and/or SEI messages. The HRD **500** may then perform conformance testing operations on the bitstream **551** based on the information in such HRD parameters. As a specific example, the HRD **500** may determine one or more CPB delivery schedules from the HRD parameters. A delivery schedule specifies timing for delivery of video data to and/or from a memory location, such as a CPB and/or a DPB. Hence, a CPB delivery schedule specifies timing for delivery of AUs, DUs **553**, and/or pictures, to/from the CPB **543**. It should be noted that the HRD **500** may employ DPB delivery schedules for the DPB **547** that are similar to the CPB delivery schedules.

Video may be coded into different layers and/or OLSs for use by decoders with varying levels of hardware capabilities as well for varying network conditions. The CPB delivery schedules are selected to reflect these issues. Accordingly, higher layer sub-bitstreams are designated for optimal hardware and network conditions and hence higher layers may receive one or more CPB delivery schedules that employ a large amount of memory in the CPB **543** and short delays for transfers of the DUs **553** toward the DPB **547**. Likewise, lower layer sub-bitstreams are designated for limited decoder hardware capabilities and/or poor network conditions. Hence, lower layers may receive one or more CPB delivery schedules that employ a small amount of memory in the CPB **543** and longer delays for transfers of the DUs **553** toward the DPB **547**. The OLSs, layers, sublayers, or combinations thereof can then be tested according to the corresponding delivery schedule to ensure that the resulting sub-bitstream can be correctly decoded under the conditions that are expected for the sub-bitstream. Accordingly, the HRD parameters in the bitstream **551** can indicate the CPB delivery schedules as well as include sufficient data to allow the HRD **500** to determine the CPB delivery schedules and correlate the CPB delivery schedules to the corresponding OLSs, layers, and/or sublayers.

FIG. **6** is a schematic diagram illustrating an example multi-layer video sequence **600**. The multi-layer video sequence **600** may be encoded by an encoder, such as codec system **200** and/or encoder **300** and decoded by a decoder, such as codec system **200** and/or decoder **400**, for example according to method **100**. Further, the multi-layer video sequence **600** can be checked for standard conformance by a HRD, such as HRD **500**. The multi-layer video sequence **600** is included to depict an example application for layers in a coded video sequence. A multi-layer video sequence **600** is any video sequence that employs a plurality of layers, such as layer N **631** and layer N+1 **632**.

In an example, the multi-layer video sequence **600** may employ inter-layer prediction **621**. Inter-layer prediction **621** is applied between pictures **611**, **612**, **613**, and **614** and pictures **615**, **616**, **617**, and **618** in different layers. In the example shown, pictures **611**, **612**, **613**, and **614** are part of layer N+1 **632** and pictures **615**, **616**, **617**, and **618** are part of layer N **631**. A layer, such as layer N **631** and/or layer N+1 **632**, is a group of pictures that are all associated with a similar value of a characteristic, such as a similar size, quality, resolution, signal to noise ratio, capability, etc. A layer may be defined formally as a set of VCL NAL units that share the same layer ID and associated non-VCL NAL units. A VCL NAL unit is a NAL unit coded to contain video data, such as a coded slice of a picture. A non-VCL NAL unit is a NAL unit that contains non-video data such as syntax and/or parameters that support decoding the video data, performance of conformance checking, or other operations.

In the example shown, layer N+1 **632** is associated with a larger image size than layer N **631**. Accordingly, pictures **611**, **612**, **613**, and **614** in layer N+1 **632** have a larger picture size (e.g., larger height and width and hence more samples) than pictures **615**, **616**, **617**, and **618** in layer N **631** in this example. However, such pictures can be separated between layer N+1 **632** and layer N **631** by other characteristics. While only two layers, layer N+1 **632** and layer N **631**, are shown, a set of pictures can be separated into any number of layers based on associated characteristics. Layer N+1 **632** and layer N **631** may also be denoted by a layer ID. A layer ID is an item of data that is associated with a picture and denotes the picture is part of an indicated layer. Accordingly, each picture **611-618** may be associated with a corresponding layer ID to indicate which layer N+1 **632** or layer N **631** includes the corresponding picture. For example, a layer ID may include a NAL unit header layer ID (nuh_layer_id), which is a syntax element that specifies an identifier of a layer that includes a NAL unit (e.g., that include slices and/or parameters of the pictures in a layer). A layer associated with a lower quality/smaller image size/smaller bitstream size, such as layer N **631**, is generally assigned a lower layer ID and is referred to as a lower layer. Further, a layer associated with a higher quality/larger image size/larger bitstream size, such as layer N+1 **632**, is generally assigned a higher layer ID and is referred to as a higher layer.

Pictures **611-618** in different layers **631-632** are configured to be displayed in the alternative. As a specific example, a decoder may decode and display picture **615** at a current display time if a smaller picture is desired or the decoder may decode and display picture **611** at the current display time if a larger picture is desired. As such, pictures **611-614** at higher layer N+1 **632** contain substantially the same image data as corresponding pictures **615-618** at lower layer N **631** (notwithstanding the difference in picture size). Specifically, picture **611** contains substantially the same image data as picture **615**, picture **612** contains substantially the same image data as picture **616**, etc.

Pictures **611-618** can be coded by reference to other pictures **611-618** in the same layer N **631** or N+1 **632**. Coding a picture in reference to another picture in the same layer results in inter-prediction **623**. Inter-prediction **623** is depicted by solid line arrows. For example, picture **613** may be coded by employing inter-prediction **623** using one or two of pictures **611**, **612**, and/or **614** in layer N+1 **632** as a reference, where one picture is referenced for unidirectional inter-prediction and/or two pictures are referenced for bidirectional inter-prediction. Further, picture **617** may be coded by employing inter-prediction **623** using one or two of pictures **615**, **616**, and/or **618** in layer N **631** as a reference, where one picture is referenced for unidirectional inter-prediction and/or two pictures are referenced for bidirectional inter-prediction. When a picture is used as a reference for another picture in the same layer when performing inter-prediction **623**, the picture may be referred to as a reference picture. For example, picture **612** may be a reference picture used to code picture **613** according to inter-prediction **623**. Inter-prediction **623** can also be referred to as intra-layer prediction in a multi-layer context. As such, inter-prediction **623** is a mechanism of coding samples of a current picture by reference to indicated samples in a reference picture that is different from the current picture where the reference picture and the current picture are in the same layer.

Pictures **611-618** can also be coded by reference to other pictures **611-618** in different layers. This process is known as inter-layer prediction **621**, and is depicted by dashed arrows. Inter-layer prediction **621** is a mechanism of coding samples of a current picture by reference to indicated samples in a reference picture where the current picture and the reference picture are in different layers and hence have different values of nuh_layer_id. For example, a picture in a lower layer N **631** can be used as a reference picture to code a corresponding picture at a higher layer N+1 **632**. As a specific example, picture **611** can be coded by reference to picture **615** according to inter-layer prediction **621**. In such a case, the picture **615** is used as an inter-layer reference picture. An inter-layer reference picture is a reference picture used for inter-layer prediction **621**. In most cases, inter-layer prediction **621** is constrained such that a current picture, such as picture **611**, can only use inter-layer reference picture(s) that are included in the same AU **627** and that are at a lower layer, such as picture **615**. When multiple layers (e.g., more than two) are available, inter-layer prediction **621** can encode/decode a current picture based on multiple inter-layer reference picture(s) at lower levels than the current picture.

A video encoder can employ a multi-layer video sequence **600** to encode pictures **611-618** via many different combinations and/or permutations of inter-prediction **623** and inter-layer prediction **621**. For example, picture **615** may be coded according to intra-prediction. Pictures **616-618** can then be coded according to inter-prediction **623** by using picture **615** as a reference picture. Further, picture **611** may be coded according to inter-layer prediction **621** by using picture **615** as an inter-layer reference picture. Pictures **612-614** can then be coded according to inter-prediction **623** by using picture **611** as a reference picture. As such, a reference picture can serve as both a single layer reference picture and an inter-layer reference picture for different coding mechanisms. By coding higher layer N+1 **632** pictures based on lower layer N **631** pictures, the higher layer N+1 **632** can avoid employing intra-prediction, which has much lower coding efficiency than inter-prediction **623** and inter-layer prediction **621**. As such, the poor coding efficiency of intra-prediction can be limited to the smallest/lowest quality pictures, and hence limited to coding the smallest amount of video data. The pictures used as reference pictures and/or inter-layer reference pictures can be indicated in entries of reference picture list(s) contained in a reference picture list structure.

The pictures **611-618** may also be included in access units (AUs) **627**. An AU **627** is a set of coded pictures that are included in different layers and are associated with the same output time during decoding. Accordingly, coded pictures in the same AU **627** are scheduled for output from a DPB at a decoder at the same time. For example, pictures **614** and **618** are in the same AU **627**. Pictures **613** and **617** are in a different AU **627** from pictures **614** and **618**. Pictures **614** and **618** in the same AU **627** may be displayed in the alternative. For example, picture **618** may be displayed when a small picture size is desired and picture **614** may be displayed when a large picture size is desired. When the large picture size is desired, picture **614** is output and picture **618** is used only for inter-layer prediction **621**. In this case, picture **618** is discarded without being output once inter-layer prediction **621** is complete.

For conformance testing purposes, the AUs **627** may be further divided into DUs **628**. A DU **628** can be defined as an AU **627** or a subset of an AU **627** including one or more VCL NAL units in an AU **627** and associated non-VCL NAL units. Stated differently, a DU **628** can contain a single coded picture along with syntax elements as desired to support decoding the picture. In a single layer bitstream, a DU **628** is an AU **627**. In a multi-layer bitstream, a DU **628** is a subset of an AU **627**. The distinction between AUs **627** and DUs **628** may be employed when performing conformance tests at a HRD. For example, some conformance tests are configured to be applied to each AUs **627**, while other conformance tests are configured to be applied to each DU **628** in each AU **627**. A conformance test that is applied to one or more entire AUs **627** can be referred to as an AU level operation. A conformance test that is applied to one or more DUs **628** can be referred to as a DU level operation. Accordingly, AU level is a description of an operation as being applied to one or more entire AUs **627**, and hence applied to one or more entire groups of pictures sharing the same output time. Further, DU level is a description of an operation as being applied to one or more entire DUs **628**, and hence that is applied to one or more pictures.

FIG. **7** is a schematic diagram illustrating an example bitstream **700**. For example, the bitstream **700** can be generated by a codec system **200** and/or an encoder **300** for decoding by a codec system **200** and/or a decoder **400** according to method **100**. Further, the bitstream **700** may include a multi-layer video sequence **600**. In addition, the bitstream **700** may include various parameters to control the operation of a HRD, such as HRD **500**. Based on such parameters, the HRD can check the bitstream **700** for conformance with standards prior to transmission toward a decoder for decoding.

The bitstream **700** includes a VPS **711**, one or more SPSs **713**, a plurality of picture parameter sets (PPSs) **715**, a plurality of slice headers **717**, image data **720**, a buffering period (BP) SEI message **716**, a PT SEI message **718** and/or a DUI SEI message **719**. A VPS **711** contains data related to the entire bitstream **700**. For example, the VPS **711** may contain data related OLSs, layers, and/or sublayers used in the bitstream **700**. An SPS **713** contains sequence data common to all pictures in a coded video sequence contained in the bitstream **700**. For example, each layer may contain one or more coded video sequences, and each coded video sequence may reference a SPS **713** for corresponding parameters. The parameters in a SPS **713** can include picture sizing, bit depth, coding tool parameters, bit rate restrictions, etc. It should be noted that, while each sequence refers to a SPS **713**, a single SPS **713** can contain data for multiple sequences in some examples. The PPS **715** contains parameters that apply to an entire picture. Hence, each picture in the video sequence may refer to a PPS **715**. It should be noted that, while each picture refers to a PPS **715**, a single PPS **715** can contain data for multiple pictures in some examples. For example, multiple similar pictures may be coded according to similar parameters. In such a case, a single PPS **715** may contain data for such similar pictures. The PPS **715** can indicate coding tools available for slices in corresponding pictures, quantization parameters, offsets, etc.

The slice header **717** contains parameters that are specific to each slice in a picture. Hence, there may be one slice header **717** per slice **727** in the video sequence. The slice header **717** may contain slice type information, filtering information, prediction weights, tile entry points, deblocking parameters, etc. It should be noted that in some examples, a bitstream **700** may also include a picture header, which is a syntax structure that contains parameters that apply to all slices **727** in a single picture **725**. For this reason, a picture header and a slice header **717** may be used interchangeably in some contexts. For example, certain parameters may be moved between the slice header **717** and a picture header depending on whether such parameters are common to all slices **727** in a picture **725**.

The image data **720** contains video data encoded according to inter-prediction and/or intra-prediction as well as corresponding transformed and quantized residual data. For example, the image data **720** may include layers **723**, pictures **725**, and/or slices **727**. A layer **723** is a set of VCL NAL units that share a specified characteristic (e.g., a common resolution, frame rate, image size, etc.) as indicated by a layer ID, such as a nuh_layer_id, and associated non-VCL NAL units. For example, a layer **723** may include a set of pictures **725** that share the same nuh_layer_id as well as associated parameter sets and/or SEI messages. A layer **723** may be substantially similar to layers **631** and/or **632**. A nuh_layer_id is a syntax element that specifies an identifier of a layer **723** that includes at least one NAL unit. For example, the lowest quality layer **723**, known as a base layer, may include the lowest value of nuh_layer_id with increasing values of nuh_layer_id for layers **723** of higher quality. Hence, a lower layer is a layer **723** with a smaller value of nuh_layer_id and a higher layer is a layer **723** with a larger value of nuh_layer_id. Layers **723** can also be included an OLS. An OLS is a set of layers **723** for which one or more layers **723** are specified as an output layer(s). An output layer is any layer **723** that is designated for output and display at a decoder. Layers **723** that are not output layers can be included in an OLS to support decoding an output layer, for example via inter-layer prediction.

A picture **725** is an array of luma samples and/or an array of chroma samples that create a frame or a field thereof. For example, a picture **725** is a coded image that may be output for display or used to support coding of other picture(s) **725** for output. A picture **725** contains one or more slices **727**. A slice **727** may be defined as an integer number of complete tiles or an integer number of consecutive complete coding tree unit (CTU) rows (e.g., within a tile) of a picture **725** that are exclusively contained in a single NAL unit. The slices **727** are further divided into CTUs and/or coding tree blocks (CTBs). A CTU is a group of samples of a predefined size that can be partitioned by a coding tree. A CTB is a subset of a CTU and contains luma components or chroma components of the CTU. The CTUs/CTBs are further divided into coding blocks based on coding trees. The coding blocks can then be encoded/decoded according to prediction mechanisms.

A SEI message is a syntax structure with specified semantics that conveys information that is not needed by the decoding process in order to determine the values of the samples in decoded pictures. For example, the SEI messages may contain data to support HRD processes or other supporting data that is not directly relevant to decoding the bitstream **700** at a decoder. A BP SEI message **716** is a SEI message that contains HRD parameters for initializing a HRD to manage a CPB for testing corresponding OLSs and/or layers **723**. A PT SEI message **718** is a SEI message that contains HRD parameters for managing delivery information for AUs at the CPB and/or the DPB for testing corresponding OLSs and/or layers **723**. A DUI SEI message **719** is a SEI message that contains HRD parameters for managing delivery information for DUs at the CPB and/or the DPB for testing corresponding OLSs and/or layers **723**.

It should be noted that the bitstream **700** can be coded as a sequence of NAL units. A NAL unit is a container for video data and/or supporting syntax. A NAL unit can be a VCL NAL unit or a non-VCL NAL unit. A VCL NAL unit is a NAL unit coded to contain video data. Specifically, a VCL NAL unit contains a slice **727** and an associated slice header **717**. A non-VCL NAL unit is a NAL unit that contains non-video data such as syntax and/or parameters that support decoding the video data, performance of conformance checking, or other operations. Non-VCL NAL units may include a VPS NAL unit, a SPS NAL unit, and a PPS NAL unit, which contain a VPS **711**, a SPS **713**, and a PPS **715**, respectively. The non-VCL NAL unit may also include a SEI NAL unit that can contain a BP SEI message **716**, a PT SEI message **718**, and/or a DUI SEI message **719**. Accordingly, an SEI NAL unit is a NAL unit that contains an SEI message. It should be noted that the preceding list of NAL units is exemplary and not exhaustive.

A HRD, such as HRD **500**, can be employed to check the bitstream **700** for conformance to standards. The HRD can employ HRD parameters to perform conformance tests on the bitstream **700**. HRD parameters **735** can be stored in a syntax structure in the VPS **711** and/or the SPS **713**. HRD parameters **735** are syntax elements that initialize and/or define operational conditions of an HRD. The BP SEI message **716**, PT SEI message **718**, and/or a DUI SEI message **719** contain parameters that further define operations of the HRD for particular sequences, AUs, and/or DUs based on the HRD parameters **735** in the VPS **711** and/or the SPS **713**.

In some video coding systems, the BP SEI message **716**, PT SEI message **718**, and/or a DUI SEI message **719** may contain parameters that directly reference the VPS **711**. This dependency creates certain difficulties. For example, the bitstream **700** may be encoded in various layers **723** and/or OLSs. When a decoder requests an OLS, the encoder, a slicer, and/or an intermediate storage server can transmit an OLS of the layers **723** to the decoder based on decoder capabilities and/or based on current network conditions. Specifically, the encoder, slicer, and/or storage server employs a bitstream extraction process to remove the layers **723** outside the OLS from the bitstream **700**, and transmits the remaining layers **723** toward the decoder. This process allows many different decoders to each obtain different representations of the bitstream **700** based on decoder side conditions. As noted above, the VPS **711** contains data related to the OLSs and/or layers **723**. However, some OLSs contain a single layer **723**. When an OLS with a single layer **723** is transmitted to a decoder, the decoder may have no need for the data in the VPS **711** as the data in the SPS **713**, PPS **715**, and slice headers **717** may be sufficient to decode a single layer **723** bitstream. In order to avoid transmitting unneeded data, the encoder, slicer, and/or storage server may remove the VPS **711** as part of the bitstream extraction process. This approach may be beneficial as this approach may increase the coding efficiency of the sub-bitstream that extracted and transmitted to the decoder. However, the dependency of the BP SEI message **716**, PT SEI message **718**, and/or a DUI SEI message **719** may create errors when the VPS **711** is removed. Specifically, omitting the VPS **711** can cause the SEI messages to return an error as the data upon which they depend in the VPS **711** is not received at the decoder when the VPS **711** is removed. Further, the HRD checks the bitstream for conformance by mimicking the decoder. As such, the HRD may check an OLS with a single layer **723** without parsing the VPS **711**. Accordingly, the HRD in some systems may be unable to resolve the parameters in the BP SEI message **716**, the PT SEI message **718**, and/or the DUI SEI message **719**, and hence the HRD may be unable to check such OLSs for conformance.

Bitstream **700** is improved to correct the problems described above. Specifically, parameters are added to the BP SEI message **716**, PT SEI message **718**, and/or a DUI SEI message **719** to remove the dependency on the VPS **711**. Accordingly, the BP SEI message **716**, PT SEI message **718**, and/or a DUI SEI message **719** can be completely parsed and resolved by the HRD and/or decoder even when the VPS **711** is omitted for OLSs that include a single layer **723**. The dependency may be removed by including a du_hrd_params_present_flag **731** and a du_cpb_params_in_pic_timing_ sei_flag **733** in one or more of the SEI messages. In the example shown, the du_hrd_params_present_flag **731** and the du_cpb_params_in_pic_timing_sei_flag **733** are included in the BP SEI message **716**.

The du_hrd_params_present_flag **731** is a syntax element that specifies whether the HRD should operate on an AU level or a DU level. An AU level is a description of an operation as being applied to one or more entire AUs (e.g., applied to one or more entire groups of pictures sharing the same output time). A DU level is a description of an operation as being applied to one or more entire DUs (e.g., applied to one or more pictures). In a specific example, the du_hrd_params_present_flag **731** is set to one when specifying that DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level, and is set to zero when specifying that DU level HRD parameters are not present and the HRD operates at the AU level.

When the HRD operates at the DU level (e.g., when du_hrd_params_present_flag **731** is set to one), the HRD should refer to DU parameters, such as a CPB removal delay **737**. The CPB removal delay **737** is a syntax element that specifies a CPB removal delay for DUs, which is an amount time that one or more DUs (pictures **725**) may remain in a CPB prior to transfer to a DPB in a HRD. However, the relevant CPB removal delay **737** may be included in the PT SEI message **718**, or the DUI SEI message **719**, depending on the example. The du_cpb_params_in_pic_timing_sei_flag **733** is a syntax element that specifies whether DU level CPB removal delay **737** parameters are present in the PT SEI message **718** or the DUI SEI message **719**. In a specific example, the du_cpb_params_in_pic_timing_sei_flag **733** is set to one when specifying that that DU level CPB removal delay **737** parameters are present in a PT SEI message **718** and no DUI SEI message **719** is available. Further, the du_cpb_params_in_pic_timing_sei_flag **733** can be set to zero when specifying that DU level CPB removal delay **737** parameters are present in a DUI SEI message **719** and PT SEI messages **718** do not include DU level CPB removal delay **737** parameters.

By including the du_hrd_params_present_flag **731** and the du_cpb_params_in_pic_timing_sei_flag **733** in the SEI messages, the SEI messages do not depend on the VPS **711**. Hence, the BP SEI message **716**, the PT SEI message **718**, and/or the DUI SEI message **719** can be parsed even when the VPS **711** is omitted from the bitstream **700**. Accordingly, the HRD can properly parse the BP SEI message **716**, the PT SEI message **718**, and/or the DUI SEI message **719** and perform conformance tests on OLSs with a single layer. Further, the decoder can parse and use the syntax elements in the BP SEI message **716**, the PT SEI message **718**, and/or the DUI SEI message **719** as desired to support decoding processes. As a result, the functionality of the encoder and the decoder is increased and errors are avoided. Further, removing the dependency between the SEI messages and the VPS **711** supports removal of the VPS **711** in certain cases, which increases coding efficiency, and hence reduces processor, memory, and/or network signaling resource usage at both the encoder and the decoder in such cases.

The preceding information is now described in more detail herein below. Layered video coding is also referred to as scalable video coding or video coding with scalability. Scalability in video coding may be supported by using multi-layer coding techniques. A multi-layer bitstream comprises a base layer (BL) and one or more enhancement layers (ELs). Example of scalabilities includes spatial scalability, quality/signal to noise ratio (SNR) scalability, multi-view scalability, frame rate scalability, etc. When a multi-layer coding technique is used, a picture or a part thereof may be coded without using a reference picture (intra-prediction), may be coded by referencing reference pictures that are in the same layer (inter-prediction), and/or may be coded by referencing reference pictures that are in other layer(s) (inter-layer prediction). A reference picture used for inter-layer prediction of the current picture is referred to as an inter-layer reference picture (ILRP). FIG. **6** illustrates an example of multi-layer coding for spatial scalability in which pictures in different layers have different resolutions.

Some video coding families provide support for scalability in separated profile(s) from the profile(s) for single-layer coding. Scalable video coding (SVC) is a scalable extension of the advanced video coding (AVC) that provides support for spatial, temporal, and quality scalabilities. For SVC, a flag is signaled in each macroblock (MB) in EL pictures to indicate whether the EL MB is predicted using the collocated block from a lower layer. The prediction from the collocated block may include texture, motion vectors, and/or coding modes. Implementations of SVC may not directly reuse unmodified AVC implementations in their design. The SVC EL macroblock syntax and decoding process differs from the AVC syntax and decoding process.

Scalable HEVC (SHVC) is an extension of HEVC that provides support for spatial and quality scalabilities. Multiview HEVC (MV-HEVC) is an extension of HEVC that provides support for multi-view scalability. 3D HEVC (3D-HEVC) is an extension of HEVC that provides support for 3D video coding that is more advanced and more efficient than MV-HEVC. Temporal scalability may be included as an integral part of a single-layer HEVC codec. In the multi-layer extension of HEVC, decoded pictures used for inter-layer prediction come only from the same AU and are treated as long-term reference pictures (LTRPs). Such pictures are assigned reference indices in the reference picture list(s) along with other temporal reference pictures in the current layer. Inter-layer prediction (ILP) is achieved at the prediction unit level by setting the value of the reference index to refer to the inter-layer reference picture(s) in the reference picture list(s). Spatial scalability resamples a reference picture or part thereof when an ILRP has a different spatial resolution than the current picture being encoded or decoded. Reference picture resampling can be realized at either picture level or coding block level.

VVC may also support layered video coding. A VVC bitstream can include multiple layers. The layers can be all independent from each other. For example, each layer can be coded without using inter-layer prediction. In this case, the layers are also referred to as simulcast layers. In some cases, some of the layers are coded using ILP. A flag in the VPS can indicate whether the layers are simulcast layers or whether some layers use ILP. When some layers use ILP, the layer dependency relationship among layers is also signaled in the VPS. Unlike SHVC and MV-HEVC, VVC may not specify OLSs. An OLS includes a specified set of layers, where one or more layers in the set of layers are specified to be output layers. An output layer is a layer of an OLS that is output. In some implementations of VVC, only one layer may be selected for decoding and output when the layers are simulcast layers. In some implementations of VVC, the entire bitstream including all layers is specified to be decoded when any layer uses ILP. Further, certain layers among the layers are specified to be output layers. The output layers may be indicated to be only the highest layer, all the layers, or the highest layer plus a set of indicated lower layers.

The preceding aspects contain certain problems. For example, the nuh_layer_id values for SPS, PPS, and APS NAL units may not be properly constrained. Further, the TemporalId value for SEI NAL units may not be properly constrained. In addition, setting of NoOutputOfPriorPicsFlag may not be properly specified when reference picture resampling is enabled and pictures within a CLVS have different spatial resolutions. Also, in some video coding systems suffix SEI messages cannot be contained in a scalable nesting SEI message. As another example, buffering period, picture timing, and decoding unit information SEI messages may include parsing dependencies on VPS and/or SPS.

In general, this disclosure describes video coding improvement approaches. The descriptions of the techniques are based on VVC. However, the techniques also apply to layered video coding based on other video codec specifications.

One or more of the abovementioned problems may be solved as follows. The nuh_layer_id values for SPS, PPS, and APS NAL units are properly constrained herein. The TemporalId value for SEI NAL units is properly constrained herein. Setting of the NoOutputOfPriorPicsFlag is properly specified when reference picture resampling is enabled and pictures within a CLVS have different spatial resolutions. Suffix SEI messages are allowed to be contained in a scalable nesting SEI message. Parsing dependencies of BP, PT, and DUI SEI messages on VPS or SPS may be removed by repeating the syntax element decoding_unit_hrd_params_present_flag in the BP SEI message syntax, the syntax elements decoding_unit_hrd_params_present_flag and decoding_unit_cpb_params_in_pic_timing_sei_flag in the PT SEI message syntax, and the syntax element decoding_unit_cpb_params_in_pic_timing_sei_flag in the DUI SEI message.

An example implementation of the preceding mechanisms is as follows. An example general NAL unit semantics is as follows.

A nuh_temporal_id_plus1 minus 1 specifies a temporal identifier for the NAL unit. The value of nuh_temporal_id_plus1 should not be equal to zero. The variable TemporalId may be derived as follows:

TemporalId=nuh_temporal_id_plus1−1

When nal_unit_type is in the range of IDR_W_RADL to RSV_IRAP_13, inclusive, TemporalId should be equal to zero. When nal_unit_type is equal to STSA_NUT, TemporalId should not be equal to zero.

The value of TemporalId should be the same for all VCL NAL units of an access unit. The value of TemporalId of a coded picture, a layer access unit, or an access unit may be the value of the TemporalId of the VCL NAL units of the coded picture, the layer access unit, or the access unit. The value of TemporalId of a sub-layer representation may be the greatest value of TemporalId of all VCL NAL units in the sub-layer representation.

The value of TemporalId for non-VCL NAL units is constrained as follows. If nal_unit_type is equal to DPS_NUT, VPS_NUT, or SPS_NUT, TemporalId is equal to zero and the TemporalId of the access unit containing the NAL unit should be equal to zero. Otherwise if nal_unit_type is equal to EOS_NUT or EOB_NUT, TemporalId should be equal to zero. Otherwise, if nal_unit_type is equal to AUD_NUT, FD_NUT, PREFIX_SEI_NUT, or SUFFIX_SEI_NUT, TemporalId should be equal to the TemporalId of the access unit containing the NAL unit. Otherwise, when nal_unit_type is equal to PPS_NUT or APS_NUT, TemporalId should be greater than or equal to the TemporalId of the access unit containing the NAL unit. When the NAL unit is a non-VCL NAL unit, the value of TemporalId should be equal to the minimum value of the TemporalId values of all access units to which the non-VCL NAL unit applies. When nal_unit_type is equal to PPS_NUT or APS_NUT, TemporalId may be greater than or equal to the TemporalId of the containing access unit. This is because all PPSs and APSs may be included in the beginning of a bitstream. Further, the first coded picture has TemporalId equal to zero.

An example sequence parameter set RBSP semantics is as follows. An SPS RBSP should be available to the decoding process prior to being referenced. The SPS may be included in at least one access unit with TemporalId equal to zero or provided through external mechanism. The SPS NAL unit containing the SPS may be constrained to have a nuh_layer_id equal to the lowest nuh_layer_id value of PPS NAL units that refer to the SPS.

An example picture parameter set RBSP semantics is as follows. A PPS RBSP should be available to the decoding process prior to being referenced. The PPS should be included in at least one access unit with TemporalId less than or equal to the TemporalId of the PPS NAL unit or provided through external mechanism. The PPS NAL unit containing the PPS RBSP should have a nuh_layer_id equal to the lowest nuh_layer_id value of the coded slice NAL units that refer to the PPS.

An example adaptation parameter set semantics is as follows. Each APS RBSP should be available to the decoding process prior to being referenced. The APS should also be included in at least one access unit with TemporalId less than or equal to the TemporalId of the coded slice NAL unit that refers the APS or provided through an external mechanism. An APS NAL unit is allowed to be shared by pictures/slices of multiple layers. The nuh_layer_id of an APS NAL unit should be equal to the lowest nuh_layer_id value of the coded slice NAL units that refer to the APS NAL unit. Alternatively, an APS NAL unit may not be shared by pictures/slices of multiple layers. The nuh_layer_id of an APS NAL unit should be equal to the nuh_layer_id of slices referring to the APS.

In an example, removal of pictures from the DPB before decoding of the current picture is discussed as follows. The removal of pictures from the DPB before decoding of the current picture (but after parsing the slice header of the first slice of the current picture) may occur at the CPB removal time of the first decoding unit of access unit n (containing the current picture). This proceeds as follows. The decoding process for reference picture list construction is invoked and the decoding process for reference picture marking is invoked.

When the current picture is a coded layer video sequence start (CLVSS) picture that is not picture zero, the following ordered steps are applied. The variable NoOutputOfPriorPicsFlag is derived for the decoder under test as follows. If the value of pic_width_max_in_luma_samples, pic_height_max_in_luma_samples, chroma_format_idc, separate_colour_plane_flag, bit_depth_luma_minus8, bit_depth_chroma_minus8 or sps_max_dec_pic_buffering_minus1[Htid] derived from the SPS is different from the value of pic_width_in_luma_samples, pic_height_in_luma_samples, chroma_format_idc, separate_colour_plane_flag, bit_depth_ luma_minus8, bit_depth_chroma_minus8 or sps_max_dec_pic_buffering_minus1[Htid], respectively, derived from the SPS referred to by the preceding picture, NoOutputOfPriorPicsFlag may be set to one by the decoder under test, regardless of the value of no_output_of_prior_pics_flag. It should be noted that, although setting NoOutputOfPriorPicsFlag equal to no_output_of_prior_pics_flag may be preferred under these conditions, the decoder under test is allowed to set NoOutputOfPriorPicsFlag to one in this case. Otherwise, NoOutputOfPriorPicsFlag may be set equal to no_output_of_prior_pics_flag.

The value of NoOutputOfPriorPicsFlag derived for the decoder under test is applied for the HRD, such that when the value of NoOutputOfPriorPicsFlag is equal to 1, all picture storage buffers in the DPB are emptied without output of the pictures they contain, and the DPB fullness is set equal to zero. When both of the following conditions are true for any pictures k in the DPB, all such pictures k in the DPB are removed from the DPB. Picture k is marked as unused for reference, and picture k has PictureOutputFlag equal to zero or a corresponding DPB output time is less than or equal to the CPB removal time of the first decoding unit (denoted as decoding unit m) of the current picture n. This may occur when DpbOutputTime[k] is less than or equal to DuCpbRemovalTime[m]. For each picture that is removed from the DPB, the DPB fullness is decremented by one.

In an example, output and removal of pictures from the DPB is discussed as follows. The output and removal of pictures from the DPB before the decoding of the current picture (but after parsing the slice header of the first slice of the current picture) may occur when the first decoding unit of the access unit containing the current picture is removed from the CPB and proceeds as follows. The decoding process for reference picture list construction and decoding process for reference picture marking are invoked.

If the current picture is a CLVSS picture that is not picture zero, the following ordered steps are applied. The variable NoOutputOfPriorPicsFlag can be derived for the decoder under test as follows. If the value of pic_width_max_in_luma_samples, pic_height_max_in_luma_samples, chroma_format_idc, separate_colour_plane_flag, bit_depth_luma_minus8, bit_depth_chroma_minus8 or sps_max_dec_pic_buffering_minus1[Htid] derived from the SPS is different from the value of pic_width_in_luma_samples, pic_height_in_luma_samples, chroma_format_idc, separate_colour_plane_flag, bit_depth_luma_minus8, bit_depth_chroma_minus8 or sps_max_dec_pic_buffering_minus1[Htid], respectively, derived from the SPS referred to by the preceding picture, NoOutputOfPriorPicsFlag may be set to one by the decoder under test, regardless of the value of no_output_of_prior_pics_flag. It should be noted that although setting NoOutputOfPriorPicsFlag equal to no_output_of_prior_pics_flag is preferred under these conditions, the decoder under test can set NoOutputOfPriorPicsFlag to one in this case. Otherwise, NoOutputOfPriorPicsFlag can be set equal to no_output_of_prior_pics_flag.

The value of NoOutputOfPriorPicsFlag derived for the decoder under test can be applied for the HRD as follows. If NoOutputOfPriorPicsFlag is equal to one, all picture storage buffers in the DPB are emptied without output of the pictures they contain and the DPB fullness is set equal to zero. Otherwise (NoOutputOfPriorPicsFlag is equal to zero), all picture storage buffers containing a picture that is marked as not needed for output and unused for reference are emptied (without output) and all non-empty picture storage buffers in the DPB are emptied by repeatedly invoking a bumping process and the DPB fullness is set equal to zero.

Otherwise (the current picture is not a CLVSS picture), all picture storage buffers containing a picture which are marked as not needed for output and unused for reference are emptied (without output). For each picture storage buffer that is emptied, the DPB fullness is decremented by one. When one or more of the following conditions are true, the bumping process is invoked repeatedly while further decrementing the DPB fullness by one for each additional picture storage buffer that is emptied until none of the following conditions are true. A condition is that the number of pictures in the DPB that are marked as needed for output is greater than sps_max_num_reorder_pics[Htid]. Another condition is that a sps_max_latency_increase_plus1[Htid] is not equal to zero and there is at least one picture in the DPB that is marked as needed for output for which the associated variable PicLatencyCount is greater than or equal to SpsMaxLatencyPictures[Htid]. Another condition is that the number of pictures in the DPB is greater than or equal to SubDpbSize[Htid].

An example general SEI message syntax is as follows.

```
                                                                Descriptor
sei_payload( payloadType, payloadSize ) {
  if( nal_unit_type = = PREFIX_SEI_NUT )
    if( payloadType = = 0 )
      buffering_period( payloadSize )
    else if( payloadType = = 1 )
      pic_timing( payloadSize )
    else if( payloadType = = 3 )
      filler_payload( payloadSize )
    else if( payloadType = = 130 )
      decoding_unit_info( payloadSize )
    else if( payloadType = = 133 )
      scalable_nesting( payloadSize )
    else if( payloadType = = 145 )
    dependent_rap_indication( payloadSize )
        // Specified in ITU-T H.SEI | ISO/IEC 23002-7.
    else if( payloadType = = 168 )
      frame_field_info( payloadSize )
    else
      reserved_sei_message( payloadSize )
  else /* nal_unit_type = = SUFFIX_SEI_NUT */
    if( payloadType = = 3 )
      filler_payload( payloadSize )
    if( payloadType = = 132 )
      decoded_picture_hash( payloadSize )
        // Specified in ITU-T H.SEI | ISO/IEC 23002-7.
    else if( payloadType = = 133 )
      scalable_nesting( payloadSize )
    else
      reserved_sei_message( payloadSize )
  if( more_data_in_payload( ) ) {
    if( payload_extension_present( ) )
      reserved_payload_extension_data                           u(v)
    payload_bit_equal_to_one /* equal to 1 */                   f(1)
    while( !byte_aligned( ))
      payload_bit_equal_to_zero /* equal to 0 */                f(1)
  }
}
```

An example scalable nesting SEI message syntax is as follows.

```
                                                                Descriptor
scalable_nesting( payloadSize ) {
  nesting_ols_flag                                              u(1)
  if( nesting_ols_flag ) {
    nesting_num_olss_minus1                                     ue(v)
    for( i = 0; i <= nesting_num_olss_minus1; i++ ) {
      nesting_ols_idx_delta_minus1[ i ]                         ue(v)
      if( NumLayersInOls[ NestingOlsIdx[ i ] ] > 1 ) {
        nesting_num_ols_layers_minus1[ i ]                      ue(v)
```

-continued

```
                                                                   Descriptor
      for( j = 0; j <= nesting_num_ols_layers_minus1[ i ]; j++ )
        nesting_ols_layer_idx_delta_minus1[ i ][ j ]               ue(v)
    }
  }
} else {
  nesting_all_layers_flag                                          u(1)
  if( !nesting_all_layers_flag ) {
    nesting_num_layers_minus1                                      ue(v)
    for( i = 1; i <= nesting_num_layers_minus1; i++ )
      nesting_layer_id[ i ]                                        u(6)
  }
}
nesting_num_seis_minus1                                            ue(v)
while( !byte_aligned( ))
  nesting_zero_bit /* equal to 0 */                                u(1)
for( i = 0; i <= nesting_num_seis_minus1; i++ )
  sei_message( )
}
```

An example scalable nesting SEI message semantics is as follows. A scalable nesting SEI message provides a mechanism to associate SEI messages with specific layers in the context of specific OLSs or with specific layers not in the context of an OLS. A scalable nesting SEI message contains one or more SEI messages. The SEI messages contained in the scalable nesting SEI message are also referred to as the scalable-nested SEI messages. Bitstream conformance may require that the following restrictions apply when SEI messages are contained in a scalable nesting SEI message.

An SEI message that has payloadType equal to one hundred thirty-two (decoded picture hash) or one hundred thirty-three (scalable nesting) should not be contained in a scalable nesting SEI message. When a scalable nesting SEI message contains a buffering period, picture timing, or decoding unit information SEI message, the scalable nesting SEI message should not contain any other SEI message with payloadType not equal to zero (buffering period), one (picture timing), or one hundred thirty (decoding unit information).

Bitstream conformance may also require that the following restrictions apply on the value of the nal_unit_type of the SEI NAL unit containing a scalable nesting SEI message. When a scalable nesting SEI message contains an SEI message that has payloadType equal to zero (buffering period), one (picture timing), one hundred thirty (decoding unit information), one hundred forty five (dependent RAP indication), or one hundred sixty eight (frame-field information), the SEI NAL unit containing the scalable nesting SEI message should have a nal_unit_type set equal to PREFIX_SEI_NUT. When a scalable nesting SEI message contains an SEI message that has payloadType equal to one hundred thirty-two (decoded picture hash), the SEI NAL unit containing the scalable nesting SEI message should have a nal_unit_type set equal to SUFFIX_SEI_NUT.

A nesting_ols_flag may be set equal to one to specify that the scalable-nested SEI messages apply to specific layers in the context of specific OLSs. The nesting_ols_flag may be set equal to zero to specify that that the scalable-nested SEI messages generally apply (e.g., not in the context of an OLS) to specific layers.

Bitstream conformance may require that the following restrictions are applied to the value of nesting_ols_flag. When the scalable nesting SEI message contains an SEI message that has payloadType equal to zero (buffering period), one (picture timing), or one hundred thirty (decoding unit information), the value of nesting_ols_flag should be equal to one. When the scalable nesting SEI message contains an SEI message that has payloadType equal to a value in VclAssociatedSeiList, the value of nesting_ols_flag should be equal to zero.

A nesting_num_olss_minus1 plus one specifies the number of OLSs to which the scalable-nested SEI messages apply. The value of nesting_num_olss_minus1 should be in the range of zero to TotalNumOlss−1, inclusive. The nesting_ols_idx_delta_minus1[i] is used to derive the variable NestingOlsIdx[i] that specifies the OLS index of the i-th OLS to which the scalable-nested SEI messages apply when nesting_ols_flag is equal to one. The value of nesting_ols_idx_delta_minus1[i] should be in the range of zero to TotalNumOlss−2, inclusive. The variable NestingOlsIdx[i] may be derived as follows:

if(i==0)

$$\text{NestingOlsIdx}[i]=\text{nesting\_ols\_idx\_delta\_minus1}[i]$$

else

$$\text{NestingOlsIdx}[i]=\text{NestingOlsIdx}[i-1]+\text{nesting\_ols\_idx\_delta\_minus1}[i]+1$$

The nesting_num_ols_layers_minus1[i] plus one specifies the number of layers to which the scalable-nested SEI messages apply in the context of the NestingOlsIdx[i]-th OLS. The value of nesting_num_ols_layers_minus1[i] should be in the range of zero to NumLayersInOls[NestingOlsIdx[i]]−1, inclusive.

The nesting_ols_layer_idx_delta_minus1[i][j] is used to derive the variable NestingOlsLayerldx[i][j] that specifies the OLS layer index of the j-th layer to which the scalable-nested SEI messages apply in the context of the NestingOlsIdx[i]-th OLS when nesting_ols_flag is equal to one. The value of nesting_ols_layer_idx_delta_minus1[i] should be in the range of zero to NumLayersInOls[nestingOlsldx[i]]-two, inclusive.

The variable NestingOlsLayerldx[i][j] may be derived as follows:

if(j==0)

$$\text{NestingOlsLayerldx}[i][j]=\text{nesting\_ols\_layer\_idx\_delta\_minus1}[i][j]$$

else

$$\text{NestingOlsLayerldx}[i][j]=\text{NestingOlsLayerldx}[i][j-1]+\text{nesting\_ols\_layer\_idx\_delta\_minus1}[i][j]+1$$

The lowest value among all values of LayerIdInOls[NestingOlsIdx[i]][NestingOlsLayerIdx[i][0]] for i in the range of zero to nesting_num_olss_minus1, inclusive, should be equal to nuh_layer_id of the current SEI NAL unit (e.g., the SEI NAL unit containing the scalable nesting SEI message). The nesting_all_layers_flag may be set equal to one to specify that the scalable-nested SEI messages generally apply to all layers that have nuh_layer_id greater than or equal to the nuh_layer_id of the current SEI NAL unit. The nesting_all_layers_flag may be set equal to zero to specify that the scalable-nested SEI messages may or may not generally apply to all layers that have nuh_layer_id greater than or equal to the nuh_layer_id of the current SEI NAL unit.

The nesting_num_layers_minus1 plus one specifies the number of layers to which the scalable-nested SEI messages generally apply. The value of nesting_num_layers_minus1 should be in the range of zero to vps_max_layers_minus1-GeneralLayerIdx[nuh_layer_id], inclusive, where nuh_layer_id is the nuh_layer_id of the current SEI NAL unit. The nesting_layer_id[i] specifies the nuh_layer_id value of the i-th layer to which the scalable-nested SEI messages generally apply when nesting_all_layers_flag is equal to zero. The value of nesting_layer_id[i] should be greater than nuh_layer_id, where nuh_layer_id is the nuh_layer_id of the current SEI NAL unit.

When the nesting_ols_flag is equal to one, the variable NestingNumLayers, specifying the number of layer to which the scalable-nested SEI messages generally apply, and the list NestingLayerId[i] for i in the range of zero to NestingNumLayers−1, inclusive, specifying the list of nuh_layer_id value of the layers to which the scalable-nested SEI messages generally apply, are derived as follows, where nuh_layer_id is the nuh_layer_id of the current SEI NAL unit:

```
if( nesting_all_layers_flag ) {
   NestingNumLayers =
vps_max_layers_minus1 + 1 − GeneralLayerIdx[ nuh_layer_id ]
   for( i = 0; i < NestingNumLayers; i ++)
      NestingLayerId[ i ] = vps_layer_id[ GeneralLayerIdx[ nuh_layer_id ] + i ]        (D-2)
} else {
   NestingNumLayers = nesting_num_layers_minus1 + 1
   for( i = 0; i < NestingNumLayers; i ++)
      NestingLayerId[ i ] = ( i == 0 ) ? nuh_layer_id : nesting_layer_id[ i ]
}
```

The nesting_num_seis_minus1 plus one specifies the number of scalable-nested SEI messages. The value of nesting_num_seis_minus1 should be in the range of zero to sixty three, inclusive. The nesting_zero_bit should be set equal to zero.

FIG. **8** is a schematic diagram of an example video coding device **800**. The video coding device **800** is suitable for implementing the disclosed examples/embodiments as described herein. The video coding device **800** comprises downstream ports **820**, upstream ports **850**, and/or transceiver units (Tx/Rx) **810**, including transmitters and/or receivers for communicating data upstream and/or downstream over a network. The video coding device **800** also includes a processor **830** including a logic unit and/or central processing unit (CPU) to process the data and a memory **832** for storing the data. The video coding device **800** may also comprise electrical, optical-to-electrical (OE) components, electrical-to-optical (EO) components, and/or wireless communication components coupled to the upstream ports **850** and/or downstream ports **820** for communication of data via electrical, optical, or wireless communication networks. The video coding device **800** may also include input and/or output (I/O) devices **860** for communicating data to and from a user. The I/O devices **860** may include output devices such as a display for displaying video data, speakers for outputting audio data, etc. The I/O devices **860** may also include input devices, such as a keyboard, mouse, trackball, etc., and/or corresponding interfaces for interacting with such output devices.

The processor **830** is implemented by hardware and software. The processor **830** may be implemented as one or more CPU chips, cores (e.g., as a multi-core processor), field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), and digital signal processors (DSPs). The processor **830** is in communication with the downstream ports **820**, Tx/Rx **810**, upstream ports **850**, and memory **832**. The processor **830** comprises a coding module **814**. The coding module **814** implements the disclosed embodiments described herein, such as methods **100**, **900**, and **1000**, which may employ a multi-layer video sequence **600** and/or a bitstream **700**. The coding module **814** may also implement any other method/mechanism described herein. Further, the coding module **814** may implement a codec system **200**, an encoder **300**, a decoder **400**, and/or a HRD **500**. For example, the coding module **814** may be employed signal and/or read various parameters as described herein. Further, the coding module may be employed to encode and/or decode a video sequence based on such parameters. As such, the signaling changes described herein may increase the efficiency and/or avoid errors in the coding module **814**. Accordingly, the coding module **814** may be configured to perform mechanisms to address one or more of the problems discussed above. Hence, coding module **814** causes the video coding device **800** to provide additional functionality and/or coding efficiency when coding video data. As such, the coding module **814** improves the functionality of the video coding device **800** as well as addresses problems that are specific to the video coding arts. Further, the coding module **814** effects a transformation of the video coding device **800** to a different state. Alternatively, the coding module **814** can be implemented as instructions stored in the memory **832** and executed by the processor **830** (e.g., as a computer program product stored on a non-transitory medium).

The memory **832** comprises one or more memory types such as disks, tape drives, solid-state drives, read only memory (ROM), random access memory (RAM), flash memory, ternary content-addressable memory (TCAM), static random-access memory (SRAM), etc. The memory **832** may be used as an over-flow data storage device, to store programs when such programs are selected for execution, and to store instructions and data that are read during program execution.

FIG. **9** is a flowchart of an example method **900** of encoding a video sequence into a bitstream, such as bitstream **700**, by employing a SEI message that may not depend on a VPS. Method **900** may be employed by an encoder, such as a codec system **200**, an encoder **300**, and/or a video coding device **800** when performing method **100**. Further, the method **900** may operate on a HRD **500** and hence may perform conformance tests on a multi-layer video sequence **600**.

Method **900** may begin when an encoder receives a video sequence and determines to encode that video sequence into a multi-layer bitstream, for example based on user input. At step **901**, the encoder encodes a plurality of coded pictures into a bitstream. For example, the coded pictures can be organized into layers to create a multi-layer bitstream. Further, each coded picture can be included in a DU. The coded pictures can also be included in AUs, where an AU contains a set of pictures from different layers that have the same output time. A layer may include a set of VCL NAL units with the same layer ID and associated non-VCL NAL units. For example, the set of VCL NAL units are part of a layer when the set of VCL NAL units all have a particular value of nuh_layer_id. A layer may include a set of VCL NAL units, where each VCL NAL unit contains a slice of an encoded picture. The layer may also contain any parameter sets used to code such pictures where such parameters are included in non-VCL NAL units. The layers may be included in one or more OLSs. One or more of the layers may be output layers (e.g., each OLS contains at least one output layer). Layers that are not an output layer are encoded to support reconstructing the output layer(s), but such supporting layers are not intended for output at a decoder. In this way, the encoder can encode various combinations of layers for transmission to a decoder upon request. The layer can be transmitted as desired to allow the decoder to obtain different representations of the video sequence depending on network conditions, hardware capabilities, and/or user settings.

At step **903**, the encoder can encode a current SEI message into the bitstream. The current SEI message may be a BP SEI message, a PT SEI message, or a DUI SEI message, depending on the example. The current SEI message comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream. The du_hrd_params_present_flag can further specify whether a HRD operates at an AU level or a DU level. An AU level indicates that HRD processes are applied to entire AUs and a DU level indicates that HRD processes are applied to individual DUs. As such, the du_hrd_params_present_flag can specify a granularity of conformance tests (e.g., AU granularity or DU granularity). In a specific example, the du_hrd_params_present_flag can be set to one when specifying that DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level. Further, the du_hrd_params_present_flag can be set to zero when specifying that DU level HRD parameters are not present and the HRD operates at the AU level.

The current SEI message may also include a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message. The du_cpb_params_in_pic_timing_sei_flag may further specify whether DU level CPB removal delay parameters are present in a DUI SEI message. In a specific example, the du_cpb_params_in_pic_timing_sei_flag can be set to one when specifying that the DU level CPB removal delay parameters are present in a PT SEI message and no DUI SEI message is available. Further, the du_cpb_params_in_pic_timing_sei_flag can be set to zero when specifying that DU level CPB removal delay parameters are present in a DUI SEI message and PT SEI messages do not include DU level CPB removal delay parameters. The preceding constraints and/or requirements ensure that the bitstream conforms with, for example, VVC or some other standard, modified as indicated herein. However, the encoder may also be capable of operating in other modes where it is not so constrained, such as when operating under a different standard or a different version of the same standard.

At step **905**, an HRD can perform a set of bitstream conformance tests on the bitstream based on the current SEI message. For example, the HRD can read the du_hrd_params_present_flag to determine whether to test the bitstream at the AU level or whether DU parameters are present which would allow for testing at the DU level as well. Further, the HRD can read the du_cpb_params_in_pic_timing_sei_flag to determine whether the DU parameters, if present, can be found in a DUI SEI message or a PT SEI message. The HRD can then obtain the desired parameters from the indicated SEI messages and perform the conformance tests based on those parameters. Based on the forgoing flags, the current SEI message does not depend on a VPS. As such, the current SEI message can be completely parsed and resolved even when a VPS is not available. Accordingly, the conformance tests operate properly even when testing is performed on an OLS with a single layer and hence a VPS is not available to the HRD as the VPS is not configured for transmission as part of the OLS.

At step **907**, the encoder can store the bitstream for communication toward a decoder upon request. The encoder can also transmit the bitstream toward the decoder as desired.

FIG. **10** is a flowchart of an example method **1000** of decoding a video sequence from a bitstream, such as bitstream **700**, that employs a SEI message that may not depend on a VPS. Method **1000** may be employed by a decoder, such as a codec system **200**, a decoder **400**, and/or a video coding device **800** when performing method **100**. Further, method **1000** may be employed on a multi-layer video sequence **600** that has been checked for conformance by a HRD, such as HRD **500**.

Method **1000** may begin when a decoder begins receiving a bitstream of coded data representing a multi-layer video sequence, for example as a result of method **900** and/or in response to a request by the decoder. At step **1001**, the decoder receives a bitstream comprising a coded picture in one or more VCL NAL units. For example, the bitstream may include one or more layers including the coded picture. Further, each coded picture can be included in a DU. The coded pictures can also be included in AUs, where an AU contains a set of pictures from different layers that have the same output time. A layer may include a set of VCL NAL units with the same layer ID and associated non-VCL NAL units. For example, the set of VCL NAL units are part of a layer when the set of VCL NAL units all have a particular value of nuh_layer_id. A layer may include a set of VCL NAL units where each VCL NAL unit contain a slice of a coded picture. The layer may also contain any parameter sets used to code such pictures where such parameters are included in non-VCL NAL units. The layers may be included in an OLS. One or more of the layers may be output layers. Layers that are not an output layer are encoded to support reconstructing the output layer(s), but such supporting layers are not intended for output. In this way, the decoder can obtain different representations of the video sequence depending on network conditions, hardware capabilities, and/or user settings.

The bitstream also comprises a current SEI message. The current SEI message may be a BP SEI message, a PT SEI message, or a DUI SEI message, depending on the example. The current SEI message comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream. The du_hrd_params_present_flag can further specify whether a HRD at the encoder operates at an AU level or a DU level. An AU level indicates that HRD processes are applied to entire AUs and a DU level indicates that HRD processes are applied to individual DUs. As such, the du_hrd_params_present_flag can specify a granularity of conformance tests (e.g., AU granularity or DU granularity). In a specific example, the du_hrd_params_present_flag can be set to one when specifying that DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level. Further, the du_hrd_params_present_flag can be set to zero when specifying that DU level HRD parameters are not present and the HRD operates at the AU level.

The current SEI message may also include a du_cpb_params_in_pic_timing_sei_flag that specifies whether DU level CPB removal delay parameters are present in a PT SEI message. The du_cpb_params_in_pic_timing_sei_flag may further specify whether DU level CPB removal delay parameters are present in a DUI SEI message. In a specific example, the du_cpb_params_in_pic_timing_sei_flag can be set to one when specifying that that DU level CPB removal delay parameters are present in a PT SEI message and no DUI SEI message is available. Further, the du_cpb_params_in_pic_timing_sei_flag can be set to zero when specifying that DU level CPB removal delay parameters are present in a DUI SEI message and PT SEI messages do not include DU level CPB removal delay parameters.

In an embodiment, the video decoder expects a du_hrd_params_present_flag and a du_cpb_params_in_pic_timing_sei_flag to indicate the presence and/or location of DU level parameters as described above based on VVC or some other standard. If, however, the decoder determines that this condition is not true, the decoder may detect an error, signal an error, request that a revised bitstream (or a portion thereof) be resent, or take some other corrective measures to ensure that a conforming bitstream is received.

At step **1003**, the decoder can decode the coded picture from the VCL NAL units to produce a decoded picture. For example, the decoder can determine that the bitstream has been checked for conformance to standards based on the presence of the current SEI message. Accordingly, the decoder can determine that the bitstream is decodable based on the presence of the current SEI message. It should be noted that, in some cases, the OLS received at the decoder may contain a single layer. In such cases, the layer/OLS may not include a VPS. Due to the presence of the du_hrd_params_present_flag and the du_cpb_params_in_pic_timing_sei_flag, the current SEI message does not depend on the VPS. As such, the lack of VPS does not cause errors when current SEI message is parsed. At step **1005**, the decoder can forward the decoded picture for display as part of a decoded video sequence.

FIG. **11** is a schematic diagram of an example system **1100** for coding a video sequence using a bitstream that employs a SEI message that may not depend on a VPS. System **1100** may be implemented by an encoder and a decoder such as a codec system **200**, an encoder **300**, a decoder **400**, and/or a video coding device **800**. Further, the system **1100** may employ a HRD **500** to perform conformance tests on a multi-layer video sequence **600** and/or a bitstream **700**. In addition, system **1100** may be employed when implementing method **100**, **900**, and/or **1000**.

The system **1100** includes a video encoder **1102**. The video encoder **1102** comprises an encoding module **1103** for encoding a coded picture into a bitstream. The encoding module **1103** is further for encoding into the bitstream a current SEI message that comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream. The video encoder **1102** further comprises a HRD module **1105** for performing a set of bitstream conformance tests on the bitstream based on the current SEI message. The video encoder **1102** further comprises a storing module **1106** for storing the bitstream for communication toward a decoder. The video encoder **1102** further comprises a transmitting module **1107** for transmitting the bitstream toward a video decoder **1110**. The video encoder **1102** may be further configured to perform any of the steps of method **900**.

The system **1100** also includes a video decoder **1110**. The video decoder **1110** comprises a receiving module **1111** for receiving a bitstream comprising a coded picture and a current SEI message that comprises a du_hrd_params_present_flag that specifies whether DU level HRD parameters are present in the bitstream. The video decoder **1110** further comprises a decoding module **1113** for decoding the coded picture to produce a decoded picture. The video decoder **1110** further comprises a forwarding module **1115** for forwarding the decoded picture for display as part of a decoded video sequence. The video decoder **1110** may be further configured to perform any of the steps of method **1000**.

A first component is directly coupled to a second component when there are no intervening components, except for a line, a trace, or another medium between the first component and the second component. The first component is indirectly coupled to the second component when there are intervening components other than a line, a trace, or another medium between the first component and the second component. The term "coupled" and its variants include both directly coupled and indirectly coupled. The use of the term "about" means a range including ±10% of the subsequent number unless otherwise stated.

It should also be understood that the steps of the exemplary methods set forth herein are not necessarily required to be performed in the order described, and the order of the steps of such methods should be understood to be merely exemplary. Likewise, additional steps may be included in such methods, and certain steps may be omitted or combined, in methods consistent with various embodiments of the present disclosure.

While several embodiments have been provided in the present disclosure, it may be understood that the disclosed systems and methods might be embodied in many other specific forms without departing from the spirit or scope of the present disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated in another system or certain features may be omitted, or not implemented.

In addition, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, components, techniques, or methods without departing from the scope of the present disclosure. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and may be made without departing from the spirit and scope disclosed herein.

What is claimed is:

1. A method implemented by a decoder, the method comprising:

receiving a bitstream comprising a coded picture, a sequence parameter set (SPS), a picture parameter set (PPS), and a decoding unit (DU) hypothetical reference decoder (HRD) parameters present flag (du_hrd_params_present_flag) that specifies whether DU level HRD parameters are present in the bitstream, wherein the SPS is included in at least one access unit with temporal identifier (TemporalId) equal to zero, and the PPS is included in at least one access unit with TemporalId less than or equal to a TemporalId of a PPS network abstraction layer (NAL) unit, wherein the du_hrd_params_present_flag further specifies an HRD can be operated at an access unit (AU) level or a DU level, wherein the du_hrd_params_present_flag is set to one when specifying that the DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level, and wherein the du_hrd_params_present_flag is set to zero when specifying that the DU level HRD parameters are not present and the HRD operates at the AU level; and

decoding the bitstream to produce a decoded picture.

2. The method of claim 1, wherein the bitstream further comprises a DU coded picture buffer (CPB) parameters in picture timing (PT) supplemental enhancement information (SEI) flag (du_cpb_params_in_pic_timing_sei_flag) that specifies whether DU level CPB removal delay parameters are present in a PT SEI message.

3. The method of claim 2, wherein the du_cpb_params_in_pic_timing_sei_flag further specifies whether the DU level CPB removal delay parameters are present in a decoding unit information (DUI) SEI message.

4. The method of claim 3, wherein the du_cpb_params_in_pic_timing_sei_flag is set to one when specifying that the DU level CPB removal delay parameters are present in a PT SEI message and no DUI SEI message is available, and wherein the du_cpb_params_in_pic_timing_sei_flag is set to zero when specifying that the DU level CPB removal delay parameters are present in a DUI SEI message and PT SEI messages do not include the DU level CPB removal delay parameters.

5. The method of claim 1, wherein the du_hrd_params_present_flag is contained in a Buffering Period (BP) supplemental enhancement information (SEI) message or a decoding unit information (DUI) SEI message.

6. The method of claim 1, wherein the du_hrd_params_present_flag is included in multiple locations in the bitstream.

7. The method of claim 1, wherein a value of a TemporalId of a sub-layer representation is allowed to be a greatest value of TemporalId of all video coding layer (VCL) NAL units in the sub-layer representation.

8. A non-transitory storage medium storing an encoded bitstream that, when decoded by a decoding device, is used by the decoding device to generate a video, the encoded bitstream comprising:

a coded picture, a sequence parameter set (SPS), a picture parameter set (PPS), and a decoding unit (DU) hypothetical reference decoder (HRD) parameters present flag (du_hrd_params_present_flag) that specifies whether DU level HRD parameters are present in the bitstream,

wherein the SPS is included in at least one access unit with temporal identifier (TemporalId) equal to zero, and the PPS is included in at least one access unit with TemporalId less than or equal to a TemporalId of a PPS network abstraction layer (NAL) unit,

wherein the du_hrd_params_present_flag further specifies an HRD can be operated at an access unit (AU) level or a DU level,

wherein the du_hrd_params_present_flag is set to one when specifying that the DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level, and

wherein the du_hrd_params_present_flag is set to zero when specifying that the DU level HRD parameters are not present and the HRD operates at the AU level.

9. The non-transitory storage medium of claim 8, wherein the bitstream further comprises a DU coded picture buffer (CPB) parameters in picture timing (PT) supplemental enhancement information (SEI) flag (du_cpb_params_in_pic_timing_sei_flag) that specifies whether DU level CPB removal delay parameters are present in a PT SEI message.

10. The non-transitory storage medium of claim 9, wherein the du_cpb_params_in_pic_timing_sei_flag further specifies whether the DU level CPB removal delay parameters are present in a decoding unit information (DUI) SEI message.

11. The non-transitory storage medium of claim 10, wherein the du_cpb_params_in_pic_timing_sei_flag is set to one when specifying that the DU level CPB removal delay parameters are present in a PT SEI message and no DUI SEI message is available, and wherein the du_cpb_params_in_pic_timing_sei_flag is set to zero when specifying that the DU level CPB removal delay parameters are present in a DUI SEI message and PT SEI messages do not include the DU level CPB removal delay parameters.

12. The non-transitory storage medium of claim 8, wherein the du_hrd_params_present_flag is contained in a Buffering Period (BP) supplemental enhancement information (SEI) message or a decoding unit information (DUI) SEI message.

13. The non-transitory storage medium of claim 8, wherein the du_hrd_params_present_flag is included in multiple locations in the bitstream.

14. The non-transitory storage medium of claim 8, wherein a value of a TemporalId of a sub-layer representation is allowed to be a greatest value of TemporalId of all video coding layer (VCL) NAL units in the sub-layer representation.

15. A method implemented by an encoder, the method comprising:

encoding a bitstream comprising a coded picture, a sequence parameter set (SPS), a picture parameter set (PPS), and a decoding unit (DU) hypothetical reference decoder (HRD) parameters present flag (du_hrd_params_present_flag) that specifies whether DU level HRD parameters are present in the bitstream, wherein the SPS is included in at least one access unit with temporal identifier (TemporalId) equal to zero, and the PPS is included in at least one access unit with TemporalId less than or equal to a TemporalId of a PPS network abstraction layer (NAL) unit, wherein the du_hrd_params_present_flag further specifies an HRD can be operated at an access unit (AU) level or a DU level, wherein the du_hrd_params_present_flag is set to one when specifying that the DU level HRD parameters are present and the HRD can be operated at the AU level or the DU level, and wherein the du_hrd_params_present_flag is set to zero when specifying that the DU level HRD parameters are not present and the HRD operates at the AU level; and

storing the bitstream.

16. The method of claim **15**, wherein the bitstream further comprises a DU coded picture buffer (CPB) parameters in picture timing (PT) supplemental enhancement information (SEI) flag (du_cpb_params_in_pic_timing_sei_flag) that specifies whether DU level CPB removal delay parameters are present in a PT SEI message.

17. The method of claim **16**, wherein the du_cpb_params_in_pic_timing_sei_flag further specifies whether the DU level CPB removal delay parameters are present in a decoding unit information (DUI) SEI message.

18. The method of claim **17**, wherein the du_cpb_params_in_pic_timing_sei_flag is set to one when specifying that the DU level CPB removal delay parameters are present in a PT SEI message and no DUI SEI message is available, and wherein the du_cpb_params_in_pic_timing_sei_flag is set to zero when specifying that the DU level CPB removal delay parameters are present in a DUI SEI message and PT SEI messages do not include the DU level CPB removal delay parameters.

19. The method of claim **15**, wherein the du_hrd_params_present_flag is contained in a Buffering Period (BP) supplemental enhancement information (SEI) message or a decoding unit information (DUI) SEI message.

20. The method of claim **15**, wherein the du_hrd_params_present_flag is included in multiple locations in the bitstream.

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