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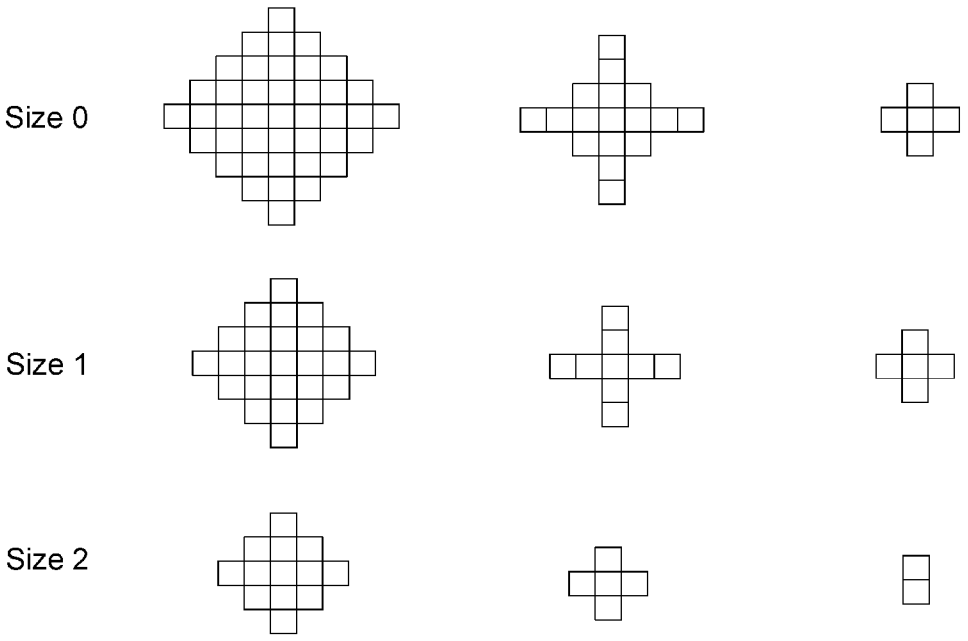


FIG. 9

(57) Abstract: Systems, devices, and methods are described herein for reducing syntax cost associated with adaptive loop filters. An example method may involve identifying a filter comprising a coefficient. The method may involve determining an encoding procedure based on context information associated with at least one of: a location of the coefficient associated with the filter or a size of the filter. The method may involve encoding the coefficient using the determined encoding procedure. The method may involve including, in video data, the encoded coefficient.

[Continued on next page]

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SYNTAX COST REDUCTION FOR ADAPTIVE LOOP FILTERS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of European Provisional Patent Application No. EP23306024.3, filed June 27, 2023, the contents of which are hereby incorporated by reference herein.

BACKGROUND

[0002] Video coding systems may be used to compress digital video signals, e.g., to reduce the storage and/or transmission bandwidth needed for such signals. Video coding systems may include, for example, block-based, wavelet-based, and/or object-based systems.

SUMMARY

[0003] Systems, devices, and methods are described herein for reducing the syntax cost associated with adaptive loop filters. An example method (e.g., for video encoding) may involve identifying a filter and a coefficient associated with the filter. The method may involve determining an encoding procedure based on context information associated with at least one of: a location of the coefficient associated with the filter or a size of the filter. The method may involve encoding the coefficient using the determined encoding procedure. The method may involve including, in video data, the encoded coefficient.

[0004] Determining the encoding procedure based on the context information may involve determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter. Encoding the coefficient using the determined encoding procedure may involve encoding the coefficient using the exponential Golomb equation of the determined order.

[0005] Determining the encoding procedure based on the context information may involve determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter. The order of the exponential Golomb equation may increase as a distance between the coefficient and a center of the filter decreases.

[0006] An indication of the size of the filter may be received. Determining the encoding procedure based on the context information may involve determining the encoding procedure based on the size of the filter.

[0007] The coefficient may be a first coefficient associated with the filter. A second coefficient associated with the filter may be identified. The second coefficient may neighbor the first coefficient and be earlier in a decoding order than the first coefficient. Encoding the first coefficient using the determined encoding procedure may involve encoding the first coefficient based on a difference between a first value associated with the first coefficient and a second value associated with the second coefficient.

[0008] Encoding the coefficient using the determined encoding procedure may involve encoding the coefficient using an entropy encoder.

[0009] The method may involve determining a first sign associated with the first coefficient based on a second sign associated with a second coefficient. The second coefficient may neighbor the first coefficient. The first sign associated with the first coefficient may be encoded.

[0010] A video decoding device may include a processor that is configured to implement any of the actions described herein.

[0011] An example method (e.g., for video decoding) may involve identifying a filter and a coefficient associated with the filter. The method may involve determining a decoding procedure based on context information associated with at least one of: a location of the coefficient associated with the filter or a size of the filter. The method may involve decoding the coefficient using the determined decoding procedure. The method may involve decoding a coding block based on the coefficient.

[0012] Determining the decoding procedure based on the context information may involve determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter. Decoding the coefficient using the determined decoding procedure may involve decoding the coefficient using the exponential Golomb equation of the determined order.

[0013] Determining the decoding procedure based on the context information may involve determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter. The order of the exponential Golomb equation may increase as a distance between the coefficient and a center of the filter decreases.

[0014] An indication of the size of the filter may be received. Determining the decoding procedure based on the context information may involve determining the decoding procedure based on the size of the filter.

[0015] The coefficient may be a first coefficient associated with the filter. A second coefficient associated with the filter may be identified. The second coefficient may neighbor the first coefficient and be earlier in a decoding order than the first coefficient. Decoding the first coefficient using the

determined decoding procedure may involve decoding the first coefficient based on a difference between a first value associated with the first coefficient and a second value associated with the second coefficient.

[0016] Decoding the coefficient using the determined decoding procedure may involve decoding the coefficient using an entropy encoder.

[0017] A first sign associated with the first coefficient may be determined based on a second sign associated with a second coefficient, wherein the second coefficient neighbors the first coefficient. The first sign associated with the first coefficient may be decoded.

[0018] A video decoding device may include a processor that is configured to implement any of the actions described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1A is a system diagram illustrating an example communications system in which one or more disclosed embodiments may be implemented.

[0020] FIG. 1B is a system diagram illustrating an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1A according to an embodiment.

[0021] FIG. 1C is a system diagram illustrating an example radio access network (RAN) and an example core network (CN) that may be used within the communications system illustrated in FIG. 1A according to an embodiment.

[0022] FIG. 1D is a system diagram illustrating a further example RAN and a further example CN that may be used within the communications system illustrated in FIG. 1A according to an embodiment.

[0023] FIG. 2 is a diagram showing an example block-based video encoder.

[0024] FIG. 3 is a diagram showing an example video decoder.

[0025] FIG. 4 is a diagram showing an example of a system in which various aspects and examples may be implemented.

[0026] FIG. 5 illustrates example adaptive loop filter (ALF) shapes.

[0027] FIG. 6 illustrates an example ALF derivation of a final filtered sample.

[0028] FIG. 7 illustrates example filter shape of a signaled filter.

[0029] FIG. 8 illustrates an example filter with coefficients.

[0030] FIG. 9 illustrates example filter size sets.

[0031] FIGs. 10A and 10B illustrate example scanning orders of coefficients.

DETAILED DESCRIPTION

[0032] A detailed description of illustrative embodiments will now be described with reference to the various Figures. Although this description provides a detailed example of possible implementations, it should be noted that the details are intended to be exemplary and in no way limit the scope of the application.

[0033] FIG. 1A is a diagram illustrating an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, etc., to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), zero-tail unique-word DFT-Spread OFDM (ZT UW DTS-s OFDM), unique word OFDM (UW-OFDM), resource block-filtered OFDM, filter bank multicarrier (FBMC), and the like.

[0034] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a RAN 104/113, a CN 106/115, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d, any of which may be referred to as a “station” and/or a “STA”, may be configured to transmit and/or receive wireless signals and may include a user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a subscription-based unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, a hotspot or Mi-Fi device, an Internet of Things (IoT) device, a watch or other wearable, a head-mounted display (HMD), a vehicle, a drone, a medical device and applications (e.g., remote surgery), an industrial device and applications (e.g., a robot and/or other wireless devices operating in an industrial and/or an automated processing chain contexts), a consumer electronics device, a device operating on commercial and/or industrial wireless networks, and the like. Any of the WTRUs 102a, 102b, 102c and 102d may be interchangeably referred to as a UE.

[0035] The communications systems 100 may also include a base station 114a and/or a base station 114b. Each of the base stations 114a, 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, 102d to facilitate access to one or more communication networks, such as the CN 106/115, the Internet 110, and/or the other networks 112. By way of example, the base stations 114a, 114b may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, a gNB, a NR NodeB, a site controller, an access point (AP), a wireless router, and the like. While the base stations 114a, 114b are each depicted as a single element, it will be appreciated that the base stations 114a, 114b may include any number of interconnected base stations and/or network elements.

[0036] The base station 114a may be part of the RAN 104/113, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, etc. The base station 114a and/or the base station 114b may be configured to transmit and/or receive wireless signals on one or more carrier frequencies, which may be referred to as a cell (not shown). These frequencies may be in licensed spectrum, unlicensed spectrum, or a combination of licensed and unlicensed spectrum. A cell may provide coverage for a wireless service to a specific geographical area that may be relatively fixed or that may change over time. The cell may further be divided into cell sectors. For example, the cell associated with the base station 114a may be divided into three sectors. Thus, in one embodiment, the base station 114a may include three transceivers, i.e., one for each sector of the cell. In an embodiment, the base station 114a may employ multiple-input multiple output (MIMO) technology and may utilize multiple transceivers for each sector of the cell. For example, beamforming may be used to transmit and/or receive signals in desired spatial directions.

[0037] The base stations 114a, 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, 102d over an air interface 116, which may be any suitable wireless communication link (e.g., radio frequency (RF), microwave, centimeter wave, micrometer wave, infrared (IR), ultraviolet (UV), visible light, etc.). The air interface 116 may be established using any suitable radio access technology (RAT).

[0038] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station 114a in the RAN 104/113 and the WTRUs 102a, 102b, 102c may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface 115/116/117 using wideband CDMA (WCDMA). WCDMA may include communication

protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink (DL) Packet Access (HSDPA) and/or High-Speed UL Packet Access (HSUPA).

[0039] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as Evolved UMTS Terrestrial Radio Access (E-UTRA), which may establish the air interface 116 using Long Term Evolution (LTE) and/or LTE-Advanced (LTE-A) and/or LTE-Advanced Pro (LTE-A Pro).

[0040] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as NR Radio Access , which may establish the air interface 116 using New Radio (NR).

[0041] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement multiple radio access technologies. For example, the base station 114a and the WTRUs 102a, 102b, 102c may implement LTE radio access and NR radio access together, for instance using dual connectivity (DC) principles. Thus, the air interface utilized by WTRUs 102a, 102b, 102c may be characterized by multiple types of radio access technologies and/or transmissions sent to/from multiple types of base stations (e.g., a eNB and a gNB).

[0042] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.11 (i.e., Wireless Fidelity (WiFi), IEEE 802.16 (i.e., Worldwide Interoperability for Microwave Access (WiMAX)), CDMA2000, CDMA2000 1X, CDMA2000 EV-DO, Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), GSM EDGE (GERAN), and the like.

[0043] The base station 114b in FIG. 1A may be a wireless router, Home Node B, Home eNode B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, an industrial facility, an air corridor (e.g., for use by drones), a roadway, and the like. In one embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In an embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In yet another embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT (e.g., WCDMA, CDMA2000, GSM, LTE, LTE-A, LTE-A Pro, NR etc.) to establish a picocell or femtocell. As shown in FIG. 1A, the base station 114b may have a direct

connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the CN 106/115.

[0044] The RAN 104/113 may be in communication with the CN 106/115, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. The data may have varying quality of service (QoS) requirements, such as differing throughput requirements, latency requirements, error tolerance requirements, reliability requirements, data throughput requirements, mobility requirements, and the like. The CN 106/115 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 104/113 and/or the CN 106/115 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104/113 or a different RAT. For example, in addition to being connected to the RAN 104/113, which may be utilizing a NR radio technology, the CN 106/115 may also be in communication with another RAN (not shown) employing a GSM, UMTS, CDMA 2000, WiMAX, E-UTRA, or WiFi radio technology.

[0045] The CN 106/115 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or the other networks 112. The PSTN 108 may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet 110 may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and/or the internet protocol (IP) in the TCP/IP internet protocol suite. The networks 112 may include wired and/or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another CN connected to one or more RANs, which may employ the same RAT as the RAN 104/113 or a different RAT.

[0046] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities (e.g., the WTRUs 102a, 102b, 102c, 102d may include multiple transceivers for communicating with different wireless networks over different wireless links). For example, the WTRU 102c shown in FIG. 1A may be configured to communicate with the base station 114a, which may employ a cellular-based radio technology, and with the base station 114b, which may employ an IEEE 802 radio technology.

[0047] FIG. 1B is a system diagram illustrating an example WTRU 102. As shown in FIG. 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, non-removable memory 130,

removable memory 132, a power source 134, a global positioning system (GPS) chipset 136, and/or other peripherals 138, among others. It will be appreciated that the WTRU 102 may include any sub-combination of the foregoing elements while remaining consistent with an embodiment.

[0048] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, and the like. The processor 118 may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While FIG. 1B depicts the processor 118 and the transceiver 120 as separate components, it will be appreciated that the processor 118 and the transceiver 120 may be integrated together in an electronic package or chip.

[0049] The transmit/receive element 122 may be configured to transmit signals to, or receive signals from, a base station (e.g., the base station 114a) over the air interface 116. For example, in one embodiment, the transmit/receive element 122 may be an antenna configured to transmit and/or receive RF signals. In an embodiment, the transmit/receive element 122 may be an emitter/detector configured to transmit and/or receive IR, UV, or visible light signals, for example. In yet another embodiment, the transmit/receive element 122 may be configured to transmit and/or receive both RF and light signals. It will be appreciated that the transmit/receive element 122 may be configured to transmit and/or receive any combination of wireless signals.

[0050] Although the transmit/receive element 122 is depicted in FIG. 1B as a single element, the WTRU 102 may include any number of transmit/receive elements 122. More specifically, the WTRU 102 may employ MIMO technology. Thus, in one embodiment, the WTRU 102 may include two or more transmit/receive elements 122 (e.g., multiple antennas) for transmitting and receiving wireless signals over the air interface 116.

[0051] The transceiver 120 may be configured to modulate the signals that are to be transmitted by the transmit/receive element 122 and to demodulate the signals that are received by the transmit/receive element 122. As noted above, the WTRU 102 may have multi-mode capabilities. Thus, the transceiver 120 may include multiple transceivers for enabling the WTRU 102 to communicate via multiple RATs, such as NR and IEEE 802.11, for example.

[0052] The processor 118 of the WTRU 102 may be coupled to, and may receive user input data from, the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128 (e.g., a liquid

crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor 118 may also output user data to the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128. In addition, the processor 118 may access information from, and store data in, any type of suitable memory, such as the non-removable memory 130 and/or the removable memory 132. The non-removable memory 130 may include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory 132 may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, and the like. In other embodiments, the processor 118 may access information from, and store data in, memory that is not physically located on the WTRU 102, such as on a server or a home computer (not shown).

[0053] The processor 118 may receive power from the power source 134, and may be configured to distribute and/or control the power to the other components in the WTRU 102. The power source 134 may be any suitable device for powering the WTRU 102. For example, the power source 134 may include one or more dry cell batteries (e.g., nickel-cadmium (NiCd), nickel-zinc (NiZn), nickel metal hydride (NiMH), lithium-ion (Li-ion), etc.), solar cells, fuel cells, and the like.

[0054] The processor 118 may also be coupled to the GPS chipset 136, which may be configured to provide location information (e.g., longitude and latitude) regarding the current location of the WTRU 102. In addition to, or in lieu of, the information from the GPS chipset 136, the WTRU 102 may receive location information over the air interface 116 from a base station (e.g., base stations 114a, 114b) and/or determine its location based on the timing of the signals being received from two or more nearby base stations. It will be appreciated that the WTRU 102 may acquire location information by way of any suitable location-determination method while remaining consistent with an embodiment.

[0055] The processor 118 may further be coupled to other peripherals 138, which may include one or more software and/or hardware modules that provide additional features, functionality and/or wired or wireless connectivity. For example, the peripherals 138 may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (for photographs and/or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, a Virtual Reality and/or Augmented Reality (VR/AR) device, an activity tracker, and the like. The peripherals 138 may include one or more sensors, the sensors may be one or more of a gyroscope, an accelerometer, a hall effect sensor, a magnetometer, an orientation sensor, a proximity sensor, a temperature sensor, a time sensor; a geolocation sensor; an altimeter, a light

sensor, a touch sensor, a magnetometer, a barometer, a gesture sensor, a biometric sensor, and/or a humidity sensor.

[0056] The WTRU 102 may include a full duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for both the UL (e.g., for transmission) and downlink (e.g., for reception) may be concurrent and/or simultaneous. The full duplex radio may include an interference management unit to reduce and or substantially eliminate self-interference via either hardware (e.g., a choke) or signal processing via a processor (e.g., a separate processor (not shown) or via processor 118). In an embodiment, the WRTU 102 may include a half-duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for either the UL (e.g., for transmission) or the downlink (e.g., for reception)).

[0057] FIG. 1C is a system diagram illustrating the RAN 104 and the CN 106 according to an embodiment. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 104 may also be in communication with the CN 106.

[0058] The RAN 104 may include eNode-Bs 160a, 160b, 160c, though it will be appreciated that the RAN 104 may include any number of eNode-Bs while remaining consistent with an embodiment. The eNode-Bs 160a, 160b, 160c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the eNode-Bs 160a, 160b, 160c may implement MIMO technology. Thus, the eNode-B 160a, for example, may use multiple antennas to transmit wireless signals to, and/or receive wireless signals from, the WTRU 102a.

[0059] Each of the eNode-Bs 160a, 160b, 160c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the UL and/or DL, and the like. As shown in FIG. 1C, the eNode-Bs 160a, 160b, 160c may communicate with one another over an X2 interface.

[0060] The CN 106 shown in FIG. 1C may include a mobility management entity (MME) 162, a serving gateway (SGW) 164, and a packet data network (PDN) gateway (or PGW) 166. While each of the foregoing elements are depicted as part of the CN 106, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0061] The MME 162 may be connected to each of the eNode-Bs 162a, 162b, 162c in the RAN 104 via an S1 interface and may serve as a control node. For example, the MME 162 may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, 102c, and the like. The

MME 162 may provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM and/or WCDMA.

[0062] The SGW 164 may be connected to each of the eNode Bs 160a, 160b, 160c in the RAN 104 via the S1 interface. The SGW 164 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The SGW 164 may perform other functions, such as anchoring user planes during inter-eNode B handovers, triggering paging when DL data is available for the WTRUs 102a, 102b, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0063] The SGW 164 may be connected to the PGW 166, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0064] The CN 106 may facilitate communications with other networks. For example, the CN 106 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices. For example, the CN 106 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 106 and the PSTN 108. In addition, the CN 106 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers.

[0065] Although the WTRU is described in FIGS. 1A-1D as a wireless terminal, it is contemplated that in certain representative embodiments that such a terminal may use (e.g., temporarily or permanently) wired communication interfaces with the communication network.

[0066] In representative embodiments, the other network 112 may be a WLAN.

[0067] A WLAN in Infrastructure Basic Service Set (BSS) mode may have an Access Point (AP) for the BSS and one or more stations (STAs) associated with the AP. The AP may have an access or an interface to a Distribution System (DS) or another type of wired/wireless network that carries traffic in to and/or out of the BSS. Traffic to STAs that originates from outside the BSS may arrive through the AP and may be delivered to the STAs. Traffic originating from STAs to destinations outside the BSS may be sent to the AP to be delivered to respective destinations. Traffic between STAs within the BSS may be sent through the AP, for example, where the source STA may send traffic to the AP and the AP may deliver the traffic to the destination STA. The traffic between STAs within a BSS may be considered and/or referred to as peer-to-peer traffic. The peer-to-peer traffic may be sent between (e.g., directly between) the source and destination STAs with a direct link setup (DLS). In certain representative embodiments, the DLS may use an 802.11e DLS or an 802.11z tunneled DLS (TDLS).

A WLAN using an Independent BSS (IBSS) mode may not have an AP, and the STAs (e.g., all of the STAs) within or using the IBSS may communicate directly with each other. The IBSS mode of communication may sometimes be referred to herein as an "ad-hoc" mode of communication.

[0068] When using the 802.11ac infrastructure mode of operation or a similar mode of operations, the AP may transmit a beacon on a fixed channel, such as a primary channel. The primary channel may be a fixed width (e.g., 20 MHz wide bandwidth) or a dynamically set width via signaling. The primary channel may be the operating channel of the BSS and may be used by the STAs to establish a connection with the AP. In certain representative embodiments, Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) may be implemented, for example in in 802.11 systems. For CSMA/CA, the STAs (e.g., every STA), including the AP, may sense the primary channel. If the primary channel is sensed/detected and/or determined to be busy by a particular STA, the particular STA may back off. One STA (e.g., only one station) may transmit at any given time in a given BSS.

[0069] High Throughput (HT) STAs may use a 40 MHz wide channel for communication, for example, via a combination of the primary 20 MHz channel with an adjacent or nonadjacent 20 MHz channel to form a 40 MHz wide channel.

[0070] Very High Throughput (VHT) STAs may support 20MHz, 40 MHz, 80 MHz, and/or 160 MHz wide channels. The 40 MHz, and/or 80 MHz, channels may be formed by combining contiguous 20 MHz channels. A 160 MHz channel may be formed by combining 8 contiguous 20 MHz channels, or by combining two non-contiguous 80 MHz channels, which may be referred to as an 80+80 configuration. For the 80+80 configuration, the data, after channel encoding, may be passed through a segment parser that may divide the data into two streams. Inverse Fast Fourier Transform (IFFT) processing, and time domain processing, may be done on each stream separately. The streams may be mapped on to the two 80 MHz channels, and the data may be transmitted by a transmitting STA. At the receiver of the receiving STA, the above described operation for the 80+80 configuration may be reversed, and the combined data may be sent to the Medium Access Control (MAC).

[0071] Sub 1 GHz modes of operation are supported by 802.11af and 802.11ah. The channel operating bandwidths, and carriers, are reduced in 802.11af and 802.11ah relative to those used in 802.11n, and 802.11ac. 802.11af supports 5 MHz, 10 MHz and 20 MHz bandwidths in the TV White Space (TVWS) spectrum, and 802.11ah supports 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz bandwidths using non-TVWS spectrum. According to a representative embodiment, 802.11ah may support Meter Type Control/Machine-Type Communications, such as MTC devices in a macro coverage area. MTC devices may have certain capabilities, for example, limited capabilities including

support for (e.g., only support for) certain and/or limited bandwidths. The MTC devices may include a battery with a battery life above a threshold (e.g., to maintain a very long battery life).

[0072] WLAN systems, which may support multiple channels, and channel bandwidths, such as 802.11n, 802.11ac, 802.11af, and 802.11ah, include a channel which may be designated as the primary channel. The primary channel may have a bandwidth equal to the largest common operating bandwidth supported by all STAs in the BSS. The bandwidth of the primary channel may be set and/or limited by a STA, from among all STAs in operating in a BSS, which supports the smallest bandwidth operating mode. In the example of 802.11ah, the primary channel may be 1 MHz wide for STAs (e.g., MTC type devices) that support (e.g., only support) a 1 MHz mode, even if the AP, and other STAs in the BSS support 2 MHz, 4 MHz, 8 MHz, 16 MHz, and/or other channel bandwidth operating modes. Carrier sensing and/or Network Allocation Vector (NAV) settings may depend on the status of the primary channel. If the primary channel is busy, for example, due to a STA (which supports only a 1 MHz operating mode), transmitting to the AP, the entire available frequency bands may be considered busy even though a majority of the frequency bands remains idle and may be available.

[0073] In the United States, the available frequency bands, which may be used by 802.11ah, are from 902 MHz to 928 MHz. In Korea, the available frequency bands are from 917.5 MHz to 923.5 MHz. In Japan, the available frequency bands are from 916.5 MHz to 927.5 MHz. The total bandwidth available for 802.11ah is 6 MHz to 26 MHz depending on the country code.

[0074] FIG. 1D is a system diagram illustrating the RAN 113 and the CN 115 according to an embodiment. As noted above, the RAN 113 may employ an NR radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 113 may also be in communication with the CN 115.

[0075] The RAN 113 may include gNBs 180a, 180b, 180c, though it will be appreciated that the RAN 113 may include any number of gNBs while remaining consistent with an embodiment. The gNBs 180a, 180b, 180c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the gNBs 180a, 180b, 180c may implement MIMO technology. For example, gNBs 180a, 108b may utilize beamforming to transmit signals to and/or receive signals from the gNBs 180a, 180b, 180c. Thus, the gNB 180a, for example, may use multiple antennas to transmit wireless signals to, and/or receive wireless signals from, the WTRU 102a. In an embodiment, the gNBs 180a, 180b, 180c may implement carrier aggregation technology. For example, the gNB 180a may transmit multiple component carriers to the WTRU 102a (not shown). A subset of these component carriers may be on unlicensed spectrum while the remaining component carriers may be on licensed spectrum. In an embodiment, the gNBs 180a, 180b,

180c may implement Coordinated Multi-Point (CoMP) technology. For example, WTRU 102a may receive coordinated transmissions from gNB 180a and gNB 180b (and/or gNB 180c).

[0076] The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using transmissions associated with a scalable numerology. For example, the OFDM symbol spacing and/or OFDM subcarrier spacing may vary for different transmissions, different cells, and/or different portions of the wireless transmission spectrum. The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using subframe or transmission time intervals (TTIs) of various or scalable lengths (e.g., containing varying number of OFDM symbols and/or lasting varying lengths of absolute time).

[0077] The gNBs 180a, 180b, 180c may be configured to communicate with the WTRUs 102a, 102b, 102c in a standalone configuration and/or a non-standalone configuration. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c without also accessing other RANs (e.g., such as eNode-Bs 160a, 160b, 160c). In the standalone configuration, WTRUs 102a, 102b, 102c may utilize one or more of gNBs 180a, 180b, 180c as a mobility anchor point. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using signals in an unlicensed band. In a non-standalone configuration WTRUs 102a, 102b, 102c may communicate with/connect to gNBs 180a, 180b, 180c while also communicating with/connecting to another RAN such as eNode-Bs 160a, 160b, 160c. For example, WTRUs 102a, 102b, 102c may implement DC principles to communicate with one or more gNBs 180a, 180b, 180c and one or more eNode-Bs 160a, 160b, 160c substantially simultaneously. In the non-standalone configuration, eNode-Bs 160a, 160b, 160c may serve as a mobility anchor for WTRUs 102a, 102b, 102c and gNBs 180a, 180b, 180c may provide additional coverage and/or throughput for servicing WTRUs 102a, 102b, 102c.

[0078] Each of the gNBs 180a, 180b, 180c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the UL and/or DL, support of network slicing, dual connectivity, interworking between NR and E-UTRA, routing of user plane data towards User Plane Function (UPF) 184a, 184b, routing of control plane information towards Access and Mobility Management Function (AMF) 182a, 182b and the like. As shown in FIG. 1D, the gNBs 180a, 180b, 180c may communicate with one another over an Xn interface.

[0079] The CN 115 shown in FIG. 1D may include at least one AMF 182a, 182b, at least one UPF 184a,184b, at least one Session Management Function (SMF) 183a, 183b, and possibly a Data Network (DN) 185a, 185b. While each of the foregoing elements are depicted as part of the CN 115, it

will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0080] The AMF 182a, 182b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N2 interface and may serve as a control node. For example, the AMF 182a, 182b may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, support for network slicing (e.g., handling of different PDU sessions with different requirements), selecting a particular SMF 183a, 183b, management of the registration area, termination of NAS signaling, mobility management, and the like. Network slicing may be used by the AMF 182a, 182b to customize CN support for WTRUs 102a, 102b, 102c based on the types of services being utilized WTRUs 102a, 102b, 102c. For example, different network slices may be established for different use cases such as services relying on ultra-reliable low latency (URLLC) access, services relying on enhanced massive mobile broadband (eMBB) access, services for machine type communication (MTC) access, and/or the like. The AMF 162 may provide a control plane function for switching between the RAN 113 and other RANs (not shown) that employ other radio technologies, such as LTE, LTE-A, LTE-A Pro, and/or non-3GPP access technologies such as WiFi.

[0081] The SMF 183a, 183b may be connected to an AMF 182a, 182b in the CN 115 via an N11 interface. The SMF 183a, 183b may also be connected to a UPF 184a, 184b in the CN 115 via an N4 interface. The SMF 183a, 183b may select and control the UPF 184a, 184b and configure the routing of traffic through the UPF 184a, 184b. The SMF 183a, 183b may perform other functions, such as managing and allocating UE IP address, managing PDU sessions, controlling policy enforcement and QoS, providing downlink data notifications, and the like. A PDU session type may be IP-based, non-IP based, Ethernet-based, and the like.

[0082] The UPF 184a, 184b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N3 interface, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices. The UPF 184, 184b may perform other functions, such as routing and forwarding packets, enforcing user plane policies, supporting multi-homed PDU sessions, handling user plane QoS, buffering downlink packets, providing mobility anchoring, and the like.

[0083] The CN 115 may facilitate communications with other networks. For example, the CN 115 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 115 and the PSTN 108. In addition, the CN 115 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers. In one

embodiment, the WTRUs 102a, 102b, 102c may be connected to a local Data Network (DN) 185a, 185b through the UPF 184a, 184b via the N3 interface to the UPF 184a, 184b and an N6 interface between the UPF 184a, 184b and the DN 185a, 185b.

[0084] In view of Figures 1A-1D, and the corresponding description of Figures 1A-1D, one or more, or all, of the functions described herein with regard to one or more of: WTRU 102a-d, Base Station 114a-b, eNode-B 160a-c, MME 162, SGW 164, PGW 166, gNB 180a-c, AMF 182a-b, UPF 184a-b, SMF 183a-b, DN 185a-b, and/or any other device(s) described herein, may be performed by one or more emulation devices (not shown). The emulation devices may be one or more devices configured to emulate one or more, or all, of the functions described herein. For example, the emulation devices may be used to test other devices and/or to simulate network and/or WTRU functions.

[0085] The emulation devices may be designed to implement one or more tests of other devices in a lab environment and/or in an operator network environment. For example, the one or more emulation devices may perform the one or more, or all, functions while being fully or partially implemented and/or deployed as part of a wired and/or wireless communication network in order to test other devices within the communication network. The one or more emulation devices may perform the one or more, or all, functions while being temporarily implemented/deployed as part of a wired and/or wireless communication network. The emulation device may be directly coupled to another device for purposes of testing and/or may perform testing using over-the-air wireless communications.

[0086] The one or more emulation devices may perform the one or more, including all, functions while not being implemented/deployed as part of a wired and/or wireless communication network. For example, the emulation devices may be utilized in a testing scenario in a testing laboratory and/or a non-deployed (e.g., testing) wired and/or wireless communication network in order to implement testing of one or more components. The one or more emulation devices may be test equipment. Direct RF coupling and/or wireless communications via RF circuitry (e.g., which may include one or more antennas) may be used by the emulation devices to transmit and/or receive data.

[0087] This application describes a variety of aspects, including tools, features, examples or embodiments, models, approaches, etc. Many of these aspects are described with specificity and, at least to show the individual characteristics, are often described in a manner that may sound limiting. However, this is for purposes of clarity in description, and does not limit the application or scope of those aspects. Indeed, all of the different aspects may be combined and interchanged to provide further aspects. Moreover, the aspects may be combined and interchanged with aspects described in earlier filings as well.

[0088] The aspects described and contemplated in this application may be implemented in many different forms. FIGS. 5-10B described herein may provide some embodiments, but other embodiments are contemplated. The discussion of FIGS. 5-10B does not limit the breadth of the implementations. At least one of the aspects generally relates to video encoding and decoding, and at least one other aspect generally relates to transmitting a bitstream generated or encoded. These and other aspects may be implemented as a method, an apparatus, a computer readable storage medium having stored thereon instructions for encoding or decoding video data according to any of the methods described, and/or a computer readable storage medium having stored thereon a bitstream generated according to any of the methods described.

[0089] In the present application, the terms "reconstructed" and "decoded" may be used interchangeably, the terms "pixel" and "sample" may be used interchangeably, the terms "image," "picture" and "frame" may be used interchangeably.

[0090] The terms HDR (high dynamic range) and SDR (standard dynamic range) may be used in this disclosure. Those terms often convey specific values of dynamic range to those of ordinary skill in the art. However, additional embodiments are also intended in which a reference to HDR is understood to mean "higher dynamic range" and a reference to SDR is understood to mean "lower dynamic range." Such additional embodiments are not constrained by any specific values of dynamic range that might often be associated with the terms "high dynamic range" and "standard dynamic range."

[0091] Various methods are described herein, and each of the methods comprises one or more steps or actions for achieving the described method. Unless a specific order of steps or actions is required for proper operation of the method, the order and/or use of specific steps and/or actions may be modified or combined. Additionally, terms such as "first", "second", etc. may be used in various embodiments to modify an element, component, step, operation, etc., such as, for example, a "first decoding" and a "second decoding". Use of such terms does not imply an ordering to the modified operations unless specifically required. So, in this example, the first decoding need not be performed before the second decoding, and may occur, for example, before, during, or in an overlapping time period with the second decoding.

[0092] Various methods and other aspects described in this application may be used to modify modules, for example, in-loop filters modules (265 and 365), of a video encoder 200 and decoder 300 as shown in FIG. 2 and FIG. 3, respectively. Moreover, the subject matter disclosed herein presents aspects that are not limited to VVC or HEVC, and may be applied, for example, to any type, format or version of video coding, whether described in a standard or a recommendation, whether pre-existing or future-developed, and extensions of any such standards and recommendations (e.g., including VVC

and HEVC). Unless indicated otherwise, or technically precluded, the aspects described in this application may be used individually or in combination.

[0093] Various numeric values are used in examples described in the present application, such as coefficients, filter sizes, etc. These and other specific values are for purposes of describing examples and the aspects described are not limited to these specific values.

[0094] FIG. 2 is a diagram showing an example video encoder (e.g., an example block-based hybrid video encoder) 200. Variations of example encoder 200 are contemplated, but the encoder 200 is described below for purposes of clarity without describing all expected variations.

[0095] Before being encoded, the video sequence may go through pre-encoding processing (201), for example, applying a color transform to the input color picture (e.g., conversion from RGB 4:4:4 to YCbCr 4:2:0), or performing a remapping of the input picture components in order to get a signal distribution more resilient to compression (for instance using a histogram equalization of one of the color components). Metadata may be associated with the pre-processing, and attached to the bitstream.

[0096] In the encoder 200, a picture is encoded by the encoder elements as described below. The picture to be encoded is partitioned (202) and processed in units of, for example, coding units (CUs). Each unit is encoded using, for example, either an intra or inter mode. When a unit is encoded in an intra mode, it performs intra prediction (260). In an inter mode, motion estimation (275) and compensation (270) are performed. The encoder decides (205) which one of the intra mode or inter mode to use for encoding the unit, and indicates the intra/inter decision by, for example, a prediction mode flag. Prediction residuals are calculated, for example, by subtracting (210) the predicted block from the original image block.

[0097] The prediction residuals are then transformed (225) and quantized (230). The quantized transform coefficients, as well as motion vectors and other syntax elements, are entropy coded (245) to output a bitstream. The encoder can skip the transform and apply quantization directly to the non-transformed residual signal. The encoder can bypass both transform and quantization, i.e., the residual is coded directly without the application of the transform or quantization processes.

[0098] The encoder decodes an encoded block to provide a reference for further predictions. The quantized transform coefficients are de-quantized (240) and inverse transformed (250) to decode prediction residuals. Combining (255) the decoded prediction residuals and the predicted block, an image block is reconstructed. In-loop filters (265) are applied to the reconstructed picture to perform, for example, deblocking/SAO (Sample Adaptive Offset) filtering to reduce encoding artifacts. The filtered image is stored at a reference picture buffer (280).

[0099] FIG. 3 is a diagram showing an example of a video decoder 300. In example decoder 300, a bitstream is decoded by the decoder elements as described below. Video decoder 300 generally performs a decoding pass reciprocal to the encoding pass as described in FIG. 2. The encoder 200 also generally performs video decoding as part of encoding video data.

[0100] In particular, the input of the decoder includes a video bitstream, which may be generated by video encoder 200. The bitstream is first entropy decoded (330) to obtain transform coefficients, motion vectors, and other coded information. The picture partition information indicates how the picture is partitioned. The decoder may therefore divide (335) the picture according to the decoded picture partitioning information. The transform coefficients are de-quantized (340) and inverse transformed (350) to decode the prediction residuals. Combining (355) the decoded prediction residuals and the predicted block, an image block is reconstructed. The predicted block may be obtained (370) from intra prediction (360) or motion-compensated prediction (i.e., inter prediction) (375). In-loop filters (365) are applied to the reconstructed image. The filtered image is stored at a reference picture buffer (380). For a given picture, the contents of the reference picture buffer 380 on the decoder 300 side may be identical to the contents of the reference picture buffer 280 on the encoder 200 side for the same picture.

[0101] The decoded picture can further go through post-decoding processing (385), for example, an inverse color transform (e.g., conversion from YCbCr 4:2:0 to RGB 4:4:4) or an inverse remapping performing the inverse of the remapping process performed in the pre-encoding processing (201). The post-decoding processing can use metadata derived in the pre-encoding processing and signaled in the bitstream.

[0102] FIG. 4 is a diagram showing an example of a system in which various aspects and embodiments described herein may be implemented. System 400 may be embodied as a device including the various components described below and is configured to perform one or more of the aspects described in this document. Examples of such devices, include, but are not limited to, various electronic devices such as personal computers, laptop computers, smartphones, tablet computers, digital multimedia set top boxes, digital television receivers, personal video recording systems, connected home appliances, and servers. Elements of system 400, singly or in combination, may be embodied in a single integrated circuit (IC), multiple ICs, and/or discrete components. For example, in at least one example, the processing and encoder/decoder elements of system 400 are distributed across multiple ICs and/or discrete components. In various embodiments, the system 400 is communicatively coupled to one or more other systems, or other electronic devices, via, for example, a

communications bus or through dedicated input and/or output ports. In various embodiments, the system 400 is configured to implement one or more of the aspects described in this document.

[0103] The system 400 includes at least one processor 410 configured to execute instructions loaded therein for implementing, for example, the various aspects described in this document. Processor 410 can include embedded memory, input output interface, and various other circuitries as known in the art. The system 400 includes at least one memory 420 (e.g., a volatile memory device, and/or a non-volatile memory device). System 400 includes a storage device 440, which can include non-volatile memory and/or volatile memory, including, but not limited to, Electrically Erasable Programmable Read-Only Memory (EEPROM), Read-Only Memory (ROM), Programmable Read-Only Memory (PROM), Random Access Memory (RAM), Dynamic Random Access Memory (DRAM), Static Random Access Memory (SRAM), flash, magnetic disk drive, and/or optical disk drive. The storage device 440 can include an internal storage device, an attached storage device (including detachable and non-detachable storage devices), and/or a network accessible storage device, as non-limiting examples.

[0104] System 400 includes an encoder/decoder module 430 configured, for example, to process data to provide an encoded video or decoded video, and the encoder/decoder module 430 can include its own processor and memory. The encoder/decoder module 430 represents module(s) that may be included in a device to perform the encoding and/or decoding functions. As is known, a device can include one or both of the encoding and decoding modules. Additionally, encoder/decoder module 430 may be implemented as a separate element of system 400 or may be incorporated within processor 410 as a combination of hardware and software as known to those skilled in the art.

[0105] Program code to be loaded onto processor 410 or encoder/decoder 430 to perform the various aspects described in this document may be stored in storage device 440 and subsequently loaded onto memory 420 for execution by processor 410. In accordance with various embodiments, one or more of processor 410, memory 420, storage device 440, and encoder/decoder module 430 can store one or more of various items during the performance of the processes described in this document. Such stored items can include, but are not limited to, the input video, the decoded video or portions of the decoded video, the bitstream, matrices, variables, and intermediate or final results from the processing of equations, formulas, operations, and operational logic.

[0106] In some embodiments, memory inside of the processor 410 and/or the encoder/decoder module 430 is used to store instructions and to provide working memory for processing that is needed during encoding or decoding. In other embodiments, however, a memory external to the processing device (for example, the processing device may be either the processor 410 or the encoder/decoder

module 430) is used for one or more of these functions. The external memory may be the memory 420 and/or the storage device 440, for example, a dynamic volatile memory and/or a non-volatile flash memory. In several embodiments, an external non-volatile flash memory is used to store the operating system of, for example, a television. In at least one embodiment, a fast external dynamic volatile memory such as a RAM is used as working memory for video coding and decoding operations, such as, for example, MPEG-2 (MPEG refers to the Moving Picture Experts Group, MPEG-2 is also referred to as ISO/IEC 13818, and 13818-1 is also known as H.222, and 13818-2 is also known as H.262), HEVC (HEVC refers to High Efficiency Video Coding, also known as H.265 and MPEG-H Part 2), or VVC (Versatile Video Coding, a new standard being developed by JVET, the Joint Video Experts Team).

[0107] The input to the elements of system 400 may be provided through various input devices as indicated in block 445. Such input devices include, but are not limited to, (i) a radio frequency (RF) portion that receives an RF signal transmitted, for example, over the air by a broadcaster, (ii) a Component (COMP) input terminal (or a set of COMP input terminals), (iii) a Universal Serial Bus (USB) input terminal, and/or (iv) a High Definition Multimedia Interface (HDMI) input terminal. Other examples, not shown in FIG. 4, include composite video.

[0108] In various embodiments, the input devices of block 445 have associated respective input processing elements as known in the art. For example, the RF portion may be associated with elements suitable for (i) selecting a desired frequency (also referred to as selecting a signal, or band-limiting a signal to a band of frequencies), (ii) down-converting the selected signal, (iii) band-limiting again to a narrower band of frequencies to select (for example) a signal frequency band which may be referred to as a channel in certain embodiments, (iv) demodulating the down-converted and band-limited signal, (v) performing error correction, and (vi) demultiplexing to select the desired stream of data packets. The RF portion of various embodiments includes one or more elements to perform these functions, for example, frequency selectors, signal selectors, band-limiters, channel selectors, filters, downconverters, demodulators, error correctors, and demultiplexers. The RF portion can include a tuner that performs various of these functions, including, for example, down-converting the received signal to a lower frequency (for example, an intermediate frequency or a near-baseband frequency) or to baseband. In one set-top box embodiment, the RF portion and its associated input processing element receives an RF signal transmitted over a wired (for example, cable) medium, and performs frequency selection by filtering, down-converting, and filtering again to a desired frequency band. Various embodiments rearrange the order of the above-described (and other) elements, remove some of these elements, and/or add other elements performing similar or different functions. Adding

elements can include inserting elements in between existing elements, such as, for example, inserting amplifiers and an analog-to-digital converter. In various embodiments, the RF portion includes an antenna.

[0109] Additionally, the USB and/or HDMI terminals can include respective interface processors for connecting system 400 to other electronic devices across USB and/or HDMI connections. It is to be understood that various aspects of input processing, for example, Reed-Solomon error correction, may be implemented, for example, within a separate input processing IC or within processor 410 as necessary. Similarly, aspects of USB or HDMI interface processing may be implemented within separate interface ICs or within processor 410 as necessary. The demodulated, error corrected, and demultiplexed stream is provided to various processing elements, including, for example, processor 410, and encoder/decoder 430 operating in combination with the memory and storage elements to process the data stream as necessary for presentation on an output device.

[0110] Various elements of system 400 may be provided within an integrated housing, Within the integrated housing, the various elements may be interconnected and transmit data therebetween using suitable connection arrangement 425, for example, an internal bus as known in the art, including the Inter-IC (I2C) bus, wiring, and printed circuit boards.

[0111] The system 400 includes communication interface 450 that enables communication with other devices via communication channel 460. The communication interface 450 can include, but is not limited to, a transceiver configured to transmit and to receive data over communication channel 460. The communication interface 450 can include, but is not limited to, a modem or network card and the communication channel 460 may be implemented, for example, within a wired and/or a wireless medium.

[0112] Data is streamed, or otherwise provided, to the system 400, in various embodiments, using a wireless network such as a Wi-Fi network, for example IEEE 802.11 (IEEE refers to the Institute of Electrical and Electronics Engineers). The Wi-Fi signal of these examples is received over the communications channel 460 and the communications interface 450 which are adapted for Wi-Fi communications. The communications channel 460 of these embodiments is typically connected to an access point or router that provides access to external networks including the Internet for allowing streaming applications and other over-the-top communications. Other embodiments provide streamed data to the system 400 using a set-top box that delivers the data over the HDMI connection of the input block 445. Still other embodiments provide streamed data to the system 400 using the RF connection of the input block 445. As indicated above, various embodiments provide data in a non-streaming

manner. Additionally, various embodiments use wireless networks other than Wi-Fi, for example a cellular network or a Bluetooth network.

[0113] The system 400 can provide an output signal to various output devices, including a display 475, speakers 485, and other peripheral devices 495. The display 475 of various embodiments includes one or more of, for example, a touchscreen display, an organic light-emitting diode (OLED) display, a curved display, and/or a foldable display. The display 475 may be for a television, a tablet, a laptop, a cell phone (mobile phone), or other device. The display 475 can also be integrated with other components (for example, as in a smart phone), or separate (for example, an external monitor for a laptop). The other peripheral devices 495 include, in various examples of embodiments, one or more of a stand-alone digital video disc (or digital versatile disc) (DVR, for both terms), a disk player, a stereo system, and/or a lighting system. Various embodiments use one or more peripheral devices 495 that provide a function based on the output of the system 400. For example, a disk player performs the function of playing the output of the system 400.

[0114] In various embodiments, control signals are communicated between the system 400 and the display 475, speakers 485, or other peripheral devices 495 using signaling such as AV.Link, Consumer Electronics Control (CEC), or other communications protocols that enable device-to-device control with or without user intervention. The output devices may be communicatively coupled to system 400 via dedicated connections through respective interfaces 470, 480, and 490. Alternatively, the output devices may be connected to system 400 using the communications channel 460 via the communications interface 450. The display 475 and speakers 485 may be integrated in a single unit with the other components of system 400 in an electronic device such as, for example, a television. In various embodiments, the display interface 470 includes a display driver, such as, for example, a timing controller (T Con) chip.

[0115] The display 475 and speakers 485 can alternatively be separate from one or more of the other components, for example, if the RF portion of input 445 is part of a separate set-top box. In various embodiments in which the display 475 and speakers 485 are external components, the output signal may be provided via dedicated output connections, including, for example, HDMI ports, USB ports, or COMP outputs.

[0116] The embodiments may be carried out by computer software implemented by the processor 410 or by hardware, or by a combination of hardware and software. As a non-limiting example, the embodiments may be implemented by one or more integrated circuits. The memory 420 may be of any type appropriate to the technical environment and may be implemented using any appropriate data storage technology, such as optical memory devices, magnetic memory devices, semiconductor-based

memory devices, fixed memory, and removable memory, as non-limiting examples. The processor 410 may be of any type appropriate to the technical environment, and can encompass one or more of microprocessors, general purpose computers, special purpose computers, and processors based on a multi-core architecture, as non-limiting examples.

[0117] Various implementations involve decoding. "Decoding", as used in this application, can encompass all or part of the processes performed, for example, on a received encoded sequence in order to produce a final output suitable for display. In various embodiments, such processes include one or more of the processes typically performed by a decoder, for example, entropy decoding, inverse quantization, inverse transformation, and differential decoding. In various embodiments, such processes also, or alternatively, include processes performed by a decoder of various implementations described in this application, for example, receiving an encoded filter comprising an encoded coefficient; determining, based on a location of the encoded coefficient relative to a center coefficient, an order of an exponential-Golomb code; and decoding the encoded coefficient with the exponential-Golomb code of the determined order, etc.

[0118] Other example processes that may be performed by a decoder include receiving an encoded set of filters, wherein the encoded set of filters comprises a plurality of encoded coefficients; receiving an indication of a size index associated with the encoded set of filters; and decoding the plurality of encoded coefficients based on the size index, etc.

[0119] Other example processes that may be performed by a decoder include receiving a set of encoded filter coefficients; decoding a first filter coefficient and a second filter coefficient of the set of encoded filter coefficients to determine a first value of the first filter coefficient and a second value of the second filter coefficient; determining a difference between the first value and the second value; and decoding a third filter coefficient based on the difference between the first value and the second value, etc.

[0120] As further embodiments, in one example "decoding" refers only to entropy decoding, in another embodiment "decoding" refers only to differential decoding, and in another embodiment "decoding" refers to a combination of entropy decoding and differential decoding. Whether the phrase "decoding process" is intended to refer specifically to a subset of operations or generally to the broader decoding process will be clear based on the context of the specific descriptions and is believed to be well understood by those skilled in the art.

[0121] Various implementations involve encoding. In an analogous way to the above discussion about "decoding", "encoding" as used in this application can encompass all or part of the processes performed, for example, on an input video sequence in order to produce an encoded bitstream. In

various embodiments, such processes include one or more of the processes typically performed by an encoder, for example, partitioning, differential encoding, transformation, quantization, and entropy encoding. In various embodiments, such processes also, or alternatively, include processes performed by an encoder of various implementations described in this application, for example, identifying a filter comprising a coefficient; determining, based on a location of the coefficient relative to a center coefficient, an order of an exponential-Golomb code; encoding the coefficient with the exponential-Golomb code of the determined order to generate an encoded coefficient; and including, in video data, the encoded coefficient, etc.

[0122] Other example processes that may be performed by an encoder include identifying, based on rate distortion, a set of filters, wherein the set of filters comprises a plurality of coefficients; determining a size index associated with the set of filters; encoding the plurality of coefficients to generate a plurality of encoded coefficients; and including, in video data, the plurality of encoded coefficients and an indication of the size index, etc.

[0123] Other example processes that may be performed by an encoder include identifying a set of filter coefficients; encoding a first value of a first filter coefficient of the set of encoded filter coefficients, and a second value of a second filter coefficient of the set of encoded filter coefficients; determining a difference between the first value and the second value; and encoding a third filter coefficient based on the difference between the first value and the second value, etc.

[0124] Other example processes that may be performed by an encoder include identifying a filter comprising a first coefficient and a second coefficient; encoding a value of the first coefficient using an exponential-Golomb code to generate a binary code having a first bitlength; identifying a second bitlength for representing a value of the second coefficient; and encoding the second coefficient with a modified exponential-Golomb code to generate an encoded second coefficient, wherein a prefix of the encoded second coefficient comprises n zero-bits, and wherein n is the difference between the second bitlength and the first bitlength, etc.

[0125] Other example processes that may be performed by an encoder include identifying a filter comprising a set of coefficients; encoding the set of coefficients using an entropy coder, wherein a probability associated with each coefficient of the set of coefficients depends on a corresponding spatial position of the coefficient; and including, in video data, the encoded set of coefficients, etc.

[0126] Other example processes that may be performed by an encoder include identifying a first sign of a first coefficient, and a second sign of a second coefficient; determining a third sign of a sum of the first coefficient and the second coefficient; encoding a fourth sign of a third coefficient based on the third sign of the sum; and including, in video data, the encoded fourth sign, etc.

[0127] As further examples, in one embodiment "encoding" refers only to entropy encoding, in another embodiment "encoding" refers only to differential encoding, and in another embodiment "encoding" refers to a combination of differential encoding and entropy encoding. Whether the phrase "encoding process" is intended to refer specifically to a subset of operations or generally to the broader encoding process will be clear based on the context of the specific descriptions and is believed to be well understood by those skilled in the art.

[0128] When a figure is presented as a flow diagram, it should be understood that it also provides a block diagram of a corresponding apparatus. Similarly, when a figure is presented as a block diagram, it should be understood that it also provides a flow diagram of a corresponding method/process.

[0129] Various embodiments refer to rate distortion optimization. In particular, during the encoding process, the balance or trade-off between the rate and distortion is usually considered, often given the constraints of computational complexity. The rate distortion optimization is usually formulated as minimizing a rate distortion function, which is a weighted sum of the rate and of the distortion. There are different approaches to solve the rate distortion optimization problem. For example, the approaches may be based on an extensive testing of all encoding options, including all considered modes or coding parameters values, with a complete evaluation of their coding cost and related distortion of the reconstructed signal after coding and decoding. Faster approaches may also be used, to save encoding complexity, in particular with computation of an approximated distortion based on the prediction or the prediction residual signal, not the reconstructed one. Mix of these two approaches can also be used, such as by using an approximated distortion for only some of the possible encoding options, and a complete distortion for other encoding options. Other approaches only evaluate a subset of the possible encoding options. More generally, many approaches employ any of a variety of techniques to perform the optimization, but the optimization is not necessarily a complete evaluation of both the coding cost and related distortion.

[0130] The implementations and aspects described herein may be implemented in, for example, a method or a process, an apparatus, a software program, a data stream, or a signal. Even if only discussed in the context of a single form of implementation (for example, discussed only as a method), the implementation of features discussed can also be implemented in other forms (for example, an apparatus or program). An apparatus may be implemented in, for example, appropriate hardware, software, and firmware. The methods may be implemented in, for example, a processor, which refers to processing devices in general, including, for example, a computer, a microprocessor, an integrated circuit, or a programmable logic device. Processors also include communication devices, such as, for

example, computers, cell phones, portable/personal digital assistants ("PDAs"), and other devices that facilitate communication of information between end-users.

[0131] Reference to "one embodiment," "an embodiment," "an example," "one implementation" or "an implementation," as well as other variations thereof, means that a particular feature, structure, characteristic, and so forth described in connection with the embodiment is included in at least one embodiment. Thus, the appearances of the phrase "in one embodiment," "in an embodiment," "in an example," "in one implementation," or "in an implementation", as well any other variations, appearing in various places throughout this application are not necessarily all referring to the same embodiment or example.

[0132] Additionally, this application may refer to "determining" various pieces of information. Determining the information can include one or more of, for example, estimating the information, calculating the information, predicting the information, or retrieving the information from memory. Obtaining may include receiving, retrieving, constructing, generating, and/or determining.

[0133] Further, this application may refer to "accessing" various pieces of information. Accessing the information can include one or more of, for example, receiving the information, retrieving the information (for example, from memory), storing the information, moving the information, copying the information, calculating the information, determining the information, predicting the information, or estimating the information.

[0134] Additionally, this application may refer to "receiving" various pieces of information. Receiving is, as with "accessing", intended to be a broad term. Receiving the information can include one or more of, for example, accessing the information, or retrieving the information (for example, from memory). Further, "receiving" is typically involved, in one way or another, during operations such as, for example, storing the information, processing the information, transmitting the information, moving the information, copying the information, erasing the information, calculating the information, determining the information, predicting the information, or estimating the information.

[0135] It is to be appreciated that the use of any of the following "/", "and/or", and "at least one of", for example, in the cases of "A/B", "A and/or B" and "at least one of A and B", is intended to encompass the selection of the first listed option (A) only, or the selection of the second listed option (B) only, or the selection of both options (A and B). As a further example, in the cases of "A, B, and/or C" and "at least one of A, B, and C", such phrasing is intended to encompass the selection of the first listed option (A) only, or the selection of the second listed option (B) only, or the selection of the third listed option (C) only, or the selection of the first and the second listed options (A and B) only, or the selection of the first and third listed options (A and C) only, or the selection of the second and third

listed options (B and C) only, or the selection of all three options (A and B and C). This may be extended, as is clear to one of ordinary skill in this and related arts, for as many items as are listed.

[0136] Also, as used herein, the word "signal" refers to, among other things, indicating something to a corresponding decoder. For example, in some embodiments the encoder signals (e.g., to a decoder) a size index of a filter or set of filters, etc. In this way, in an embodiment the same parameter is used at both the encoder side and the decoder side. Thus, for example, an encoder can transmit (explicit signaling) a particular parameter to the decoder so that the decoder can use the same particular parameter. Conversely, if the decoder already has the particular parameter as well as others, then signaling may be used without transmitting (implicit signaling) to simply allow the decoder to know and select the particular parameter. By avoiding transmission of any actual functions, a bit savings is realized in various embodiments. It is to be appreciated that signaling may be accomplished in a variety of ways. For example, one or more syntax elements, flags, and so forth are used to signal information to a corresponding decoder in various embodiments. While the preceding relates to the verb form of the word "signal", the word "signal" can also be used herein as a noun.

[0137] As will be evident to one of ordinary skill in the art, implementations may produce a variety of signals formatted to carry information that may be, for example, stored or transmitted. The information can include, for example, instructions for performing a method, or data produced by one of the described implementations. For example, a signal may be formatted to carry the bitstream of a described embodiment. Such a signal may be formatted, for example, as an electromagnetic wave (for example, using a radio frequency portion of spectrum) or as a baseband signal. The formatting may include, for example, encoding a data stream and modulating a carrier with the encoded data stream. The information that the signal carries may be, for example, analog or digital information. The signal may be transmitted over a variety of different wired or wireless links, as is known. The signal may be stored on a processor-readable medium.

[0138] Many embodiments are described herein. Features of embodiments may be provided alone or in any combination, across various claim categories and types. Further, embodiments may include one or more of the features, devices, or aspects described herein, alone or in any combination, across various claim categories and types . For example, features described herein can be implemented in a bitstream or signal that includes information generated as described herein. The information can allow a decoder to decode a bitstream, the encoder, bitstream, and/or decoder according to any of the embodiments described. For example, features described herein can be implemented by creating and/or transmitting and/or receiving and/or decoding a bitstream or signal. For example, features described herein can be implemented a method, process, apparatus, medium storing instructions,

medium storing data, or signal. For example, features described herein can be implemented by a TV, set-top box, cell phone, tablet, or other electronic device that performs decoding. The TV, set-top box, cell phone, tablet, or other electronic device can display (e.g., using a monitor, screen, or other type of display) a resulting image (e.g., an image from residual reconstruction of the video bitstream). The TV, set-top box, cell phone, tablet, or other electronic device can receive a signal including an encoded image and perform decoding.

[0139] A syntax cost of adaptive loop filter (ALF) syntax elements may be reduced. Feature(s) described herein may be extended to other (e.g., any other) in-loop or post-filter where coefficients are signaled in the bitstream.

[0140] Feature(s) associated with ALFs are provided herein. An ALF may be based on adaptive filters. Adaptive filters may be applied to reduce the mean squared error (MSE) between the original and the reconstructed samples. For example, adaptive filters may be applied to reduce the mean squared error (MSE) between the original and the reconstructed samples using Wiener-based filtering. An ALF may be the last post-filter applied to the output of sample adaptive offset (SAO).

[0141] An ALF may include a classification of non-overlapping sub-blocks (e.g., based on local sample gradients of the sub-blocks). For a class (e.g., each class), a specific filter may be applied (e.g., from among the different filters signaled in the bitstreams). Based on the classification, a geometric transformation of coefficients within a filter shape (e.g., 90-degree rotation, diagonal or vertical flip, etc.) may be applied.

[0142] Feature(s) associated with filter shape are provided herein.

[0143] One or more (e.g., two) filter shapes (e.g., 7×7 diamond shape and/or 5×5 diamond shape) may be used for Luma and Chroma components (e.g., a 7×7 diamond shape for Luma components and/or 5×5 diamond shape for Chroma components, as shown in FIG. 5). A square (e.g., each square) may correspond to a Luma or a Chroma sample. The center square may denote the current to-be-filtered sample. To reduce the signaling overhead and/or the number of multiplications, the filter coefficients may use point-symmetry.

[0144] FIG. 5 illustrates example ALF filter shapes. For example, as shown on the left of FIG. 5, a 5×5 diamond may be used for Chroma components. As shown on the right of FIG. 5, a 7×7 diamond may be used for Luma components.

[0145] An integer filter coefficient (e.g., each integer filter coefficient), c_i, may be represented with n-bit fractional precision. DC may denote the lowest frequency of a signal (e.g., an average of the signal). DC neutrality may be preserved. For example, preserving DC neutrality may indicate that a filter will

preserve the average of the signal. To preserve DC neutrality, the sum of coefficients of one filter may be (e.g., must be) equal to $128 = 1 \ll n$.

$$2\left(\sum_{i=0}^{N-2} c_i\right) + c_{N-1} = 128 \quad (1)$$

[0146] In an example, n may be equal to 7.

[0147] In Eq. (1), the number of coefficients, N, may be equal to 13 for a 7x7 filter shape. In Eq. (1), the number of coefficients, N, may be equal to 7 for a 5x5 filter shape.

[0148] Feature(s) associated with linear filtering are provided herein.

[0149] A filtered sample value $\bar{R}(x, y)$ may be obtained (e.g., because of point-symmetry and DC neutrality) by adding the reconstructed sample $R(x, y)$ and a weighted sum of the differences between the to-be-filtered sample $R(x, y)$ and its neighboring samples:

$$\bar{R}(x,y) = R(x,y) + \left(\left[\sum_{i=0}^{N-2} c_i \times (\Delta R_i^+ + \Delta R_i^-)\right] + 64\right) \gg 7 \quad (2)$$

with:

$$\begin{aligned} \Delta R_i^+ &= R(x + x_i, y + y_i) - R(x,y) \\ \Delta R_i^- &= R(x - x_i, y - y_i) - R(x,y) \end{aligned} \quad (3)$$

where $(x + x_i, y + y_i)$ and $(x - x_i, y - y_i)$ are the coordinates of the reconstructed samples corresponding to the i-th coefficient c_i (e.g., point symmetry).

[0150] Feature(s) associated with non-linear filtering are provided herein.

[0151] If non-linear ALF is enabled, Eq. (2) may be modified as follows:

$$\bar{R}(x,y) = R(x,y) + \left[\sum_{i=0}^{N-2} c_i \times (f_i^+ + f_i^-) + 64\right] \gg 7 \quad (4)$$

with:

$$\begin{aligned} f_i^+ &= \min\big(b_i, \max\big(-b_i, R(x + x_i, y + y_i) - R(x,y)\big)\big) \\ f_i^- &= \min\big(b_i, \max\big(-b_i, R(x - x_i, y - y_i) - R(x,y)\big)\big) \end{aligned} \quad (5)$$

where b_i is the clipping parameter for the coefficient c_i. The clipping parameter b_i may be determined based on a clipping index d_i. For example, the clipping parameter b_i may be derived as follows:

$$b_i = \begin{cases} 2^{BD} & \text{when } d_i = 0 \\ 2^{BD-1-2d_i} & \text{otherwise} \end{cases} \quad (6)$$

where BD denotes the sample bit depth. In examples, d_i may be 0, 1, 2 or 3.

[0152] Feature(s) associated with luma sub-block classification are provided herein.

[0153] Filter adaptation at sub-block level may apply (e.g., only apply) to Luma. A sub-block (e.g., each sub-block, for example, 4×4) may be classified based on the sub-block's directionality (D) and/or Laplacian activity (A).

[0154] The activity value A may be mapped to the range of 0 to 4, inclusively. The quantized value may be denoted as $\hat{A}$. A Luma sub-block (e.g., each Luma sub-block) may be categorized into a class. For example, a Luma sub-block may be categorized into a class of the 25 classes represented by:

$$C = 5D + \hat{A} \quad (7)$$

[0155] A class (e.g., each class) may have an assigned filter (e.g., its own filter assigned). Classification may not be applied for Chroma.

[0156] Feature(s) associated with geometric transformations are provided herein.

[0157] A geometric transformation (e.g., a rotation or diagonal and/or vertical flipping) may be applied to the filter coefficients (e.g., before filtering each Luma sub-block). The geometric transformation may be applied, for example, depending on the sub-block gradient values. The geometric transformation may align the directionally of the different blocks (e.g., to reduce the number of ALF classes). For example, applying the geometric transformation may allow a sub-block with a horizontal edge and a sub-block with a vertical edge to both have the same directionality D.

[0158] Feature(s) associated with coding tree block (CTB)-level filter selection are provided herein. Adaptive loop filtering may involve filter adaptation at the CTB level (e.g., in addition to the Luma sub-block-level classification).

[0159] A Luma CTB may use a filter set calculated for the current slice. A Luma CTB may use a filter set (e.g., one of the filter sets) calculated for the already-coded slices. A Luma CTB may use an offline trained filter set (e.g., from N offline trained filter sets, for example, where N = 16). Within a Luma CTB (e.g., each Luma CTB), a filter (e.g., from the chosen filter set) to be applied to a sub-block (e.g., each sub-block) may be determined based on the class C calculated in Eq. (7) for the block.

[0160] Chroma may use (e.g., only use) CTB-level filter adaptation. One or more (e.g., up to 8) filters may be used for Chroma components in a slice. A CTB (e.g., each CTB) may select one of the filters.

[0161] Feature(s) associated with ALF syntax are provided herein.

[0162] Filter coefficients and/or clipping indices may be carried in one or more ALF adaptation parameter sets (APSs). An ALF APS may include one or more (e.g., up to 8) Chroma filters and/or a (e.g., one) Luma filter set (e.g., with up to 25 filters). An index i_C may be included for each Luma class (e.g., each of the 25 Luma classes). Classes having the same index i_C may share the same filter. By merging different classes, the number of bits used (e.g., required) to represent the filter coefficients may be reduced. The absolute value of a filter coefficient may be represented using a zero-order exponential-Golomb code and (e.g., followed by) a sign bit for non-zero coefficients. If clipping is enabled, a clipping index may be signaled for a filter coefficient (e.g., each filter coefficient) using a (e.g., two-bit) fixed length code.

[0163] Filter control syntax elements may include one or more (e.g., two) types of information. ALF On/Off flags may be signaled at sequence-, picture-, slice-, and/or CTB-levels. Chroma ALF may be enabled at picture- and/or slice-level if (e.g., only if) Luma ALF is enabled at the corresponding level. Filter usage information may be signaled at picture-, slice-, and/or CTB-level (e.g., if ALF is enabled at that level). Referenced ALF APS IDs may be coded at slice-level or at picture-level (e.g., if all the slices within the picture use the same APSs). Luma component may reference one or more (e.g., up to 7) ALF APSs. Chroma components may reference a (e.g., 1) ALF APS. For a Luma CTB, an index may be signaled. The index may indicate which ALF APS or offline-trained Luma filter set is used. For a Chroma CTB, the index may indicate which filter in the referenced APS is used.

[0164] Feature(s) associated with encoder-side processes are provided herein.

[0165] The encoder may calculate value(s) of ALF syntax (e.g., as described herein) by minimizing a rate-distortion cost. The rate-distortion cost may be a weighted sum of the distortion (e.g., measured as the square error between the original samples and the sample after applying the ALF filter) and the number of bits used (e.g., required) to transmit ALF syntax elements.

[0166] Filter coefficients may be calculated by solving one or more Wiener-Hopf equations. The statistics used (e.g., required) to calculate filter coefficients and estimate distortion may be collected for the possible combinations (e.g., all possible combinations) of clipping indices. The statistics may be collected for a CTB (e.g., separately for each CTB). In the case of a Luma component, the statistics may be collected for a class of a CTB (e.g., each class of each CTB).

[0167] ALF developments may be unstandardized. Feature(s) associated with a classifier (e.g., a new classifier) and fixed filtering for Luma are provided herein.

[0168] A classifier may be based on Luminance bands. C0 may denote the legacy Laplacian-based classifier. C1 may denote the classifier (e.g., the band classifier) based on Luminance bands.

[0169] One or more (e.g., three) different sets of filters (e.g., F0, F1 and F2) may be used to filter a Luma sample. Sets F0 and F1 may include fixed filters (e.g., filters with coefficients trained for classifiers C0 and C1). Coefficients of filters in set F2 may be signaled. In an example, $R_0(x,y)$ and $R_1(x,y)$ may denote the intermediate sample values filtered by F0 and F1, respectively. The filter F2 may be applied to $R_0(x,y)$, $R_1(x,y)$, and the neighboring samples to derive a final filtered sample. For example, the final filtered sample may be represented as:

$$\bar{R}(x,y) = R(x,y) + \left[\sum_{i=0}^{19} c_i \times (f_i^+ + f_i^-)\right] + \left[\sum_{i=20}^{21} c_i \times g_i\right] \quad (8)$$

where $f_i^{+/-}$ denotes the clipped difference between a neighboring sample and $R(x,y)$, and g_i denotes the clipped difference between $R_{20-i}(x,y)$ and a current sample value. FIG. 6 illustrates the derivation of the final filtered sample (e.g., using an ALF process).

[0170] F0 and F1 may be pre-learned filters trained on classifiers C0 and C1, respectively. F2 may be signaled. F2 may use either classifier C0 or C1. The filter coefficients $(c_i)_{0\le i\le 21}$ may be signaled.

[0171] FIG. 7 illustrates an example filter shape of the signaled filter F2. Filter shapes and sizes may be changed. Samples may be considered before deblocking in the signaled filter, as illustrated in FIG. 7.

[0172] Signaled filter input may be diversified. For example, filter input may be diversified with collocated samples in reference pictures, pre-DBF samples (e.g., that have been filtered by a fixed filter), or residual samples. A classifier based on residue L1 may be used.

[0173] Feature(s) associated with exponential-Golomb coding are provided herein.

[0174] An exponential-Golomb code (e.g., also sometimes referred to as an exp-Golomb code) is a type of universal code. An exponential-Golomb code (e.g., an order-zero exponential-Golomb code) may be used to encode a (e.g., any) non-negative integer x. For example, the non-negative integer x may be encoded, using an order-zero exponential-Golomb code, by: converting $x+1$ to binary to obtain a bit string; counting the number of bits in the bit string; subtracting one from the counted number of bits to obtain a value y; and adding y starting zero bits preceding the bit string.

[0175] A non-negative integer x may be encoded using an order-k exponential-Golomb code by: encoding $\lfloor x/2^k \rfloor$ using an order-zero exponential-Golomb code, as described above; encoding $(x \ mod \ 2^k)$ in binary; and concatenate the two binary strings.

[0176] An ALF may include one or more syntax elements. For example, a syntax element in the APS may include the signaled filters (e.g., including coefficients and, if applicable, clipping indices). A syntax element at slice-level may control an ALF mode. A syntax element for a CTU (e.g., each CTU) may include a syntax element to control the ALF application (e.g., on/off, filter index, etc.).

[0177] Variants of the syntax element in the APS may involve one or more of: use of adaptive exponential-Golomb coding (e.g., depending on the filter coefficient position and/or QP/TID); use of an adaptive filter size; use of differential coefficient coding; use of spatially predicted exponential-Golomb parameters; use of entropy coding; and/or use of sign prediction.

[0178] Feature(s) associated with adaptive exponential-Golomb coding are provided herein. FIG. 7 illustrates an example transmitted coefficients shape. The APS coding the filter set (e.g., up to 25 filters) may include the number of filters to encode, the value and sign of each coefficient absolute values, and/or the clipping index for each coefficient.

[0179] The coefficients may be encoded using order-zero exponential-Golomb coding or a set of two different order exponential-Golomb codes.

[0180] FIG. 8 illustrates an example of a filter with coefficients a, b, and c. In an example, the order of the exponential-Golomb code may be different per coefficient location. For example, for a coefficient close to the center (e.g., coefficient “a” in FIG. 8), the order of the exponential-Golomb code may be larger (e.g., because the coefficient is likely to be larger). For extreme coefficients (e.g., coefficient “c” in FIG. 8), the order of the exponential-Golomb code may be smaller.

[0181] In an example, the relationship between the distance to the center and the order of the exponential-Golomb code may be coded in a look-up table (LUT). The LUT may be known at both the encoder side and the decoder side. In an example, several LUTs may be available. In this case, the LUT to use may be signaled in the APS (e.g., before decoding the coefficients). In an example, the index of the LUT to use may be determined (e.g., deduced) based on a quantization parameter (QP) of the slice and/or the temporal depth (TiD) of the frame.

[0182] If several filters are signaled, the feature(s) described herein may be used for each filter (e.g., individually). For some filters, the central value may not be coded (e.g., the central value may be deduced, for example, assuming a filter of norm 1).

[0183] Feature(s) associated with adaptive filter size are provided herein.

[0184] To reduce the syntax cost of the coefficients and provide more flexibility on the signaled filters' size, the size of the filters may be decoded (e.g., first decoded).

[0185] FIG. 9 illustrates example filter size sets (e.g., with three sizes for a set of three filters). For example, if the size is signaled as size 0, the top filters (e.g., with many coefficients) may be used. As another example, if the size is signaled as size 2, smaller filters (e.g., with fewer coefficients) may be used to transmit. The encoder may choose the filter to send (e.g., based on rate-distortion optimization (RDO)). The encoder may transmit the index of the chosen size set in the APS.

[0186] Feature(s) associated with differential coefficient coding are provided herein.

[0187] In an example, the coefficients may be encoded from the central coefficient to the most external coefficient(s). For example, FIGs. 10A and 10B illustrate example scanning orders from the central coefficient of the filters to the most external coefficients. FIG. 10A illustrates an example scanning order without symmetry constraints. FIG. 10B illustrates an example of symmetrical coefficients (e.g., a scanning order with symmetry constraints, which may be assumed in some examples). If a "low pass" filter set is used, the coefficient level (e.g., absolute value) may (e.g., is likely to) decrease with the coefficient index.

[0188] In an example, the difference with the already-decoded absolute value of pre-defined neighbors may be encoded (e.g., instead of coding the absolute value of the coefficient). For example, the coefficient of index 13 may be encoded as the difference with the coefficient of index 3.

[0189] In an example, a plurality of neighbors may be used to encode the difference. For example, the average of pre-defined set of neighbors, expressed below, may be used:

$$C(13) = V(13) - 1/3\ (V(9) + V(3) + V(10)) \tag{9}$$

where $V(x)$ is the value (e.g., absolute value) of the coefficient at index x and $C(x)$ is the value to encode in the bitstream.

[0190] In an example, for a non-symmetrical filter, the coefficient may be encoded as a difference with the coefficient of same distance in the same filter (e.g., if available). For example, as illustrated in FIG. 10A, the coefficients may be encoded as:

$$C(23) = V(23) - V(22) \tag{10}$$

$$C(24) = V(24) - 1/2(V(22) + V(23)) \tag{11}$$

[0191] Feature(s) associated with predicted exponential-Golomb parameters are provided herein.

[0192] To minimize the syntax of the exponential-Golomb code of a coefficient (e.g., each coefficient), the number of bits to encode (e.g., except for the first coefficient) may be predicted by the number of bits of the last decoded coefficient (e.g., the prefix of the exponential-Golomb code). The

number of bits above the number of bits of the last decoded coefficient (e.g., most recently decoded coefficient) may be encoded (e.g., instead of coding the $(number\ of\ bits - 1)$ needed to encode a coefficient). The number of bits above the last number of bits (e.g., of the most recently decoded coefficient) may be encoded as a string of zeros (0s), terminated by a one (1).

[0193] For example, as illustrated in FIG. 10, V(1) = 213 may be a normal exponential-Golomb code (e.g., an order-zero exponential-Golomb code). The code may be 0000000 (e.g., $(number\ of\ bits - 1)$) 1101 0110 (e.g., $value + 1$). In this example, the last decoded value (e.g., the most recent previously decoded value) took n_1 = 8 bits to encode.

[0194] Continuing the example, if V(2) = 150, n_2 = 8 bits may be used to encode 150. The prefix of the code may become $max(0, n_2 - n_1)$ zeros, followed by a 1 (e.g., the code may be $n_2 - n_1$ zeros (no zeros) 1 (terminator) 1001 0110 (value)). If V(3)=160, n_3 = 8 bits may be used to encode 160, and the code may be $n_3 - n_2$ zeros (e.g., no zeros) 1 (terminator) 1010 0000 (value). If V(4) = 100, n_4 = 7 bits may be used to encode 100, and the code may be $n_4 - n_3$ zeros (e.g., no zeros) 1 (terminator) 0110 0100 (value). If V(5) = 90, n_5 = 7 bits may be used to encode 90, and the code may be $n_5 - n_4$ zeros (e.g., no zeros) 1 (terminator) 101 1010 (value). If V(6) = 230, n_6 = 8 bits may be used to encode 230, and the code may be 0 ($n_6 - n_5$ = 1 zero) 1 (terminator) 1110 0110 (value).

[0195] An example decoder may use a previous number of bits (e.g., number of bits of the most recently decoded coefficient) as a predictor for the number of bits associated with the coefficient currently being decoded.

[0196] Instead of using the last coefficient to predict the number of bits, the already-decoded neighbors may be used (e.g., using the same method as for the differential coding).

[0197] The exponential-Golomb encoding may be (e.g., may always be) used for the coefficient. The order of the exponential-Golomb code may be deduced from the length of the last decoded coefficient (e.g., the most recently decoded coefficient). The order of the code may minimize the encoding cost of the last decoded coefficient (or this order -1). For example, the order used to encode a coefficient may be the same as (or may be 1 order less than) the order of the previous coefficient. The order used to encode coefficients may be (e.g., inferred to be) a monotonic decreasing function with the coefficients index.

[0198] Feature(s) associated with entropy coding are provided herein. The coefficients may be encoded using an entropy coder.

[0199] The probability associated with a coefficient (e.g., each coefficient, depending on their spatial position) may be fixed and/or known to both encoder and decoder. For example, Huffman code may be used to encode the coefficients. The difference (e.g., as described above) may be entropy coded.

[0200] Feature(s) associated with sign prediction are provided herein. If an entropy coder is used, the sign of a coefficient (e.g., each coefficient) may be coded depending on the sign of the neighboring coefficients (e.g., that have already been decoded).

[0201] For example, in FIG. 8, to encode the sign of coefficient c, the sum of coefficients a and b may be computed. If the sum is positive, the probability associated with a negative sign for c may be p>0.5. Similarly, if the sum is negative, the probability associated with a positive sign for c is p>0.5 (e.g., p=0.8).

[0202] The sum of previously-decoded coefficients (e.g., all already-decoded coefficients) along the line passing by the center may be used.

[0203] If the center value of the filter is not signaled (e.g., because of DC-neutrality the center value is deduced from 1 - the sum of all other coefficients), the sum of the neighbors (e.g., neighboring coefficients) may be biased with a value v. The value v may be a fixed value (e.g., ½ or ¼ of the maximum value of a coefficient). The value v may be approximated as the average value of the absolute values of the closest coefficients (e.g., index 3, 4, 5, and 6 in FIG. 10A).

[0204] Although features and elements are described above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. In addition, the methods described herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. Examples of computer-readable media include electronic signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, RNC, or any host computer.

CLAIMS

What is Claimed:

1. A method for video encoding, the method comprising:

identifying a filter and a coefficient associated with the filter;

determining an encoding procedure based on context information associated with at least one of: a location of the coefficient associated with the filter or a size of the filter;

encoding the coefficient using the determined encoding procedure; and

including, in video data, the encoded coefficient.

2. The method of claim 1, wherein determining the encoding procedure based on the context information comprises determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter, and encoding the coefficient using the determined encoding procedure comprises encoding the coefficient using the exponential Golomb equation of the determined order.

3. The method of claim 1, wherein determining the encoding procedure based on the context information comprises determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter, and wherein the order of the exponential Golomb equation increases as a distance between the coefficient and a center of the filter decreases.

4. The method of claim 1, wherein the method further comprises receiving an indication of the size of the filter, and determining the encoding procedure based on the context information comprises determining the encoding procedure based on the size of the filter.

5. The method of claim 1, wherein the coefficient is a first coefficient associated with the filter, the method further comprises identifying a second coefficient associated with the filter, the second coefficient neighbors the first coefficient and is earlier in a decoding order than the first coefficient, and encoding the first coefficient using the determined encoding procedure comprises encoding the first coefficient based on a difference between a first value associated with the first coefficient and a second value associated with the second coefficient.

6. The method of claim 1, wherein encoding the coefficient using the determined encoding procedure comprises encoding the coefficient using an entropy encoder.

7. The method of claim 1, wherein the coefficient is a first coefficient, and the method further comprises:

determining a first sign associated with the first coefficient based on a second sign associated with a second coefficient, wherein the second coefficient neighbors the first coefficient; and

encoding the first sign associated with the first coefficient.

8. A video encoding device comprising a processor, wherein the processor is configured to implement the steps of the method according to any one of claims 1-7.

9. A method for video decoding, the method comprising:

identifying a filter and a coefficient associated with the filter;

determining a decoding procedure based on context information associated with at least one of: a location of the coefficient associated with the filter or a size of the filter;

decoding the coefficient using the determined decoding procedure; and

decoding a coding block based on the coefficient.

10. The method of claim 9, wherein determining the decoding procedure based on the context information comprises determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter, and decoding the coefficient using the determined decoding procedure comprises decoding the coefficient using the exponential Golomb equation of the determined order.

11. The method of claim 9, wherein determining the decoding procedure based on the context information comprises determining an order of an exponential Golomb equation based on the location of the coefficient associated with the filter, and wherein the order of the exponential Golomb equation increases as a distance between the coefficient and a center of the filter decreases.

12. The method of claim 9, wherein the method further comprises receiving an indication of the size of the filter, and determining the decoding procedure based on the context information comprises determining the decoding procedure based on the size of the filter.

13. The method of claim 9, wherein the coefficient is a first coefficient associated with the filter, the method further comprises identifying a second coefficient associated with the filter, the second coefficient neighbors the first coefficient and is earlier in a decoding order than the first coefficient, and decoding the first coefficient using the determined decoding procedure comprises decoding the first coefficient based on a difference between a first value associated with the first coefficient and a second value associated with the second coefficient.

14. The method of claim 9, wherein decoding the coefficient using the determined decoding procedure comprises decoding the coefficient using an entropy encoder.

15. The method of claim 9, wherein the coefficient is a first coefficient, and the method further comprises:

determining a first sign associated with the first coefficient based on a second sign associated with a second coefficient, wherein the second coefficient neighbors the first coefficient; and

decoding the first sign associated with the first coefficient.

16. A video decoding device comprising a processor, wherein the processor is configured to implement the steps of the method according to any one of claims 9-15.

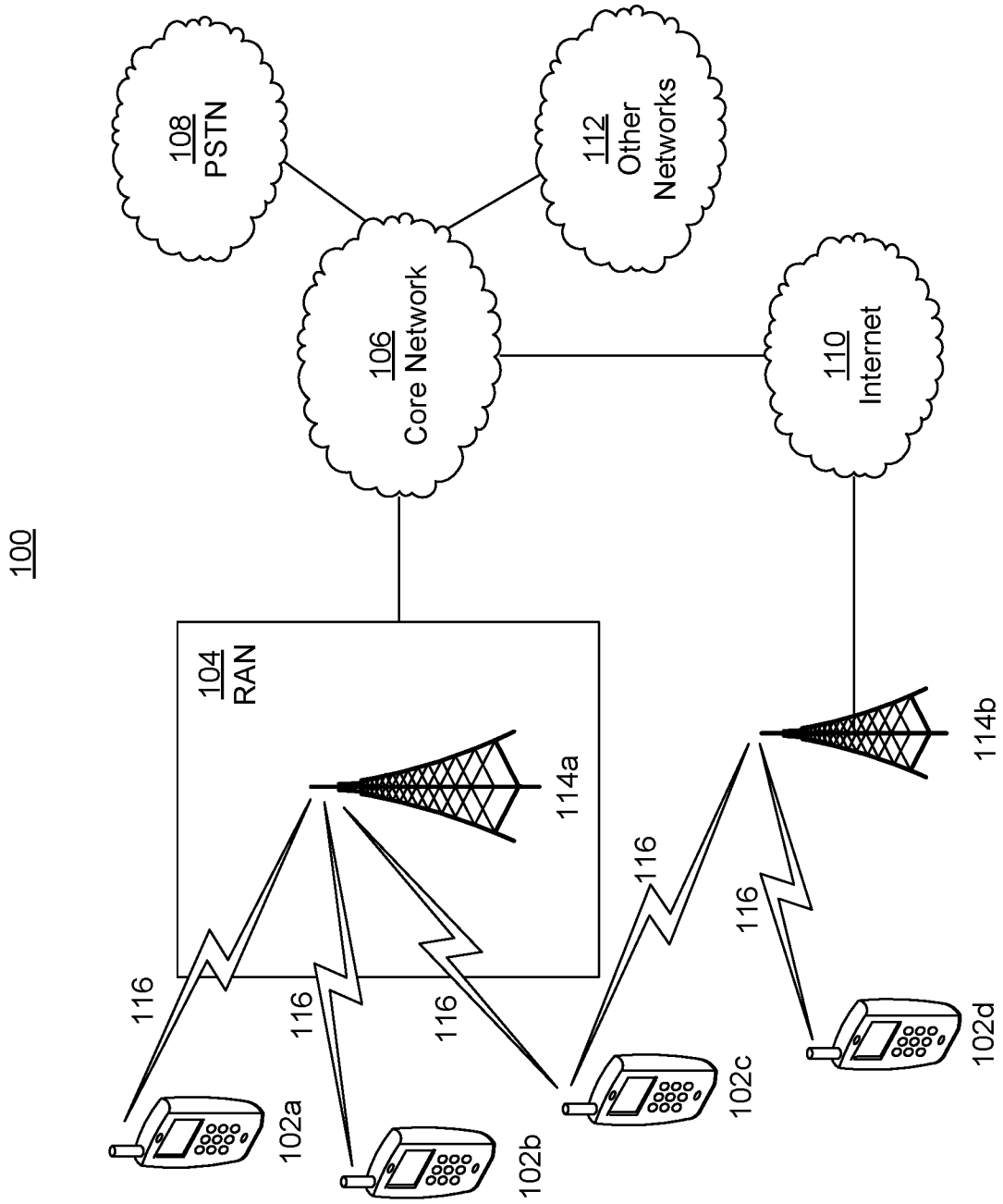

100
108 PSTN
112 Other Networks
106 Core Network
110 Internet
104 RAN
114a
114b
116
102a
102b
102c
102d

FIG. 1A

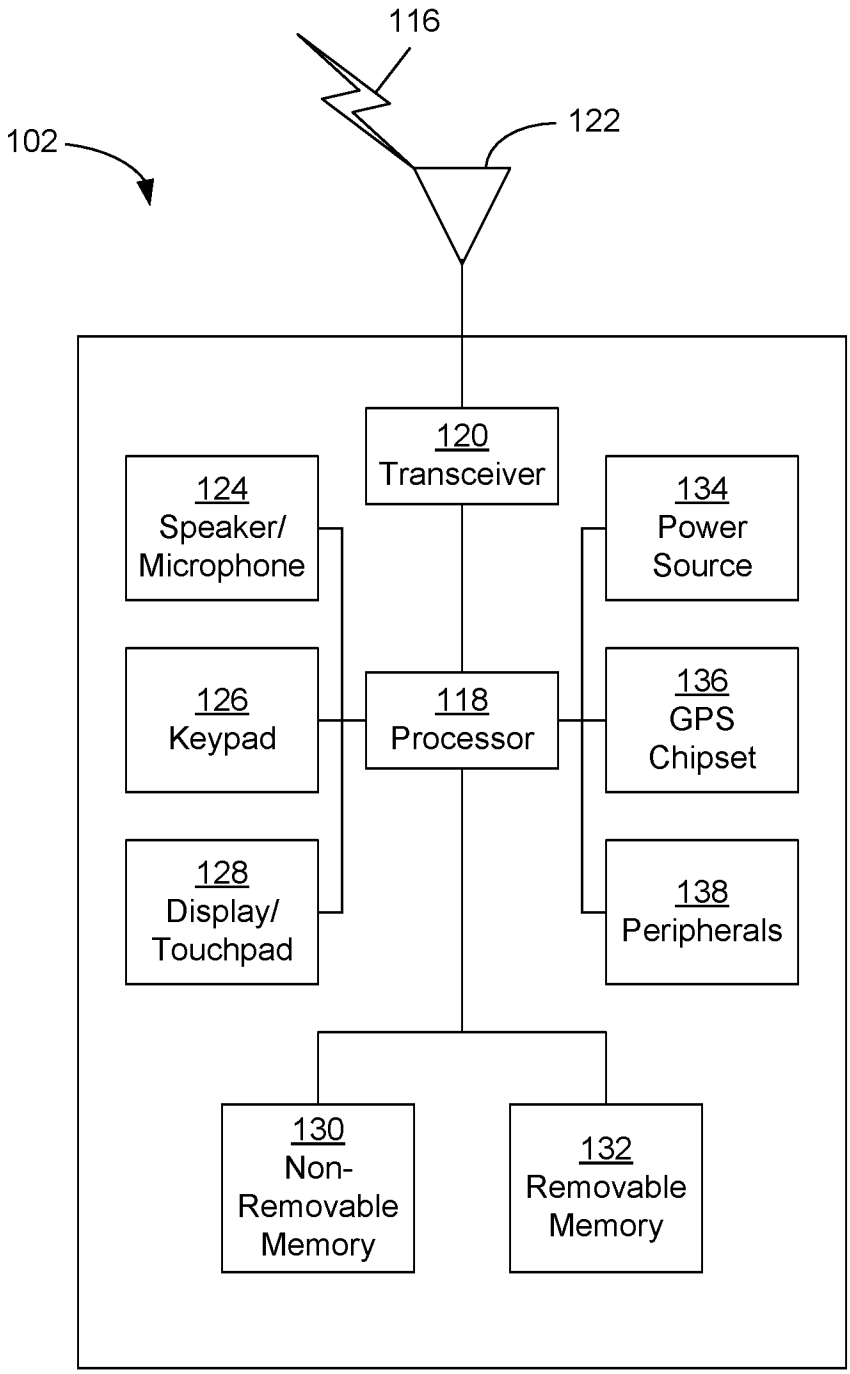

116
122
102
120
Transceiver
124
Speaker/
Microphone
134
Power
Source
126
Keypad
118
Processor
136
GPS
Chipset
128
Display/
Touchpad
138
Peripherals
130
Non-
Removable
Memory
132
Removable
Memory

FIG. 1B

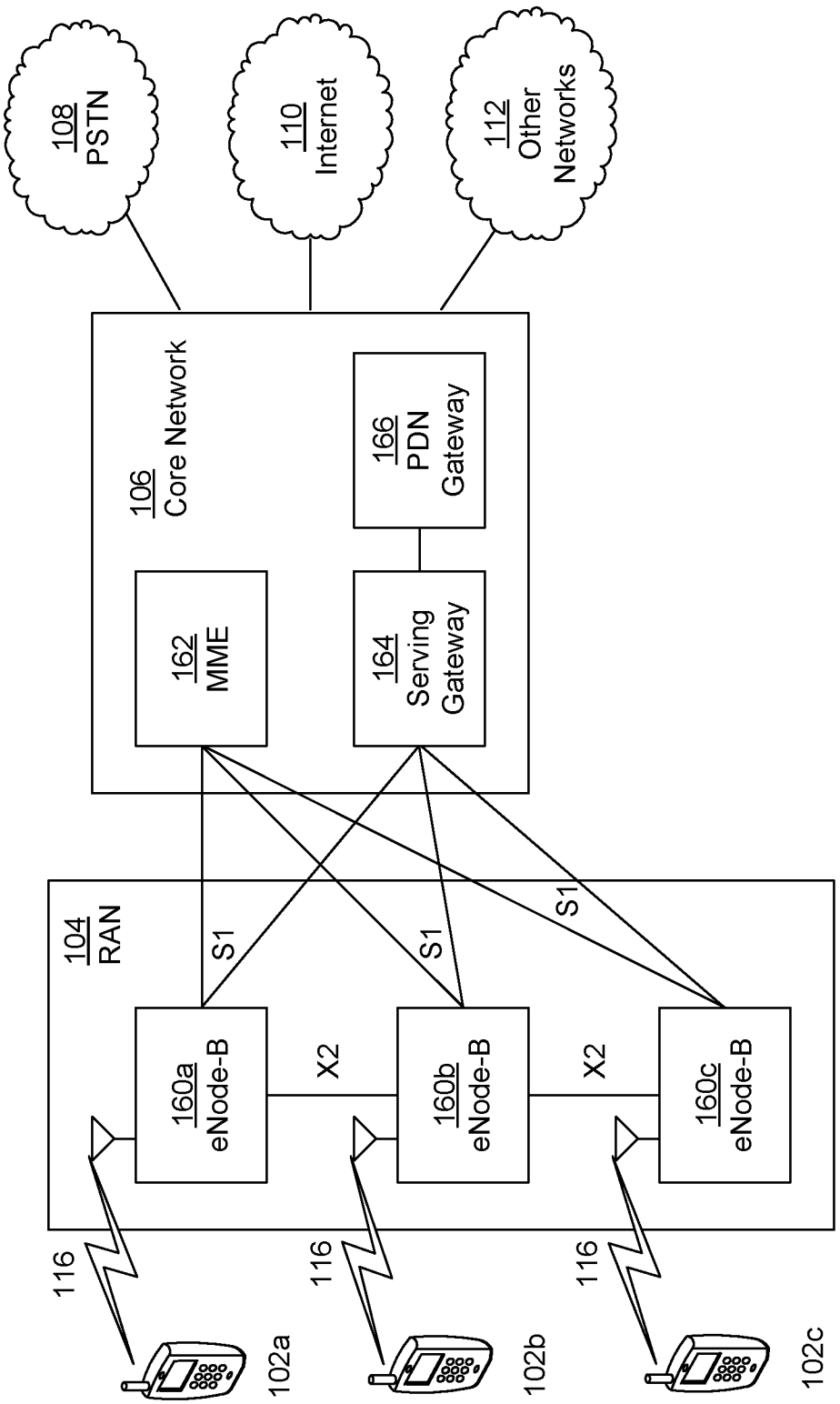

108 PSTN
110 Internet
112 Other Networks
106 Core Network
166 PDN Gateway
162 MME
164 Serving Gateway
104 RAN
S1
S1
S1
160a eNode-B
160b eNode-B
160c eNode-B
X2
X2
116
116
116
102a
102b
102c

FIG. 1C

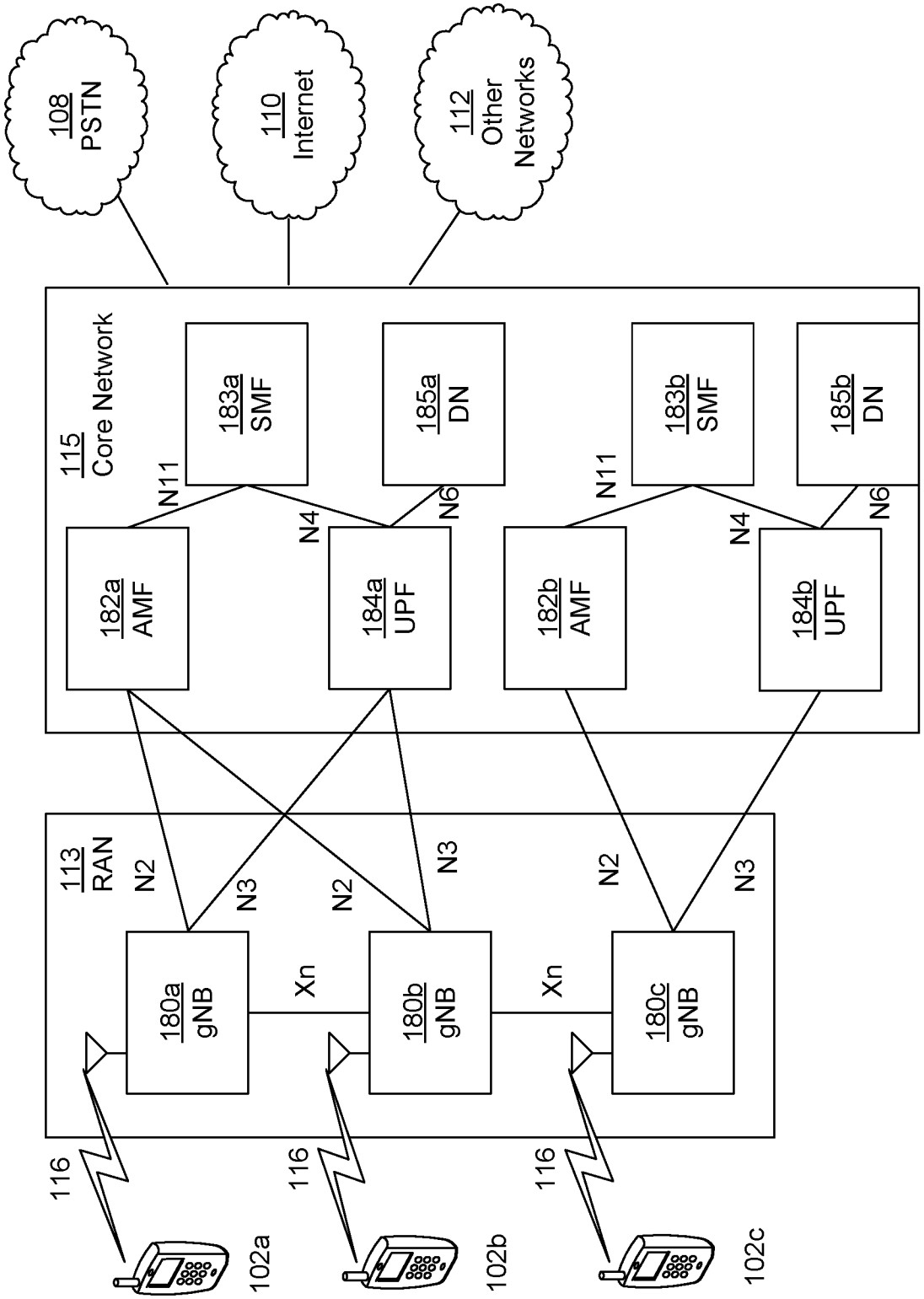

108 PSTN
110 Internet
112 Other Networks
115 Core Network
183a SMF
185a DN
183b SMF
185b DN
N11
N6
N4
182a AMF
184a UPF
182b AMF
184b UPF
113 RAN
N2
N3
180a gNB
Xn
180b gNB
180c gNB
116
102a
102b
102c

FIG. 1D

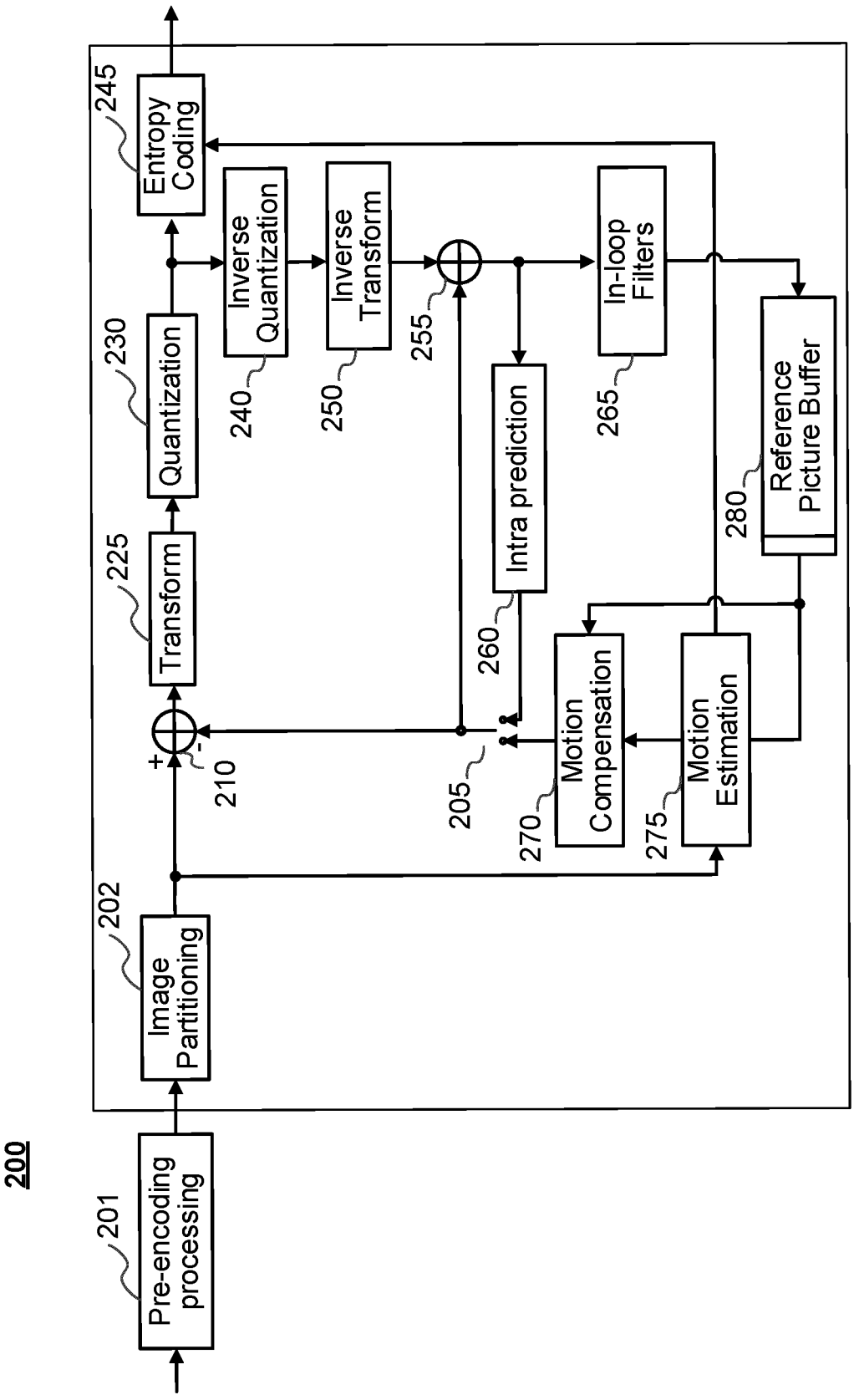

200
201
Pre-encoding processing
202
Image Partitioning
210
+
-
225
Transform
230
Quantization
240
Inverse Quantization
250
Inverse Transform
255
245
Entropy Coding
205
260
Intra prediction
270
Motion Compensation
275
Motion Estimation
265
In-loop Filters
280
Reference Picture Buffer

FIG. 2

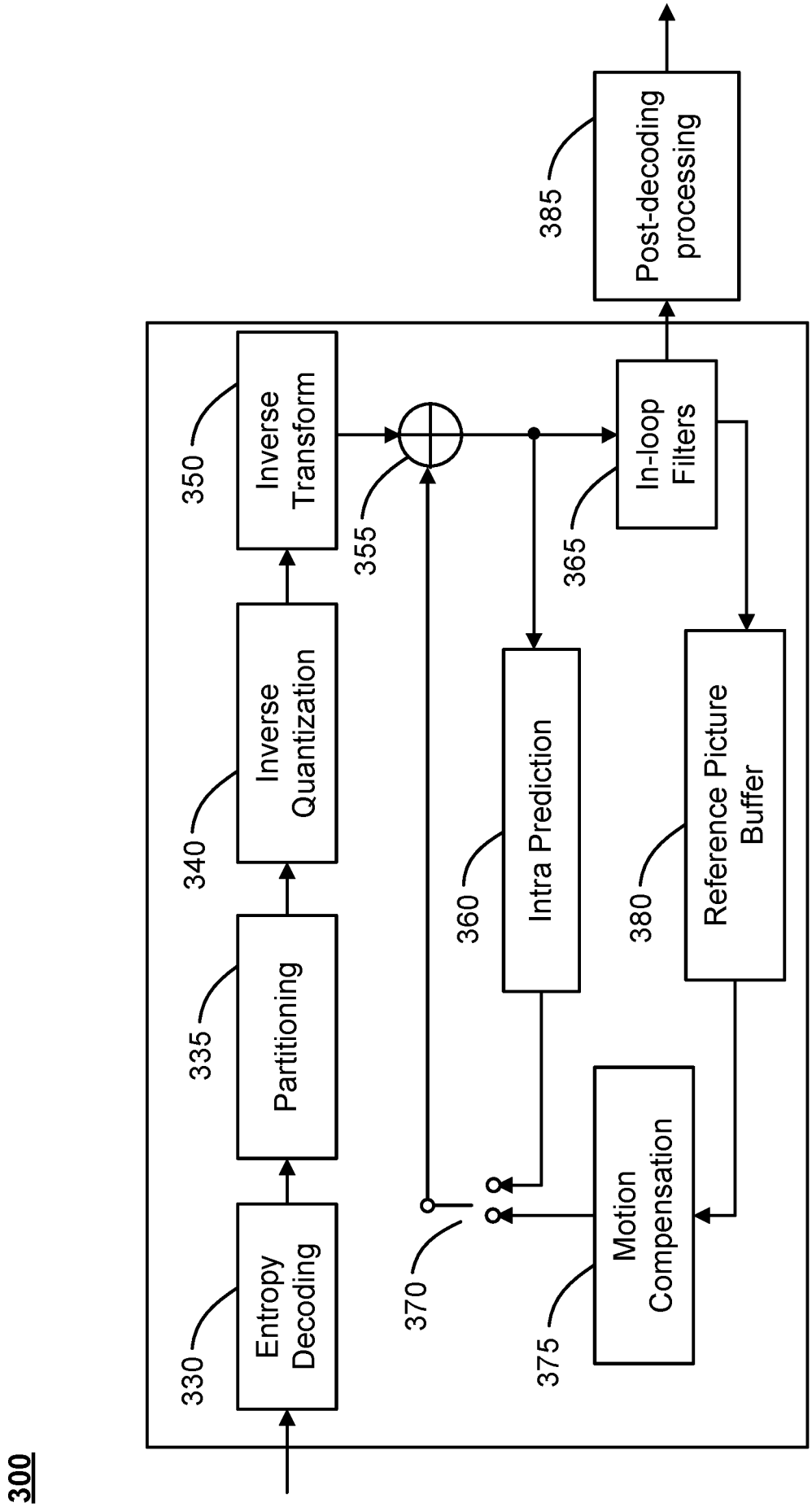

300
330
Entropy Decoding
335
Partitioning
340
Inverse Quantization
350
Inverse Transform
355
360
Intra Prediction
365
In-loop Filters
370
375
Motion Compensation
380
Reference Picture Buffer
385
Post-decoding processing

FIG. 3

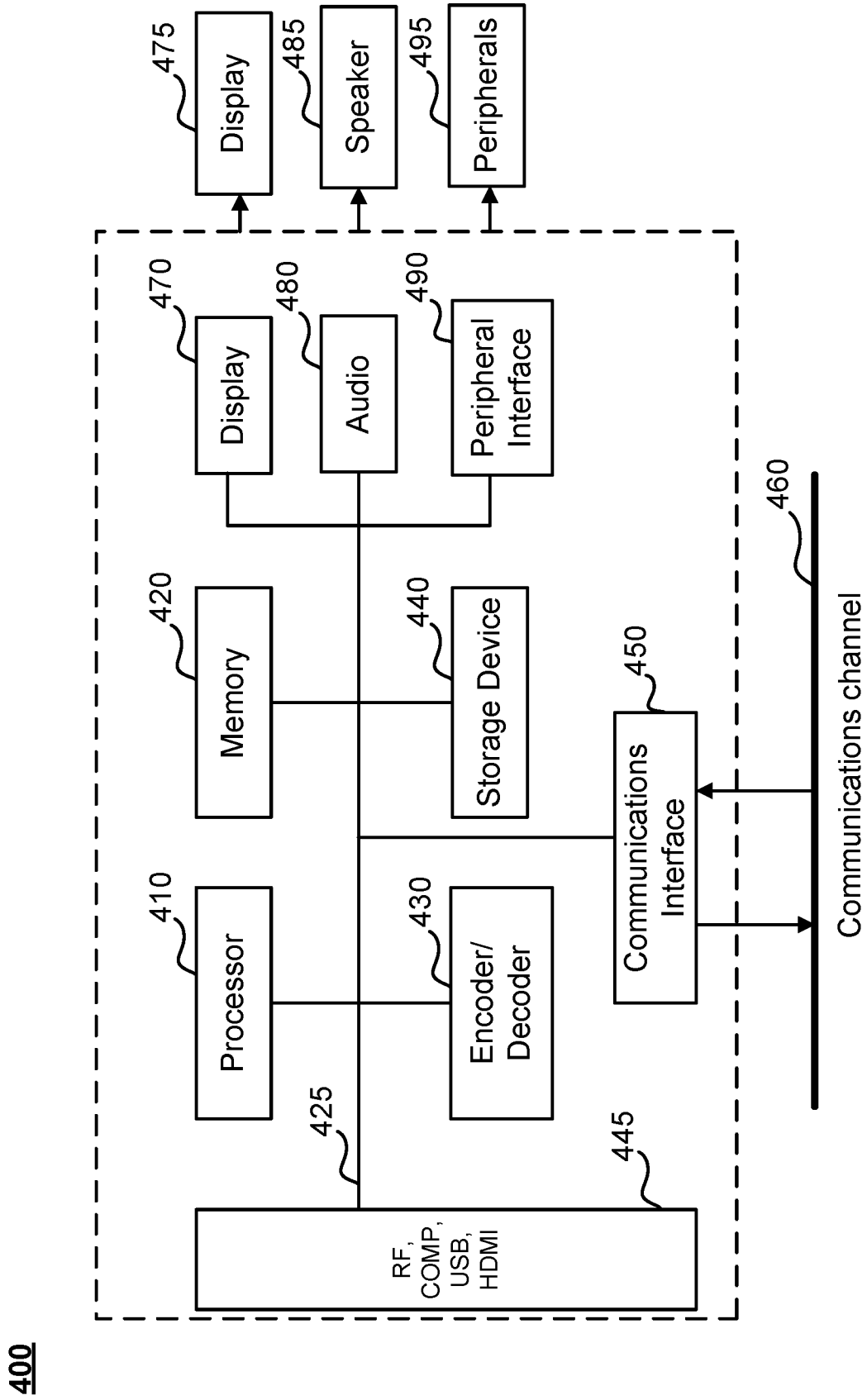

400
475
Display
485
Speaker
495
Peripherals
470
Display
480
Audio
490
Peripheral Interface
420
Memory
440
Storage Device
450
Communications Interface
460
Communications channel
410
Processor
430
Encoder/ Decoder
425
445
RF, COMP, USB, HDMI

FIG. 4

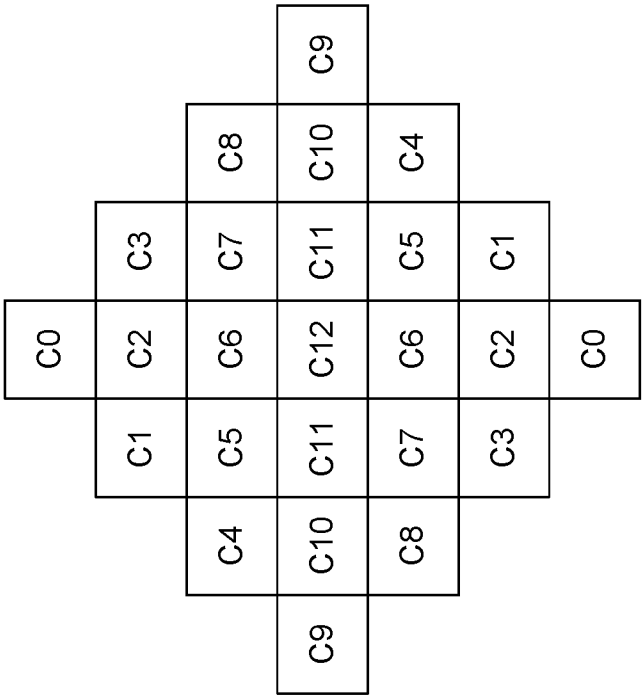
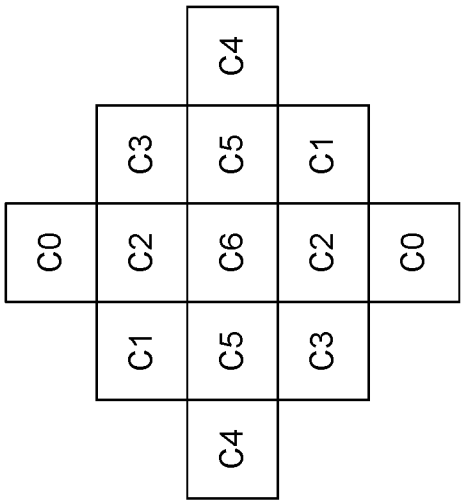

C9
C8 C10 C4
C3 C7 C11 C5 C1
C0 C2 C6 C12 C6 C2 C0
C1 C5 C11 C7 C3
C4 C10 C8
C9

FIG. 5


C4
C3 C5 C1
C0 C2 C6 C2 C0
C1 C5 C3
C4

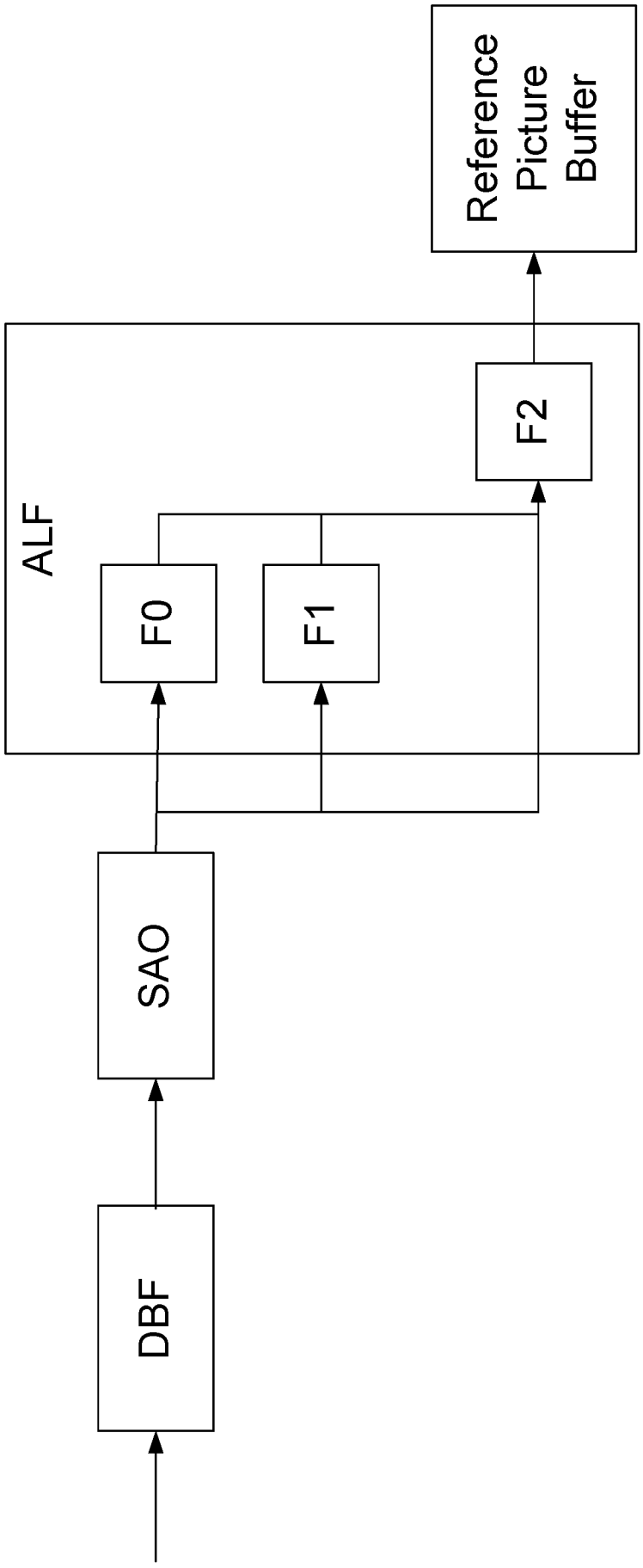


FIG. 6

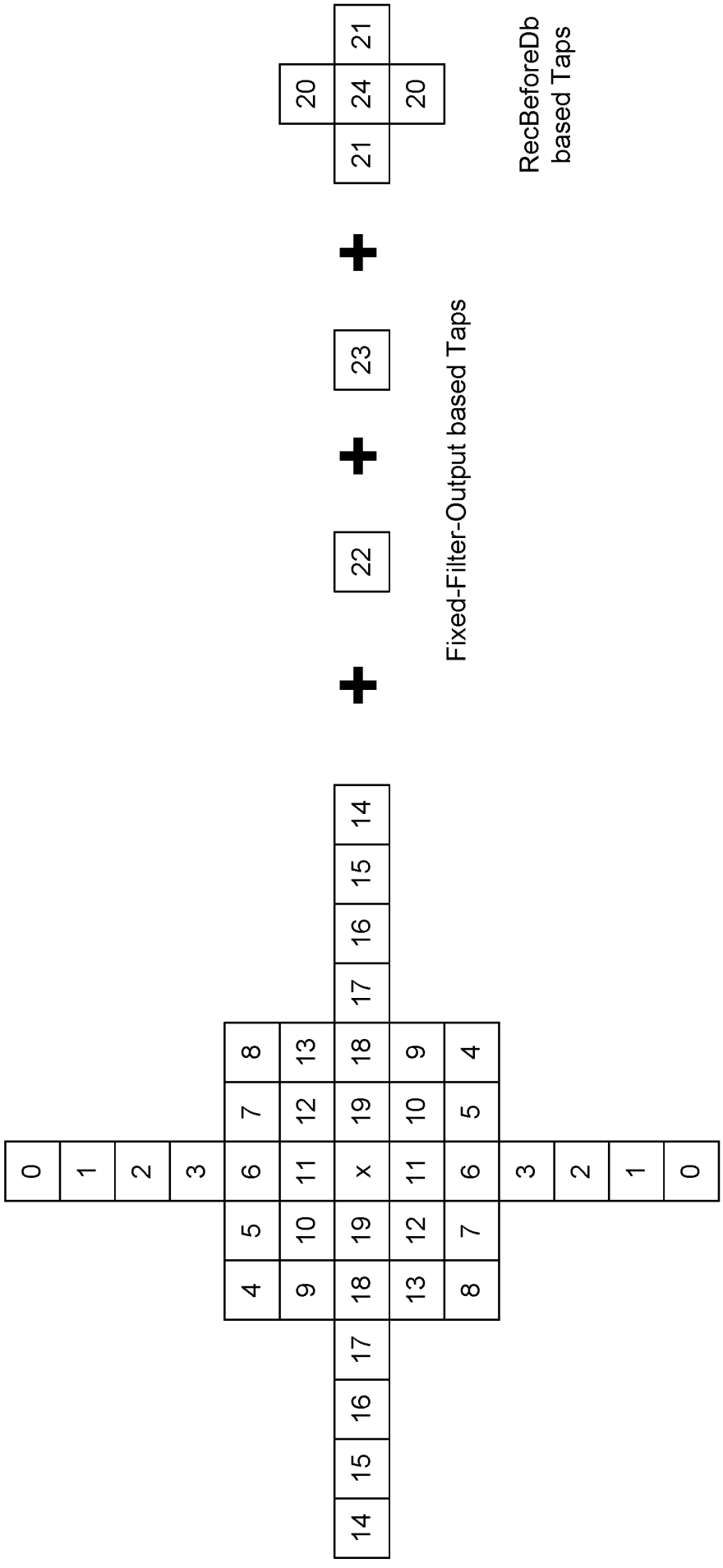

0 1 2 3 6 11 x 11 6 3 2 1 0
4 9 18 13 8
5 10 19 12 7
7 12 19 10 5
8 13 18 9 4
14 15 16 17
Spatial Taps
22
23
Fixed-Filter-Output based Taps
20 21 24 20 21
RecBeforeDb based Taps

FIG. 7

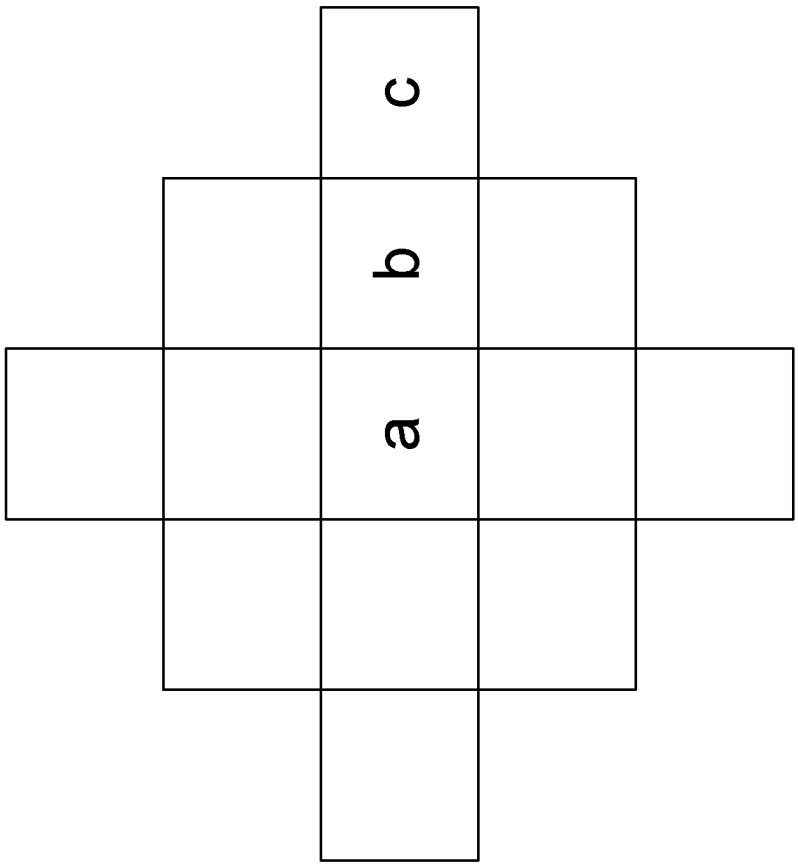


FIG. 8

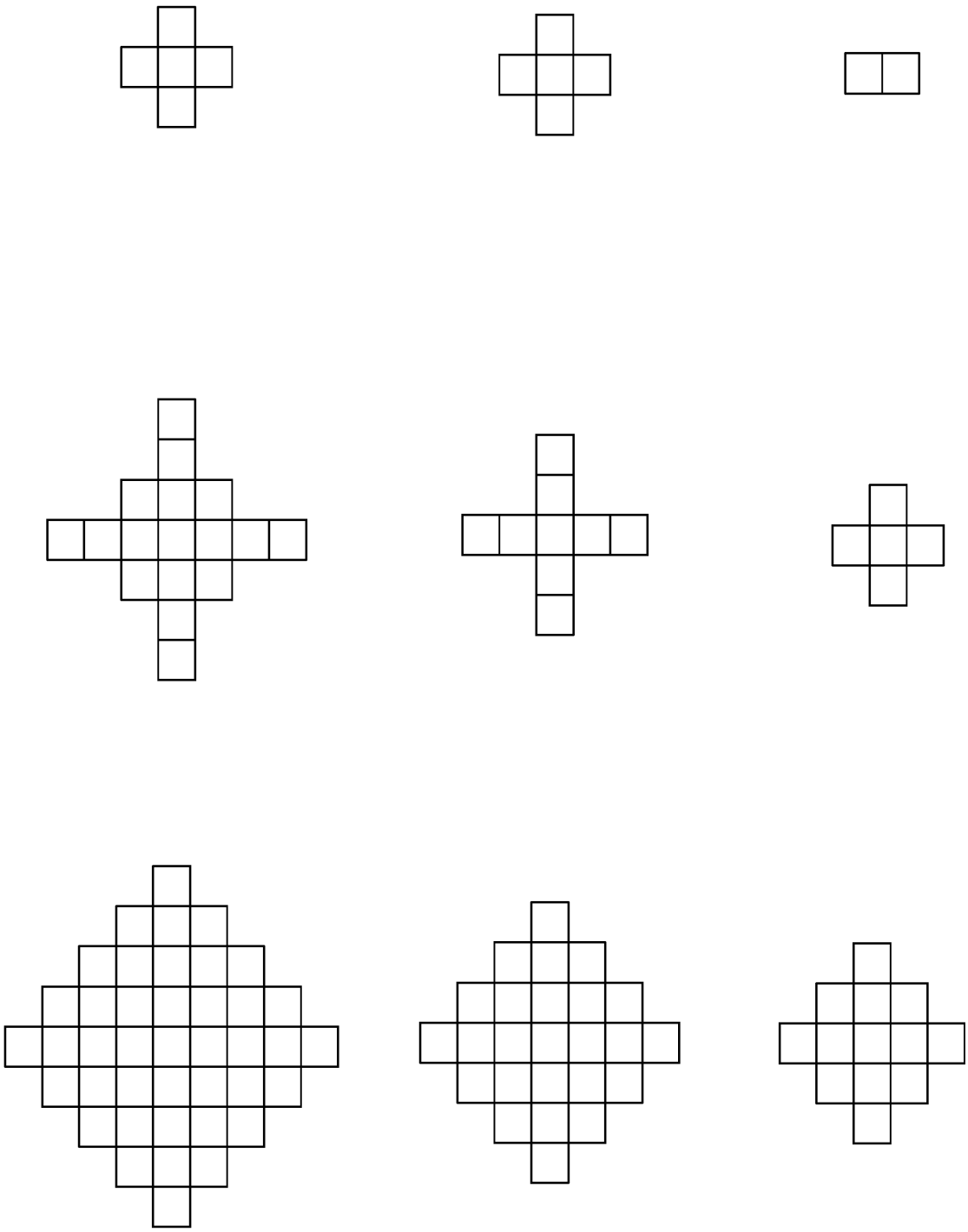
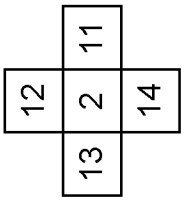
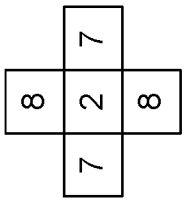


FIG. 9





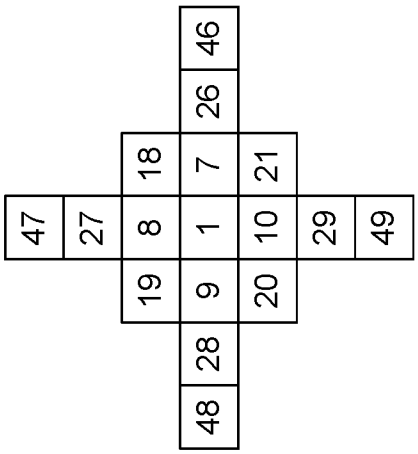


FIG. 10A

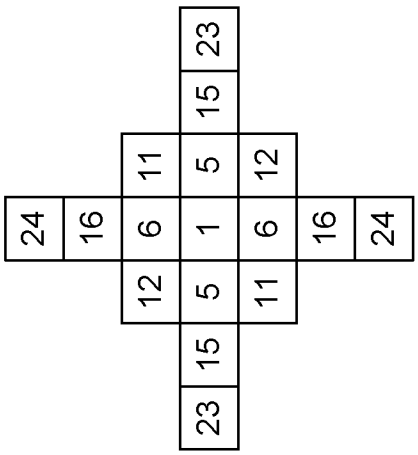
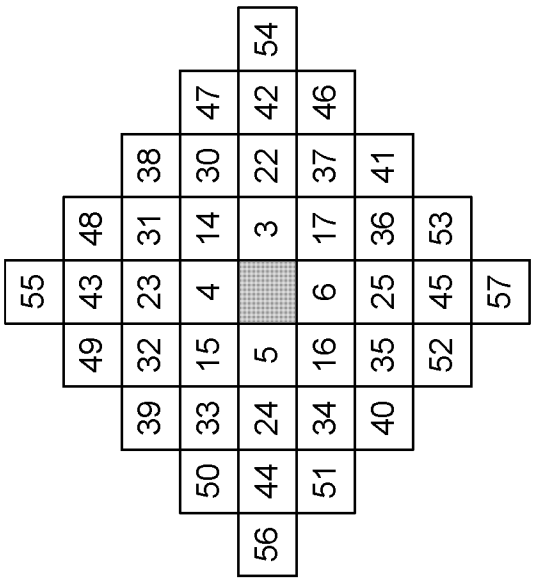
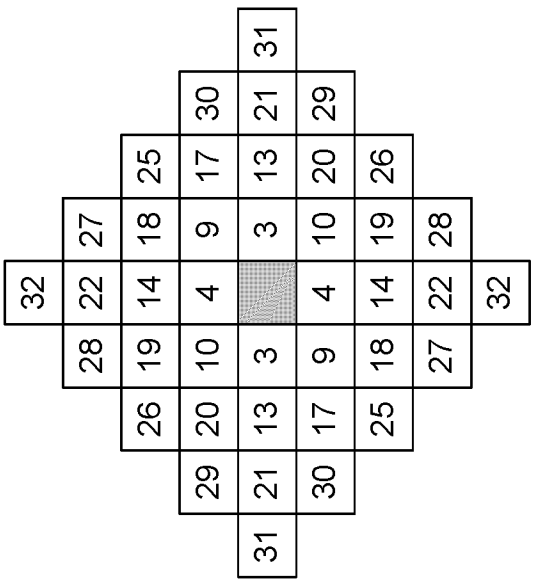


FIG. 10B





INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/066148

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04N19/117 H04N19/13 H04N19/196 H04N19/70 H04N19/82
H04N19/91

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017/324962 A1 (KARCZEWICZ MARTA [US] ET AL) 9 November 2017 (2017-11-09) paragraphs [0037], [0038], [0073] - paragraph [0105]; figures 4-6	1-3,6, 8-11,14, 16

X	US 2020/404263 A1 (HU NAN [US] ET AL) 24 December 2020 (2020-12-24)	1,2,6, 8-10,14, 16
A	paragraph [0142]; figures 3-7	3,11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 July 2024	13/09/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lombardi, Giancarlo

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2024/066148

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
1-3, 6, 8-11, 14, 16

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 6, 8-11, 14, 16

   Method of coding of the coefficients associated with a filter by means of exponential Golomb coding dependent on the location of a filter coefficient, wherein the order of exponential Golomb coding increases as a distance between coefficient location and central location of the filter decreases.

   ---

2. claims: 4, 12

   Method of coding of the coefficients associated with a filter, wherein coding depends on the size of the filter.

   ---

3. claims: 5, 13

   Method of coding of the coefficients associated with a filter, wherein the value of a filter coefficient is predicted from the value of a previously coded filter coefficient.

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4. claims: 7, 15

   Method of coding of the coefficients associated with a filter, wherein the sign of a current coefficient is coded based on the sign of a neighbouring coefficient.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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